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Effect of eutrophication on molluscan community composition in the Lake Dianchi (China, Yunnan)

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ABSTRACT

In this paper, three historical biodiversity datasets (from 1940s, 1980–1999 and 2000–2004) and results from the recent inventory are used to trace the long-term changes of the mollusks in the eutrophic Lake Dianchi. Comparison of the obtained results with those of earlier investigations performed during the period of 1940s and 1980–1999 as well as 2000–2004 showed that changes have occurred in the interval. There were 31 species and 2 sub-species recorded prior to the 1940s, but the species richness decreased from a high level of 83 species and 7 sub-species to 16 species and one sub-species from 1990s to the early of 21st century in lake body. Species from the genera of *Kunmingia*, *Fenouilia*, *Paraprygula*, *Erhaia*, *Assiminea*, *Galba*, *Rhombuniopsis*, *Unionea* and *Aforpareysia* were not found in Dianchi basin after 2000. The species from the genera *Lithoglyphopsis*, *Tricula*, *Bithynia*, *Semisulcospira* and *Corbicula* were only found in the springs and upstream rivers. Anoxia and the changing of substrates and fish species composition could explain why molluscan community composition changed in eutrophic Lake Dianchi. Additionally, the different sampling methods and ignore of the specific groups in earlier studies are cause for *Sphaerium* and *Pisidium* first found in our study. This study is first time to enlarge the investigation region to the Dianchi basin. Although some endemic species disappeared in the lake body, they still distribute in the springs and upstream rivers. The springs and upstream rivers are important refuges for mollusks.

Introduction

Mollusca is an extremely varied phylum with an estimate of 80,000–130,000 described species, while freshwater mollusca comprise ~5% of the world's mollusca fauna (Strong et al. 2008). Freshwater mollusks are useful tools as pollution indicators through assessments of the molluscan community composition and monitoring the heavy metal contamination (e.g. Salanki et al. 2003; Yang et al. 2005; W.G. Wang et al. 2004; Jou and Liao 2006). However, siltations from agriculture, organic pollution, pesticides, heavy metal loading, and habitat degradation have threatened the freshwater mollusks. In additional, food culture has affected diversity in Lake Dianchi. The local people believe that the snail is nutritious and treat the constipation, insomnia and fever, etc. (Li 1993). The quantity of production was huge, the fish men could harvest 1,000,000 kg snails in the Lake Dianchi per year before 1980s (Tchang and Cheng 1945; Peng 2002), however, due to the over-harvest and pollution, the quantity of production decreased to20,000 kg in 2000 (Peng 2002). There are 471 species of freshwater mollusks listed in the 2009 IUCN Red List of Threatened Species (http://www.iucnredlist.org), 10 species are from China, 4 of which are from Lake Dianchi (IUCN 2009). Although there are many investigations that indicate influence of eutrophication on changes in the abundance and composition of mollusks in North American and European (e.g. Carlsson 2001; Clarke 1979; Arter 1989; Nakamura and Kerciku 2000; Timm et al. 2006; Gray 2004; Zettler and Daunys 2007; Neves et al. 1997), the data concerning Asia is sparse.

The Dianchi basin is 2920 km^2 in extent and is located between the watersheds of the Jinshajiang-Yangtze, Honghe and Pearl rivers at an altitude of 1990 m. With an area of nearly 300 km^2 Lake Dianchi (24°51′N, 102°42′E) is one of the largest freshwater lakes in Yunnan, it is a eutrophic lake. The lake body is approximately 40 km long (north to south) and 12.5 km at its widest point, with an average water depth of 4.7 m and a maximum depth of 10.9 m (Yang et al. 2004). The lake body is divided into two parts, the small northern Cao Hai (inner lake), and the much larger Wai Hai (outer lake). The two parts of the lake have been separated by the construction of a causeway. Around the lake, there are 17 rivers and at least 20 springs flowing into the lake. The outflow from the Waihai is to the Tanglangchuan River at the southwest of the lake (Zhang et al. 2005). With the development of agriculture, industry and urbanization in the region, increasing sewage discharge has had an effect on changing the freshwater biodiversity structure (Luo et al. 2006; Yang et al. 2004; Gong et al. 2009). Aquatic macrophytes decreased

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Table 1
Characteristics of recent and historical molluscan surveys of the Lake Dianchi used for comparison.

Survey	Sampling method	Number of stations	Geographic range	Reference
1940s	Unknown or dredging	Unknown	Inshore of the lake, water depth <2 m	Tchang and Tsi (1949a,b) and Tchang (1948)
1980–1999	Hand net, dredging and Petersen grabs	About 15	Whole lake body	Wang (1985, 1988) and Zhang et al. (1997)
		47	Whole lake body	Chinese Academy of Sciences (1989)
2000–2004	Petersen grabs, dredging	20	Offshore of the lake	Wang et al. (2002, 2007) and L.Z. Wang et al. (2004)
This study	Hand net and dredging	37	Lake body, upstream rivers and springs	

from 90 to 6.8% of the lake area from the 1950s to the early of 21st century (Yang et al. 2004). Number of diatom species decreased from 21 to 9 during the period of 1958–2007 (Gong et al. 2009). However, the study on changing of mollusks structure in eutrophic Lake Dianchi is sparse. Additionally, investigation area was limited in the lake body by investigators. Here we test the use of historical biodiversity datasets in tracing the long-term changes of mollusks diversity in the eutrophic lake.

