1st June 2015

Larval community dynamics in an artificial habitat created for conservation of a local population of the endangered brackish water damselfly, *Mortonagrion hirosei* (Odonata: Coenagrionidae)

Mamoru Watanabe

Graduate School of Life and Environmental Sciences, University of Tsukuba, Tsukuba, Ibaraki 305-8572, Japan; <watanabe@kankyo.envr.tsukuba.ac.jp>

Received 8th October 2014; revised and accepted 28th March 2015

Abstract. Brackish water ecosystems in estuaries are highly threatened due to land development, the improvement of embankments, and reclamation. Several threatened species of dragonflies and damselflies inhabit these ecosystems. The brackish water damselfly, *Mortonagrion hirosei* Asahina, 1972, has been an important focus of conservation studies. Here, we describe a conservation project for *M. hirosei* begun in 2003, and review the data collected in order to quantify details of the species' life cycle, especially larvae and larval environment. An artificially established reed community was created as a habitat for this damselfly, and water depth, salinity, and water temperature in the reed bed were continuously monitored thereafter. Because this damselfly is univoltine, the number and distribution of the odonate larvae in the experimental habitat in May, or presence of last-instar larvae of *M. hirosei*, were considered suitable indices of colonisation success. Since many odonate adults, including *M. hirosei*, visited the habitat in the first year and laid eggs, high larval diversity was found in the second year. Although the salinity of water in the reed bed varied because cyclical tidal fluctuations, the saline water gradually excluded odonate larvae that inhabit freshwater only. However, *M. hirosei* survived, and the larval population increased year by year. Consequently, the odonate larval diversity in the artificial habitat decreased, while the population of *M. hirosei* was maintained.

Key words. Dragonfly, Zygoptera, salinity, Common reed, *Phragmites australis*, Japan

Introduction

One important cause of insect extinctions is the destruction of natural biotopes. Management of estuarine landscapes has intensified in recent years due to great losses of historical wetlands and the prevalence of drought. Odonate species that have specific biotope preferences and/or are restricted to certain localities could be threatened (Steytler & Samways 1995). Dragonflies are often used as bioindicators, especially to assess the ecological quality of wetlands (Chovanec & Raab 1997). Together with the restoration or construction of habitats, the conservation of aquatic ecosystems is the most important element of dragonfly protection (Raab et al. 1996).

In *Mortonagrion hirosei* Asahina, 1972, the main causes of decline are somewhat interrelated but can be attributed mainly to habitat loss and fragmentation largely resulting from water management practices (e.g., drainage, neglect, infilling) and pollution. Such man-made disasters have seriously damaged *M. hirosei* populations to the point of threatening their continued existence in naturally established reed communities (Hirose 1985). Because of the low vagility of *M. hirosei* adults (Watanabe & Mimura 2004), the discontinuity of their fragmented habitats has further threatened their survival in many localities. Intensive conservation projects are essential to prevent the local extinction of this species. Campbell et al. (2002) pointed out that the monitoring of biological or ecological factors in a newly created habitat should be divided into three categories: monitoring of each plan's focal species, monitoring of associated species, and monitoring of the habitat.

Anthropogenic modifications of aquatic habitats have been demonstrated to affect the richness of odonate species (Hofmann & Mason 2005). In addition, the quality of the adjacent terrestrial habitat must be considered, which is also highly influenced by human activity, as most odonate adults forage and roost away from water for much of their lives. Where natural biotopes have been lost, it might be possible to recreate them, in terms of both the terrestrial and aquatic plant community, especially for strongly dispersing Anisoptera. Nonetheless, there has been little consideration of the terrestrial plant community required for habitat conservation of *M. hirosei*, which tends to be restricted to the same reed community throughout its life span because the adults do not undertake maiden flights of any significant distance (Watanabe & Mimura 2003).

Reed communities established in brackish water determine the occurrence of *M. hirosei*, as its adults select the understory of these structures for perching, foraging, mating, and oviposition (Watanabe & Mimura 2004). In addition to the reed community structure required by adults, one of the major abiotic factors that may limit their distribution is salinity, since the eggs and larvae tolerate saline conditions, but their predators often do not. Natural selection thus seems to favor *M. hirosei* in dense reed communities established in brackish water, though *Ischnura senegalensis* (Rambur, 1842), which is a main predator of *M. hirosei*, can also tolerate saline conditions.

Local abiotic factors such as temperature and water chemistry are thought to influence the invertebrate community structure through trophic processes via the effects of dissolved nutrients on the quantitative and qualitative nature of a phytoplankton community and the microbial and aquatic fungal processing of detritus on the bed. De Marco et al. (1999) showed that ponds with more extreme conditions (with extensive plant cover or complete absence of vegetation) had lower odonate species richness than those with intermediate conditions. Odonate larvae are predators that live in freshwater environments. High numbers of odonate species have been correlated with greater macrophyte coverage (Raebel et al. 2012) and with the abundance of other macro-invertebrates (Foote & Hornung 2005). Conversely, the odonate number and species richness were lower with increased turbidity (D'Amico et al. 2004), and appeared to be lower with increased nutrient loads (Raebel et al. 2012). In addition, either positive or negative relationships were found, depending on specific species, with shade, reed cover, bank height (Steytler & Samways 1995; Hofmann & Mason 2005), the presence of fish (Morin 1984), pond size, and pond age (Kadoya et al. 2004). Therefore, since newly constructed freshwater ponds provide few biotic interactions, rapid colonization by dragonflies has been recorded (Moore 1991).

