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Short and flat grass preferred by adults of the endangered dragonfly *Sympetrum pedemontanum elatum* (Odonata: Libellulidae)

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Abstract

Sympetrum pedemontanum (Müller in Allioni) (Odonata: Libellulidae) is widely distributed across the Eurasian continent and its neighboring islands. However, the populations of its subspecies *S. pedemontanum elatum* (Selys) in Japan have been rapidly decreasing with the loss of habitats in rural and suburban areas since the 1970s. For the conservation of this subspecies, which is now listed as endangered in many prefectures, it is important to understand the habitat preferences of the adults. Previous studies indicate that adult males of this species tend to fly on the flat surface of rice paddy fields. Thus, we hypothesized that they preferred short and flat grass. Field experiments in the Sakasegawa River, Hyogo Prefecture, Japan, showed that adult *S. p. elatum* significantly preferred the trimmed grass of *Phragmites japonica* to untreated shaggy grass, regardless of sex. Our results indicate the importance of grass management for the conservation of this species, not only in and around paddy fields but also in fluvial habitats, which are abundant in Japan.

Key Words: Conservation, Semi-natural grassland, Rice paddy field, *Phragmites japonica*, Satoyama

Introduction

Semi-natural grasslands, which are abundant in agricultural landscapes, play an important role in maintaining insect diversity (Green 1990; Katoh et al. 2009; Kiehl et al. 2010; Őckinger and Smith 2007; Tscharntke and Greiler 1995); however, they are rapidly decreasing, which endangers some insect species especially in Europe (Bourn and Thomas 2002; Lindborg et al. 2008; Morris 2000; Thomas 1995) and Japan (Katoh et al. 2009; Uematsu et al. 2010). Various types of grass treatment, such as grazing, cutting, and burning, are often crucial for the conservation of endangered or critical species of Lepidoptera (Bourn and Thomas 1993; Pöyry et al. 2006; Thomas 1984), Orthoptera (Gardiner et al. 2002; Gröning et al. 2007), and Coleoptera (Niemelä and Baur 1998) in terrestrial grasslands. However, there have been only a few studies focusing on the effects of grass treatment on the behavior and abundance of Odonata in riparian habitats (e.g., Ueda et al. 2004), although many extensive studies are available on the conservation of dragonflies and damselflies (e.g., Corbet 1999; Fox and Cham 1994; New 1995; Samways 1994; Samways and Steytler 1996; Tichanek and Tropek 2015).

Adults of *Sympetrum pedemontanum* (Müller in Allioni), an attractive darter widely distributed across the Eurasian continent and its neighboring islands, often inhabit semi-natural grasslands and rice paddy fields in rural agricultural landscapes (Higashikawa et al. 2016; Lockwood 2007; Taguchi and Watanabe 1985). Although it is categorized as a Least Concern (LC) species in the IUCN Red List, this species is now threatened in some European countries and Japan (Higashikawa et al. 2016; IUCN 2015).

Notably, the subspecies *S. p. elatum* (Selys) is exposed to an even higher extinction risk, especially in Japan (Higashikawa et al. 2016). Until the 1970s, this subspecies was one of the most common dragonflies, along with some other *Sympetrum* species, found in the traditional agricultural landscapes called ‘‘satoyama’’ in Japan (Aoki 2013; Ishida et al. 1988; Kadoya et al. 2009). However, it has been rapidly decreasing in population in both rural and suburban areas and is now listed as Extinct (EX) in Chiba Prefecture, Critically Endangered (CR) in Nagasaki Prefecture, Vulnerable (VU) in Tokyo Metropolis, and Near Threatened (NT) in other eight prefectures (Association of Wildlife Research and EnVision 2013). Loss of larval habitat is likely one of the most critical factors in its recent decline in Japan (Higashikawa et al. 2016), but little is known about the importance of adult habitat use for the conservation of this species.

Larvae of *S. p. elatum* are typically found in either weakly flowing or shallow and stagnant water, especially in sunny, seepage-fed, terraced paddy fields, or slowly running ditches and channels in open fields in hilly areas (Aoki 1998, 2013;

Higashikawa et al. 2016; Ishida et al. 1988; IUCN 2015; Kawachino 2015; Kondo et al. 2005; Maeto et al. 2003; Muraki 2010; Yagi et al. 2006). Adults usually emerge in early summer (most in early July), and weakly fly or perch on short grass near the water from which they emerged, until they mature in mid-summer (late July to August) in Honshu (Aoki 1998, 2013; Higashikawa et al. 2016; Ishida et al. 1988; Ozono et al. 2013). Such habitat preference of the adult *S. p. elatum* at the immature stage is different from that of many other *Sympetrum* species in Japan (e.g., *S. frequens, S. striolatum, S. eroticum, S. risi, S. infuscatum*), which migrate as young adults into forest areas or to the forest edge (Aoki 1998, 2013; Ishida et al. 1988; Ozono et al. 2013).

In the mature stage, the adult males and females of *S. p. elatum* form tandem pairs on the grass (Fig. 1c). According to Taguchi and Watanabe (1985), males search for females to make tandem pairs in a low-flight across rice paddy fields, which have short and flat grass. After copulation, the tandem pairs or independent females lay eggs at the edge of the water, dipping their abdomen into the sediment with the males performing guarding flights. The eggs tend to be laid in shallow, stagnant, or slightly flowing water (Aoki 2013; Higashikawa et al. 2016). The adults typically disappear by the end of November (Ishida et al. 1988; Yagi et al. 2006).

