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THE IMPACT OF FORESTRY ON DRAGONFLY DIVERSITY IN CENTRAL SWEDEN

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Abstract

A survey of 32 lakes for dragonfly larvae, aquatic plants and forestry regime in the surrounding boreal forests was performed. The highest diversity was found in undisturbed forests. Lakes rich in aquatic plants were shown also to be rich in dragonflies. A rich plant community is proposed to provide a wider range of micro-habitats thereby increasing dragonfly biodiversity. If the forest surrounding a lake has been logged, a decrease in the species-richness of dragonflies with partivoltine life-cycles can be observed after a 5 year "lag phase." Increased fluctuations in water temperature and leakage of nutrients into the water are two possible causes. Univoltine species are not affected and appear to be less dependent on constant water conditions. The water plant community is only moderately affected, but a slight decrease in the number of species can be observed. A return to more species-rich conditions can be observed after more than 15 years, but whether the original community is restored or replaced with more "trivial" species is an open question.

Introduction

Wetlands such as lakes, ponds and, perhaps the most important component, moors, constitute a significant part of the Swedish boreal forests. The post-glacial forest landscape in Scandinavia is an immense mosaic where numerous water bodies are integrated with large areas of swampy forest, containing a high level of biodiversity (e.g. Hörnberg et al., 1995). Since the boreal forests are nothing but numerous patches (wetlands and drier areas) it is apparent that the wetlands with their special flora and fauna must not be treated separately from the surrounding forest but as an integrated part of it. Changes in the wetlands affect the surrounding forest and vice versa.

Many studies concerning the colonisation of dragonflies into different wetlands (mostly man-made ponds) have been made, both in temperate and tropical areas (e.g. Wildermuth & Krebs, 1983; Moore, 1991; Steytler & Samways, 1995; Samways, 1998). The opposite aspect, the decline of species due to human activities, is also a very popular topic. The cause of this decline is often change of land use, pollution or increased farming and various other human activities (Moore, 1980, 1986; Wildermuth

& Krebs, 1983; Ruddek, 1990; Adomssent, 1994). In Europe, human land use has made several species of dragonflies threatened (van Tol & Verdonk, 1988), which has prompted many governments to enact measures of protection (e.g. Pedersen & Holmen, 1994).

In the boreal forest, timber management is important and undoubtedly has effects on the dragonfly fauna inhabiting the wetlands in the forest mosaic. Rith-Najarian (1998) studied the dragonfly fauna along the upper Mississippi River in Minnesota and found that recently cleared areas contained the lowest number of species and the lowest species diversity. The highest diversity were found in old-growth forest areas. If timber management affects the fauna of running waters, the same must apply for standing waters. In this paper I ask the question: What will happen to a species-rich dragonfly fauna in a small lake when the hydrological conditions are rapidly changed due to clear-cutting of the surrounding forest? Are all species affected similarly or do some species-groups have a greater tolerance to change? Since the dragonfly fauna is in many ways dependent on the composition of water plants in the lake (Buchwald, 1992, 1994), the plant communities at the water's edge are also included in this study.

Materials and methods

During the summers of 1996 and 1997, 32 lakes near the Baltic Sea Coast in the province of Uppland, Central Sweden (approx. 60°30'N, 18°E) were sampled for dragonfly larvae. Only small lakes with a surface area of <0.25 km^2 were chosen since larger lakes tend to have a more heterogeneous shoreline, which makes it difficult to sample all microhabitats present. Sampling was carried out using a standard water net with a mesh size of 1.5 mm and sweeping it through the aquatic vegetation close to the shoreline down to a depth of approx. 0.5 m. Depending on the size of the lake, all larvae found in a section of up to 30 m of the shoreline were collected. In smaller lakes this section was reduced in order to avoid negative impact on species survival at the site. Between 150 and 200 larvae from each site were considered to mirror the actual species composition in the lake. All larvae were fixed in 80% ethanol with an additive of 4% formaldehyde to preserve pigment patterns and determined according to Norling & Sahlén (1997). The two species, *Coenagrion puella* and *C. pulchellum*, could not be separated and were treated as one species.

Since only larvae were used in the study, actual breeding of the species was confirmed at each site and vagrants automatically excluded. For further clarity, the dragonfly species were separated into two sub-groups, i.e. univoltine and partivoltine species. It was assumed that species belonging to the first sub-group would be less selective with regard to the quality of the breeding-water than those in the second group due to them often overwintering as eggs or young larvae followed by a short period of larval growth in spring (the genera *Lestes* and *Sympetrum* in the area; cf. Table 1).

