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ASIA/OCEANIA REPORT

Forest expansion affects Odonata assemblage in floodplain: a case study in the Kiso River, central Japan

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Abstract

In floodplains, which are highly modified and less inundated, trees are expanding, thus raising concerns regarding their impact on freshwater organisms. We analyzed the relationship between forest expansion and the change in Odonata (dragonflies and damselflies) assemblage over an extended period of time in the floodplain with ponds of the Kiso River, central Japan. In the 1970s, the ponds were mainly surrounded by grasslands, and approximately 80% of Odonata species were non-forest species. However, the number of forest species increased and that of non-forest species largely decreased with the forest expansion over the past five decades, resulting in almost a similar number of forest and non-forest species in 2021. Whereas the abundance of the non-forest species had been greater than that of the forest species until the 2000s, the difference has been much smaller in the 2010s, and the non-forest species occupied approximately only 30% of the number of individuals in 2021. The forest expansion may have reduced the open-lentic habitats for the non-forest species, which require riparian grasslands for resting, foraging, and reproduction, and may disturb the immigration of non-forest species from the adjacent rice paddy fields and rivers. The development of canopy cover over the waterbodies may have decreased the light and temperature above and within the ponds, which might have caused a decline in species that prefer warm and open-water environments. Maintaining shifting-mosaic patterns of vegetation around the floodplain waterbodies through active management may be effective in conserving floodplain Odonata communities, including both forest and non-forest species.

Keywords Conservation · Damselfly · Dragonfly · Floodplain ponds · River regulation

Introduction

In floodplains, terrestrial and aquatic habitats show shifting-mosaic patterns with different magnitudes and frequencies of flood disturbances (Nakamura et al. 2007, 2020; Washitani 2007). Inundation and the associated microtopographic changes are important processes in the formation of lentic waterbodies (Nagayama et al. 2015; Negishi et al. 2014; Ward et al. 2002) and the surrounding grasslands (Duranel et al. 2007; Hughes 1997; Toogood et al. 2008). However, floodplains are becoming modified and reduced worldwide (Erwin 2009; Tockner and Stanford 2002; Waltham et al. 2019), and the inundation frequency in the remaining floodplains has decreased due to flow regulation by dams (Johnson 1994; Takahashi and Nakamura 2011), bed-level lowering through sediment mining (Dufour et al. 2015; Rinaldi 2003), and the fixation of water routes (Takaoka et al. 2014). Reduced disturbance has led to the expansion of floodplain forests (Nakamura et al. 2017, 2020) and retarded the formation of floodplain waterbodies (Hänfling et al. 2004; Ward et al. 2002). The few scattered remnant ponds, oxbow lakes, and former river channels in floodplains have become covered by the forest canopy, resulting in closed shady spaces (Nagayama et al. 2015; Negishi et al. 2014).

Understanding the effects of forest expansion on lentic habitats is important for the conservation of floodplain ecosystems. Canopy cover over the lentic habitats may increase the supply of tree leaf litter but decreases the light availability and temperature of the air and water, which can considerably affect aquatic organisms that prefer open water

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(Negishi et al. 2014; Richardson 2008). However, the relationship between forest expansion and changes in the freshwater assemblages of lentic habitats in floodplains has not been well studied. Odonata (dragonflies and damselflies) are sensitive to vegetation changes around their aquatic habitats (Dolný et al. 2014; French and McCauley 2018; Higashikawa et al. 2017), therefore, this taxon may be suitable to investigate the effects of forest expansion on the freshwater assemblage in lentic habitats of floodplains.

In this study, we aimed to determine the effect of forest expansion on the Odonata assemblage in a floodplain with lentic habitats. The Kiso River, located in central Japan, has a chain of ponds called the "*Kasamatsu Tombo Tengoku* Park", in which "*Tombo Tengoku*" means a tremendous number of Odonata. The park has been conserved since the 1970s as an important lentic habitat for many floodplain Odonata species, and the citizens and the river administration monitored the Odonata assemblage until 2013 (Ando 2000, 2015; Kiso River Upstream Office 2009, 2012). Aerial photographs of the park that have been taken every few years over the last 50 years (Geospatial Information Authority of Japan 2020) clearly show vegetation succession from grassland to forest around the ponds and an increase in canopy cover over the waterbodies. We referred to previous records of Odonata species and surveyed the current status of the Odonata assemblage in the park. We then quantified the change in forest area in the habitat over the years and analyzed the relationship between forest expansion and the change in the Odonata assemblage.