Materials and methods

The historical information on molluscan in the Lake Dianchi comes from three major stages. The first stage is before 1940s, the investigations were carried out in 1942 but the species list also includes information from earlier studies (Tchang 1948; Tchang and Tsi 1949a,b; Tchang and Hsia 1949). Later on, the most extensive inventory of the molluscan in the Lake Dianchi was performed during several surveys in the period from 1980 to 1999 (Huang and Zhang 1986, 1990; Wang 1985, 1988; Zhang et al. 1997; Chinese Academy of Sciences 1989). The third stage is during the period from 2000 to 2004, investigations were focus on the changing of macrozoobenthos in eutrophic Lake Dianchi (Wang et al. 2002, 2007; L.Z. Wang et al. 2004).

From March 2005 to March 2008, an intensive sampling was carried out every four months. 37 adlittoral stations (including rivers, springs and inshore of the lake) were sampled using a handnet (Fig. 1). This handnet consists of a metal frame of approximately 0.3 m by 0.3 m to which a conical net is attached with a mesh size of minimum 300 and maximum 500 μm. The frame is attached to a 1.5 m long shaft. Sampling effort is proportionally distributed over all accessible aquatic habitats. This includes the bed substrate (stones, sand or mud), macrophytes (floating, submerged, emerged) and all other natural or artificial substrates, floating or submerged in the water. For the rivers, kick sampling is performed by vertically positioning the handnet on the bed and turning over bottom material located immediately upstream by foot or hand. For offshore of the lake, mollusks are sampled using a dredge, the mesh size of dredge is about 2 cm. The samples pass through a 50 μm mesh net. Samples were marked and preserved with 75% alcohol, the mollusks were picked up in the room. The identification of mollusks was performed under microscope (Leica S6D, 6.3–40×). Mollusks were identified mainly based on Fulton (1906, 1914), Tchang and Hsia (1949), Tchang and Tsi (1949a,b), Tsi et al. (1985), Liu et al. (1979, 1993), and Davis et al. (1984, 1985). Sampling design characteristics are compared in Table 1.

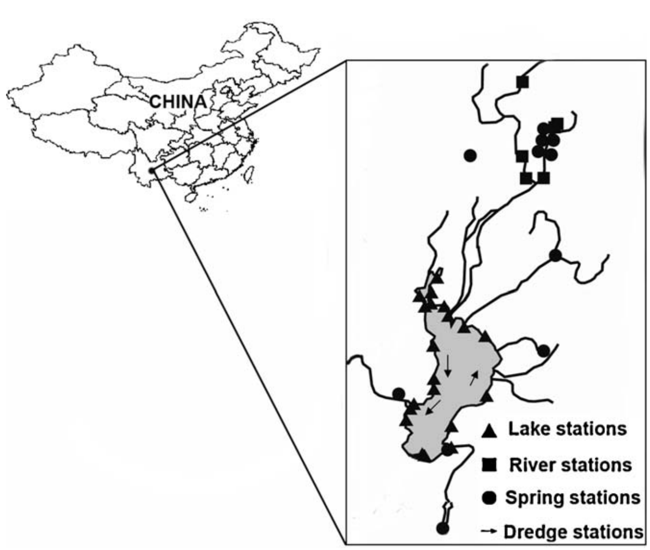

Fig. 1. Map of Lake Dianchi and basin of this lake and the sample stations.

Total phosphorus (mg/L) data were gathered from Meng (1999) and Zhang (2007). Water transparency data measured by Secchi disk depth were collected from Tchang (1948), Li et al. (1963), Meng (1999) and Zhang (2007).

Results

Altogether, 33 species and 4 sub-species belonging to 11 families were collected in Dianchi Basin. This included 29 species and one sub-species of class GASTROPODA and 4 species and 3 sub-species of class BIVALVIA. Among them, 16 species and one sub-species distributed in lake body belong to 6 families.

Species richness and composition have both changed radically over the past 60 years. There was 31 species and 2 sub-species recorded prior to the 1940s, but the species richness decreased from a high level of 83 species and 7 sub-species (Huang and Zhang, 1986, 1990; Wang 1985, 1988; Zhang et al. 1997) to 16 species and one sub-species from 1990s to the early of 21st century in lake body (Table 2). Species composition changed from predominant CAENOGASTROPODA snails to mostly BASOMMATOPHORA snails (Fig. 2). In 1940s, there were 17 species and 2 sub-species of CAENOGASTROPODA snails were record, but only 7 species were found in our survey, nearly 41% species disappeared from Dianchi basin before 2005. The situation of HETEROCONCHIA bivalves was worse than CAENOGASTROPODA snails, which the species of *Corbicula* drastically disappeared from the lake body. Conversely, the species of *Physella acuta* was first found in the lake after 2000, and the species of BASOMMATOPHORA snails gradually changed to the predominance species from 1940s to the early of 21st century. There was two species (*Anodonta fenouilii* and *Rhombuniopsis tauriformis*) recorded in PALAEOHETERODONTA in the 1940s, but 10 species, and 3 sub-species bivalve species were recorded during the period of 1980–1999; most of them were from the genus *Anodonta*. In our survey, only one species of *A. fenouilii* and one sub-species (*A. woodiana woodiana*) were found in the lake body.

