Habitat requirements of *Orthetrum coerulescens* and management of a secondary habitat in a highly man-modified landscape (Odonata: Libellulidae)

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ABSTRACT

Due to the destruction of its primary habitats, the West Palaearctic libellulid *Orthetrum coerulescens* has suffered much decline in central Europe. However, at the regional scale it has survived in a variety of secondary habitat, such as draining ditches. In order to find adequate measures for its conservation and promotion, habitat use and habitat recognition of *O. coerulescens* were investigated by description and experimentation at fenland ditches in a small nature reserve in the Swiss Plateau. This breeding habitat, which harbours a viable population, had been restored and maintained for 25 years. The most densely populated sites comprised small ditches between 40-70 cm wide, with rather sparse vegetation of narrow-leaved plants and that had parts of the water surface uncovered; the peaty, mud ground was partly overgrown with submerged pads of stonewort (*Chara* spp.). Water was mainly supplied by seepage springs with a mixture of local slow flow that were hardly recognizable and shallow sites, which were used for oviposition. In hot summer spells the water temperature could exceed 30°C. Some freezing occurred in winter, but the mud was permanently ice-free. The development of the breeding population, which comprised more than 200 individuals in 2006, was followed over two subsequent years. My data indicate that conservation and promotion of *O. coerulescens* populations in small ditches can be achieved by relatively simple habitat maintenance, such as a rotational strategy of clearing ditches, using of small weirs to prevent or protract desiccation and annual cutting of the surrounding litter meadows.

INTRODUCTION

In industrialized and densely populated countries the primary habitats of many Odonata species have largely been destructed or degraded (Corbet 1999: 564 ff.). As result of the landscape changes a number of ecologically specialized species have declined or become extinct on a regional or national scale, as demonstrated for *Nehalennia speciosa* (Charpentier) in Europe (Bernard & Wildermuth 2005). Yet, some species have persisted in the face of anthropogenic habitat modification, often by

colonizing secondary biotopes that are similar to the ecological conditions of their primary habitats. In contrast to primary biotopes small secondary water bodies need to be maintained in order to function as viable larval habitats of specialists. In some cases this requires a sophisticated system of management such as the rotational model aimed at *Leucorrhinia pectoralis* (Charpentier), another species that is endangered in Europe (Wildermuth & Schiess 1983; Wildermuth 2001). As a prerequisite for effective practical conservation, an appropriate knowledge on the specific habitat requirements of a focus species is needed (e.g. Wildermuth 1992).

One species that has adopted certain secondary habitats is *Orthetrum coerulescens*, a libellulid that is widespread in Europe (Kalkman 2006). *O. coerulescens* inhabits natural streams, flushes, seepages and runnels in areas of moorland, but also secondary waters like draining ditches, streamlets in gravel pits and rivulets in partly exploited peat-bogs. While many authors have described the variety habitats used by this species (e.g. Buchwald 1983, 1989; Wildermuth & Krebs 1983; Clausnitzer 1988; Müller 1992; Weihrauch 1998; Buchwald & Schmidt 1990; Sternberg & Buchwald 2000, White 2006), as well as its reproductive behaviour (e.g. Heymer 1969; Parr 1983; Huber 1984; Miller & Miller 1989; Lee 1994; White 2008), comparatively few studies have quantified aspects of its population biology (see Juillerat 2002; Kéry & Juillerat 2004). As a consequence of human impact many central European populations of *O. coerulescens* have declined or become extinct (e.g. for Switzerlerland cf. Ris 1886; Juillerat 2005). Therefore, this species is considered, on a national scale, to vary from near threatened to endangered in Austria (Raab 2006), Belgium (De Knijf 2006; Goffart 2006), Germany (Ott & Piper 1998), The Netherlands (Ketelaar & Kalkman) 2002 and Switzerland (Gonseth & Monnerat 2002). In this study I report on a viable population in the Swiss Plateau that established itself in recently cleared fenland that possesses restored and maintained drainage ditches. The study was aimed at conservation and promotion of *O. coerulescens* in a secondary habitat and comprised various ecological aspects such as size and phenology of the annual populations. I demonstrate for *O. coerulescens* that successful population conservation may be achieved by relatively simple modes of habitat management.