Materials and methods

Study site and quantification of forest expansion

This study was conducted in the *Kasamatsu Tombo Tengoku* Park, in the middle stream of the Kiso River, located in Gifu Prefecture, central Japan (Fig. 1). The spatial size of the park was approximately 500 m × 160 m. The park has six ponds, which were separated from the Kiso River mainstream because of river modifications in the 1920s (Kiso River Upstream Office 2009). The ponds were

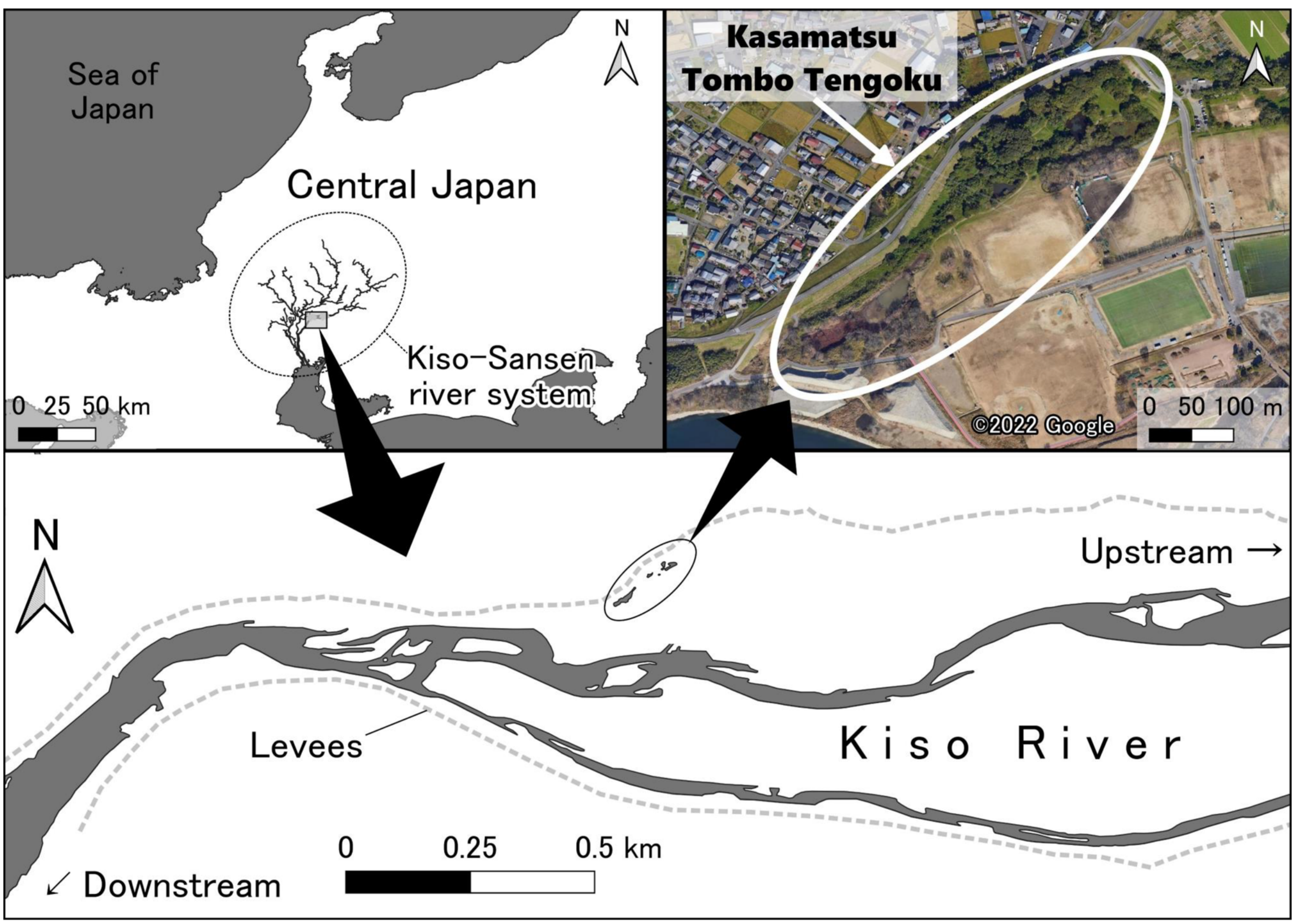

Fig. 1 Schematic map of the location of the *Kasamatsu Tombo Tengoku* Park in central Japan. *Map data, ©2022 Google Satellite*. The satellite image was obtained on 12th April 2023