Interspecific and intraspecific interactions between larval odonates may be described in terms of their size relations (Corbet 1999: 164 ff.). Large odonate larvae limit the movements of small odonate larvae and prey upon them. McPeek (2008) pointed out that mortality due to both cannibalism and predation of larvae by other odonates appeared to be the dominant factor limiting the abundance of many species and that the intensity of predation depends on the structural complexity of the environment.

The aim of this paper is to describe an 11-year conservation project for *M. hirosei* begun in 2003, with the addition of new data since the last report (Iwata & Watanabe 2009). In particular, this study focuses on the importance of the larval phase in the local population regulation in *M. hirosei*.

Changes in the odonate assemblages in the artificial reed community are documented in order to assess how environmental characteristics could determine the conservation of the *M. hirosei* population in an artificial community within an estuarine landscape.

Study site: Natural habitat and artificial habitat

The study area (Fig. 1) was located in Ise, Mie Prefecture, Japan (34°29'N, 136°42'E). The area had been extensively farmed. Although several reed communities remained along the edges of rice paddy fields in the area, these were highly fragmented and distant from each other and did not form a network. In fact, one of the habitats of *Mortonagrion hirosei* found in 1998 (10 × 50 m) consisted of a small, relatively straight, slow-flowing stream consisting of freshwater mixed with domestic waste and saline water at high tide. Human settlements were on the north side and rice paddy fields were located on the south side of the stream. Little pesticide was used on the rice paddy fields during the flight season. To the east the stream continued to Ise-Bay and the sea. A pure and dense community of Common reed *Phragmites communis* (430 m²) was established within the stream and formed a dense cover of reed shoots over the shallow brackish water (Matsu'ura & Watanabe 2004). The salinity of the stream was 6.7‰ on average from April 2003 to March 2005. The mean density of live and withered reed stems was 440 per m² corresponding to a mean distance of approximately 5 cm between reed stems. No reeds had been trimmed until the project began and they remained about 2–2.5 m tall for its duration.

In January 2003, the artificial habitat was created in rice paddy fields that were already inhabited by the zygopterans, *Ischnura asiatica* Brauer, 1865, *I. senegalensis*, and *Mortonagrion selenion* (Ris, 1916) and several species of Anisoptera (Watanabe & Matsu'ura 2006). Nearby reed rhizomes were transplanted for rapid physical construction of the habitat for *M. hirosei* (2,065 m²), which on its southern side was bordered by natural habitat. The approximately 1 m wide corridor between the natural and artificial habitats was expected to allow colonization by *M. hirosei* adults. The salinity in the artificial habitat was maintained by three inlets supplying brackish water. However, the salinity and reed density were not uniform in the area due to fluctuations in rainfall and tidal height as well as fluctuations in the microtopography of the reed beds. MATSU'URA & WATANABE (2004) reported that the salinity was highest in the western part of the created habitat and lowest in the eastern part.

In 2003, the reed density in the natural habitat was about 20 shoots/ 625 cm² (25 × 25 cm), and the mean natural height of the reeds was 130 cm during the flying season of *M. hirosei*. In the artificial habitat, the reed density was about 17 shoots/625 cm², with a mean height of 40 cm less than that in the natural habitat, indicating that the reed community established in the first year was an open habitat. Reeds rooted through the artificial habitat bottoms, providing dense stems of cover within a couple of years after they had been planted (MATSU'URA & WATANABE 2004). Colonisation of the reeds was thus a rapid process.

In 2003, the first year of the artificially established reed community, a few *I. senegalensis* adults were observed in late April, probably due to the immigration of larvae attached to reed rhizomes during the transplanting (WATANABE et al. 2008). After June, the population of *I. senegalensis* increased because of the immigration of adults from the abandoned rice paddy fields and ponds near the artificial habitat. However, there were no *M. hirosei*

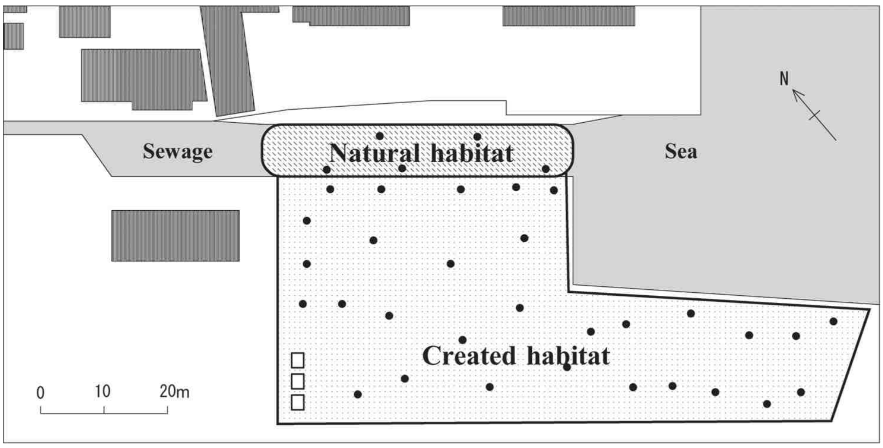

Figure 1. Study site in Ise, Mie Prefecture, Japan, showing the natural and artificial habitats of *Mortonagrion hirosei*. The three squares indicate inlets of brackish water. Dots show the sampling sites for survey of odonate larvae and abiotic factors. The dark shaded areas signify residential houses surrounded by cultivated fields.

adults detected in May, indicating that no larvae had immigrated when the reed rhizomes were transplanted. A few adults were detected near the original habitat in early June, and the number of adults increased slightly in July. No tenerals were observed throughout the flying season. Therefore, a certain number of *M. hirosei* adults apparently had emigrated from their natal habitat, though the structure of the artificially established community in terms of the reed density and light environment was not yet suitable for them.

