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Alpine wetlands in the Lhasa River Basin, China

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Abstract: The Lhasa River Basin is one of the typical distribution regions of alpine wetlands on the Tibetan Plateau. It is very important to get a better understanding of the background and characteristics of alpine wetland for monitoring, protection and utilization. Wetland construction and distribution in the basin were analyzed based on multi-source data including field investigation data, CBERS remote sensing data and other thematic data provided by 3S technology. The results are (1) the total area of wetlands is 209,322.26 hm^2, accounting for 6.37% of the total land area of the basin. The wetlands are mainly dominated by natural wetland, with artificial wetland occupying only 1.09% of the wetland area; marsh wetland is the principal part of natural wetland, dominated by *Kobresia littledalei* swampy meadow which is distributed in the river source area and upstream of Chali, Damshung and Medro Gongkar counties. The ratio and type of wetlands in different counties differ significantly, which are widely distributed in Chali and Damshung counties (accounting for 62% of the total wetland area). (2) The concentrated vertical distribution of wetlands is at an elevation of 3600–5100 m. The wetlands are widely distributed throughout the Yarlung Zangbo River Valley from river source to river mouth into the Yarlung Zangbo River. Marsh wetland is dominant in the source area and upstream of the river, with the mosaic distribution of lakes, *Kobresia littledalei* and *Carex moorcroftii* swampy meadow, shrubby swamp and river; as for the middle-down streams, the primary types are river wetland and flooded wetland. The distribution is in a mosaic pattern of river, *Kobresia humilis* and *Carex moorcroftii* swampy meadow, *Phragmites australis* and subordinate grass marsh, flooded wetland and artificial wetland.

Keywords: Lhasa River Basin; alpine wetland; classification system; distribution; 3S technology

1 Introduction

Wetland, known as the “kidneys of the earth”, is an ecosystem that serves as an intermediate between land ecosystem and aquatic ecosystem, with unique water, soil and vegetation characteristics (Mitsch *et al*., 1993; Chen, 1995; Brinson and Malvarez, 2002). The Tibetan Plateau wetland ecosystem, with the richest natural biodiversity and the most important

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ecological barrier function in high altitude area, is sensitive to global change and is considered as a symbol of global change. The construction and distribution of environmental interactions of the wetland system are key to understanding their function and rational utilization and protection of wetlands. In China, papers related to Tibetan wetlands have been published since the 1960s (Chai *et al*., 1965). Great progress was made in the studies on status and protection, restoration and reconstruction, environmental and hydrological effect, dynamic changes of wetland ecosystem in the late 1990s (Zhu *et al*., 2003; Bai *et al*., 2004; Cao *et al*., 2005; Wang *et al*., 2007). Some results indicate that with the effect of global change and human activities, Tibetan wetlands have noticeably shrunk and degraded, leading to a series of eco-environmental problems (Tian *et al*., 2004; Liu *et al*., 2006; Pan *et al*., 2007; Bai *et al*., 2008).

The Yarlung Zangbo River Valley in southern Tibet is one of the primary distribution regions of alpine wetland in the Tibetan Plateau. The Lhasa River Basin is a major tributary of the Yarlung Zangbo River, and serves as a core region of politics, economy, culture, traffic and religion in Tibet Autonomous Region (Chu *et al*., 2000; Qiong and La, 2000). Alpine wetlands are abundant, including river wetland, lake wetland, marsh wetland and so on; among which, Lhalu wetland in the city of Lhasa is a typical plateau city wetland (Zhang *et al*., 2000). Most wetlands in the basin are used as pasture; thus, both the quantity and distribution of wetland resources affect economic progress and people's living standard. At present, a distribution map of wetland with high resolution and wetland database is absent, which restricts management and protection of wetland resources. In this paper, the construction characteristics and spatial distribution law of wetlands in the Lhasa River Basin are analyzed systematically by 3S technology based on field investigation and remote sensing interpretation data (Mc Dougall, 2003; Wu *et al*., 2007; Niu *et al*., 2009). The results provide important reference to protection and restoration of wetland ecosystem, regulation and utility of wetland resources, and a scientific basis for monitoring wetland change in the region.

2 The study area

The Lhasa River is 551 km long with a total drainage area of 32,471 km^2, lying in a range from 90°05′E–93°20′E to 29°20′N–31°15′N (Figure 1). High mountains and deep gorges are distributed as a mosaic with a slight incline from north to southwest. The topography is divided into high mountain landform, Damshung-Yambajan basin landform, and high and middle mountain valley landform. The altitude in the basin ranges from 3500 m to 7162 m with an average altitude of about 5400 m. It belongs to plateau temperate semi-arid monsoon climate region, with abundant sunlight and low temperature. The average temperature is about –1.7–9.7℃ and the average annual precipitation is about 460 mm. Alpine cold desert soil appears above 5200 m and alpine meadow soil is found on slopes at about 5000 m. It is well vegetated with alpine meadow, alpine steppe, marsh, shrub, forest, etc. (Gong *et al*., 2006); meadow and marsh are mainly distributed in the Damshung Valley, river source and Lhasa river valley with dominant species including *Kobresia littledale* and *Kobresia humilis* as well as marsh plants of *Phragmites australis*, *Polygonum lapathifolium*, and *Hippuris vulgaris* and *Scirpus validus*. Wild animals in the wetlands are also plentiful, including birds such as *Grus nigricollis*, *Tadorna ferruginea* and *Anser indicus* as well as high mountains frog and *Schizothorax*. The basin covers ten counties: the area just outside the Lhasa