mainly surrounded by grasslands until the 1970s but are currently covered by deciduous broad-leaved trees, such as *Celtis sinensis* and *Salix chaenomeloides* (Fig. 2). We referred to aerial photographs of the park over the years to elucidate the change in vegetation (i.e., grassland to forest), and we selected the photographs taken from April to November, when the forest canopy of the deciduous trees was visible, in 1969, 1975, 1980, 1985, 2000, 2006, 2010, 2014, and 2018 (Geospatial Information Authority of Japan 2020; Fig. 3). The forest area (FA, m^2) and area of canopy cover over the waterbodies (ACW, m^2), which were likely to affect the occurrence of the Odonata species (Calvão et al 2022; Ichinose and Morita 2002), in the park, were quantified for each year using the GIS vector data generated from the photographs. We then considered the linear and quadratic approximations to estimate the temporal changes in the FA and ACW from 1969 to 2018 and selected the model with the better fit based on the coefficient of determination (R^2). We analyzed the aerial photographs and polygon data using QGIS software version 3.16 Hannover (QGIS Development Team 2020).

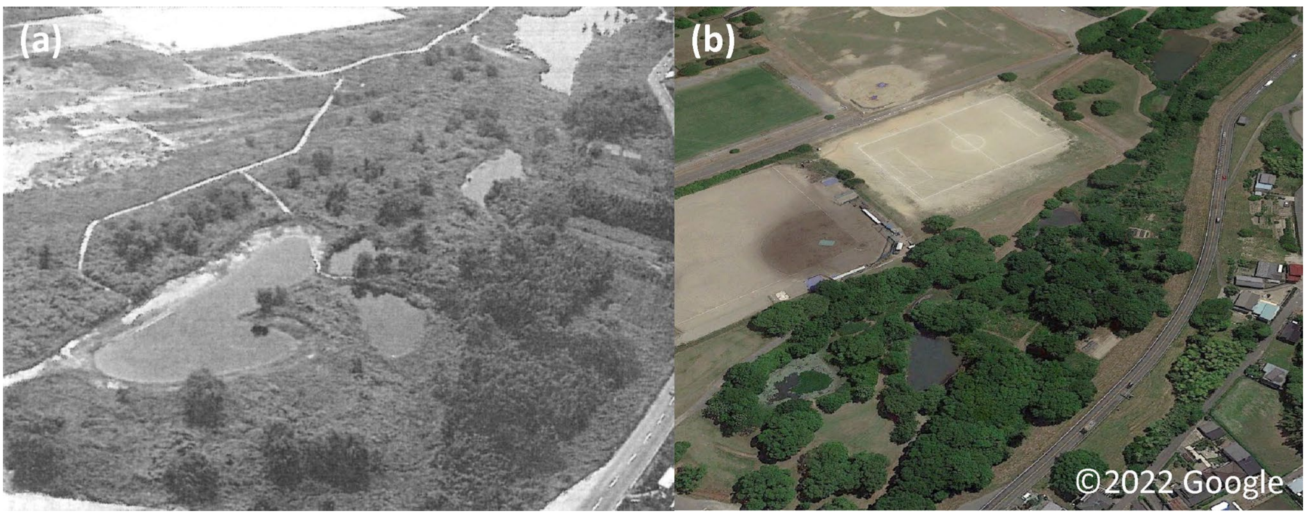

Fig. 2 *Kasamatsu Tombo Tengoku* Park in 1977 **(a)** and 2017 **(b)**, seen obliquely from the upper northwest. Photo images **(a)** and **(b)** were obtained from Kiso River Upstream Office (1978) and Google Earth, respectively. The satellite image **(b)** was obtained on 8th January 2024