In 2004 and 2005, the established reed community had developed and the shoot density had reached about 40 thin shoots/625 cm^2 over the whole area, while it was 25 shoots/625 cm^2 in the natural habitat. Since partial cutting was conducted in the autumn of 2005 in both the natural and artificial habitat, the reed density with normal shoot size was about 19 shoots/625 cm^2 in both habitats. There were still a few small open patches with low reed density inside the natural habitat in 2006. Details of the dynamics of the newly established reed community adjacent to the southern part of the natural habitat were reported by Matsu'ura & Watanabe (2004) and Morimoto et al. (2010).

Materials and methods

Water depth (accuracy 0.1 cm) and salinity degree (accuracy 0.1 ‰) were measured in 5 and 30 sites for natural and artificial habitat, respectively (Fig. 1). A specific conductivity meter (Horiba ES-12) was used monthly to calculate the salinity throughout the survey period.

Litter bags containing leaves and stems of reeds were used as traps to collect aquatic animals in the natural and artificial habitat. Twenty-five litter bags (10 × 25 cm with 2 mm mesh) including reed leaves (3.0 g fresh weight) and stems (20.0 g fresh weight) were randomly exposed in November 2006. To identify and count the aquatic animals trapped, five litter bags were examined in each of the following months: December 2006 and February, May, August, and November 2007.

From 2004 to 2013, once per year in early May a survey of larval odonates was conducted by the use of a hand-net to account for late instar larvae of *Mortonagrion hirosei* and overwintering species as well as early instar larvae of spring-hatching species. At each sampling, we set up 5 and 30 sampling sites (0.25 × 0.25 m) from the natural and artificially established reed communities, respectively (Fig. 1). We then collected and identified odonate larvae found in each sampling site.

Since the onset of the flight season of *M. hirosei* was in late May, sampling of odonate larvae in early May facilitated the assessment of the total emerged adult population. In addition, because young larvae of the species hibernating in the egg stage could be sampled early in May, it was possible to compare the entire odonate larval community in the established habitat with that of the natural habitat. When early instars of odonate larvae of spring-hatched species were collected, they were reared for the development of distinguishing characteristics. Except for the odonate larvae, aquatic invertebrates trapped in the litter bags were preserved in 70 % ethanol and identified later in the laboratory. Samples were identified to the lowest identifiable taxonomic level.

Changes in the distribution of odonate larvae in the artificial habitat were examined using the m^*/m method, where m is the mean number of individuals and m^* is the mean crowding (Lloyd 1967). Iwao (1968) showed that m^*/m represents the relative aggregation pattern. When m^*/m is less than 1, the distribution is uniform. When m^*/m is equal or greater than 1, it means random or aggregated distribution, respectively.

Results

The water depth and salinity of the natural reed community bed was affected by rainfall and by entering tidal seawater. In 2004 and 2009, heavy rainfall due to monsoons in the days preceding the survey increased the water depth by more than 10 cm (Fig. 2). On the other hand, although several fine days with low humidity led up to the survey day, the water depth was not greatly affected (2008 and 2010). In the natural habitat, then, the water depth was mostly less than 5 cm throughout the survey period. However, the water depth in the artificial habitat did not fluctuate because the water supply in the habitat was fully controlled, with excess water being discharged from the habitat.

The average salinity in the natural habitat varied between 1 and 10 ‰ (Fig. 3). Except for 2006 due to extraordinarily high tide, the change in the salinity in the artificial habitat was similar to that in the natural habitat.

Several cm of detritus including mainly leaves and stems of dead reeds accumulated on the bottom of the reed community in the artificial habitat, providing a suitable environment for *Mortonagrion hirosei*. A few small water pools with a water depth of several cm in the artificial habitat contained small fish, but few larvae of *M. hirosei* were present. No frogs or toads were seen.

The aquatic animals in the litter bags were detected via movement through the screen of the litter bag and removed through the screen. Table 1 shows that a total of six classes of animals were trapped in the natural habitat with an average of six species in each litter trap. Chironomidae were the dominant insect family, while on average five larvae of *M. hirosei* were found in each bag.

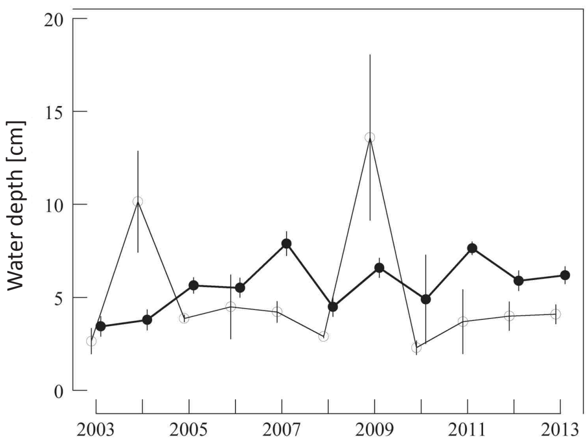

Figure 2. Yearly fluctuation of water depth on the day of odonate larvae sampling in May, in an artificial habitat of *Mortonagrion hirosei* at the study site in Ise, Mie Prefecture, Japan. Open and closed circles represent the natural and artificial habitats, respectively. Bars correspond to SD.

