Chapter 21
Red-Eared Slider *Trachemys scripta elegans* (Wied-Neuwied)

Kai Ma and Haitao Shi

Abstract The red-eared slider (*Trachemys scripta elegans*) is listed as one of the 100 worst invasive species in the world. At present, it is widely distributed in aquatic habitats in China. In order to collect detailed ecological data in invaded regions, to clarify the invasive status, ecological impacts and adaptative mechanisms, and to provide data for legislation and management, we conducted a series of studies on the invasion ecology of the exotic red-eared slider from 2008 to 2014 in China. The results showed that this slider species has a high ecological tolerance and behavioral plasticity, which result in a strong competitive ability and a large preponderance in local communities. The slider poses a big threat to native biodiversity and ecosystems in China. All our results suggest that we should enact laws to ban the import of sliders and to make a scientific management of turtle farms, pet markets, and animal release. In addition, the propaganda and public education should be regularly done to enhance the knowledge and public awareness of negative effects of biological invasions.

Keywords Invasive species • Red-eared slider • Population status • Adaptive mechanism • Ecological impacts

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Fig. 21.1 The red-eared slider (Photo by Kai Ma)

21.1 Introduction

The red-eared slider (*Trachemys scripta elegans*) is a medium-sized semi-aquatic freshwater turtle. It is the most common subspecies of the slider (*T. scripta*) that includes yellow-bellied slider (*T. s. scripta*), red-eared slider (*T. s. elegans*) and Cumberland slider (*T. s. troostii*) (Seidel 2002). The red-eared slider has a conspicuous wide red postorbital stripe, narrow chin stripes, a transverse yellow bar on each pleural, and a plastral pattern consisting of a dark blotch or an ocellus on each scute (Ernst 1990; Fig. 21.1).

The red-eared slider is native to eastern United States and northeastern Mexico. It occupies the Mississippi Valley from Illinois to the Gulf of Mexico, including 19 states of USA (Alabama, Arkansas, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Mississippi, Missouri, Nebraska, New Mexico [eastern], Ohio, Oklahoma, Tennessee, Texas, West Virginia) and two states of Mexico (Nuevo Leon, Tamaulipas) (Ernst 1990). By the end of the Second World War, the demand for pet turtles increased dramatically, leading to the prosperous commercial turtle farming in USA and then a huge amount of the red-eared sliders exported to many countries (Bringsøe 2006). So far, this slider has been introduced into more than 70 countries and regions in Europe, Africa, Oceanica, Asia and America (Kraus 2009; van Dijk et al. 2011; Fig. 21.2). As this species is omnivorous (Collins 1982) and has an extensive ecological tolerance (Willmore and Storey 2005) and strong diffusion ability (Burke et al. 1995), it is listed as one of the 100 worst invasive species in the world (Lowe et al. 2000).

Since 1986, the red-eared slider was introduced into mainland China *via* Hong Kong, as a pet owing to its tenacious vitality, colourful body and low price (Shi et al. 2008). The number of sliders exported to China from the USA reached 4.65 million in 1998, 4.71 million in 1999, and 7.5 million in 2000 (CITES 2003). In early years of this century, a massive scale of red-eared slider farming boomed in China, for example, in 2005 to the total number of farmed red-eared sliders reached 25 million in five provinces, including Jiangsu, Zhejiang, Hunan, Guangdong and Hainan (Xu et al. 2006). So far, this slider is widely distributed in central and southern China

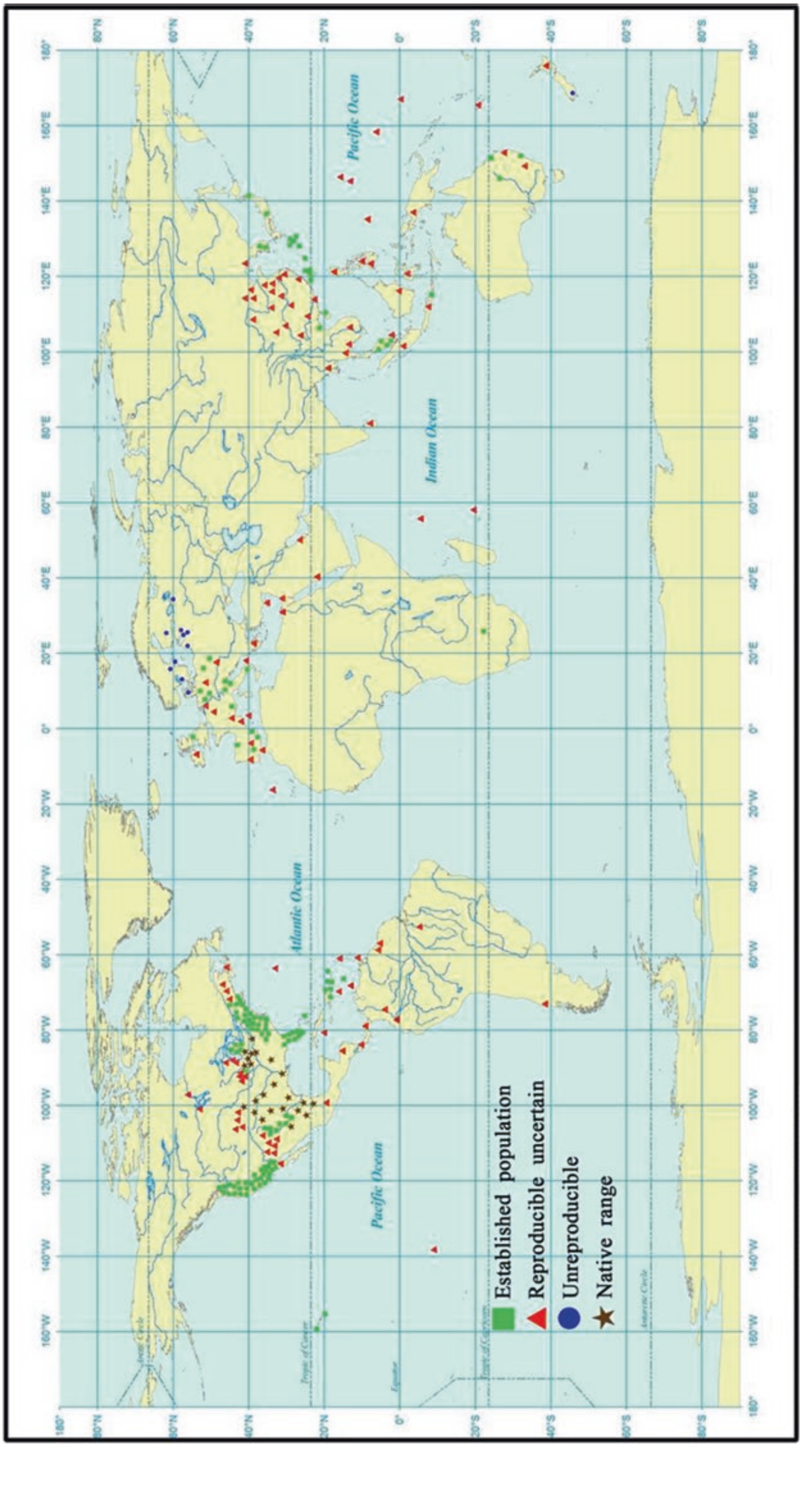

Fig. 21.2 The distribution of red-eared slider around the world

where it poses a threat to native biodiversity (Shi et al. 2009). In order to clarify the population status, mechanisms of ecological adaptation, impacts on the environments and society, and to develop control measures in China, a series of studies on the invasion ecology of the exotic red-eared slider have been conducted since 2008 by the Chelonian conservation biology research group of Hainan Normal University under the leadership of professor Haitao Shi.

