



# Reproductive habitat provisioning promotes survival and reproduction of the endangered endemic damselfly *Calopteryx exul*

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## Abstract

Effective habitat management is predicted to have positive effects on populations and species of conservation concern. Although studies have shown that ecological processes such as colonization can be promoted after habitat management, we still need more information on the survival and reproductive consequences at the individual level in order to reach positive conservation outcome. Here we assess the effects of reproductive habitat supplementation (host oviposition plant) on survival and mating success of an endangered endemic damselfly, *Calopteryx exul*, using capture-mark-recapture data. We first determined that the species prefer to oviposit on floating leaves of *Potamogeton* spp. Based on Cormack-Jolly-Seber modeling, we found that recapture and survival probabilities were positively affected by the number of the host oviposition patches of the host plant. Moreover, we showed a strong positive relationship between adult lifespan and lifetime mating success. Our results suggest that host-plant provisioning for reproduction not only increases the survival of individuals, but also increases the number of matings per lifetime. The procedure of supplying reproductive sites may enhance population growth of threatened odonates and other aquatic insects.

**Keywords** Conservation · Restoration · Oviposition · Odonates · Plants · Oviposition · Algeria

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## Introduction

Habitat degradation is one of the major causes of species extinction in various ecosystems. The increase in human-related activities has damaged the natural habitat of species, leading to biodiversity loss with imminent effects on ecosystem functioning and human well-being (Díaz et al. 2006). It is imperative to understand the ecology of threatened species and find globally-feasible solutions in order to maintain existing populations and recover extinct populations of species of conservation concern (Akçakaya et al. 2018; Sanderson 2006).

There is evidence that freshwater habitat is under huge anthropogenic pressure (Darwall et al. 2011; Galewski et al. 2011). Although freshwater ecosystems cover less than 1% of world's surface, they harbor a highly diverse fauna and flora (Dudgeon et al. 2006; Strayer and Dudgeon 2010). Importantly, freshwater animal diversity is related to vegetation availability (Biggs et al. 2005; Goertzen and Suhling 2013; Hassall et al. 2011) which suggests that the latter might be essential for the maintenance of the diversity of communities. In fact, since many freshwater animals

depend on aquatic macrophytes, the latter represent a biological vacuum which attracts species and increases diversity (Lucena-Moya and Duggan 2011; Thomaz and Cunha 2010). Such ecological properties have crucial importance in conservation and management of biodiversity.

One of the most studied insect groups in freshwater ecosystems are odonates (dragonflies and damselflies) (Córdoba-Aguilar 2008). The global diversity of odonates was estimated to about 7000 species (Kalkman et al. 2008). Species are generally either exophytic (lay their eggs in the water and on other substrates) or endophytic species (lay their eggs inside plant tissue). For the latter, many species are plant-specialist (Andersen et al. 2016; Corbet 1999), that is, they select a few plant species with specific properties (anatomical and mechanical) to lay eggs (Matushkina and Gorb 2007; Matushkina et al. 2016). On one hand, plant-dependence makes the odonate species vulnerable because if the plant disappears the species will not lay eggs, and thus the population will vanish. On the other hand, the plant-dependence may make the restoration of populations easier because providing the target plant (substrate provision) species in the preferred habitats will promote colonization. Unfortunately, knowledge on the plant preferences is lacking for many species, particularly of those of conservation concern. Moreover, although substrate provision has been shown to enhance colonization and increase population size (Khelifa and Mellal 2017), there is no data showing any effects on the survival of individuals.

In this study, the oviposition site selection was examined on a natural population with two field experiments in which different plant species are manipulated. We then analyzed capture-mark-recapture (CMR) data carried out in Northeast Algeria to: (1) estimate survival probability of males and females using Cormack-Jolly-Seber models, (2) assess the effects of substrate provision on survival probability, and (3) examine the link between survival probability and mating success by analyzing the relationship between the number of matings per lifetime and lifespan. These aspects which are crucial for the conservation of the species have not been studied before.

## Materials and methods

### Study area

The oviposition site selection study was conducted in a stream (El Fedjoudj P) situated upstream of the Seybouse watershed, Northeast Algeria (36.4726°N, 7.3763°E). The watercourse of relatively fast water flow was on average 2 m width and 0.7 m depth.

The CMR study was carried out on a site (El Fedjoudj S) located in the Seybouse watershed, Northeast Algeria. The

site is 5 km away from El Fedjoudj P (36.4776°N, 7.3990°E) and is characterized with an average width of 12 m and an average depth of 1.2 m. In both sites, vegetation in the bank mostly consisted of *Typha angustifolia*, *Paspalum distichum*, and a few patches of floating leaves of *Potamogeton nodosus* or *P. pectinatus*. Apart from *C. exul* there are other coexisting damselflies such as *Platynemis subdilatata*, *Coenagrion caerulescens*, and *Ischnura graellsii*, and Dragonflies such as *Gomphus lucasii*.