Apart from rice paddy fields, adults of *S. p. elatum* are often distributed along weakly flowing streams that have managed grass on the riverbeds (Yagi et al. 2006), which tends to be also ‘‘short and flat’’ in adult period of the dragonfly. However, the preference of this habitat for adult *S. p. elatum* is largely unknown.

Inspired by observations of the frequent searching flights of males across rice paddy fields (Taguchi and Watanabe 1985), we hypothesize that *S. p. elatum* adults prefer short and flat grass. To test this hypothesis, we carried out two field experiments involving grass trimming. We first compared the abundance of adults among non-trimmed, trimmed, and totally cut grass in small plots in 2015. Then, in 2016, we also verified how experimental grass trimming on a larger scale would increase the abundance and reproductive behavior of *S. p. elatum* adults. All of the experiments were conducted along a lowland, mild-slope river in Japan.

Materials and methods

Study site

The field experiments were made at the Sakasegawa River, Takarazuka City, Hyogo Prefecture, Japan (34°79´ N 135°34´ E; at 60–90 m above sea level; average slope 3.7%) (Fig. 1a, b). The population of *S. p. elatum* at this river has been abundant and stable (more than 18,000 individuals) in recent years (Adachi et al. 2007; Fujii et al.

2008; Yagi 2005; Yagi et al. 2006), so we used this as an example of prime habitat. Almost all tall grass on this river is *Phragmites japonica* Steud. (Poaceae). Although the grass is cut every year in late spring to beautify the river, it grows thick and the surface is rather shaggy by early September (Fig. 1b).

Comparison of number of *S. p. elatum* adults among three different grass treatments in 2015

Design and treatments

In September 2015, we compared the abundance of adult *S. p. elatum* among small grass quadrats (ca. 6 m^2) of non-trimmed (N), trimmed (T), and grass cut at ground level (C) (Fig. 2b). We established four experimental sections along the river (34°79´5059 N 135°34´6486 E, 34°79´3679 N 135°34´5045 E, 34°79´3014 N 135°34´4507 E, 34°79´1422 N 135°34´3273 E, spaced 60 m or more apart) (Fig. 1a). Within each section, three rectangular plots (2 m × 3 m) of different treatment conditions were set: (N) non-trimmed (grass height was variable (0.6 m–2.0 m) so that the surface was shaggy), (T) trimmed (grass was cut at about 0.6 m tall and flat), and (C) cut at ground level (grass was cut very short and the riverbed was exposed) (Fig. 2b). None of the plots included any water areas (0.5 m from nearby streams), and the plots were placed in random order and spaced 8 m or more apart (Fig. 2a). Grass cutting was conducted on September 5, 2015.

Counting the number of adults

The number of adult dragonflies was counted on five sunny days from September 18 to 23. Counting was conducted in the morning (10 AM–11 AM) and afternoon (1 PM–2 PM). In each period, the number of adults (those perching and flying were not discriminated) in the three plots in each section was simultaneously counted for 15 min. The number of adults was statistically compared between N and T plots.

Comparison in the number of perching and flying adults or tandem pairs of *S. p. elatum* between two different grass treatments in 2016

Design and treatments

In September 2016, we compared the number of adults and tandem pairs in large and circular plots (ca. 25π m^2) between non-trimmed (N) and trimmed (T) plots of grass after the T plots were trimmed. We established four experimental sections along the river (34°79´5578 N 135°34´6844 E, 34°79´3679 N 135°34´5045 E, 34°79´1773 N 135°34´3699 E, 34°79´1422 N 135°34´3273 E, spaced 60 m or more apart) (Fig. 1a). Within each section, two circular plots of 5 m diameter were set, each spaced 25 m or more apart, including a shallow stream with some stagnation (Fig. 3a). We profiled the surface structure of grass by measuring grass height at 1 m intervals along three directions from the center to the periphery of each plot just before trimming (Fig. S1). In a plot of each section, grass was thick and shaggy (N of Fig. 3b). In another plot, grass was trimmed at about 0.6 m height and flat on September 10, 2016 (T of Fig. 3b).

Counting the number of adults and tandem pairs

The number of adult dragonflies (perching or flying) and tandem pairs (ovipositing or not) in each plot was counted using binocular glasses (Kepler 8 × 20, field 6.5°) from the riverside levee, for 5 min in the morning and afternoon (the same as in 2015) on five sunny days both before (August 31 to September 9) and after trimming (September 12 to 19). The statistical comparison between N and T plots was conducted, respectively, for the number of perching adults, flying adults, and tandem pairs after grass trimming.

Statistical analysis

Statistical analyses were conducted using generalized linear mixed models (GLMMs) in IBM SPSS Statistics (version 22). Because no individuals perched on the C plots during study period in 2015, these data were not included in the analysis. The dependent variable for the experiment in 2015 was the number of adults in each plot on each day, while those for the experiment in 2016 were the number of perching adults, flying adults, and tandem pairs in each plot on each day, all of which were modeled using a Poisson distribution with a log-link function. For each dependent variable, a model was selected on the basis of Akaike information criterion (AIC) (Table S2). The fixed variables selected were treatments (N vs. T), sex, time zones (morning and afternoon), and first- and second-order interactions among them for the number of adults in the experiment in 2015; treatments, sex, time zones for the number of perching and flying adults in the experiment in 2016; treatments, time zones, and an interaction between them for the number of all tandem pairs in the experiment in 2016; and treatments for the number of ovipositing tandem pairs in the experiment in 2016. In the same manner, the random variables selected were sections and dates for the number of adults in 2015 and for the number of flying adults and tandem pairs in 2016; and sections, dates, and the total number of adults in each plot before trimming for the number of perching adults in 2016. To confirm the significance of interactions between fixed variables, the full model was also run for each dependent variable.