21.2 Occurrence Status

We investigated the geographical distributions of the red-eared turtles across the whole China for the purpose of understanding the invasion status of this species. The survey showed that there was not only a huge consumer demand but also a very large scale of slider breeding nationwide. Moreover, this turtle has a wider field distribution range than any native turtles in China. Thus, the question is why the exotic species can be so successful.

To answer this question, we chose four typical study sites that differ in latitude, climate zone, habitat type and altitude: Nanjing section of Yangtze River (NYR), Gutian Nature Reserve (GNR), Haikou section of Nandu River (HNR), and Qionghai section of Wanquan River (QWR) (Table 21.1).

21.2.1 Distribution

The red-eared turtle has been farmed in 17 provinces of China, most of which locate in eastern China (Liu et al. 2011; Fig. 21.3). At present, some provinces such as Jiangsu, Zhejiang, Hunan, Guangdong and Hainan have a large number of farms.

A large number of slider trade markets have been established throughout the country, even in some remote districts such as Xinjiang, Tibet, Heilongjiang and Yongxing Island, South China Sea. The trade scale is extremely huge, for example, the average daily traded amount reaches tens of thousands of individuals both in Huadiwan and Qingping pet markets, Guangzhou city. Furthermore, the slider was also found in the Free Life Pond of 51 temples in 18 provinces (Liu et al. 2011; Fig. 21.3).

Table 21.1 The general situation of study sites

Study sites	Geographical coordinates	Climate zone	Habitat type	Altitude
NYR	N 32°04′, E 118°42′	Northern subtropics	River	5 m
GNR	N 23°06′, E 114°47′	Southern subtropics	Stream	250 m
HNR	N 20°04′, E 110°37′	Tropic	Estuary	6 m
QWR	N 19°15′, E 110°27′	Tropic	River	6 m

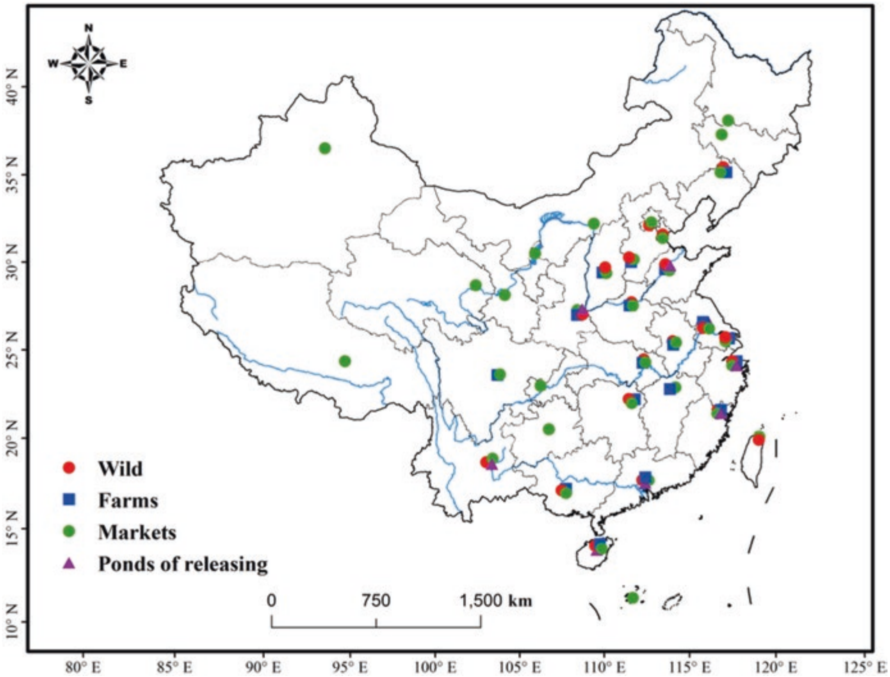

Fig. 21.3 Distribution of the red-eared slider in China

According to the field survey, the red-eared turtle is widely distributed in 22 provinces of China, covering an area of more than 3 million km^2. Its distribution areas are mainly in the central and southern China (Liu et al. 2011; Fig. 21.3).

21.2.2 *Dispersal Pathway*

In China, the red-eared slider for trade purpose came from both import and farming, of which only a small part were eaten as food and most were released into the wild by people, including religious release, faulty release, and abandoned pets. In addition, some captive turtles could escape to the wild (Ma 2013; Fig. 21.4).

Religious release is the main reason for the wide distribution of this turtle in the wild in China. The people in religious conscience believe that release animals can rescue these creatures, but most of them adopted the wrong way that would probably result in biological invasions (Agoramoorthy and Hsu 2007; Liu et al. 2013). The religious people usually did not consider whether these animals are invasive species.

In addition, the turtle species is considered as an auspicious and long-lived animal in Chinese traditional culture, and the ritual freeing of turtles will bring good

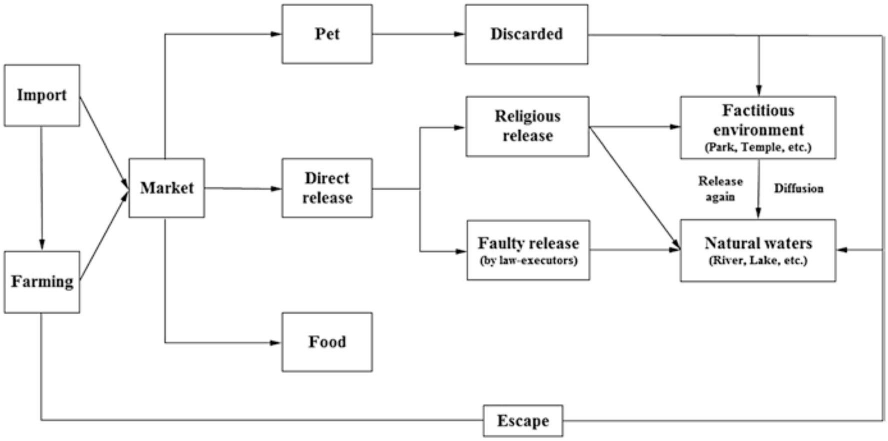

Fig. 21.4 Diffused pathway of red-eared slider in China

luck to the people who are praying. The red-eared slider is the most common turtle species in trade markets, and its price is far lower than native turtles. Thus, the religious people prefer to release the red-eared turtles into the wild.

