AQUATIC VASCULAR PLANTS FROM THE SANJIANG PLAIN, NORTHEAST CHINA

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(Received 21st Dec 2020; accepted 3rd Mar 2021)

Abstract. Sanjiang plain is recognized as a biodiversity hotspot in China, and knowledge of aquatic vascular plant species is essential for long-term wetland conservation programs. This investigation provided a checklist of aquatic vascular plants for the Sanjiang plain wetland, and information about the influences of water depth on their parameters. Based on the inventory, 149 species were identified, belonging to 86 genera, 44 families and 32 orders. Of these, Cyperales was the most diverse order with 26 species, followed by Graminalis (14 species). Cyperaceae and Gramineae were the most species-rich families (26 and 14 species, respectively). *Carex* and *Polygonum* were the most species-rich genera with 14 and 9 species, respectively. Our analyses displayed that the availability of water depth influenced the increased cover and height of aquatic vascular plants. Wetland conservation should be a high priority to prevent vascular plants in the Sanjiang plain.

Keywords: *inventory, plant species, checklist, correlations, wetlands*

Introduction

Diverse wetland types are naturally highly dynamic (Wang et al., 2018), due to natural processes at the ecosystem level, e.g. seasonal and non-seasonal fluctuations of water levels, succession to other habitats, the lateral movement of rivers and the activity of large herbivores (Jian, 2008; Bilz et al., 2011). Wetlands play a vital role in maintaining biodiversity (Mitsch and Gosselink, 1993; Gopal and Junk, 2001), regulating regional micro-climate, maintaining groundwater level and cleaning air, and have a strong ability of water purification (Xiaomin, 1996; Herath, 2004; Jian, 2008; Chen et al., 2008; Zhang, 2010).

Wetlands have been modified since humans first started to grow crops and keep livestock (Wang et al., 2018), from minor diversions to form stock ponds up to hard defenses, channelization and damming of major rivers and streams (Bilz et al., 2011).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1904_26892699

Modification of wetland systems and complexes disrupts connections between populations by increasing the distance between patches further enhancing the probability of extinction (Bilz et al., 2011; Wang et al., 2018). Fragmentation of wetland habitats also leads to the decrease in total surface area (Wang et al., 2018), which affects the total size of wetland biodiversity, as well as the size of the remaining habitat patches increasing their vulnerability (Xiaomin, 1996; Jian, 2008; Bilz et al., 2011).

Aquatic plants provide a wide range of functions in freshwater ecosystems (Bilz et al., 2011). They supply the water with oxygen, fix atmospheric carbon, recycle nutrients, regulate water temperature and light, protect against erosion in flowing water and where the banks or margins are threatened by backwash from boat traffic (Murillo et al., 2009; Bilz et al., 2011). They also provide vital habitat and food for fish and aquatic invertebrates, which themselves support other animals and humans (Hamilton and Hamilton, 2006; Bilz et al., 2011). Their abundance, composition and productivity play key roles in the processes of wetland structure and functions (Janousek and Folger, 2013).

For centuries, most of wetland has been used by humans to produce food, and provide living space (Herath, 2004; Bilz et al., 2011). Consequently, vascular plant species are to a large extent dependent upon semi-natural habitats created and maintained by human activity (Liu et al., 2019), particularly traditional, non-intensive forms of land management (Bilz et al., 2011; Spyreas, 2019). Wetlands are under pressure from agricultural irrigation (Spaling, 1995; Wang and Sheng, 2005), urbanization (Liu et al., 2019), infrastructure development, tourism pressure, acidification, eutrophication and desertification (Yi et al., 1994; Mensing et al., 1998; Foley et al., 2005; Zhang, 2010; Bilz et al., 2011; Mahmood et al., 2014; Perugini et al., 2017). In China, 80% of the wetlands that once existed have been destroyed or degraded due to unsustainable use patterns (Lu, 2009), causing losses of biodiversity (Zhang, 2010).

Many vascular plant species are directly affected by overexploitation (Wang and Sheng, 2005), persecution and impacts of alien invasive species, as well as climate change being set to become an increasingly serious threat in the future (Bilz et al., 2011). The inventories on vascular plant diversity in temperate zone are still insufficient and will have to be based on collections, which is also an important objective of all herbaria in the world. In this study, we aimed (1) at providing a checklist of vascular plants; and (2) at assessing the correlations between vascular plant metrics and water depth in the Sanjiang Plain wetlands.