Results

The raw data are shown in Table S1. Males were more abundant than females in total counts (males to females ratios were 74:33 in 2015 and 376:276 in 2016). Fourteen tandem pairs including ten of those ovipositing were observed in 2016. There was no significant interaction among fixed variables during either experiment (Table 1, 2, 3).

Grass trimming in 2015 significantly affected the number of male and female adults (Table 1), which were more abundant in T than in N (Fig. 4). Sex was also significantly related to the abundance of adults in 2015, reflecting the skewed ratio of males to females. As mentioned previously, no individuals were observed in the C plots.

Grass trimming in 2016 also significantly affected the number of perching and flying adults (Table 2), which were more abundant in T than in N (Fig. 5a). The effect of sex was again significant as in 2015 (Table 2 and Fig. 5c). Moreover, the effect of time zone was also significant (Table 2), although the direction was different between perching and flying adults, whereby perching adults were more abundant in the afternoon, while flying adults were more abundant in the morning (Fig. 5b).

The numbers of tandem pairs, total and those ovipositing, were not significantly different between N and T (Table 3), although they did tended to be larger in T than in N in the morning (Fig. 6).

Discussion

The results of our experiments in 2015 and 2016 show that adult *S. p. elatum* clearly prefer short and flat grass to tall and shaggy grass, which supports our hypothesis. The active flight of adults on short and flat surface of grass in the morning in the experiment in 2016 concurs with the observation by Taguchi and Watanabe (1985), which linked this observation with increased reproductive opportunity. However, the contribution of grass trimming for their reproductive behavior could not be statistically confirmed in the present study, probably because the number of tandem pairs observed during the experimental period was too small.

In our experiments, the effects of two different factors (i.e., flatness and shortness of the trimmed grass) could not be separated. However, we consider that they may both affect the gathering behavior of *S. p. elatum* adults on trimmed grass, either additively or synergistically. Grass flatness can improve visibility (Taguchi and Watanabe 1985), which is important for dragonfly adults relying on the visual sense in both predation (e.g., Corbet 1999; Miller 1995) and reproduction (e.g., Corbet 1999; Takahashi and Watanabe 2009, 2010; Watanabe 2015). It can also contribute to a sewing-like motion in male flights over the grass in their search for females (Taguchi and Watanabe 1985). In addition, the shortness of the grass may facilitate the recognition of water surfaces by tandem pairs or females for oviposition.

Generally, most Libellulidae adults in Japan perch on grass around water (Aoki 1998, 2013; Ishida et al. 1988; Kondo et al. 2005; Ozono et al. 2013). The grass plays important roles for them, acting as a scaffold for safe emergence (Corbet 1999; Ishida et al. 1988), resting (Corbet 1999), foraging (Ozono et al. 2013), courtship behavior of males (Ueda et al. 2004), and safe oviposition (Rehfeldt 1992). It is possible, that making the grass short and flat may further intensify the foraging or reproductive capabilities of *S. p. elatum* adults.

Conversely, in the field experiment in 2015, no *S. p. elatum* adults were present in the C plots, indicating that they rarely use bare field. Because *S. p. elatum* adults are weak fliers and spend most of their lives on grass near the water from where they emerged (Aoki 1998, 2013; Higashikawa et al. 2016; Ishida et al. 1988; Kondo et al. 2005; Ozono et al. 2013; Taguchi and Watanabe 1985), cutting the grass at the ground level may deprive them of their habitats, or if the amount of cutting is extreme, may eliminate the local population. On the other hand, it is known that bare fields provide reflected heat for dragonfly in thermoregulation (Corbet 1999), but this seems not to be applicable to species that exhibit reproductive behavior in the still-warm temperatures of late summer. Perhaps there are some exceeding risks for *S. p. elatum* to perch on the bare fields, such as being exposed to predators or missing scaffolds for resting, foraging, and reproduction.

Although we focused on mature *S. p. elatum* adults in order to evaluate the importance of grass trimming for their reproductive behavior (Taguchi and Watanabe

1985), short flat grass may also be important for immature adults of this species. Indeed, individuals have been observed to perch or fly on rice grass in paddy fields almost all day regardless of maturation stage (Taguchi and Watanabe 1985). Additional studies are necessary in order to confirm this theory.

Notably, the present study is not the first to investigate dragonfly for a particular grass environment. It is well known that males of the endangered Japanese dragonfly *Nannophya pygmaea* (Odonata: Libellulidae) often use short grass for perching in their territorial mating behavior (Ueda et al. 2004). This previous study supports our theory that grass structure may critically affect inhabitance or reproduction in various dragonfly species. In fact, these data suggest that management of the “short and flat” grass structure, which is abundant in rice paddy fields in Japan, may be essential for the inhabitance and conservation of *S. p. elatum* in fluvial habitats. Before dams and levees were built, such natural uniform grasslands extended broadly in floodplains along rivers in Japan, where the succession of annual or biennial herbaceous grass is regularly reset by flood disturbances (Washitani 2007). *S. p. elatum* may have used such repeatedly renewed grasslands in floodplains, and afterward expanded its habitat to rice paddy fields as people started rice farming.