There two kinds of religious releases: group release and individual release. The group releases are normally sponsored by religious associations and temples, performed by holding a grand ceremony, and have a low frequency. For this type of release, usually a huge number of turtles are released in a single activity, and Chinese characters and/or religious patterns are not carved on shells. By contrast, the individual releases are an unorganized behavior performed by the believers, with no or only a simple ceremony being held, and at a higher frequency; a few of animals are released in a single activity, and usually carved with Chinese characters (e.g. Buddha, name, date of freeing, etc.) and/or religious patterns on shells. The turtles carved with symbols would be able to live longer than those turtles without symbols (Ma 2013). This is because turtles with symbols would not be captured by local fishermen who believe that selling or killing such turtles is an infelicitous thing. Therefore, ritual release of animals may threaten ecological safety.

Furthermore, pet abandoned, faulty release and farming escape are the important ways of red-eared turtles entering into wild environments. Although the slider hatchlings look gentle and lovely, the aggressiveness will increase gradually as the body size increases. For this reason, most pet owners choose to discard them after the slider becomes a large one. In some cases, policemen treat the confiscate exotic species (such as *T. s. elegans*, *Chelydra serpentina*) as native species and release them into the wild, because they lack related professional knowledge. In addition, as turtle farms are normally built in the wild and there are often a large number of mature red-eared turtles in breeding pools (where gravid females are present), some turtles probably escape and establish the natural breeding populations in the wild.

It is a remarkable fact that artificial habitats (such as park, temple) play a role as transit station in promoting the red-eared turtles spread into the wild. In China, we can find the free-living sliders in almost all pools in park and temples (Liu et al. 2011). Ponds are used for short storage of turtles used for releasing into the wild. There is a common phenomenon; the administrators of park and temple would release lots of sliders into the natural waters at a nonscheduled way. For example, in 2009, more than 100 sliders from the pond of Boao monastery were released into the Wanquan River by the local monks in Qionghai, Hainan Island. After releasing, the turtles probably disperse into the neighboring wild regions.

Taken together, in China, a large number of imports and the breeding of red-eared turtles have made this exotic species become the most common turtles in trade markets. Such a case appears to have promoted the conscious or unconscious releases of this turtle into the wild by religionists, law-executors and pet owners, which poses a great threat to the local biodiversity.

21.2.3 Population Structure

The red-eared slider could be found in all of the research areas where it is a dominant species in local communities. The population structure of sliders is seriously unbalanced in the wild, such as the heavy sex ratio deviation and a very low percentage of juveniles. It had a clear female-biased sex ratio in the Yangtze River, Wanquan River and Gutian Nature Reserve. In Nandu River, however, the sex ratio was slightly male biased.

This pattern is mainly associated with the releasing of a large number of captive sliders into the wild (Ma 2013; Wang 2013). In turtle farms, some warming measures were taken to increase hatching rate and shorten incubation period. As a result, the female would hatch at a higher rate than the male under a relatively high incubation temperature, because the slider is a temperature-dependent sex determination species (Willingham 2005). Thus, more female sliders derived from farms were released into the wild, and caused a clear female-biased sex ratio. However, a slightly male-biased sex ratio may be due to a relatively high natural mortality rate of female sliders at the surveyed site in Nandu River, where there is estuary brackish water environment (Yang 2014). In addition, adult sliders were sold much more than juveniles in markets due to high profits. Consequently, some commercial aspects in the farming of sliders, together with many "creature-releasing" activities, have a strong impact on the population structure of feral sliders.

The relative density of red-eared turtles is much higher than that of native turtles, ranging from 0.0015 to 1.25 per trap day. The proportion of sliders in all of freshwater turtles is extremely high. The maximum is 98.7% in Nandu River, and the minimum is 60.2% in Yangtze River. In fact, the degree of endangered of Chinese native turtles is far beyond our imagination (Table 21.2).

Table 21.2 The collected turtles in all of study sites

Species name	Origin	Total numbers	Percentage
Red-eared turtle *T. s. elegans*	Exotic	302	83.0%
Chinese pond turtle *Mauremys reevesii*	Native	36	9.9%
Chinese stripe-necked turtle *Mauremys sinensis*	Native	18	4.9%
Common snapping turtle *Chelydra serpentina*	Exotic	3	0.8%
Beal's eyed turtle *Sacalia bealei*	Native	3	0.8%
Southeast Asian box turtle *Cuora amboinensis*	Exotic	2	0.5%

Table 21.3 The home range of red-eared slider in different studies

Locality	Habitat	Sample size	Females' home range (hm^2)	Males' home range (hm^2)	Total home range (hm^2)	Study period (month)	References
QWR	River	19 F, 8 M	11.39	1.83	8.15	21	Ma et al. (2013)
GNR	Stream	13 F, 8 M	2.16	10.26	5.25	17	Zhou et al. (2013)
HNR	Estuary	5 F, 7 M	3.26	4.23	3.83	10	Yang and Shi (2014)
South Carolina, USA	Lake	7 F, 9 M	36.53	103.53	74.22	16	Schubauer et al. (1990)

Note: home range is an area that exploited by animals for feeding, mating, reproducing and other normal activities

21.3 Mechanisms of Population Establishment and Spread

21.3.1 Ecological Adaptability

21.3.1.1 Home Range

The home range area of sliders in China (about 3–8 hm^2) was much smaller than that in its native range (about 74 hm^2) (Table 21.3). This suggests that the sliders do not move for a long distance after introductions, possibly due to the plenitudinous availability of food, stabile habitats and suitable climate in China. In other words, the slider can grow and reproduce safely within a limited range. Such a life style would help reduce the potential risk from predators, and also reduce the energy cost that would otherwise be required to maintain population fitness after spreading to a larger range.

Population sex ratio and the type of habitat may be the main factors affecting the home range of red-eared turtles in China. The home range of males was significantly wider than that of females in the HNR (Yang and Shi 2014) and the GNR (Zhou et al. 2013). On the contrary, the situation was reversed in the QWR (Ma et al. 2013). Such a difference was attributed to the difference in sex ratio and habitat between the two localities. In the populations with male-biased sex ratio, males need a larger range of activity for reproduction purpose as compared with the males in female-biased populations. As a result, the energy that males invest for mating may be greatly affected by sex ratio (Thomas et al. 1999), as reflected in the distance of males' movement (Ma et al. 2013). Similarly, females need a larger range of activity in a river habitat than in a stream habitat. In the river habitat, water level changes quickly and drastically, thus female turtles have to move a longer distance for nesting (Tucker and Moll 1997; Ma 2013).