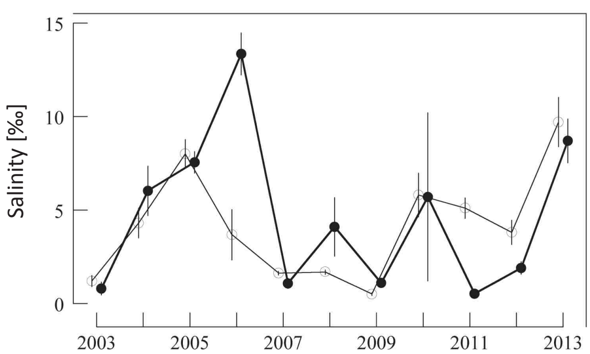

Figure 3. Yearly changes in the salinity on the day of odonate larvae sampling in May, in an artificial habitat of *Mortonagrion hirosei* at the study site in Ise, Mie Prefecture, Japan. Open and closed circles represent the natural and artificial habitats, respectively. Bars correspond to SD.

Species richness in the artificial habitat was low, particularly in its eastern part, which was located more distant from the natural habitat than the western part. On average, 4.8 species and 2.4 species were found in the western part and the eastern part of the artificial habitat, respectively. The number of each species trapped in the artificial habitat was smaller than that trapped in the natural habitat, though few significant differences were seen (Tab. 1). Larvae of *M. hirosei* and *I. senegalensis* were trapped in both parts of the artificial habitat. Although gastropods were not found in the artificial habitat, this was colonized by other aquatic insects, which appeared to increase as they became more sheltered by dead leaves and dead stems of the reeds.

In the natural habitat, only *M. hirosei* larvae were found during the 10-year survey period, except for 2011 when one *I. senegalensis* larva was collected at the edge of the natural habitat. In the artificial habitat, a total of 1,348 odonate larvae including *M. hirosei* were collected over the 10-year survey period. These included three species of Zygoptera [*Ischnura asiatica* (Brau-

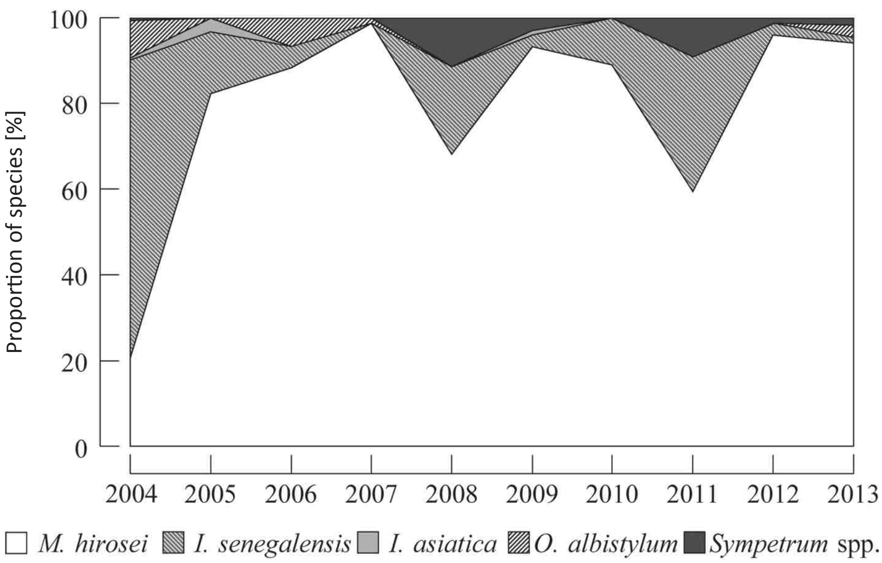

Figure 4. Annual change in the species assemblage in an artificial habitat of *Mortonagrion hirosei* at the study site in Ise, Mie Prefecture, Japan. Total number of larvae for each year was 253 in 2004, 124 in 2005, 200 in 2006, 87 in 2007, 132 in 2008, 76 in 2009, 73 in 2010, 234 in 2011, 100 in 2012, and 69 in 2013.

Table 1. List of aquatic taxa trapped in litter bags (± SE), set up in November 2006 and examined from December 2006 to November 2007, in reed communities of a natural and an artificial habitat of *Mortonagrion hirosei* at the study site in Ise, Mie Prefecture, Japan. Dunnett's C-test was used to determine the significant difference from the number in the natural reed community (* – 0.05> *p* >0.01, ** – *p* <0.01).

