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GREAT CRESTED NEWTS (*TRITURUS CRISTATUS*) AS INDICATORS OF AQUATIC PLANT DIVERSITY

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In a field study in south central Sweden, we analysed the diversity of macrophytes in paired samples of ponds in a total of five geographically separated sites. Each pair of ponds involved one pond with presence of great crested newts (*Triturus cristatus*) and one pond in which newts were absent. Ponds with presence of great crested newts had a significantly higher mean number of plant species than ponds without newts. Newts occurred in ponds that tended to have a lower amount of pond area covered by surface vegetation, although this difference was not statistically significant. Macrophyte diversity also tended to increase more steeply in ponds with *T. cristatus*, compared with ponds without newts. Broad-leaved pond weed (*Potamogeton natans*) and square-leaved liverwort (*Chiloscyphus pallescens*) were among the plants that were most associated with presence of great crested newts. Plant diversity had a slightly more nested structure for ponds with great crested newts than for those without, which indicates a more homogeneous plant species assemblage in the former group of ponds. Overall, the results indicate that the great crested newt may be a reliable and useful indicator species for high plant species richness in ponds and small wetlands, which may be valuable for environmental monitoring and conservation in pond landscapes.

Key words: Amphibia, habitat selection, pond succession, species distribution patterns

INTRODUCTION

A common assumption in modern conservation is that some species can be used as reliable indicators of biological diversity. Such ‘indicator species’ are assumed to mirror changes in population processes, species distributions and viability in other taxa, at both local and regional scales, thus providing a tool for measuring and monitoring effects on biodiversity (Pearson, 1995). Selecting suitable indicator species is both difficult and controversial, and is often made with incomplete background information (Simberloff, 1998; Caro & O´Doherty, 1999; Noss, 1999; Simberloff, 1999; Hess & King, 2002). However, a primary requirement must be that the species really has the ability to indicate the attributes of concern for conservation (Lindenmayer, 1999). Because few species have been tested or validated empirically for their value as indicators, studies of co-occurrence patterns and of the strength of correlations in diversity patterns among taxa are needed (Simberloff, 1998; Lindenmayer, 1999; Noss, 1999; Simberloff, 1999).

The great crested newt, *Triturus cristatus*, is a caudate amphibian (family Salamandridae) with a biphasic life-cycle including both terrestrial and aquatic habitats. As such, it appears to fulfil all criteria for indicator species suggested by Caro & O´Doherty (1999), namely: (1) it is widely distributed (Griffiths, 1996); (2) it has high demands for habitat quality and is potentially restricted to mature and stable environments (Oldham *et al.*, 2000; Malmgren, 2001); (3) it has a well-known biology (Thiesmeier & Kupfer, 2000; Arntzen, 2003); and (4) it is easy to sample and observe, at least in its aquatic phase (Langton *et al.*, 2001). Although the aquatic habitat requirements of this species have been examined in detail (Beebee, 1985; Pavignano *et al.*, 1990), we have not been able to find any published report where its potential value as a biodiversity indicator has been tested. Of particular interest is the functional relationship between the great crested newt and its environment, especially since distribution and abundance of aquatic vegetation appear important for the species (e.g., Griffiths *et al.*, 1996; Oldham *et al.*, 2000; Langton *et al.*, 2001). Aquatic plants control the productivity of invertebrate prey (e.g., Oertli *et al.*, 2002), provide safe egg-laying sites (e.g., Miaud, 1993, 1994; Marco *et al.*, 2001), and offer protection from predators (Griffiths *et al.*, 1996; Oldham *et al.*, 2000). Thus, plant diversity has both structural and functional value in pond ecosystems, and the hypothesis that there is a relationship between distribution patterns of great crested newts and aquatic plant species richness merits further investigation.

We conducted a pilot study to examine if the great crested newt has any value as an indicator of plant diversity in ponds. Specifically, we tested if patterns of plant species richness are different in ponds where great crested newts are present compared with ponds where they are absent.