Besides, the home range of red-eared slider has also been compared with native turtles in China, such as *Mauremys sinensis*. The red-eared slider and *M. sinensis* were found to have a similar home range area, however, the former had a significantly larger intraspecific home range overlap than the latter (Ma et al. 2013). The interspecific home range overlap degree between the two species was as large as 0.20 ± 0.02[1] (Ma et al. 2013). The results suggest that the red-eared turtles are less restricted by spatial factors, and can adapt well to living in groups with high density. This feature was also observed in populations in other countries. In Savannah River in South Carolina, USA, for example, the population density of red-eared slider could reach a maximum of 1000 individuals per hm^2 (Gibbons and Avery 1990a). However, *M. sinensis* showed an obviously dispersed spatial pattern. Therefore, there is a potential interspecific competition between the sliders and native turtles on space resources, and *M. sinensis* may need more space for population growth.

21.3.1.2 Habitat

The red-eared slider can adapt to different types of habitats very well, including rivers (Liu 2011; Wang 2013), streams (Hu 2012), and even in brackish water (Salinity 5.3–14.6‰) environments (Liu 2011; Yang 2014). Studies on habitat selection and microhabitat utilization showed that this species prefers to live in various freshwater areas, in particular those abundant with aquatic animals and plants, moderate canopy density, suitable concealment and basking places, and still or slow flowing shallow water (Liu 2011; Hu 2012). It also prefers to live in brackish water habitats which are abundant with algae, moderate canopy density, high hidden degree, and near-shore shallow water (Yang 2014).

[1]The home range overlap degree was measured by overlap index that range is between zero and one. And a higher value means more overlap in home range.

Furthermore, Wang (2013) conducted an extensive comparative study on the habitat selection between the sliders and *M. sinensis* in the QWR. The results showed that both species favored the habitat type of riparian vegetation. The Levin's niche breadth of the sliders is higher than that of *M. sinensis*, which suggests that the sliders have a higher adaptability to new environments. There are very high interspecific overlaps between two species for all variables of microhabitats. These imply a possibility of competition between the invasive turtle and the native *M. sinensis* over spatial resources.

In addition, Chen et al. (2014) evaluated the habitat suitability for the red-eared slider by the "3S technology" (GPS, RS, GIS) in the QWR. The result showed that elevation, distance to water and human disturbance have a significantly influence on the habitat selection of slides. The red-eared slider preferred to the areas with an altitude of 0-15 m, a distance of 200-400 m from human disturbance to water, and a distance below 100 m from artificial forest to water. According Markov prediction model, the suitable habitat of red-eared slider will continue to increase in the next 30 years, which suggests that the sliders will spread easily and native turtles will be highly effected (Chen 2014).

21.3.1.3 Diets

The red-eared slider is an typical opportunistic omnivorous animal who consumes a wide variety of invertebrates (shellfishes, snails, shrimps, crabs, insects), vertebrates (fishes, frogs, lizards, snakes, birds, rodents), and plants (algae, ferns, seed plants) in China. Of these foods, 41 species belong to animals in 35 genera of 29 families, and 49 species belong to higher plants in 43 genera of 27 families (Table 21.4). In fact, the food varieties are far more than the above mentioned, as some prey diets could not be detected and identified by stomach flushing and fecal analysis techniques due to the strong digestion ability of sliders.

There was a significant difference in the ratio of animals and plant materials eaten by the red-eared turtle. Sliders consumed more animals than plants in the QWR and HNR (Liu 2011; Wang et al. 2013; Yang 2014), where mollusks and fishes, and fishes, shrimps and crabs are the major food, respectively. However, they consumed more plants than animals in the GNR (Hu 2012), where ferns, graminaceous grass, and commelinaceae are the major food.

Furthermore, the red-eared slider has a diet difference with the one of native turtle species (*M. sinensis*; Wang et al. 2013). For example, in QWR, the slider takes native snails and fishes as the most important food items, while grass makes up the majority of the diet of *M. sinensis*. For this reason, a large number of indigenous aquatic species are eaten by the slider, which harms the native ecosystems directly. It may also play a negative role in the process of community succession, by changing the structure of local communities. As a result, it promotes biological invasions of other alien species, such as apple snail (*Ampullaria gigas*) and water hyacinth (*Eichhornia crassipes*).

Table 21.4 The diet composition of food items in stomach and feces of red-eared slider in different study area in China

Food items							Sample size	Study area	References
Kingdom	Phylum	Class	Order	Family	Genus	Species			
Animalia	Mollusca	Lamellibranchia	Mytiloida	Mytilidae	*Modiolus*	*M. modiolus*	202 (127 F, 33 M, 42 J)	QWR	Liu (2011) and Wang (2013)
						M. philippinarum			
			Unionoida	Unionidae	*Anodonta*	*A. globosula*			
						A. woodiana			
			Veneroida	Corbiculidae	*Corbicula*	*C. fluminea*			
						C. nitens			
		Gastropoda	Mesogastropoda	Thiaridae	*Melaniodes*	*M. tuberculata*			
					Sermyla	*S. riqueti*			
				Melanidae	*Brotia*	*B. swinhoei*			
				Viviparidae	*Angulyagra*	*A. polyzonata*			
					Bellamya	*B. purificata*			
				Ampullariidae	*Ampullaria*	*A. gigas*[a]			
	Arthropoda	Crustacea	Decapoda	Palaemonidae	*Macrobrachium*	*M. hainanense*			
				Potamidae	UN				
		Insecta	UN						
	Chordata	Osteichthyes	UN						
		Aves	UN						
		Mammalia	Rodentia	UN					

(continued)

Table 21.4 (continued)

Food items							Sample size	Study area	References
Kingdom	Phylum	Class	Order	Family	Genus	Species			
Plantae	Angiospermae	Monocotyledoneae	Farinosae	Pontederiaceae	*Eichhornia*	*E. crassipes*[a]			
				Commelinaceae	*Commelina*	*C. communis*			
			Arales	Araceae	*Pistia*	*P. stratiotes*			
					Typhonium	*T. giganteum*			
				Lemnaceae	*Lemna*	*L. minor*			
			Graminales	Gramineae	*Phragmites*	*P. karka*			
					Bambusa	*B. blumeana*			
					Eleusine	*E. indica*			
		Dicotyledoneae	Centrospermae	Amaranthaceae	*Alternanthera*	*A. philoxeroides*[a]			
						A. pungens[a]			
			Urticales	Moraceae	*Ficus*	*F. heterophylla*			
			Tubiflorae	Convolvulaceae	*Ipomoea*	*I. aquatica*			
			Myrtiflorae	Onagraceae	*Ludwigia*	*L. octovalvis*			
			Euphorbiales	Euphorbiaceae	*Phyllanthus*	*P. niruri*			
			Rosales	Leguminosae	*Pongamia*	*P. pinnata*			
			Umbelliflorae	Umbelliferae	UN				