### Study species

*Calopteryx exul* (Zygoptera, Calopterygidae) is an endemic endangered damselfly that exists only in Tunisia, Algeria, and Morocco. Large populations were found in Northeast Algeria (Khelifa et al. 2016), but a recent study reported the extinction of important subpopulations and thus suggests that the species should be listed as critically endangered (Khelifa and Mellal 2017). The damselfly lives in rivers and streams with relatively fast-flowing water. The males are territorial and guard patches of floating plants where females lay eggs. A very little is known about the ecology and demography of the species, particularly the oviposition site selection.

### Oviposition site selection

To determine oviposition site selection, we carried out two field experiments that consisted of providing three plant species on which *C. exul* females have been observed to lay eggs. These plants are *Potamogeton nodosus*, *Typha angustifolia*, and *Paspalum distichum*. These species are the most dominant species in the banks of the Seybouse River, and most populations of *C. exul*. We set one territory with three patches of each plant species of equal surfaces (40×40 cm) in a part of the watercourse where the water flow was relatively fast (preferred habitat for the species). In experiment 1, from 11 to 16 June 2010, we recorded the species at which the female first lands. In fact, damselflies can recognize the preferred plant species for oviposition by vision and first land on it (Lambret et al. 2015; Martens 2001). We removed the female after she landed to avoid the effect of conspecific cues on substrate choice (Byers and Eason 2009; Martens 1993). In experiment 2, from 24 to 30 June 2010, to understand where eggs are mostly laid, we recorded the time spent ovipositing on each plant species. Oviposition duration is often correlated with the number of eggs laid (Corbet 1999).

### Capture-mark-recapture

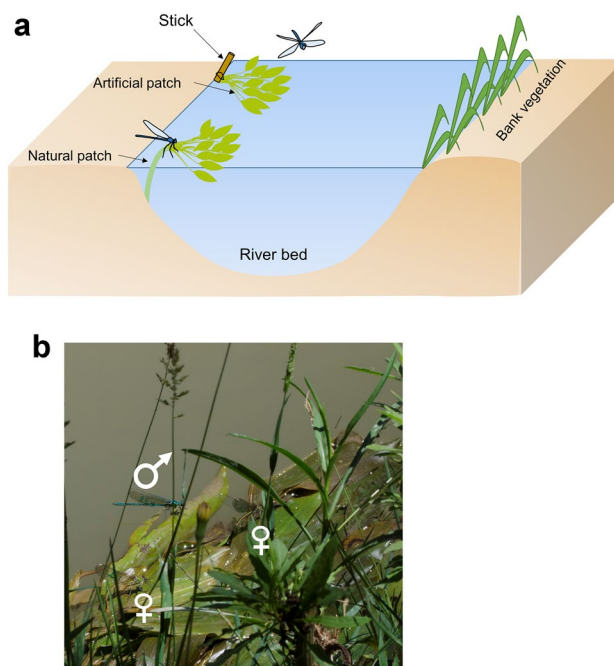
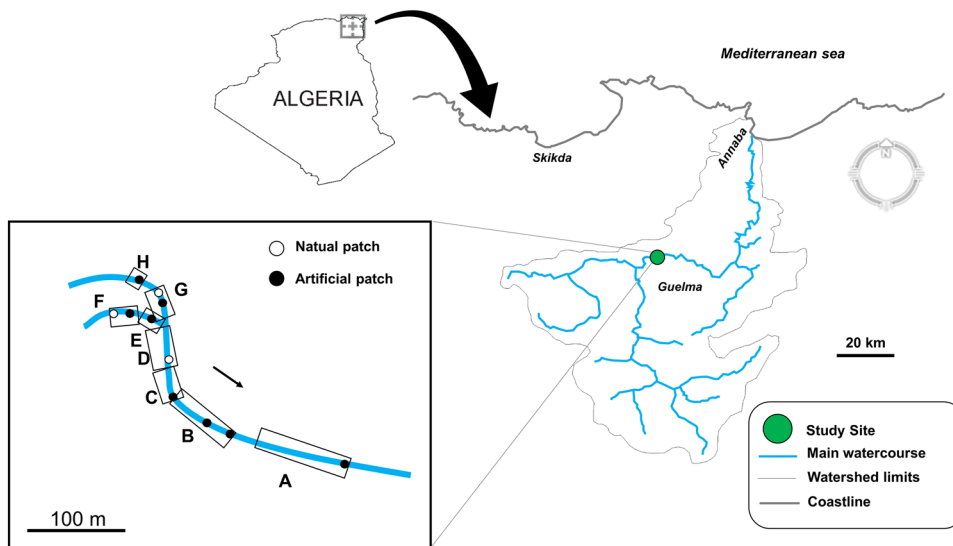
The study area was limited to 400 m based on the occurrence of the species. In fact, the closest viable population is at least 2 km away. The site was divided into 8 sections

within which sampling was possible (Fig. 1). Within a 400 m transect, adults of *Calopteryx exul* were daily captured with a hand net, marked with a permanent marker, and released for subsequent recovery between 21 May and 2 July 2016. For each occasion, we noted the sex and reproductive state of each individual. The reproductive state of males was recorded as reproductive (when we observed copulation, oviposition, or guarding ovipositing females) or not (when none of the latter was recorded). Thus since the male can mate with several females during a day, this measure reflects only whether the male mated or not during a particular day.