STUDY SITE AND METHODS

The study was carried out in a 1.5 ha fen near Hinwil Switzerland (47°17.87'N, 08°48.82'E; 550 m a.s.l.). The small area named 'Chuderriet' was part of the nature reserve 'Drumlinlandschaft Zürcher Oberland'. This nature reserve consisted of a 1.7 km² core zone, which comprised a number of mostly forested drumlins that were interspersed with fragmented, largely exploited, bogs and litter meadows and was surrounded by intensely used agricultural and urban landscape. Between ca 1970 and 1980 the 'Chuderriet' was not used as litter meadow. It became densely overgrown by large shrubs and therefore unhabitable for Odonata. In winter 1981/82 the area was cleared and the meadows were restored, including the original system of draining ditches with an overall length of ca 330 m. The ditches were mainly fed by water originating from scattered seepages at the foot of the adjacent drumlin. In 1989 it was first recognized that the ditches had been colonized by *Orthetrum coerulescens*, some 4 km away from the nearest known site with a permanent popu-

lation of this species. For 25 years subsequently, the area has been regularly main-
tained by annual cutting of the vegetation, removal of neophytes (*Solidago gigantea*)
and by a sporadic manual or mechanical clearing of the ditches. In order to delay des-
iccation of the ditches during hot summer periods with no or little precipitation, six
simple and controllable weirs have been installed successively (Figs 1, 2c).

Extensive monitoring of *O. coerulescens* began in 1989 and was intensified in
2006 and 2007. In order to assess the annual population size and to collect pheno-
logical data, the ditches were divided into six sections (Fig. 1) and were inspected
every one to three days depending on the weather conditions between 2.5 h before
and 2.5 h after solar noon. Counts were made of tenerals, exuviae (though these
were not systematically searched for), territorial males, females, copulations and
ovipositions. Random samples were made of all Odonata larvae that inhabited the
ditches. The following habitat parameters were recorded: width of the ditches at
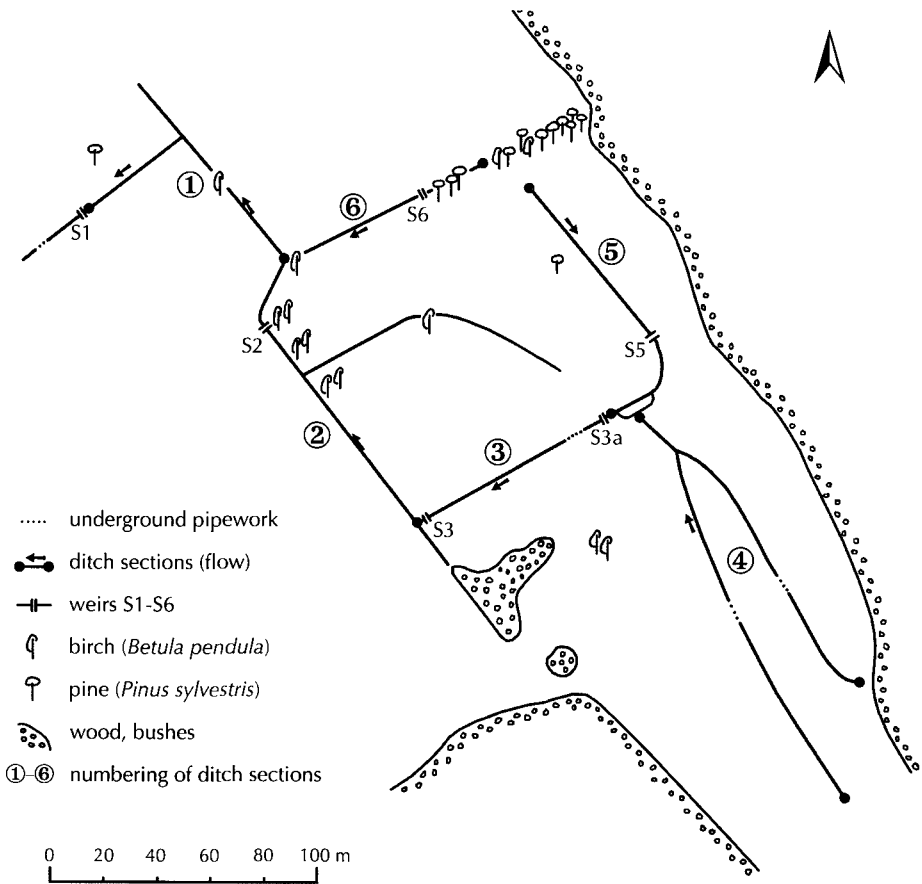

underground pipework

ditch sections (flow)

weirs S1-S6

birch (*Betula pendula*)

pine (*Pinus sylvestris*)

wood, bushes

①-⑥ numbering of ditch sections

0   20   40   60   80   100 m

Figure 1: The study site 'Chuderriet' with the system of drainage ditches. The monitoring tran-
sects followed the ditches that were divided into six sections 1-6. S1-S6 show the sites of con-
trollable weirs that largely protract desiccation of the ditches during dry and hot periods.

water level, depth of the ditches between shoulder and firm ground, density of emergent vegetation, visibility of open water, temperature, water flow, depth of water and depth of the muddy sediment.