Materials and methods

Research area and data collection

The Sanjiang plain is located at 129°11'E─135°05'E and 43°49'N─48°27'N in Heilongjiang Province, Northeast China (Cui and Liu, 1999; Zhang, 2010; Liu et al., 2019). We collected data in summer of years 2016, 2017 and 2020 in two wetland sites of the Sanjiang plain, including the Qixing River Basin (Qixing River Nature Reserve and Sanhuan Pao Nature Reserve, which are connected) at east longitude 132°00'22"─132°24"46", north latitude 46°39'45"─46°48'24" (Chen et al., 2008; Fu et al., 2020), and the Sanjiang National Nature Reserve at east longitude 133°43′-134°47′E, north latitude 47°26′-48°23′N (Teng et al., 2006).

The inventory was conducted on the wetland vegetation plots of 1 m x 1 m. A total of 194 and 385 sampling plots were investigated in the Qixing River Basin and Sanjiang National Nature Reserve, respectively. In each plot, water depth (m) was measured using

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1904_26892699

longline method when aquatic vascular plant samples were investigated. And then the vascular plant metrics, include density (ind./m^2) and cover (%) were recorded, and height of plants (cm) was measured using Tape measure. In order to identify aquatic vascular plant species, we used identification keys of Steward (1958); Shengtian (2003); Yi (2008); Thiombiano et al. (2015); Wąsowicz (2020).

Statistical analysis

We computed mean values of plant density (ind./m^2), cover (%), height (cm) and water depth (cm) using paired t-test in R software (version 4.0.3) to compare these two wetland sampling sites (Qixing River Basin and Sanjiang National Nature Reserve).

Pearson correlation test was performed using RcmdrPlugin.FactorMineR package in R software (Kuhnert and Venables, 2005; Borcard et al., 2011) to evaluate the concordance between depth of water and vascular plant variables (density, cover and height). We calculated statistical significance at **p-value* < 0.05 and ***p-value* < 0.01.

Results and discussion

List of aquatic vascular plant species in the wetlands of Sanjiang plain

A total of 149 species of aquatic vascular plants were identified, belonging to 86 genera, 44 families and 32 orders. Of these, Cyperales was the most diverse order with 26 species, followed by Graminalis (14). Cyperaceae and Gramineae (Poaceae) were the most species-rich vascular plant families in the wetlands of the Sanjiang Plain (26 and 14 species, respectively). The most represented genera were C*arex* (14) and *Polygonum* (9) (*Table 1*). Our findings were consistent with checklists of Keddy (2000); Sieben et al. (2010); Zizka et al. (2015); dos Santos Oliveira et al. (2019) reporting that Cyperaceae and Gramineae were the families with the highest numbers of vascular plant species in the wetland habitats. The highest species-rich of these two families was probably due to the success in dispersion of sexual propagules (Santamaría, 2002) and ubiquitous distribution of species with relevant morphological characteristics that enable them to spread vegetatively (Goetghebeur, 1998).

We recorded 100 species in the Qixing River Basin and 80 species in the Sanjiang National Nature Reserve (*Table 1*). Our study showed that species richness was higher in the Qixing River Basin and differed significantly in both wetland sites (paired t-test, $p = 0.0177$). That may be due to the fact that more species have been collected in deeper waters in the Qixing River Basin than in the Sanjiang National Nature Reserve (paired t-test, $p = 0.001$; *Fig. 1d*).

Table 1 showed that 31 species were identified in both sites; include *Alisma plantago-aquatica*, *Artemisia atrovirens*, *Caltha palustris*, *Carex appendiculata*, *Carex pseudo-curaica*, *Cirsium japonicum*, *Comarum palustre*, *Calamagrostis angustifolia*, *Equisetum fluviatile*, *Galium aparine*, *Glyceria spiculosa*, *Hypericum japonicum*, *Inula japonica*, *Iris laevigata*, *Lysimachia davurica*, *Lythrum salicaria*, *Menyanthes trifoliata*, *Nuphar pumilum*, *Nymphoides peltata*, *Phragmites australis*, *Polygonum hydropiper*, *Polygonum thunbergii*, *Sagittaria trifolia*, *Salvinia natans*, *Scirpus validus*, *Sium suave*, *Stachys baicalensis*, *Stellaria filicaulis*, *Stellaria radians*, *Typha orientalis*, and *Zizania iatifolia*.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1904_26892699

Table 1. *Aquatic vascular plant species list from the Sanjiang plain, Northeast China*

