Urban Ecosystems (2019) 22:757–768
https://doi.org/10.1007/s11252-019-00859-5

Appropriate management practices help enhance odonate species richness of small ponds in peri-urban landscapes

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Abstract

Adult odonate biodiversity was investigated to understand their relationship with pond management practices and environmental conditions in a rapidly urbanized landscape. Twenty-four farm ponds in Taoyuan City were selected and classified into five pond groups based on pond management practices. In total, 21 species, 17 genera, and 6 families of odonates were recorded for a total of 5701 individuals between June 2014 and July 2015. The abundance of Odonata was unrelated to pond size or distance to the nearest pond; however, odonate species richness was negatively and significantly correlated with pond size. Pond management practices considerably affected pond aquatic macrophytes and dike construction materials. Ecology park ponds under intense human management and undisturbed ponds without any human management had higher species richness than did the ponds in the other three fish farming groups. Species richness was highest in small and human-modified ponds. By contrast, species richness was lowest in two fish farming pond groups. These results suggest that pond management practices can increase or reduce odonate species richness depending on the alteration of pond microhabitat features. Our observations suggest that the enhanced habitat quality of small ponds provides an opportunity to protect freshwater biodiversity for local governmental civil servants in urbanized landscapes.

Keywords Pond size · Odonates · Freshwater biodiversity · Urbanization · Aquatic macrophytes

Introduction

According to a 2014 United National report, the urban population (54%) has exceeded the rural population globally (United Nations 2014). The urbanization process can directly and indirectly influence biodiversity by affecting the survival and distribution of species through habitat loss, habitat fragmentation, pollution, and other environmental change (Wood et al. 2003; Dudgeon 2010; Collen et al. 2014). Global freshwater biodiversity is under severely threatened by many urbanized stressors; therefore, freshwater biodiversity conservation and freshwater habitat protection have become crucial worldwide. Although farm ponds are man-made freshwater bodies that are often less than 2 ha (Biggs et al. 2005), they have considerable ecological importance and are hotspots of freshwater biodiversity despite their small sizes (Oertli et al. 2002; Nicolet et al. 2004; Williams et al. 2004; Davies et al. 2008; Céréghino et al. 2012). In addition, the connectivity between ponds can play a vital role in helping freshwater species adapt to environmental changes (Thornhill et al. 2017).

Farm ponds are common in agricultural landscape worldwide. In particular, farm ponds can be potential alternative habitats for numerous freshwater species and provide multiple ecosystem services similar to natural wetlands (Brand and Snodgrass 2010; Sayer et al. 2012; De Marco et al. 2014). Taoyuan City has the most agricultural irrigation ponds in Taiwan; this creates a unique agricultural landscape in this area. The geology and topography of Taoyuan City render it difficult to collect and store water in this region, resulting in irrigation problems for agriculture during the dry season. Residents of Taoyuan City constructed farm ponds for agricultural irrigation more than 200 years ago, and these farm ponds represent a specific human–environment interaction.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11252-019-00859-5) contains supplementary material, which is available to authorized users.

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However, due to the economic transition in Taiwan, the irrigation function of farm ponds has gradually diminished. Urban expansions have simultaneously transformed farmland area and farm ponds to urban land use, and further destroyed wildlife habitats (Fang et al. 2009; Huang et al. 2012). The number of farm ponds in Taoyuan City was estimated to reach 8846 ponds in the early twentieth century (Department of Land Administration, Taoyuan 2016). In the 1970s, there were 3290 farm ponds; however, this number decreased to only 1858 in 2005 (Huang et al. 2012). In 2011, this number further decreased, and only 1001 ponds were reported to remain (Yu et al. 2013). Because the number and area of ponds has decreased in Taoyuan City, the remaining ponds have become crucial habitats for freshwater biodiversity conservation.

Farm ponds can substantially contribute to regional and local freshwater biodiversity (Williams et al. 2004; Davies et al. 2008; Sayer et al. 2012); however, the freshwater biodiversity of the man-made environment has rarely been discussed, and small–scale habitats have often been ignored until recent studies reported on it (Céréghino et al. 2014; Blicharska et al. 2016). Farm ponds in Taoyuan Tableland possess environmental heterogeneity due to different land uses and human management practices; thus, these farm ponds provide a favorable opportunity to investigate farm pond biodiversity and pond management at the local scale. This study investigated the relationship between the environmental characteristics of farm ponds and freshwater biodiversity among ponds with different management practices. We evaluated whether freshwater biodiversity varies depending on pond management practices and whether freshwater biodiversity is related to the quality of pond microhabitat and the characteristics of urban landscape.

The order Odonata, which includes both dragonflies and damselflies, was selected as a bioindicator in this study because of its common presence in freshwater pond communities. Because Odonata are carnivorous insects and key predators in freshwater ecosystems, they play an important ecological role in structuring freshwater pond communities (Samways and Steytler 1996). During their complex life history, odonate species need both aquatic and terrestrial habitats for their larval and adult life stages. The use of adult odonates as indicator species can reflect not only the condition of ponds (Angélibert et al. 2010; Dolný et al. 2014) but also the condition of the surrounding terrestrial habitats interrupted by human activities (Simaika and Samways 2011; Raebel et al. 2012). In the present study, adult odonate biodiversity was investigated to understand their relationship with pond management practices and environmental conditions in a rapidly urbanized landscape.

