Seasonal pattern of waterbird communities at Lake Dianchi, Yunnan–Guizhou Plateau, south-west China

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Habitat use and requirements of waterbird assemblages are often spatiotemporally variable. Conservation management needs to be planned to consider seasonally-occurring waterbird communities. The Yunnan–Guizhou Plateau is an important wintering region for waterbirds in China. It is unclear how wetlands on the plateau are consistently utilised as habitat by waterbirds across different seasons. We conducted three surveys per month over two years from March 2013 to February 2015 at Lake Dianchi, the largest lake on the Yunnan–Guizhou Plateau, to determine multi-year waterbird species composition, annual similarity in species composition, and migratory consistency of species to better inform waterbird conservation. We detected approximately 60,000 individuals of 93 waterbird species at Dianchi. Annual species richness exhibited three peaks representing spring, autumn and winter migratory seasons. Year-on-year similarity in species composition was high for different groups, especially residents and summer visitors. The annual variation in waterbirds abundance exhibited a single peak in winter because of the high abundance of Anatidae and Laridae. Charadriiformes, such as shorebirds and plovers, had relatively low numbers of individuals, but exhibited high (R = 0.95, P < 0.01) to modest (R = 0.57, P < 0.01) migration consistency during the northward (spring) and southward (autumn) migrations. We highlight the importance of Dianchi for waterbird conservation. We suggest that waterbird conservation activities such as monitoring schemes should consider seasonal variation, especially for waders during the migratory seasons.

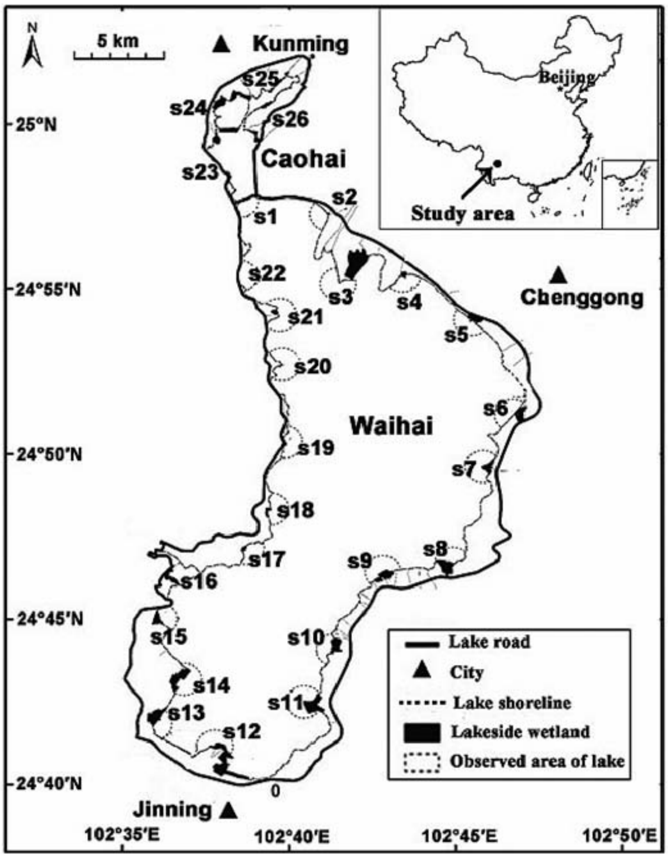
INTRODUCTION

Approximately 50% of the extent of natural wetlands worldwide have been drained over the past century (Fraser & Keddy 2005, Gong *et al.* 2010, Ramsar Convention Secretariat 2013). As a result, waterbird populations have declined dramatically globally (Cao *et al.* 2008, Ma *et al.* 2014). Approximately 38% of waterbird species are currently in decline worldwide, and the situation is especially serious in Asia, where the largest extent of remaining waterbird habitat occurs, and where about half of the 361 waterbird species are declining, with at least 18% globally threatened (Wetlands International 2012, BirdLife International 2020). In China, 32.3% of 260 waterbird species are declining (Wang *et al.* 2018). In response to these alarming trends, many conservation measures have been adopted to protect wetlands, including natural wetland restoration and the construction of artificial wetlands (Giosa *et al.* 2018). Meanwhile, robust population monitoring data remain relevant in informing wetland management for waterbird conservation outcomes.

Seasonal and perennial wetlands are exceptionally productive habitats that support high densities and diversities of species (Costa *et al.* 2018). Various wetland types are used by different seasonal assemblages of waterbirds. For example, tidal/intertidal mudflats are used by shorebirds as stopover sites during the migratory season in the Yellow Sea in eastern Asia (e.g. Studds *et al.* 2017), the Wadden Sea in Europe (van Roomen *et al.* 2012) and elsewhere. Meanwhile, the diversity of freshwater wetlands including farm ponds are used by many waterfowl such as ducks in winter (e.g. Lai *et al.* 2018, Hsu *et al.* 2019). The distribution and habitat use of many waterbird species are often dynamic across space and time (Runge *et al.* 2014, Marra *et al.* 2015). Therefore, conservation policies and management practices should take such variation into consideration to address the particular habitat needs of migratory waterbirds during the breeding, stopover and wintering periods to better conserve them (Isola *et al.* 2000, Parsons 2002, Ma *et al.* 2010). Clearly, conservation at any given wetland site needs to be based on scientific knowledge about waterbird population dynamics over the annual cycle (Amano *et al.* 2018).

China spans a large geographical area, and its various climates and landforms support complex habitats and a rich diversity of ecosystems (Xu *et al.* 1999, Tang *et al.* 2006). The wetlands of China can be broadly divided into six zones (Chen 1998). Those of the Yunnan–Guizhou Plateau (hereafter 'YGP') consist of one of these six zones, and lie in the south-western part of China. The YGP has always been regarded as an important wintering area for geese, ducks, gulls and some medium- to large-sized shorebirds, cranes and storks (Chen 1998, Cui *et al.* 2014). Accordingly, most studies in this region have focused on the composition of wintering waterbirds (Wang *et al.* 2016), including several at Lake Dianchi (hereafter 'Dianchi'), the largest lake on the YGP (e.g. Yang *et al.* 1988, Han *et al.* 2000, Wu *et al.* 2008), although some studies have also addressed the annual composition of waterbirds (e.g. Wang *et al.* 2016, Luo *et al.* 2019). However, few studies have actually looked at the multi-year species composition of waterbirds at Dianchi.

Figure 1. Study area and sampling sites at Dianchi.



In particular, it remains unknown whether migratory waterbirds consistently use Dianchi as a stopover site across multiple years (i.e. whether migrants display 'migratory consistency'). In this study, we conducted surveys at Dianchi to first ascertain its multi-annual species composition and migratory consistency. We then discuss the conservation implications of our findings.

