

**SPATIAL DISTRIBUTION AND SPECIES COMPOSITION
OF LARVAL ODONATA IN THE ARTIFICIAL REED
COMMUNITY ESTABLISHED AS A HABITAT FOR
MORTONAGRION HIROSEI ASAHINA
(ZYGOPTERA: COENAGRIONIDAE)**

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Yearly changes in the odonate larval community were surveyed for 4 yr after setting up an artificial reed community adjacent to the original habitat of *Mortonagrion hirosei*, an endangered brackish water sp. Only *M. hirosei* larvae were found in the original habitat during the survey period. In the first yr of the established habitat, *Ischnura senegalensis* was the dominant sp. in the larval community. Although the abundance of *M. hirosei* larvae increased year by year, becoming the most abundant sp. after the second year, the species composition of the larval community of the established habitat was different between the West and East because of environmental factors, such as saline concentration and reed shoot density. *M. hirosei* larvae had expanded their distribution to the entire area of the established habitat in 2005, while the distribution of *I. senegalensis* had been restricted to several patchy areas in accordance with a decrease in their population. There was a negative relationship between the number of *M. hirosei* and *I. senegalensis* larvae. The prey-predator relationship and competitive relationship between the 2 spp. should have affected the population dynamics and distribution of *M. hirosei*. The odonate larval community and habitat environment that is optimal for *M. hirosei* conservation are discussed from the viewpoint of both biotic and abiotic factors.

INTRODUCTION

Dragonflies have been used as bioindicators because of their species composition and species richness being influenced directly by the environmental condition of

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wetlands (WATSON, et al., 1982; CHOVANEC, 1998). A certain area inhabited by many odonate species tends to be regarded as "a suitable habitat for dragonflies" because of high species richness and diversity (STEWART & SAMWAYS, 1998; CHOVANEC, 1997). CHWALA & WARINGER (1996) clarified that species richness increases at ponds with abundant aquatic and semi aquatic plants used by dragonflies for oviposition rather than at ponds shaded by trees without aquatic vegetation. On the other hand, HIGASHI & WATANABE (1998) found high species richness in artificial ponds located at the upper stream of rice paddy fields which had both open and closed environments, because odonate adults that prefer each environment can coexist. Thus, both larvae and adults of dragonflies are dependent on the water environment, as well as the aquatic and aerial vegetations.

Mortonagrion hirosei has been designated as one of the endangered odonate species (IUCN, 2004). The adults inhabit the understory of dense reed communities established in brackish water. In Japan, about 30 local populations have been discovered, mainly on Honshu Island, and all of them are located in estuaries (MATSUDA et al., 2002). In recent years, various development projects such as shore protection, reclamation works and river improvements, have disturbed much of the natural biotic environment of estuarines, including reed communities, and thus the habitats of *M. hirosei* (SOMEYA, 1998) are declining (HIROSE, 1985; HARA, 2000). Intensive conservation projects are essential for preventing the local extinction of this species.

In 1998, an isolated small habitat of *M. hirosei* was discovered in the estuarine near Miyagawa River, Mie Prefecture, Japan, in an area where a construction project for a sewage treatment plant was going to be undertaken (WATANABE & MIMURA, 2004). In order to preserve the local population of *M. hirosei*, a reed community was artificially established on the abandoned rice paddy fields adjacent to the original habitat by transplanting reed rhizomes in January 2003 (WATANABE & MATSU'URA, 2006).