The short and flat grass structure of rice grass in paddy fields is typically well-maintained in rural farmlands called satoyama, where recent changes in the water management of these fields are most likely the main cause of the decline of *S. p. elatum* and other riparian species (Higashikawa et al. 2016). Therefore, it may be more important for the conservation of this species in the satoyama landscapes to improve the aquatic habitat for larvae than the management of grass structure for the adults.

In contrast, grass around slowly flowing rivers or streams in rural and suburban areas has been abandoned or, if still present, tends to be thick and shaggy due to lack of weeding. Grass trimming in these riparian areas would provide appropriate conditions for use by *S. p. elatum*. Regular cutting of tall grass has also recently been implemented for riverbed and riverbank beautification in some suburban rivers (such as the Sakasegawa River). This may well offer good habitats for *S. p. elatum*. Indeed, almost all river habitats of this species are restricted to such grass-managed suburban rivers at least in Hyogo Prefecture (Yagi et al. 2006). However, the grass must be short and flat for *S. p. elatum* in its adult period, and thus, the intensity and the timing of grass cutting should be properly managed.

In conclusion, we carried out two grass trimming field experiments in order to observe the effects on the abundance of adults among non-trimmed, trimmed, and totally cut grass in small plots in 2015 as well as how grass trimming on a larger scale would increase the abundance and reproductive behavior of *S. p. elatum* adults in 2016. In doing so, we have highlighted a distinct preference for short and flat grass for adult dragonfly of this particular species. Taken together, these data provide a foundation for further study as well as an initial step in the effort to conserve *S. p. elatum*.

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Figures and tables

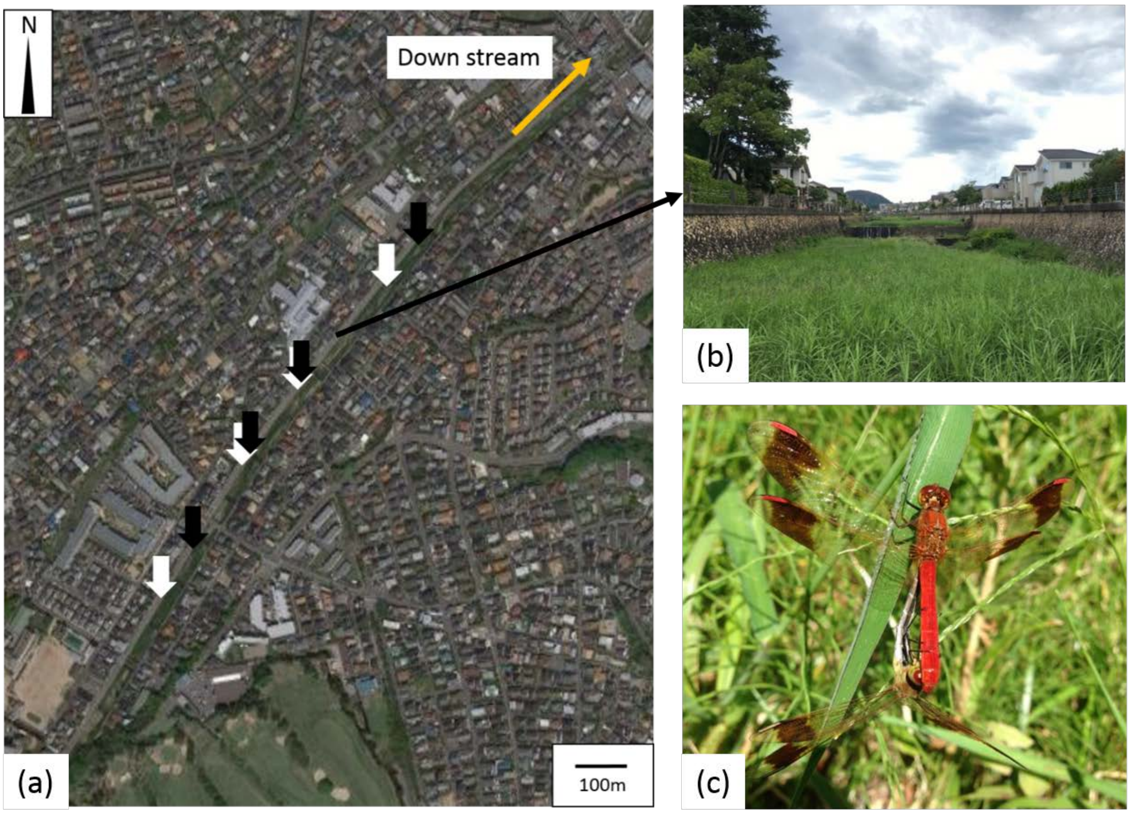


Fig. 1. a Locations of the experimental sections (white arrows 2015, black arrows 2016) along the Sakasegawa River, Takarazuka City, Hyogo Prefecture, Japan. **b** Ground-level view of the habitat of *S. p. elatum* along the river (August 22, 2016). **c** A tandem pair of *S. p. elatum*