Animalia	Mollusca	Lamellibranchia	Veneroida	Veneridae	*Paphia*	*P. amabilis*	80 (26 F, 41 M, 13 J)	HNR	Liu (2011) and Yang (2014)
		Gastropoda	Mesogastropoda	Potamodidae	*Cerithidea*	*C. ornata*			
				Viviparidae	*Bellamya*	*B. purificata*			
					Angulyagra	*A. polyzonata*			
				Thiaridae	*Melaniodes*	*M. tuberculata*			
	Arthropoda	Crustacea	Decapoda	Palaemonidae	*Macrobrachium*	*M. hainanense*			
				Penaeidae	*Penaeus*	*P. monodon*			
						P. merguiensis			
	Chordata	Osteichthyes	Perciformes	Cichidae	*Tilapia*	*T. nilotica*[a]			
						T. mossabica[a]			
				Gobiidae	*Periophthalmus*	*P. cantonensis*			
		Amphibia	Anura	Bufonidae	*Bufo*	*B. melanostictus*			
		Reptilia	Squamata	Scincidae	*Mabuya*	*M. multifasciata*			
				Colubridae	*Xenochrophis*	*X. piscator*			
		Aves	UN						
		Mammalia	Rodentia	UN					

(continued)

Table 21.4 (continued)

Food items							Sample size	Study area	References
Kingdom	Phylum	Class	Order	Family	Genus	Species			
Plantae	Chlorophyta	Chlorophyceae	Cladophorales	Cladophoraceae	*Cladophora*	UN			
	Angiospermae	Monocotyledoneae	Farinosae	Pontederiaceae	*Monochoria*	*M. vaginalis*			
			Liliflorae	Liliaceae	*Asparagus*	*A. schoberioides*			
			Graminales	Gramineae	*Phragmites*	*P. australis*			
					Eleusine	*E. indica*			
					Setaria	*S. viridis*			
		Dicotyledoneae	Tubiflorae	Convolvulaceae	*Ipomoea*	*I. pes-caprae*			
				Verbenaceae	*Lantana*	*L. camara*[a]			
					Clerodendrum	*C. inerme*			
			Centrospermae	Aizoaceae	*Sesuvium*	*S. portulacastrum*			
			Campanulales	Compositae	*Silybum*	*S. marianum*			
					Praxelis	*P. clematidea*[a]			
					Parthenium	*P. hysterophorus*[a]			
			Rosales	Leguminosae	*Cassia*	*C. surattensis*			
					Pongamia	*P. pinnata*			
			Rubiales	Rubiaceae	*Borreria*	*B. stricta*			
					Paederia	*P. scandens*			
			Verticillatae	Casuarinaceae	*Casuarina*	*C. equisetifolia*			

Animalia	Mollusca	Gastropoda	Neogastropoda	Melongenidae	*Hemifusus*	*H. tuba*	84 (57 F, 25 M, 2 J)	GNR	Hu (2012)
	Arthropoda	Insecta	Coleoptera	Elateridae	*Campsosternus*	*C. auratus*			
				Lucanidae	*Neolucanus*	*N. sinicus*			
				Rutelidae	*Mimela*	UN			
			Hemiptera	Coreidae	*Homoeocerus*	*H. marginellus*			
			Odonata	Libellulidae	UN				
			Orthoptera	Pyrgomorphidae	*Atractomorpha*	UN			
	Chordata	Osteichthyes	Cypriniformes	Cyprinidae	*Carassius*	*C. auratus*			
					Puntius	*P. semifasciolatus*			
					Cyprinus	*C. carpio*			
			Perciformes	Channidae	*Channa*	*C. maculata*			
		Amphibia	Anura	Bufonidae	*Bufo*	*B. melanostictus*			
				Ranidae	*Hylarana*	*H. guentheri*			
						H. latouchii			
		Reptilia	Squamata	Scincidae	*Sphenomorphus*	*S. indicus*			
				Colubridae	*Xenochrophis*	*X. piscator*			
					Sinonatrix	*S. percarinata*			

(continued)

Table 21.4 (continued)

Food items							Sample size	Study area	References
Kingdom	Phylum	Class	Order	Family	Genus	Species			
Plantae	Pteridophyta	Filicopsida	Eufilicales	Athyriaceae	*Callipteris*	*C. esculenta*			
				Lygodiaceae	*Lygodium*	*L. scandens*			
	Angiospermae	Monocotyledoneae	Farinosae	Commelinaceae	*Commelina*	*C. communis*			
			Graminales	Gramineae	*Leersia*	*L. hexandra*			
					Phragmites	*P. australis*			
					Miscanthus	*M. floridulus*			
					Bambusa	UN			
			Cyperales	Cyperaceae	*Cyperus*	UN			
		Dicotyledoneae	Centrospermae	Amaranthaceae	*Alternanthera*	*A. philoxeroides*[a]			
					Celosia	*C. argentea*			
			Umbelliflorae	Umbelliferae	*Oenanthe*	*O. rosthornii*			
					Hydrocotyle	*H. sibthorpioides*			
			Myrtiflorae	Onagraceae	*Ludwigia*	*L. hyssopifolia*			
			Geraniales	Oxalidaceae	*Oxalis*	*O. corniculata*			
			Campanulales	Compositae	*Scorzonera*	*S. albicaulis*			
			Parietales	Theaceae	*Eurya*	*E. nitida*			
			Urticales	Moraceae	*Ficus*	*F. variolosa*			
			Tubiflorae	Acanthaceae	*Hygrophila*	*H. salicifolia*			
			Rosales	Leguminosae	*Caesalpinia*	*C. crista*			
			Polygonales	Polygonaceae	*Polygonum*	*P. lapathifolium*			
			Primulales	Primulaceae	*Lysimachia*	*L. fortunei*			

[a]Exotic species; *UN* Unrecognized, *F* Females, *M* Males, *J* Juveniles

Table 21.5 The basic data of reproduction effort of red-eared slider in China

Turtle No.	Laying date	Clutch size	Hatchlings	Hatchability (%)	Incubation period (days)	Study area
174	2012.04.25	11	0	0	–	QWR
188	2012.04.27	11	0	0	–	
186	2012.04.28	10	0	0	–	
197	2012.05.12	14	4	28.6	74	
196	2012.05.14	13	0	0	–	
194	2012.05.14	13	2	15.4	72	
188	2012.05.18	12	2	16.7	78	
194	2012.06.06	15	3	20.0	57	
83	2013.05.02	11	5	45.5	64	HNR
102	2013.05.05	10	1	10.0	56	
102	2013.05.26	8	5	62.5	61	
104	2013.05.14	12	4	33.3	68	
115	2013.05.27	14	0	0	–	

21.3.1.4 Reproduction

The red-eared turtles can successful reproduce in the wild in southern China. Natural nests and hatching turtles were both found in the QWR and HNR (Li 2013; Yang 2014; Table 21.5). There was no direct evidence that it can reproduce in the GNR. But such an possibility exists, because in this locality both natural nests and juveniles less than one year old were found, and hatching turtles emerged from the artificial nests in the wild (Zhou 2013).