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MATERIALS AND METHODS

We examined potential breeding ponds for great crested newts as part of a species survey in Örebro county, south-central Sweden, in the summer of 2002. Ten larger sites with several ponds were surveyed, using standardized visual observation and funnel traps in parallel for three consecutive nights at each pond in April-June, complemented with a survey for larvae by dip-netting two times at each pond in August (Gustafson *et al.*, 2004). We randomly selected five of the sites for a detailed study of aquatic plant communities (Table 1). The sites were situated several kilometers from each other (range 22.2-73.5 km, mean 33.3 km ± 4.4 SE). In each of the selected sites, we randomly selected one pond with confirmed occurrence (observations of breeding adults) of great crested newts and one where the species was found to be absent during all survey attempts. The two sites in each pair were separated by a maximum of 480 m and a minimum of 60 m (Table 1), which is within normal dispersal distance of the great crested newt (Jehle, 2000; Jehle & Arntzen, 2000; Schabetsberger *et al.*, 2004; Jehle *et al.* 2005*a*; Jehle *et al.* 2005*b*). This design provided us with ten ponds comprising a set of five matched presence/absence pairs.

During the last two weeks of July, at the peak of the vegetation period, aquatic macrophytes were sampled by establishing transects across the ponds with a width of 0.5 m. The transects were laid out to cover the centre of the ponds where there was a maximum of visible vegetation, and reaching 1 m up on the shore from the water's edge. Along each transect, and down to a maximum depth of 1.5 m, all vascular plants and mosses were collected and identified. In cases where grazing damage or other factors made identification to species impossible, plants were at least identified to genus or family. The surface vegetation cover was estimated visually as the area covered by emerging plants (i.e. those with floating leaves and those with leaves protruding above the water surface, combined) as a proportion of the total pond area.

The number of identified plant species was used as a measure of plant species richness in each of the ponds. We used a paired two-sample *t*-test, assuming equal variance, to test if great crested newt occurrence reliably indicated a high diversity of plants. To test the hypothesis that plant diversity increases more steeply in ponds occupied by great crested newts compared with non-inhabited ponds, we performed a Type II regression analysis according to Sokal & Rohlf (1995). Thus, the relationship was estimated by Pearson's product-moment correlation and a reduced major axis regression, since both variables were measured with the same unit and with equal error. We also performed a Spearman correlation analysis on the relationship between plant diversity and surface vegetation cover in ponds to see if these factors correlated with presence and absence data.

Potential associations between plant species and occurrence of great crested newts were examined with a hypergeometric probability test. We also used the nestedness temperature calculator (Atmar & Patterson,

TABLE 1. Description of surveyed ponds at five aquatic plant community study sites. Pond data are presented with coordinates from the Swedish national grid (RT90), a short habitat description, presence or absence of great crested newts (*T. cristatus*), depth of pond (m), area of pond surface (m^2), the amount of surface vegetation cover (%), and the number of identified plant species. Distances between the two ponds in every area are also presented. Pond names are given for reference, with short designations in parentheses.

Ponds	Coordinates	Description	*T. cristatus*	Pond depth (m)	Pond surface area (m^2)	Surface veg. cover (%)	No. plant species	Pond distance (m)
Grönelid (A1)	6513459 /1426238	Pond in grazed pasture	Absent	1.5	40	50	22	60
Grönelid (A2)	6513483 / 1426148	Pond in grazed pasture	Present	3	300	25	36	
Lekeberga (B1)	6567645 / 1447242	Oxbow pond in grazed pasture	Absent	0.5	100	95	20	480
Lekeberga (B2)	6568176 / 1447304	Oxbow pond in grazed pasture	Present	1.5	200	80	42	
Kortorp (C1)	6539777 / 1468172	Marsh in coniferous forest	Absent	0.5	100	90	20	270
Kortorp (C2)	6539926 / 1468444	Pond in grazed pasture	Present	0.75	50	60	28	
Rockebro (D1)	6533124 / 1436718	Tarn in coniferous forest	Absent	0.5	30	90	12	270
Rockebro (D2)	6533024 / 1436992	Tarn in coniferous forest	Present	0.5	70	70	11	
Oset (E1)	6573005 / 1469627	Pond in grazed marsh	Absent	1.5	350	3	33	170
Oset (E2)	6572983 / 1469438	Pond in grazed marsh	Present	1.5	400	30	37	

1993), which describes species distribution patterns by calculating the degree of nestedness in the data. To simplify, with this method, a perfectly nested system has a temperature of 0° and lacks all randomness, whereas a system lacking all order has a temperature of 100°. The calculations were based on the observation matrices, separately for ponds with and without *T. cristatus*.