Order	Family	Species	QRB	SNNR
Alismatales	Najadaceae	*Najas minor*	1	
	Araceae	*Lemna minor*		1
	Alismataceae	*Alisma plantago-aquatica*	1	1
		Sagittaria trifolia	1	1
	Butomaceae	*Butomus umbellatus*	1	
	Potamogetonacaea	*Potamogeton crispus*	1	
		Potamogeton natans	1	
		Potamogeton perfoliatus	1	
Acorales	Acoraceae	*Acorus calamus*	1	
Apiales	Apiaceae	*Sium suave*	1	1
Asparagales	Iridaceae	*Belamcanda chinensis*	1	
		Iris laevigata	1	1
	Orchidaceae	*Habenaria sagittifera*		1
Asterales	Asteraceae	*Achillea millefolium*		1
		Aster tataricus	1	
		Bidens bipinnata		1
		Bidens pilosa	1	
		Carduus crispus		1
		Centipeda minima		1
		Saussurea salicifolia	1	
		Sonchus arvensis	1	
		Xanthium sibiricum	1	
	Menyanthaceae	*Nymphoides peltata*	1	1
Brassicales	Brassicaceae	*Rorippa globosa*		1
Callitrichales	Callitrichaceae	*Callitriche palustris*		1
Campanulales	Compositae	*Artemisia annua*	1	
		Artemisia atrovirens	1	1
		Artemisia aurata	1	
		Artemisia lavandulaefolia	1	
		Artemisia mongolica	1	
		Artemisia rubripes	1	
		Artemisia scoparia	1	
		Cirsium japonicum	1	1
		Cirsium setosum	1	
		Inula japonica	1	1
		Inula salicina	1	
Caryophyllales	Amaranthaceae	*Chenopodium album*		1
		Chenopodium glaucum		1
		Chenopodium hybridum	1	
	Caryophyllaceae	*Stellaria filicaulis*	1	1
		Stellaria radians	1	1
Ceratophyllales	Ceratophyllacaea	*Ceratophyllum demersum*	1	
		Ceratophyllum oryzetorum	1	
Cucurbitales	Cucurbitaceae	*Actinostemma tenerum*	1	
Cyperales	Cyperaceae	*Calamagrostis epigejos*	1	
		Carex appendiculata	1	1
		Carex bohemica	1	
		Carex brownii		1
		Carex cryptocarpa	1	
		Carex dispalata		1
		Carex humida	1	
		Carex kirganica	1	
		Carex lasiocarpa		1
		Carex limosa	1	
		Carex miyabei	1	

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Order	Family	Species	QRB	SNNR
		Carex pseudo-curaica	1	1
		Carex rhynchophysa		1
		Carex schnimdtii	1	
		Carex vesicaria	1	
		Eleocharis intersita	1	
		Eleocharis dulcis	1	
		Eriophorum gracile	1	
		Eriophorum polystachion		1
		Eriophorum vaginatum		1
		Pycreus globusus		1
		Scirpus nipponicus		1
		Scirpus orientalis		1
		Scirpus triqueter		1
		Scirpus validus	1	1
		Scirpus yagaar		1
Equisetales	Equisetaceae	*Equisetum fluviatile*	1	1
		Equisetum hyemale	1	
Ericales	Primulaceae	*Lysimachia davurica*	1	1
		Lysimachia thyrsiflora	1	
Fabales	Fabaceae	*Glycine soja*	1	
		Lathyrus palustris		1
		Lathyrus quinquenervius	1	
Gentianales	Rubiaceae	*Adina pilulifera*	1	
		Galium aparine	1	1
		Galium dahuricum		1
Geraniales	Geraniaceae	*Geranium dahuricum*	1	
Graminalis	Gramineae	*Agrostis divaricatissima*		1
		Agrostis sibirica		1
		Beckmannia syzigachne		1
		Calamagrostis angustifolia	1	1
		Calamagrostis langsdorfii	1	
		Echinochloa crus-galli		1
		Elymus dahuricus	1	
		Glyceria acutiflora	1	
		Glyceria spiculosa	1	1
		Phragmites australis	1	1
		Poa annua	1	
		Setaria glauca	1	
		Setaria virdis		1
		Zizania iatifolia	1	1
Juncales	Juncaceae	*Juncus effusus*	1	
Lamiales	Lamiaceae	*Amethystea caerulea*	1	
		Lamium barbatum	1	
		Lycopus uniflorus		1
		Scutellaria pekinensis		1
		Scutellaria scordifolia	1	
		Stachys baicalensis	1	1
		Stachys chinensis	1	
		Stachys japonica	1	
	Plantaginaceae	*Plantago depressa*	1	
		Veronica serpyllifolia		1
		Veronicastrum tubiflorum		1
Malpighiales	Hypericaceae	*Hypericum japonicum*	1	1
	Salicaceae	*Salix myrtilloides*		1
		Salix rosmarinifolia		1
		Salix viminalis		1
	Violaceae	*Viola patrinii*		1