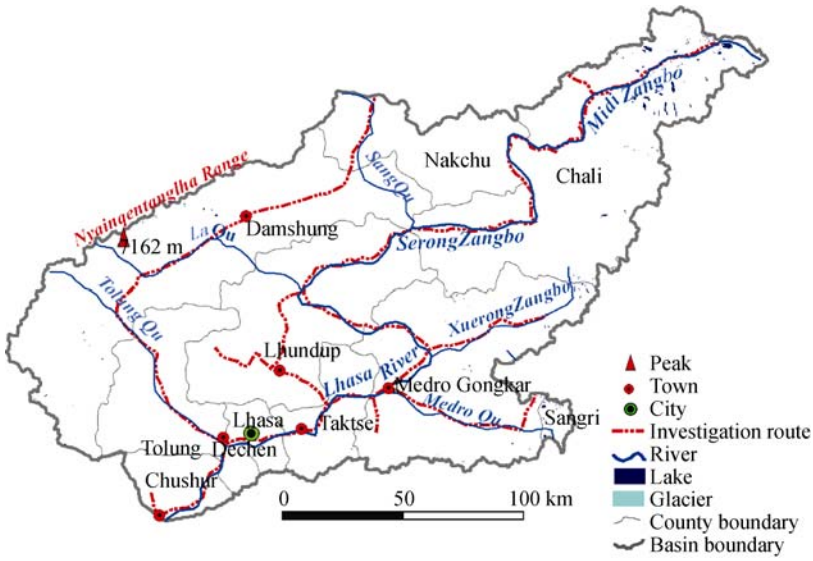

Figure 1 Location of the Lhasa River Basin and investigated route, China

city gate, Chushur, Tolung Dechen, Damshung, Nakchu, Chali, Lhundup, Medro Gongkar, Taktse and a part of Sangri. The population was over 500,000 in 2007; the river's source area belongs to pastoral area, while the middle and downstreams are farming-pastoral areas.

3 Data and method

In this paper, data source includes remote sensing data, other auxiliary special topic data and field investigation data. Study methods are mainly based on remote sensing interpretation and ArcGIS analysis.

3.1 Data source

3.1.1 Remote sensing data

RS images are CBERS digital images in 2006 with a spatial resolution of 20 m; they are provided free of charge by China Resources Satellite Application Center. The study area consists 12 scenes covering the path range of P22-P25 and R65-R67. Because of the special geographical location with high altitude and many cloudy days in the summer, it is difficult to get clear images during the growing season. Therefore, images of January 1st (2 scenes), January 21st (4 scenes), January 27th (1 scene), and January 30th (3 scenes) in 2006 were chosen according to the factual situation. A small part of image is covered by snow, but it is not very important. Other auxiliary high resolution images were downloaded from Google Earth.

3.1.2 Auxiliary special topic data

The auxiliary data include topographic map (scale 1:100,000; 1970), China vegetation map (scale 1:1,000,000; 2004), land use map (1:100,000; 2000), etc.; "Tibetan Vegetation" (1988), "China Vegetation" (1980) and field investigation material are taken as references for vegetation type and features. DEM data, with a spatial resolution of 90 m, were obtained from the official website of SRTM.

3.1.3 Field investigation data

The wetland types, position and vegetation data were collected from three field investigations and samplings in the Lhasa River Basin in October 2007, February 2008 and September 2008. The field investigation followed five routes along "Lhasa city–Tolung Dechen–Yambajan–Damshung–Nakchu–Chali" (Figure 1), covering a range of ten counties and 21 nature reserves. Investigation contents include GPS waypoint and track, vegetation type and community constitution, and typical samplings of plant community. One hundred and sixty plant samples and 600 symbol points of land use and land cover type were accomplished.