RESULTS

In total, we identified 117 plant species during the study (99 vascular plants, 17 mosses, 1 charophyte). The number of species found per pond is presented in Table 1. The five most frequently recorded species were floating sweet-grass (*Glyceria fluitans*; represented in 8 of the 10 ponds), marsh bedstraw (*Galium palustre*; 8 of 10), soft rush (*Juncus effusus*; 7 of 10), bottle sedge (*Carex rostrata*; 7 of 10) and common sedge (*Carex nigra*; 7 of 10). No single plant species was found in all ten ponds, and 50 species (43 %) were found in only one pond. The variation in number of plant species per pond was high (range 11–42, mean 26.1±3.4 SE). Ponds with and without great crested newts had a cumulative plant species richness of 93 and 68 species, respectively. In general, ponds with great crested newts had a significantly higher mean plant species richness (on average 30.8±5.4 SE) than ponds in which the species was absent (on average 21.4±3.4 SE) (paired *t*-test: t=2.35, df=4, P<0.05). Although ponds with *T. cristatus* had a significantly higher plant species richness compared with the absence-ponds, there was no significant linear relationship (Pearson's product-moment correlation; r=0.68, P>0.05). Only one study site (D) went against the general pattern of higher plant species richness in *T. cristatus* ponds and this site also had the lowest overall species richness. Although ponds with great crested newts had a lower amount and less variation in area covered by surface vegetation (mean cover 53.0±10.91% SE, range 25–80%) than ponds where the species was absent (mean cover 65.6±17.63% SE, range 3–95%), the difference was not statistically significant (paired *t*-test, t=1.23, df=4, P>0.05). Plant diversity declined as the amount of pond surface vegetation cover increased (Fig. 1), but this tendency was not significant either (Spearman's correlation test; r=-0.55, P>0.05).

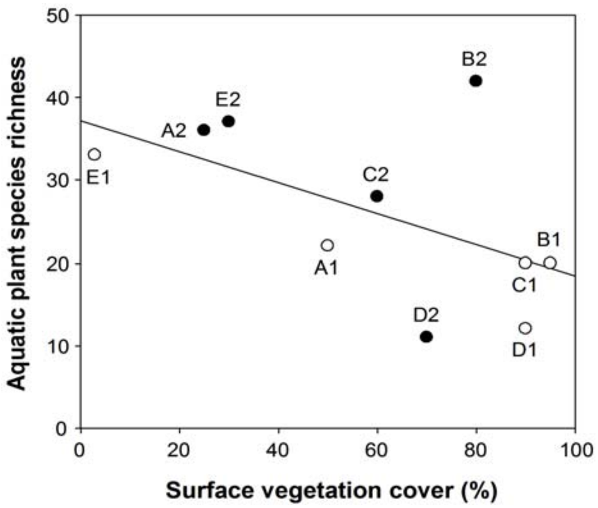

FIG. 1. Relationship between aquatic plant species richness and pond vegetation cover in the ten studied ponds. Filled and open circles represent, respectively, ponds where great crested newts were present and absent. Pond designations follow Table 1.

