Ecological Research (2001) **16**, 543–553

Habitat use and diversity of waterbirds in a coastal lagoon around Lake Biwa, Japan

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We investigated habitat use and diversity of waterbirds at one of the coastal and satellite lagoons around Lake Biwa, which is a registered wetland of the Ramsar Convention in Japan. To evaluate the importance for waterbirds of a lagoon around the freshwater lake, we conducted 26 censuses over 1 year on seven blocks with different landscape elements in a small lagoon. A total of 25 species were found and most of them (72%) belonged to a guild in which birds forage without diving. Species density (per ha) and diversity was high in blocks where *Zizania latifolia* Turcz and *Phragmites australis* L. reed beds existed. Not all of the waterbird species were feeding all the time, but were often resting in their preferred blocks, suggesting that they use the lagoon as both a refuge and a feeding site. Habitats with a structural reed bed community and shallow waters (<1 m depth) may be crucial determinants of high waterbird diversity in this small lagoon around which many people live.

Key words: feeding behavior; landscape elements, resting behavior; waterfowl; wetland.

INTRODUCTION

A coastal lagoon formed at the seashore is usually an important wetland for waterbirds. Waterbirds inhabit or temporally use wetlands because of the diversity of microhabitats for feeding, nesting and resting, as well as food richness in the water (Mitsch & Gosselink 1986). Although the size of a wetland is often a crucial determinant of waterbird richness and abundance (Brown & Dinsmore 1986; Baldassarre & Bolen 1994; Hoyer & Canfield 1994; Suter 1994), trophic status and/or shallowness are also major factors influencing waterbird richness and abundance (e.g. Isozaki *et al*. 1992; Johnsgard 1992; Acuna *et al*. 1994; Hoyer & Canfield 1994; Matsubara *et al*. 1994; Suter 1994; McKnight 1998; Colwell & Taft 2000). Because of shallowness caused by tidal fluctuations in the water level, a coastal lagoon usually provides waterbirds with different feeding opportunities at varying water depths (Acuna *et al*. 1994; Ntiamoa-Baidu *et al*. 1998).

Lake Biwa is an ancient tectonic freshwater lake, and is the largest in Japan (616 km^2). It is characterized by the presence of more than 30 coastal and satellite lagoons called 'Naiko' (Kurata 1992; Kada 1999; Kawanabe 1999; Minobe & Kuwamura 2001). Coastal lagoons around Lake Biwa are all static, eutrophic and shallower than 2 m deep, with aquatic emergent macrophytes forming dense reed beds on the water edges. However, in all of the lagoons, reclamation has been carried out entirely or partially (Kurata 1992; Kada 1999). The lagoons have the same water level as the lake and are all connected to the lake through narrow channels, thus constituting a part of the lake ecosystem (Kurata 1992; Minobe & Kuwamura 2001). Accordingly, the water level of the lagoons around the lake fluctuates seasonally, usually within the range of 1 m (Minobe & Kuwamura 2001), unlike lagoons at the seashore.

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Received 15 January 2001.

Accepted 12 April 2001.

At the shore zone of Lake Biwa, waterbird habitat use and species richness have been well studied (Sugawa 1991, 1992; Kumode 1994). For instance, Sugawa (1992) observed a total of 70 356 waterbirds of 58 species along the shore zone, and correlated their species density with the distance from the shoreline to a 2 m-deep point. However, in coastal lagoons around the lake, waterbird ecology has not been investigated; the lagoons have not previously been recognized as good habitats for waterbirds. Although the lake and the shore zone has been a registered wetland of the Ramsar Convention (a convention regarding wetlands of international importance, especially waterfowl habitats), the lagoons around the lake have not been listed (Moriya 1994).

In the present study, we investigated habitat use and diversity of waterbirds in a lagoon landscape in relation to landscape elements. To minimize the effects of local differences in food abundance and water quality on the local density and diversity of waterbirds, we selected a small lagoon. The aim of the present study was to evaluate the importance for waterbirds of a coastal lagoon around a freshwater lake, and to understand the important elements of the lagoon landscape for supporting high species richness and diversity of waterbirds.

METHODS

Study site and blocks with different landscape elements

A field study was conducted at the Matsunoki 'Naiko' lagoon (0.14 km^2), where reed beds surround about two-thirds of the water edge. We made a field map based on an aerial photograph and observations (Fig. 1). To understand the importance of the lagoon landscape on habitat use and the diversity of waterbirds that forage in the water, the study site was divided into seven blocks based on landscape elements observed in summer (Table 1; Fig. 1): (i) the treeless straight reed bed (straight reed bed); (ii) the open cove reed bed (open cove); (iii) the wooded intricate reed bed (intricate reed bed); (iv) the river mouth reed bed (river mouth); (v) the vegetated bay reed bed (vegetated bay); (vi) the reclaimed waterfront (waterfront), and (vii) the offshore block (offshore). All blocks, except the offshore one, are 50 m shore zones. Water depth was measured from the shoreline or the edge of the reed bed to a point 50 m offshore every 10 m at the center of each block (Fig. 1) on 15 October 1997 when the water level was −41 cm (compared to the Lake Biwa standard level (BSL), 84.37 m above sea level).