METHODS

Study area

Dianchi (24.666–25.033°N 102.616–102.800°E) is an ancient tectonic lake located in Kunming, the capital city of Yunnan province (Figure 1). It is one of the larger lakes in the upper Yangtze basin, and the largest lake on the YGP, with an area of 309 km^2. Dianchi comprises two connected lake areas, known as Caohai and Waihai respectively. Caohai has a water surface area of 10.7 km^2 and a mean water depth of 2.5 m; Waihai has a water surface area of 297.9 km^2 and a mean water depth of 4.3 m. The waterline of the Dianchi lake system is stable at 1,886.9 m asl (Jin *et al.* 2006, Yang *et al.* 2010).

Dianchi plays an important role in shaping the local climate, and it supplies water for industry, agriculture and fisheries as well as being an important recreational site in Yunnan. However, the lake has been heavily eutrophic since the 1980s as a result of massive discharges of municipal and industrial sewage. Along with Taihu and Chaohu lakes and the Liao, Huai and Hai rivers, Dianchi has been listed as one of the 'Three Lakes and Three Rivers' which are the focus of the Chinese national program of pollution control (SEPAC 2004). Several projects have been adopted to reduce pollution in these wetlands. Under one of these programmes, artificial wetlands have been constructed by relocating farmlands, factories and residential buildings away from the lakeside (Deng *et al.* 2005, Wang *et al.* 2012a,b, Xiang *et al.* 2013).

Sampling strategy

In the Caohai area, we surveyed the lake body from four obstruction-free sites (s23–s26); we also surveyed artificial wetlands on the lakeshore, which are located between the shoreline and the road encircling the lake. Overall, the entire Caohai area of Dianchi and its associated artificial wetlands were surveyed in our study.

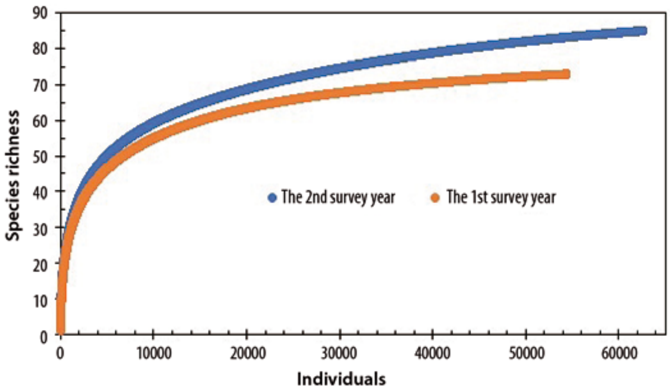
In the Waihai area, we conducted systematic sampling every 5–7 km along the shoreline to establish 22 visually obstruction-free sites. For surveys in the lake body, we established 1 km-radius sampling plots from these observation sites. We also surveyed the variably sized, artificial wetlands on the lakeshore, which were located near the observation sites (Figure 1).

Waterbird counts

We used binoculars (Olympus 10 × 42 EX WP I) and a telescope (Carl Zeiss DiaScope 85T*FL) to count waterbirds. We divided each sampling plot into several discrete compartments on the lake using causeways or physical barriers as boundaries to facilitate our bird counting (Bibby *et al.* 2000, Cao *et al.* 2011). We used the 'look-see' counting method to count most species directly. We estimated the abundance of flocking species such as Common Black-headed Gull *Larus ridibundus* and Common Coot *Fulica atra* by counting in groups of 10, 20, 50, 100 or 500 individuals, and estimating what proportion of the flock the counted individuals represented (Bibby *et al.* 2000). At the lakeside artificial wetlands, we adopted the spot-map census method to mark the species and respective counts of individuals onto prepared maps (Bibby *et al.* 2000).

We conducted pre-surveys in February 2013 and formal surveys three times each month (i.e. early, middle and late parts of each month) from March 2013 to February 2015. We defined the period between March 2013 and February 2014 as the first survey year, and the period between March 2014 and February 2015 as the second survey year. In total, we conducted 36 surveys during each survey year. We surveyed waterbirds counterclockwise along the lakeshore site by site. For each survey, we spent three consecutive days from dawn to dusk. To reduce biases resulting from variable survey time (Conway 2011), we divided our sampling sites into three groups (Group 1, consisting of sites s1–s10; Group 2, consisting of sites s11–s16; Group 3, consisting of sites s17–s26) according to the amount of time each group would take to survey. For early-, middle- and late-month surveys, we started our daily survey from Group 1, Group 2 and Group 3, respectively. The time windows may be advanced or delayed by one to two days if weather conditions were adverse (e.g. rain, heavy fog, snow or gales) (Bibby *et al.* 2000, Conway 2011).

Figure 2. Rarefaction curves based on species and individuals of waterbirds at Lake Dianchi, China.



Our rarefaction curves indicated that our sampling effort was high enough to allow us to reliably assess the waterbird composition of Dianchi and its variation over our study period (Figure 2).

Statistical analysis

Species richness and abundance

In our analyses, we defined the seasons as spring (March–May), summer (June–August), autumn (September–November) and winter (December–February). We analysed waterbird species richness, abundance (number of individuals), dominance and annual (year-on-year) similarity over two full-year cycles spanning March 2013 to February 2015. We defined monthly species richness as the cumulative number of species recorded across all survey sites at Dianchi over the three surveys within each month combined; we defined total species richness as the total number of species in all surveys combined during two years. We defined the cumulative number of individuals in a survey detected from all survey areas of Dianchi as the abundance for each species. We used the maximum abundance of each species in each month to quantify monthly abundance, and we used the maximum abundance of each species in all 72 surveys to quantify the total abundance during the two years. We used the percentage of species abundance in all surveys pooled over our two-year dataset to define the dominance of each species as: dominant (≥ 10%), common (1%–10%) and rare (≤ 1%) (Howes & Bakewell 1989).

Across-year similarity of species diversity

We used the Jaccard similarity index to compare the annual similarity in species composition (Magurran 2004) and excluded species considered as vagrants in our analyses. The Jaccard index (J) was calculated as:

$$J = (A \cap B)/(A \cup B)$$

where A is the species composition in the first survey year and B is the species composition in the second survey year.

Migration consistency and stopover duration

A location can be considered a stopover site for bird migration if a given species displays migration consistency (such as annual or

Figure 3. Month-to-month variation in waterbird species richness at Lake Dianchi, China. The '1' and '2' represent the first and second survey years respectively.