The emerged and submerged vegetation was sampled at each site by randomly laying out 6 squares with an area of 0.25 m^2 and noting the plant species enclosed.

Table 1. Dragonfly species found in the 32 surveyed lakes. Numbers in brackets indicate the number of lakes the individual species were found in.

*Lestes sponsa** (22)	*Cordulia aenea* (8)
*L. dryas** (9)	*Somatochlora metallica* (1)
Erythromma najas (5)	*S. flavomaculata* (5)
Coenagrion armatum (1)	*Epitheca bimaculata* (1)
C. hastulatum (21)	*Leucorrhinia albifrons* (4)
C. lunulatum (4)	*L. dubia* (8)
C. johanssoni (2)	*L. rubicunda* (19)
C. puella/pulchellum (12)	*L. pectoralis* (3)
Enallagma cyathigerum (6)	*Libellula quadrimaculata* (26)
Aeshna caerulea (1)	*Orthetrum cancellatum* (1)
A. juncea (25)	*Sympetrum flaveolum** (6)
A. osiliensis (1)	*S. danae** (15)
A. grandis (22)	*S. vulgatum** (12)
A. viridis (2)	*S. striolatum** (4)
Brachytron pratense (1)	*S. sanguineum** (2)

* = univoltine species.

A brief survey of the surroundings in a circle of 1 km^2 centred at each lake was performed and notes on any type of forestry activities in the area were taken. Forestry measures now mainly consist of clear-cutting or, rarely, a more selective logging, but in the past (>15 years ago) ditching in order to reduce the water level was sometimes performed. Based on data from the local forestry company (Korsnäs AB) and my own observations, the lakes were sorted into 3 classes: (1) No forestry in the area or forestry measures that took place more than 15 years ago; (2) Recent forestry activities, i.e. 0-5 years ago; and (3) Forestry measures undertaken 6-15 years ago. All forested areas are planted with new trees during the first five years after clear-cutting, and allowing another ten years for the growth of the new trees was estimated to be sufficient to re-establish stable hydrological conditions in the area. These new conditions, however, need not be the same as the original ones. In spite of that, lakes where forestry measures were carried out more than 15 years ago were pooled with those without any forestry into class 1 in this study due to few observations and similar species-numbers.

A presence-absence matrix, ranking the lakes from high to low according to number of species present and ranking the species according to number of lakes they occur in were set up sensu Atmar & Patterson (1993). Species more likely to be present in only species-rich lakes will accumulate to one side of this matrix.

Statistical analyses were carried out using the programme Minitab for Windows™ release 11.12 (Minitab, 1996).

Nomeaclature of Odonata follows Norling & Sahlén (1997) according to which the species are systematically arranges in Tables 1 and 2.

Results

A total of 30 dragonfly species was encountered in the area as a whole (Table 1). The number of species breeding in a single lake ranged from 2 to 14, with an average of 7.5. The number of water plant species in the lakes varied between 1 and 15, the average being 10. Altogether 47 plant species were found. The number of dragonfly species was correlated to that of the plants (Regression=0.35; r^2=0.23; F=8.89; P<0.01) although the correlation is only moderately strong.

One way analyses of variance revealed significant differences between the number of dragonfly species present in the 3 classes of forestry (df=2; F=3.92; P<0.05) but for aquatic plants this was not the case (df=2; F=0.43; P>0.65; Fig. 1), although a certain decrease in the number of plant species was observed. Partivoltine species demonstrated an even more significant difference (F=5.22; P<0.02), whereas the distribution of univoltine species did not differ significantly among classes (F=0.77; P>0.45) (Fig. 2). There was no difference in species number between class 1 and 2, either for all species (F=0.20; P>0.65) or counting just partivoltine species (F=0.10; P>0.75). After pooling classes **1** and 2, the difference to class 3 becomes even more pronounced (all species: F=7.77; P<0.01; univoltine species: F=10.65; P<0.004).

In the presence-absence-matrix, 8 species were distinguished to occur in relatively species-rich lakes only, 2 univoltine and 6 partivoltine species (Table 2). Most of them occur only in southern Sweden, some of them reaching further to the north along the Baltic coast.

