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ORIGINAL PAPER

Macroarthropod species richness and conservation priorities in *Stratiotes aloides* (L.) lakes

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Abstract Species with narrow ranges and specialised traits are most at risk, and the extinction wave is further enhanced by coextinctions. We studied the conservation value and indicator potential of *Stratiotes aloides*, an aquatic macrophyte that has declined considerably in Europe. Our purpose was to determine whether *S. aloides* could be used as an indicator of a valuable habitat in terms of macroarthropod diversity and species richness. The potential occurrence of an internationally endangered *Stratiotes*-habitat specialist, the dragonfly *Aeshna viridis*, can increase the conservation value of plant colonies. *S. aloides* beds harboured diverse macroarthropod fauna often containing species of conservation concern, including *A. viridis*. *Stratiotes* is a potential indicator of a valuable habitat, and its indicator value is enhanced by the easy identification of the species. However, its use as an indicator of a defined macroarthropod community is limited because no particular community type is connected to it. We suggest that protecting *Stratiotes* simultaneously conserves valuable arthropod fauna, including *A. viridis*.

Keywords *Aeshna viridis* · Biodiversity · Coextinction · Eutrophic lakes · Indicator species · Water soldier

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Introduction

Habitat loss is the most direct threat to biodiversity worldwide (Pimm and Raven 2000; Pullin 2002), and at current rates of habitat destruction the worst may yet be to come (Pimm and Raven 2000; Thomas et al. 2004). Numerous species have suffered from human impact, but species with narrow ranges and specialised traits are even more vulnerable than more widely distributed or generalist ones (Pimm and Raven 2000; Brook et al. 2003; Altizer et al. 2007). The modern extinction wave is further enhanced by coextinctions, in which the loss of one species leads to the extinction of others dependent on it (Koh et al. 2004; Altizer et al. 2007). In making decisions on biodiversity conservation, connections between species and the effects of species extinction on other species should also be taken into account.

Parallel to other ecosystems, the biological diversity of freshwater fauna is declining at an increasingly rapid pace (Richter et al. 1997; Ricciardi and Rasmussen 1999). One of most significant threats to freshwater ecosystems are land-use activities causing alterations in sediment loads and nutrient inputs, interactions with exotic species, and impoundment operations resulting in flow regulation, fragmentation and altered hydrology (Richter et al. 1997;

Ricciardi and Rasmussen 1999; Sala et al. 2000). The consequences of climate change are also thought to be most severe in freshwater environments (Abell 2002). More species and habitat information is needed to assist in selecting priorities for protection (Abell 2002).

To aid conservation decisions and to resolve conflicts between natural values and human exploitation, different means have been used to evaluate and conserve biological diversity. In an ideal world, a community under threat would be thoroughly studied prior to deciding on conservation measures. In reality this is often impossible because of a lack of funding, time and/or professional personnel. To save time and money, species, taxa and groups of organisms have been used that are assumed to indicate the conservation values of their community or ecosystem (e.g. Launer and Murphy 1994; Lambeck 1997; Rubinoff 2001; Poiani et al. 2001, Suter et al. 2002; Rainio and Niemelä 2003; Roberge and Angelstam 2004). The outcome of using conservation surrogates (e.g. keystone, flagship, umbrella and focal species) has varied. In some cases a multi-species approach has been successful (Beccaloni and Gaston 1995; Chase et al. 2000; Carroll et al. 2001; Kati et al. 2004; Roberge and Angelstam 2004); sometimes studies of a single species have been valuable (Launer and Murphy 1994; Britten and Rust 1996; Martikainen et al. 1998; Fleishman et al. 2001; Suter et al. 2002; Caro 2003). The central idea at all times has been to evaluate and protect part of biological diversity via conserving surrogates.