Table 1 Landscape elements of the seven blocks

	Area (ha)	Emergent aquatic plants *Phragmites australis*	Emergent aquatic plants *Zizania latifolia*	Littoral trees Shrubs	Littoral trees Trees	Floating-leaved plants (in summer)	Shape of the water edge
Offshore	2.67	−	−	−	−	−	−
Treeless straight reed bed	1.03	+	+	−	−	−	Straight
Open cove reed bed	0.25	+	+	−	+	−	Cove
Wooded intricate reed bed	0.53	+	+	−	+	−	Notched or interdigitated
River mouth reed bed	0.36	+	−	+	−	−	The mouth of a brook
Vegetated bay reed bed	0.83	+	−	−	−	+	Bay
Reclaimed waterfront	1.14	−	−	−	−	−	Straight, reclaimed with soil
Total	6.81						

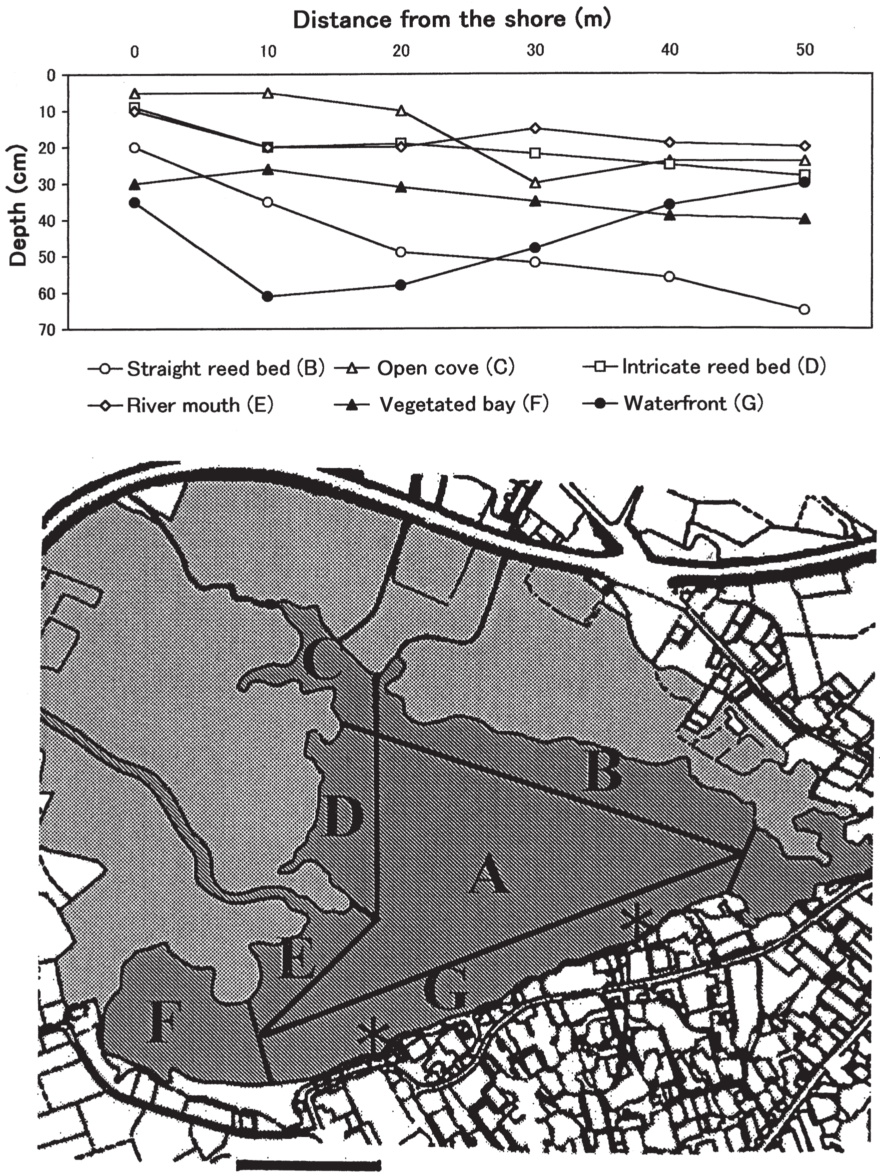

Fig. 1. Map of the study site, indicating the seven blocks: offshore block (A), treeless straight reed bed (B), open cove reed bed (C), wooded intricate reed bed (D), river mouth reed bed (E), vegetated bay reed bed (F), reclaimed waterfront (G), and water-depth profiles of each block except for the offshore block. The light shaded area is the reed-bed community and the darker shaded area is the open water. Asterisks indicate sites where censuses were carried out. Bar = 100 m. The top indicates north.