### Substrate provisioning

The study site naturally contained only three patches of *Potamogeton* spp. We increased the number of patches gradually to 10 by adding artificial patches collected from a different site. Because some oviposition patches were lost over time, we recorded the number of patches every visit and replaced the lost patches in the following sampling occasion. Figure S1 shows the number of patches for each sampling occasion. The artificial oviposition patches were placed specifically in areas where the water flow and bank vegetation were suitable for the damselfly (successful reproduction) (Khelifa 2013). Each patch was about 0.7–0.8 m<sup>2</sup>, that is the surface covered by the leaves and stems of the floating plant. The artificial patch containing leaves and stems of the aquatic plant were attached with a wire and the stems were planted in the bank’s soil. The artificial reproductive sites were shown to be effective in attracting individuals and promote reproduction (Fig. 2) (Khelifa and Mellal 2017).

**Fig. 1** Location map of the study site in the Seybouse watershed, Northeast Algeria. Oviposition patch E was constantly removed by fishermen, and thus the maximal number of patches was 10. (Color figure online)



**Fig. 2** Artificial oviposition site. **a** Field setting for artificial oviposition site. **b** The artificial site was built by leaves and stems of *Potamogeton nodosus* for *Calopteryx exul* oviposition. The oviposition patch is occupied by a male and two ovipositing females

### Statistical analyses

Statistical analyses were carried out with the R3.4.0 software. To assess the oviposition site selection during landing, we used a logistic regression with landing (coded as 1 or 0) as a response variable and plant species as an explanatory variable. To reveal which species is the most used as oviposition site, we carried out a one-way ANOVA in which oviposition duration was used as the response

variable and plant species as an explanatory variable. Tukey post hoc tests were used for pairwise comparison between treatments. Before using CJS modeling, we tested the goodness of fit of the model using the `release.gof` function from RMark (Amstrup et al. 2010). All three tests (Test2, Test3, and Total) assessing trap-release and transience showed non-significance ( $P > 0.50$ ), which imply that the data are suitable for Cormack-Jolly-Seber (CJS) modeling. Detection and survival probabilities were estimated with CJS model using RMark package (Laake 2013). We used a step-by-step procedure to select the best model. First, we fixed the survival parameter ( $\Phi$ ) and increased the complexity of the model for detection parameter ( $p$ ) by sequentially adding sex, time, air temperature and the number of oviposition site, including interactions. After ranking the models based on the AICc (corrected Akaike information criterion), we selected the most parsimonious one with lowest AICc. For survival probability, we fixed the detection parameter to the best model for  $p$ , then we increased the complexity of the model for  $\Phi$  by adding the same covariates for  $p$ . We used AICc and parsimony to select the best model for survival. The parameters were estimated with the `get.real` function from the RMark package and to predict both parameters across time-varying covariate.

To evaluate the link between lifespan, territory supplementation and mating success, we used three surrogate variables. First, we used lifetime mating success (LMS)—the number of times that an individual was observed mating (copulation or oviposition) during its lifespan. Second, we estimated the apparent lifespan as the number of days between first capture and last observation. Third, we counted for each individual the sum of territories that were available during their lifespan. For instance, if an individual was observed in the site during 3 days in which the number of territories was 10, the total number was counted as 30. We used a Poisson model to regress the LMS against the estimated lifespan, total number of territories and sex.

## Results

### Capture-mark-recapture data

A total of 238 individuals (140 females and 98 males) were captured and marked. The sex ratio of our sample was significantly female biased ( $\chi^2 = 7.41$ ,  $df = 1$ ,  $P = 0.006$ ). Of the total number of individuals, 144 (60.5%) were subsequently recorded after release. The number of captured individuals was not homogenous across the eight sections ( $\chi^2 = 7.41$ ,  $df = 7$ ,  $P < 0.0001$ ), varying from 5 in section D to 76 in section A (Table 1).

**Table 1** Number of males and females capture in each section of the study site

Section	Total no. individuals	No. females	No. males
A	76	48	28
B	60	31	29
C	8	5	3
D	5	1	4
E	19	11	8
F	30	22	8
G	23	10	13
H	17	12	5
Total	238	140	98

**Table 2** Summary statistics of the logistic regression assessing the landing probability of *C. exul* females on three potential oviposition plant substrates

	Estimate	Std. Error	z value	P
Intercept	-2.890	1.027	-2.813	0.0049
Substrate [Potamogeton]	3.920	1.152	3.403	0.0006
Substrate [Typha]	1.569	1.171	1.339	0.1805

The base level is *Paspalum distichum*, used as intercept for contrast calculations