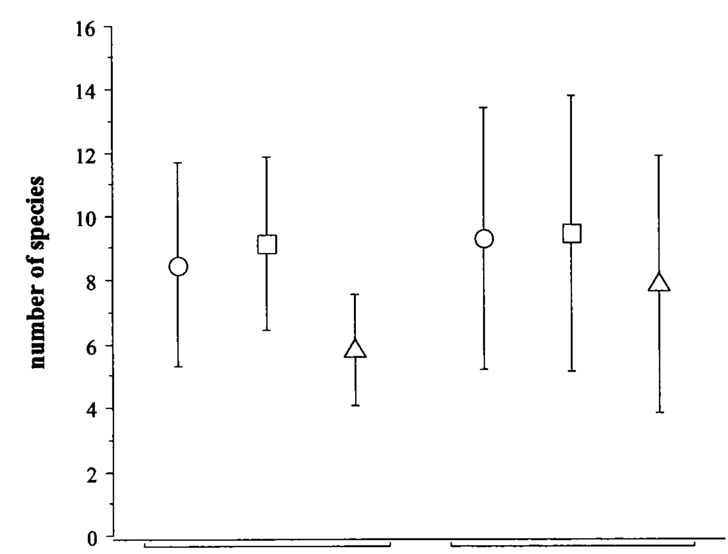

Figure 1. Number of species of dragonflies and aquatic plants in the three categories of forestry (mean ± sd). Circle = Class 1; no or "old" forestry. Square = Class 2; "new" forestry (0-5 yr). Triangle = Class 3; "medium-old" forestry (6-15 yr).

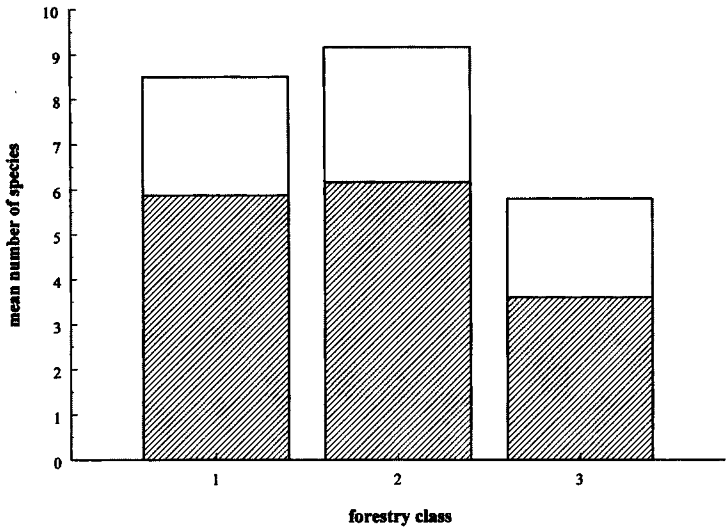

Figure 2. Mean number of dragonfly species (partivoltine species = striped; univoltine species = white) in the 3 forestry classes (defined in Fig. 1). Only partivoltine species decrease significantly ($P<0.004$) in class 3 whereas the small reduction in univoltine species is non-significant.

Table 2. Dragonfly species more likely to be found in species-rich lakes only and their current distribution in Sweden. The fictive border separating "South" and "North" is at about 61° N.

Coenagrion lunulatum	Southern (Baltic coast in north)
Erythromma najas	Southern (Baltic coast in north)
Aeshna viridis	Southern
Somatochlora flavomaculata	Southern (small area in north)
Leucorrhinia albifrons	Southern (Baltic coast in north)
L. pectoralis	Southern
Sympetrum sanguineum	Southern (old record in north)
S. striolatum	Southern

Discussion

In previous studies it has been shown that certain dragonfly species prefer to live in an environment with a specific composition of aquatic plants (House, 1991; Buchwald, 1992, 1994). A well-known example in Europe is the association of *Aeshna viridis* with lakes and ponds containing the water-lily, *Stratiotes aloïdes* (e.g. Robert, 1958; Norling, 1971, 1975). However, this association between dragonflies and plants is never absolute and may vary among different areas.

This 'water plant-dragonfly species' association is generally evident in that the lakes with the highest number of dragonfly species also had the highest number of aquatic plants. This connection is hardly surprising since lakes with a high number of plant species can be expected to offer suitable habitats for more dragonfly species. It is likely that even a species which is selective in its choice of breeding water would be able to find its favoured plant composition at least somewhere in a lake rich in plant species. In some species displaying a strong plant association, selectivity in the choice of breeding waters may lead to a reluctance to disperse after emergence, as in the central European species *Ceriagrion tenellum* (Buchwald, 1994). It may also result in a small chance to spread due to lack of suitable habitats in spite of a good ability to disperse as in *Orthetrum coerulescens* in central Europe (Buchwald & Schmidt, 1990). As species with these kinds of demands tend to become rarer in Europe today, they will eventually be confined to their isolated localities indefinitely, with no possibility of spreading (or surviving).