3.2 Method

3.2.1 Processing, interpretation, evaluation and revision of remote sensing image

RS images were processed and interpreted under ERDAS9.1 platform. Bands 4, 3 and 2 were compounded to false color image. Control points that were chosen from the topographic map were taken to achieve geometrical correction while utilizing a quadratic polynomial fitting method. Pixel resembling was processed by the nearest neighbor method. Errors of the revised image were less than one pixel (20 m×20 m) according to the RMS test (Cai *et al*., 2007; Wang *et al*., 2007; Zhu *et al*., 2003). The entire image of the study area was achieved by the image mosaic. Wetland and relevant land cover type were established by visual interpretation. Based on field investigation, topographic map, vegetation map, land use map and high resolution image of Google Earth, a database of wetland interpretation symbols, including 13 types and 288 symbol points, were built. The data time of the RS images used is winter. Therefore, a large part of the study area is covered by snow and ice, and wetland information is incomplete. Thus, it is difficult to discriminate seasonal wetland formed by permafrost melting, which increases the difficulty of interpretation. So many other RS data and investigation data were consulted to make comparative analysis so as to improve interpretation precision.

3.2.2 Construction of classification system and characteristic of interpretation

Based on wetland classification systems used home and abroad (Scott and Jones, 1995; Pressey and Adam, 1995; The Ramsar Convention Bureau, 2000; Tang *et al*., 2003; Liu *et al*., 2006), an alpine wetland classification system was constructed based on remote sensing. The classification system includes two types in Class 1, seven types in Class 2, nine types in Class 3, and 13 types in Class 4 (Table 1).

3.2.3 Precision test

The precision of interpretation of remote sensing image refers to the ratio of an accurate interpretation patch to a sampled patch. There are a total of 2033 patches of wetlands in the study area and 286 sampled patches were chosen. The test results indicate that the precision of interpretation of each type of land cover is above 90% (Table 2), that of lake wetland reaches 100%, and that of subordinate grass marsh is the lowest with 90%.

3.2.4 Spatial analysis and mapping

Spatial analysis and mapping of wetlands were accomplished using the ArcGIS9.2 platform. In order to finish the analysis along the altitude gradients, the DEM data were divided into 23 zones with an elevation interval of 100 m from 3500 m to 5800 m. Then wetland area and

Table 1 Wetland classification system and interpretation signal of the Lhasa River Basin, China

Classification				Interpretation characteristic of wetland type	Image
Class 1	Class 2	Class 3	Class 4		
Natural wetland	River wetland	River wetland	River wetland (river)	Watercourse of plain river in the basin appears black or blue-black colour with wider river valley, both sides of the watercourse are pink, with more settlements and farmland on beach and terrace of river.	
				Mountain river appears light blue or white. The shallow water is mixed with ice and snow on winter image. Developed in mountain, watercourse is narrow, both sides are meadows.	
	Flooded wetland	Flooded wetland (flood plain /island)	Weedy wet meadow	Distributed in flood plain and island, light pink, composed of *Kobresia*, *Carex* and *Gramineae*. Communities are different in height and coverage because of regional differentiation.	
			Hippophae rhamnoides	Dominant species is *Hippophae rhamnoides*, with community height of 3 m, and coverage of 90%, which is distributed mainly in Medro Gongkar County, copper brown.	
			Beach gravel	Distributed in flood plain or island, vegetation coverage is less than 5%, with light blue or off-white colour and even texture.	
	Lake wetland	Lake wetland	Lake wetland (lake)	Distributed in river source and river valley, blue or black, irregular, the boundary between water and land is clear.	
	Marsh wetland	Grass marshes	*Phragmites australis marsh*	Dominant species is *Phragmites australis*, with community height of 1.5 m and coverage 95%. Distributed by the river with black color and abnormal shape.	
			Subordinate grass marsh	Dominant species are *Hippuris vulgaris*, *Eleocharis vulgaris* and *Polygonum lapathifolium* with community height being about 30–45 cm and coverage 70%–85%. Light red, with black water mark.	
		Swampy meadow	*Kobresia littledalei* Swampy meadow	Dominant species is *Kobresia littledalei* with grass hill and lowland in mosaic distribution. Community height is 35–45 cm and coverage is 90%. It is located on the alluvial basin in the piedmont with high altitude. Dark brown and uneven because of ice and snow.	
			Kobresia humilis+ *Carex moorcroftii* swampy meadow	Dominant species are *Kobresia humilis*, *K. littledalei* and *Carex moorcroftii*. Community height is 25–35 cm and coverage is 85%–90%. Distributed in wide valley with middle-down altitude. Dark red, obvious texture.	
		Shrubby swamp	*Potentilla fruticosa* shrub	Constructive species is *Potentilla fruticosa* shrub. Distributed in upstream valley. Community height is 80–90 cm, coverage is about 80%, black brown, and even texture.	
	Wetland of irrigation purpose	Reservoir	Reservoir	Distributed in valley of middle-down stream, blue or black, obvious geometric characteristic, line and sheeted shape with traces of artificial shaping. Even texture, clear boundary.	
Artificial wetland	Wetland of aquaculture purposes	Pond	Pond	Similar characteristics of a reservoir with small surface area and regular shape.	
	Wetland of ecological purpose	Seasonal flooded wetland	Man-made beach forest	Dominant species are man-made poplar and willow, distributed in wide seasonal flooded plain, red color. Smaller area, more patches.	