In Hainan Island, Li (2013) and Yang (2014) conducted an extensive study on the reproductive ecology of red-eared slider in the QWR and HNR, respectively. In general, the reproduction of red-eared slider starts in February and lasts to the end of August. The females lay their eggs predominantly from mid-April to mid-June, with the peak occurring from late April to late May. They prefer to nests and lay eggs in such places that are located on gentle sunny slope, near shore, abundant with vegetation, with the soil being soft, wet and weakly acidic but not muddy.

Furthermore, we also detected the number and size of follicles of feral female sliders by ultrasonic technique in the QWR from October 2011 to September 2012 (Li et al. 2013; Fig. 21.5). The data showed that the females had a breeding frequency of 2.48 clutches per year, which suggests that sliders have a great reproductive ability. Such a reproductivity probably should contribute to its wide spread and population development in the wild.

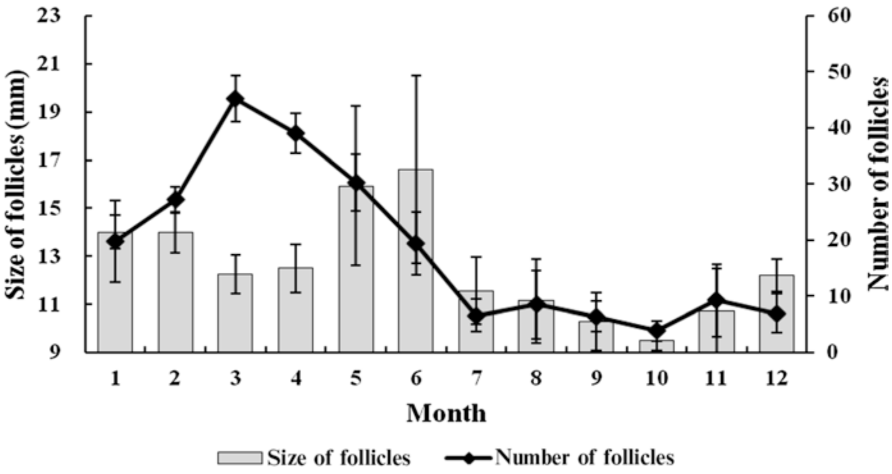

Fig. 21.5 The mean size and number of follicles per month of feral female sliders in the QWR

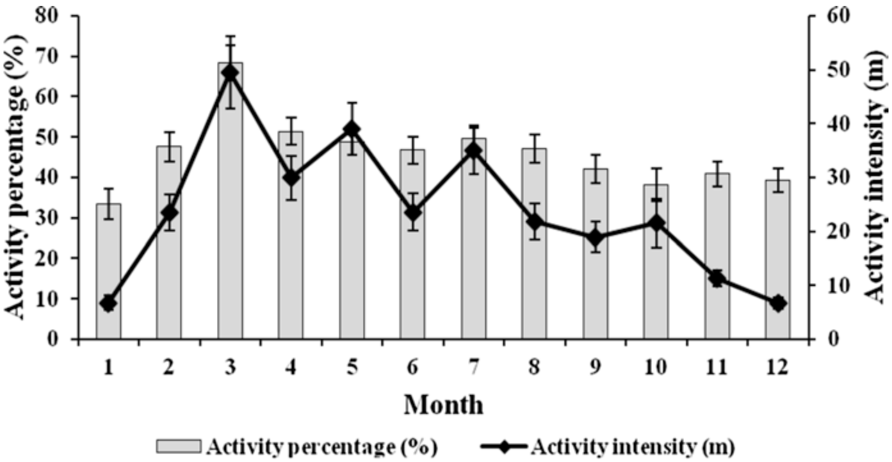

Fig. 21.6 Annual activity rhythm of red-eared slider

21.3.1.5 Behavior

Ma (2013) conducted an extensive study on the activity rhythm of the red-eared slider in the QWR from November 2011 to October 2012. The sliders are active in every month, and they do not enter hibernation and aestivation (Fig. 21.6). They are primarily diurnal exhibiting a unimodal pattern in daily activity (Fig. 21.7). Overall, the red-eared slider performs very well under local climate conditions, because the temperature is suitable (The annual average temperature 28.1°C was just within the most suitable activity temperature range between 28°C and 29°C for sliders).

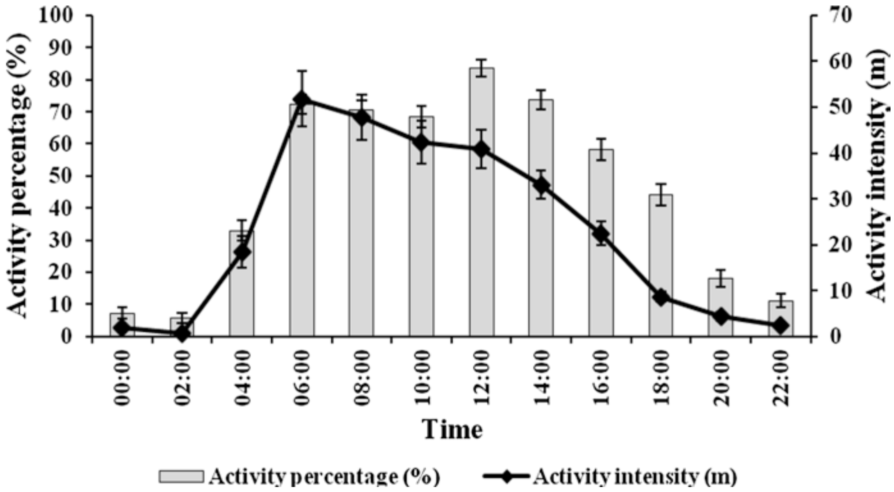

Fig. 21.7 Daily activity rhythm of red-eared slider

Temperature may be an indispensable reason why this species could make a successful invasion in Hainan Island.

In the daily activity of sliders, the basking behavior is a very important thermoregulation process. For this reason, we studied the basking habit in the QWR (Ma 2013). Basking time showed a clear unimodal pattern, with a peak in 11:00–13:00. The body surface temperature was significantly higher during periods of basking in comparison to periods of non-basking. During basking, the temperature of carapace surface increased at a rate of 0.18°C/min, and as the basking end it reached approximately 36°C. The results suggest that sliders have a thermal preference, and they could fully and effectively exploit the thermal heterogeneity of surrounding environments.