During the eutrophication of Lake Dianchi, the species from several genera disappeared in Dianchi basin from 1940s to the early of 21st century. The species from nine following genera: *Kunmingia*, *Fenouilia*, *Paraprygula*, *Erhaia*, *Assiminea*, *Galba*, *Rhombuniopsis*, *Unionea* and *Aforpareysia* were not found after 2000 in Dianchi basin. Although the species from the genera *Lithoglyphopsis*, *Tric-*

Table 2
Faunistic composition of mollusks of Lake Dianchi and basin of this lake; E: endemic species. *: recorded species.

Taxon		1940s	1980–1999	2000–2004	2005–2008 (lake body)	2005–2008 (lake basin)
GASTROPODA						
CAENOGASTROPODA						
Viviparidae						
Angulyagra polyzonata (Frauenfeld)			*			
A. oxytropoides (Heude)			*			
Cipangopaludina lecythoides (Benson)		*	*			
C. lecythoides aubryana (Heude)	E	*	*			*
C. lecythoides fluminalis (Heude)		*	*			
C. ventricosa (Heude)		*	*			*
C. ventricosa (Heude)			*			
C. ampullacea (Charpentier)		*	*			
C. chinensis (Heude)			*		*	*
C. cathayensis (Heude)			*		*	*
C. haasi (Prashad)			*			
C. latissima (Dautzenberg et H. Fischer)			*			
C. ampulliformis (Souleyet)			*			
C. dianchiensis Zhang	E		*		*	*
Bellamya aeruginosa (Reeve)			*			*
B. delavayana (Heude)			*			
B. angularis (Müller)			*			
B. quadrata (Benson)			*			*
B. limnophila (Mabille)			*		*	*
Margarya melanioides Nevill		*	*	*	*	*
M. monodi Dautzenberg et H. Fischer	E	*	*		*	*
M. tropidophora (Mabille)		*	*			
M. bicostata Tchang *et* Tsi			*			
Pomatiopsidae						
Kunmingia gredleri (Neumayr)	E	*	*			
K. costata (Tchang et Tsi)		*	*			
K. constricta (Tchang et Tsi)		*	*			
K. kunmingensis (Liu et al)			*			
Fenouilia kreitneri (Neumayr)		*	*			
Paraprygula coggini Annandale et Prasghad			*			
Lithoglyphopsis ovatus Liu et al.			*			
L. grandis Liu et al			*			*
L. fuchsianus (Moellendorff)			*			
Tricula gregoriana Annandale			*			*
T. montana Benson			*			
T. ludongbini Davis et Guo			*			*
Amnicolidae						
Erhaia kunmingensis Davis et Guo	E		*			
Bithyniidae						
Parafossarulus striatulus (Benson)			*		*	*
Bithynia fuchsiana (Moellendorff)			*			*
Assiminea violacea subangulata Heude			*			
Semisulcospiridae						
Semisulcospira dulcis (Fulton)	E	*	*			*
S. lauta (Fulton)	E	*	*			*
S. inflata Tchang et Tsi	E	*	*			*
S. scrupea Fulton	E	*	*			
S. scrupea debilis (Fulton)	E	*	*			
S. aubryana (Heude)	E	*	*			
S. vultuosa (Fulton)		*	*			*
S. cancellata (Benson)	E	*	*			
BASOMMATOPHORA						
Physidae						
Physella acuta Draparnaud				*	*	*
Lymnaeidae						
Radix swinhoei (H. Adams)		*	*	*	*	*
R. patuia (Troschel)		*	*	*		
R. yunnanensis (Nevill)		*	*	*	*	*
R. peregra (Müeller)		*	*			*
R. ovata (Oraparnaud)		*	*	*	*	
R. rufescens (Gray)		*	*			
R. rubiginosa (Michelin)		*	*		*	*
R. auricularia (Troshel)			*	*	*	
R. plicatula (Benson)			*	*	*	*
R. succinea Deshayes			*			*
R. luteola Lamarck			*			
R. siamensis Somerby			*			
R. lagotis (Schrank)			*	*		
Galba truncatula (Müller)		*	*			
G. andersoniana (Nevill)			*			

Table 2 (*Continued*).