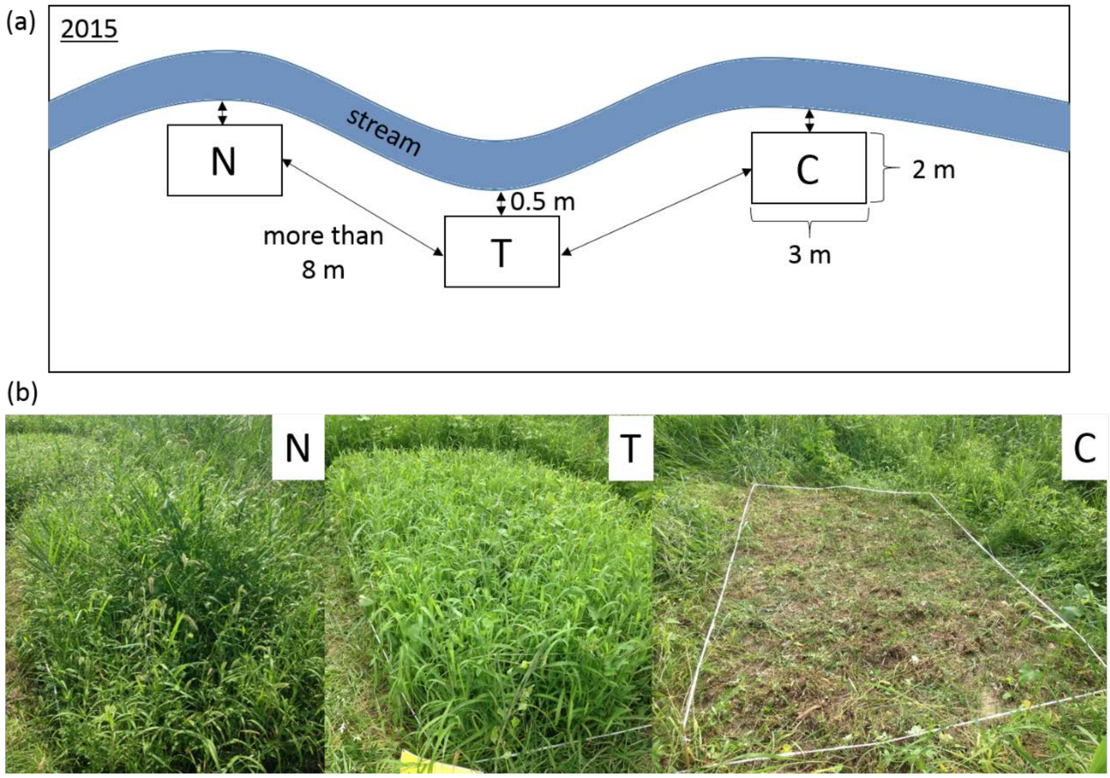


Fig. 2. a Schematic map of an experimental section in 2015. Rectangles indicate plots. **b** Experimental plots of non-trimmed (N) and trimmed (T) grass, and the plot cut at ground level (C)

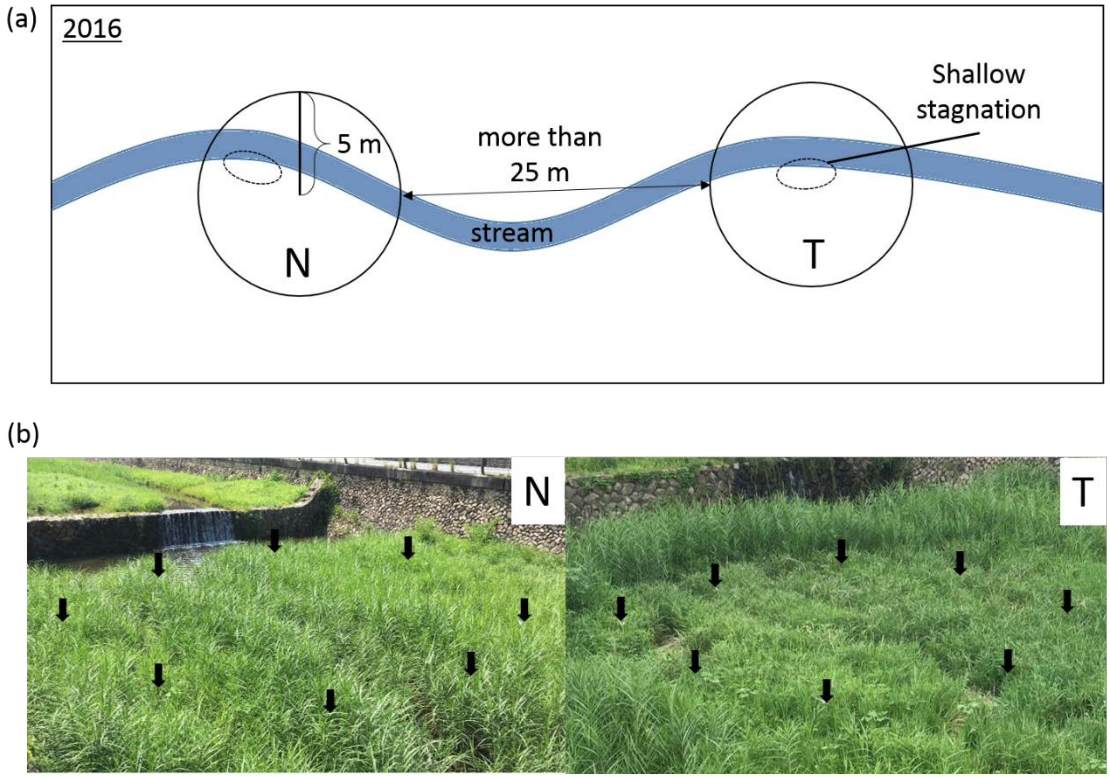


Fig. 3. a Schematic map of an experimental section in 2016. Circles indicate plots. Dotted ovals indicate shallow stagnant water along the stream. **b** Experimental plots of non-trimmed (N) and trimmed (T) grass. The arrows indicate the peripheral marks of each circular plot