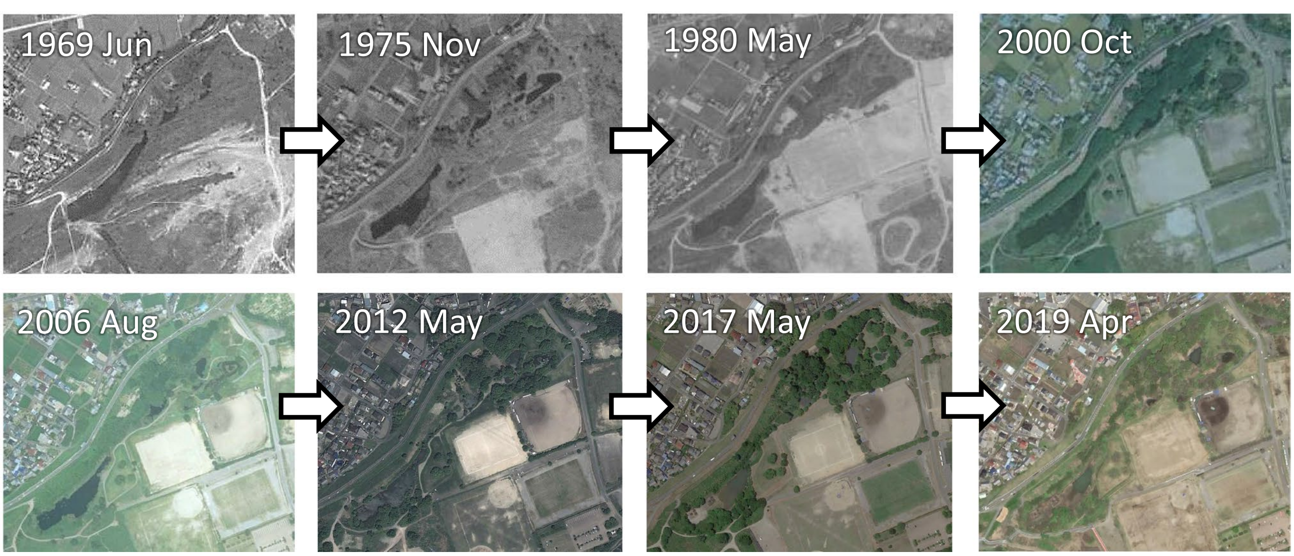

Fig. 3 Aerial photographs showing the vegetation change in the *Kasamatsu Tombo Tengoku* Park over the years (Geospatial Information Authority of Japan 2020)

Historical data reference and survey of Odonata species

Odonata adults in the *Kasamatsu Tombo Tengoku* Park had been surveyed 15 times from 1970 to 2013 by citizens and the river administration, and 51 species including many floodplain species of Lestidae, Coenagrionidae, Aeshnidae, and Libellulidae were recorded (Ando 2000, 2015; Foundation of River and Watershed Environment Management 1983; Kasamatsu Town 1973, 1989, 2005; Kiso River Upstream Office 1978, 2009, 2012; Yamamoto 1971). In particular, ten surveys from 1983 covered the seasons when adult Odonata appear (i.e., spring to autumn). Line transect censuses were conducted (Ando 2000, 2015; Kiso River Upstream Office 2012), but the number of individuals for each observed species was categorized (few: 1–5; not few: 6–25; many: > 25) in the surveys from 1983 to 2004 and 2013 (Ando 2000; 2015). Similar categories of the number of individuals were used in the surveys from 2009 to 2011 (few: 1–10; many: 11–100; considerably many: > 100) (Kiso River Upstream Office 2012). To understand the current status of the Odonata species, we surveyed the Odonata adults in the park in the middle of each month from April to October 2021. According to the survey methods described by Ando (2000), we observed Odonata adults on sunny and windless mornings by walking a total of 650 m along the shorelines of the six ponds for two hours, and the species and the number of individuals were recorded.

The observed Odonata species were then classified into "forest species" or "non-forest species" based on the work by Ozono et al. (2021), which describes the habitat use of each species in detail. Species that were described as being forest dependent at least at a certain stage of their life history were regarded as forest species, whereas those with no description of forest dependence were regarded as non-forest species. As lotic species were considered to be less dependent on the studied floodplain ponds, we eliminated four lotic species, *Atrocalopteryx atrata*, *Sympetrum pedemontanum elatum*, *Sieboldius albardae*, and *Davidius nanus* from the following analysis.