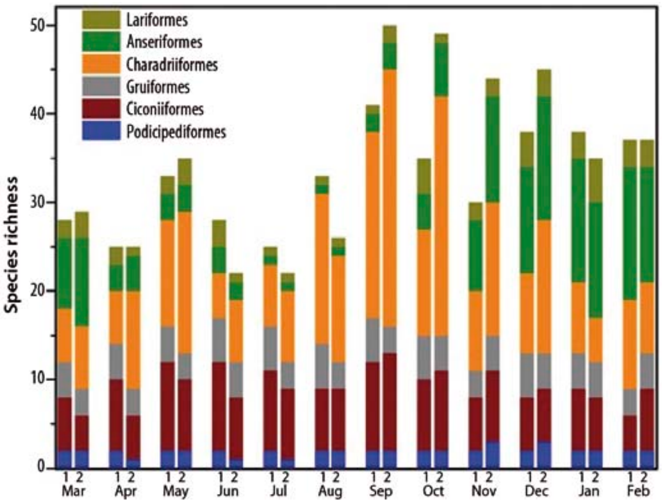
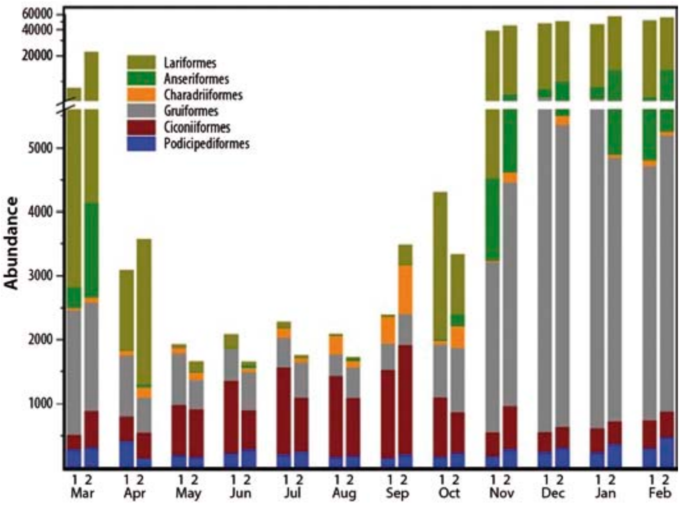


Figure 4. Month-to-month variation in waterbird abundance at Lake Dianchi, China. The '1' and '2' represent the first and second survey years respectively.



seasonal consistency) (Ewert *et al.* 2005). A species can be considered to display high migration consistency in a location if the arrival (Julian) days on which the species is observed are significantly correlated between seasons or years (Thorup *et al.* 2013). To avoid counting rare species with a low number of individuals at Dianchi, we focused on species which were observed in both survey years and whose observed abundance was no less than 10 individuals each year, for our analyses on migration consistency. We recorded the date the species was first observed (in spring or autumn) as the arrival time in Julian calendar days, from which we then calculated the correlations between spring—spring, autumn—autumn and spring—autumn using Pearson's correlation to assess its migration consistency (Thorup *et al.* 2013). We also recorded the last observation date as the departure time, which we used together with the arrival dates to calculate the stopover duration for each species during each migration season. Using this information, we assessed the difference in stopover duration across species with ANOVA tests. If a species was only observed once (e.g. passage migrants such as Marsh Sandpiper *Tringa stagnatilis*), we defined its stopover duration as a default of 10 days, which is the time duration between two consecutive surveys.

RESULTS

Species composition

We detected 93 species belonging to six orders and 14 families during all surveys from February 2013 to February 2015 (see Appendix 1). The species present in the two survey years consisted of 14 residents (15.05% of total species detected), five summer visitors (5.38%), 42 migrants (45.16%), 30 winter visitors (32.26%) and two vagrants (2.15%). The Glossy Ibis *Plegadis falcinellus* and Asian Openbill *Anastomus oscitans* were considered vagrants to our study sites for the following reasons: (1) they were recorded only in the first survey year at Dianchi, (2) the Glossy Ibis vanished from China for more than 50 years and was only recently rediscovered in Yunnan as a vagrant (Han *et al.* 2013, Zhao *et al.* 2013), and (3) the Asian Openbill was a new record for the species in China in 2006 and is dramatically increasing across south China as a non-breeding dispersant, which might be caused by natural range expansion (Jian & Ning 2010, Han *et al.* 2016).

The extent of dominance differed across species. Only one species, the Common Black-headed Gull (64.05%) can be considered a dominant species. Eight species were considered common, namely Gadwall *Anas strepera* (8.68%), Common Coot (8.35%), Brown-headed Gull *L. brunnicephalus* (4.52%), Eurasian Wigeon *A. penelope* (3.20%), Little Egret *Egretta garzetta* (1.79%), Common Moorhen *Gallinula chloropus* (1.34%), Northern Shoveler *A. clypeata* (1.32%) and Chinese Pond Heron *Ardeola bacchus* (1.01%). The remaining 84 species were considered rare.

Monthly species richness varied consistently in both survey years, with peaks in May, September and December, and representing the spring, autumn and winter periods respectively. However, migratory species richness in spring and autumn were asymmetrical, with species richness in autumn highest. The higher species peak (50 species) was in September. The second peak occurred in December and the third occurred in May. These peaks reflected the increase in Charadriiformes during spring and autumn migration, and in Anseriformes in winter. Over the years, species richness was lowest in summer, with the lowest observed species diversity in June and July, with only 22 species observed in each month (Figure 3).

Monthly waterbird abundance exhibited a single peak in winter, during which approximately 60,000 individuals across all species were observed. Most species were winter visitors. The most common orders represented were Lariformes, Anseriformes and Gruiformes (Figure 4), and the most common species were the Common Black-headed Gull (42,565 individuals), Brown-headed Gull (3,002 individuals), Gadwall (5,771 individuals), Eurasian Wigeon (2,130 individuals) and Common Coot (5,549 individuals). The remaining orders were represented by far fewer individuals. Among migratory species, Charadriiformes were most abundant in September, particularly the Grey-headed Lapwing *Vanellus cinereus* (513 individuals), Pacific Golden Plover *Pluvialis fulva* (100 individuals) and Black-winged Stilt *Himantopus himantopus* (180 individuals). Among resident species, high levels of abundance were observed for the Common Moorhen (893 individuals), Little Egret (1,187 individuals), Cattle Egret *Bubulcus ibis* (240 individuals) and Little Grebe *Tachybaptus ruficollis* (278 individuals) (see Appendix 1).

Annual similarity in species composition

Sixty-five species were recorded in both survey years. Year-on-year similarity in species composition was fairly high across different groups of waterbirds, especially residents (92.86%) and summer visitors (100%) (Table 1).

Migration consistency and stopover duration

Ten species were analysed for their migration consistency over the two survey years, namely the Spotted Redshank *Tringa erythropus*,

Table 1. **Year-on-year species similarity of waterbirds at Lake Dianchi, China.**

Status	A	B	A ∩ B	A ∪ B	Jaccard similarity (%)
Residents	13	14	13	14	92.86
Summer visitors	5	5	5	5	100.00
Migrants	29	39	26	42	61.90
Winter visitors	24	27	21	30	70.00
All	71	85	65	91	71.43

A is the species richness for the first survey year; **B** is the species richness for the second survey year.