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
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Order	Family	Species	QRB	SNNR
		Viola phalacrocarpa	1	
Menyanthes	Menyanthaceae	*Menyanthes trifoliata*	1	1
Myrtales	Lythraceae	*Lythrum salicaria*	1	1
		Trapa litwinowii		1
	Onagraceae	*Epilobium angustifolium*	1	
		Epilobium hirsutum	1	
Nymphaeales	Nymphaeaceae	*Nymphaea tetragona*	1	
		Nuphar pumilum	1	1
Pandanales	Typhaceae	*Sparganium stoloniferum*	1	
		Typha angustifolia	1	
		Typha minima	1	
		Typha orientalis	1	1
Polygonales	Polygonaceae	*Polygonum amphibium*	1	
		Polygonum aviculare		1
		Polygonum hydropiper	1	1
		Polygonum korshinskianum		1
		Polygonum lapathifolium		1
		Polygonum maackianum		1
		Polygonum orientalis		1
		Polygonum persicaria		1
		Polygonum thunbergii	1	1
Polypodiales	Thelypteridaceae	*Thelypteris palustris*		1
Ranunculales	Ranunculaceae	*Anemone dichotoma*		1
		Caltha palustris	1	1
Rosales	Rosaceae	*Comarum palustre*	1	1
		Potentilla chinensis	1	
		Sanguisorba officinalis		1
		Sanguisorba parviflora		1
		Sanguisorba teriuifolia	1	
		Spiraea salicifolia		1
		Vicia amoena	1	
		Vicia cracca	1	
		Vicia japonica	1	
	Urticaceae	*Urtica cyanescens*		1
Salviniales	Salviniaceae	*Salvinia natans*	1	1
Saxifragales	Haloragaceae	*Myriophyllum verticillatum*	1	
Scrophulariales	Lentibulariaceae	*Utricularia vulgaris*	1	
Total			100	80

QRB = Qixing River Basin, SNNR = Sanjiang National Nature Reserve, 1 = present

The comparison of mean values of vascular plant density, cover, height and water depth

As shown in the *Fig. 1a-d*, the mean values of density (ind./m^2), cover (%), height (cm) did not change significantly in these two wetland sampling sites (paired t-test, $p = 0.2889$, $p = 0.7113$, $p = 0.4915$, respectively). While the environmental factor, water depth varied significantly in both wetland sites (paired t-test, $p = 0.0017$). It was observed that *Calamagrostis angustifolia* (Gramineae) was species with high mean values of density in both sites, the Sanjiang National Nature Reserve with (360 ind./m^2) and the Qixing River Basin (287 ind./m^2). We recorded *Zizania iatifolia* (Gramineae) as species with high mean value of cover (89.67 %) in the Sanjiang National Nature Reserve. While in the Qixing River Basin, *Calamagrostis angustifolia* (Gramineae) has been identified as species with high mean value of cover (50.99%). In comparison to the height, *Zizania iatifolia* (Gramineae) had high mean values in both sites, the Sanjiang National Nature Reserve

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
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(240.83 cm) and the Qixing River Basin (165.71 cm). We registered species, *Nuphar pumilum* (Nymphaeaceae), in an average water depth more than 150 cm in the Qixing River Basin. While *Zizania iatifolia* (Gramineae) was recorded at 36.25 cm of water depth in the Sanjiang National Nature Reserve.

