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Symposium

Crassula helmsii in U.K. Ponds: Effects on Plant Biodiversity and Implications for Newt Conservation[1]

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Abstract: We conducted preliminary investigations into some of the potential effects of Australian swamp stonecrop, a nonnative invasive aquatic plant in the U.K., on native pond plants and newt populations. Four studies were carried out in the northwest of England, in the field and under controlled conditions, during the period 2002 to 2003. Six plant species, which are important to newts as an egg-laying substrate, showed significant germination suppression up to 83% under Australian swamp stonecrop. However, there was no significant effect of Australian swamp stonecrop on pond seed banks, and no significant loss of plant species was observed in ponds invaded by the weed. Smooth newt eggs hatched at a later developmental stage when laid on Australian swamp stonecrop compared with those laid on the native substrate watercress, generally considered to be a preferred species. No significant differences in developmental stage at hatching could be detected between substrates in the great crested newt, a protected species.

Nomenclature: Australian swamp stonecrop or New Zealand pigmyweed, *Crassula helmsii* (Kirk) Cockayne; watercress, *Rorippa nasturtium-aquaticum* (L.) Hayek; great crested newt, *Triturus cristatus* (Laurenti, 1768); smooth newt, *Triturus vulgaris* (Linnaeus, 1758).

Additional index words: Aquatic plants, invasive, nonnative, species interactions, urodele amphibians.

INTRODUCTION

The northwest of England is host to a nationally important population of the protected great crested newt as well as the more common smooth newt. Ponds are the primary breeding habitat for newts, and the high density of ponds in this region has allowed stable metapopulations of great crested newts to develop (Langton et al. 2001). When breeding, newts wrap single eggs in submerged leaves of marginal plants, a behavior that is believed to be selective (Hosie and Potter 2000). *Triturus* newts are believed to prefer broad-leaved marginal plants with flexible leaves (Diaz-Paniagua 1986), for example, watercress, a plant known to be used by newts for egg laying (Boothby 2000; Hosie and Potter 2000).

Australian swamp stonecrop is a nonnative invasive plant from Australasia that is spreading through UK ponds. Anecdotal evidence suggests that through competition Australian swamp stonecrop is capable of reducing the diversity of plants at pond margins (Dawson and Warman 1987; Leach and Dawson 1999); however, this remains to be tested and quantified. If newts are selective in their choice of egg-laying substrate, there are implications for their conservation if Australian swamp stonecrop reduces plant diversity in ponds. Reduced breeding success of great crested newts has already been observed in a pond invaded by Australian swamp stonecrop partly because of loss of species used by the newts for egg laying since invasion (Watson 1999). In addition, Australian swamp stonecrop has small, inflexible leaves, potentially providing a very different environment for egg development to leaves of preferred plant species.

Clearly, an understanding of how Australian swamp stonecrop could be outcompeting native marginal pond plants is desirable because anecdotal evidence for suppression can only give limited insights into mechanisms used by this weed. This work describes four studies that were undertaken to examine the potential effect of Australian swamp stonecrop on pond plant diversity and newt egg development.

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MATERIALS AND METHODS

Germination. A laboratory study was conducted to investigate the effect of Australian swamp stonecrop on seed germination in 15 marginal pond plant species native to the UK. These species have been recorded as substrates for great crested newt eggs in the northwest of England (Boothby 2000). The number of seeds of each species in individual seed-tray plots was determined by a pilot study of their germination characteristics (data not shown). Australian swamp stonecrop mats were constructed by weaving strands of plant material through plastic garden mesh. These were placed over six randomly chosen trays, leaving six trays as controls. Trays were kept at room temperature (22 to 25 C) for 30 d under waterlogged conditions with a photoperiod of 14 h following the standard Intermediate Steady Propagation regime (Hunt and Mackay 1993). After treatment, seedlings were harvested and counted. Data were arcsine transformed before analysis. The data were analyzed by ANOVA with a split-plot randomized block design; the Australian swamp stonecrop was the main-plot treatment and species was the subplot treatment. Differences in treatment means were determined using LSD.