Table 2. **Pearson's correlation coefficients of arrival times across migration seasons for migrant waterbirds at Lake Dianchi, China.**

		SP_2	AU_1	AU_2
SP_1	Correlation coefficient	0.95**	-0.11	0.25
	Significance	0.00	0.74	0.35
	N	11	11	16
SP_2	Correlation coefficient		-0.07	0.26
	Significance		0.89	0.42
	N		7	12
AU_1	Correlation coefficient			0.57**
	Significance			0.00
	N			29

Note: * = $p < 0.05$; ** = $p < 0.01$. SP_1 and SP_2 are the arrival times during the spring migration of the first and second survey years, respectively; AU_1 and AU_2 are the arrival times during the autumn migration of the first and second survey years, respectively.

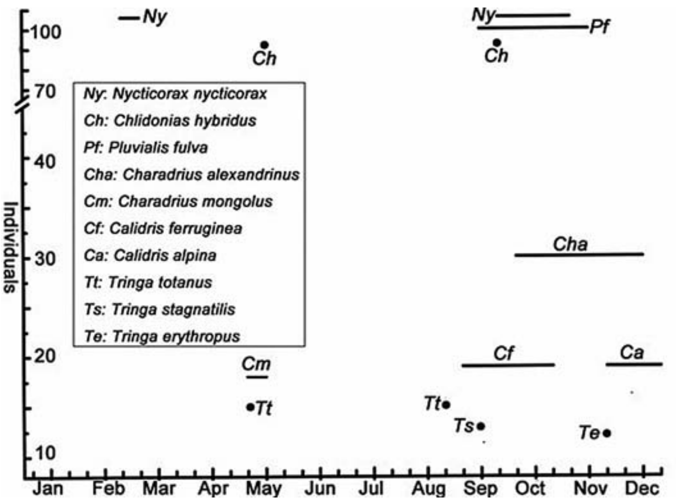
Common Redshank *T. totanus*, Marsh Sandpiper, Black-crowned Night Heron *Nycticorax nycticorax*, Pacific Golden Plover, Lesser Sand Plover *Charadrius mongolus*, Kentish Plover *C. alexandrinus*, Dunlin *Calidris alpina*, Curlew Sandpiper *C. ferruginea* and Whiskered Tern *Chlidonias hybridus*. Our results showed high consistency ($R = 0.95$, $P < 0.01$) during the northward (spring) migration period, moderate consistency ($R = 0.57$, $P < 0.01$) during the southward (autumn) migration period, and no consistency between the northward-southward (spring-autumn) migrations at Dianchi respectively (Table 2).

The mean stopover duration of the migratory waterbird at Lake Dianchi was 40.00 ± 8.70 (SE) days, with highly significant differences among species ($F_9 = 4.60$, $P = 0.001$). In addition, both species richness and individual species abundance during the spring migration season were less than that of the autumn migration season (Figure 5).

DISCUSSION

In this study, we observed 93 waterbird species at Dianchi, accounting for 36% of the total number of waterbird species in China (Wang *et al.* 2018). We observed higher waterbird species richness than was observed during previous studies at Dianchi (Appendix 2). This may have resulted from the following reasons. For example, we conducted two intensive, year-round surveys, composed of three surveys monthly, of the entire lake and its artificial lakeshore wetlands. Both the spatial and temporal coverage of our study is more extensive than previous studies, which had mainly focused on the winter period and at partial sections of the lake. Luo (2014) conducted a two-year survey at Dianchi; however, their survey effort, at once per month, was far lower than our study. There were only 19 migrant species observed in Luo (2014), considerably fewer than the 42 species detected in this study. This may be because some migrants were undetected given their short stopover duration. Moreover, it is

Figure 5. Monthly maximum number of individuals and migratory patterns of 10 waterbird species at Dianchi, China. The black bars in the plot represent the approximate duration of presence of species that occurred over our surveys. The black dots represent species that were detected over single surveys.



possible that the artificial lakeside wetlands created in recent years have attracted more waterbirds, especially migrant waders (Wang *et al.* 2016, Luo *et al.* 2019). Nevertheless, one caveat is that our study mainly focused on the nearshore zone of Dianchi. Species inhabiting the middle waters of the lake were not surveyed, and thus species diversity in these sections may have been underestimated. That is, the actual richness of waterbird species of the lake can be expected to be higher than what was observed in this study. Regardless, our study highlights the important role of Dianchi and other wetlands on the YGP for waterbird populations and their conservation.

Variation in species richness across the year demonstrated a triple-peak pattern, with the spring and autumn migration seasons as well as winter having the highest species richness, whereas abundance at the lake peaked only in winter. The pattern of high species occurrence and abundance during the winter months was mainly driven by species from two families, Anatidae and Laridae, which used the exposed areas of water on the lake as habitat. The lake body appears large enough to sustain extensive habitats for ducks and gulls. The diversity peaks during the spring and autumn seasons held relatively high species richness of shorebirds but low abundance, and this was probably because the limited extent of artificial wetlands on the lakeshore may not be adequate to support high abundances of shorebirds. In addition, the year-on-year similarity in species composition was fairly high for different resident groups, indicating that many species occur consistently on the lake and thus highlighting its conservation value for different groups of waterbirds. Thus, we suggest that the relevant authorities involved in the conservation management of the lake consider the important role of Dianchi for various waterbirds across different seasons, and take added measures to protect this important wetland ecosystem.

The migratory patterns of shorebirds in inland wetlands are less understood in comparison with that of coastal wetland sites in China (Luo *et al.* 2019). Our study showed that migratory waders used inland wetlands (Dianchi in this case) consistently. The occurrence of waterbird species displayed high consistency during the northward (spring) migration and moderate consistency during the southward (autumn) migration. Previous studies of bird migration on the YGP have been mainly conducted at ringing (banding) stations at mountain passes where most birds captured by nets were Passeriformes (Wang & Zhao 2009, Yang *et al.* 2009, Zhao *et al.* 2014). At these sites, few waterbirds were captured and these were mainly Ardeidae and Rallidae (Wang & Zhao 2009, Zhao *et al.* 2014). Among Charadriiformes species, only Pintail Snipe *Gallinago stenura*, Common Snipe *G. gallinago*, Eurasian Woodcock *Scolopax rusticola*, Little Ringed Plover *Charadrius dubius* and Grey-headed Lapwing were captured (Chu *et al.* 1998, Wu & Li 1999, Huang *et al.* 2006, Han *et al.* 2007, Yang *et al.* 2009, Luo *et al.* 2012, Zhao *et al.* 2014). The findings of our study show that YGP forms a major migration corridor not only for passerines but also for waterbird migrants.