*Illustrations: Some permanent glacier and snow cover are distributed in this basin. Few researchers believe they belong to wetland, but this attitude has not been unified internationally. The wetlands referred in this paper do not include the permanent ice and snow cover.

Table 2 The precision test of interpretation of each wetland type in the Lhasa River Basin, China

Class 4	Total patches	Sampled patches	Precision of interpretation (%)	Class 4	Total patches	Sampled patches	Precision of interpretation (%)
River	47	7	98	*Kobresia littledalei* Swampy meadow	461	64	95
Weedy wet meadow	186	26	90	*Kobresia humilis*+ *Carex moorcroftii* swampy meadow	147	21	91
Hippophae rhamnoides	65	9	98	*Potentilla fruticosa* shrub	6	1	93
Beach gravel	156	22	95	Reservoir	3	1	92
Lake	259	36	100	Pond	11	2	90
Phragmites australis marsh	4	1	92	Man-made beach forest	82	12	95
Subordinate grass marsh	22	3	90				

wetland types at a certain altitude zone were calculated through the grid extension model in ArcInfo 9.2 by command Zonalstats. Other statistical analysis was achieved in EXCEL.

4 Distribution characteristics of wetlands in the Lhasa River Basin

4.1 Spatial pattern of wetland system

In the Lhasa River Basin, wetland characteristics are evident, the proportion of different wetland types covering total wetland area differs greatly. In every county, wetland construction is different. In another, there are specific distribution patterns in horizontal and vertical scale.

4.1.1 Structure of wetland types

The total wetland area in the Lhasa River Basin is 209,322.26 hm^2, accounting for 6.37% of the total land area. Figure 2 shows the location and distribution of wetland type in the basin, with the main wetland type being natural wetland; the artificial wetland covers only 1.09% of the total wetland area (Table 3). Among the natural wetlands, marsh wetland is predominant, accounting for 68.77% of the total wetland area. It can be concluded that the *Kobresia littledalei* swampy meadow wetland is absolutely the dominant wetland type, with large distribution area in many patches. Its largest patches area is located in Damshung Basin, being about 15,743.15 hm^2. The number of patches of artificial wetland, *Phragmites australis* marsh and shrubby swamp wetland is smaller.

In the Lhasa River Basin, the wetland ratio and wetland types of different counties are evidently different. Chali and Damshung counties, located in the river source area, are abundant, occupying 38% and 26% of the total wetland area respectively in wetland (Table 4). The wetland area of the city of Lhasa is the fewest with only 2%. The highest wetland ratio appears in Chali and Taktse counties, being 11.05% and 8.76% respectively. The wetland diversity is high in Taktse, Medro Gongkar, Lhundup and Chushur counties and the city of Lhasa with more than eight wetland types. However, wetland diversity in Damshung and Chali counties with larger wetland area is low, containing less than five wetland types.