21.3.1.6 Physiology

In laboratories, the red-eared turtle has a strong tolerance to environmental stresses, by giving a series of physiological and biochemical responses to harsh conditions. As compared with the native species *M. sinensis*, embryos of sliders had a higher survival on ammonium nitrate and acid stresses (Fu et al. 2012a, b, 2013; Li et al. 2014b), as do the juveniles on the chronic nitrite stress (Zhang et al. 2011). This suggests that, when facing ambient stress, the slider is probably able to improve its anti-oxidant ability and nonspecific immunity function by certain approaches, such as increasing the number of haemocyte and changing the morphology of red blood cell. In addition, the slider also has stronger starvation endurance than *M. sinensis* (Wei et al. 2012). This suggests that the slider may conserve food much efficiently and would reduce basal metabolic rate in the case of food shortage.

Moreover, the red-eared slider has a high adaptability to salinity stress. They are able to survive over three months in the brackish water with a salinity below 15‰ (Zhang 2014). This is because sliders can increase blood osmotic pressure by balancing the entry of NaCl with the secretion of aldosterone decreased, and by accumulating blood urea for osmoregulation effectors (Hong et al. 2014; Zhang et al. 2014). Besides, they also improved the metabolic level by increasing blood-sugar content and enzymatic activities to provide energy required for resisting salinity stress (Shu et al. 2012).

21.3.2 The Role of Local Communities Impedance

No native predators that hunt the adult, juvenile, or hatching sliders have been found in China. But some small animals can destroy the eggs of sliders, who are called nest predators. Nest predation is a primary cause of partial reproductive failure of sliders in the wild. This is the only spontaneous resistance force so far discovered that are exerted by native biological communities. Nest predation should have prevented the population growth of sliders, and as a consequence, have repressed their invasions to a certain extent.

For example, in Hainan island, eggs in the nest were primarily eaten by Taiwanese kukrisnakes (*Oligodon formosanus*) and ants (*Polyrhachis dives* and *Pheidole indica*), and the predation rates in the QWR and HNR reached 33.3% and 22.0%, respectively (Li 2013; Yang 2014). In the GNR, nearly all of nest predators were ants, including *Pheidole* sp., *Pheidologeton* sp., *Camponotus albosparsus*, *Camponotus nicobaresis*, *Plagiolepis mthneyi*, *Tapinoma melanocephalum*, *Paratrechina bourbonica*, which made an overall predation rate of approximately 65.6% (Zhou 2013).

Furthermore, Li et al. (2014a) investigated the type of nest predators, predation rates and the breeding success of the red-eared slider by simulating artificial nests at the Diaoluoshan village, Diaoluo Nature Reserve in Hainan island, which is the typical habitat of Indo-Chinese box turtle (*Cuora galbinifrons*). The result showed that 66.7% of nests were depredated and small mammals (51.3%, such as *Niviventer fulvescens* and *Tupaia belangeri*) and ants (28.8%) were the main predators.

In addition, the predation rates in the nature reserve (e.g. Gutian Nature Reserve & Diaoluo Nature Reserve) were higher than in the areas more disturbed by human activities, such as the QWR and HNR that locate on urban peripheral regions. This suggests that the community with higher biodiversity and more stable structure might have a relatively stronger resistance to alien species. In other words, the red-eared turtle is probably ready to invade such areas that suffer from habitat loss, degradation, and fragmentation.

21.4 Impacts

21.4.1 Impacts on Native Turtle Species

In order to get a scientific evaluation of the red-eared slider's impacts on native turtle species, we have conducted a series of comparative studies on this slider and the representative of indigenous species. In China, the red-eared slider lives with at least 14 native turtle species (e.g. *Mauremys sinensis*, *M. reevesii*, *M. mutica*, etc.) which account for 50% of total freshwater turtle species. Living in the same habitats have resulted in interspecific competition, including exploitation competition, interference competition and apparent competition (Shi et al. 2009; Ma et al. 2013; Wang 2013).

Firstly, the red-eared slider with a huge number of individuals would consume and occupy a lot of resources, such as food, basking sites, and nesting sites, which may induce intensive exploitation competition with native turtles. Such a type of competition has been found between the slider and *M. sinensis*. The two species have a sympatric distribution, and exploit the same spatial and food resources (Ma 2013; Wang 2013). As the sliders are more agile, aggressive and efficient in competition for food than *M. sinensis*, the native species obviously stands in the disadvantaged position in the competition (Zhao et al. 2013).

Secondly, the red-eared slider attacks the native turtles through biting, climbing, swiping, and pushing, and disturbing the courtship and mating activities of native turtles. Sometimes, sliders even mate with native turtles and produce hybrids, thereby negatively affecting reproduction and population development of the natives. For example, we found the hybrid of the red-eared slider and Chinese stripe-necked turtle in November 2007 in the Huadiwan market, Guangzhou (Shi et al. 2009; Fig. 21.8). Thus, the sliders might have polluted the genetic constitution of feral populations of native turtles through reproductive interference and hybridization (Ma et al. 2015).

Fig. 21.8 The hybrid of *T. s. elegans* and *M. sinensis* (Photo by Shi-Ping Gong)

Thirdly, apparent competition occurs when both native turtles and the sliders are captured by human. As the wild population of feral sliders grows, the number of turtle-capturing fishermen (including professional turtle hunters) is increasing (Ma 2013; Wang 2013). However, hunters prefer to capture the native turtles, which may have the higher price of aboriginal species (e.g. *M. sinensis* is about 200 RMB/kg vs. 80 RMB/kg of feral *T. s. elegans*). This phenomenon raises the risk for native turtles being captured and thus poses a serious threat to the indigenous animals in China.

In conclusion, if the slider population grows, then the fitness of vulnerable native turtles may be reduced due to the lack of available spatial and food resources. As a result, native species might be squeezed out of suitable habitats over time and finally extinct.

21.4.2 Impacts on Human Health

The red-eared turtle may have a potential risk on human health by transmitting Salmonellosis, one of the important anthropozoonosis caused by *Salmonella*. In human beings, especially children and people with weak immune systems, *Salmonella* causes diarrhoea, cramps, fever, and nausea, and can lead to more serious complications such as blood poisoning, meningitis, or even death (Tauxe et al. 1985; Centers for Disease Control Prevention 2007). There are about 130 million people each year infected by this pathogen and suffer from enterogastritis in the world (Pang et al. 1995). In the United States, Salmonellosis is a significant public health concern, which causes about 1.4 million illnesses and 400 deaths each year (Voetsch et al. 2004). Of them, large numbers of *Salmonella* infections have been traced back to pet terrapins, most of which were *T. s. elegans* (Ramsay et al. 2007).