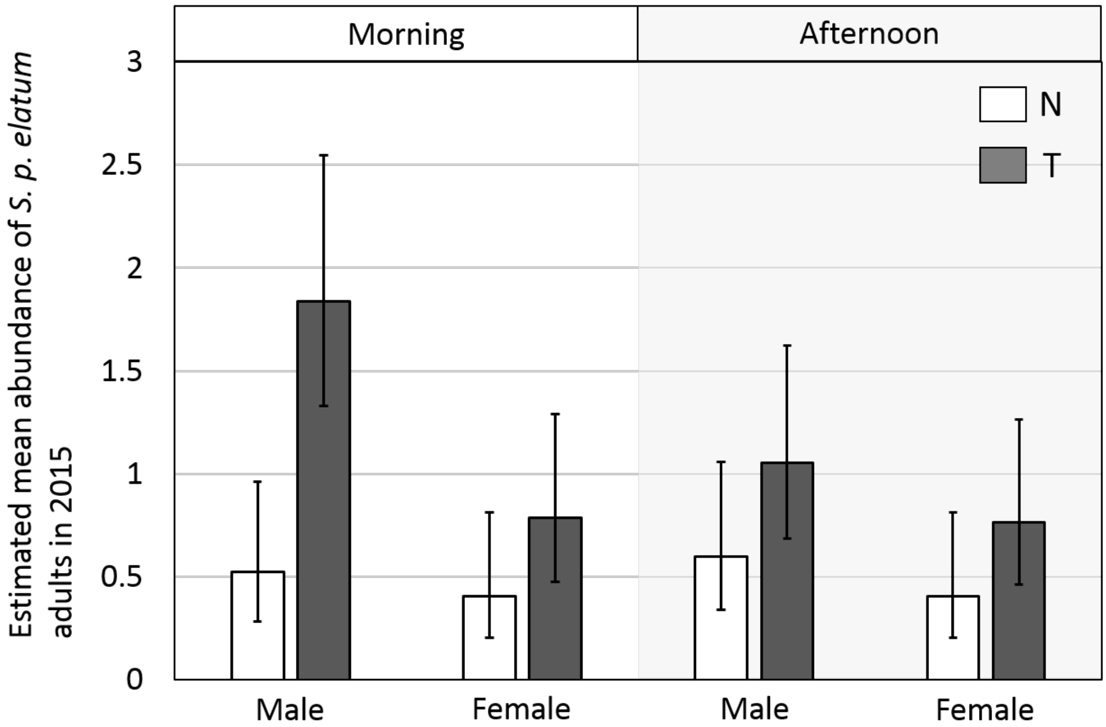
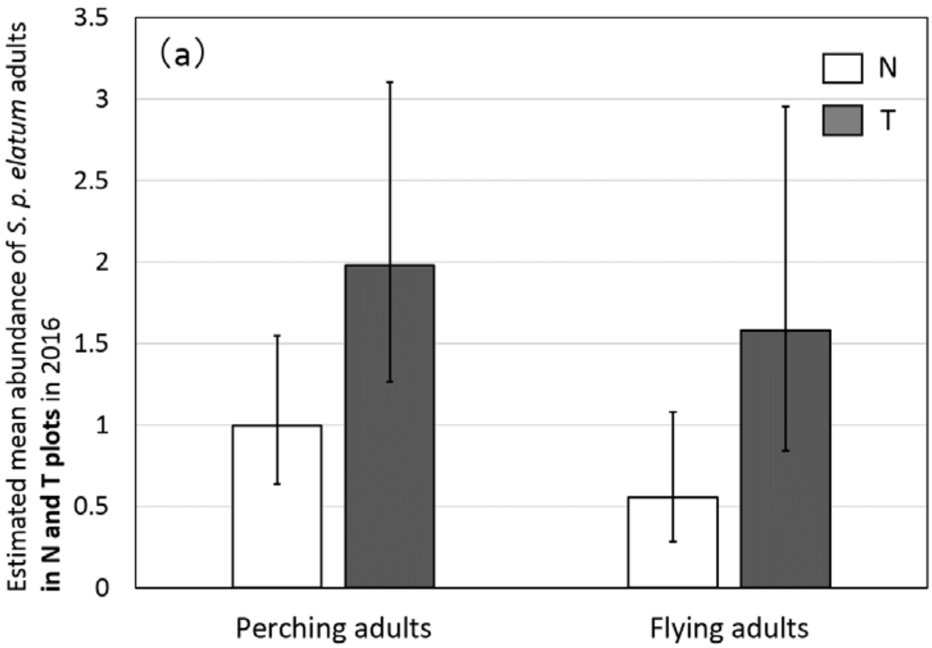
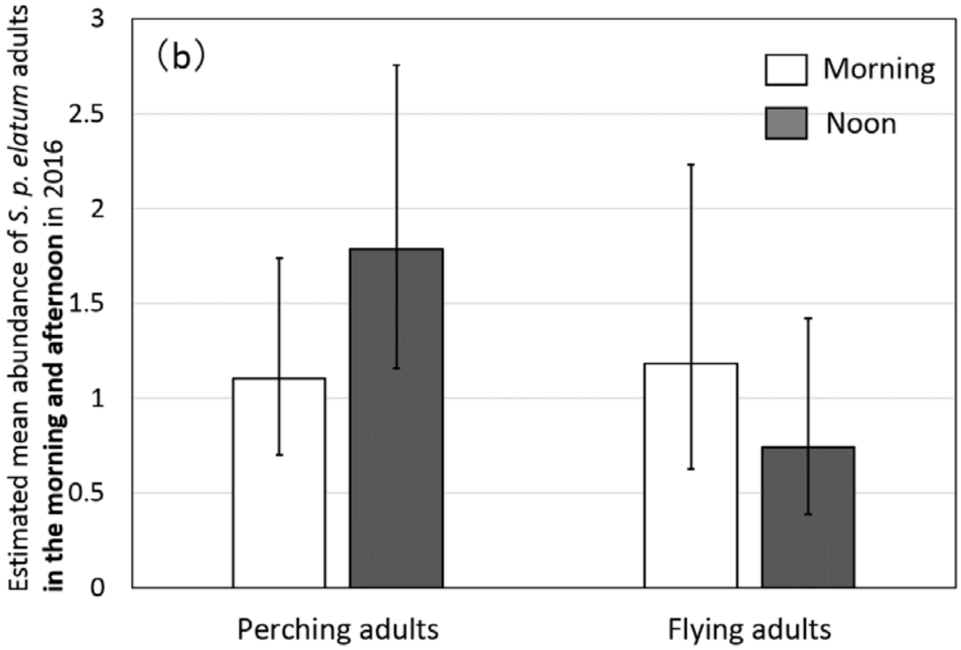