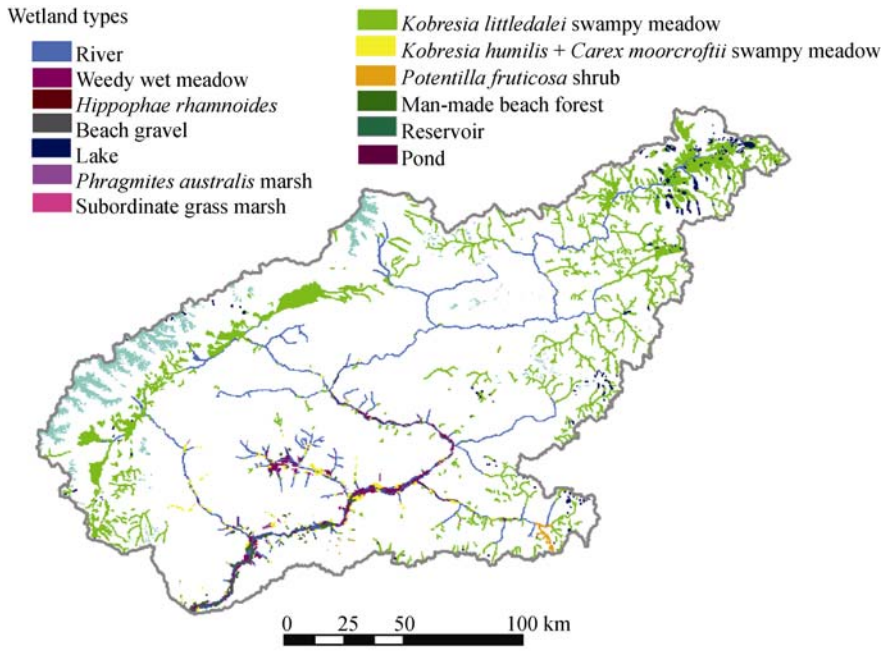

Figure 2 Wetland distribution of the Lhasa River Basin, China

Table 3 Structure of wetland system in the Lhasa River Basin, China

Wetland type				Area statistics		
Class 1	Class 2	Class 3	Class 4	Area (hm^2)	Proportion (%)	Proportion of Class 2 (%)
Natural wetland	River wetland	River	River	25281.98	12.08	12.08
	Flooded wetland	Flooded wetland	Weedy wet meadow	20649.37	9.86	14.70
			Hippophae rhamnoides	917.71	0.44	
			Beach gravel	9220.49	4.40	
	Lake wetland	Lake	Lake	7003.34	3.35	3.35
	Marsh wetland	Grass marsh	*Phragmites australis* marsh	555.10	0.27	68.77
			Subordinate grass marsh	411.22	0.20	
		Swampy meadow	*Kobresia littledalei* swampy meadow	136970.24	65.43	
			Kobresia humilis+ *Carex moorcroftii* swampy meadow	5064.31	2.41	
		Shrubby swamp	*Potentilla fruticosa* shrub	964.33	0.46	
Artificial wetland	Wetland of irrigation purpose	Reservoir	Reservoir	253.07	0.12	0.12
	Wetland of aquaculture purposes	Pond	Pond	76.54	0.04	0.04
	Wetland of ecological purpose	Seasonal flooded wetland	Man-made beach forest	1954.57	0.94	0.94
Sum				209322.26	100.00	100.00

Table 4 Wetland construction of different counties in the Lhasa River Basin, China (unit: hm^2)

Wetland (Class 4) type	Damshung	Nakchu	Chali	Lhundup	Tolung Dechen	Chushur	Lhasa city	Taktse	Medro Gongkar	Sangri
River	3772	1474	3980	5350	1995	1330	784	2468	4067	62
Weedy wet meadow	44			6355	2305	1613	376	5310	4630	
Hippophae rhamnoides				357					554	
Beach gravel				1038	2067	3227	1233	829	840	
Lake	512		5200					11	762	518
Phragmites australis marsh						63	438	53		
Subordinate grass marsh				247	27	70	30	24	21	
Kobresia littledalei swampy meadow	48857	5489	67888	1532	1384	20	11	470	10872	449
Kobresia humilis+ *Carex moorcroftii* swampy meadow	30	2	34	1481	864	117	443	1461	646	
Potentilla fruticosa shrub								58	910	
Reservoir				240					11	
Pond				60		8	1	4	3	
Man-made beach forest				293	459	472	231	478	8	
Area (hm^2) statistics	53215	6965	77102	16953	9101	6920	3547	11166	23324	1024
Proportion to the total wetland area (%)	26	3	38	8	4	3	2	5	11	0.5
Account of Class 4 type	5	3	4	10	7	9	9	11	12	3
Wetland ratio [x] (%)	7.79	3.09	11.05	4.00	3.63	8.00	7.28	8.76	4.56	4.87

[x]Wetland ratio is the proportion of wetland area within a county and the total area of the county.

4.1.2 Horizontal distribution characteristics of wetland system

The marsh wetland is dominant in the source and upstream of the river, while river wetland and flooded wetland are primary types in the river valley of middle and down streams (Figures 2 and 3). Influenced by hydrological conditions, variations of relative height, terrain and composition of the earth surface, there are regional differentiations in spatial distribution and wetland types. From river source to river mouth of the Yarlung Zangbo River, distribution structure of wetlands is lake–*Kobresia littledalei* and *Carex moorcroftii* swampy meadow–*Phragmites australis* marsh and subordinate grass marsh–flooded wetland, river wetland is seen throughout the area. The altitude of the river valley is the lowest, and the river network is densely and evenly distributed. Different land cover types, such as weedy wet meadow, *Hippophae rhamnoides* and beach gravel, are distributed in the floodplain adjacent to the river, due to the difference in topographic characteristics and hydrological conditions. *H. rhamnoides* is mainly distributed in the valley of Mozhumaqu. Subordinate grass marsh and *Phragmites australis* marsh are in the bottomland with perennial water, but plant community types vary according to different levels of the water table. Swampy meadow wetland, the core of wetland system in a basin, is located in Damshung and Yangbajan Basin, river source, lakeside with impeded drainage, bottomland, floodplain with water spreading out, shallow water overflow belt of piedmont and front edge of glacier. Marsh wetland is not only important winter grazing ground, but also habitat and special area for many precious species of plants and animals. Lake wetland lies in the Lhasa River source, including

Maidika area in Chali county, Mozhumaqu source in Medro Gongkar county, under the snow-line in Damshung and Yambajan, playing an important rule in regulating runoff of river and alpine climate. Artificial wetland is distributed mainly in the farming area of the river valleys.