Materials and methods

Study area and pond site selection

Taoyuan Tableland is located in northwest Taiwan and has a subtropical monsoon climate and is one of the Taiwan’s rapidly growing urban areas. From1971 to 2006, 211 km^2 of agricultural land was estimated to have been converted into urban land (Huang et al. 2012). For example, agricultural land was the major land cover accounting for an area of approximately 421 km^2 in 1971, whereas the dominant land cover was built-up areas covering 441 km^2 of this region in 2006 (Huang et al. 2012). According to census data, the population of Taoyuan City was 2,147,763 in 2016. The mean annual temperature in Taoyuan is 23 °C with July being the hottest month with an average temperature of 27 °C and January being the coldest month with an average temperature of 13 °C. The annual mean precipitation ranges from 1500 to 2000 mm and the annual mean humidity is approximately 89% in this region.

Farm ponds are widely distributed across Taoyuan Tableland because of its unique underlying geology and geomorphology. We surveyed 24 ponds in Taoyuan (Fig. 1). These ponds were classified into five groups based on pond management practices, and the characteristics of these ponds are listed in Table 1. The odonate species and environmental characteristics of the ponds were surveyed between June 2014 and July 2015, and the weather condition of each pond was recorded during the survey period.

Monitoring of adult odonates

Adult odonates in the 24 ponds were surveyed by the first author (W-C Chien) on seven occasions between June 2014 and July 2015 to take the seasonal changes occurring in Odonata fauna into consideration. A standardized survey of adult odonates was conducted along the edge of each study pond on sunny days between 8:00 and 17:00. Survey biases caused by the diurnal movement of dragonflies were prevented by deliberately varying the time of the day at which surveys were conducted at each pond and the sampling period. In detail, sampling time periods were divided into morning (8:00–11:00), noon (11:00–14:00), and afternoon (14:00–17:00). The sampling time designed to each pond was divided equally at different time period during our study period. Depend on the pond size, the sampling period of each pond was between 40 min to 60 min. Adult odonates were identified on the basis of sight or photographs. When necessary, individuals were

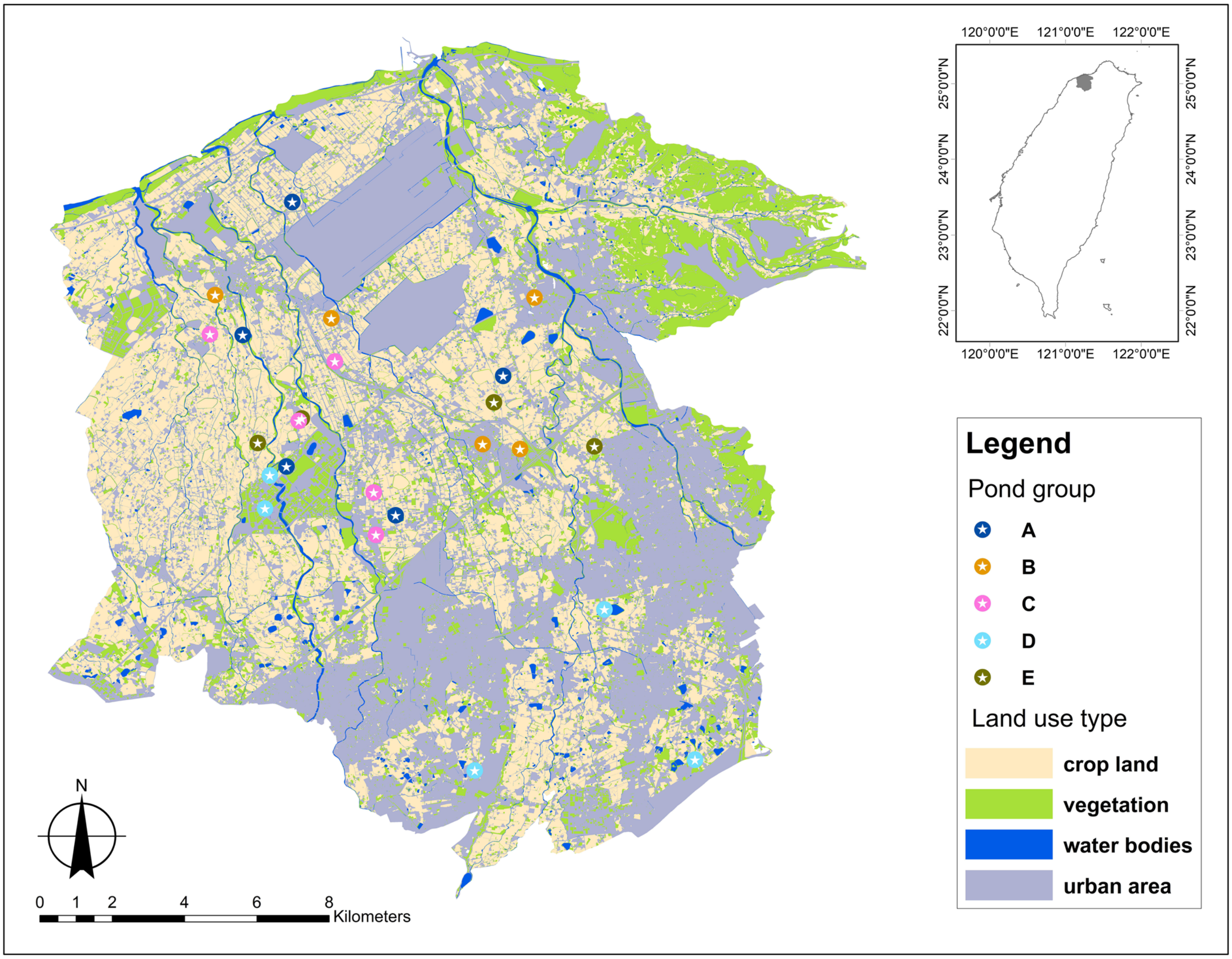

Fig. 1 Land use and location of 24 ponds studied in Taoyuan City, Taiwan

caught using a hand net and released after identification. Species were identified using a standard guide for odonates in Taiwan (Tsou 2005). Adult odonates prefer to perch on plants and select their habitats on vegetation; thus, we recorded the aquatic vegetation condition of ponds, including the presence of emergent and floating plants. In addition, we recorded the height of plants by walking along pond shores and measuring plant height at every 50 steps within 1-m zones of the pond shore and subsequently averaged these plant heights to determine the pond vegetation conditions. The pond embankment materials were observed and grouped into cement, stone rock, concrete mixed with soil, and soil mixed with grass.