Taxon		1940s	1980–1999	2000–2004	2005–2008 (lake body)	2005–2008 (lake basin)
Planorbidae						
H. umbilicalis (Benson)			*	*	*	*
Gyraulus convexiusculus (Hutton)			*	*		*
G. albus (Müller)			*			*
G. compressus (Hutton)			*			*
BIVALVIA						
HETEROCONCHIA						
Corbiculidae						
Corbicula praeterita (Heude)		*	*			
C. ferruginea Heude		*	*			
C. andersoniana (Nevill)		*	*			
C. fluminea (Müller)			*			
C. largillierti (Philippi)			*			*
C. soriniana Heude			*			
C. obtruncata Heude			*			
C. methoria Heude			*			
C. fenouilliana Heude		*	*			
C. subobliqua Heude			*			
Sphaeriidae						
Sphaerium sp.						*
Pisidium sp.						*
PALAEOHETERODONTA						
Unionidae						
Anodonta fenouilii (Heude)	E	*	*		*	*
A. woodiana woodiana (Lea)			*		*	*
A. w. pacifica (Heude)			*			*
A. w. elliptica (Heude)			*			*
A. berigiana Middendorff			*			
A. piscatora (Heude)			*			
A. vescoiana (Heude)			*			
A. pumila (Heude)			*			
A. latirplana Huang et Zhang			*			
Rhombuniopsis tauriformis Fulton	E	*	*			
Unionea fagana Dehays et Jullien			*			
U. ovatiquadreta Huang et Zhang			*			
Aforpareysia hunanensis (Hass)			*			

Data in 1940s from Tchang (1948), Tchang and Tsi (1949a,b), and Tchang and Hsia (1949); in 1980–1999 from Huang and Zhang (1986, 1990), Wang (1985, 1988), Zhang et al. (1997), and Chinese Academy of Sciences (1989); in 2000–2004 from Wang et al. (2002, 2007) and L.Z. Wang et al. (2004).

ula, *Bithynia*, *Semisulcospira* and *Corbicula* were found in Dianchi basin, they only distributed in the springs and upstream rivers. In the lake body, species from the genera *Cipangopaludina*, *Margarya*, *Bellamya*, *Physella*, *Radix* and *Anodonta* are present species.

Fourteen endemic species (including 12 snails and 2 bivalve species) were recorded in Lake Dianchi basin (Table 2). During the past 60 years, only 5 species and 1 sub-species endemic snail (*Cipangopaludina lecythoides aubryana*, *C. dianchiensis*, *Margarya monodi*, *Semisulcospira dulcis*, *S. lauta* and *S. inflate*) and one endemic bivalve species (*A. fenouilii*) were found in 2005–2008. *C. dianchiensis* and *A. fenouilii* were found in 2005–2008 in the lake body, and other species were found only in the springs and upstream rivers. At the time of the previous investigations, *P. acuta*, *Sphaerium* sp. and *Pisidium* sp. were not registered, but in our investigation, the *Sphaerium* sp. and *Pisidium* sp. are common in the springs and *P. acuta* was found both in lake body and springs.

Level of water quality has drastically changed during the last 60 years. The average transparency was about 102 cm in 1942, but it decreased to 54 cm in 2005 (Fig. 3), and the total phosphorus increased from 0.046 mg/L in 1982–1983 to 0.187 mg/L in 2005 (Fig. 4). The transparency and total P had the worst value in 1999, the transparency was 42 cm and the total P was 0.331 mg/L.

Discussion

Due to the waste pollution, pesticide from agriculture, unsustainable water extraction for irrigation, stock and urban use, the water quality of Lake Dianchi gradually deteriorated from the 1980s, and it was even worse in 1999 (Figs. 3 and 4). The changing of water quality probably has resulted the changing of mollusks community in the Lake Dianchi. The abundance of tolerant pollution species increased, such as species of *Radix*, *Physella* and *Parafossarulus*, but most of sensitive species, species of *Semisulcospira*, *Kunmingia*, *Tricula*, *Corbicula* and *Lithoglyphopsis* have disappeared in the lake body.

The mollusk's ecological features, such as life habit, mode of respiration, sexual reproductive and ability to withstand desiccation, may determine the mollusk community structure in eutrophic lake. Kołodziejczyk et al. (2009) mentioned that anoxia might be such a disaster to the mollusks species in eutrophic lakes, especially in CAENOGASTROPODA snails. CAENOGASTROPODA snails are strongly associated with the bottom, therefore the species is most exposed to the anoxia influence, however, snails of BASOMMATOPHORA could be able to capture and use the oxygen released by plants during photosynthesis and in some the BASOMMATOPHORA snails' cavity is filled with water and functions as a branchium or gill (Kołodziejczyk et al. 2009; Clarke 1979; Brönmark and Hansson 2005). The species of *Pisidium* and *Sphaerium* always distribute in the stony or sandy bottom, but the substrate has been covered due to increased organic material load in course of eutrophication (Zettler and Daunys 2007). Anoxia and changing of substrate might be possible explanations why benthic mollusks disappeared in the lake body. Additionally, the changing of fish species composition could be a reason why the unionid mussel disappeared in the eutrophic lake. There is the strong dependence of unionid mussel on fish as hosts for larval development and dispersal, when the species composition of the fish community changes, the prob-