The sections of the various ditches differed in some abiotic features, therefore enabling a comparison of factors that presumably contributed to the attractiveness for reproductively active adults. In order to test the hypothesis that adult *O. coerulescens* recognize the oviposition sites by small patchy or linear, freely visible water surfaces, three experiments were conducted:

(1) Ditch section 2 featured lush emergent vegetation, mainly consisting of *Carex acutiformis* and *Phragmites australis*, almost covering the entire water surface. Here all the plant stems and leaves (20-25/dm^2) were cut just above the water surface within an area of 0.6 x 0.8 m. After removal of the cut material the water was clearly visible, only interspersed by cut stems. The presence and behaviour of adults were recorded before and after the habitat manipulation, and a comparison was made between the cut area and the adjacent vegetated parts of the ditch.

(2) A similar experiment was conducted on the moderately overgrown ditch section 4, where the vegetation was cleared from a 4 m-stretch (Fig. 2d). Next, the water surface was covered with aluminium foil (4.0 x 0.6 m), which reflects sunlight but does not polarize light horizontally as the surface of small water bodies does (Schwind 1991; Bernáth et al. 2002). The presence and behaviour of the adults was compared between situations with and without aluminium foil.

(3) A sheet of black plastic foil (0.2 x 3 m), which reflects horizontally polarized sunlight similar to flat water surfaces and therefore is attractive to Odonata (cf. Wildermuth 1998), was placed on completely dry vegetation where the water course of the narrow ditch 4 ran underground in pipework.

All experiments were conducted under optimal weather conditions (air temperature > 20°C, sunshine, calm) that corresponded to high population density and frequent reproduction activity of *O. coerulescens*. For statistical analyses, χ^2-test, Kolmogorov-Smirnov-test and Mann-Whitney-test were used (Zar 1984).

RESULTS

Habitat characteristics

The ditches ran within litter meadows containing mixed plant communities, mainly consisting of gramineous and rather low vegetation – mostly Caricetum davallianae and, to a lesser extent, Molinietum caeruleae – interspersed by *Phragmites australis* in a park-like landscape with scattered trees (*Pinus sylvestris, Betula pendula*) and bushes (*Salix* spp.). The rendezvous-sites and the larval habitats of *Orthetrum coerulescens* were characterized by the following features: (1) ditches mostly 40-70 cm wide (range 25-200 cm) and 10-40 cm deep between ditch shoulder and water surface, depth of water at most sites 1-20 cm (Figs 2a, b) but increasing to up to 50 cm behind weirs (Fig. 2c), longitudinal slope of ditches low (≥ 8‰), no or just slightly visible water flow that rarely exceeded 5-15 cm/s especially near the seepages;

Figure 2: Rendezvous-sites and larval habitats at draining ditches in the 'Chuderriet' — (a) small ditch with shallow water and sparse emergent vegetation ideal for reproduction of *Orthe-trum coerulescens*; (b) the same ditch as in (a) in winter – as this ditch is fed by seepages ice is only formed superficially and the mud is left unfrozen; (c) simple wooden weir with plastic plug for emptying the ditch during the harvest period of the adjacent litter meadows; (d) small ditch after untimely cutting of the vegetation – experimental situation at ditch section 4.

(2) submerged vegetation (mainly consisting of *Chara* spp.) absent or patchy; emergent vegetation sparse to lush with narrow-leaved plants – predominantly *Carex davalliana* and *C. flava* near spring mire seepages, *C. acutiformis* and *C. rostrata* at lower reaches of ditches, and *Phragmites australis*; (3) ground covered with loose mud consisting of peat on clayey ground mostly 15-35 cm, reaching a maximum depth of 50 cm, and with many sites rust-coloured by bacteria-produced iron oxides (Figs 4a, c); (4) water surface patchily covered with thin floating layer of biogene manganese oxides (Fig. 4b). The water temperature near the surface largely followed the air temperature over long distances except from the stretches close to the seepages along section 4, which exhibited a temperature gradient. During hot summer spells the water temperature sometimes exceeded 30°C. In winter only superficial icing of the water was observed, leaving the mud permanently ice-free.

Phenology and population size

Developmental timing differed considerably between the two focus years. In 2006, after a cool and wet May, the emergence period started in early June and the reproductive period ceased at the end of July, reaching a peak in mid-June; June and July were hot and dry, but August had heavy precipitation. In 2007 (Fig. 3), after a mild winter and an unusually warm and dry April, the emergence period started during the second half of May. Between June and August, however, the weather was variable and often wet. Accordingly, the reproductive activity of *O. coerulescens* was interrupted, attaining a peak in early July and ending in the second half of August. Adult censuses were much larger in 2006, with the maximal number of territorial males per transect reaching 115 (mean = 72.6 ± 30.3, range = 2-115, n = 16) in contrast with 2007 when a maximum of 64 (mean = 28.9 ± 15.6, range = 1-64, n = 30) males were observed. The corresponding values for females equal 18 (mean = 6.4 ± 5.8, range = 0-18, n = 16) and 6 (mean = 1.4 ± 1.9, range = 0-6, n = 30).