Table 1 Description of five pond groups with different pond management practices

group	n	pond management strategy
A	5	fish farm ponds used for fish production only
B	5	fish farm ponds used for fish production and also provide a walking path along pond waterfront for visitors
C	5	fish farm ponds used for recreational fishing and fish production
D	5	ponds in ecology parks are designed to preserves biodiversity and provide ecological education attractions to tourists
E	4	ponds without specific pond management strategy

Pond water quality

Pond water quality was assessed on the same day of the odonate species survey between June 2014 and July 2015. We chose three sampling sites evenly spaced around the pond perimeter at its edge for each pond to examine the water quality in situ by using a YSI Pro2030 DO/conductivity meter (YSI Incorporated, Yellow Springs, Ohio, USA) to measure water temperature, dissolved oxygen (%) and conductivity (mS/cm) and using a HANNA HI 8424 pH meter (HANNA Instruments, Ann Arbor, Michigan, USA) to determine the pH of the pond water.

Farm pond landscape parameters

The landscape surrounding farm ponds provides several crucial resources and conditions for adult odonates and these adjacent landscapes can be as crucial as the aquatic habitat itself (Corbet 1999). FORMOSAT-2 satellite imagery with a high resolution of 2-m panchromatic data on the Taoyuan area (January 17, 2014) was utilized to generate and calculate the landscape coverage surrounding the farm ponds and pond areas by using ArcMap 10.2.1 (ESRI, USA) and ENVI 4.8 (ExelisVIS, USA) software. The land use and land cover types were classified as (1) crop land, (2) vegetation, (3) water body and (4) urban area (Table 2). Land use and land cover categories were identified and mapped as polygons. The percentage cover of land use types was estimated for circular areas by using the center location of the ponds and a radius ranging from 100 m to 200, 400, 800, and 1600 m (corresponding to the total surface areas of 0.03, 0.125, 0.5, 2, and 8 km^2, respectively). The distance to the closest neighboring pond and the number of neighboring farm ponds within a 1600-m radius for each study pond were also determined.

Data analysis

The Kruskal–Wallis test, a nonparametric statistical method, was used to examine the differences in environmental characteristics among the five pond groups. If a significant result was obtained ($P < 0.1$), the Mann–Whitney U test was used to compare the differences among pond groups. All significance tests were two-tailed, and the significance level was set at 0.05 unless otherwise specified. The Spearman correlation coefficient was used to determine the correlations between different environmental variables and odonate richness or abundance. Statistical comparison was performed using the Minitab statistical program (Version 17.1.0).

Before multivariate analysis was performed, all odonate community composition data were transformed into log (X + 1) and the percentages of land use data for each pond were transformed using the arcsine square root. In addition, all environmental variables were standardized. Detrended correspondence analysis (DCA) was first conducted to determine whether a linear or unimodal-based ordination method should be applied for ordination analysis. To exclude rare species before conducting multivariate analyses, we first ranked the species from the most to the least abundant within all the survey dataset and defined 25% least abundant species as rare (Magurran 2004). Species occurring in 5 or fewer ponds (less than 25% study sites) was also defined as rare. From the 24 ponds studied, 6 species with less than 10 individuals or those occurring in less than 5 ponds were excluded from this analysis. From the 24 ponds studied, 6 species with less than 10 individuals or those occurring in less than 5 ponds were excluded from this analysis. The DCA results indicated that the gradient length of the first axis was 2.069 SD less than 3 SD (SD units of species turnover). Therefore, a linear model with redundancy analysis (RDA) was considered the appropriate ordination method for identifying the relationships between environmental variables and odonate community composition (Ter Braak and Prentice 1988; Šmilauer and Lepš 2014).

We used 15 odonata species and 11 environmental variables (the presence of emergent plant, the presence of floating plant, pond size, pH, DO, conductivity, riparian plant height, distance to nearest pond, percentage of crop land, percentage of urban land, and the numbers

Table 2 Land use/cover classification scheme in this study

land use/cover types	description
crop land	cultivated land, agricultural area, crop fields, vegetable land
vegetation	deciduous forest, woodland, grassland
water body	river, lakes, ponds, reservoirs
urban area	build-up area for residential, commercial and services, industrial, transportation, roads, or other urban bare soil

of neighbor farm ponds within 1.6 km radius) for RDA. To prevent the multicollinearity problem, we eliminated variables that showed a high correlation from variance inflation factor (VIF) evaluation from the initial RDA. The VIF values of DO (9.46) and pH (9.83) were greater than 5 and were thus excluded from RDA (Hair Jr et al. 2016). The VIF values of the remaining nine environmental variables were less than 3 (range 1.37–2.65) after DO and pH variables were eliminated. The relationships between odonate community composition and environmental variables were explored through RDA. DCA and RDA were performed using the VEGAN (2.4–5) package in R version 3.4.2 (R Core Team 2017).