One species pair that is linked to habitat destruction and coextinction consists of a water macrophyte *Stratiotes aloides* L. (Hydrocharitaceae) and a dragonfly *Aeshna viridis* L. (Anisoptera). *S. aloides*, the water soldier, also has potential as a conservation surrogate, since plant aggregations maintain diverse macroinvertebrate communities (Higler 1977; de Jong 2001; Koperski 2002; Tarkowska-Kukuryk 2006). *S. aloides* is a perennial whose range of occupancy includes Central, Eastern and Northern Europe and Central Asia (Cook and Urmi-König 1983). Since its spine-leaved, rigid rosettes often form dense accumulations, *S. aloides* creates a spatially complex and sheltered habitat. Although most species that live on *Stratiotes* are generalists that benefit from the sheltered habitat, there are also some *S. aloides*-specialists. One of them is the dragonfly *A. viridis*, the green hawker. The females of this species mostly oviposit in *S. aloides* leaves (Münchberg 1956; Askew 1988); during the larval phase, *S. aloides* beds protect the larvae against predation by fish (Rantala et al. 2004) and other dragonfly larvae (Suutari et al. 2004).

During the last decades *S. aloides* has declined considerably in Europe, due mainly to excessive eutrophication (Schmidt 1975; Toivonen 1985; Toivonen and Bäck 1989; Smolders et al. 1996) enhanced by other factors such as a changed hydrological situation (Roelofs 1991). A declining trend in population numbers has also been detected in Finland (Toivonen 1985; Toivonen and Bäck 1989; Rassi et al. 2001), where *S. aloides* grows at in its northern limit in Europe (Cook and Urmi-König 1983). Because of the loss of suitable breeding habitats supporting *S. aloides*, *A. viridis* has likewise suffered a radical decline (Schmidt 1975; Rassi et al. 2001). *A. viridis* is protected by the Habitats Directive of the European Union (Anonymous 1992) and by national legislation in many European countries. If the presence of *A. viridis* in an *S. aloides* population goes undetected, the plant receives no protection and the dragonfly disappears if *S. aloides* is destroyed. Similarly, if non-occupied *S. aloides* populations that overlap with the distribution of *A. viridis* become extinct, the potential range of occupation of *A. viridis* diminishes.

Because of the connection between *S. aloides* and *A. viridis*, the biological richness of *S. aloides* beds, and some features of conservational status of *S. aloides*, we studied the conservation value and indicator potential of *S. aloides*. Our purpose was to determine whether the occurrence of *S. aloides* could be used as an indicator of valuable habitat in terms of species richness and biodiversity of epiphytic macroarthropod species. Our study was conducted in southern Finland, where lakes inhabited by *S. aloides* and *A. viridis,* as well as eutrophic waters without *S. aloides,*are found. If lakes with *S. aloides* fostered a richer fauna than lakes without the species, and in particular if *S. aloides* presence tended to co-occur with arthropod species of conservation concern, *S. aloides* would deserve special conservation attention. The presence of the plant is much easier and less costly to detect than the presence of most arthropod species; thus *S. aloides* may provide a cost-efficient conservation tool for managers if it tends to indicate overall species richness of arthropod fauna.

Methods

Study area

Our study was conducted in the Häme and Pirkanmaa region in southern Finland (61°30′N, 24°20′E) over an area of 50 × 80 km. To study differences in species richness in *S. aloides* lakes and other eutrophic lakes, we sampled 14 lakes, eight of them supporting *S. aloides*. The minimum distance between lakes was 0.8 km. All study sites were eutrophic, with rich emergent, floating-leaved and submerged aquatic flora. Macrophytes covered at least one-third of the surface area of the lakes, or bays of large lakes, studied. The surface area of lakes and bays varied greatly, from a few hectares to more than hundred hectares. All the areas studied were shallow, with a maximum depth of only a few meters. The bottom substrate was mud.

Macroarthropod samples

Macroarthropod samples were taken in late May–early June 2000 (sweep samples) and in September of the same year (traps). We took eight samples from each lake with a 2-min sweep with a pond net (D-shape; width 35 cm, height 25 cm, mesh size 0.4 mm). In *S. aloides* lakes, the samples were taken from *S. aloides* patches. In other eutrophic lakes, they were taken from the lower littoral zone vegetation (depth 0.5–1.0 m), where *S. aloides* would usually occur. To obtain a more extensive picture of the species richness at our study locations, we placed three cylinder-like traps covered with nets (mesh size 0.5 mm) (description of traps in Bagge 1999) in each study lake. The traps were left overnight (ca. 17 h) on the bottom. In *S. aloides* lakes, they were placed among *S. aloides* stands and in other eutrophic lakes among the bottom vegetation in the lower littoral zone. Two traps were provided with fish bait, one with a yellow light-stick. The arthropods captured by pond net and traps were conserved in 70% ethanol. L. Paasivirta and J. Salmela identified all specimens to the species level with a microscope. In the few cases where species-level identification was impossible, individuals were identified to the next higher systematic level.