Seed Banks. Effects of the presence or absence of Australian swamp stonecrop on seed bank density and plant species richness were investigated in exposed soils at pond margins and soils submerged below approximately 100 mm of water. Seed banks were sampled by pooling four cores (55-mm diameter and 100-mm depth) from 0.5 × 0.5–m quadrats placed randomly in the four conditions. Three samples were taken from each condition at six sites. Data from each condition were pooled before analysis.

Samples were prepared for germination using the method of Ter Heerdt et al. (1996). The concentrated material was spread onto sand in seed trays for seedling emergence. Trays were supplemented with a general fertilizer and kept waterlogged, illuminated with natural light at temperatures between 20 and 30 C for 24 wk. Seedlings were removed when identifiable or were potted on for later identification. Data were $x + 0.5$ square root transformed before analysis by mixed-between subjects ANOVA.

Pond Surveys. Surveys were carried out to determine whether plant species loss could be detected in ponds invaded by Australian swamp stonecrop. A desktop study of pond surveys in the northwest of England identified 19 ponds in the region containing the weed between 1995 and 1998, with comprehensive plant species lists for each (Guest and Bentley 1999). Where possible, these ponds were resurveyed for plant species (September 2002); if Australian swamp stonecrop was still present, ponds were included in the analysis (n = 13). A representative sample of ponds in the region that did not contain the weed was also resurveyed (n = 9). A repeated measures ANOVA was conducted to compare total species numbers at time 1 (original surveys) and time 2 (resurveys) in ponds with and without Australian swamp stonecrop.

Newt Egg Development. Gravid, female smooth newts (n = 55) and great crested newts (n = 43) were collected from two ponds during the breeding season using bottle traps (under English Nature license). Newts were housed individually in tanks filled with aged tap water, were fed, and remained in tanks for 48 h, where they were presented with either Australian swamp stonecrop or watercress as potential egg-laying substrate. At 24-h intervals, eggs were removed from the tanks still attached to their substrate. Eggs of individual females were placed together in containers (2 L) half filled with water from the tanks they were laid in. Water temperature was maintained between 16 and 19 C, the recommended temperature for the rearing of newt larvae being 18 C (Gallien and Bidaud 1959). New hatchlings were collected and examined twice daily under a light microscope using natural daylight. The developmental stage on hatching was determined using the species-specific criteria developed by Glucksohn (1931), where larvae are categorized according to physiological features. Mann–Whitney U tests were conducted to explore the effect of substrate on developmental stage at hatching for both species.

RESULTS AND DISCUSSION

Germination Effects. Four of the plant species tested failed to germinate and were not included in the analysis. There was a significant effect of Australian swamp stonecrop presence on germination (F = 47.45, P = 0.0001). Without Australian swamp stonecrop cover, the mean germination of seeds (all species pooled) was 46.6% and with cover was reduced to 24.7%. There was also a significant interaction effect between Australian swamp stonecrop presence and the species tested (F = 10.17, P < 0.0001). The presence of Australian swamp stonecrop was found to significantly reduce germination in six species of plant (Figure 1). In comparison with the controls, germination was significantly reduced by 83% in *Epilobium hirsutum*, 69% in *Lythrum salicaria*, 56% in *Mentha aquatica*, 51% in *Ranunculus sceleratus*,

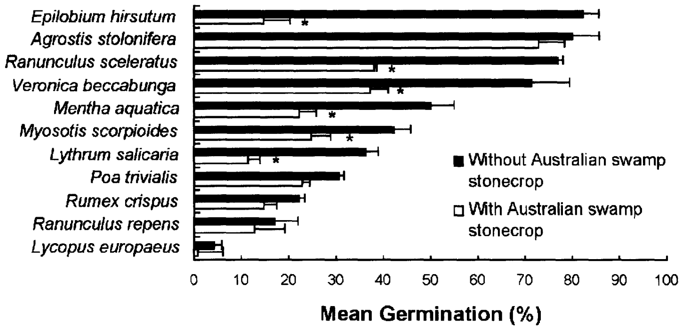

Figure 1. Germination characteristics of species used by great crested newts for egg laying subjected to Australian swamp stonecrop and control conditions. * Indicates species with significantly suppressed germination under Australian swamp stonecrop cover. LSD = 9.1.