Results

Physicochemical and microhabitat characteristics in five pond groups

The surface area of the 24 ponds ranged between 0.2 and 9.9 ha. In particular, 80% of the ponds (4 of 5) from group D were less than 2 ha in size. By contrast, the average area of the other pond groups was more than 5 ha (Table 3). The mean pH of pond water exceeded 8 except for pond water from group D during the study period (Table 3). The water conductivity from pond groups C and D was significantly lower than that from pond groups A, B, and E during the study period (Table 3).

Pond management practices have strongly influenced pond macrophytes and dike construction materials. Three types of fish farm ponds (groups A, B and C) contained no aquatic macrophytes, except for one pond from group B that contained emergent plants. Ponds from groups A and B were mainly designed for fish production and had concrete dike walls. Ponds from group C designed for both recreational fishing and fish production comprised a diverse range of materials for building dikes (2 concrete, 2 rock and 1 mixed with concrete and soil). All the ponds in ecology parks (group D) contained both emergent and floating plants and dike walls constructed using soil mixed with grass. By contrast, ponds without any specific pond management strategy (group E) possessed diverse pond characteristics. For example, the dike walls of two ponds from group E were constructed using soil mixed with grass, one pond from group E was constructed using concrete, and the other one was constructed using concrete mixed with soil. In addition, two ponds from group E contained both emergent and floating plants, but the other two ponds contained no aquatic macrophytes.

Landscape characteristics in the five pond groups

The results of the nonparametric Kruskal–Wallis test indicated that the percentage cover of land use types ranging from 100, 200, 400, 800, to 1600 m for each pond group did not significantly differ among these radius buffers. Therefore, the landscape characteristics of the pond groups were observed only in landscape variables within a 1600-m radius buffer (Table 4). The distance to the nearest neighboring pond considerably varied within the same group and among groups. However, no significant difference was observed among the five pond groups for both distance to the nearest neighboring pond and the number of ponds within a 1600-m radius. Ponds in ecology parks (group D) had the highest percentage (48.8%) of urban land use and the lowest percentage (29%) of cropland within a 1600-m radius buffer. In particular, the percentage of cropland

Table 3 Mean physicochemical and landscape characteristics (mean ± standard deviation) of farm ponds with different management practices

pond group	A	B	C	D	E
n	5	5	5	5	4
pond area (ha)[1]	6.54 ± 2.74^{a}	5.06 ± 1.41^{a}	5.70 ± 3.30^{a}	1.16 ± 0.86^{b}	5.15 ± 3.24^{a}
pH[1]	8.39 ± 0.86^{a}	8.91 ± 1.09^{ab}	8.93 ± 1.05^{bc}	7.89 ± 0.89^{d}	8.79 ± 0.99^{abc}
conductivity (mS/cm) [1]	0.62 ± 0.41^{a}	0.65 ± 0.48^{a}	0.33 ± 0.12^{b}	0.28 ± 0.08^{b}	0.44 ± 0.17^{a}
DO (%)	57.1 ± 28.0^{a}	80.5 ± 41.0^{ab}	83.3 ± 30.6^{b}	62.3 ± 30.0^{a}	59.7 ± 33.1^{a}
riparian plant height (cm) [1]	$83. \pm 9.0^{a}$	59.0 ± 38.0^{abc}	61.6 ± 33.2^{ac}	48.8 ± 9.9^{c}	111.2 ± 24.9^{b}
macrophyte species type*	1	1.2	1	3	1.5
pond wall materials#	1	1	1.8	4	3
presence of fish	Yes	Yes	Yes	Yes	Yes

[1] : pond groups with the same letters did not exhibit a statistical difference in the Mann–Whitney U test at $P < 0.05$

*1: no macrophyte; 2: emergent plants only; 3: emergent and floating plants

1: concrete; 2: rock or stone block; 3: mixed with concrete and soil; 4: soil mixed with grass

Table 4 Mean landscape characteristics (mean ± standard deviation) of the five pond groups based on the FORMOSAT-2 satellite imagery with a high resolution of 2-m panchromatic data in the Taoyuan City (January 17, 2014)

pond group	A	B	C	D	E
n	5	5	5	5	4
% of crop land use within 1600 m buffer[1]	52.6 ± 9.7^{a}	43.4 ± 5.7^{a}	52.4 ± 13.9^{a}	29.0 ± 11.9^{b}	49.8 ± 12.7^{ab}
% of urban land use within 1600 m buffer[1]	27.4 ± 8.2^{a}	37.8 ± 12.6^{ab}	25.6 ± 14.1^{a}	48.8 ± 11.7^{b}	33.5 ± 18.0^{ab}
number of ponds within 1600 m buffer	7.2 ± 3.1	6.2 ± 1.5	9.2 ± 2.8	9.0 ± 2.7	10.0 ± 2.8
distance to the nearest neighboring pond (m)	436 ± 345	394 ± 275	240 ± 136	293 ± 246	75 ± 67

[1] : Kruskal–Wallis test results indicated significant differences at $P < 0.1$; pond groups with the same letters did not exhibit a statistical difference in the Mann–Whitney U tests results at $P < 0.1$

and urban land use within a 1600-m radius buffer significantly differed between ponds in group D and ponds in groups A and C. The percentage of urban land use within a 1600-m radius buffer significantly differed between ponds in group D and ponds in group B.

Species characteristics of Odonata in five pond groups

In total, 21 species, 17 genera, and 6 families of odonates were recorded for a total of 5701 individuals at 24 farm ponds during 7 visits between June 2014 and July 2015. Among the six families identified in this study, Libelullidae was dominant (52.4%), followed by Coenagrionidae (19%), Platycnemididae (9.5%), Gomphidae (9.5%), Aeshnidae (4.8%), and Corduliidae (4.8%). *Brachythemis contaminata* was the most abundant odonate species in all ponds with 2598 individuals, followed by *Orthetrum sabina sabina* in 23 ponds with 883 individuals and *Ischnura senegalensis* in 22 ponds with 864 individuals. By contrast, two species, *Agriocnemis pygmaea* (10 individuals) and *Brachydiplax chalybea flavovittata* (39 individuals), were limited to only one group D pond. *Urothemis signata yiei* and *Anax parthenope julius* were found in only two and five ponds, respectively, with less than 10 individuals.