In China, we found that the feral sliders have a high rate of carrying pathogenic *Salmonella*. Shen et al. (2011) detected the pathogen in 68 red-eared turtle individuals from Nandu River, Wanquan River and Haikou East Lake in Hainan Island. They found that 54.4% of these turtles carried *Salmonella*, and the rate in Nandu River, Wanquan River and Haikou East Lake reached 53.85%, 58.82% and 50%, respectively. The indentified *Salmonella* serotypes included *S*. Litchfiled, *S*. Chailey, *S*. Senftenberg, *S*. Newport, *S*. Tshiongwe, and *S*. Stanley. The rate did not vary significantly with sex, but it was significantly higher in juveniles than in adults (Shen 2011). Furthermore, *Salmonella* Pomona, a highly pathogenic serotype, was isolated from free-living exotic red-eared sliders in the wild in China for the first time (Gong et al. 2014). In the samples collected from the Gutian Nature Reserve, Guangdong province, the carrying rate of *S*. Pomona was 39% ($n = 41$), with 40% ($n = 25$) in juveniles and 38% ($n = 16$) in adult turtles.

Overall, the red-eared slider is promoting the spread of *Salmonella* in human and aquatic ecosystems. People have the possibility of being infected with this pathogen by direct or indirect contacts with red-eared turtles (Fig. 21.9). Therefore, lots of red-eared sliders in pet/food markets and in the wild are potentially huge sources of infection for *Salmonella*, posing a great potential threat to public health and ecosystems of China by transmitting Salmonellosis (Gong et al. 2014).

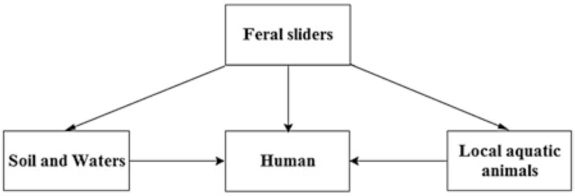

Fig. 21.9 The route of transmission in Salmonellosis via *T. s. elegans*

21.5 Management and Control

In the context of threatened and endangered species, introductions of alien turtle species should always be stiffly banned and governments should prevent the importation of freshwater turtles (Cadi and Joly 2003). In face of the serious threats from the exotic red-eared turtle, we need to take some measures to prevent or reduce such damages.

Firstly, enact relevant laws which ban the import of *T. s. elegans*. In 1975, the U.S. Food and Drug Administration prohibited the sale of turtles below 4 in. (ca. 10 cm) in carapace length in the United States and Canada because they could transmit salmonellosis by carrying bacterial pathogens *Salmonella* and *Arizona* (Bringsøe 2006). In 1997, the 16-member European Union banned the import of red-eared sliders on the grounds that they were having a deleterious effect on the indigenous European pond terrapin (*E. orbicularis*) (Ramsay et al. 2007). In 2001, the Ministry of Environment of South Korea banned the import of red-eared sliders due to potential ecosystem disturbance (Lee and Park 2010). However, currently in China, there have not been any laws and regulations to ban the import of *T. s. elegans*, hence about 8 million sliders still are imported into the country through various ways every year (Shi et al. 2009). Therefore, legislation should be enacted by the Chinese government as soon as possible.

Secondly, make a standardized management of turtle farms and trade markets. In the past, people in China always thought that the commercial production of turtles would greatly reduce the demands and consumption of wild native turtles. Actually, however, the massive culture of sliders could not alleviate the survival pressure posed on the wild natives. It appears difficult to change people's preference for eating wildlife, but instead more people might be attracted to eat and play turtles, which, in turn, impels a lot of hunters to catch wild turtles. To be worse, once a native turtle is caught, then it is very likely eaten as food or medicine; but if a slider is caught, it is usually released again into waters due to the cheap price. For these reasons, turtle farms and markets should be under strict supervision and control to prevent the farmed sliders from escaping. In addition, an appropriate tax-raise in slider farming has to be advised. Simultaneously, it is also urgent to strengthen the monitoring of farms and markets (including internet markets) and prohibit the sale of endangered wild turtles.

Thirdly, make a scientific management on the activity of freeing animals. Obviously, releasing animals into the wild is an effort which has very strong professional. A variety of factors, such as the origin of animals (alien or indigenous), ecological habits, individual health status, the time and place of releasing, have to be considered by professionals. However, as these aspects involved much knowledge in biology and ecology, non-professionals are almost impossible to get all of them. Thus, we need to take some measures to reduce irresponsible releasing of animals: (1) The releasing activities by religious groups should be supervised by the local government to forbid the releasing of alien species; (2) Establish the Animal Sanctuaries and Rescue Centre, and persons who have seen, bred or captured sliders are encouraged to contact a professional team; and (3) Train law-executors and managers of wildlife to enable them to identify invasive species.

Fourthly, enhance education and awareness of the public. Indeed, most people are not clear on the knowledge and awareness of biological invasions. Thus, public education on invasive species could be an effective strategy for preventing religious release and abandoned pets, particularly invasive species (Liu et al. 2013). In this context, we should pay more attention to the propaganda role of network and media, hold more popular science lectures, and broadcast more scientific documentaries about exotic species to the public. Information campaigns *via* the media should encourage people to better care for their pets/turtles and refrain from releasing them into the wild. All pet shops should be compelled to provide proper care sheets to buyers about how to deal with turtles and other animals, and required to tell customers the potential risk of salmonella infection. Billboards, which prohibit release red-eared slider, should be established in all of the parks and at the edge of natural waters, to inform the people that releasing sliders will cause eco-catastrophe.

21.6 Conclusion

The red-eared slider is an opportunistic omnivorous animal who has a strong competitive ability. This turtle can adapt to various environments, whether it is clear lakes, reservoirs, or muddy ponds, ditches, or even brackish waters in estuary; we could find them in almost all contaminated and uncontaminated waters, which has been become one of the most widely distributed invasive species in the world. On the one hand, the red-eared slider has a extend niche, the various physiological activities in tolerance to different ecological factors, and even in some environmental stresses; on the other hand, the red-eared slider has a strong behavioral adaptability and plasticity, it can adjust and change itself to adapt to all kinds of environmental conditions. The study found that, the red-eared slider can effectively utilize all kinds of resources, usually occupied and ruled the habitats which are the most conducive to its life.

Apart from all the own characteristics of red-eared slider, human factors played a key role in successful invasions. The surveys found that the wild distribution of red-eared slider was mainly concentrated in the waters surrounding the cities with high population and developed economy, and “released by people” is the main way causing sliders into natural environments.

At present, the threats from the red-eared slider are becoming extremely serious. In order to protect our fragile ecosystems and declining biodiversity, we still need to increase investment in scientific research, continue to carry out the studies on demographic characteristics (density, growth rate, survival rate, age composition, sex ratio, diffusion, etc.) of sliders. Monitoring the temporal and spatial changes of population for a long-term, and strengthen efforts to propaganda combining the government and social forces together to control this pest species.

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