Before the transplantation, the abandoned rice paddy fields had been kept as a shallow open water environment, with *Ischnura senegalensis*, *I. asiatica*, *M. selenion* and several anisopteran species inhabiting (WATANABE & MATSU'URA, 2006). Because these odonate species are predators or competitors for *M. hirosei* in both larval and adult stages (HIROSE & KOSUGE, 1973; NISHU, 1997; INOUE & TANI, 1999), allowing their invasion to the established habitat might affect the local population dynamics of *M. hirosei*. POLLARD (1991) stated that species-specific odonate larval distributions are correlated with water quality. In order to prevent odonate species except for *M. hirosei* from entering to the established habitat, the water environment had to be managed and the saline water supplied at a concentration about the same as that of the brackish water in the original habitat (MATSU'URA & WATANABE, 2004). The saline concentration of brackish water has been kept at 5 to 15‰ in order to exclude *I. asiatica* and *M. selenion* from the established habitat because they had little tolerance against

15‰ salinity (IWATA & WATANABE, 2004). However, *I. senegalensis* seemed to have a certain saline tolerance and to be able to inhabit a brackish water environment. There have been many reports showing that several *Ischnura* species have as high a saline tolerance for brackish water as *M. hirosei* (FOX & CHAM, 1994). KEFFORD (2006) reported that *I. heterosticta* accelerates their larval development more under a certain concentration of saline water than in fresh water. IWATA & WATANABE (2004) also showed that both *M. hirosei* and *I. senegalensis* have almost the same saline tolerance of up to 15‰. Therefore, excluding *I. senegalensis* from the established reed community is critical for maintaining the local population of *M. hirosei*.

Because of the world wide decline of wetland areas, the construction of artificial aquatic habitats have been conducted as compensation for ecologically degraded regions (MOORE, 1991; CHOVANEC & RAAB, 1997). BANG (2001) reported the odonate species composition in a constructed wetland and the relationship between odonate communities and environmental factors which determine their species richness. However, there have been few studies focusing on the conservation of a single odonate species. Although there are several projects for the habitat conservation of *M. hirosei* in Japan (YAMANE et al., 2004), planning and monitoring based on quantitative data have not yet been reported.

In the present study we clarified the changes of species composition in the larval dragonfly community including *M. hirosei* in the artificially established habitat from 2003 to 2006. The results will represent the dispersion process of *M. hirosei* from the original habitat, and suggest the interspecific relations among the coexisting odonate species in the established habitat. An evaluation of the established habitat for *M. hirosei* is also discussed.

MATERIAL AND METHODS

STUDY SITE – The original habitat of *M. hirosei* was a reed community located in Ise city, Mie prefecture, Japan (34°29'N, 136°42'E). The habitat was 430m² and covered with dense reed shoots on shallow brackish water (WATANABE et al., 2002) the salinity of which was 6.7‰ on average from April 2003 to March 2005.

The established habitat, a created reed community (2065m²) was adjacent to the southern part of the original habitat. The water salinity was artificially maintained by the 3 infalls supplying the brackish water. However, the saline concentration and reed density were not uniform in the area, probably due to rainfall and differences of micro-topography. We divided the established habitat into 3 subareas from west to east, according to different environmental factors, such as reed density, water depth, and saline concentration. The western subarea (A) was 725m² and comprised 3 infalls for brackish water supply. The eastern subarea (C), which was 570m², had several small areas dried up. The middle subarea (B) was 770m², and had an intermediate environmental conditions between A and C. MATSUURA & WATANABE (2004) reported saline concentration was the highest at the western part of the established habitat and the lowest at the eastern part on average from April 2003 to March 2005, though there was no considerable difference after 2006. The mean saline concentration in 2006 were 4.0‰, 4.7‰, and 4.7‰ at the western, the middle and the eastern part of the established, respectively (unpublished), while it was 2.1‰ at the original habitat.

In 2003, reed density at the original habitat was about 20 shoots / 625cm² (25cm×25cm quadrat), and the mean natural height of reed was 130cm during the flying season of *M. hirosei*. On the other hand, the reed density at the established habitat was about 17 shoots / 625cm², where the mean height was 40cm shorter than that in the original habitat, indicating that the established habitat of the first year was open. In 2004 and 2005, the established reed community had developed and the shoot density had reached about 40 shoots / 625cm² in whole area, while it was 25 shoots / 625cm² in the original habitat. Since partial mowing was conducted in the autumn of 2005 both at the original and the established habitat, the reed density was about 19 shoots / 625cm² in both habitats. However, there were a few small open patches with low reed density inside the original habitat in 2006.