Water samples

In September 2000, we took two separate water samples from each study site to determine whether *S. aloides* lakes and other eutrophic lakes differed in certain aspects of water quality. The alkalinity, pH, conductivity, and total phosphorus and total nitrogen content of the water samples were analyzed using standard methods at the Institute of Environmental Research in Jyväskylä, Finland. For statistical tests, we used the mean of the two samples.

Data analyses

We calculated the biodiversity index for all arthropod orders studied except for Lepidoptera and Megaloptera, since our samples contained only two species belonging to these orders. We computed the Shannon–Wiener function as a biodiversity index (H'):

$$H' = \sum_{i=1}^{s} (p_i) \log_e(p_i)$$

where S is the number of species and p_i is the proportion of the total sample belonging to the ith species (Krebs 1998). We used non-parametric tests because the requirements for parametric testing were not fulfilled. The results reported give two-tailed significances. Since we had preliminary information of the existence of *A. viridis* in some study areas, we represent our results with and without *A. viridis*. We analyzed the data using the SPSS-Statistical Package (version 14.0).

Results

Species richness

In total, 24,169 individuals of 259 different species or higher systematic group were identified from our samples. In the total number of species per lake, there was a clear trend of *S. aloides* lakes being more species-rich than other eutrophic study lakes (Table 1). Because we had foreknowledge of *A. viridis* populations in our study area, we analysed the data also without *A. viridis* and the trend was similar (Mann–Whitney U-test; $U = 9.5$; $P = 0.061$). Of taxonomic groups, the number of odonate species was higher in *S. aloides* lakes (Table 1). The trend remained when *A. viridis* was excluded from analyses (Mann–Whitney

Table 1 Differences in total species numbers of macroarthropod orders in eight *S. aloides* lakes and six lakes without *S. aloides* in southern Finland

Order	*S. aloides* present			*S. aloides* absent			Test	
	Mean	SD	No. of species	Mean	SD	No. of species	*U*	*P*
Diptera	38	7	91	37	7	84	22	0.796
Ephemeroptera	5	2	14	4	1	9	13	0.141
Odonata	11	4	17	7	2	14	7.5	0.032
Lepidoptera	2	1	2	1	1	1	3	0.004
Trichoptera	8	1	20	7	2	19	16	0.278
Megaloptera (Sialidae)	0	1	2	0	1	2	23	0.871
Heteroptera	12	3	26	8	4	32	10.5	0.078
Coleoptera	18	7	56	15	4	45	15	0.242
Arachnae + Hydrachnellae	12	6	29	12	4	28	21	0.695
Total species number	106	16	257	90	14	234	9	0.053

Statistical test: Mann–Whitney *U*-test

U-test; $U = 9$; $P = 0.051$). Also lepidopteran species were more numerous in *S. aloides* lakes (Table 1). Other arthropod groups showed no difference between lake types (Table 1).

Shannon–Wiener diversity

The highest Shannon–Wiener diversity was found in the order of Diptera, the lowest in the order of Ephemeroptera (Table 2). *Stratiotes aloides* lakes harboured slightly higher biodiversity in the order of Trichoptera than other eutrophic study lakes (Table 2). Other arthropod groups showed no differences between lake types (Table 2).

Conservation priority species

Stratiotes aloides lakes harboured more species of conservation priority than other study lakes (Mann–Whitney *U*-test; $U = 5.5$; $P = 0.012$; Table 3). Three out of the six conservation priority species were odonates that prefer eutrophic waters (Table 3). However, when *A. viridis* was excluded from the data this difference was no longer detected (Mann–Whitney *U*-test; $U = 12$; $P = 0.092$). Apart from this species, we found some other dragonfly species (*Leucorrhinia caudalis* and *Leucorrhinia pectoralis*) included in the list of the Habitat Directive in *S. aloides* lakes (Table 3); these species, however, coexisted with *A. viridis* in one lake only. The remaining three species (Table 3) also typically occur in nutrient-rich habitats. Two of these species, the coleopteran *Dytiscus latissimus* L. and the ephemeropteran *Caenis robusta* Eaton, were also found in other than *S. aloides* lakes. A faunistically interesting although at least as yet unprotected species detected in four *S. aloides* lakes was the caddisfly *Tricholeiochiton fagesii* Guinard (Trichoptera, Hydroptilidae), previously recorded at only two sites in Finland (Salokannel et al. 2004).