### Oviposition site preference

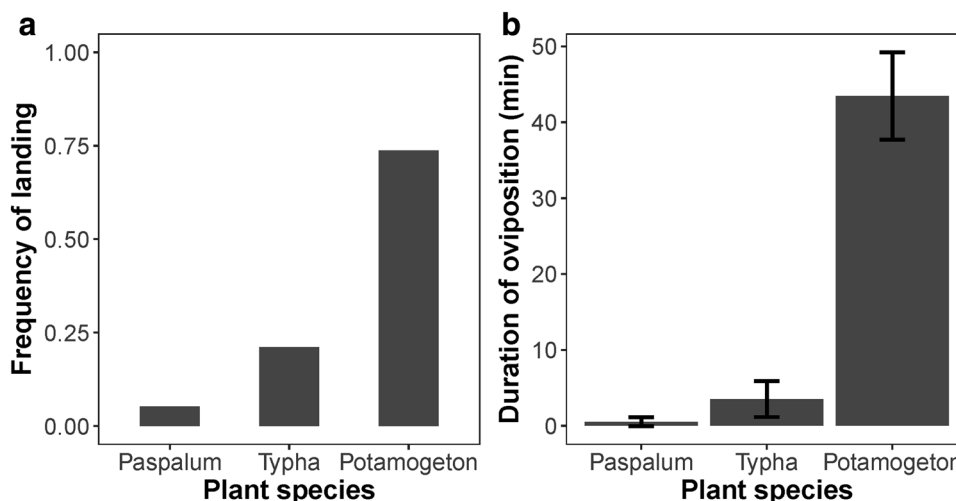
The field experiment assessing the probability of landing on a specific plant was based on 26 females.

We found that there was a clear preference for *Potamogeton nodosus* (Table 2). The respective landing frequencies for *P. nodosus*, *T. angustifolia* and *P. distichum* were 0.74, 0.21 and 0.05, respectively (Fig. 3a). Another field experiment carried out on 15 females surveying the time spent ovipositing on each substrate type showed a similar pattern (ANOVA:  $F_{2,42} = 169$ ,  $P < 0.0001$ ). The average oviposition duration was  $47.5 \pm 8.87$  min. Tukey post hoc tests showed that *P. nodosus* was highly significantly used for oviposition with respect to *T. angustifolia* ( $P < 0.0001$ ) and *P. distichum* ( $P < 0.0001$ ), but no significant difference between the latter two species ( $P = 0.48$ ). The species spent 91.5%, 7.4% and 1.1% of the oviposition time on *P. nodosus*, *T. angustifolia*, and *P. distichum*, respectively (Fig. 3b). Thus, the two experiments showed a preference for *P. nodosus* as oviposition substrate in *C. exul*.

### Survival probability

Based on a constant CJS model for recapture and survival [ $\Phi(\cdot) p(\cdot)$ ], we estimated an average recapture rate of 0.41 [95% CI 0.38–0.45] and an average survival rate of 0.84

**Fig. 3** Oviposition site selection of *Calopteryx exul*. **a** Frequency of landing of females on three types of substrates. **b** Average time of oviposition in three types of substrates. Error bars indicate 95% confidence intervals



**Table 3** Model selection results for detection probability of the Cormack-Jolly-Seber for capture-mark-recapture data of *Calopteryx exul*

Model	npar	AICc	$\Delta$ AICc	Weight	Deviance
<b>Phi(.)p(Sex + N.patches)</b>	<b>4</b>	<b>2139.95</b>	<b>0.00</b>	<b>0.7324</b>	<b>1653.29</b>
Phi(.)p(Sex * N.patches)	5	2141.96	2.01	0.2675	1653.27
Phi(.)p(Sex + time)	45	2160.78	20.83	0.0000	1586.04
Phi(.)p(Sex + Time)	4	2166.01	26.06	0.0000	1679.35
Phi(.)p(Sex * Time)	5	2166.76	26.81	0.0000	1678.07
Phi(.)p(Sex)	3	2170.18	30.23	0.0000	1685.54
Phi(.)p(N.patches)	3	2213.38	73.43	0.0000	1728.74
Phi(.)p(Time)	3	2233.05	93.10	0.0000	1748.41
Phi(.)p(.)	2	2233.19	93.24	0.0000	1750.57
Phi(.)p(time)	44	2234.86	94.91	0.0000	1662.40

Only the top 10 models are shown and the selected model is in bold. The dot (.) refers to a constant model  
N.patches refers to the number of patches (territories)

[0.82–0.86]. To estimate the recapture and survival rate for each sex, we used the model  $Phi(sex) p(sex)$ . The recapture rate of males was 0.56 [0.51–0.61] whereas that of females was 0.29 [0.25–0.33]. There was no difference between the survival rate of males (0.84 [0.80–0.86]) and that of females (0.84 [0.82–0.87]).