INSECTS – Generally, odonate species have a so-called maiden flight immediately after their emergence leaving the water and spending several days in forests or grasslands until they are sexually matured (CORBET, 1999). However, *M. hirosei* do not show the maiden flight activity and stay inside the reed community where they emerge. They usually spend almost all of their lifetime perching on reed stems or leaves at 20cm above the water surface (WATANABE & MIMURA, 2004). They fly to shift to another perching site 5 times an hour and each flight is less than 30 cm, indicating that their home range of activity is very limited. *I. senegalensis* adults prey on *M. hirosei* adults along the edge of the reed community (NISHU, 1997), and the other odonate species, such as *Orthetrum albistylum* could be the predator for *M. hirosei*. Though there have been few report on the activities of *M. hirosei* larvae, most larvae tend to perch on submerged litter near the water surface.

FIELD SAMPLING – We set up 5 quadrates (0.25 m×0.25 m) in the original habitat and 10 quadrats in each subarea, as shown in Figure 1. We sampled odonate larvae in the original and established habitats in November 2003, May and November 2004, May and November 2005, and May 2006 (6 sampling dates).

Since the onset of the flight season of *M. hirosei* is late May, sampling in early May facilitated the assessment of the total adult population that emerged. In addition, because young larvae of the species that hibernated at the egg stage could be sampled in May, the entire odonate larval community in the established habitat was comparable with that in the original habitat. The difficulty of collecting larvae due to their small body size might also affect the data for the November samplings. Thus, we used the sampling data in November for the analysis of larval distribution especially for the species that hibernated at the larval stage.

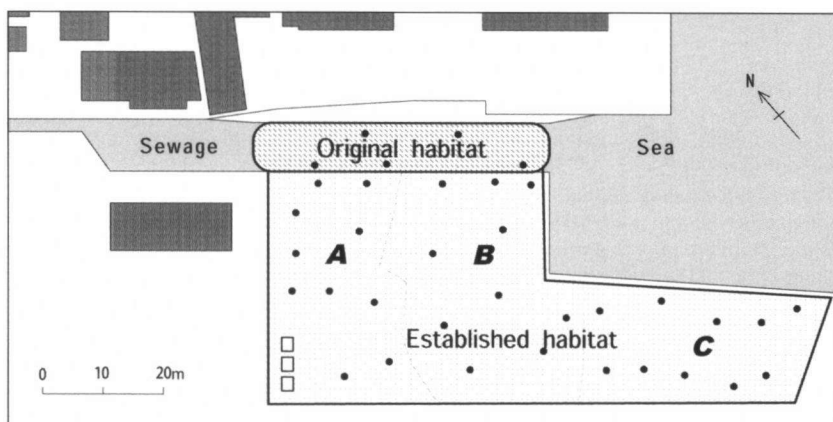


Fig. 1. Map of the study area including the original habitat and the artificial established habitat. Each dot shows a quadrat for sampling Odonata larvae. Three open squares indicate the infalls that supply brackish water to the established habitat. A, B and C show the western, middle and eastern side of the established habitat, respectively. Stippled rectangles indicate residences.