Territorial males occupied all six ditch sections throughout the reproduction period. The highest male density per transect, calculated per 10 m stretches for the total length of all ditches, equalled 3.5 in 2006 (4 July) and 1.9 in 2007 (20 June). However, the abundance differed between sections 1-6, for example between 0.9 and 8.0 on 4 July 2006 and between 0.5 and 3.4 on 20 June 2007; these differences were not significant (Kolmogorov-Smirnov-test, 2006: D = 0.281, n = 19.2, p < 0.1; 2007: D = 0.133, n = 12.0, p > 0.2). Tenerals, copulation and ovipositing behaviour were observed, without exception, at all sections during 2006-2007, implying that all six sections were suitable for reproduction.

Density of vegetation

Stretches with dense vegetation, where the cover was more than 60%, sedges were up to 0.8 m high and surmounted by single reeds that attained 1.5-2 m in height, and hardly visible open water were generally avoided by both sexes. In such areas, there were between 200-250 leaves/stems of *Carex acutiformis* and two to three reed stems m^{-2}. Sites with less dense vegetation, e.g. localities with 80-100 blades/stalks and five reed stems or no *Carex*-vegetation with 15 reed plants m^{-2}, were almost permanently occupied by territorial males.

At a very densely overgrown stretch of section 2, a 0.5 m^2 section of the emergent vegetation was completely cut near the water surface. As a consequence the formerly unoccupied site was occupied subsequently by one male at every (n = 14) monitoring
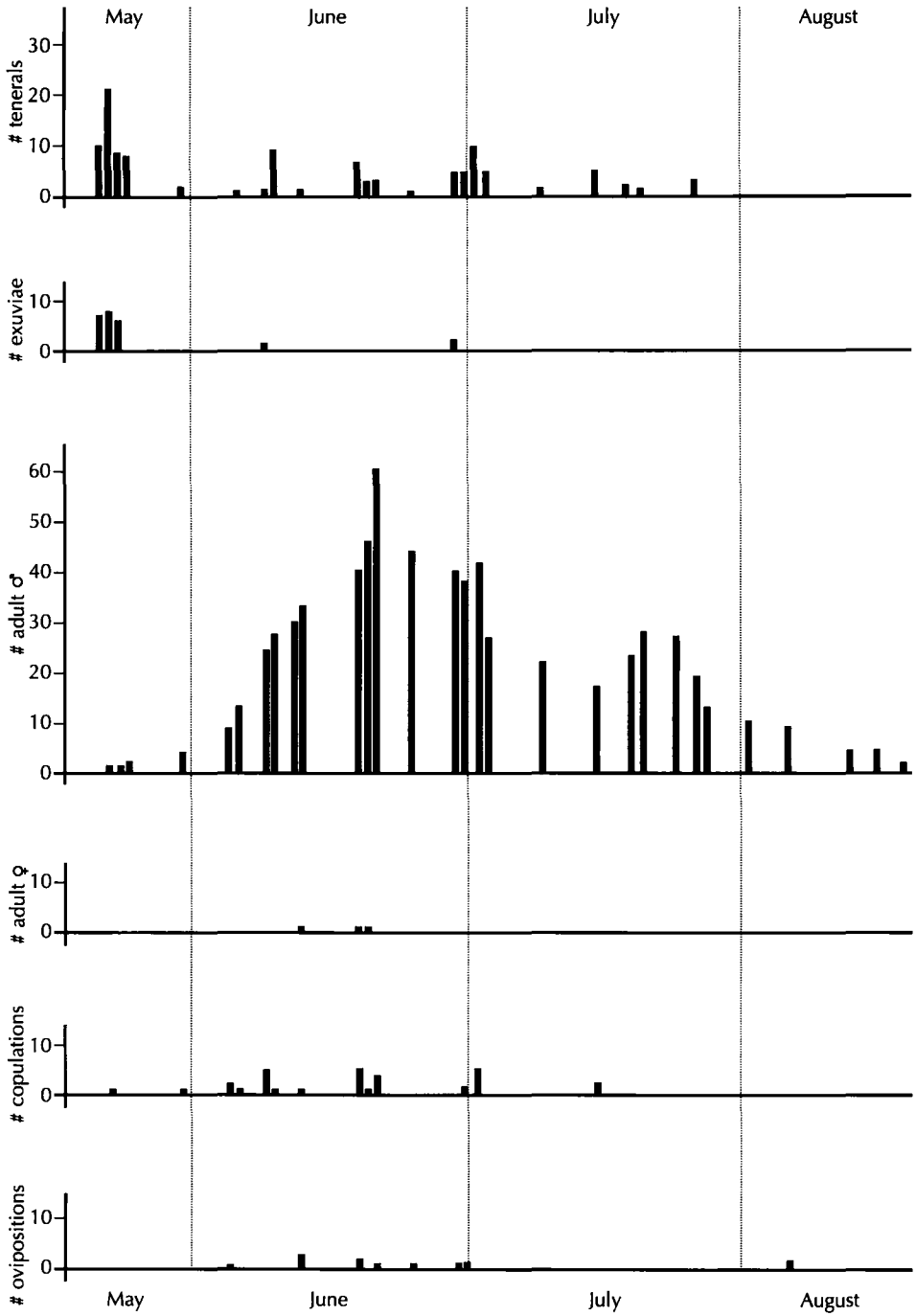
Figure 3: Seasonal development of the population of *Orthetrum coerulescens* in the 'Chuder-riet' in 2007.