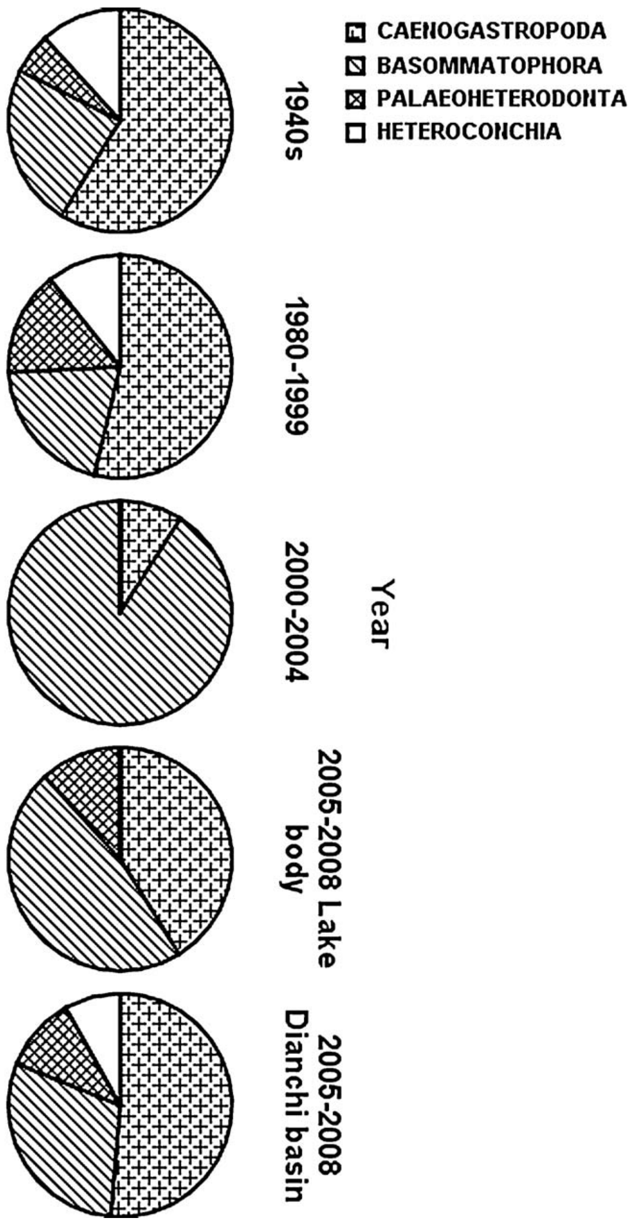

Fig. 2. The changing of mollusks composition during the last 60 years in Lake Dianchi.

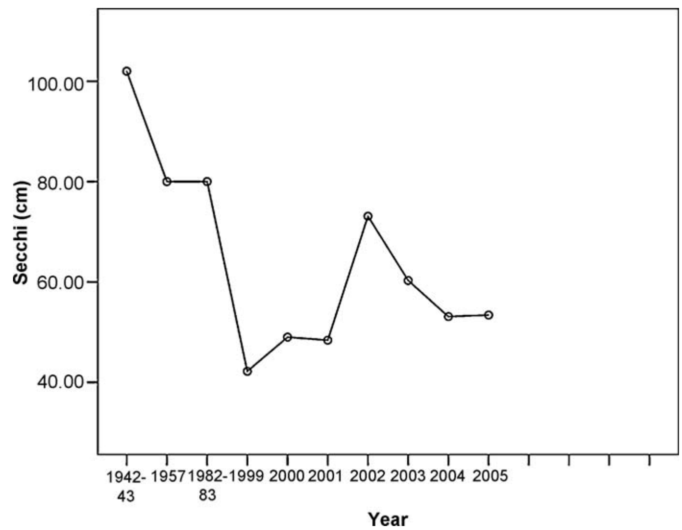

Fig. 3. The changing of Secchi disk visibility from 1942 to 2005 in Lake Dianchi (data from Li et al. 1963; Tchang 1948; Meng 1999; Zhang 2007).

ability of infection of fish by glochidian can change also, due to differences in infection rates of different fish species (Arter 1989; Killeen et al. 2004).

In 1940s, 31 species and 2 sub-species were recorded, however, the number of taxa increased to 82 species and 7 sub-species during the period of 1980–1999. The species number of all of families (except the family Semisulcospiridae) has notably increased. Chinese Academy of Sciences (1989) mentioned that many unionid mussels found in 1980–1999 was associated with introducing of economic fishes and macrophytes by human after 1958 (Gong et al. 2009; Wang and Dou 1998). Additionally, person identify the mollusks always according to the sculpture, shell shape, color or other external characters, however, the shell may be prone to environmental pressures and cases of phenotypic plasticity in shell morphology (e.g. Arter 1989; Palmer 1985; Trussell and Smith 2000; Shu et al. 2010; Reed and Janzen 1999; Warner 1996). Our molecular study indicated four species of *Margarya* and *C. dianchiensis* are synonym species (unpublished). In a review on Asian *Corbicula*, Morton (1986) mentioned when morphological variation was considered together with data on ecology, physiology, demography and reproductive behavior, only two biological species could be recognized in east Asia, freshwater *C. fluminea* (Müller, 1774) and estuarine *C. fluminalis* (Müller, 1774). Additional Kijviriya et al. (1991) indicated that all Thai *Corbicula* species are referable to a single species, *C. fluminea*. Hence, these consequences could indicate that many species from one genus (such as the genus *Cipangopaludian*, *Bellamya*, *Kunmingia*, *Radix*, *Corbicula* and *Anodonta*) could the variance of one or few species. The validity of these species may be settled using molecular data in the future.