There are several wetland distribution patterns in the Lhasa River Basin. In river source and upstream valley, wetland construction is the mosaic pattern of "lake–*Kobresia littledalei* and *Carex moorcroftii* swampy meadow–swamp" and river; in wide valley of middle-down stream, distribution mode is another mosaic pattern of river and *"Kobresia humilis and Carex moorcroftii* swampy meadow–*Phragmites australis* and subordinate grass marsh–flooded wetland" and artificial wetlands for different purposes.

4.1.3 Vertical distribution characteristics of wetland

In the basin, the wetland's vertical elevation variance is more than 3600 m. Influenced by the topographic characteristics and combination conditions of temperature and moisture, wetlands are distributed in three ranges of 3600–3900 m, 4200–4400 m and 4700–5100 m respectively, accounting for 18.93%, 15.04% and 43.46% of the total wetland area each, or a total of 77.44%. The wetland's area ranging from 4900 m to 5000 m is the largest, covering 16.49% of the total area, in each 100 m altitude zone; and wetland becomes less and less at above 5000 m. At an altitude ranging from 3600 m to 4200 m and 4300 m to 4700 m, wetland area gradually increases. Wetland types of Class 4 are abundant at the altitude ranging from 3700 m to 3900 m (11 types). In addition, along with altitude rising and dropping, the number of wetland type gradually reduces, and is the least in the area with the highest altitude (Figure 4a), presenting an obvious decreasing tendency. At altitudes from 3500 m to 4200 m, 4300 m to 4800 m and 5200 m to 5800 m, the changing tendency of wetland area is consistent to that of wetland types. Then, vertical distribution of each wetland type is summarized in Table 5.

The vertical distribution characteristics of a single type of wetland are obvious, which is mainly distributed in areas with an altitude of 3500–5800 m (Figures 3 and 4a). From high to low altitude, wetland distribution mode is *Kobresia littledalei* swampy meadow-lake–

Table 5 Distributed scope of different wetland types in the Lhasa River Basin, China

Wetland types	Elevation (m)
River	>3500
Lake	>4200, in particular 4800–5100
Weedy wet meadow	3600–4000
Hippophae rhamnoides	3800–4100
Beach gravel	3500–3700
Kobresia littledalei swampy meadow	3700–5600, in particular 4200–4300 and 4700–5100
Kobresia humilis+ *Carex moorcroftii* swampy meadow	3600–4200
Phragmites australis marsh	3600–3800
Subordinate grass marsh	3600–3800
Potentilla fruticosa shrub	4500–4700
Reservoir and pond	3700–3900
Man-made forest	3500–3800

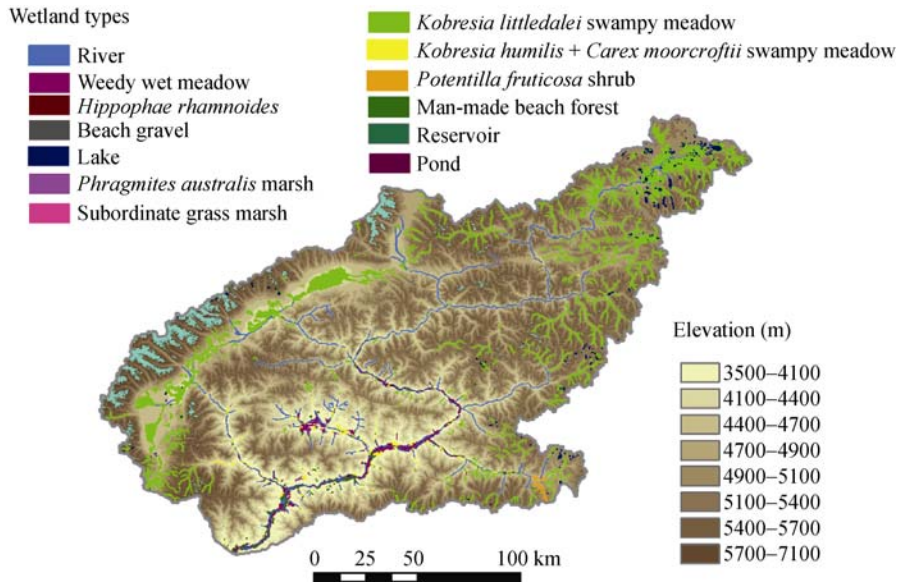

Figure 3 Relationship between the wetland distribution and altitude in the Lhasa River Basin, China