Field observations

To describe habitat use and abundance of waterbirds, we conducted visual censuses of each block from either of two observation sites (Fig. 1) with binoculars (×8) or a telescope (×20–45) between 13.00 and 17.00 h at intervals of 2 weeks for 1 year from September 1996 (Fig. 2). In the present study, waterbirds are defined as birds that usually forage in water, such as ducks, gulls, egrets and plovers. We observed each individual for a few seconds, recording its species name, location and behavior (feeding, swimming, resting or courtship). We could not distinguish between individuals of three species of the genus *Egretta*, that is, *Egretta alba*, *Egretta intermedia* and *Egretta garzetta*, because trees or shrubs at the water edge made observations too difficult.

Statistical analysis

Waterbirds often use different habitats in different seasons. To understand the relative importance of a habitat in the lagoon for waterbirds over 1 year, we pooled our census data. For data analysis, we

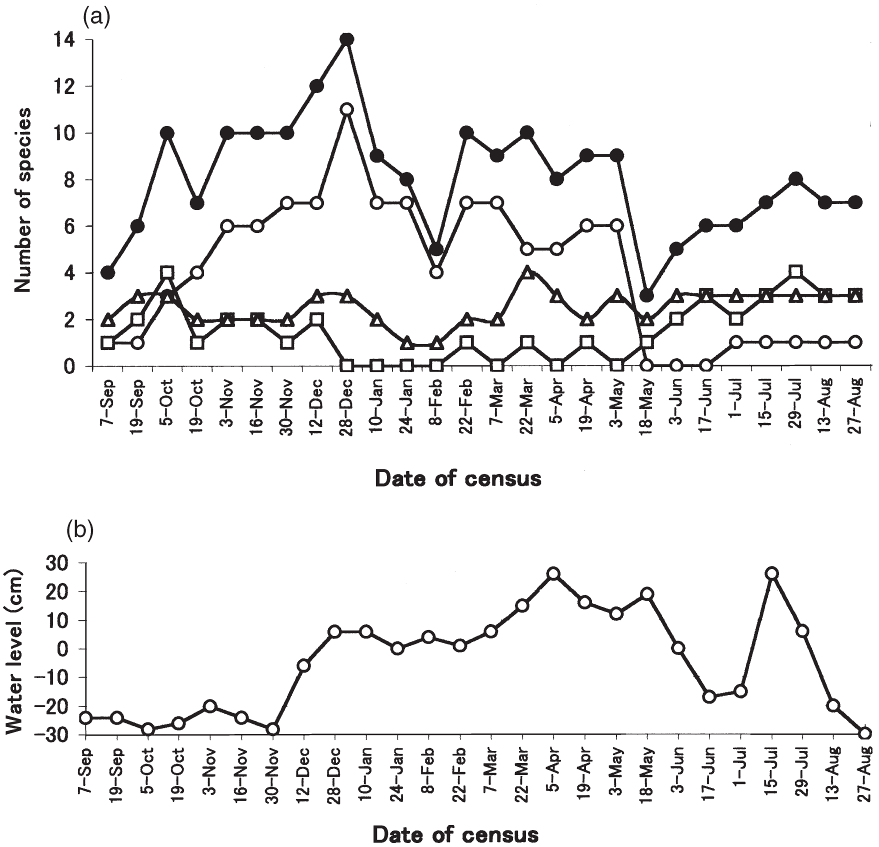

Fig. 2. (a) Number of waterbird species observed in each census. —○—, Waterfowl; —□—, herons and egrets; —△—, others; —●—, total. (b) Water level fluctuation in the study period.

used non-parametric tests because of the small sample sizes ($n = 26$). 'Preferred' means that there was a significant difference ($P < 0.01$) in the number of a waterbird species per census between blocks.

RESULTS

Species richness and diversity in blocks with different landscape elements

A total of 25 waterbird species were observed (Table 2). The 25 species were comprised of 11 dabbling ducks, seven shorebirds and seven diving waterbirds including one gull. Most of them (72%) belonged to a guild that forage without diving. Thirteen species (52%) were waterfowl (Anatidae) of the genera *Anas*, *Aythya*, *Anser* and *Cygnus*. Total species richness in a census fluctuated greatly and was correlated with the richness of waterfowl (Fig. 2, Spearman's correlation coefficient = 0.809, $P < 0.0001$, $n = 26$) but was not correlated with that of shorebirds or other birds (Spearman's correlation coefficient < 0.163, $P >$ 0.41 in each case, $n = 26$). Total species richness was not correlated with water level, which fluctuated between −30 cm and +26 cm (Fig. 2, Spearman's correlation coefficient = −0.109, $P = 0.55$, $n = 26$).