Aquatic invertebrate group	Taxon	Natural habitat	Artificial habitat	
			East	West
Insecta, Neuropterida, Megaloptera	Sialidae	0.2±0.2	0	0
Insecta, Odonata, Coenagrionidae	*Mortonagrion hirosei*	5.0±3.5	2.2±1.4	1.0±1.0
	Ischnura senegalensis	0	0.6±0.6	0.2±0.2
Insecta, Coleoptera	Colymbetinae	0.2±0.2	0	0
Insecta, Diptera	Chironomidae	108.2±37.1	39.2±16.5	50.0±7.4
	Stratiomyidae	3.2±0.7	1.0±0.4	1.8±1.0
	Tipulidae	0	1.4±1.0	0
Insecta, Lepidoptera, Crambidae	Acentropinae (=Nymphulinae)	0	0.8±0.4*	0
Crustacea, Amphipoda, Talitridae	*Platorchestia crassicornis*	12.0±3.1	4.0±2.8	1.0±0.4*
Crustacea, Amphipoda, Anisogammaridae	*Jesogammarus hinumensis*	23.4±11.6	19.0±10.2	0.2±0.2
Crustacea, Amphipoda, Melitidae	*Melita* sp.1	0.4±0.2	0	0
	Melita sp.2	0	0.6±0.6	0
Crustacea, Isopoda, Sphaeromatidae	*Gnorimosphaeroma rayi*	42.8±14.3	22.4±19.2	0
Polychaeta	Polychaeta	18.4±3.8	12.0±2.6	2.0±1.0**
Oligochaeta	Oligochaeta	16.0±2.2	10.2±2.6	3.0±0.9**
Gastropoda	Gastropoda	0.4±0.4	0	0
Bivalvia	Bivalvia	0.2±0.2	0	0
Mean number of taxa per litter bag		6.2±0.4	4.8±0.5*	2.4±0.3**

er, 1865), *I. senegalensis*, *M. hirosei*] and two anisopteran taxa [*Orthetrum albistylum* (Selys, 1848), *Sympetrum* spp.; Fig. 4].

Ischnura senegalensis was the dominant species in 2004, accounting for 171 individuals out of a total of 253 larvae collected. The proportion of *M. hirosei* in the larval community was about 20 %, indicating that a few

M. hirosei adults had emigrated from the natural habitat in 2003. In 2005, the number of *M. hirosei* larvae drastically increased and it then represented the dominant species, indicating that the species composition gradually became the same as that in the natural habitat, while a small population of *I. senegalensis* remained. Although the species composition of the larval community after 2006 fluctuated, both *I. senegalensis* and *Sympetrum* spp. coexisted with *M. hirosei*. In 2006, the number of *M. hirosei* larvae increased and made up 90 % of the larval community, though larvae of *Sympetrum* spp. were still collected.

The diversity index (Shannon-Weaver H') for the larval community of Odonata was calculated. Because in the natural habitat only *M. hirosei* was found, the index in each year was 0. In the artificial habitat the diversity in-

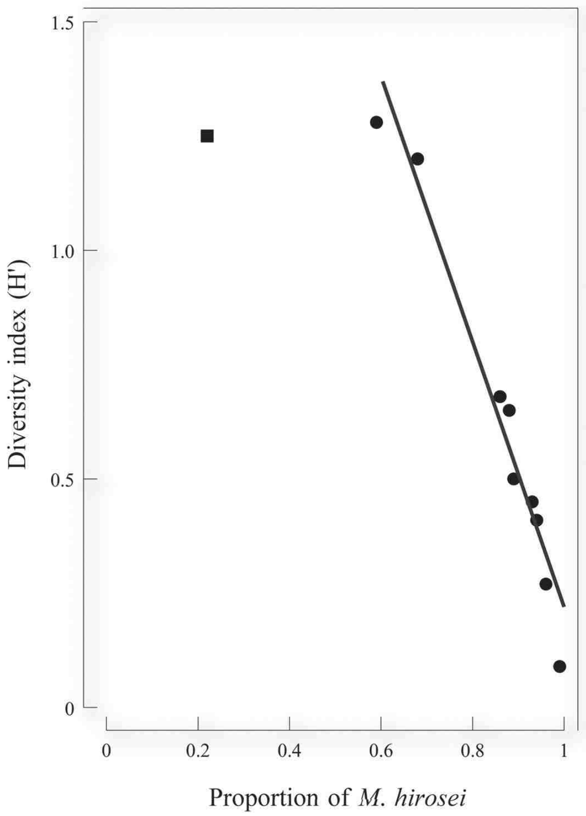

Figure 5. Correlation between the proportion of *Mortonagrion hirosei* larvae of the total larvae and the diversity index (H') in the larval community in an artificial habitat of *Mortonagrion hirosei* at the study site in Ise, Mie Prefecture, Japan. Square represents 2004, circles the years 2005-2013, from which the regression was calculated (y = 3.12–2.9x, $r^2 = 0.95$, $p < 0.01$).

dex in 2004 was 1.25. In 2005, the dominant species changed to *M. hirosei* (107 individuals out of a total 124 larvae), while the number of other odonate species decreased. Then, the proportion of *M. hirosei* population in the larval community increased and the diversity index decreased. Therefore, except in 2004, the proportion of *M. hirosei* was negatively related to the larval diversity index, as shown in Figure 5.