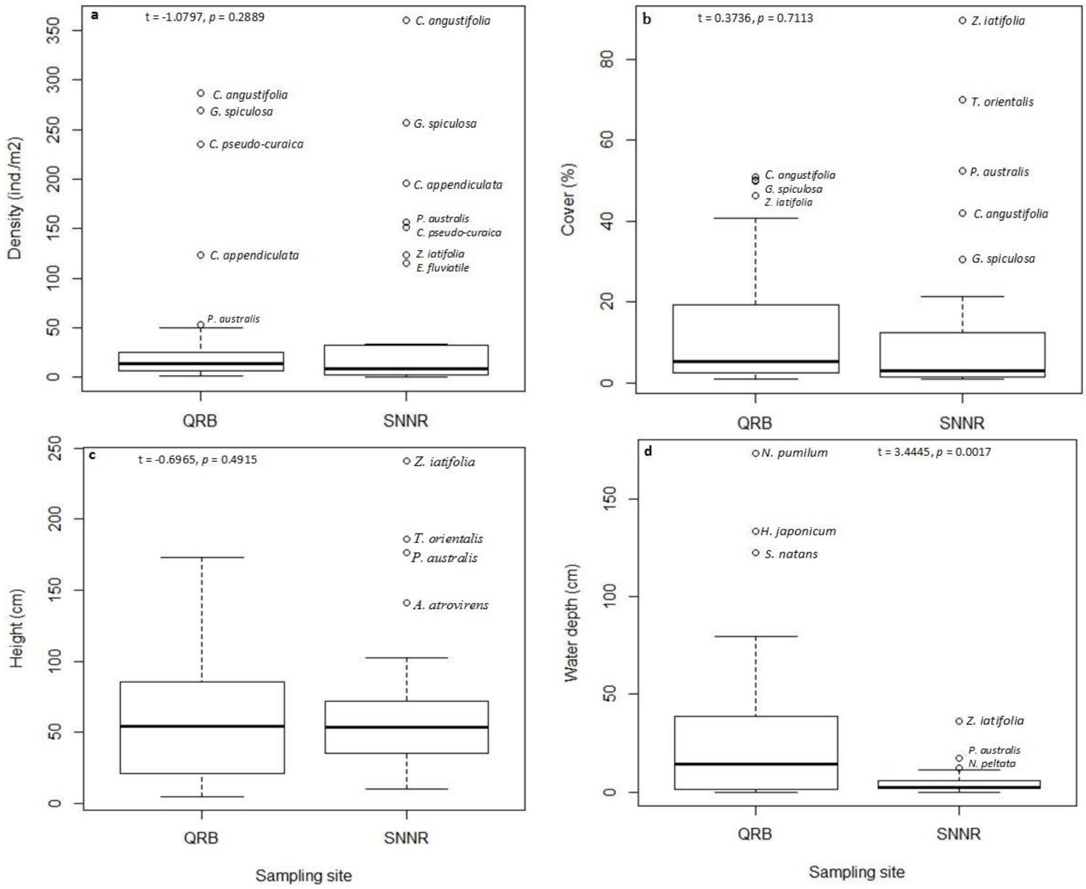

Figure 1. *Comparison of mean values of a) density, b) cover, c) height and d) water depth of vascular plant species identified in both sampling sites. QRB = Qixing River Basin, SNNR = Sanjiang National Nature Reserve*

Looking at the dominance, both wetland sites were dominated by Gramineae. Previous studies of Mbayngone et al. (2008); Ouédraogo et al. (2011); Assédé et al. (2012); Nacoulma (2012); Zizka et al. (2015); Seregin and Stepanova (2020) showed the same record that Gramineae was dominant family in the wetland biotopes. Due to human activity, original wetland, typically covered with Gramineae, degraded to marsh meadow and further to typical meadow land (Lu et al., 2007; Wang et al., 2018).

Correlations of mean water depth and vascular plant variables

Our analyses displayed that plant density did not change significantly with water depth in both wetland sites (p = 0.6862, *Fig. 2a* and p = 0.1785, *Fig. 2b*). Cover of plant was positively correlated with water depth (r = 0.4113, p = 0.0214, *Fig. 2c* and r = 0.6367, p = 0.0001, *Fig. 2d*). The best model demonstrated that water depth had a significant effect on height of plant (r = 0.5009, p = 0.0041, *Fig. 2e* and r = 0.5419, p = 0.0016, *Fig. 2f*).

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DOI: http://dx.doi.org/10.15666/aeer/1904_26892699