RESULTS

In the original habitat, only *M. hirosei* larvae were found in the spring sampling for 3 years (Fig. 2). In the established habitat, in contrast, *I. senegalensis* was the most abundant species for each subarea in 2004. In subarea A, the proportion of *M. hirosei* population in the larval community was less than 10%, indicating a few *M. hirosei* adults entered and laid eggs from the original habitat in 2003. In 2005, the number of *M. hirosei* larvae drastically increased and then *M. hirosei* represented the most abundant species. In 2006, only *M. hirosei* larvae were collected in subarea A, indicating that the species composition became the same as in the original habitat. In subarea B, although the number of *M. hirosei* larvae occupied 40% of the larval community in 2004, *I. senegalensis* was the most abundant species. Then the number of *M. hirosei* larvae increased, and became the most abundant species in 2005, while small *I. senegalensis* population remained. The species composition of the larval community in 2006 was similar to that in 2005, with the coexistence of both *I. senegalensis* and *Sympetrum* spp. Only one *M. hirosei* larva was collected in subarea C in 2004, indicating that less *M. hirosei* females entered to this subarea for oviposition compared to the other subareas. Consequently, the species composition in 2004 was mainly dominated by *I. senegalensis* and *I. asiatica* despite that *I. asiatica* prefer to fresh water environment. In 2005, the population of *M. hirosei* larvae increased to 60% in the larval community, which was the lowest among the subareas. In 2006, the number of *M. hirosei* larvae increased and occupied 90% of the larval community, although several larvae of *Sympetrum* spp. were collected.

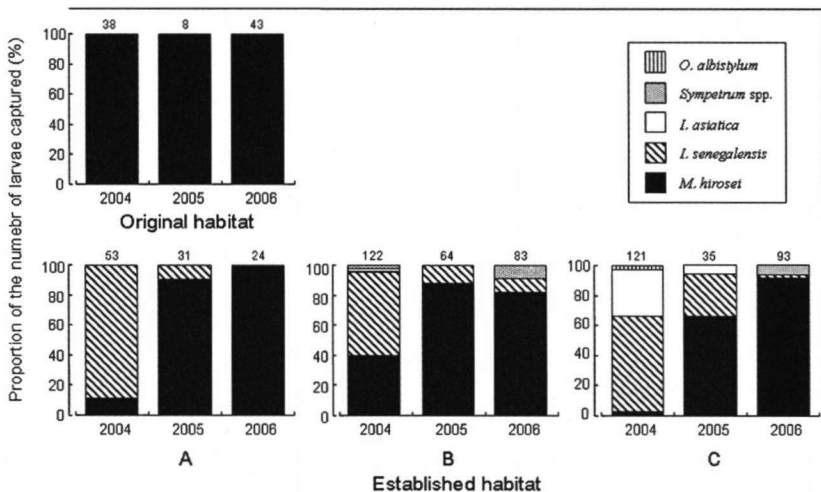


Fig. 2. Yearly changes in species composition of Odonata larvae in the spring community in the established habitat and the original habitat. The numerals indicate the mean number of larvae collected.

The diversity index (Shannon-Weaver H') of each subarea and the original habitat were calculated. Because a single species of *M. hirosei* was found during 3 years in the original habitat, the index in each year was 0. The diversity index in subarea A was 0.51 and 0.46 in 2004 and 2005, respectively, and decreased to 0 in 2006. On the other hand, the indices of B and C in 2004 were around 1 and fluctuated during 3 years.

Because *M. hirosei* is a univoltine species, the larvae in early May belong to the same generation as those in the last November. In the original habitat, the mean density of larvae collected at each quadrat was 0.6 in November 2004 and 1.6 in May 2005 (Tab. I). Such discrepancy was also found between November 2005 (2.0) and May 2006 (8.6). The mean density of larvae sampled at subareas B and C was significantly lower than that in the original habitat in November 2003. The autumn sampling in 2003 might indicate that female dispersal in the established habitat from the original habitat in the first year was still restricted. The similar distribution found in the autumn sampling in subareas A and C in May 2004 suggested that the distribution of *M. hirosei* was still partial in the established habitat. After 2004, there were no significant differences in the mean density of *M. hirosei* larvae collected between the original and established habitats except for subarea A in May 2006, suggesting that the larvae had inhabited with almost the same density.