The seasonal distribution and abundance of Odonata are presented in Fig. 2. During the survey period, the number of species was relatively high from June 2014 to October 2014 and from June 2015 to July 2015, and the maximum number of odonate adults was observed from September 2014 to October 2014 (Fig. 2). Among the five pond groups surveyed, the number of species was highest in group D with 20 species and was lowest in groups A and B with 10 species during the entire survey period. Overall, group D had the highest species richness among the five pond groups, and groups B and D had a higher abundance of odonates than did the other three groups (Fig. 3).

The mean abundance of Odonata did not significantly differ among the five pond groups. The mean abundance, richness, and biodiversity index of the five pond groups from seven repeated Odonata surveys are shown in Fig. 4. Species richness and biodiversity index did not differ significantly among the pond groups. Among the three types of fish farm ponds, species richness in group C ponds significantly differed from that in group A and B ponds; however, species richness in group C ponds did not significantly differ from that in group D and E ponds. In particular, Simpson's diversity index and the Shannon–Weiner index differed significantly between group B ponds and ponds in other groups. Among the five pond groups, group B ponds had the lowest Odonata diversity.

Relationship between Odonata diversity and pond characteristics

The Spearman rank correlation between Odonata species richness or abundance and pond characteristics is shown in Table 5 and is listed separately for dragonflies and damselflies in Table 6. Odonate species richness was negatively and significantly correlated with pond size in 24 ponds ($r = -0.513$, $P = 0.01$). The abundance of Odonata was unrelated to pond size or distance to the nearest pond. However, the abundance of damselflies was negatively correlated with pond size ($r = -0.46$, $P = 0.02$). Pond density in a 800-m radius showed a weak negative association with species abundance ($r = -0.385$, $P = 0.06$); however, this trend was not observed for pond density in a 400- or 1600-m radius. Odonata comprises dragonflies and damselflies; these two suborder groups differ in body sizes and habitat requirements. These two suborder groups may exhibit different responses to pond size or landscape characteristics. However, the results of the correlation between pond size and the richness of dragonflies or damselflies were found to be similar to those of the correlation between pond size and the richness of Odonata species (Tables 5

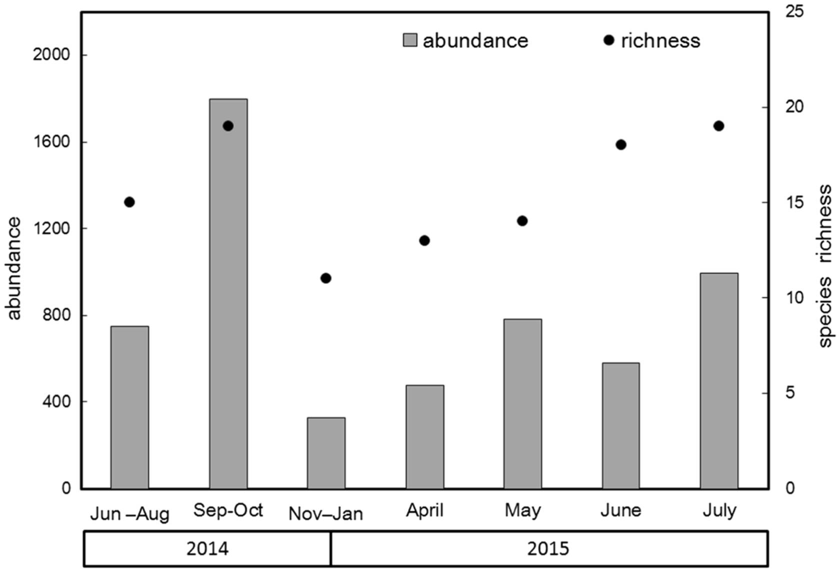

Fig. 2 Abundance and species richness of Odonata during 7 visits from June 2014 to July 2015

and 6). In addition, the percentage of urban land use or crop land use within a radius buffer of 100, 200, 400, 800 or 1600 m indicated no significant association with the richness of Odonata species.

Relationship between Odonata assemblages and environmental factors

The total variation of 56.2% in the Odonata data was related to nine environmental variables according to the RDA results (42.60% on the first axis in RDA and 21.32% on the second axis in RDA). The first axis in RDA exhibited a strong positive correlation with floating and emergent plants and a negative correlation with pond size. The first axis in RDA roughly represents aquatic macrophytes in ponds. By contrast, the second axis in RDA was positively correlated with the percentage of cropland and negatively correlated with riparian plant height and the percentage of urban area. The RDA results indicated that most Odonata species were in the positive part of the first axis, characterized by pond aquatic macrophytes (Fig. 5). However, the location of three odonate species, namely *O. sabina sabina*, *Sinictinogomophus clavatus*, and *O. pruinosum neglectum*, in the negative part of the first axis suggests that the presence of these species was more related to pond size. In addition, the location of *B. contaminata* and *O. sabina sabina* in the negative part of the second axis suggests that their presence was related to the percentage of urban area and riparian plant height.