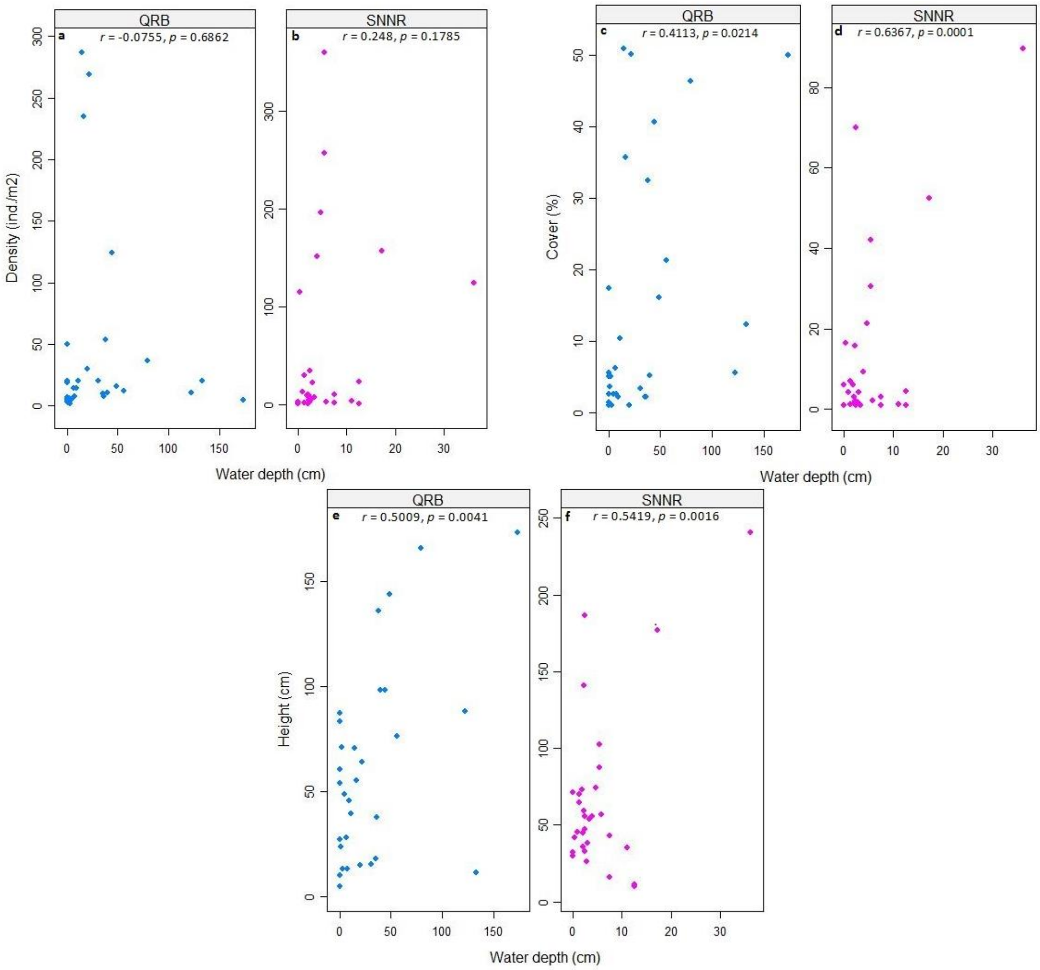

Figure 2. *The relationships between water depth and vascular plant metrics of species identified in both reserves; a) density, b) cover and c) height. QRB = the Qixing River Basin, SNNR = the Sanjiang National Nature Reserve*

The results suggested that the availability of water depth influenced on vascular plant species population in the Sanjiang plain wetlands. Lu and He (2018) found that vascular plant species with high range size were more likely to be discovered in China.

Aquatic vascular plant families with temperate affinities (Crow, 1993; dos Santos Oliveira et al., 2019), like Potamogetonacaea and Haloragaceae were only collected in the Qixing River Basin. We recorded one plant species (Du et al., 2018), *Glycine soja* (Fabaceae), which is under national protection in the Qixing River Basin (NRIHP, QRWNRMS, 1999; Xianghua, 2007; Jian, 2008; Du et al., 2018). We suggest that its importance highlights the need for conservation approaches, and alternative livelihoods should be pressing for wetland protection in the Sanjiang plain (Zhou and Liu, 2005).

Conclusion

Overall, both wetland sites provided an important aquatic vascular plant species richness. Our analyses provided information that water depth could be one of the driver environmental parameters to influence the increase the cover and height of aquatic vascular plants, except the density. These data should be completed with further studies,

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DOI: http://dx.doi.org/10.15666/aeer/1904_26892699

which are required to assess the effects of other environmental factors on aquatic vascular plant metrics in order to grow databases and achieve long-term wetland conservation goals. The findings might recommend further studies on wetland plant diversity for setting conservation priorities; conservation status assessment of plant species and their common English names; and GIS mapping of wetland habitats and land-cover of the Sanjiang Plain.

Acknowledgements. This research was supported by Open Foundation of Hebei Key Laboratory of Wetland Ecology and Conservation (No. HKLK201907), which the authors gratefully acknowledge.

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