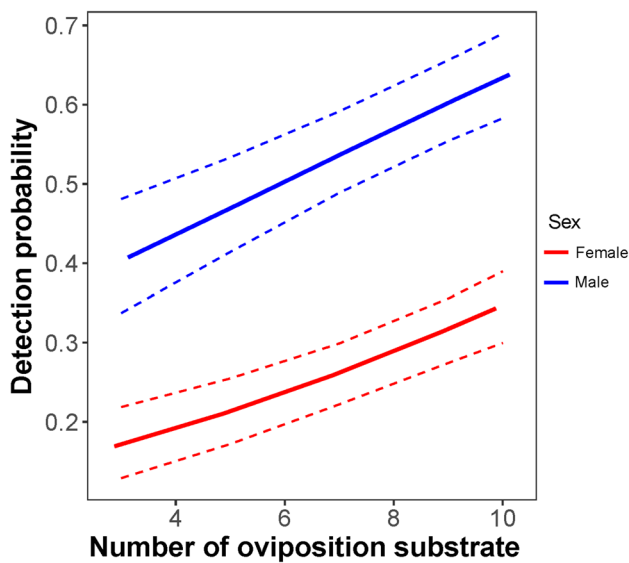
We tested the effects of a set of covariates on both the recapture and survival and ranked the models based on the AICc (Tables 3, 4). The best model for recapture rate includes sex and the number of oviposition patches, and it predicts that the higher the number of oviposition substrate the higher the recapture rate (Fig. 4). The most parsimonious model for survival rate includes only the number of oviposition patches and predicts an increase of survival with the increase of the number of oviposition patches (Fig. 5).

**Table 4** Model selection results for survival probability of the Cormack-Jolly-Seber for capture-mark-recapture data of *Calopteryx exul*

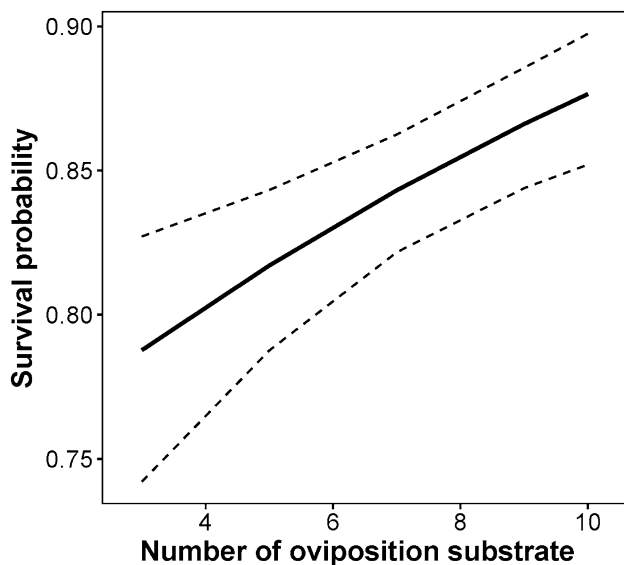
Model	npar	AICc	$\Delta$ AICc	Weight	Deviance
Phi(Sex + N.patches + Time)p(Sex + N.patches)	7	2125.79	0.00	0.6514	1633.03
<b>Phi(N.patches)p(Sex + N.patches)</b>	<b>5</b>	<b>2128.69</b>	<b>2.90</b>	<b>0.1528</b>	<b>1640.00</b>
Phi(Sex * N.patches)p(Sex + N.patches)	7	2128.91	3.12	0.1370	1636.15
Phi(Sex + N.patches)p(Sex + N.patches)	6	2130.69	4.90	0.0562	1639.97
Phi(.)p(Sex + N.patches)	4	2139.95	14.16	0.0005	1653.29
Phi(.)p(Sex + N.patches)	4	2139.95	14.16	0.0005	1653.29
Phi(Sex + Time)p(Sex + N.patches)	6	2140.20	14.40	0.0005	1649.47
Phi(Sex * Time)p(Sex + N.patches)	7	2141.36	15.57	0.0003	1648.60
Phi(Sex)p(Sex + N.patches)	5	2141.71	15.92	0.0002	1653.02
Phi(Body)p(Sex + N.patches)	5	2141.84	16.05	0.0002	2131.75

Only the top 10 models are shown and the selected model is in bold. The dot (.) refers to a constant model  
N.patches refers to the number of patches (territories)





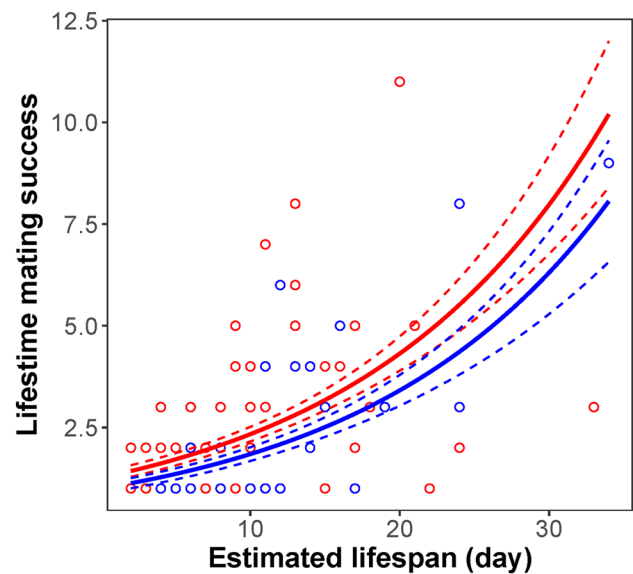
**Fig. 4** Predicted detection probability of *Calopteryx exul* across a number of oviposition patches of *Potamogeton nodosus*. Dashed lines are 95% confidence intervals. Red refers to female and blue refers to male. (Color figure online)