Our study did not find strong evidence of northward–southward migration consistency in abundances for most migratory species at Dianchi. Delmore *et al.* (2012) used light-level geolocators to track a number of species and found that the migrants detected inland were often associated with loop migration. We speculate that the migration routes of some waterbird species (e.g. species better associated with coastal wetlands) at Dianchi might be looped because of the location of the lake far inland. Thus, most migrants likely moved through Dianchi in the autumn from northern breeding areas to southern wintering areas, but they could use other (more easterly) sites rather than Dianchi during their return trips. Future studies through satellite tracking of these species at the individual level may confirm this.

Our study found that both species richness and abundance in the autumn period were much higher than in spring. These findings were consistent with other studies of bird migration in Yunnan (Zhao *et al.* 2014). In general, birds migrate faster in spring than in autumn because of competition for early arrival at breeding grounds (Nilsson *et al.* 2013). Thus, it is possible that the stopover durations of migrants at Dianchi were far shorter in spring, therefore explaining the lower number of species observed at surveys during this period. Our limited understanding of the migration pattern of species at Dianchi suggests that more monitoring work for waterbirds such as shorebirds during the migratory seasons is needed, partly because previous studies have focused only on specific groups of wintering waterbirds such as ducks. Moreover, because most of the lakeside artificial wetlands of Dianchi were built as wetland parks for water purification and human recreation, some wader species could be negatively affected by human recreational activities (Klein 1993, Cardoni *et al.* 2008). Therefore, wetland management activities here should include specific measures to protect waders from human disturbance.

In sum, we observed 93 waterbird species at Dianchi over two years of surveys, accounting for 36% of the total number of waterbird species in China. The annual species richness demonstrated a triple-peak pattern during the spring and autumn migratory seasons and during winter, and the annual similarity in species composition was fairly high for different groups, especially residents and summer visitors. The total number of waterbird individuals showed the highest peak in winter largely because of the high occurrence of Anatidae and Laridae. Although the waders showed a low number of individuals, they occurred consistently over the survey period. Our findings showed that we should recognise the importance of Dianchi in waterbird protection on the Yunnan–Guizhou Plateau. We suggest that conservation and wetland management programmes in Dianchi should include waterbird monitoring schemes and conservation measures and consider seasonal usage of the lake by different groups of waterbirds, and especially for shorebirds during the migration period.

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REFERENCES

Amano, T., Székely, T., Sandel, B., Nagy, S., Mundkur, T., Langendoen, T., Blanco, D., Soykan, C. U. & Sutherland, W. J. (2018) Successful conservation of global waterbird populations depends on effective governance. *Nature* 553: 199–202.

Bibby, C. J., Burgess, N. D., Hill, D. A. & Mustoe, S. (2000) *Bird census techniques*. Second edition. London: Academic Press.

Birdlife International (2020) Species dashboard. Accessed at https://bit.ly/3jQBvCv on 25/03/2020.

Cao, L., Barter, M. & Lewthwaite, R. (2008) The declining importance of the Fujian Coast, China, for wintering waterbirds. *Waterbirds* 31: 645–650.

Cao, L., Barter, M., Zhao, M., Meng, H. & Zhang, Y. (2011) A systematic scheme for monitoring waterbird populations at Shengjin Lake, China: methodology and preliminary results. *Chinese Birds* 2: 1–17.

Cardoni, D. A., Favero, M. & Isacch, J. P. (2008) Recreational activities affecting the habitat use by birds in Pampa's wetlands, Argentina: implications for waterbird conservation. *Biol. Conserv.* 141: 797–806.

Chen, K. L. (1998) Wetlands and waterbirds of China. *Bull. Bio.* 33: 2-4. (In Chinese.)

Chu, G., Wang, Z., Kiyoaki, O., Qian, F. & Zhang, X. (1998) Study on the bird banding in autumn in Longqingguan, Yunnan Province. *Sci. Silvae Sin.* 34: 66-73. (In Chinese.)

Conway, C. J. (2011) Standardized North American marsh bird monitoring protocols. *Waterbirds* 34: 319–346.

Costa, H. C. M., Peres, C. A. & Abrahams, M. I. (2018) Seasonal dynamics of terrestrial vertebrate abundance between Amazonian flooded and unflooded forests. *PeerJ* 6: e5058.

Cui, P., Wu, Y., Ding, H., Wu, J., Cao, M. C., Chen, L., Chen, B., Lu, X. Q. & Xu, H. G. (2014) Status of wintering waterbirds at selected locations in China. *Waterbirds* 37: 402–409.

Delmore, K. E., Fox, J. W. & Irwin, D. E. (2012) Dramatic intraspecific differences in migratory routes, stopover sites and wintering areas, revealed using light-level geolocators. *P. Roy. Soc. B-Biol. Sci.* 279: 45824589.

Deng, F., Xu, S. J., Xu, X. H., Deng, F. S., Wu, G., Li, Q., Fu, B. & Zhang, L.Y. (2005) Selection and application of plants in constructed wetlands for pollution treatment of Dianchi Lake. *Acta Sci. Nat. Univ. Sunyatseni.* 44: 299–303.

Ewert, D., Soulliere, G. J., Macleod, R., Shieldcastle, M., Rodewald, P., Fujimura, E., Shieldcastle, J. & Gates, R. (2005) *Migratory bird stopover site attributes in the western Lake Erie basin*. Final report to The George Gund Foundation.

Fraser, L. & Keddy, P. (2005) *The world's largest wetlands: ecology and conservation*. Cambridge: Cambridge University Press.

Giosa, E., Mammides, C. & Zotos, S. (2018) The importance of artificial wetlands for birds: a case study from Cyprus. *PLoS ONE* 13(5): e0197286.

Gong, P., Niu, Z., Cheng, X., Zhao, K., Zhou, D., Guo, J., Liang, L., Wang, X., Li, D., Huang, H., Wang, Y., Wang, K., Li, W., Wang, X., Ying, Q., Yang, Z., Ye, Y., Li, Z., Zhuang, D., Chi, Y., Zhou, H. & Yan, J. (2010) China's wetland change (1990–2000) determined by remote sensing. *Sci. China-Earth Sci.* 53: 1036–1042.

Han, L. X., Chen, C. X., Chu, T., Wang, Q. Y. & Zhou, W. (2000) A survey on waterfowls and waders of Dian Lake in winter. Pp.270-278 in China Ornithological Society, Wild Bird Society of Taipei & China Wildlife Conservation Association, eds. *Studies on Chinese ornithology: proceedings of the 4th ornithological symposium of Mainland & Taiwan, China*. Beijing: China Forestry Publishing House. (In Chinese.)

Han, L. X., Han, B., Liang, D. & Gao, G. (2016). Range expansion of Asian Open-billed Storks in Southwest China. *Sichuan J. Zool.* 35: 149–153. (In Chinese.)