Mean species density (the number of species per ha) varied among blocks (Fig. 3). The species density was low at the reclaimed waterfront and the offshore block, where no habitat less than 30 cm deep and no reed beds existed. Only three and eight species in the waterfront and in the offshore block were observed, respectively (Table 2). There were highly significant differences in species density per census among the seven blocks (Friedman test, $\chi^2 = 90.4$, $P < 0.0001$) but were not among the dates of census (Friedman test, $\chi^2 = 37.9$, $P = 0.04$). Although species richness was highest in the treeless straight reed bed (Table 2), the mean species density was not greatest there (Fig. 3). Species density also varied among five blocks that contained reed beds (Friedman test, $\chi^2 = 33.8$, $P < 0.0001$) but no significant differences among the dates (Friedman test, $\chi^2 = 35.4$,

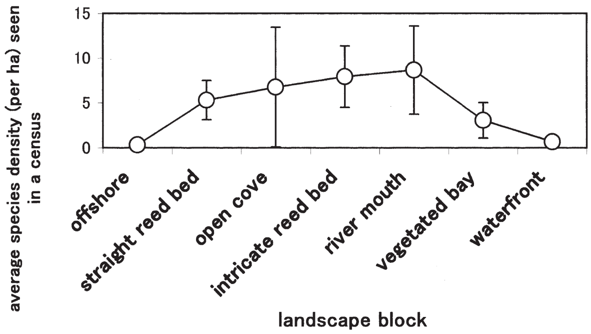

Fig. 3. Average species density (per hectare) of waterbirds in each block, with a 95% error bar.

$P > 0.05$). Among the five blocks, species density was lowest at the vegetated bay reed bed where a habitat less than 20 cm deep did not exist.

The Shannon's diversity index (H′) was high in the three blocks with reed beds of *Zizania latifolia* and *Phragmites australis* (Tables 1 and 2). *Zizania* reed beds fringed *Phragmites* reed beds in shallows less than 20 cm deep. Species diversity was not associated with the water surface area of blocks (Spearman's correlation coefficient $= -0.28$, $P = 0.75$, $n = 7$).

Habitat preference and behavior of individual species within the lagoon

The average population density (per ha) of individual species in each block is shown in Table 2. Here we focused on species that were found in at least 7 out of 26 censuses.

Four shorebirds of the Ardeidae, the gray heron *Ardea cinerea* and *Egretta* spp., were frequently observed (Table 2). Shorebirds of the Charadriidae and Scolopacidae were never observed during the study period, although they appeared in other periods when water level was unusually low (S. Mae, pers. obs., 1997). Gray heron were observed throughout the year, except January, and they preferred the wooded intricate reed bed and the open cove reed bed. Most individuals foraged at the water edges, but some were resting (Fig. 4a) on littoral trees or on the ground. *Egretta* spp. were seen between July and December. They also foraged at the water edges, preferring the wooded intricate reed bed and the river mouth reed bed, and some were resting at trees and shrubs.

Nine waterfowl species (Anatidae), eight dabbling ducks and one diver, were frequently observed. Since they are basically winter birds, they were observed between October and May, except the spot-bill duck *Anas poecilorhyncha*, which breeds at Lake Biwa and was seen from March to December. The spot-bill duck, a large dabbling duck, is nocturnal and this species preferred the blocks that contained reed beds (Fig. 4b). The Bewick's swan *Cygnus columbianus*, the largest waterfowl in Lake Biwa, preferred the treeless straight reed bed and the wooded intricate reed bed (Fig. 4a); they often foraged on the offshore side of the two blocks, although they were never found in the offshore block. A large flock of the green-winged teal *Anas crecca*, the smallest dabbling duck in Lake Biwa, preferred the vegetated bay reed bed, the river mouth reed bed and the wooded intricate reed bed. They were nocturnal and most were resting (Fig. 4a). Courtship behavior was occasionally observed at the vegetated bay. The mallard *Anas platyrhynchos*, a large dabbling duck, was also nocturnal and most of this species rested in blocks containing reed beds (Fig. 4a). The gadwall *Anas strepera*, a middle-sized dabbling duck, preferred the straight reed bed for a feeding site (Fig. 4a). A large flock of this species appeared only once in the offshore block. The northern shoveler *Anas clypeata*, a plankton feeder, appeared in all blocks except the reclaimed waterfront, but foraged mainly at the offshore block (Fig. 4a). The Eurasian wigeon *Anas penelope*, a middle-sized dabbling duck, preferred the treeless straight reed bed and the river mouth reed bed for feeding sites (Fig. 4a). The northern pintail *Anas acuta*, a middle-sized dabbling duck, showed no specific habitat preference. The Eurasian pochard *Aythya ferina*, a diving duck, was found resting or sometimes feeding in the treeless straight reed bed (Fig. 4b).