The mean density of *I. senegalensis* larvae decreased with year (Tab. II). In the original habitat, *I. senegalensis* was not collected except for November 2004, probably as a consequence of partial mowing. In the established habitat, the mean density of the larvae was significantly larger than in the original habitat until November 2004. However, these differences disappeared after May 2005, while a

Table I

The number of *M. hirosei* larvae sampled per quadrat in the established habitat compared with that in the original habitat (\pm S.E.). A, B and C mean the western, middle, and eastern side of the established habitat, respectively

Sampling date	Original habitat	Established habitat		
		A	B	C
2003 November	1.3 \pm 0.4 (4)	0.2 \pm 0.2 (4)	0.2 \pm 0.2* (8)	0.0 \pm 0.0* (4)
2004 May	6.0 \pm 0.8 (5)	0.6 \pm 0.5**(10)	4.8 \pm 3.0 (10)	0.1 \pm 0.1**(10)
November	0.6 \pm 0.4 (5)	1.4 \pm 0.6 (10)	1.5 \pm 1.1 (10)	0.5 \pm 0.3 (10)
2005 May	1.6 \pm 0.5 (5)	2.8 \pm 1.4 (10)	5.6 \pm 3.4 (10)	2.3 \pm 0.9 (10)
November	2.0 \pm 0.7 (5)	4.3 \pm 1.7 (10)	7.7 \pm 3.4 (10)	7.0 \pm 3.0 (10)
2006 May	8.6 \pm 0.8 (5)	3.5 \pm 1.0**(10)	5.7 \pm 2.8 (10)	8.5 \pm 0.8 (10)

(): Number of quadrats sampled

* and ** show the number of larvae that was different from that in the original habitat with the probability of less than 0.05 and 0.01, respectively, using the Mann-Whitney U-test.

small number of *I. senegalensis* larvae were collected in the established habitat.

Changes in the distribution of both *M. hirosei* and *I. senegalensis* larvae in the established 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 unity or more than 1, it means random or aggregated distribution, respectively.

As shown in Figure 3, m^*/m for *M. hirosei* in May 2004 was high, indicating intensive concentrated distribution, while m^*/m for *I. senegalensis* was 1.81, which might indicate a random distribution. In fact, *M. hirosei* had been found in only a few quadrates and *I. senegalensis* had distributed widely in the established habitat. Afterward, *M. hirosei* female might disperse and oviposit around the entire area of the established habitat, resulting in low m^*/m of the larvae, while that of *I. senegalensis* larvae had been increasing. In May 2006, the m^*/m for *M. hirosei* and *I. senegalensis* was 2.0 and 6.6, respectively. It was revealed that the distribution of *M. hirosei* had become random, while *I. senegalensis*, in contrast, showed intensive concentrated distribution. In particular, m^*/m of *M. hirosei* sharply decreased from May to November of 2004. Because m^*/m in November reflected the oviposition area by the females, the females in the summer of 2004 must have dispersed and oviposited over the entire area of the established habitat.

As shown in Figure 4, there was a negative relationship between the number of *M. hirosei* and *I. senegalensis* larvae in subarea A (Spearman ρ -test, $p = 0.007$). Similar tendencies were observed in subareas B and C, though there were no significant correlations. The distribution and population size of *I. senegalensis* in the established habitat might affect those of *M. hirosei*.

Table II

The number of *I. senegalensis* larvae sampled per quadrate in the established habitat compared with that in the original habitat (\pm S.E.). A, B and C mean the western, middle, and eastern side of the established habitat, respectively

Sampling date	Original habitat	Established habitat		
		A	B	C
2003 November	0.0 \pm 0.0 (4)	9.2 \pm 5.6* (4)	11.3 \pm 4.0* (8)	0.3 \pm 1.1* (4)
2004 May	0.0 \pm 0.0 (5)	4.7 \pm 2.4* (10)	7.0 \pm 2.2* (10)	7.9 \pm 1.6* (10)
November	0.2 \pm 0.2 (5)	0.8 \pm 0.4 (10)	4.8 \pm 1.7* (10)	2.0 \pm 0.8 (10)
2005 May	0.0 \pm 0.0 (5)	0.3 \pm 0.3 (10)	0.1 \pm 0.1 (10)	0.3 \pm 0.2 (10)
November	0.0 \pm 0.0 (5)	0.0 \pm 0.0 (10)	1.1 \pm 0.7 (10)	0.6 \pm 0.3 (10)
2006 May	0.0 \pm 0.0 (5)	0.2 \pm 0.2 (10)	0.6 \pm 0.5 (10)	0.2 \pm 0.1 (10)

(): Number of quadrates sampled

* shows the number of larvae that was different from that in the original habitat with the probability of less than 0.05, using the Mann-Whitney U-test.