Water quality

The study lakes were nutrient-rich and their pH was near neutral (range 6.35–8.05). No differences in alkalinity, pH, conductivity, total nitrogen or total phosphorus were found between *Stratiotes* lakes and other eutrophic lakes (Table 4).

Discussion

Stratiotes aloides lakes are shown to be species-rich and faunistically interesting waters in Finland too, and when found should receive special attention as indicators of valuable habitat. Lakes occupied by *Stratiotes* harboured slightly more species of conservation concern than other eutrophic lakes. In studies conducted in Central Europe, water soldier stands have similarly been recorded as inhabited by a diverse macroinvertebrate fauna (Higler 1977; de Jong 2001; Koperski 2002; Tarkowska-Kukuryk 2006). Since we had foreknowledge of *A. viridis* populations in our study area, we also analysed the data without

Table 2 Differences in Shannon–Wiener diversity indexes of macroarthropod orders in eight *S. aloides* lakes and six lakes without *S. aloides* in southern Finland

Order	*S. aloides* present		*S. aloides* absent		Test	
	Mean	SD	Mean	SD	*U*	*P*
Diptera	2.66	0.47	2.71	0.34	21	0.699
Ephemeroptera	0.91	0.35	0.87	0.23	21	0.699
Odonata	1.83	0.38	1.57	0.28	11	0.098
Trichoptera	1.44	0.27	1.14	0.26	9	0.053
Heteroptera	1.62	0.35	1.69	0.44	23	0.897
Coleoptera	2.26	0.51	1.91	0.22	14	0.197
Arachnae + Hydrachnellae	1.84	0.47	1.99	0.34	21	0.699

Statistical test: Mann–Whitney *U*-test

Table 3 Numbers of conservation priority species in *S. aloides* lakes and lakes without *S. aloides* in southern Finland

Order	Species	Classification	Lake type	
			S. aloides present	*S. aloides* absent
Coleoptera	*Dytiscus latissimus* (L.)	Dir. II, IV	0	1
	Graphoderus bilineatus (De Geer9	Dir. II, IV	1	0
Ephemeroptera	*Caenis robusta* (Eaton)	NT	3	1
Odonata	*Aeshna viridis* (Eversm.)	EN, Dir. IV	5	0
	Leucorrhinia caudalis (Charp.)	Dir. IV	2	0
	Leucorrhinia pectoralis (Charp.)	Dir. II, IV	1	0

Classification abbreviations: Dir. II/IV, European Union Habitat Directive species, appendix II/IV; NT, near threatened; EN, endangered

Table 4 Water quality differences in eight *S. aloides* lakes and six lakes without *S. aloides* in southern Finland

Variable	*S. aloides* present		*S. aloides* absent		Test	
	Mean	SD	Mean	SD	*U*	*P*
Alkalinity (mmol/dm^3)	0.45	0.20	0.53	0.14	16	0.301
pH	6.95	0.49	7.05	0.39	15	0.244
Conductivity (mS/m)	13.1	8.7	11.1	4.36	23	0.897
Total nitrogen (mg/dm^3)	0.96	0.78	1.11	0.52	15	0.245
Total phosphorus (mg/dm^3)	0.08	0.07	0.08	0.06	21.5	0.747

Statistical test: Mann–Whitney *U*-test

A. viridis. Analysed in this manner, the difference between the two lake types in the number of species of conservation concern generally diminished. The trend whereby *S. aloides* lakes were more diverse in overall species richness was detected in our study, but was somewhat weakened by excluding *A. viridis*.