The lakes with the highest number of dragonflies (and plants) were all situated in old woodland. There had been forestry activities in the areas, but only a long time ago. Rith-Najarian (1998) found the same link between species diversity and old forests in riverine dragonflies in Minnesota. Apparently undisturbed forest is a component necessary to keep high diversity of dragonflies in boreal forest. Given the assumption that selective, "rare" species will find only lakes and rivers in old growth areas acceptable for breeding, the implications of forestry impact on these habitats are severe. The number of sites with a wide array of microhabitats for dragonflies have decreased significantly and this will make dispersal difficult for species dependent on particular plant-compositions or other factors necessary for egg or larval development. Lack of suitable larval habitats has been observed in the stream-dwelling *Cordulegaster boltoni* in Wales, where conifer plantations have eroded the normal stream margins of moorland and deciduous forest (Ormerod et al., 1990)

Norling (1984a and pers. comm.) has studied the life cycles of several dragonfly species in Central Sweden. He reports that when the forest surrounding one of his study areas was logged the larval development in some species was shortened from the normal 3-4 years to 2-3 years, probably resulting from increased solar heating of the lake. Another effect was a significant increase in population size due to the short-term release of nutrients into the water caused by the logging. In the following year the population returned to a longer development time. The long-term effects on the life cycles in an area with clear-cuts has not yet been thoroughly investigated, but it is tempting to propose that dragonfly life cycles in any given undisturbed lake, provided that it is located in a closed forest that limits solar radiation, are "slow" in comparison to lakes in recently logged areas where changing conditions will induce the species to develop faster. High water temperatures are, in general, favourable to many insect taxa (e.g. Nordlie & Arthur, 1981), including many dragonflies (Waringer, 1983; Baker & Feltmate, 1987; Pritchard, 1989; Mathavan, 1990; Krishnaraj & Pritchard, 1995), but temperature needs to be combined with other factors, e.g. food availability.

Some species (cf. Norling, 1984a; also 1976, 1984b and 1984c) thus seem to be able to adapt their life cycles, apparently without any obvious problems. This plasticity with regard to life cycles is probably what keeps most of the rarer species alive in a changing environment such as a lake after logging. The life-cycle changes of dragonflies in this study seem to occur gradually over a period of years. Other insect populations have also shown similar "slow" responses to disturbance, e.g. carabid beetle diversity after forest fires and clear-cutting (Lenski, 1982; Niemelä et al., 1993; Haila et al., 1994; Wikars, 1995).

But what causes the decrease in the number of species? In the present study, the number of partivoltine dragonflies are clearly diminished by forestry while the number of plants and the univoltine dragonflies are not. The plants seem to react more slowly to imposed hydrological changes than the dragonflies and but a slight decrease is noted. Over a longer time span, the plants would perhaps also show a significant decrease. Possibly the wider temperature range in a lake exposed by logging is one of the key factors in the selective decrease of dragonflies. Temperature is an important limiting factor for many animals in the northern range of their distribution. Sjögren Gulve (1994) found the average water temperature in May to regulate whether the Pool frog (*Rana lessonae Camerano*) was present in small lakes or not. The same sensitivity to temperature extremes may be used to explain the absence of some dragonfly species in lakes surrounded by clear-cuts. Many of the dragonfly species in the area are on the northern limits of their distribution; so the similarity to the conditions for the Pool frog is obvious (cf. distribution maps for Sweden in Sahlén, 1996 or Sandhall, 1986). If the selective species of dragonflies are sensitive to changes in temperature, they would quickly become eliminated by the harsh environment resulting when a small lake is surrounded by clear-cuts. All selective species occurring in this area of Sweden should thus be ones with a southern distribution. More northern species, selective or not, have in some cases the ability to endure dry periods as well as freezing within their 3-4 years of development (Johansson & Nilsson, 1991). Water temperature may therefore be of less importance further to the north. I found that the species which disappeared from clear-cut areas all have a southern distribution in Sweden (Table 2). Three of them (*Coenagrion lunulatum, Erythromma najas* and *Leucorrhinia albifrons*) also occur along the Baltic Sea coast further to the north where winters are somewhat (if not much) less severe than in the inland. Water temperature, at least in this part of Sweden, seems to play a crucial role in dragonfly distribution.