Different sampling methods and ignore of the specific groups in earlier studies could be potential sources of differences in the results from the four time periods. It is unclear, how samples have been collected and sorted in 1940s (only dredging was noted) as well as number and locations of stations remain unknown (Table 1). However, according to the description, sampling sites were restricted to the inshore of lake, the water depth was less than 2 m (Tchang and Tsi 1949a,b; Tchang 1948). In contrast, very extensive survey carried out in the whole lake body using dredging, and hand net as well as Petersen grabs during the period 1980–1999 (Wang 1985, 1988; Zhang et al. 1997; Chinese Academy of Sciences

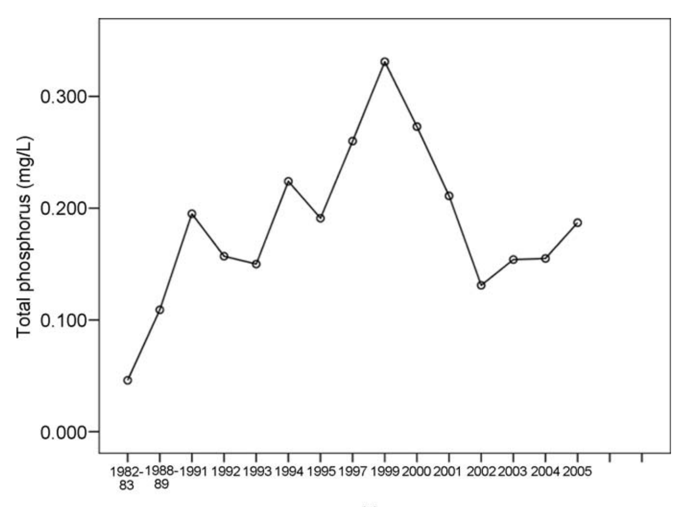

Fig. 4. The changing of total phosphorus from 1982 to 2005 (data from Meng 1999; Zhang 2007).

1989). Although many species were described from a littoral part, the authors most likely visited numerous offshore stations remains unclear. In the 2000–2004, Petersen grabs and dredging was used in the offshore of lake (Wang et al. 2002, 2007; L.Z. Wang et al. 2004). It can be concluded that, only dredge was used in 1940s, the sampling effort was considerably lower than in 1980–1999; therefore, most likely widespread and characteristic species (particularly for species of Viviparidae and Semisulcospiridae snails as well as Unionidae mussels) did occur in samples only. In contrast, comprehensive species list from 1980 to 1999 exhaustively reflects lake's biodiversity status 20 years ago. Since inshore stations are more efficient in covering biodiversity, we do no anticipate major differences between 1940s and 1980–1999 datasets due to sampling design. However, the surveys focused on the offshore of lake during the period 2000–2004, it was possible cause for a few mollusks found. In our opinion, the cause of ignore of the specific groups in earlier studies seem to be most likely. There are numerous examples of it, e.g. the taxonomical expertise for determining sphaeriid species (*Pisidium* and *Sphaerium*) is one reason for the enlarged species list in our study.

Additionally, in our study is the first time to enlarge the survey region to Dianchi basin. Although most of mollusks species disappear in the lake body, some mollusks still distribute in the springs and upstream rivers. These springs and upstream rivers are important refuge for them. To avoid the extinction of indigenous species in these springs and rivers, conservation measures for the biodiversity of mollusks is urgently needed, and more comprehensive studies should be carried out.

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References

Arter, H.E., 1989. Effect of eutrophication on species composition and growth of freshwater mussels (Mollusca, Unionidae) in Lake Hallwil (Agrgam Aargau, Switzerland). Aquat. Sci. 51 (2), 87–99.

Brönmark, C., Hansson, L.A., 2005. The Biology of Lakes and Ponds, 2nd ed. Oxford University Press.

Carlsson, R., 2001. Freshwater snail communities and lake classification, An example from the Åland Islands, Southwestern Finland. Limnologica 31, 129–138.

Chinese Academy of Sciences, 1989. Nanjing Institute of Geography and Limnology, Lanzhou Institute of Geology, Institute of Geochemistry, Nanning Institute of Geology and Paleontology. Environments and Sedimentation of Fault Lakes, Yunnan Province. Science Press, Beijing.

Clarke, A.H., 1979. Gastropods as indicators of trophic lake stages. The Nautilus 94 (4), 138–142.

Davis, G.M., Guo, Y.H., Hoagland, K.E., Chen, P.L., Zheng, L.C., Yang, H.M., Chen, J.C., Zhou, Y.F., 1985. Anatomy and systematics of *Triculina* (Prosobranchia: Pomatiopsidae: Triculinae), freshwater snails from Yunnan, China, with descriptions of new species. Proc. Acad. Nat. Sci. Philadelphia 138 (2), 466–575.

Davis, G.M., Kuo, Y.H., Hoagland, K.E., Chen, P.L., Yang, H.M., Chen, D.J., 1984. *Kunmingia*, a new genus of Triculinae (Gastropoda: Pomatiopsidae) from China, Phenetic and Cladistic relationships. Proc. Acad. Nat. Sci. Philadelphia 136, 165–193.