**Fig. 5** Predicted survival probability (with 95% confidence intervals) of *Calopteryx exul* across a number of oviposition patches of *Potamogeton nodosus*. Dashed lines are 95% confidence intervals

### Relationship between lifespan and mating success

The average estimated lifespan was 8.02 [95% CI 6.60–9.45] days for females and 7.66 [6.19–9.12] days for males. The maximum estimated lifespan was 33 days and 34 days for females and males, respectively. Lifetime mating success (LMS) had an average of 2.26 [1.84–2.67] for females with a maximum of 11, and 1.75 [1.36–2.13] for males with



**Fig. 6** Predicted lifetime mating success (with 95% confidence intervals) across the lifespan of *Calopteryx exul*. Dashed lines are 95% confidence intervals. Red refers to female and blue refers to male. (Color figure online)

**Table 5** Summary results of the Poisson model regressing lifetime mating success across lifespan, sex, and territory availability of *Calopteryx exul*

	Estimate	Std. Error	z value	P
Intercept	0.1468	0.0786	1.868	0.0618
Lifespan	0.0254	0.0106	2.403	0.0163
Sex[Male]	-0.3792	0.1134	-3.344	0.0008
N.patches	0.0098	0.0018	5.414	<0.00001

Female is used as an intercept for contrast calculations

N.patches refers to the number of patches (territories)

a maximum of 9. Table 5 shows a summary statistics for the Poisson model regressing LMS by estimated lifespan, number of territories available during lifespan, and sex. The model predicts that the estimated lifespan affects positively LMS and that females show slightly higher LMS than males (Fig. 6). Interestingly, there was a positive effect of the sum of the territories that were available on LMS.

### Discussion

We used a natural population of the endemic endangered damselfly, *Calopteryx exul*, to examine the oviposition site selection and the potential effects of increasing the carrying capacity of oviposition sites on individual survival using CMR data. We also investigated the relationship between lifespan and lifetime mating success to evaluate the link

between longevity and fitness. The study showed that (1) providing more oviposition sites increases survival probability of both sexes and detection rate, and (2) individuals with longer lifespan reproduce more frequently than those with a shorter lifespan. Although theory predicts that increasing carrying capacity should increase individual survival (Birch 1948; Sibly et al. 2005), our study is the first to report this relationship for *Calopteryx exul*, a species that needs an urgent conservation plan.

Non-detection of individual means either the individual is really outside the study site (true negative) or within the study site, but not observed (false negative) (Cordero-Rivera and Stoks 2008). CMR models deal with false negatives and estimate the probability of detection. In our study, providing more oviposition substrates increased the detection probability of both males and females. This could be explained by the mating system of the species. Males of *C. exul* are territorial, that is a single male usually guard one patch of oviposition substrate where multiple females lay eggs. More patches mean more territories, which relaxes the intraspecific interference between males, often leading to exclusion of some males either outside the study area or in terrestrial habitats (Bowler and Benton 2005; Plaistow and Siva-Jothy 1996). For the choosy females who typically require courtship for mating, the availability of multiple oviposition patches in one area might promote copulation and philopatry for oviposition site because a conspecific is often used as a cue for habitat quality assessment (Martens 1994; Martens and Rehfeldt 1989). This reduces the probability of migration outside the study area to seek for oviposition sites (Stettmer 1996). These results suggest that supplementing oviposition sites might enhance the reproductive activity of individuals in a given site, which might ultimately be a potential method for establishing new populations of threatened species.

Interestingly, provisioning oviposition sites significantly increased the survival probability of both males and females. The explanation for this pattern might also be related to the species mating system. Adding more oviposition patches reduces male dispersal due to male–male interference or female searching for oviposition site and increases female agglomeration in reproductive sites. Mortality costs of dispersal have been well documented (Bonte et al. 2012), and predation is one of the main costs. For instance, in the closely related damselfly, *C. splendens*, mean adult survival is 8% lower in individuals that disperse, compared to those that do not (Chaput-Bardy et al. 2010). In order to prove that improving reproductive habitats by providing oviposition sites is a potential management plan that could benefit *C. exul*, it is essential to link the procedure to individual fitness.

Individuals surviving longer have more opportunities to reproduce, and thereby to contribute to the next generation (Rodríguez-Muñoz et al. 2010). To test that, we assessed the relationship between lifespan and lifetime mating success.