Besides waterfowl, three diving waterbirds (Podicipedidae, Rallidae and Phalacrocoracidae) were frequently observed. The little grebe *Tachybaptus ruficollis* and the common coot *Fulica atra*, the most common species in the shore zone of Lake Biwa throughout the year, were found in almost all censuses. The little grebe appeared everywhere, even in the reclaimed waterfront and the offshore block (Fig. 4b), but preferred reed beds. The common coot showed a range of behaviors (Fig. 4b)

Table 2 Population density (per ha) of individual species in each block in 26 censuses [mean (SD)]

	Common Name	No. in census	Offshore	Treeless straight reed bed	Open cove reed bed
Shorebirds					
Ardea cinerea	Grey heron	19	0	3.4 (5.3)	15.1 (43)
Egretta spp.	Three species of Egrets	14	0	2.7 (6.2)	0.4 (1.3)
Nycticorax nycticorax	Night heron*	4	0	18.4 (36)	2.0 (4.0)
Bubulcus ibis	Cattle egret	4	0	0	1.0 (2.0)
Botaurus stellaris	Bittern	2	0	0.5 (0.6)	0
Dabbling ducks					
Cygnus columbianus	Bewick's swan	7	0	20.5 (25)	3.4 (9.0)
Anas poecilorhyncha	Spot-bill duck*	16	0	3.2 (2.9)	12.0 (32)
Anas crecca	Green-winged teal*	16	0	29.4 (29)	27.0 (45)
Anas platyrhynchos	Mallard*	11	0	5.6 (6.8)	0.7 (2.4)
Anas strepera	Gadwall	9	12.9 (38)	47.4 (77)	5.3 (16)
Anas clypeata	Northern shoveler	12	0.7 (2.2)	1.5 (2.0)	0.7 (1.5)
Anas penelope	Eurasian wigeon	10	0	3.2 (3.4)	0
Anas acuta	Northern pintail	7	0	17.7 (25)	5.1 (11)
Anas falcate	Falcated duck	5	0.2 (0.5)	1.6 (1.4)	0.8 (1.7)
Anas formosa	Baikal teal	2	0	1.0 (1.3)	0
Anser albifrons	White-fronted goose	3	0	0.3 (0.5)	0
Diving waterbirds					
Aythya ferina	Eurasian pochard	10	0.0 (0.1)	8.9 (7.2)	0.8 (2.5)
Aythya fuligula	Tufted duck	2	0	0.97 (1.3)	0
Tachybaptus ruficollis	Little grebe	24	0.5 (0.8)	3.5 (5.0)	2.3 (3.5)
Podiceps cristatus	Great crested grebe	5	0	1.0 (0.6)	0
Fulica atra	Common coot	23	0.1 (0.5)	3.1 (2.9)	0.3 (1.1)
Phalacrocorax carbo	Common cormorant	13	0.1 (0.1)	0.5 (0.6)	0.3 (1.1)
Larus ridibundus	Black-headed gull	1	1.0	0	0
Total species richness			8	23	18
Shannon's diversity index (H′)			1.05	3.26	2.55

The Friedman test for reed bed has been applied to all blocks except offshore and reclaimed waterfront; *nocturnal in Lake Biwa (Kumode 1994).

and preferred reed beds. The common cormorant *Phalacrocorax carbo* was found throughout the year, except in November and December, but their population density was too low in this lagoon to detect any habitat preference, although they were abundant in the lake. They were often resting, drying their wet wings on stakes in the wooded intricate reed bed, and feeding in the offshore block and the straight reed bed (Fig. 4b).

DISCUSSION

At the shore zone of Lake Biwa, 28 waterbird species that forage in water have commonly been found (Kumode 1994); they belong to the Podicipedidae, Phalacrocoracidae, Ardeidae, Anatidae, Rallidae or Laridae. At the small lagoon in the present study, most of them (23 species; 82.1%) were observed. Although the size of habitat is often a crucial determinant of waterbird richness (Brown & Dinsmore 1986; Baldassarre & Bolen 1994; Hoyer & Canfield 1994; Suter 1994), the water surface area of the present study site (0.068 km^2) was only 0.77% of that of the study site of Kumode (1994) (400 m shore zone around the lake; 88.0 km^2). Most of species found in the present study (72%) belonged to a guild in which birds forage without diving. The other five common species that were not observed in the