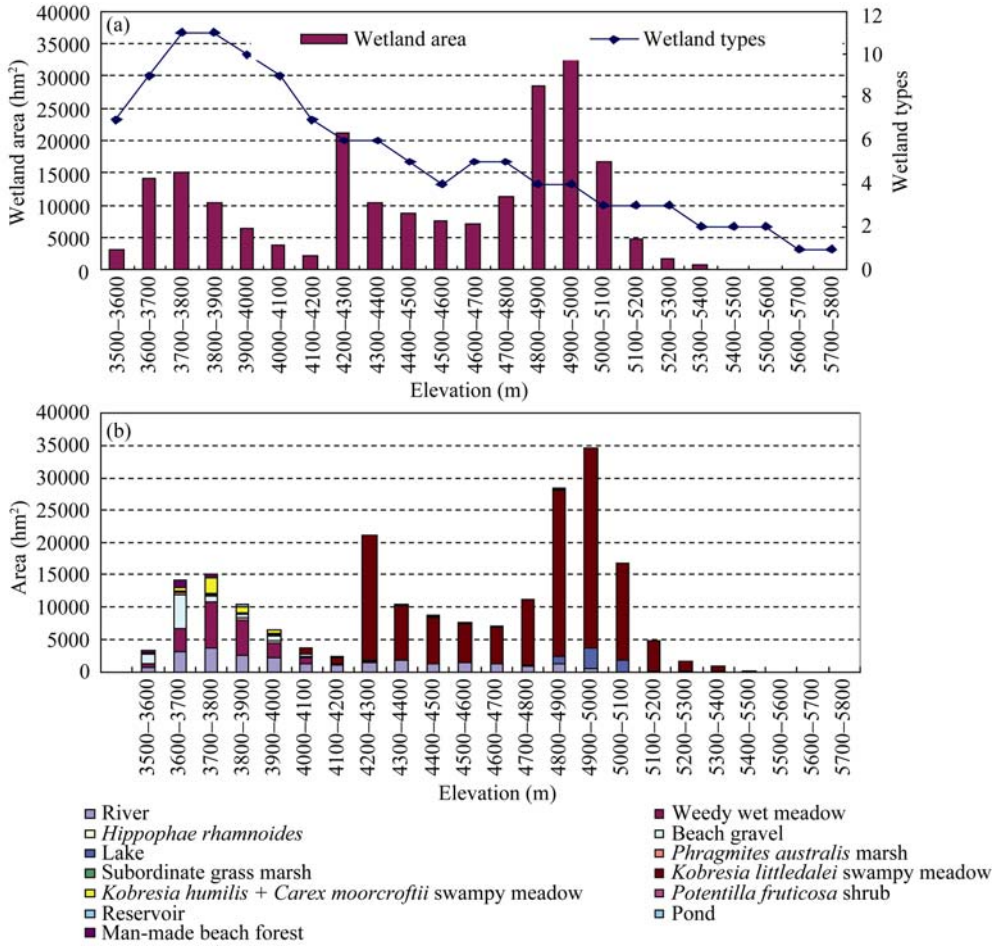

Figure 4 Wetland area and types of each altitude belt in the Lhasa River Basin, China
(a: area and type number of wetland; b: area of each wetland type)

Potentilla fruticosa swamp–*Hippophae rhamnoides–Kobresia humilis*+ *Carex moorcroftii* swampy meadow–man-made forest and weedy wet meadow–*Phragmites australis* and subordinate grass marsh, and river wetland is distributed throughout the basin (Figure 4b).

4.2 Community characteristic of marsh wetland

Marsh wetland including swampy meadow, grass marsh and shrub marsh, is the predominant part of wetland in the basin; *Kobresia littledalei* and *K. humilis*+ *Carex moorcroftii* swampy meadow are primary types of swampy meadow wetland; *Phragmites australis* marsh and subordinate grass marsh are primary types of grass marsh wetland. Because of a smaller proportion of shrub marsh wetland, its characteristic is not described. Each wetland type has many different plant community types under different micro-topographic environment, such as *K. littledalei*, *C. moorcroftii*, *K. humilis*, *P. australis*, *Potentilla anserina*, *Fimbristylis complanata*, *Hippuris vulgaris*, *Potamogeto natans*, *Utricularia aurea*, *Nymphaea alba*, *Polygonum lapathifolium*, *Halerpestes cymbalaria*, and *Eleocharis vulgaris*. The characteristics of primary herb marsh wetland are briefed as follows.

4.2.1 *Kobresia littledalei* swampy meadow

Kobresia littledalei is widely distributed at upstream and in the river source of Chali, Damshung and Medro Gongkar counties, with a large area in an altitude of about 3700–5600 m. Community coverage is above 90%, and community height is about 35–45 cm. Dominant species is *Kobresia littledalei,* with associate species including *Kobresia humilis*, *Blysmus sinocompressus, Gentiana leucomelaena* and *Pedicularis longiflora*. Species diversity is abundant: there are 30 species of higher plants that belong to 12 families and 24 genera in the sample plots. Dominant families include Cyperaceae (4 genera, 6 species), Composistae (5 genera, 5 species), Ranunculaceae (3 genera, 4 species), Primulaceae (2 genera, 2 species), Polygonaceae (2 genera, 2 species), Gentianaceae (1 genus, 3 species), and Leguminosae (1 genus, 2 species). Rush, Scrophulariaceae, Rosaceae and Caryophyllaceae include one genus and one species respectively.