We found a positive relationship between the two variables, showing that individuals with longer longevity have higher LMS. Similar findings were reported for the damselfly *Coenagrion puella* (Banks and Thompson 1987; Thompson 1990). Importantly, there was a positive relationship between the number of territories available during individual's lifespan and LMS, revealing that supplying territories increased the likelihood of mating. Therefore, oviposition site supplementation for *C. exul* does not only increase the survival of individuals, but also their reproductive success. Such information is essential components of demographic models that allow predictions of the population dynamics in damselfly wild population (Crowley et al. 1987). However, further studies are needed to assess the survival of eggs to the adult stage and the contribution of reproductive habitat supplementation to the population size in the next generation.

In conclusion, we assessed the consequences of oviposition site provisioning on the survival and reproduction of the endangered *C. exul*. We found that adding oviposition sites increased the observation frequency and the survival probability of individuals. We also showed that increased survival is associated with the increase in the number of matings. Thus, oviposition site provisioning might not only contribute to population increase in the next generations, but also to higher resilience against disturbance (Ayllón et al. 2012). We suggest that improving reproductive sites by supplementing target host plant species will potentially be an effective way to improve the conservation status of many endophytic odonates. In fact, 10 out of 18 species (55.5%) listed as endangered and critically endangered in the IUCN red list for Mediterranean odonates are endophytic. Further studies should investigate whether improving reproductive sites helps to reverse the trend of declining populations not only in odonates but also in other endophytic insects.

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## Compliance with ethical standards

**Conflict of interest** The authors confirm that there is no conflict of interest in case of the manuscript. In addition, the authors have declared that no competing interests exist.

## References

- Akçakaya HR, Bennett EL, Brooks TM, Grace MK, Heath A, Hedges S, Hilton-Taylor C, Hoffmann M, Keith DA, Long B (2018) Quantifying species recovery and conservation success to develop an IUCN Green List of Species. In: Burgman MA (ed) Conservation biology. Wiley, Hoboken
- Amstrup SC, McDonald TL, Manly BF (2010) Handbook of capture-recapture analysis. Princeton University Press, Princeton