According to Higler (1977), the invertebrate versatility of *S. aloides* stands did not depend on plant-specific structure or water chemistry factors. Our study results are consistent with his observations, since we detected no water quality factors that would explain the high species richness in *S. aloides* lakes (Table 3). This is not surprising, since both lake types were situated in the same geographical area and neither the land-use of their surroundings nor their geological or climatic conditions varied substantially. The diverse and conservationally valuable macroarthropod fauna of *S. aloides* lakes (Table 1) can most probably be explained by the generally beneficial, sheltered circumstances created by dense and spatially complex plant aggregations, a conclusion also arrived at by Higler (1977) in his extensive study of macrofaunal communities in *S. aloides* stands. He also noted that despite the observed species richness, no particular community type was connected to *S. aloides*. Our study supports this view. Although we discovered that odonate species composition was more diverse in *S. aloides* lakes and more protected dragonfly species occurred in them, all species except *A. viridis* preferred richly vegetated lakes in general or were opportunistic, with no special connection to *S. aloides*. This was likewise the case in other macroarthropod groups; the species were typical of eutrophic waters.

Since no particular community type can be linked with *S. aloides*, its use as an indicator for a defined group of organisms is limited. However, the choice of indicator depends on the type of biodiversity evaluated (Duelli and Obrist 2003). *S. aloides* can be seen as an indicator of a valuable habitat, and it has a certain significance for biodiversity conservation because of its status as a shelter plant of *A. viridis* (Rantala et al. 2004; Suutari et al. 2004) and because of its rich macroarthropod fauna. Due to its unusual and conspicuous form of growth it is easily recognisable, helping the local authorities to monitor habitat condition. Managing *S. aloides* populations is also possible; it seems to benefit from moderate dredging and the removal of competing water macrophytes (Suutari, personal observation). In the Nordic countries the water soldier reproduces vegetatively (Renman 1989), and in favourable circumstances clonal populations can expand rapidly. This facilitates the maintenance of species richness in *S. aloides* waters.

During the last decades *S. aloides* has declined noticeably in central Europe and Finland (Toivonen 1985; Roelofs 1991; Smolders et al. 1996; de Jong 2001). The reasons for this decline vary somewhat regionally, but a major cause is excessive eutrophication. Although *S. aloides* requires nutrient-rich water, in heavily eutrophicated conditions the shading of phytoplankton and macrophytes leads to its decline or disappearance. Eutrophication can also cause chemical changes that further degrade growth conditions (Smolders et al. 1996). Since *S. aloides* reproduces vegetatively (Renman 1989), its distribution is limited by its dependence on rivers, ditches and floods as dispersal canals. Sometimes the dense and spiny stands can be a local nuisance, leading to the removal of plant biomass. The total removal of *S. aloides* stands is destructive and will lead to the extinction of *A. viridis*, since this dragonfly species is dependent on it (see also Koh et al. 2004; Altizer et al. 2007).

In freshwater biodiversity conservation terrestrial land use must be taken into account as well, since it has a substantial impact on freshwater ecosystems (Sala et al. 2000; Abell 2002). Since eutrophication is the most urgent threat to *S. aloides*, the management of *Stratiotes* stands must be connected to the land use of areas surrounding the focal water bodies (Wiens 2002). Excessive nutrient run-off can be resisted at least to some extent by leaving shelter zones of intact vegetation between the shoreline and farmland. To prevent vegetation overgrowth, dredging or removal of helophytic macrophytes and nymphaeids may be needed to create better growth conditions for *S. aloides*.

To conclude: *S. aloides* was found to provide a habitat for diverse water insect fauna, often including species of conservation concern (Table 2). The potential occurrence of the internationally endangered *A. viridis* in *S. aloides* stands increases the conservation value of the plant colonies. According to Duelli and Obrist (2003), nationally rare or endangered species have a higher conservation value than common species, since they contribute more to regional or national biodiversity. This must be even more so where an internationally endangered species is concerned. Since *A. viridis* is able to move long distances to occupy new *S. aloides* patches, *Stratiotes* populations that do not support *A. viridis* but overlap with its distribution should also be considered as potential habitats of an endangered species. Non-occupied habitat patches can be important in maintaining viable populations. *S. aloides* is also a potential indicator of a valuable habitat. Its conspicuous, "pineapple-like" growth form makes it easily recognisable and less costly to detect than the presence of most arthropod species. By protecting *Stratiotes* stands and their favourable growth conditions, valuable water arthropod species can evidently be conserved at the same time.

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