Wooded intricate reed bed	River mouth reed bed	Vegetated bay reed bed	Reclaimed waterfront	Friedman test for all blocks χ^2	Friedman test for all blocks P	Friedman test for reed bed χ^2	Friedman test for reed bed P	Period present
18.7 (41)	1.8 (3.9)	0.6 (1.8)	0	50.9,	<0.0001	26.3,	<0.0001	Feb to Dec (11 months)
22.2 (40)	13.8 (32)	0.3 (1.2)	0	41.8,	<0.0001	24.3,	<0.0001	Jun to Dec (7 months)
0.5 (0.9)	0.7 (1.3)	0	0	3.0,	>0.05	1.0,	>0.05	July to Oct (4 months)
2.8 (2.4)	0	0	0	–	–	–	–	July to Oct (4 months)
0	0.2 (27)	0	0	–	–	–	–	Jun and Aug
22.6 (25)	0	0	0	26.3,	0.0001	16.6,	0.0022	Nov to Feb (4 months)
8.4 (21)	3.3 (5.1)	4.1 (5.8)	0	25.8,	0.0002	5.58,	>0.05	Mar to Dec (10 months)
127 (210)	219 (229)	96.6 (101)	0.8 (2.8)	52.0,	<0.0001	14.2,	0.006	Oct to May (8 months)
2.7 (4.1)	10.1 (15)	1.6 (5.0)	0	19.7,	0.003	7.8,	>0.05	Nov to May (7 months)
14.6 (28)	8.3 (11)	0.5 (1.6)	0	24.1,	0.0004	13.2,	0.01	Nov to Apr (6 months)
1.6 (3.8)	2.1 (3.3)	0.2 (0.6)	0	16.0,	0.013	8.8,	>0.05	Oct to May (8 months)
0.2 (0.5)	4.2 (5.7)	0.4 (0.8)	0	31.6,	<0.0001	19.2,	0.0006	Dec to May (6 months)
7.8 (11)	10.3 (18)	0	0	9.2,	>0.05	3.7,	>0.05	Oct to Feb (5 months)
4.5 (8.1)	0	0.2 (0.5)	0	8.8,	>0.05	6.2,	>0.05	Nov to May (5 months)
0	4.2 (1.9)	0	0	–	–	–	–	Nov and Dec
1.3 (1.0)	0	0	0	–	–	–	–	Nov to Dec (2 months)
1.1 (1.5)	0.6 (1.7)	0.1 (0.3)	0	43.1,	<0.0001	30.9,	<0.0001	Dec to May (6 months)
0	0	0	0	–	–	–	–	Dec and Jan
2.6 (4.3)	2.9 (3.5)	2.3 (3.2)	1.0 (1.4)	20.9,	0.0018	18.4,	0.001	Jan to Dec (12 months)
0.4 (0.8)	0	0	0	–	–	–	–	Nov to Mar (5 months)
4.3 (7.7)	3.0 (5.0)	1.9 (2.9)	0.5 (1.3)	49.9,	<0.0001	28.6,	<0.0001	Jan to Dec (12 months)
0.9 (1.6)	0	0.2 (0.4)	0	15.3,	0.017	10.3,	0.03	Jan to Oct (10 months)
0	0	0	0	–	–	–	–	Nov
21	17	15	3					
2.29	1.35	0.85	1.51					

lagoon (the greater scaup *Aythya marila*, the smew *Mergus albellus*, the ruddy-breasted crake *Porzana fusca*, the common moorhen *Gallinula chloropus* and the little tern *Sterna albifrons*) dive for feeding. Furthermore, the bittern *Botaurus stellaris* and the Baikal teal *Anas formosa*, both of which are rare species and never dive into the water (Kumode 1994), were sometimes observed in the lagoon. High species richness found in the small lagoon can be attributed to shallowness, a common factor in seashore lagoons (Acuna *et al.* 1994; Ntiamoabaidu *et al.* 1998).

Species richness and density of waterbirds that forage in water depends largely on the depth profile, because individual species usually have a preferred water depth for feeding (Johnsgard 1992; Ntiamoa-baidu *et al.* 1998; Colwell & Taft 2000). At the shore zone of Lake Biwa, the species richness of waterbirds is usually high in the shallow waters less than 3 m in depth with a gentler slope (Hamabata 1991; Sugawa 1991); species density of waterbirds is also positively correlated with the distance from the shoreline to a 2 m deep point (Sugawa 1992). Accordingly, at the present study site, we expected to find the highest species richness and density in the treeless straight reed bed, where the highest range of habitats from shallows (20 cm in depth) to deeps (65 cm in depth) existed (Fig. 1). However, species density was not highest in this block, although species richness