Fulton, H.C., 1906. Description of a new species of *Unio* (*Cuneopsis*) from Yunnan. Ann. Mag. Nat. Hist. 7 (17), 246–248.

Fulton, H.C., 1914. Descriptions of new species of *Melania* from Yunnan, Java, and the Tsushima Islands. J. Mollus. Stud. 11 (3), 163–164.

Gong, Z.J., Li, Y.L., Shen, J., Xie, P., 2009. Diatom community succession in the recent history of a eutrophic Yunnan Plateau lake, Lake Dianchi, in subtropical China. Limnology 10, 247–253.

Gray, L., 2004. Changes in water quality and macroinvertebrate communities resulting from urban stormflows in the Provo River, Utah, USA. Hydrobiologia 518, 33–46.

Huang, B.Y., Zhang, L., 1986. Freshwater Lamellibranchia from Dianchi, Yunnan, Chinese. In: Chinese Society of Malacology (Ed.), Transactions of the Chinese Society of Malacology, No. 2. Science Press, p. 171.

Huang, B.Y., Zhang, L., 1990. The distribution and environment of Unionids from Dianchi and Er-hai Lakes in Yunnan Province, Chinese. In: Chinese Society of Malacology (Ed.), Transactions of the Chinese Society of Malacology, No. 3. Science Press, Beijing, pp. 69–75.

IUCN, 2009. IUCN Red List of Threatened Species. Version 2009.2.

Jou, L.J., Liao, C.M., 2006. A dynamic artificial clam (*Corbicula fluminea*) allows parsimony on-line measurement of waterborne metals. Environ. Pollut. 135, 41–52.

Kijviriya, V., Upatham, E.S., Woodruff, D.S., 1991. Genetic studies of Asian clams, Corbicula, in Thailand: allozymes of 21 nominal species are identical. Am. Malac. Bull. 8, 97–106.

Killeen, I., Aldridge, D., Oliver, G., 2004. Freshwater Bivalves of Britain and Ireland. British Occasional Publication.

Kołodziejczyk, A., Lewandowski, K., Stańczykowska, A., 2009. Long-term changes of mollusk assemblages in bottom sediments of small semi-isolated lakes of different trophic state. Pol. J. Ecol. 57 (2), 331–339.

Li, J.Q., 1993. The utilization of Margarya from Lake Er-hai. Chin. Cuisine 13, 3–36.

Li, S.H., Yu, M.J., Li, G.Z., Zeng, J.M., Chen, J.Y., Gao, B.Y., Huang, H.J., 1963. Limnological survey of the lakes of Yunnan Plateau. Oceanol. Limnol. Sin. 5 (2), 87–114.

Liu, Y.Y., Zhang, W.Z., Wang, Y.X., 1993. Medical Malacology. China Ocean Press, Beijing (in Chinese).

Liu, Y.Y., Zhang, W.Z., Wang, Y.X., Wang, E.Y., 1979. Freshwater mollusks. In: Economic Fauna of China. Science Press, Beijing (in Chinese).

Luo, M., Duan, C., Shen, X., Yang, L., 2006. Environmental degradation and loss of species diversity in Dianchi Lake. Mar. Fish. 28, 71–78.

Meng, Y.F., 1999. The development tendency analysis of nitrogen and phosphorous content in Waihai of Dianchi Lake. Yunnan Environ. Sci. 18 (4), 32–33 (English abstract).

Morton, B., 1986. Corbicula in Asia – an update synthesis. Am. Malac. Bull. 2, 113–124.

Nakamura, Y., Kerciku, F., 2000. Effects of filter-feeding bivalves on the distribution of water quality and nutrient cycling in a eutrophic coastal lagoon. J. Mar. Syst. 26, 209–221.

Neves, R.J., Bogan, A.E., Williams, J.D., Ahlstedt, S.A., Hartfield, P.W., 1997. Status of the aquatic mollusks in the southeastern United States: a downward spiral of diversity. In: Benz, G.W., Collins, D.E. (Eds.), Aquatic Fauna in Peril: The Southeastern Perspective, pp. 43–86. Special Publication 1, Southeast Aquatic Research Institute, Decatur, GA, USA, 554 pp.

Palmer, A.R., 1985. Quantum changes in gastropod shell morphology need not reflect speciation. Evolution 39 (3), 699–705.

Peng, Q.Y., 2002. The shrimps of Lake Dianchi, Yunnan. Reservoir Fish. 22 (2), 33–34 (in Chinese).

Reed, W.L., Janzen, F.J., 1999. Natural selection by avian predators on size and colour of a freshwater snail (*Pomacea flagellata*). Biol. J. Linnean Soc. 67, 331–342.

Salanki, J., Farkas, A., Kamardina, T., Rozsa, K.S., 2003. Molluscs in biological monitoring of water quality. Toxicol. Lett. 140–141, 403–410.

Shu, F.Y., Köhler, F., Wang, H.Z., 2010. On the shell and radular morphology of two endangered species of the genus Margarya Nevill, 1877 (Gastropoda: Viviparidae) from lakes of the Yunnan Plateau, Southwest China. Mollus. Res. 30 (1), 17–24.