Statistical analysis

The effects of forest expansion on the Odonata assemblages in the *Kasamatsu Tombo Tengoku* Park were analyzed using generalized linear mixed models (GLMMs). Since the occurrence of many Odonata species could be associated with the forest abundance within a buffer of several hundred meters of aquatic habitats (Calvão et al. 2022), we focused on the forests within the park. We did not consider the influence of lentic habitats because the area of the ponds did not change significantly in these decades and there was no aquatic environmental data, such as water quality and aquatic vegetation, that corresponded to the long-term records of Odonata assemblage. In addition, we did not take the landscape factors surrounding the park into account because the condition of aquatic and terrestrial environments in the dispersal range of floodplain Odonata species (e.g., 5 km buffer) likely did not change dramatically (Higashikawa et al. 2023). In the GLMMs, the response variables were the number of forest and non-forest species, which were modeled with a Poisson distribution with a log link function. For each response variable, single regression models were constructed using standardized values of FA and ACW as the fixed variables. Because the year in which the surveys of Odonata were conducted did not necessarily coincide with the year in which the aerial photographs were taken, we used the FA and ACW in the survey years that were estimated from the regression model to predict interannual changes in these variables. The survey year was set as a random variable to take into account the changes in the local Odonata assemblage over the years. The significance of the fixed effects was tested using the Wald-z statistic. The statistical analyses were performed using the software R version 4.1.2 (R Core Team 2021). The GLMMs were run using the *glmer* function in R package *lme4* version 1.1–23 (Bates et al. 2015).

Results

The FA and ACW of the *Kasamatsu Tombo Tengoku* Park have increased quadratically from 1969 to 2020 (Fig. 4 and Table S1). In the ten surveys conducted from 1983 to 2013, a total of 51 Odonata species were recorded, and the maximum, minimum, and mean number of species per year were 38 in 1988, 27 in 1983 and 2013, and 30.2, respectively (Table S1). The proportion of abundant species categorized as “not few”, “many” or “considerably many” individuals in the past records sharply decreased for non-forest species and gradually increased for forest species (Fig. 5). We observed 29 species, including 13 forest and 16 non-forest species, in 2021. Species that had been continuously observed before 2010 but disappeared in the last 10 years were *Indolestes peregrinus*, *Lestes japonicus*, *Aeschnophlebia longistigma*, *Epitheca marginata*, and *Sympetrum kunckeli*. The number of forest species increased moderately with increasing FA ($p = 0.062$) and ACW ($p = 0.061$) in the marginally significant levels; conversely, the number of non-forest species significantly decreased with the increases in FA ($p < 0.001$) and ACW ($p < 0.001$) (Fig. 6 and Table 1).

Discussion

Floodplain forest expansion has influenced the Odonata assemblages, resulting in an increase in forest species and a decrease in non-forest species. In the 1970s, the ponds were surrounded by grasslands (Fig. 2a), and approximately 80%

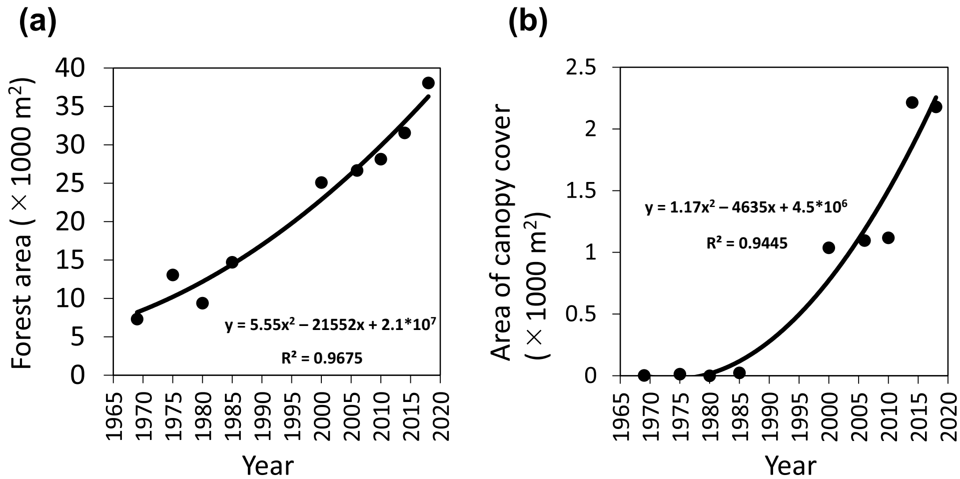

Fig. 4 Interannual changes in forest area (FA) **(a)** and area of canopy cover over the waterbodies (ACW) **(b)** in the *Kasamatsu Tombo Tengoku* Park over the years. The regression curves were fitted to quadratic approximations