The univoltine species are not affected and, being opportunists, needing open water and food for the larvae only from April to July in Central Sweden. In general, such species are often present in a wide range of habitats, including temporary waters, where some traits, like a highly flexible life cycle and temperature-linked development, are needed for their survival (cf. e.g., Williams, 1996).

Presence or absence of a species may also depend on the requirements of the other life stages, the eggs and the adults. In any case, water temperature and the age of surrounding forest are not the only factors affecting dragonfly diversity in the forest mosaics of Scandinavia. A question to pursue is if the re-established species-rich fauna present in areas logged long ago indeed contains the same species as the primeval fauna in undisturbed areas. Considering the monoculture of secondary forest plantations one may fear that the seemingly recovered biodiversity turns out to consist of trivial (i.e. "common") species only. I hope further research will prove this to be wrong.

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References

Adomssent, M. 1994. Bemerkungen zur Situation der Libellen im Kreis Herzogtum Lauenburg. Faunistisch-Oekologische Mitteilungen 6: 439-468.

Atmar W. & B. D. Patterson, 1993. The measure of order and disorder in the distribution of species in fragmented habitat. Oecologia 96: 373-382.

Baker, R. L. & B. W. Feltmate, 1987. Development of *Ischnura verticalis* (Coenagrionidae: Odonata): Effects of temperature and prey abundance. Canadian Journal of Fisheries and Aquatic Sciences 44: 1658-1661.

Buchwald, R. 1992. Vegetation and dragonfly fauna - characteristics and exampels of biocenological field studies. Vegetatio 101: 99-107.

Buchwald, R. 1994. Experimentelle Untersuchungen zu Habitatselektion und Biotopbindung bei *Ceriagrion tenellum* De Villers, 1789 (Coenagrionidae, Odonata). Zoologische Jahrbücher Abteilung für Systematik, Ökologie und Geographie der Tiere 121: 71-98.

Buchwald, R. & B. Schmidt, 1990. Der Kleine Blaupfeil (*Orthetrum coerulescens*, Odonata) in Südbaden: Spezielle Untersuchungen zu ökologischen Ansprüchen, Populationsdynamik und Gefährdung. Mitteilungen des Badischen Landesvereins für Naturkunde und Naturschutz E. V. Freiburg im Breisgau 15: 109-144.

Haila, Y., I. Hanski, J. Niemelä, P. Punttila, S. Raivio & H. Tukia, 1994. Forestry and the boreal fauna: matching management with natural forest dynamics. Annales Zoologici Fennici 31: 187-202.

Hörnberg, G., M. Ohlson & O. Zackrisson, 1995. Stand dynamics, regeneration patterns and long-term continuity in boreal old-growth *Picea abies* swamp-forests. Journal of Vegetation Science 6: 291-298.

House, N. L. 1991. Oviposition Preferences of Dragonflies and their Influence on Larval Distribution. M. Sc. Thesis, Acadia University, Wolfville, Canada.

Johansson, F. & A. N. Nilsson, 1991. Freezing tolerance and drought resistance of *Somatochlora alpestris* (Selys) larvae in boreal temporary pools (Anisoptera: Corduliidae). Odonatologica 20: 245-252.

Krishnaraj, R. & G. Pritchard, 1995. The influence of larval size, temperature, and components of the functional response to prey density on growth rates of the dragonflies *Lestes disjunctus* and *Coenagrion resolutum* (Insecta: Odonata). Canadian Journal of Zoology 79: 1672-1680.

Lenski, R. E. 1982. Effects of forest cutting on two *Carabus* species: evidence for competition for food. Ecology 63: 1211-1217.

Mathavan, S. 1990. Effect of temperature on the bio-energetics of the larvae of *Brachythemis contaminata* (Fabricius) and *Orthetrum sabina* (Drury) (Anisoptera: Libellulidae). Odonatologica 19: 153-166.

Minitab 1996. Minitab Release 11.12. Minitab Inc., State College, PA.

Moore, N. W. 1980. *Lestes dryas* Kirby - a declining species of dragonfly (Odonata) in need of conservation: Notes on its status and habitat in England, UK and Ireland. Biological Conservation 17: 143-148.

Moore, N. W. 1986. Acid water dragonflies in eastern England (UK): their decline, isolation and conservation. Odonatologica 15: 377-386.

Moore, N. W. 1991. The development of dragonfly communities and the consequences of territorial behaviour:

a 27 year study on small ponds at Woodwalton Fen, Cambridgeshire (England), UK. Odonatologica 20: 203-232.