Strong, E.E., Gargominy, O., Ponder, W.F., Bouchet, P., 2008. Global diversity of gastropods (Gastropoda: Mollusca) in freshwater. Hydrobiologia 595, 149–166.

Tchang, S., Cheng, C.T., 1945. Etude sur une paludine comestible, *Margarya melanioides*, de Tien-Chih. Culture Sino-francaise 1 (4), 1–6.

Tchang, S., 1948. Recherches limnologiques et zoologiques sur le lac de Kunming, Yunnan. Contr. Inst. Zool. Nat. Acad. Peiping 4 (1), 55–61.

Tchang, S., Hsia, W.P., 1949. The regional differences and the sexual dimorphism of two snails, Margarya melanioides Nevill and *Margarya monodi* Dautzenberg & Fischer, from the west coast of Kunming Lake. Contr. Inst. Zool. Nat. Acad. Peiping 5 (2), 67–77.

Tchang, S., Tsi, C.Y., 1949a. Liste des Mollusques d'eau douce recueillis pendant les années 1938–1946 au Yunnan et description d'éspèces nouvlles. Contr. Inst. Zool. Nat. Acad. Peiping 5 (5), 205–220.

Tchang, S., Tsi, C.Y., 1949b. A revision of the genus *Margarya* of the family Viviparidae. Contr. Inst. Zool. Nat. Acad. Peiping 5 (1), 1–26.

Timm, H., Möls, T., Timm, T., 2006. Effects of long-term non-point eutrophication on the abundance and biomass of macrozoobenthos in small lakes of Estonia. Proc. Estonian Acad. Sci. Biol. Ecol. 55 (3), 187–198.

Trussell, G.C., Smith, C.D., 2000. Induced defenses in response to an invading crab predator: an explanation of historican and geographic phenotypic change. Proc. Natl. Acad. Sci. U.S.A. 97 (5), 2123–2127.

Tsi, C.Y., Ma, X.T., Liu, Y.Y., Chen, D.N., Wang, Y.X., Zhang, W.Z., Gao, J.X., 1985. Fauna Photo Sinica (Mollusk, vol. 4). Science Press, Beijing (in Chinese).

Wang, L.Z., 1985. A research of bigger invertebrates in Yunnan Dianchi Lake. J. Yunnan Univ. 7 (Suppl.), 73–84.

Wang, L.Z., 1988. An ecological study on mollusca population in Plateau Lakes of Yunnan. J. Yunnan Univ. 10 (Suppl. (31)), 37–43.

Wang, L.Z., Liu, Y.D., Chen, L., Xiao, B.D., Liu, J.T., Wu, Q.L., 2007. Benthic macroinvertebrate communities in Dianchi Lake Yunnan and assessment of its water. Acta Hydrobiol. Sin. 31 (4), 590–593.

Wang, L.Z., Liu, Y.D., Xiao, B.D., 2004. Benthos in the enclosures in the Dianchi Lake. Reservoir Fish. 131, 49–51.

Wang, L.Z., Xu, X.Q., Zhou, W.B., Xiao, H., 2002. A study on the zoobenthos in Macunwan and Haidongwan Region of Dianchi Lake Yunnan. J. Yunnan Univ. 24 (2), 134–139.
Wang, S.M., Dou, H.S., 1998. Chinese Lake. Science Press, Beijing.
Wang, W.G., Wang, L.Z., Liu, Y.D., Xiao, B.D., Yang, Y., Bao, C.X., Zhu, G.H., 2004. Accumulation of metals in a clam *Anodonta woodiana elliptica* bred in Dianchi lake water. J. Yunnan Univ. 26 (6), 541–543.
Warner, G.F., 1996. Factors affecting the selection of pond snail prey by signal crayfish. Freshw. Crayfish 11, 194–202.
Yang, J., Wang, H., Zhu, H.Y., Gong, X.Q., Yu, R.P., 2005. Bioaccumulation of heavy metals in *Anodonta woodiana* from Wulihu area of Taihu lake. Resour. Environ. Yangtze Basin 14 (3), 362–366.
Yang, Z.P., Zhang, X., Liu, A.R., 2004. Study on aquatic vegetation change in Dianchi Lake. J. Southwest Forestry College 24 (1), 27–30 (English abstract).
Zettler, M.L., Daunys, D., 2007. Long-term macrozoobenthos changes in a shallow boreal lagoon: comparison of a recent biodiversity inventory with historical data. Limnologica 37, 170–185.
Zhang, N.G., Hao, T.X., Wu, C.Y., Chen, Y.X., Zhang, W., Li, J.K., Zhang, Y., 1997. A research of freshwater gastropoda from Yunnan. Stud. Mar. Sin. 39, 15–25.
Zhang, W., Li, Y., Wang, R.N., 2005. The research of biodiversity for the species of phytoplankton in Dianchi Lake, Kunming, China. J. Yunnan Univ. 27 (2), 170–175 (English abstract).
Zhang, Z.Z., 2007. Study on nitrogen and eutrophication of Dianchi lake. Environ. Sci. Stud. 26 (6), 34–36 (English abstract).