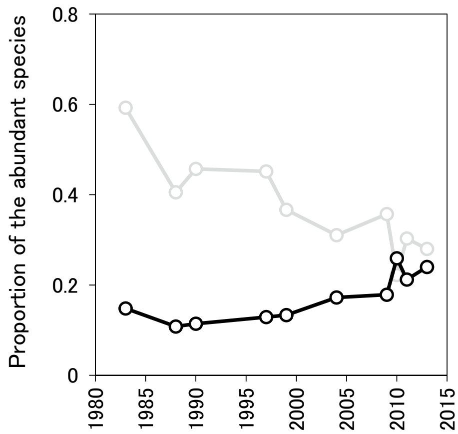

Fig. 5 Interannual changes in the proportion of the abundant species categorized as "not few", "many" or "considerably many" individuals for non-forest (gray) and forest (black) species in the past records

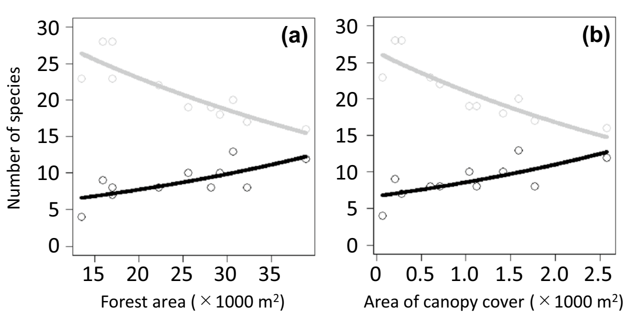

Fig. 6 Generalized linear mixed models (GLMMs) to predict the number of non-forest species (gray) and forest species (black) from the forest area (FA) **(a)** and area of canopy cover over the waterbodies (ACW) **(b)**

of the species were non-forest species (Fig. 6) and most of them were abundant (Fig. 5). This indicates that the Odonata assemblage in the 1970s consisted of species typical of open-lentic habitats. However, the number of non-forest species largely decreased and that of forest species gradually increased with the expansion of forest area and area of canopy cover over the waterbodies until the 2010s, resulting in the decreased dominancy of non-forest species (Figs. 5 and 6). Four species that disappeared in the past few decades are non-forest species preferring open-lentic habitats (Ozono et al. 2021). The number of forest and non-forest species was almost the same in 2021, and non-forest species occupied approximately only 30% of the proportion of individuals (Table S1).

Open-lentic habitats that exist outside of the inter-levee floodplain are mostly rice paddy fields and irrigation ponds in agricultural areas in Japan, but they are degrading due to chemical and physical modifications (Higashikawa and Yoshimura 2021; Higashikawa et al. 2016, 2019). Thus, floodplain open ponds are considered valuable as remaining habitats. However, in the *Kasamatsu Tombo Tengoku* Park, forest expansion may have reduced the open habitats like grasslands in the floodplain which non-forest Odonata species need for resting, foraging, and reproduction (Higashikawa et al. 2017, 2018; Khelifa et al. 2021; Ozono et al. 2021). Whereas the forest cover is a crucial dispersal pathway for riparian organisms (Skagen et al. 1998; Todd et al. 2009), the forest can be a migration barrier for non-forest Odonata species (Keller et al. 2012; Purse et al. 2003). The expanded forest in the *Kasamatsu Tombo Tengoku* Park may disturb the immigration of non-forest species from the adjacent rice paddy fields and mainstream of the Kiso River into the park. As immigrants are important for the persistence of small, isolated populations (Pröhl et al. 2021), the potential forest barrier might shrink populations of non-forest species in the park. The increased canopy cover over the waterbodies may have decreased light and temperature above and within the ponds (Negishi et al. 2014; Richardson 2008), likely resulting in the population decline of species

Table 1 Generalized linear mixed models (GLMMs) to examine effects of the forest area (FA) and area of canopy cover over the waterbodies (ACW) on the numbers of forest and non-forest species