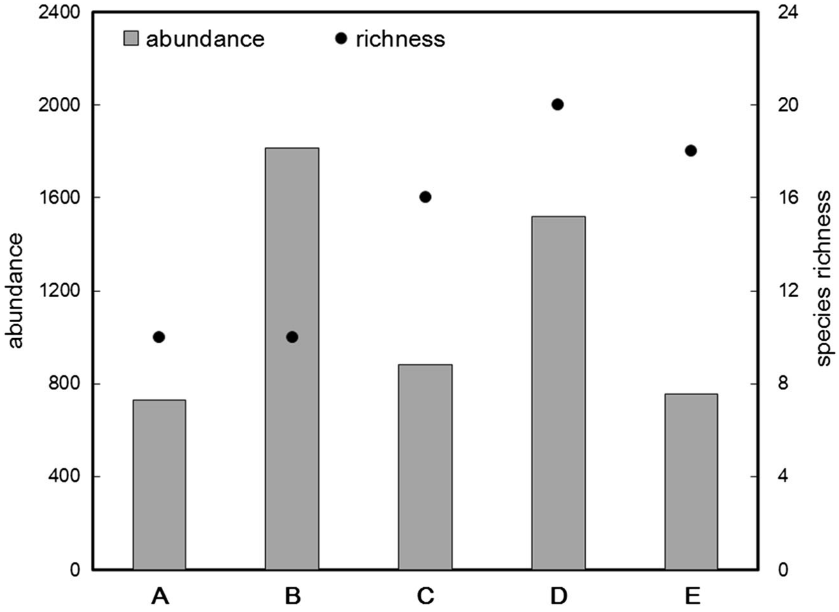

Fig. 3 Total abundance and species richness of Odonata in each pond group between June 2014 and July 2015

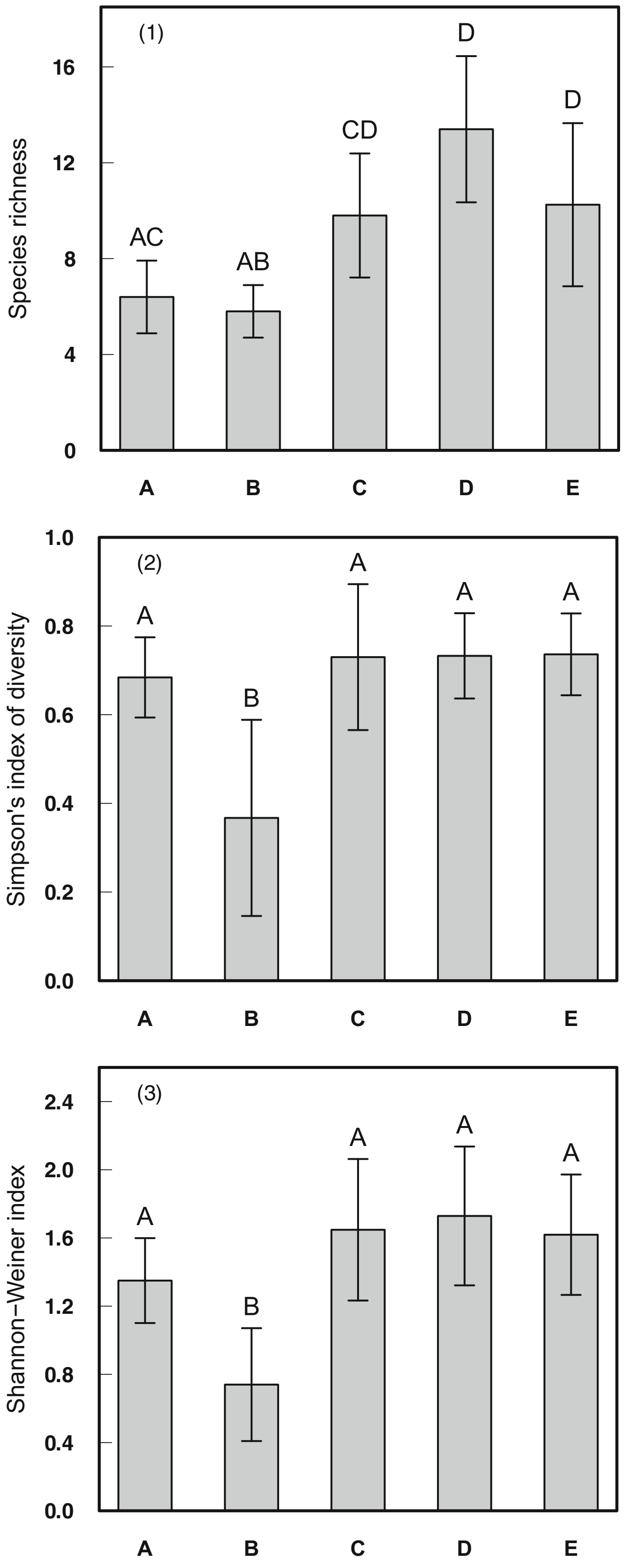

Fig. 4 Mean species richness and biodiversity index of Odonata in each pond group from repeated Odonata surveys between June 2014 and July 2015. Pond groups with the same letters did not show a statistical difference in Mann–Whitney U test results at $P < 0.05$

Table 5 Spearman rank correlation between species richness or abundance and pond characteristics

	richness		abundance	
	r	p	r	p
pond size	−0.513	0.01	−0.046	0.83
distance to nearest pond	−0.126	0.56	0.258	0.22
pond density				
in 400 m radius	0.125	0.56	−0.046	0.83
in 800 m radius	−0.147	0.49	−0.385	0.06
in 1600 m radius	0.326	0.12	−0.282	0.18