Han, L. X., Huang, S. L., Yuan, Y. C. & Qiu, Y. L. (2007) Fall migration dynamics of birds on Fenghuang Mountain, Yunnan Province. *China. Zool. Res.* 28: 35–40. (In Chinese.)

Han, L. X., Yang, Y. F., Han, B. & Zhang, H. K. (2013) Return of *Plegadis falcinellus* in China. *Forest and Humankind* 5: 28–35. (In Chinese.)

Howes, J. & Bakewell, D. (1989) *Shorebird studies manual*. Kuala Lumpur: Asian Wetland Bureau.

Hsu, C. H., Chou, J. Y. & Fang, W. T. (2019) Habitat selection of wintering birds in farm ponds in Taoyuan, Taiwan. *Animals* 9(3): 113.

Huang, S. L., Han, L. X., Gao, S. Z. & Luo, Z. Y. (2006) Diversity of migratory birds during autumn nights in Fenghuang Mountains, Nanjian County, Yunnan Province. *Zool. Res.* 27: 163–168. (In Chinese.)

Isola, C. R., Colwell, M. A., Taft, O. W. & Safran, R. J. (2000) Interspecific differences in habitat use of shorebirds and waterfowl foraging in managed wetlands of California's San Joaquin Valley. *Waterbirds* 23: 196–203.

Jian, A. & Ning, Y. (2010) A new distribution site of the Asian Open-billed Stork (*Anastomus oscitans*) in southwestern China. *Chinese Birds* 1: 259–260.

Jin, X. C., Wang, L. & He, L. P. (2006) Lake Dianchi: experience and lessons learned brief. Pp.159–178 in International Lake Environment Committee (ed.) *Managing lakes and their basins for sustainable use: a report for lake basin managers and their stakeholders*. Kusatsu, Japan: International Lake Environment Committee Foundation.

Lai, C. H., Lin, S. H., Tsai, C. Y. & Chen, S. H. (2018) Identifying farm pond habitat suitability for the Common Moorhen (*Gallinula chloropus*): a conservation-perspective approach. *Sustainability* 10: 1352.

Klein, M. L. (1993) Waterbird behavioral-responses to human disturbances. *Wildl. Soc. Bull.* 21: 31–39.

Luo, K. (2014) Communities and habitat selection of wetlands birds in the lakeshore-wetland around the Dianchi Lake. MSc dissertation. Yunnan University, Kunming, China. (In Chinese.)

Luo, K., Wang, Z. J., Wu, Z. L., An, Q. Y., Guo, Z. H., Zhao, L. S., Wang, Z. J., Wang, X. R. & Li, G. C. (2012) Diversity of autumn nocturnal migrating bird in Dazhongshan bird-banding site, Northern Ailao Mountains. *Sichuan J. Zool.* 31: 641–646. (In Chinese.)

Luo, K., Wu, Z., Bai, H. & Wang, Z. (2019) Bird diversity and waterbird habitat preferences in relation to wetland restoration at Dianchi Lake, south-west China. *Avian Res.* 10: 21.

Ma, Z., Melville, D. S., Liu, J., Chen, Y., Yang, H., Ren, W., Zhang, Z., Piersma, T. & Li, B. (2014) Rethinking China's new great wall: massive seawall construction in coastal wetlands threatens biodiversity. *Science* 346: 912–914.

Ma, Z. J., Cai, Y. T., Li, B. & Chen, J. K. (2010) Managing wetland habitats for waterbirds: an international perspective. *Wetlands* 30: 15–27.

Magurran, A. E. (2004) *Measuring biological diversity*. Oxford, U.K.: Blackwell.

Marra, P. P., Cohen, E. B., Loss, S. R., Rutter, J. E. & Tonra, C. M. (2015) A call for full annual cycle research in animal ecology. *Biol. Lett.* 11: 20150552.

Nilsson, C., Klaassen, R. H. G. & Alerstam, T. (2013) Differences in speed and duration of bird migration between spring and autumn. *Am. Nat.* 181: 837–845.

Parsons, K. (2002) Integrated management of waterbird habitats at impounded wetlands in Delaware Bay, USA. *Waterbirds* 25: 25–41.

Ramsar Convention Secretariat (2013) *The Ramsar convention manual: a guide to the convention on wetlands* (Ramsar, Iran, 1971). Sixth edition. Gland, Switzerland: Ramsar Convention Secretariat.

van Roomen, M., Laursen, K., van Turnhout, C., van Winden, E., Blew, J., Eskildsen, K., Günther, K., Hälterlein, B., Kleefstra, R., Potel, P., Schrader, S., Luerssen, G. & Ens, B. J. (2012) Signals from the Wadden Sea: population declines dominate among waterbirds depending on intertidal mudflats. *Ocean Coast Manag.* 68: 79–88.

Runge, C. A., Martin, T. G., Possingham, H. P., Willis, S. G. & Fuller, R. A. (2014) Conserving mobile species. *Front. Ecol. Environ.* 12: 395–402.

State Environmental Protection Administration of China (SEPAC) (2004) *Tenth five-year plan of the water pollution prevention and control for "Three Rivers and Three Lakes"*. Beijing: Chemical Industry Press.

Studds, C. E., Kendall, B. E., Murray, N. J., Wilson, H. B., Rogers, D. I., Clemens, R. S., Gosbell, K., Hassell, C. J., Jessop, R., Melville, D. S., Milton, D. A., Minton, C. D. T., Possingham, H. P., Riegen, A. C., Straw, P., Woehler, E. J. & Fuller, R. A. (2017) Rapid population decline in migratory shorebirds relying on Yellow Sea tidal mudflats as stopover sites. *Nat. Comm.* 8: 1–7.

Tang, Z. Y., Wang, Z. H., Zheng, C. Y. & Fang, J. Y. (2006) Biodiversity in China's mountains. *Front. Ecol. Environ.* 4: 347-352.

Thorup, K., Vardanis, Y., Tøttrup, A. P., Kristensen, M. W. & Alerstam, T. (2013) Timing of songbird migration: individual consistency within and between seasons. *J. Avian Biol.* 44: 1–9.

Wang, R., Wu, F., Chang, Y. & Yang, X. (2016) Waterbirds and their habitat utilization of artificial wetlands at Dianchi lake: implication for waterbird conservation in Yunnan–Guizhou Plateau lakes. *Wetlands* 36: 1087–1095.

Wang, X. D., Kuang, F. L., Tan, K. & Ma, Z. J. (2018) Population trends, threats, and conservation recommendations for waterbirds in China. *Avian Res.* 9: 14.

Wang, Z., Zhang, Z., Zhang, J., Zhang, Y., Liu, H. & Yan, S. (2012a) Large-scale utilization of water hyacinth for nutrient removal in Lake Dianchi in China: the effects on the water quality, macrozoobenthos and zooplankton. *Chemosphere* 89: 1255–1261.