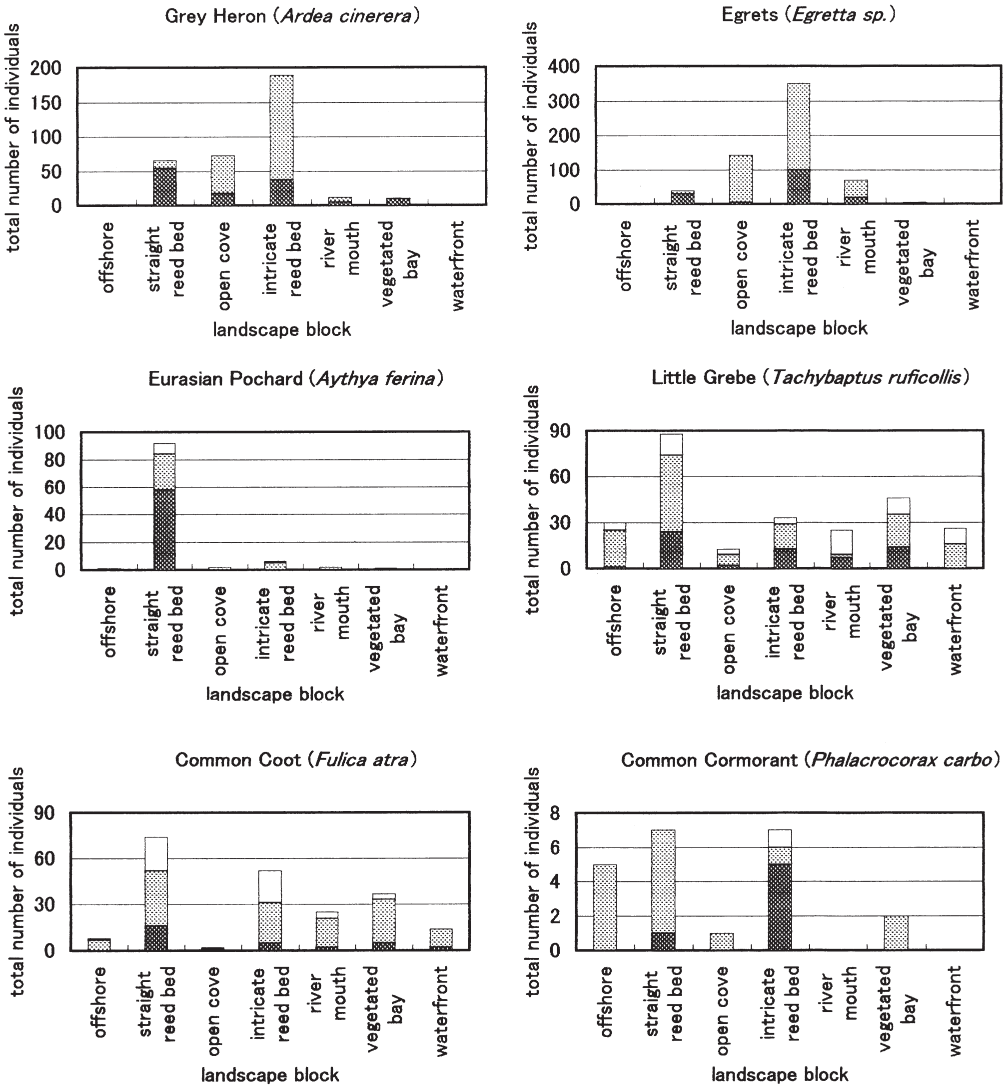

Fig. 4. Total number of individuals of each species and their behaviors in each block. Shorebirds and diving waterbirds are shown in (a) and dabbling ducks are shown in (b). Less frequently observed species are omitted. □, swimming behavior; ▨, feeding behavior; ▩, resting behavior; ■, courtship behavior.

was highest because of the large area. Species richness and density were high in the relatively small open cove and the wooded intricate reed beds, where no habitats deeper than 30 cm (at a water level of −41 cm) existed, and especially low at the reclaimed waterfront and the offshore zone, where no habitats shallower than 30 cm existed. These results suggest that in the small lagoon around Lake Biwa shallows less than 30 cm in depth are crucial determinants of the species richness and density of waterbirds. Since water level fluctuated by 56 cm during the census period, the maximum water depth of such shallows should have been between 41 cm and 97 cm.

For waterbirds that feed in water without diving, the maximum depth of feeding sites is usually determined by the neck and leg length of the species. For example, few waterbird species (except diving birds) forage in water deeper than 25 cm (Colwell & Taft 2000). In the grassland of the USA, shallow wetlands with average depths of 10–20 cm support high waterbird richness because of the diverse feeding sites available, which vary from exposed mud to deeper water with