DISCUSSION

The original habitat of *M. hirosei* is a brackish water environment seldom inhabited by odonate species except for a few species that are saline tolerant. In addition, dense reed shoots in the original habitat prevent odonate adults from entering the reed community (MATSU'URA & WATANABE, 2004). Consequently, the odonate larval community was simple, as it was dominated by *M. hirosei*. In order to conserve this species in an artificially established reed community, therefore, the diversity of the larval community must be kept as low as possible, and a single species would be ideal.

Because odonate larvae are generalists from the viewpoint of their foraging behavior, in which they feed on conspecific and heterospecific larvae as their prey, intra-guild predation might severely affect the respective larval population dynamics and then the larval community. When several odonate species coexist together, large larvae will generally kill and eat small larvae (WISSINGER, 1987; JOHANSON, 1992; ANHOLT, 1994). BAKER (1986) reported that when *Enallagma ebrium* and *I. verticalis* coexist, small-sized larvae in both species are fed by large-sized larvae irrespective of the species. WISSINGER (1988) also stated that in a fishless pond, the mortality of each odonate species in the larval community is more influenced by intra-guild predation than by other factors, such as food limitation or hibernation. In the present study, the mean depth of the brackish water in the established habitat was about 5 cm, though several patchy areas dried up, then the habitat

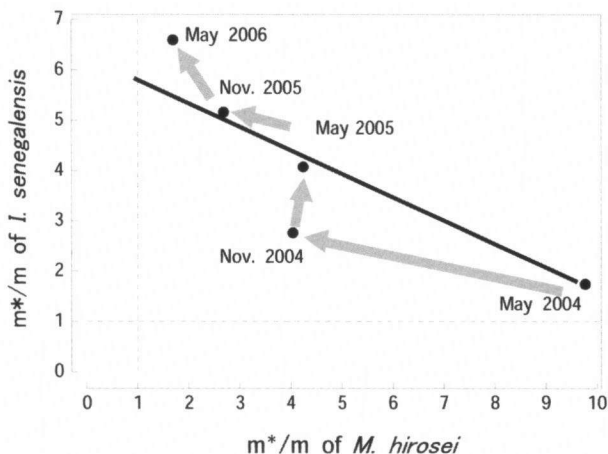


Fig. 3. Correlation of m^*/m values between *M. hirosei* and *I. senegalensis*. A solid line represents the regression which is significantly positive (Spearman ρ -test $\rho = -0.900$, $p = 0.037$). Each broken line shows the Poisson line for *M. hirosei* and *I. senegalensis*, respectively.

seemed to be unsuitable for fishes that affect larval mortality. Therefore, in order to maintain the population of *M. hirosei*, it is necessary to prevent the predation not only by fish but also by other odonates.

Odonate larvae generally adapt to interspecific competition in a community and avoid disturbance by their predators when coexisting (McPEEK, 1990; LIMA & DILL, 1990; PADEFFKE & SUH-

LING, 2003). *Sympetrum fonscombii* larvae reduce their locomotory activity in the presence of larger larvae of *Orthetrum cancellatum* (SUHLING & LEPKOJUS, 2001). JOHANSON (1993) showed a similar result for *Coenagrion hastulatum*, which performs the behavior of rotating and freezing rather than swimming when their predator advances towards them. In contrast, when *Enallagma* larvae inhabit lakes with anisopteran predators, they show behavioral adaptations for increased swimming activity in order to avoid predation (McPEEK & SCHROT, 1996). However, *M. hirosei* seemingly has not developed anti-predator activity during their life history because the larvae appeared not to experience any coexistence with odonate larvae.