- Andersen E, Nilsson B, Sahlén G (2016) Survival possibilities of the dragonfly *Aeshna viridis* (Insecta, Odonata) in southern Sweden predicted from dispersal possibilities. *J Insect Conserv* 20:179–188
- Ayllón D, Almodóvar A, Nicola GG, Parra I, Elvira B (2012) Modelling carrying capacity dynamics for the conservation and management of territorial salmonids. *Fish Res* 134:95–103
- Banks MJ, Thompson DJ (1987) Lifetime reproductive success of females of the damselfly *Coenagrion puella*. *J Anim Ecol* 56:815–832
- Biggs J, Williams P, Whitfield M, Nicolet P, Weatherby A (2005) 15 years of pond assessment in Britain: results and lessons learned from the work of Pond Conservation. *Aquat Conserv* 15:693–714
- Birch LC (1948) The intrinsic rate of natural increase of an insect population. *J Anim Ecol* 17(1):15–26
- Bonte D, Van Dyck H, Bullock JM, Coulon A, Delgado M, Gibbs M, Lehoucq V, Matthysen E, Mustin K, Saastamoinen M (2012) Costs of dispersal. *Biol Rev* 87:290–312
- Bowler DE, Benton TG (2005) Causes and consequences of animal dispersal strategies: relating individual behaviour to spatial dynamics. *Biol Rev* 80:205–225
- Byers CJ, Eason PK (2009) Conspecifics and their posture influence site choice and oviposition in the damselfly *Argia moesta*. *Ethology* 115:721–730
- Chaput-Bardy A, Grégoire A, Baguette M, Pagano A, Secondi J (2010) Condition and phenotype-dependent dispersal in a damselfly, *Calopteryx splendens*. *PLoS ONE* 5:e10694
- Corbet P (1999) Dragonflies: behaviour and ecology of Odonata. Harley Books, Colchester
- Cordero-Rivera A, Stoks R (2008) Mark-recapture studies and demography. In: Córdoba-Aguilar A (ed) Dragonflies and damselflies: model organisms for ecological and evolutionary research. Oxford University Press, Oxford, pp 7–20
- Córdoba-Aguilar A (2008) Dragonflies and Damselflies: model organisms for ecological and evolutionary research. Oxford University press, Oxford
- Crowley P, Nisbet R, Gurney W, Lawton J (1987) Population regulation in animals with complex life-histories: formulation and analysis of a damselfly model. In: Advances in ecological research, vol 17. Elsevier, New York, pp 1–59
- Darwall W, Smith K, Allen D, Holland R, Harrison I, Brooks E (2011) The diversity of life in African freshwaters: underwater, under threat: an analysis of the status and distribution of freshwater species throughout mainland Africa. The diversity of life in African freshwaters: underwater, under threat: an analysis of the status and distribution of freshwater species throughout mainland Africa
- Díaz S, Fargione J, Chapin FS III, Tilman D (2006) Biodiversity loss threatens human well-being. *PLoS Biol* 4:e277
- Dudgeon D, Arthington AH, Gessner MO, Kawabata Z-I, Knowler DJ, Lévêque C, Naiman RJ, Prieur-Richard A-H, Soto D, Stiassny ML (2006) Freshwater biodiversity: importance, threats, status and conservation challenges. *Biol Rev* 81:163–182
- Galewski T, Collen B, McRae L, Loh J, Grillas P, Gauthier-Clerc M, Devictor V (2011) Long-term trends in the abundance of Mediterranean wetland vertebrates: from global recovery to localized declines. *Biol Conserv* 144:1392–1399
- Goertzen D, Suhling F (2013) Promoting dragonfly diversity in cities: major determinants and implications for urban pond design. *J Insect Conserv* 17:399–409
- Hassall C, Hollinshead J, Hull A (2011) Environmental correlates of plant and invertebrate species richness in ponds. *Biodivers Conserv* 20:3189–3222
- Kalkman VJ, Clausnitzer V, Dijkstra K-DB, Orr AG, Paulson DR, van Tol J (2008) Global diversity of dragonflies (Odonata) in freshwater. *Hydrobiologia* 595:351–363
- Khelifa R (2013) Flight period, apparent sex ratio and habitat preferences of the Maghribian endemic *Calopteryx exul Selys*. *Zygoptera, Odonata*, p 1853
- Khelifa R, Mellal MK (2017) Host-plant-based restoration as a potential tool to improve conservation status of odonate specialists. *Insect Conserv Divers* 10.2:151–160. <https://doi.org/10.1111/icad.12212>
- Khelifa R, Zebba R, Amari H, Mellal MK, Mahdjoub H, Kahalerras A (2016) A hotspot for threatened Mediterranean odonates in the Seybouse River (Northeast Algeria): are IUCN population sizes drastically underestimated? *Int J Odonatol* 19:1–11
- Laake J (2013) RMark: an R Interface for Analysis of Capture–Recapture Data with MARK, AFSC Processed Rep 2013-01. Alaska Fish Sci Cent, NOAA, National Marine Fisheries Service, Seattle, Washington
- Lambret P, Besnard A, Matushkina N (2015) Initial preference for plant species and state during oviposition site selection by an odonate. *Entomol Sci* 18:377–382
- Lucena-Moya P, Duggan IC (2011) Macrophyte architecture affects the abundance and diversity of littoral microfauna. *Aquat Ecol* 45:279–287
- Martens A (1993) Influence of conspecifics and plant structures on oviposition site selection in *Pyrrhosoma nymphula* (Sulzer)(Zygoptera: Coenagrionidae). *Odonatologica* 22:487–494
- Martens A (1994) Field experiments on aggregation behaviour and oviposition in *Coenagrion puella* (L.)(Zygoptera: Coenagrionidae). *Adv Odonatol* 6:49–58
- Martens A (2001) Initial preference of oviposition sites: discrimination between living and dead plant material in *Sympetma fusca* and *Coenagrion caerulescens* (Odonata: Lestidae, Coenagrionidae). *Eur J Entomol* 98:121–123
- Martens A, Rehfeldt G (1989) Female aggregation in *Platycypha caligata* (Odonata: Chlorocyphidae): a tactic to evade male interference during oviposition. *Anim Behav* 38:369–374
- Matushkina N, Gorb S (2007) Mechanical properties of the endophytic ovipositor in damselflies (Zygoptera, Odonata) and their oviposition substrates. *Zoology* 110:167–175
- Matushkina N, Lambret P, Gorb S (2016) Keeping the golden mean: plant stiffness and anatomy as proximal factors driving endophytic oviposition site selection in a dragonfly. *Zoology* 119:474–480
- Plaitow S, Siva-Jothy MT (1996) Energetic constraints and male mate-securing tactics in the damselfly *Calopteryx splendens xanthostoma* (Charpentier). *Proc R Soc Lond B* 263:1233–1239
- Rodríguez-Muñoz R, Bretman A, Slate J, Walling C, Tregenza T (2010) Natural and sexual selection in a wild insect population. *Science* 328:1269–1272
- Sanderson EW (2006) How many animals do we want to save? The many ways of setting population target levels for conservation. *Bioscience* 56:911–922
- Sibly RM, Barker D, Denham MC, Hone J, Pagel M (2005) On the regulation of populations of mammals, birds, fish, and insects. *Science* 309:607–610
- Stettmer C (1996) Colonisation and dispersal patterns of banded (*Calopteryx splendens*) and beautiful demoiselles (*C. virgo*) (Odonata: Calopterygidae) in south-east German streams. *Eur J Entomol* 93:579–593
- Strayer DL, Dudgeon D (2010) Freshwater biodiversity conservation: recent progress and future challenges. *J N Am Benthol Soc* 29:344–358
- Thomaz SM, Cunha ERd (2010) The role of macrophytes in habitat structuring in aquatic ecosystems: methods of measurement, causes and consequences on animal assemblages' composition and biodiversity. *Acta Limnol Bras* 22:218–236
- Thompson DJ (1990) The effects of survival and weather on lifetime egg production in a model damselfly. *Ecol Entomol* 15:455–462