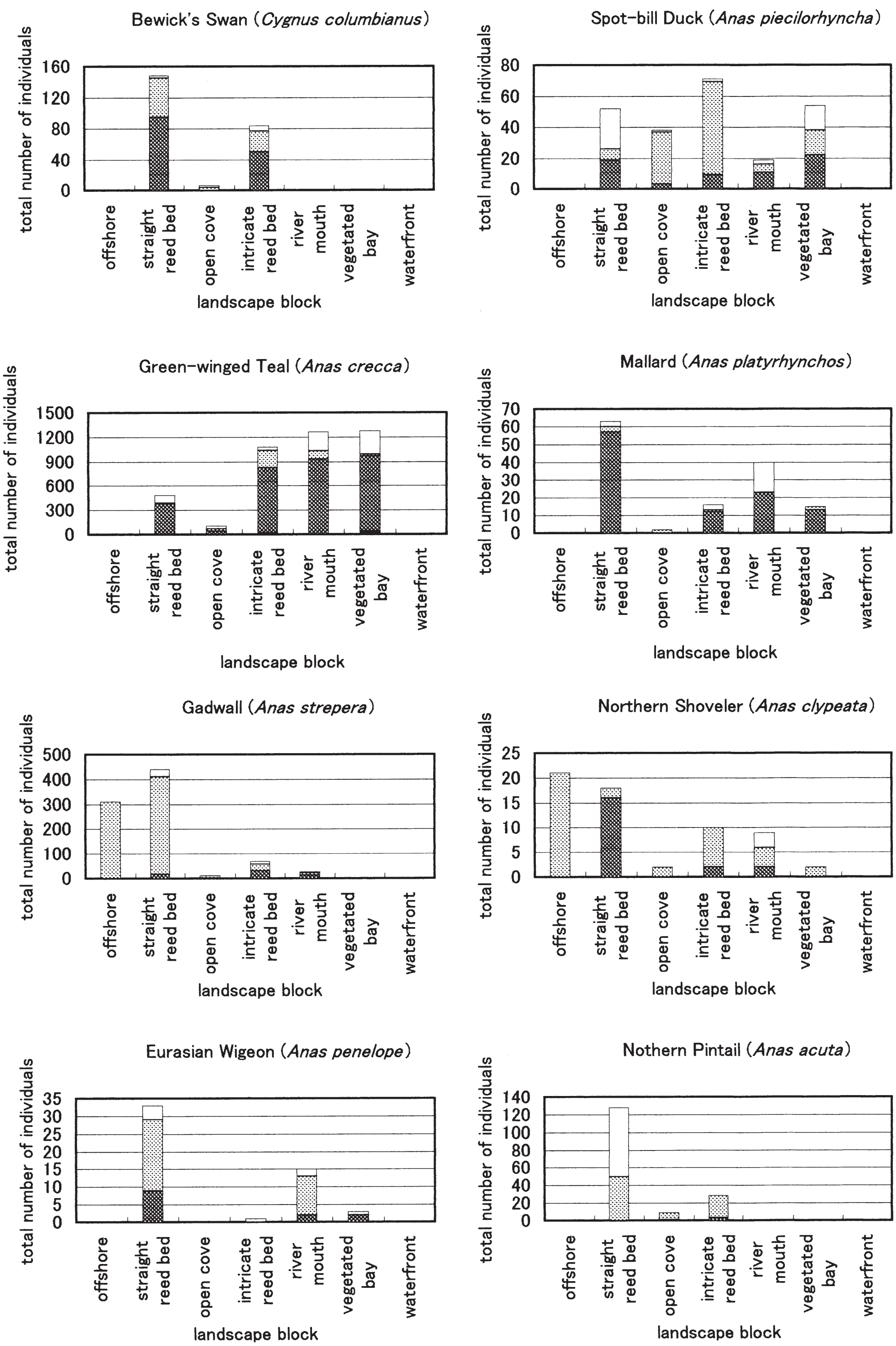

Fig. 4. *Continued*

submerged aquatic plants (Colwell & Taft 2000). However, in the present study site, the water edge did not have an exposed muddy habitat, which is often a good feeding site for shorebirds. Furthermore, species richness and density were high in the relatively deep shallows (between 41 cm and 97 cm in depth during the present study period). Waterbirds were not always feeding, but were often resting in these blocks, suggesting that they utilize shallow waters as refuges, where they can both feed and rest.

In avian communities on the land, plant structural diversity, which is correlated with vegetation richness, is usually a crucial determinant of avian richness and diversity, because it provides birds with microhabitats for feeding, nesting and roosting (Begon *et al*. 1996; Canterbury *et al*. 1999; Soderstrom & Part 1999). At the shore zone of Lake Biwa, species density of waterbirds is positively correlated with the total area of reed beds and the total area of littoral tree canopies; the larger the reed bed, the more diverse the plant species (Sugawa 1991). At the site of the present study, species density and the diversity of waterbirds were high in the blocks where *Zizania latifolia* and *Phragmites australis* reed beds existed. In addition, the open cove reed bed and the wooded intricate reed bed had littoral trees and shrubs, which seemed to provide waterbirds with good refuges or shelters. In fact, herons and egrets often utilized the trees and shrubs as roosting sites. Burger and Gochfeld (1991) pointed out that the feeding activity of sanderlings on beaches is influenced by the presence of people, when they are within 100 m of the sanderlings. In the site of the present study, people live within the vicinity of the lagoon, and the road traffic is heavy around Lake Biwa (Research Group for Natural History of Lake Biwa 1994; Kada 1999; Kawanabe 1999). The reed bed community might mitigate human disturbance to waterbirds living inside the small lagoon. Further work is required to clarify the effects of human disturbance on waterbird richness and diversity. Observations on habitat use and diversity of waterbirds in relation to landscape elements at the shore zone of Lake Biwa, as well as at other lagoons around the lake, are necessary to compare to the results of this study. In conclusion, the coastal lagoons around Lake Biwa can be important habitats for waterbirds and should be protected.

ACKNOWLEDGEMENTS

We are grateful to Yasunobu Yanagisawa, Satoshi Yamagishi and Jiro Kikkawa for valuable advice on the manuscript, and to Kayoko Kameda and Munetsugu Kawashima for suggestions on the study. We also wish to thank Shingo Maeda for assisting with measuring water depth. This work was supported in part by a Grant-in-Aid for Science Research no. 08780149 for A. H, a Guest Scientist at the Center for Ecological Research, Kyoto University.

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