Although the species composition and species richness in the established habitat became similar to the original habitat as a whole, some differences remained among the subareas. The western area of the established habitat with a higher saline concentration due to the infalls and the highest reed shoot density among the subareas appeared to be a suitable environment for *M. hirosei* adults (MORIMOTO et al., 2006). The odonate larvae except *M. hirosei* disappeared from subarea A in 2006. On the other hand, subareas B and C allowed a few species without high saline tolerance to survive, due to the low saline concentration during 4 years. Because both subareas were located far from the infalls, the saline concentration was easily affected by rainfall and decreased.

While the exclusion of the odonate larvae except for *M. hirosei* from the established habitat was incomplete for 4 years after the artificial reed community was set up, *M. hirosei* had expanded its distribution all over the area and increased in population, and was dominant in the odonate community. In 2006, a few species remained in the established habitat but seemed to have a little effect on the *M. hirosei* population. The original habitat included no odonate larvae except for *M. hirosei*. This result was consistent with other reports pertaining to the habitats of

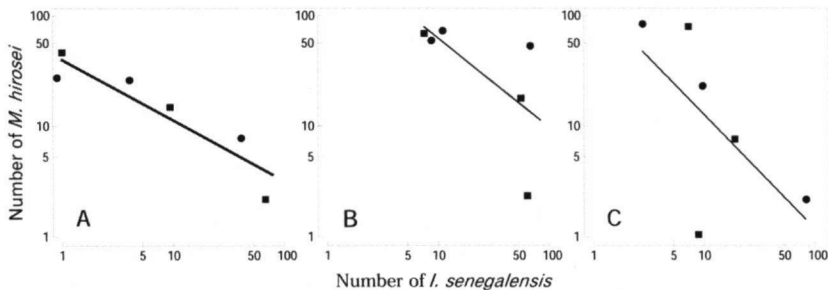


Fig. 4. Relationship between the number of *M. hirosei* and *I. senegalensis* in each sampling time for the established habitat (A-C). Circles and squares show the spring and autumn communities, respectively. Solid lines for A represent the regression with a probability less than 0.001 ($\rho = -0.899$) by the Spearman ρ -test. ρ for B and C are -0.687 ($\rho = 0.087$) and -0.657 ($\rho = 0.078$), respectively.

M. hirosei showing that only *M. hirosei* larvae are collected from the reed community bed (HIROSE & KOSUGE, 1979; HARA, 1997; NISHU, 1997). From the viewpoint of the long-term population maintenance of *M. hirosei* in the established habitat, the absolute exclusion of other species, as in the original habitat, might be necessary.

A negative relationship between the number of *M. hirosei* and *I. senegalensis* was found, probably due to the prey-predator relationship or competitive relationship between them. In the established habitat where *I. senegalensis* occupied a large proportion of the larval community, a prey-predator relationship as well as an intra-guild predation should have occurred frequently and affected the decrease of numbers of *M. hirosei*. Even though *I. senegalensis* has a similar extent of saline tolerance to *M. hirosei* (IWATA & WATANABE, 2004), the distribution of both species was negatively correlated. Because *I. senegalensis* adults generally inhabit in an open environment, an increase of reed shoot density in the established habitat makes the adults difficult to enter the dense reed community. They are speedy fliers and cover a long distance per single flight (NISHU, 1997), thus the adult distribution was restricted to relatively open areas with low reed shoot density remaining patchily in the established habitat. Consequently, the larvae of *I. senegaensis* showed high patchy distribution, especially in 2006.

In conclusion, it is clear that artificially maintaining a dense reed community and keeping a brackish water environment resulted in an increase in the *M. hirosei* population. This population became the most abundant species in the larval community of the established habitat by excluding other odonate species. Low species richness at the established habitat should be suitable for the particular species that can adapt to a severe abiotic environment.

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