Fig. 4. Estimated mean abundance of *S. p. elatum* adults in 2015. The vertical lines indicate 95% confidence intervals [CIs]





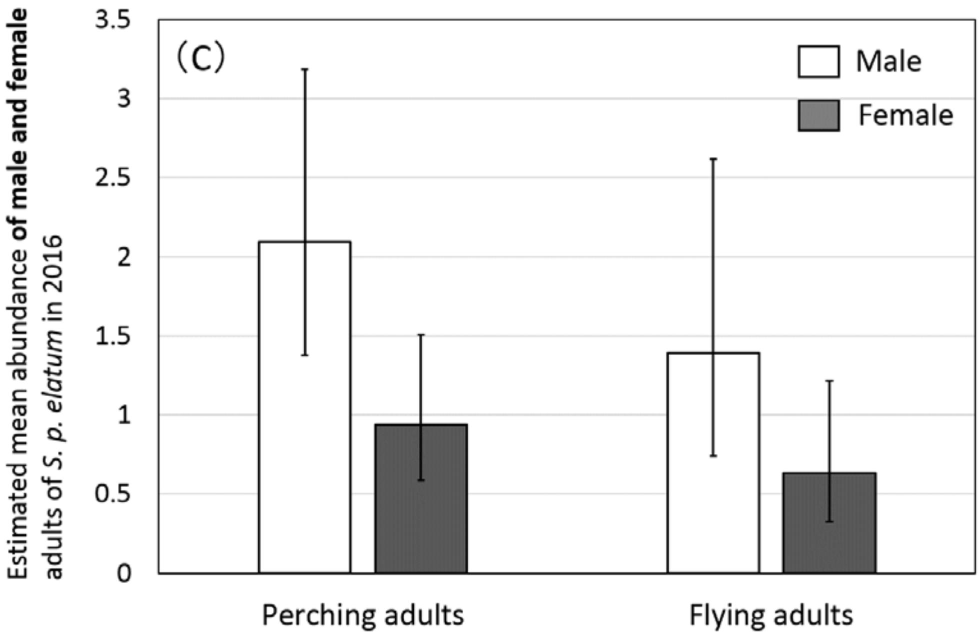


Fig. 5. Estimated mean abundance in perching and flying adults of *S. p. elatum* in N and T plots (**a**), in the morning and afternoon (**b**), and of male and female (**c**) after the time

of trimming in 2016. The vertical lines indicate 95% confidence intervals [CIs]