period during the next eight days. No males were present at the adjacent stretches with dense vegetation. Copulation was recorded at two occasions and the site was vigorously defended against conspecific intruders as well as *Somatochlora flavo-maculata* (Vander Linden) males. For the second experimental site a 4 m stretch at section 4 was selected. Due to less dense vegetation the locality was mostly occupied by two males prior to the experimental change. After clearing the site along the shallow ditch (including the border on both sides; see Fig. 2d), the site was permanently occupied by two to three males during 20 monitoring periods over the subsequent 17 days. In addition fights, copulations and ovipositions were repeatedly observed. A lack of upright vegetation did not prevent reproductive behaviour as males and copulating pairs were observed perching on, or near to, the ground.

Solar radiation

Most parts of the six sections were generally sunlit during clear days from ca 3.5 h before and 3.5 h after solar noon. Only the lower part of section 2 was shaded by trees in the morning up to about solar noon, presenting a contrast to sunlit stretches, not occupied by territorial males in the forenoon. During this time of the day the density of males (per 10 m) varied between 0 ($n = 4$) and 2.5 ($n = 4$) at the shaded areas and the adjacent sunlit stretch respectively, with similarly dense vegetation (cover ~ 40-60%) along the whole section. Towards solar noon, when the ditch section was about to experience full sunlight, two or three males were observed in the sunlit meadow nearby possibly waiting for the available habitat to warm. On the other hand, when the air temperature exceeded 28-30°C two to three males also perched in a tree shaded place of the habitat at the end of section 6 that was generally avoided at lower temperatures.

Visibility of open water

Due to hot and dry weather in June and July 2006 some stretches of all ditch sections desiccated gradually thereby presenting a natural comparison between the attractiveness of wet (Figs 4a-c) and dry (Fig. 4d) stretches of ditch for *O. coerulescens*. Males significantly (Mann-Whitney-test $U = 0$, $n_1 = 14$, $n_2 = 14$, $p < 0.001$) preferred sections with open water visible to the human eye (average of 6.2 males per 10 m; range 3.5-11.7) compared with dried-out stretches (mean = 0.8; range = 0-3.3) males. Copulations and ovipositions were seen exclusively at stretches with open water. In respect to attractiveness, no significant difference was found between sites with clear and semitranslucent water surfaces that had a thin layer of manganese oxides (Mann-Whitney-test, $U = 26.5$, $n_1 = 7$, $n_2 = 8$, $p > 0.05$). Some males established their territories also at sites with wet mud and a rough, irregularly shiny surface (Fig. 4c). However, females did not use wet mud for oviposition. Since the overall population of *O. coerulescens* was large in 2006 the gradual desiccation of the ditches caused greater crowding and male densities reached 10.0 - 11.7 per 10 m.

At section 4, where the vegetation had been cleared (Fig. 3d, see above) and the water surface was covered with aluminium foil, all territorial males ($n = 2$-3) moved away from the site and occupied only the adjacent ditch stretches where there was visible water. An absence of males was noted on each of the four monitoring periods.

Shortly after the dry stretch between the open ditch sections was lined with black plastic foil it became occupied by a territorial male. No individuals were present at this site before and after the experiment. Hence, the presence of the black plastic proved attractive to *O. coerulescens*, with 1-2 males (mean 1.4) present during 19 out of 20 checks, either perched on a reed stem, patrolling or fighting conspecifics. Moreover, one female performed dipping oviposition flight over the plastic foil.