In the hypergeometric test six plant species were significantly associated with the occurrence of great crested newts. Only two of these species were associated on a higher level of significance, namely broad-leaved pondweed (*Potamogeton natans*, P<0.05) and square-leaved liverwort (*Chiloscyphus pallescens*, P<0.05), both being found in four ponds with *T. cristatus*, but in none of the absence-ponds. Four additional species were associated at a lower level of significance (common sedge, *Carex nigra*, P<0.10; marsh willowherb, *Epilobium palustre*, P<0.10; meadowsweet, *Filipendula ulmaria*, P<0.10; bladder sedge, *Carex vesicaria*, P<0.10). Plant diversity had a slightly more nested structure for ponds with great crested newts (matrix temperature=46°) than for those without (matrix temperature=51°), which indicates a more homogeneous plant species assemblage in the former group of ponds.

DISCUSSION

Although this study is based on a limited sample, the results demonstrate that great crested newts occur in ponds with a significantly higher mean number of plant species compared to ponds where they are absent. Further, newts occurred in ponds that tended to have a lower amount and less variation in pond area covered by surface vegetation, compared to absence-ponds, although the difference was not statistically significant. A few plant species were associated with the presence of *T. cristatus*, most notably broad-leaved pondweed (*Potamogeton natans*) and square-leaved liverwort (*Chiloscyphus pallescens*). None of these species belonged to the group of species most frequently observed. Ponds with great crested newts were slightly more homogeneous than ponds in which the newt did not occur, at least from the perspective of aquatic plant species composition and nestedness.

The productivity of pond ecosystems is ultimately controlled by sun insolation, temperature and nutrient availability. In early stages of pond community succession the general openness of the pond favours phytoplankton as primary producers. In later stages macrophytes establish and contribute to a higher structural complexity (Friday, 1987). With further succession, especially in eutrophic ponds where nutrient availability is rarely limiting, diversity generally decreases and only a few macrophyte species dominate (Engelhardt & Ritchie, 2001, 2002; Loreau *et al.*, 2001). In line with the latter pattern we observed a (non-significant) tendency for plant species richness to decrease with increasing vegetation cover. However, we could not find any obvious correlations between surface vegetation cover and newt abundance, although earlier studies have shown positive relationships (Joly *et al.*, 2001).

A possible scenario explaining some of the variation in occurrence is that the great crested newt has a preference for ponds in a certain range of pond succession stages, correlated with high macrophyte diversity. Our nestedness analysis show that there is a tendency for ponds with newts to be more nested, which implies that the plant species occur in a more equilibrated coexistence in ponds with newts than in ponds without newts. This could be due to the fact that a particular pond, in its peak macrophyte diversity stage, may provide very favourable conditions for newts in terms of prey productivity, temperature regimes and availability of cover and egg-laying facilities. In later stages when the plant community is overtaken and dominated by only a few macrophyte species, and especially surface covering species, the situation for newts may quickly deteriorate. In such cases the depletion in sun insolation may cause a collapse in temperature regimes, which can cause deterioration of plant and food productivity in the pelagic zone, all of which can be negative to the reproductive success of great crested newts. Succession inevitably leads to overgrowth, which Oldham (1994) described as one of the most common threats to great crested newt populations. Earlier studies have shown that the great crested newt has its highest occurrence in ponds with a submerged plant cover of 50-75% and an emergent vegetation cover of 25-50% (Oldham, 1994; Langton *et al.*, 2001), which corresponds to ponds with a well established macrophyte flora in a mid-succession stage (Oldham *et al.*, 2000; Langton *et al.*, 2001). The higher nestedness matrix temperature for presence-ponds than absence-ponds in our study could support the hypothesis that great crested newts prefer stable and mature habitats or ponds in a favourable stage of succession (discussed in Malmgren, 2001, 2002*a,b*). Due to the low sample size however, it would be too speculative to infer too much from the present results. Pond succession and its effects on the native ecosystems is an issue that needs more attention in future studies.