Wang, Z., Zhang, Z., Zhang, J., Zhang, Y. & Yan, S. (2012b) The fauna structure of benthic macro-invertebrates for environmental restoration in a eutrophic lake using water hyacinths. *Chin. Env. Sci.* 32: 142–149. (In Chinese.)

Wang, Z. & Zhao, X. (2009) The study on banding of birds captured in the mountains of Yunnan Province. Pp.118-126 in Z. Wang, H. Huang & X. Yang (eds.) *Bird protection and its harmony with humans*. Beijing: China Forestry Publishing House. (In Chinese.)

Wetlands International (2012) *Waterbird population estimates*. Fifth edition. Wageningen, The Netherlands: Wetlands International.

Wu, J. & Li, Z. (1999) Survey on localities of bird capturing in Yunnan. *J. Yunnan Univ., Nat. Sci. Ed.* 21: 106–108, 112. (In Chinese.)

Wu, Z. R., Liu, Y. Q., Liu, H., Wang, J. H. & Han, L. X. (2008) A survey on species, number and habitats of waterfowls in Caohai of Dianchi Lake in winter. *For. Inv. Plann.* 33: 33–36. (In Chinese.)

Xiang, X. X., Wu, Z. L., Luo, K., Ding, H. B. & Zhang, H. Y. (2013) Impacts of human disturbance on the species composition of higher plants in the wetlands around Dianchi Lake, Yunnan Province of Southwest China. *Chin. J. Appl. Ecol.* 24: 2457–2463. (In Chinese.)

Xu, H., Wang, S. & Xue, D. (1999) Biodiversity conservation in China: legislation, plans and measures. *Biodivers. Conserv.* 8: 819–837.

Yang, L., Han, L. X., Wang, S. Z. & Wen, X. J. (1988) Studies on the waterfowl of Yunnan Province. *Zool. Res.* 9(sup.): 23–31. (In Chinese.)

Yang, L., Li, H. & Yang, X. J. (2010) *Wetlands of Yunnan*. Beijing: China Forestry Publishing House. (In Chinese.)

Yang, T., Wang, Z. J., Liu, L. M., Yang, X. J., An, Q. Y., Zhang, H. Y., Yang, X. M. & Lu, F. W. (2009) Diversity of the birds captured at night in Ailao Mountain, Xinping County, Yunnan Province. *Zool. Res.* 30: 303–310. (In Chinese.)

Zhao, X., Chen, M., Wu, Z. & Wang, Z. (2014) Factors influencing phototaxis in nocturnal migrating birds. *Zool. Sci.* 31: 781–788.

Zhao, X. B., Chen, M. Y., He, Z. X., Wang, Z. J. & Wu, Z. L. (2013) New bird records in Yunnan province- *Calidris alpina* and *Plegadis falcinellus*. *Sichuan J. Zool.* 32: 59. (In Chinese.)

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Appendix 1. Checklist of the waterbird species at Lake Dianchi between the first (March 2013 to February 2014) and second survey years (March 2014 to March 2015).

Species	Individuals	Percentage (%)	Dominance	Status	Month											
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
I Podicipediformes																
(1) Podicipedidae																
Llittle Grebe *Tachybaptus ruficollis*	278	0.42	*	R	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★
Great Crested Grebe *Podiceps cristatus*	196	0.29	*	W	√★	√★	√★	√	√★	√	√	√★	√★	√★	√★	√★
Black-necked Grebe *Podiceps nigricollis*	7	0.01	*	W											★	★
II Ciconiformes																
(2) Ardeidae																
Grey Heron *Ardea cinerea*	200	0.3	*	R	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★
Purple Heron *Ardea purpurea*	2	0	*	R					★	√			√★	★		★
Little Heron *Butorides striatus*	2	0	*	R	★	★										
Chinese Pond Heron *Ardeola bacchus*	670	1.01	**	M	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★
Cattle Egret *Bubulcus ibis*	240	0.36	*	R	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	★
Great Egret *Casmerodius albus*	2	0	*	M									★	★		
Little Egret *Egretta garzetta*	1,187	1.79	**	R	√	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	★
Intermediate Egret *Mesophoyx intermedia*	32	0.05	*	S	★	★	√	√	√★	√★	√★	√★	√★	√★	★	√
Black-crowned Night Heron *Nycticorax nycticorax*	106	0.1	*	M	√	★		√					√★	√★	√★	
Yellow Bittern *Ixobrychus sinensis*	20	0.03	*	S	√				√★	√★	√★	√★	√★	√★	√	√★
Von Schrenck's Bittern *Ixobrychus eurhythmus*	3	0.00	*	M					√	√	★		√	√		
Cinnamon Bittern *Ixobrychus cinnamomeus*	6	0.01	*	S				√★	√★	√★	√★	√★	√		★	
Black Bittern *Dupetor flavicollis*	1	0	*	M									★			
Great Bittern *Botaurus stellaris*	1	0	*	M	√			√					★		★	
(3) Ciconiidae																
Asian Openbill *Anastomus oscitans*	6	--	--	V			√		√	√	√					
(4) Threskiornithidae																
Glossy Ibis *Plegadis falcinellus*	11	--	--	V					√		√					
III Anseriformes																
(5) Anatidae																
Ruddy Shelduck *Tadorna ferruginea*	16	0.02	*	W	√			★						√	★	★
Common Shelduck *Tadorna tadorna*	7	0.01	*	W	√	√									√	√★
Northern Pintail *Anas acuta*	70	0.11	*	W	√★	√★							√★	★	★	★
Common Teal *Anas crecca*	414	0.62	*	W	√★	√★	√★	√						√★	√★	√★
Falcated Duck *Anas falcata*	88	0.13	*	W	√★	√★	★								★	★
Mallard *Anas platyrhynchos*	43	0.06	*	W	√★	√★	√★	√★	√★	√★					√★	√★
Spot-billed Duck *Anas poecilorhyncha*	40	0	*	R	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★
Gadwall *Anas strepera*	5,771	8.68	**	W	√★	√★	√★	★						★	√★	√★
Eurasian Wigeon *Anas penelope*	2,130	3.20	**	W	√★	√★								★	√★	√★
Garganey *Anas querquedula*	4	0.01	*	W										★	★	
Northern Shoveler *Anas clypeata*	875	1.32	**	W	√★	√★	√★								√★	√★
Red-crested Pochard *Rhodonessa rufina*	111	0.17	*	W		√	√									√
Common Pochard *Aythya ferina*	198	0.30	*	W	√★	√★									√★	√★
Ferruginous Pochard *Aythya nyroca*	137	0.2	*	W	√★	√★	√★								√★	√★
Tufted Duck *Aythya fuligula*	115	0.17	*	W	√★	√★	√★							★		√★
Baer's Pochard *Aythya baeri*	2	0	*	W		√										
Cotton Pygmy-goose *Nettapus coromandelianus*	1	0	*	M					√★	√			★	√		
Common Goldeneye *Bucephala clangula*	4	0.01	*	W	★	★										
Common Merganser *Mergus merganser*	5	0.01	*	W	√★	√★	★									√★