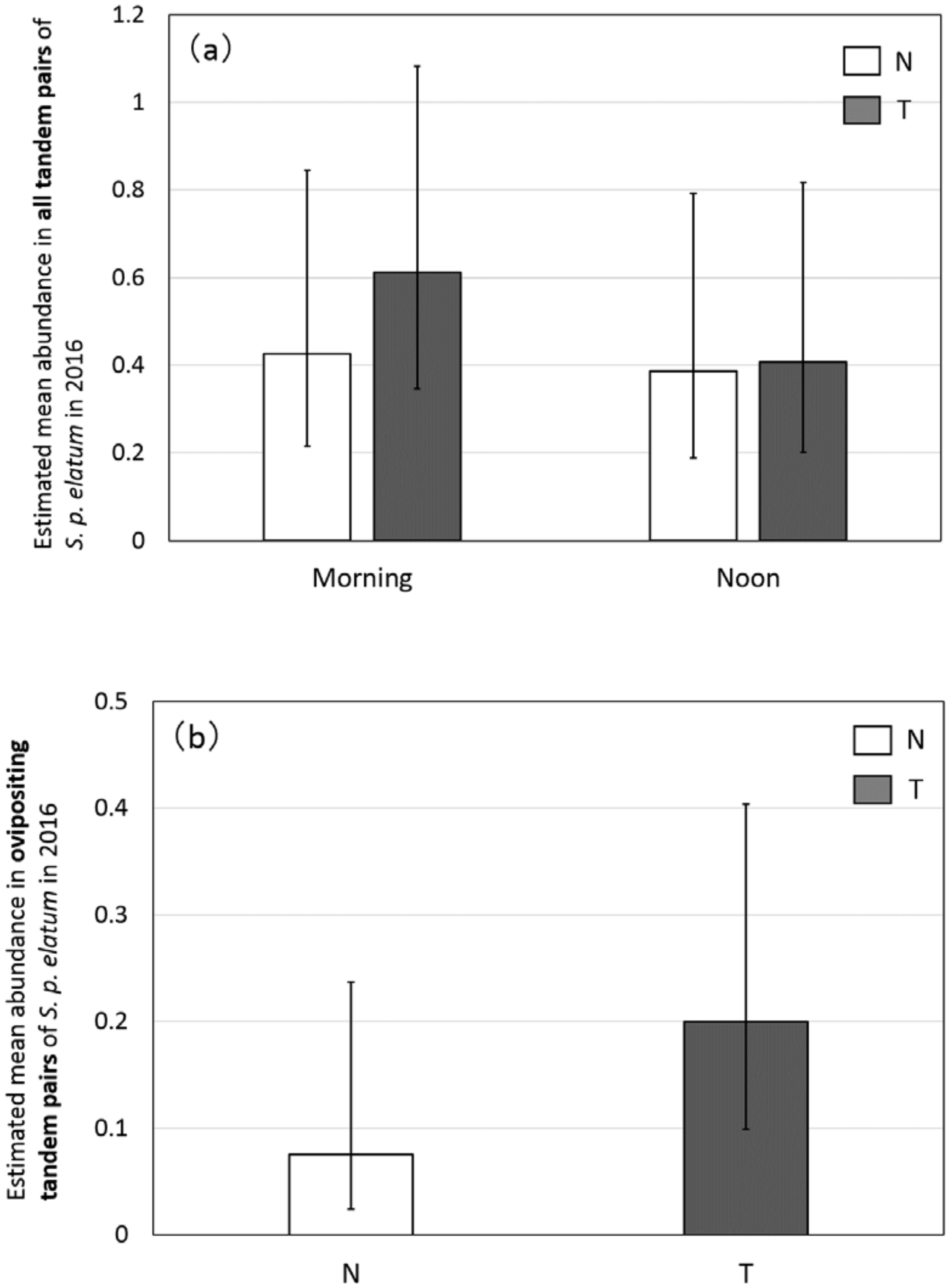


Fig. 6. Estimated mean abundance in **a** all tandem pairs and **b** ovipositing tandem pairs of *S. p. elatum* after the time of trimming in 2016. The vertical lines indicate 95%

confidence intervals [CIs]

Table 1. GLMM of the effects of fixed variables in the best model (AIC = 437.0) on the number of *S. p. elatum* adults in 2015

Fixed variables	$F_{1, 152}$	p
Grass trimming	15.415	<0.001
Time zone	0.315	0.575
Sex	5.227	0.024
Trim × sex	0.459	0.499
Time × Trim	0.827	0.365
Sex × time	0.243	0.623
Trim × sex × time	0.707	0.402

Table 2. GLMM of the effects of fixed variables in the best and the full models on the number of perching and flying adults of *S. p. elatum* in 2016

	Perching adults				Flying adults			
Model	Best		Full		Best		Full	
AIC	321.2		324.4		468.9		476	
Fixed variables	$F_{1, 156}$	p	$F_{1, 156}$	p	$F_{1, 156}$	p	$F_{1, 156}$	p
Grass trimming	34.510	<0.001	27.663	<0.001	45.100	<0.001	39.477	<0.001
Time zone	19.998	<0.001	16.635	<0.001	10.969	0.001	9.029	0.001
Sex	45.123	<0.001	41.100	<0.001	28.968	<0.001	25.199	<0.001
Trim × sex	–	–	0.407	0.524	–	–	2.018	0.157
Time × Trim	–	–	0.663	0.417	–	–	0.574	0.450
Sex × time	–	–	0.138	0.711	–	–	0.262	0.609
Trim × sex × time	–	–	2.418	0.122	–	–	0.001	0.982

Table 3. GLMM of the effects of fixed variables in the best and the full models on the number of all and ovipositing tandem pairs of *S. p. elatum* in 2016

	All tandem pairs		Ovipositing tandem pairs			
Model	Best and full		Best		Full	
AIC	240.4		67.4		69.4	
Fixed variables	$F_{1, 76}$	p	$F_{1, 78}$	p	$F_{1, 76}$	p
Grass trimming	0.372	0.544	2.099	0.151	1.482	0.227
Time zone	0.576	0.450	–	–	0.076	0.784
Time × Trimm	0.213	0.646	–	–	1.482	0.227