The diversity and structure of the macrophyte flora in ponds is important for the diversity of several other groups of organisms, especially among macroinvertebrates (e.g. Friday, 1987; Oertli *et al.*, 2002) and zooplankton (Cottenie & De Meester, 2004). Heino (2000) showed that total species diversity among macroinvertebrates increased with habitat heterogeneity. Habitat structure seemed to be more important than factors related to water chemistry in determining the structure of littoral macroinvertebrate assemblages. The macrophytic flora constitutes an important part of the habitat, which implies that a higher diversity among plants would also bring a greater heterogeneity and a higher diversity among other groups of organisms. Higher plant diversity may also by itself indicate higher water quality, longer continuity or greater productivity. Although for example Oertli *et al.* (2002) found only a weak relationship between floral diversity and amphibian species richness, there might be an indirect relationship between amphibians and macrophyte diversity. Our results suggest that higher macrophyte species diversity is positively associated with the presence of great crested newts, and other ecosystem functions may possibly be revealed by its presence.

We observed a significant association between broad-leaved pond weed (*Potamogeton natans*) and great crested newts. This plant species has a wide distribution and is common in many different water bodies. Nevertheless, we find it likely that *P. natans* is a species with a structure of importance for great crested newts, as it has big floating leaves that can serve as protection against predators and long, thin underwater-leaves that can function as an egg-laying substrate. Presence of both *P. natans* and great crested newts may also be related to ponds with long hydroperiods or permanent water. For egg laying, plants with thin and easily folded leaves are clearly preferred by great crested newt females. Sweet or flote grasses (*Glyceria* spp.), water mint (*Mentha aquatica*) and water forget-me-not (*Myosotis scorpioides*) are plants that have been demonstrated to serve this purpose (Langton *et al.*, 2001). The results of this study support that finding, as those species occurred frequently in great crested newt presence-ponds. Also, square-leaved liverwort (*C. pallescens*) was significantly associated with great crested newts, but similar to *P. natans* this species is common in wet areas and has a wide distribution. We suggest that there are no important correlations between the great crested newt and specific plant species. Instead, it is probable that particular structures, provided by certain plants, are more important, and that these macrophytes may be good indicators of a certain pond succession stage.

The results acquired from this study are particularly interesting since each pair of ponds were situated in the same area, well within dispersal distance for newts (Jehle, 2000; Jehle & Arntzen, 2000; Joly *et al.*, 2001; Malmgren, 2001) and plants (Moller & Rordam, 1985; Linton & Goulder, 2003), but geographically isolated from the next pair by several kilometres. The null hypothesis of no differences between pairs of ponds would imply that two adjacent ponds would have more similar species compositions compared with ponds in other areas, irrespective of the presence or absence of newts. Due to limited data we were unable to fully resolve this issue. It would be useful to conduct similar studies in a greater number of locations, also taking into account both the relative abundance of the different plant species and the population densities of great crested newts.

Amphibians may be useful as indicators of biodiversity changes in pond and wetland landscapes, since they have life cycles often including both terrestrial and aquatic phases, making them particularly vulnerable to habitat alterations and environmental stress (Houlahan *et al.*, 2000). One of the main reasons for declining great crested newt populations is landscape fragmentation (Griffiths *et al.*, 1996; Langton *et al.*, 2001). In Sweden, agricultural landscapes have changed dramatically during the last 50 years, resulting in a much lower amount of mosaic landscapes (Ihse, 1995). As great crested newts and many plant species are sensitive to habitat fragmentation this change implies a general decrease in diversity for amphibians as well as for the flora. In this sense this study suggests that the great crested newt may be a useful indicator of high plant species richness and perhaps also of other sensitive species in the face of habitat disturbance. Further, it emphasizes how complex amphibians are in terms of habitat selection, and this in it self deserves more investigation (e.g., Joly *et al.*, 2001; Beja & Alcazar, 2003; Jakob *et al.*, 2003).

The conservation of ponds and pond landscapes is a challenge since they constitute complex habitats with multifaceted layers of interest, both regarding the various stages of succession and the diversity of organisms (Guest, 1997). Future studies that explore interactions between occurrence patterns and diversity of different taxa and ecosystem function can therefore contribute not only to a greater understanding of species such as the great crested newt, but also aid in determining priority areas for new surveys, management plans and conservation measures, as well as provide insights in broader ecological connections. In such studies, we find that the great crested newt is a likely candidate for being an effective umbrella species for pond landscape conservation and restoration.

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