Depth of water

Territorial males were mostly present at sites with shallow water (Fig. 5). This was recognizable at section 6 (20 m long) that was bisected by a weir into two equal parts, with relatively deep (up to 50 cm), clear water upstream and shallow (1-5 cm deep) water downstream. In the upper and lower sections between zero and one male (average = 0.27) and one to five males (average = 2.47) were present (Mann-Whitney-test $U = 1.5$, $n_1 = 8$, $n_2 = 8$, $p < 0.01$). Copulations ($n = 135$) and ovipositions ($n = 26$) were almost exclusively observed at sites with shallow (1-5 cm deep) water and also those with deeper water but occupied by pads of *Chara* spp. that nearly reached or outgrew the water surface, thus feigning shallow water (Fig. 4a). Females oviposited sometimes in isolated areas as small as 7 cm diameter and 1-2 cm deep (Fig. 6).
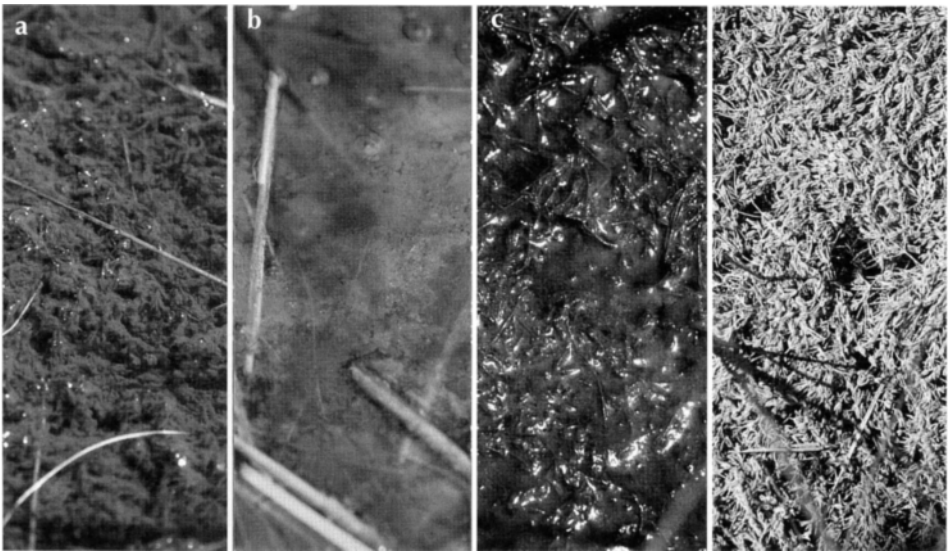

Figure 4: Oviposition substrates of *Orthetrum coerulescens* in fenland-ditches — (a) almost stagnant water with pad of *Chara* sp. growing up to near the surface, covered by precipitated Fe-oxides; (b) water surface covered by semitranslucent layer of Mn-oxides; (c) ditch site drying out with emergent *Chara*-pad; (d) *Chara*-pad completely dried out. Situations (a-c), are attractive for territorial males. For oviposition only (a, b) are suitable. (d) neither attracts males nor females.

Habitat use by adults

Territorial males typically stayed near or above the water, using vertical to horizontal plant stems or leaves as perches that allowed the oviposition site to be surveyed. Occasionally they made short feeding flights, patrolled the territory or chased odonate intruders. Copulation was initiated in mid-air and ended on a perch near to the water. After copulation the separated partners remained perched close to each other. On experimental stretches with cleared vegetation both sexes perched on remainders of the vegetation close to the ground. Oviposition was normally guarded and took place within the male territory. Tenerals, immatures and matures were regularly encountered in the adjacent litter meadows.

Microhabitat of larvae

Freely moving larvae were not observed except immediately prior to emergence. Random samples of larvae from the mud at sections 2 and 4 with a small hand net (05 vi 2006 and 16 x 2007 respectively) provided 66 *O. coerulescens*, six *Aeshna cyanea* (Müller), five *Pyrrhosoma nymphula* (Sulzer), one *Coenagrion puella* (Linnaeus) and one *Cordulegaster boltonii* (Donovan). Hence, *O. coerulescens* clearly dominated this Odonata assemblage. Exuviae were found of all these species as well as a few exuviae of *Somatochlora flavomaculata* and *Libellula quadrimaculata* Linnaeus. Most exuviae were covered with a thin layer of rust-colour originating from iron oxides in the mud. The teleost *Phoxinus phoxinus* and the amphibians *Triturus alpestris* and *T. helveticus*, which are potential vertebrate predators, were present in most ditch sections but in low densities.

Figure 5: Territorial male *Orthetrum coerulescens* perched on a cut reed stem over shallow water in a small ditch.

Figure 6: Female *Orthetrum coerulescens* ovipositing in shallow water at the edge of a ditch.

O. coerulescens in neighbouring areas

Within the entire nature reserve the species was also found at a few sites that were 0.2-1.4 km distant from the 'Chuderriet'. Two of these had ditches similar to those at the main study locality, however, the populations were small and emerging individuals were not recorded every year. Indeed, the ditches sporadically dried out completely along most sections during hot and dry periods in 2003, 2006 and 2007. Males were also seen at isolated seepage puddles and at freshly constructed ponds with floating vegetation carpets leaving small water corridors of open water between them and the pond edge thus simulating a linear water body. No successful reproduction was recorded at these sites. Otherwise *O. coerulescens* was absent from the other water bodies such as the main draining ditch, the overgrown shallow mire pools and peat ponds.