Species	Individuals	Percentage (%)	Dominance	Status	Month											
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IV Gruiformes																
(6) Rallidae																
Slaty-breasted Rail *Gallirallus striatus*	2	0	*	S						★	√					
Baillon's Crake *Porzana pusilla*	1	0	*	M					√	√		√		√		
Ruddy-breasted Crake *Porzana fusca*	15	0.02	*	R	√★	★	√	√	√★	√★	√★	√★	√★	√★		★
Black-tailed Crake *Porzana bicolor*	2	0	*	R									√		★	√
White-breasted Waterhen *Amaurornis phoenicurus*	30	0.05	*	R	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★
Watercock *Gallicrex cinerea*	1	0	*	M												√
Common Moorhen *Gallinula chloropus*	893	1.34	**	R	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★
Common Coot *Fulica atra*	5,549	8.35	**	W	√★	√★	√★	√★		√	√	√	√	√★	√★	√★
V Charadriiformes																
(7) Jacanidae																
Pheasant-tailed Jacana *Hydrophasianus chirurgus*	3	0	*	R	√	√★	√★	★	√★	★						√
(8) Rostratulidae																
Greater Painted-snipe *Rostratula benghalensis*	2	0	*	R					√★		★	√★				
(9) Charadriidae																
Northern Lapwing *Vanellus vanellus*	6	0.0	*	W	√	√										
Grey-headed Lapwing *Vanellus cinereus*	513	0.77	*	M	√★	√★	√★	√★	√★	★		★	√★	√★	√★	√★
Pacific Golden Plover *Pluvialis fulva*	100	0.15	*	M					★			√	√★	√★	√★	★
Grey Plover *Pluvialis squatarola*	24	0.0	*	M										★	★	★
Long-billed Plover *Charadrius placidus*	9	0.01	*	M						√★		√★	√★	★	√	
Little Ringed Plover *Charadrius dubius*	38	0.06	*	R	★	√★	√★	√★	√★	√★	√★	√★	★	★	★	√★
Kentish Plover *Charadrius alexandrinus*	30	0.05	*	M		√★						√	√★	√★	★	√★
Lesser Sand Plover *Charadrius mongolus*	18	0.03	*	M					√★	★			√	★	√★	
Greater Sand Plover *Charadrius leschenaultii*	2	0	*	M										★		
(10) Scolopacidae																
Whimbrel *Numenius phaeopus*	6	0.01	*	M					★			√★	√★	★		
Little Curlew *Numenius minutus*	1	0	*	M									★			
Black-tailed Godwit *Limosa limosa*	6	0.01	*	M									★	★	★	
Bar-tailed Godwit *Limosa lapponica*	2	0	*	M					★				√			
Spotted Redshank *Tringa erythropus*	12	0.02	*	M									★	√★	★	★
Common Redshank *Tringa totanus*	15	0.02	*	M				★	√★	√★	√	√★	★	★		
Common Greenshank *Tringa nebularia*	7	0.01	*	M									√★	★	★	
Green Sandpiper *Tringa ochropus*	21	0.03	*	W	√	√★	√	√★			★	√★	√★	√★	√	√★
Wood Sandpiper *Tringa glareola*	71	0.11	*	M	√	√	√★	√★	★		√★	√★	√★	√★	√	√
Common Sandpiper *Actitis hypoleucos*	14	0.02	*	M	√★	√★	★	√★	√★		√★	√★	√★	√★	√★	√★
Marsh Sandpiper *Tringa stagnatilis*	13	0.02	*	M									√★	★	★	
Pintail Snipe *Gallinago stenura*	23	0.03	*	W	√	√	★					√★	√★	√		√★
Common Snipe *Gallinago gallinago*	41	0.06	*	W	√★	√★	√★	√★	√★			√★	√★	√★	√★	√★
Swinhoe's Snipe *Gallinago megala*	1	0	*	M									★	★		
Red-necked Stint *Calidris ruficollis*	8	0.01	*	M									√★	★	★	★
Long-toed Stint *Calidris subminuta*	6	0.01	*	M							√★	√	√★	√★		
Temminck's Stint *Calidris temminckii*	30	0.05	*	W	★	★							★	★		★
Sharp-tailed Sandpiper *Calidris acuminata*	2	0	*	M									★			
Ruddy Turnstone *Arenaria interpres*	2	0	*	M									√★	√		
Curlew Sandpiper *Calidris ferruginea*	19	0.03	*	M					√★		√	√	√★	★		
Little Stint *Calidris minuta*	3	0	*	M					√★			√	√★	★		
Dunlin *Calidris alpina*	19	0.03	*	M									√		√★	★
Ruff *Philomachus pugnax*	2	0	*	M									★	★		

Species	Individuals	Percentage (%)	Dominance	Status	Month											
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
(11) Recurvirostridae																
Black-winged Stilt *Himantopus himantopus*	180	0.27	*	M				★	√★	√	★	√★	√★	√★		★
Pied Avocet *Recurvirostra avosetta*			*	M									√	★	★	★
(12) Glareolidae																
Oriental Pratincole *Glareola maldivarum*	43	0.06	*	S				★	√★	√★	√★	√	★			
Small Pratincole *Glareola lactea*	1	0	*	M				★								
(13) Phalaropodidae																
Red-necked Phalarope *Phalaropus lobatus*	4	0.01	*	M									★			
VI Lariformes																
(14) Laridae																
Heuglin's Gull *Larus heuglini*	9	0.01	*	W	√★	√★	★									√
Black-headed Gull *Larus ridibundus*	42,565	64.05	***	W	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★	√★
Brown-headed Gull *Larus brunnicephalus*	3,002	4.52	**	W	√★	√★	√★	√						√	√★	√★
Whiskered Tern *Chlidonias hybridus*	92	0.14	*	M					√★	√			★	√		
White-winged Tern *Chlidonias leucopterus*	1	0	*	M					★							
Little Tern *Sterna albifrons*	14	0.02	*	M						√						
Pallas's Gull *Larus ichthyaetus*	2	0	*	W	√★											★
Black-legged Kittiwake *Rissa tridactyla*	1	0	*	W	★											

Appendix 2. **Historical data on species richness of Lake Dianchi, China.**

Literature	Survey time	Region	Species richness
Yang *et al.* (1988)	1984, winter	whole	17
Han *et al.* (2000)	1997.10–1998.5	west part	26
Wu *et al.* (2008)	2007.1–2007.4	Caohai	20
Luo (2014)	2011.10–2013.11	whole	67
This study	2013.3–2015.2	whole	93