The distribution of larvae of all species, which was highly affected by the distribution of the dominant species, was 1.68 in 2004. On the other hand, the value of *m*/m* for *M. hirosei* in 2004 was high (9.90), indicating a highly concentrated distribution (Fig. 6). In fact, *M. hirosei* was found at only a few sampling sites near the natural habitat. Afterward, *M. hirosei* were dispersed around the entire area of the artificial habitat, resulting in a low *m*/m*. In 2005 and 2006, the *m*/m* values for *M. hirosei* were 4.34 and 2.05, respectively. As the proportion of *M. hirosei* increased over the years, the distribution pattern of all larvae depended on that of *M. hirosei*. Therefore, after 2007, the distribution pattern of *M. hirosei* was similar to that of all larvae, though it was patchily distributed in several of these years.

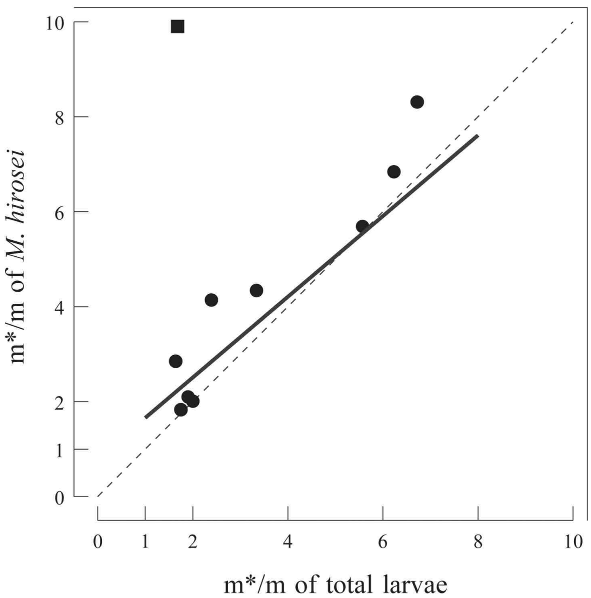

Figure 6. Correlation between the relative aggregation pattern *m*/m* of total larvae and *m*/m* of *Mortonagrion hirosei* in an artificial habitat at the study site in Ise, Mie Prefecture, Japan. Square represents 2004, circles the years 2005–2013 from which the regression was calculated (y = 0.81 + 085x, r^2 = 0.60, *p* <0.01). The broken line represents the diagonal.

Discussion

In this study it was shown that the main factors affecting the richness of odonate species were the dispersal and recruitment of these species and the species pool neighbouring the artificially created habitat. McCauley (2006) reports that either isolation or the distance to the nearest neighbour is negatively related to the number of odonate species arriving and becoming established at physically identical artificial ponds. In the present study, the artificially created habitat adjacent to the natural habitat was located in an estuary landscape consisting of rice paddy fields with small ponds, and a rich assortment of odonate species would be expected in such a setting. A diverse odonate larval community in the artificial habitat became established quickly after the first year, because there were many potential species in the neighbourhood, and because the establishment of young reed stems was not robust, resulting in substantial open water surface area (Morimoto et al. 2010). Matsu'ura & Watanabe (2004) found that adults of *Orthetrum albistylum speciosum* (Uhler, 1858), *Anax parthenope* Selys, 1839, and *Sympetrum* spp. oviposited in the newly created habitat in addition to many adults of *Ischnura asiatica*, *I. senegalensis*, and *Mortonagrion selenion* that were observed during the first year. However, as the established reed community grew year by year, the eventual decline of the odonate diversity was almost certainly due to the inhibition of visits of adult dragonflies caused by the dense reed stems, as well as to the high mortality of the larvae due to salinity. Furthermore, the full-grown reed community increased the *Mortonagrion hirosei* population by providing refuge from predators such as *I. senegalensis* by promoting the presence of macro-invertebrate prey such as aphids in the shady understory of the reeds, and by acting as a habitat selection cue mainly via the weak flight activity of adults (Watanabe & Mimura 2004). It is also possible that *M. hirosei* larvae need the vegetation for protection or for the acquisition of food of better quality or appropriate size, in the manner of Chironomidae, though they were preyed upon by other odonate larvae irrespective of body size. Therefore, the striking difference between the odonate community of the first year and those of subsequent years in the artificial habitat was linked with changes in the salinity of the water body and the aerial structure of the dense reed stems.

Besides natural habitats, man-made water bodies are also important for dragonflies and can be improved by appropriate management. Considerable improvements could be obtained by targeting a particular combination of pond options, such as rice paddy fields for *Sympetrum* species (Watanabe & Kato 2012). Therefore, sustainability of *M. hirosei* populations in the artificial habitat involves the continuous supply of salt water. However, a negative correlation was observed between the abundance of *M. hirosei* larvae and the overall diversity of larval odonates, which supports the assumption that – like most other zygopterans – *M. hirosei* is both a predator and potential prey for other odonates.

Adults of many odonate species, especially zygopterans, use aquatic vegetation as a cue for habitat selection (Corbet 1999: 17 ff.). Therefore species richness would depend indirectly on the age of ponds that are not managed. Consequently, increased structural heterogeneity in aquatic vegetation is positively correlated with an increase in aquatic macro-invertebrate abundance (Painter 1999). Odonates and other aquatic macro-invertebrates might share many of the same basic habitat requirements such as available prey and suitable substrates for concealing themselves.