Response variable	Fixed variable (standardized)	Model term	Coefficient	SE	*z* value	*p* value
Number of forest species	Forest area (FA)	Intercept	2.160	0.103	20.894	< 0.001
		FA	0.198	0.106	1.866	0.062
	Area of canopy cover (ACW)	Intercept	2.160	0.103	20.923	< 0.001
		ACW	0.191	0.102	1.874	0.061
Number of non-forest species	FA	Intercept	3.040	0.066	45.812	< 0.001
		FA	− 0.169	0.070	− 2.412	0.016
	ACW	Intercept	3.040	0.066	45.783	< 0.001
		ACW	− 0.173	0.072	− 2.395	0.017

that prefer warm and open water environments. In particular, the decrease in light of the ponds can reduce aquatic plants (Sender 2016), which are important as oviposition substrates for many non-forest species and even some forest species (Ozono et al. 2021). Although aquatic plants such as *Utricularia* sp. and *Limnophila sessiliflora* were abundant in the ponds until the 1980s (Foundation of River and Watershed Environment Management 1983), they have not been recorded in recent years. It has been reported that the rapid decrease of aquatic plants in the park may be due to the eutrophication (Foundation of River and Watershed Environment Management 1983) and invasion of non-native crayfish, *Procambarus clarkii* (Kiso River Upstream Office 2012), which are detrimental to aquatic plants (Watanabe and Ohba 2022). However, the canopy, which extends above the water surface, may be another factor that has the negative effect on aquatic plants. The floodplain forest will continue to expand, and eventually the entire park may be covered by the canopy. If riparian forests surrounding the floodplain ponds are inappropriately managed in the Kiso River, the Odonata assemblage may be composed exclusively of forest species.

We demonstrated the changes in the floodplain ecosystems due to the surrounding forest expansion, focusing on the Odonata assemblage in lentic habitats. The floodplain ponds are one of the remaining open-lentic habitats in Japan, and their conservation and management could be urgent. Terrestrial and aquatic habitats in the floodplains show shifting-mosaic patterns consisting of temporal and permanent waterbodies surrounded by grassland and forest (Fliervoet et al. 2013; Nakamura et al. 2007; Ward et al. 2002). The forest expansion and increase in forest-dependent species in the floodplain can also be considered a tipping point in the shifting-mosaic and should not necessarily have the negative impact on the Odonata diversity. The development of the small forest nearby the ponds in the 1980s might have positively affected Odonata diversity in the *Kasamatsu Tombo Tengoku* Park (Foundation of River and Watershed Environment Management 1983). However, the recent discernible reduction in open-lentic habitats and decline in non-forest Odonata species warrants serious concern. In rivers well-managed for flood control, the formation of floodplain waterbodies with grasslands become rare (Hänfling et al. 2004; Ward et al. 2002), and vegetation succession proceeds, leading to forest expansion around the remnant waterbodies (Nagayama et al. 2015). In light of this, it is necessary to maintain the shifting-mosaic patterns of the vegetation around the waterbodies by management while taking flood risks to human society into account (Fliervoet et al. 2013). For example, the idea of "Cyclic Floodplain Rejuvenation (CFR)" is that anthropogenic rejuvenation safeguards flood protection as well as nature rehabilitation objectives (Duel et al. 2001). In the CFR, the importance of mimicking the effects of floods by cutting riparian trees is emphasized (Baptist et al. 2004). Vegetation management based on these concepts may contribute to enhancement and conservation of the Odonata species diversity in the floodplains. In floodplain lentic habitats, such as ponds, oxbow lakes, and former river channels, where the surrounding forest is expanding, the cutting of riparian trees may be necessary to make open zones, which provides pathways for immigration of Odonata from nearby habitats and sufficient levels of light on the water surface. Where there are several ponds, as in the *Kasamatsu Tombo Tengoku* Park, it may be better to create different vegetation structures in the different ponds (i.e., shifting-mosaic patterns of vegetation) for both the forest and non-forest Odonata species. Considering the result of this study, a citizen's group and the river administration have collaborated and started experimental cutting of the surrounding trees, elimination of the invasive species, and dredging ponds for the exposure of the seed banks to improve the habitat environment for the Odonata species in the *Kasamatsu Tombo Tengoku* Park since 2022. Such a conservation activity with the public–private partnership is important for the environmental management of river floodplains, and monitoring of the Odonata assemblage after the experimental modification is necessary to verify the biodiversity effects of management of the floodplain lentic habitats.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10201-024-00748-7.

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Author contributions Wataru Higashikawa: conceptualization, data curation, formal analysis, investigation, methodology, resources, writing—original draft, writing—review and editing, validation, visualization. Yuki Matsuzawa: investigation, writing—review and editing. Terutaka Mori: writing—review and editing, supervision.

Data availability Data that support the findings of this study are available within the article and the supplement materials. Raw data are available from the corresponding author on reasonable request.

Declarations

Conflicts of interest The authors declare that they have no conflict of interest.

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