Discussion

Pond size and Odonata species richness

Pond size can differently affect the local diversity and community composition of freshwater taxa (Oertli et al. 2002). Oertli et al. (2002) found that pond size was crucial for the richness of adult Odonata species but not for that of Gastropoda (Sphaeriidae), Coleoptera, and Amphibia species in 80 ponds in Switzerland. Kadoya and Washitani (2004) reported that dragonfly species richness was related to pond size in 11 man-made ponds in Japan. Ruggiero et al. (2008) assessed 37 farm ponds for Odonata diversity in southwestern France and revealed that species richness correlated with pond size but not with pond use or landscape characteristics. However, Carchini et al. (2007) surveyed 21 ponds in the lowlands of central Italy and found no relationship between the species richness of Odonata larvae and pond size. Goertzen and Suhling (2013) investigated the distribution of Odonata species in 33 urban ponds distributed in Dortmund, Germany and found that pond size was related to a decrease in Odonata diversity. The authors attributed this finding mainly to the decrease in habitat quality in larger ponds. In this study, pond size was negatively related with adult Odonata species richness. Ponds in ecology parks (group D) with the smallest surface area had the highest species richness, and the species richness of ponds in group D significantly differed from those of ponds in groups A and B. This result is unsurprising given the ponds in ecology parks were designed to protect biodiversity and provide educational and recreational experiences for visitors. This finding indicated the positive effects of effective pond management on Odonata richness in small ponds.

Table 6 Spearman rank correlation between species richness or abundance and pond characteristics for dragonflies and damselflies

	dragonflies				damselflies			
	richness		abundance		richness		abundance	
	r	p	r	p	r	p	r	p
pond size	−0.483	0.01	0.079	0.71	−0.536	0.01	−0.460	0.02
distance to nearest pond	−0.111	0.61	0.194	0.36	−0.044	0.84	0.219	0.31
pond density								
in 400 m radius	0.118	0.58	−0.077	0.72	0.092	0.67	0.018	0.93
in 800 m radius	−0.130	0.55	−0.272	0.20	−0.136	0.53	−0.249	0.24
in 1600 m radius	0.324	0.12	−0.168	0.43	0.327	0.12	−0.003	0.99

Pond density and Odonata species richness

Ponds can play a crucial role in regional freshwater biodiversity (Biggs et al. 2005; Davies et al. 2008; Céréghino et al. 2014). Gledhill et al. (2008) investigated 37 urban ponds in northwest England and found a significant correlation between pond density and invertebrate species richness. In this study, no significant association was observed between pond density and Odonata species richness. This finding in agreement with those of Le Gall et al. (2018), who investigated that the presence and abundance of odonate larvae mainly depended on pond quality and vegetation within and around ponds in 3 different landscapes. These results suggest that pond features rather than local pond density can also be crucial for odonate conservation at the local level.

Pond management practices and pond features

Pond management practices can affect biodiversity conservation by altering pond microhabitat characteristics and features through various human activities (Ruggiero et al. 2008; Sayer et al. 2012; Suski et al. 2018). According to the results of the Kruskal–Wallis and Mann–Whitney U tests, the environmental characteristics of farm ponds and odonate biodiversity varied significantly for different pond management practices. In particular, the water conditions, namely pH, conductivity, and dissolved oxygen, of farm ponds were higher in all three fish farming ponds than in the ecology park ponds and abandoned ponds. The difference in pond water conditions may be due to the aquaculture activities at fish farm ponds, such as pond fertilization, water aeration, and fish feed input. All three types of fish farming ponds had concrete embankments with only riparian vegetation and no aquatic plants. Ecology park ponds have natural embankments with both aquatic and riparian vegetation. Abandoned ponds have mixed embankment types. As expected, the height of riparian plants was the lowest at ecology park ponds (group D) under intensive management and the highest at abandoned ponds (group E) without a specific management plan.

The presence and amount of aquatic macrophytes in ponds were dependent on pond management in this study. Although the advantages of aquatic vegetation for fish production are known, a lack of aquatic vegetation were found in most fish farming ponds among the three fish farm pond groups. Seven of the nine ponds from groups D and E had aquatic macrophytes and their dike walls comprised soil mixed with grass. The floating and emergent macrophytes can provide a suitable habitat for various aquatic macroinvertebrate activities, such as foraging, breeding, and predator avoidance (Thomaz and Cunha 2010). Ponds with macrophytes were positively associated with odonate diversity and abundance (Carchini et al. 2007; Honkanen et al. 2011; Raebel et al. 2012; Le Gall et al. 2018). In this study, aquatic macrophytes were found to be major factors contributing to the Odonata composition of the 24 ponds studied.

Pond management practices and Odonata species richness

Both ecology park ponds from group D and abandoned ponds from group E had higher species richness among the five pond groups. Ponds from group E could be considered a water body without direct human interference on their pond microhabitat. By contrast, group A and B ponds had the lowest species richness among the five pond groups. These two pond groups were mainly designed for fish production and were almost without aquatic macrophytes. These results suggest that pond management practices can increase or reduce Odonata