Foote & Hornung (2005) report that larval odonate diversity and abundance is positively correlated with overall aquatic macro-invertebrate diversity and abundance. Raebel et al. (2012) also point out that ponds with a complex vegetation structure are associated with increased odonate diversity and abundance, and that such ponds are mostly transparent. However, the pure reed community structure in both natural and artificial habitats (stature, height and density) appears to be important for the life cycle of *M. hirosei*, because visits of odonate adults except *M. hirosei* were affected by changes in reed heights and densities (Watanabe et al. 2008), due to their use of visual cues to assess overall breeding habitats (Corbet 1999: 15 ff.). Additionally, *M. hirosei* is a percher with weak flight, and is apt to occupy the interior of reed stands. Tall reeds provide substantial protection from wind at the community edge, indicating that shelter may be a crucial physical structural component of the *M. hirosei* habitat, as well as a barrier to the entrance of predatory species such as *I. senegalensis*.

Odonate assemblage structure in aquatic habitats is primarily determined by the presence of vegetation, including oviposition substrates.

Oviposition sites are one of the most important factors in habitat selection (Corbet 1999: 17 ff.). As demonstrated by Fincke (1986) in *Enallagma hageni* (Walsh, 1863), the females of this species prefer to lay eggs in deep water thus decreasing the risk that the eggs will dry up in the pools. In contrast, for females of *M. hirosei*, at our study site water depth does not seem to be a crucial factor for the oviposition site choice, because the artificial habitat is constantly supplied by water (e.g., Matsu'ura & Watanabe 2004).

Moore (1991) states that water bodies covered by reeds are poor habitats for dragonflies, because close stands of reeds make flight among them very difficult for flyers, particularly for Anisoptera. Watanabe et al. (2008) points out that the distribution of weak flying *M. hirosei* adults appears to contradict this rule, as the dense reed stems function as potential perching sites. There have been few reports examining the spatial distribution of odonate larvae, due to the heterogeneity of the substrate in natural aquatic habitats. However, in the present study, the bottom of the artificial habitat was rather flat and uniform, since the habitat was established on rice paddy fields. The distribution of debris such as reed leaves and stems on the bed would have been random, resulting in a random distribution of the larvae over the whole artificial habitat. Since the yearly fluctuations of water depth and salinity in the natural and artificial habitat were similar in the present study, reed growth in the artificial habitat might have been the major reason that the *M. hirosei* population grew much more quickly than those of other saline tolerant dragonfly species.

One of the factors affecting the larval community structure in the artificial habitat is tolerance of salinity. The larvae of many odonate species cannot survive in a habitat with high salinity. Although both *M. hirosei* and *I. senegalensis* larvae can survive in brackish water (Iwata & Watanabe 2004), due to the emergent parts of the reed stems only *M. hirosei* shows a significant relationship to the dense reed community. All of the small waterbodies in the shallow beds of the reed community might be prone to drying out due to the wide fluctuations in water depth in both the natural and artificial habitats. Chemical variables, such as salinity, as well as the physical and structural aspects of the reed community may be important for *M. hirosei*. In addition, a few small fish inhabited the reed bed due to the low water depth, which also may have contributed to the mortality of aquatic invertebrates including *M. hirosei* larvae.

The invertebrates colonising temporary ponds exhibit traits of r-selected species, i.e., high powers of dispersal, rapid growth, short life-span, small size, and opportunistic and generalist feeding (Williams 1997). In the present study, all the species detected besides *M. hirosei* were generalists that are widespread in central Japan. Because the artificially created habitat was established on abandoned rice paddy fields that had contained traditional aquatic invertebrate communities, similar numbers of other macro-invertebrates including a diverse assemblage of insects as well as gastropods and crustaceans were collected from both the natural and artificial habitats, suggesting that the artificially established reed community functioned effectively as a natural habitat that was suitable for the life cycle of *M. hirosei*. The conservation project is now a success. Therefore, in order to conserve the focus species in an artificial habitat, the diversity of the larval community must be kept as low as possible, and a single species would be ideal. The management recommendations suggested by this study for the conservation of the *M. hirosei* population are to control the salinity and maintain a dense reed community.

Acknowledgements

I would like to thank Dr. T. Yokoi for his critical reading of the MS. Dr. F. Weihrauch, Dr. H. Wildermuth and an anonymous reviewer also gave useful comments on the MS. Thanks are due to the local government of Mie Prefecture for their hospitality at the study site and for giving us research permission. Mr. M. Morimoto and Tamano Consultants Co., Ltd. also assisted in the field survey.

References

Campbell S.P., Clark A.L., Crampton H., Guerry A.D., Hatch L.T., Hosseini P.R., Lawler J.J. & O'Connor R.J. 2002. An assessment of monitoring efforts in endangered species recovery plans. *Ecological Applications* 12: 674-681

Chovanec A. & Raab R. 1997. Dragonflies (Insecta, Odonata) and the ecological status of newly created wetlands – Examples for long-term bioindication programmes. *Limnologica* 27: 381-392

Corbet P.S. 1999. Dragonflies: behavior and ecology of Odonata. Cornell University Press, Ithaca, NY

D'amico F., Darblade S., Avignon S., Blanc-Manel S. & Ormerod S.J. 2004. Odonates as indicators of shallow lake restoration by limiting: Comapring adult and larval responses. *Restoration Ecology* 12: 439-446

De Marco P. Jr., Latini A.O. & Reis A.P. 1999. Environmental determination of dragonfly assemblage in aquaculture ponds. *Aquaculture Research* 30: 357-364