DISCUSSION

The suitable habitat of *Orthetrum coerulescens* for reproduction at the study site is characterized by several proximate factors that are visually recognized by adults of both sexes. In this secondary habitat a combination of different features proved to be optimal for eliciting reproduction activities: the water courses are small – in this case linear and up to ca 0.5 m wide –, sunlit and sparsely overgrown by vegetation (up to ca 50% coverage); moreover, the water flow is slow or not recognizable and the water is actually or apparently shallow with mud or dense felts of submerged water plants (*Chara* spp.) near the surface and visible from above. Ideally, the water runs in open and extensively used fenland with rather low vegetation that suits for maturation and foraging of both sexes.

For successful larval development a rather thick layer of peaty detritus or muddy silt or a dense network of submerged water plants (*Chara* spp.), for example for refuge and to survive dry periods with desiccation, is required. During winter the water either does not freeze or, in doing so, merely superficially, thus leaving the sediment ice-free. Shallow and slightly running water warrants sufficient oxygen supply. Larval habitats harbour no or only low densities of potential predators such as small and predominantly young fish (*Phoxinus phoxinus*), amphibians (*Triturus* spp.) and anisopteran larvae (*Aeshna cyanea*, *Cordulegaster boltonii*). Obviously, coexistence of *O. coerulescens* with these predators is possible, due to the sedentary nature of the larvae and the availability of cryptic habitat.

Indirect indications for the requirements of *O. coerulescens* in secondary habitats may be inferred also from the temporary presence or complete absence of populations at the other water bodies throughout the nature reserve. Despite the varied sizes of ditches throughout the site, they were predominantly peat ponds, local pond-like ditch enlargements and densely overgrown shallow mire pools. Those sites that were similar to those at 'Chuderriet', but bearing only small, temporary populations, the catchment area is probably too small and the ditches insufficiently fed by seepage water so that they desiccate completely during dry and hot periods. Other uninhabited sites, the main drain included, are covered by dense and tall vegetation during the reproductive period; furthermore, they are > 2 m wide and > 0.5 m deep along some sections. Peat ponds with an open water surface of ca 10-150 m² seem

unattractive for O. *coerulescens* because they are neither linear nor sufficiently small. The brown colour of the rather deep water, resulting in restricted transparency, may also be a factor that prevents adults from colonizing the sites. In shallow mire puddles the dense vegetation may have a repulsing effect. Preference for sparsely-grown habitats that feature free soil patches is also reported from partly exploited peat bogs (Clausnitzer 1988), restored mire areas (White 2006) and revitalized streams (Buchwald & Schmidt 1990). As O. *coerulescens* tends to colonize secondary habitats in early succession stages (Buchwald & Schmidt 1990), it may be inferred that some former primary habitats were situated in dynamic floodplains with periodical rivulets in pioneer stages.

The habitat requirements of O. *coerulescens* in southern France, northern Italy, Switzerland and Germany were studied by Buchwald (1989) and Buchwald & Schmidt (1990). They found that various habitat types were suitable for this species, however calcareous spring mires with sparse vegetation, small shallow pools and drains proved to be the most important among them, probably representing the predominant primary habitat in the pre-Alpine region. In ditches and brooks within agricultural land, many of them constituting secondary habitats, the occurrence of O. *coerulescens* was mainly concentrated on sites with plant communities dominated by representatives of the associations Glycerio-Sparganietum neglecti and Phalaridetum arundinaceae - either *Sparganium erectum* (s.l.) or *Berula erecta* (Buchwald 1989) or *Phalaris arundinacea* (Buchwald & Schmidt 1990). The 'plantscape' of these habitats, which is characterized by rather broad-leaved herbaceous plants, differs considerably from the draining ditches at the study site whose vegetation is dominated by narrow-leaved, grass-like plants. It is concluded that the attractiveness of a habitat for O. *coerulescens* is rather determined by the structural and spatial arrangement of plants than by the plant communities per se (see also Clausnitzer 1988); even sites with very little or cleared vegetation are occupied by territorial males. An important feature is that the water surface is not completely covered by vegetation. As O. *coerulescens* has sporadically been recorded to breed in shallow groundwater-fed water bodies of gravel pits (Wildermuth & Krebs 1983; F. Weihrauch pers. comm.), the spectrum of secondary habitats may be wider than is generally presumed.

Although adults generally perch on plant stems during territoral behaviour and copulation (Heymer 1969; Parr 1983; Miller & Miller 1989; Buchwald & Schmidt 1990; White 2006), both sexes are adaptable and perch on or near the ground if tall plant structures are absent, for example due to habitat management. Yet, from this observation it cannot be inferred that a lack of vegetation will have negligible effect, as stems and narrow leaves of reeds and sedges are essential for emergence, as well as perches for both sexes during maturation and foraging. In this respect sunlit litter meadows providing ample insect prey would appear to be optimal habitats in contrast to intensely used agricultural land that is largely avoided by imagines (Buchwald & Schmidt 1990; Sternberg & Sternberg 2004).