4.2.2 *Kobresia humilis* +*Carex moorcroftii* swampy meadow

This kind of marsh wetland is mainly located in middle and down streams of Lhundup, Taktse and Tolung Dechen counties with an altitude of about 3600–4200 m. Dominant species include *Kobresia humilis*, *Blysmus sinocompressus* and *Carex moorcroftii.* Community coverage is about 85%–90%, and height is 25–35 cm. Associate species include *Kobresia littledalei*, *Fimbristylis complanata*, *Poa annua* and so on. There are 36 species of higher plants that belong to 16 families and 31 genera in the sample plots. Dominant families include Gramineae (6 genera, 6 species), Cyperaceae (5 genera, 8 species), Composistae (3 genera, 3 species), Ranunculaceae (2 genera, 3 species), Leguminosae (2 genera, 3 species), and Scrophulariaceae (2 genera, 2 species). Rush, Polygonaceae, Plantaginaceae, Cruciferae, Primulaceae and Rosaceae include one genus and one species respectively.

4.2.3 *Phragmites australis* and subordinate grass marsh

Phragmites australis marsh is located at the wide valley in Chushur County, Lhasa city, and Taktse County with an altitude of 3600–3700 m; subordinate grass marsh lies in Lhundup County with an altitude of about 3600–3800 m. Community coverage is 70%–80%. Domi-

nant aquatic plant communities include *Phragmites australis*, *Scirpus tabernaemontani*, *Typha latifolia, Hippuris vulgaris*, water chestnut and so on; associated species include *Halerpestes tricuspis*, *Triglochin maritimum*, *Epilobium palustre* and *Bidens cernua* etc. Sample investigations indicate that there are 25 species of higher plants belonging to 18 families and 22 genera. Dominant families include Cyperaceae (3 genera, 3 species), Gramineae (3 genera, 3 species), Ranunculaceae (1 genus, 3 species), and Triglochin palustre (one genus, two species). Rush, Bulrush, Polygonaceae, Onagraceae and Plantaginaceae include one genus and one species respectively.

5 Conclusions

(1) The total wetland area is about 209,322.26 hm^2, accounting for 6.37% of the basin area. The wetlands in the Lhasa River Basin are mainly dominated by natural wetland with marsh wetland covering 68.77% of the total wetland area, hence being the principal part of natural wetland. Marsh wetlands can be further divided into grass marsh wetland, swampy meadow wetland and shrubby swamp. *Kobresia littledalei* swampy meadow covering 65.44% of marsh wetland is distributed in the river source and upstream of Chali, Damshung and Medro Gongkar counties with a vertical distribution scope of 2000 m. Community coverage is above 90%, and the height is 35–45 cm. Dominant species is *Kobresia littledalei,* with associated species being *Kobresia humilis* and *Blysmus sinocompressus.* There are 30 species of higher plants in the sample plots. River wetland is widely distributed in the drainage basin, from source to the mouth of the Yarlung Zangbo River. Lake wetland is distributed mainly in river source where it is above alt. 4200 m in Chali, Damshung and Medro Gongkar counties; flooded wetland is distributed in the wide valley of Lhundup, Medro Gongkar, Taktse and Chushur counties, with an altitude of about 3600–4200 m. Primary type in flooded wetland is weedy wet meadow, and *Hippophae rhamnoides* lies mainly in Medro Gongkar County. The percentage of artificial wetland to total wetland area is low, exclusively located in valley farming area of low altitude in Lhundup and Medro Gongkar. Wetland ratio and wetland type differ evidently in various counties of the basin.

(2) Influenced by topography, temperature and moisture factors, regional differentiation of wetland composition and distribution are obvious. Wetland is distributed in an altitude of 3500–5800 m, especially 3600–5100 m. Marsh wetland is the primary type of wetland in the river source and upstream with a mosaic pattern of "lake–*Kobresia littledalei* and *Carex moorcroftii* swampy meadow–shrubby swamp" and river; as for wide valley of middle-down streams, river wetland and flooded wetland are the primary types of wetland, with mosaic pattern of river and "*Kobresia humilis*+ *Carex moorcroftii* swampy meadow–*Phragmites australis* and subordinate grass marsh–flooded wetland" and artificial wetland. From high to low altitude, wetland structure is *Kobresia littledalei* swampy meadow–lake–*Potentilla fruticosa* swamp–*Hippophae rhamnoides–Kobresia humilis*+ *Carex moorcroftii* swampy meadow–man-made forest and weedy wet meadow–*Phragmites australis* and subordinate grass marsh; river wetland is distributed throughout the basin.

(3) Because of the different purposes of study and application, classification of wetland system is still being explored. In this paper, a revised 4-class classification system of alpine wetlands based on remote sensing provides an important reference for constructing and im-

proving wetland classification system in the high altitude area.

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