Fincke O.M. 1986. Underwater oviposition in a damselfly (Odonata: Coenagrionidae) favors male vigilance, and multiple mating by females. *Behavioral Ecology and Sociobiology* 18: 405-412

Foote A.L. & Hornung C.L.R. 2005. Odonates as biological indicators of grazing effects on Canadian prairie wetlands. *Ecological Entomology* 30: 273-283

Hirose M. 1985. The present state of *Mortonagrion hirosei*, a new species of dragonfly first discovered in 1971. *Collecting and Breeding* 47: 390-391 [In Japanese, English title]

Hofmann T.A. & Mason C.F. 2005. Habitat characteristics and the distribution of Odonata in a lowland river catchment in eastern England. *Hydrobiologia* 539: 137-147

Iwao S. 1968. A new regression method for analysing the aggregation pattern of animal population. *Researches on Population Ecology* 10: 1-20

Iwata S. & Watanabe M. 2004. Saline tolerance of young zygopteran larvae inhabiting the emergent plants community established in estuaries. *Japanese Journal of Entomology* 7: 133-141 [In Japanese, English summary]

Iwata S. & Watanabe M. 2009. Spatial distribution and species composition of larval Odonata in the artificial reed community established as a habitat for *Mortonagrion hirosei* Asahina (Zygoptera: Coenagrionidae). *Odonatologica* 38: 307-319

Kadoya T., Suda S. & Washitani I. 2004. Dragonfly species richness on man-made ponds: effects of pond size and pond age on newly established assemblages. *Ecological Research* 19: 461-467

Lloyd M. 1967. Mean crowding. *Journal of Animal Ecology* 36: 1-30

Matsu'ura S. & Watanabe M. 2004. Dynamics of reed community artificially established for conservation of the endangered damselfly *Mortonagrion hirosei* and odonate larvae inhabiting the community. *Japanese Journal of Conservation Ecology* 9: 165-172 [In Japanese, English summary]

McCauley S.J. 2006. The effects of dispersal and recruitment limitation on community structure of odonates in artificial ponds. *Ecography* 29: 585-595

McPeek M.A. 2008. Ecological factors limiting the distributions and abundances of Odonata. In: Cordoba-Aguilar A. (Ed.), Dragonflies and damselflies: Model individuals for ecological and evolutionary research: 51-62. Oxford University Press, Oxford

Moore N.W. 1991. The development of dragonfly communities and the consequences of territorial behaviour: a 27 year study of small ponds at Woodwalton Fen, Cambridgeshire, United Kingdom. *Odonatologica* 20: 203-231

Morimoto M., Yamamura Y. & Watanabe M. 2010. Conservation ecology of the brackish water damselfly, *Mortonagrion hirosei* Asahina: Dynamics of a newly established reed community (Zygoptera: Coenagrionidae). *Odonatologica* 39: 333-340

Morin P.J. 1984. Odonate guild composition: experiments with colonization history and fish predation. *Ecology* 65: 1866-1873

Painter D. 1999. Macroinvertebrate distributions and the conservation value of aquatic Coleoptera, Mollusca and Odonata in the ditches of traditionally managed and grazing fen at Wicken Fen, UK. *Journal of applied Ecology* 36: 33-48

Raab R., Chovanec A. & Wiener A.K. 1996. Aspects of habitat selection by adult dragonflies at a newly created pond in Vienna, Austria. *Odonatologica* 25: 387-390

Raebel E.M., Merckx T., Feber R.E., Riordan P., MacDonald D.W. & Thompson D.J. 2012. Identifying high-quality pond habitats for Odonata in lowland England: implications for agri-environment schemes. *Insect Conservation and Diversity* 5: 422-432

Steytler N.S. & Samways M.J. 1995. Biotope selection by adult male dragonflies (Odonata) at an artificial lake created for insect conservation in South Africa. *Biological Conservation* 72: 381-386

Watanabe M. & Kato K. 2012. Oviposition behaviour of the dragonfly, *Sympetrum infuscatum* (Selys), mistaking dried-up rice paddy fields as suitable oviposition sites (Anisoptera: Libellulidae). *Odonatologica* 41: 159-168

Watanabe M. & Matsu'ura S. 2006. Fecundity and oviposition in *Mortonagrion hirosei* Asahina (Ris), *Ischnura asiatica* (Brauer), and *I. senegalensis* (Rambur) coexisting in estuarine landscapes of the warm temperature zone of Japan (Zygoptera: Coenagrionidae). *Odonatologica* 35: 159-166

Watanabe M. & Mimura Y. 2003. Population dynamics of *Mortonagrion hirosei* (Odonata: Coenagrionidae). *International Journal of Odonatology* 6: 65-78

Watanabe M. & Mimura Y. 2004. Diurnal changes in perching sites and low mobility of adult *Mortonagrion hirosei* Asahina inhabiting understory of dense reed community (Zygoptera: Coenagrionidae). *Odonatologica* 33: 303-313

Watanabe M., Matsu'ura S. & Fukaya M. 2008. Changes in distribution and abundance of the endangered damselfly *Mortonagrion hirosei* Asahina (Zygoptera: Coenagrionidae) in a reed community artificially established for its conservation. *Journal of Insect Conservation* 12: 663-670

Williams D.D. 1997. Temporary ponds and their invertebrate communities. *Aquatic Conservation: Marine and Freshwater Ecosystems* 7: 105-117