The ultimate factors that determine the occurrence of O. *coerulescens* at sites in Germany (Buchwald 1989) appear to be similar for Swiss populations of this species, which occur at localities with mean annual temperatures ranging from ca 5 to 11°C (Juillerat 2005). In the ditches of the study site oxygen supply is obviously sufficient in spite of presumably high (i.e. iron and manganese) bacterial activity. Other chemical parameters such as pH, carbonate and other electrolytes are of minor impor-

tance as a wide spectrum of values is tolerated (Buchwald 1989). I note that shallow water is used for oviposition. This may limit the extent of drift of the eggs to sites that are unsuitable for larval development. However, since all sites have apparently negligible or absent water flow a more plausible reason could be that shallow sites limit the amount of potential teleost predators. It seems essentail that the larval microhabitat, i.e. the mud, remains ice-free in winter. Buchwald (1989) hypothesizes that *O. coerulescens* recognizes the winterly absence of freezing by the presence of specific herbaceous plants in summer. However, no such plants grew in the ditches of the study site. It remains unknown how, or if at all, adults can recognize permanent water-bearing of a ditch in winter and also during hot and dry periods outside the reproduction period.

The quality of breeding habitats of *O. coerulescens* may be assessed by the highest recorded density of territorial males at a locality. In 2006, in the 'Chuderriet' this amounted 3.7 ♂/10 m for the entire length of the ditches, and up to 8.0 ♂/10 m for single sections – up to 11.7 ♂/10 m when crowded due to partial desiccation of the ditches. These values were exceptionally high. In 2007 the corresponding values were 1.8 ♂/10 m and 3.0 ♂/10 m, respectively. Buchwald & Schmidt (1990) found a maximal density of 3.8 ♂/10 m on a secondary biotope (meadow ditch), Heymer (1969) recorded 2.0 ♂/10 m on a primary biotope (brook) and Parr (1983) found 1.4 ♂/10 m on a nearly natural stream in heathland. Compared with these findings in Germany, France and England, the ditches in Switzerland exhibited similar or even higher male densities. Hence, this site can be regarded as a high quality secondary habitat that may harbour large annual breeding populations. According to counts resulting in numbers up to 115 males and 14 females per transect it is assumed that the overall annual population may exceed by far 200 individuals. This assessment seems realistic as it is based on calculations by Kéry & Juillerat (2004) who found a sex ratio of 1.0 and a daily survival ratio of 0.77 in a population of *O. coerulescens*. However, as recorded in two consecutive years, the annual numbers may fluctuate considerably as already observed by Parr (1983) and Buchwald (1989).

CONCLUSIONS FOR SPECIES CONSERVATION

The results of this study demonstrate that restored fen ditches with adjacent litter meadows surrounded by a highly anthropogenically-modified landscape may be colonized by viable populations of *O. coerulescens*. Obviously, the species exhibits some ecological plasticity if the main habitat factors characterizing the primary habitats are simulated to a certain extent by the secondary habitats. However, for long-term population persistence, regular management of the water regime and extensive cultivation of the surroundings is required. If the water supply of the ditches is generally low, insertion of controllable weirs can avoid or at least protract the complete desiccation of the ditches during hot and dry periods. During litter-harvest in autumn the dammed up water is drained off for a short time in order to facilitate mowing. Clearing of the ditches is needed periodically as the drains will be completely overgrown after some years. The procedure may be performed manually or mechanically and, if possible, not in a geometrical manner but rather simulating seminatural conditions with sloping banks, slight lateral extensions and local deepenings. Different sections should be treated staggered in time and space, leaving the cleared

stretches untouched for some years. Clearing of ditches may be protracted by mowing the emergent and riparian vegetation during the reproduction period thus preventing the water surface from being completely covered. The terrestrial habitat adjacent to the breeding site should be included in the management plan in order to avoid litter meadows and fallow land to be overgrown by bushes and trees. It would be favourable to maintain species-rich herbaceous vegetation with rather low density and mean height of ca. 0.5 m not being cut before September (Sternberg & Sternberg; White 2006).

The principles of habitat maintenance mentioned above are also valid for other secondary habitats of *O. coerulescens* such as meadow ditches, straightened brooks in urban and agricultural landscapes and seepage runnels in gravel pits. These water bodies face additional problems such as eutrophication or pollution by agrochemicals, and they often lack suitable terrestrial habitats (Buchwald & Schmidt 1990).

Marked individuals have been recorded to move between local breeding habitats up to 1.6 km distant from each other, and for a single male a total flight distance of at least 2.5 km was recorded (Juillerat 2002). For small revitalized water courses with conditions as described above there is good chance to be rapidly colonized by *O. coerulescens* as vagrant imagines are often found in newly created habitats (Moore 1954; Hübner 1988; Juillerat 2002; HW unpubl.).

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