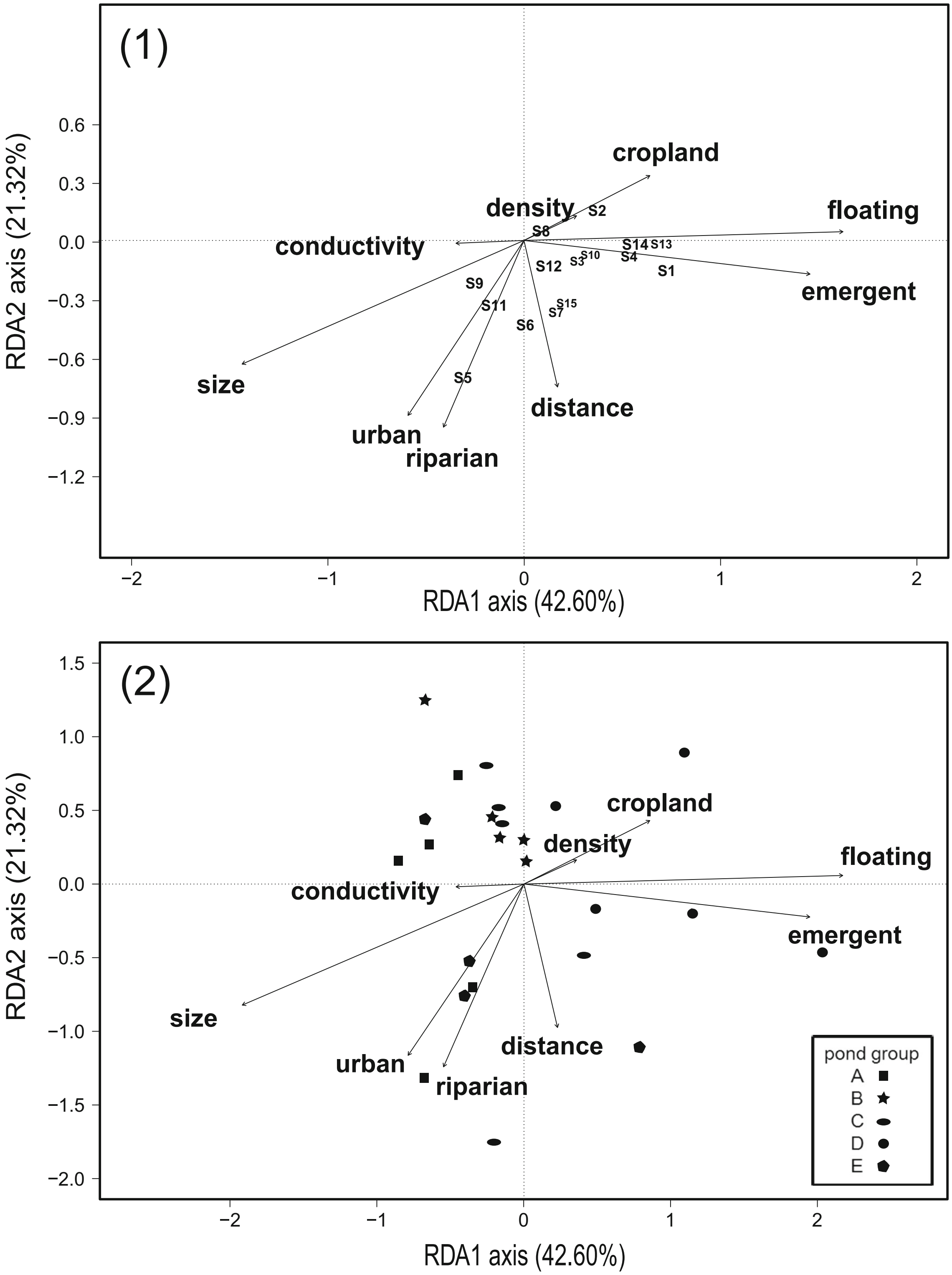

Fig. 5 Redundancy analysis (RDA) ordination plots of nine environmental variables and (1) Odonada assemblage and (2) pond groups. Abbreviations of species: S1: *Ischnura senegalensis;* S2: *Agriocnemis femina oryzae;* S3: *Copera marginipes*; S4: *Ceriagrion auranticum ryukyuanum*; S5: *Orthetrum sabina sabina;* S6: *Brachythemis contaminate*; S7: *Crocothemis servilia servilia*; S8: *Pantala flavescens*; S9: *Sinictinogomophus clavatus*; S10: *Ictinogomphus rapax*; S11: *Orthetrum pruinosum neglectum*; S12: *Diplacodes trivialis*; S13: *Urothemis signata yiei*; S14: *Rhyothemis variegata aria*; S15: *Pseudothemis zonata*

species richness depending on the alteration of pond microhabitat features.

Landscape features and Odonata species richness

Urbanization is generally considered to have negative effects on Odonata species diversity (Villalobos-Jimenez et al. 2016). Goertzen and Suhling (2013) found that city park ponds with lower Odonata species poorest were situated in urban centers in the most disturbed habitats, whereas more natural ponds with higher species richness were located in suburbs and the urban fringe. Jeanmougin et al. (2014) observed that the increased urban landscape composition surroundings of ponds negatively affected Odonata species richness. However, the surrounding land use patterns within 1600 m buffer range had no effect on species richness in this study, despite the expected influence from nearby terrestrial habitats. This result in agreement with Hill et al. (2017). They examined the aquatic macroinvertebrate diversity and community composition of 240 urban and 782 nonurban ponds in the United Kingdom and found that urban ponds supported similar numbers of invertebrate species and families as nonurban ponds.

Conclusion

In this study, the species richness was highest in small and human-modified ponds. Ecology park ponds under intense human management and undisturbed ponds without any human management had the highest species richness among the five pond groups, although small ecology park ponds were located in more urbanized areas. These findings suggest that human management of small water bodies has beneficial effects on Odonata species richness depending on the purpose of the management plan. At the pond level, we found that the adult odonate species composition was influenced by the microhabitat conditions, positively by aquatic macrophytes and negatively by pond area. The ecological functions of these ponds are generally considered ordinary and insignificant by local communities or governments; however, they do provide freshwater habitats for many Odonata species as well as other freshwater organisms. Because the number of these manmade ponds is rapidly declining, these remaining ponds can play a crucial role in protecting freshwater biodiversity in this region and should be maintained using appropriate management practices. Our observations indicate that the enhanced habitat quality of small ponds provides an opportunity to protect freshwater biodiversity for local government civil servants in urbanized landscapes.

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