Niemälä, J., L. Langor & J. R. Spence 1993. Effects of clear-cut harvesting on boreal ground-beetle assemblages (Coleoptera: Carabidae) in Western Canada. Conservation Biology 7: 551-561.

Nordlie, K. J. & J. W. Arthur, 1981. Effect of elevated water temperature on insect emergence in outdoor experimental channels. Environmental Pollution, Series A: Ecological and Biological 25: 53-66.

Norling, U. 1971. The life history and seasonal regulation of *Aeshna viridis* Eversm. in southern Sweden (Odonata). Entomologica Scandinavica 2: 170-190.

Norling, U. 1975. Livscykler hos svenska odonater. Entomologen 4: 1-14.

Norling, U. 1976. Seasonal regulation in *Leucorrhinia dubia* (Vander Linden) (Anisoptera: Libellulidae). Odonatologica 5: 245-263.

Norling, U. 1984a. Life-history patterns in the northern expansion of dragonflies. Advances in Odonatology 2: 127-156.

Norling, U. 1984b. The life cycle and larval photoperiodic responses of *Coenagrion hastulatum* (Charpentier) in two climatically different areas (Zygoptera: Coenagrionidae). Odonatologica 13: 429-449.

Norling, U. 1984c. Photoperiodic control of larval development in *Leucorrhinia dubia* (Vander Linden): a comparison between populations from northern and southern Sweden (Anisoptera: Libellulidae). Odonatologica 13: 529-550.

Norling, U. & G. Sahlén, 1997. Odonata, dragonflies and damselflies. In: Anders Nilsson (ed.) The Aquatic Insects of North Europe 2: 13-65.

Ormerod, S. J., N. S. Weatherley, & W. J. Merrett, 1990. The influence of conifer plantations on the distribution of the golden ringed dragonfly *Cordulegaster boltoni* (Odonata) in Upland Wales (UK). Biological Conservation 53: 241-252.

Pedersen, H. & M. Holmen, 1994. Fredede insekter i Danmark, del 4: Guldsmede. Entomologiske Meddelelser 62: 33-58.

Pritchard, G. 1989. The roles of temperature and diapause in the life history of a temperate-zone dragonfly: *Argia vivida* (Odonata: Coenagrionidae). Ecological Entomology 14: 99-108.

Rith-Najarian, J. C. 1998. The influence of forest vegetation variables on the distribution and diversity of dragonflies in a northern Minnesota forest landscape: A preliminary study (Anisoptera). Odonatologica 27: 335-351.

Robert, P.-A. 1958. Les Libellules. Delachaux & Niestlé, Neuchâtel.

Ruddek, J. 1990. Zur Erfassung der Libellen in Bremen und Ungebung. Abhandlungen naturwissenschaftlichen Verein zu Bremen 41: 153-160.

Sahlén, G. 1996. Sveriges trollsländor (Odonata). 2nd ed. Fältbiologernas förlag, Sollentuna.

Samways, M. J. 1998. Establishment of resident Odonata populations on the formerly waterless Cousine Island, Seychelles: An island biogeography theory (IBT) perspective. Odonatologica 27: 253-258.

Sandhall, Å. 1986. Trollsländor i Europa. Interpublishing, Stockholm.

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

Sjögren Gulve, P. 1994. Distribution and extinction patterns within a northern metapopulation of the pool frog *Rana lessonae*. Ecology 75: 1357-1367.

van Tol, J. & M. J. Verdonk, 1988. The Protection of Dragonflies (Odonata) and their Biotopes. European Committee for the conservation of Nature and Natural Resources, Strasbourg.

Waringer, J. 1983. A study on embryonic development and larval growth of *Sympetrum danae* at two artificial ponds in lower Austria (Anisoptera: Libellulidae). Odonatologica 12: 331-344.

Wikars, L.-O. 1995. Clear-cutting before burning prevents establishment of the fire-adapted *Agonum quadripunctatum* (Coleoptera: Carabidae). Annales Zoologici Fennici 32: 375-384.

Wildermuth, H & A. Krebs, 1983. Sekundäre Kleingewässer als Libellenbiotope. Vierteljahrsschrift der Naturforschenden Gesellschaft in Zürich 128: 21-42.

Williams, D. D., 1996. Environmental constraints in temporary fresh waters and their consequences for the insect fauna. Journal of the North American Benthological Society 15: 634-650.