48% in *Veronica beccabunga*, and 43% in *Myosotis scorpioides*. If Australian swamp stonecrop suppresses the germination of these species in the field, there may be potential consequences for egg-laying substrate choice in newts, which are believed to be selective in their choice of egg-laying substrate (Hosie and Potter 2000). The thickness of Australian swamp stonecrop mats over the seeds in this experiment was minimal (<10 mm). When this weed grows under optimum conditions at pond margins, mats can be up to 0.2 m thick (Dawson 1994). The results of this investigation have shown that even a thin covering of Australian swamp stonecrop can cause significant germination suppression in some plant species. Therefore, if this suppressive effect occurs under field conditions, reproduction by seed and recruitment from the seed bank could be greatly reduced at pond margins with minimal Australian swamp stonecrop presence. From this study, it is not possible to determine whether the discovered effect is because of shading by Australian swamp stonecrop or another mechanism. It is probable that when the weed reaches the high densities often reported, it would significantly reduce light to the ground level, much more than native species with more patchy growth forms.

Seed Bank Density. The presence of Australian swamp stonecrop ($F = 0.146$, P = 0.708) and the sample origin (exposed or submerged soil) ($F = 0.259$, P = 0.618) had no effect on species richness in the seed banks. The mean number of species within the seed bank sampled beneath Australian swamp stonecrop was 25.8, and from control areas of no weed cover, there was a mean of 24.8 species. The mean number of species within exposed soil was 26, and there was a mean of 24.7 species found in samples collected from submerged conditions. There was also no significant interaction between Australian swamp stonecrop and sample origin ($F = 1.957$, P = 0.182). Similarly, no significant effect on seed density in seed banks because of Australian swamp stonecrop presence ($F = 0.155$, P = 0.699) and the sample origin ($F = 0.376$, P = 0.539) could be detected. The mean number of seeds in samples collected from under Australian swamp stonecrop was $1.46 \times 10^6/\text{m}^3$, and from control areas of no weed cover, there was a mean of 1.97×10^6 seeds/m^3. The mean number of seeds in samples collected from exposed soils was $1.77 \times 10^6/\text{m}^3$, and from submerged soils, there was a mean seed number of $1.66 \times 10^6/\text{m}^3$. There was also no significant interaction between Australian swamp stonecrop presence and sample origin ($F = 1.489$, P = 0.241). Despite efforts to account for seed bank heterogeneity by pooling soil cores and samples, the data collected were very variable.

Species Number in Ponds. Plant species loss could not be detected in any of the ponds surveyed. When species numbers were compared between the time of the original pond surveys of Guest and Bentley (1999) and the resurveys conducted for this research in 2002, no significant effect of time was detected ($F = 1.51$, P = 0.233). There was also no significant interaction between time and Australian swamp stonecrop presence ($F = 0.934$, P = 0.345). In both the Australian swamp stonecrop and control ponds, a nonsignificant trend of lower species richness at the time of the second survey was observed. The number of plant species in each pond was highly variable and the available sample size small, which may have prevented significant differences in number being detected. However, the measure of species richness is coarse, and more detailed assessments of diversity–abundance may reveal any differences because of greater sensitivity. Certainly, laboratory work on germination presented in this article shows effects at the level of individual plants, if not populations.

Newt Egg Development. There was a significant difference in the developmental stage at hatching between plant substrates in smooth newt eggs ($U = 129$, P < 0.001). Larvae hatched at a later developmental stage on Australian swamp stonecrop (see Figure 2). There was no significant difference in the developmental stage at hatching between substrates in great crested newt eggs ($U = 215.5$, P = 0.889). This suggests there are significant and complex interactions between the substrate and eggs that are species specific; whether chemical or mechanical, this could not be ascertained. Whether any effects are long lasting or are detrimental to the newly hatched newt larvae may be an area for future research.

The field data from these investigations is coarse and

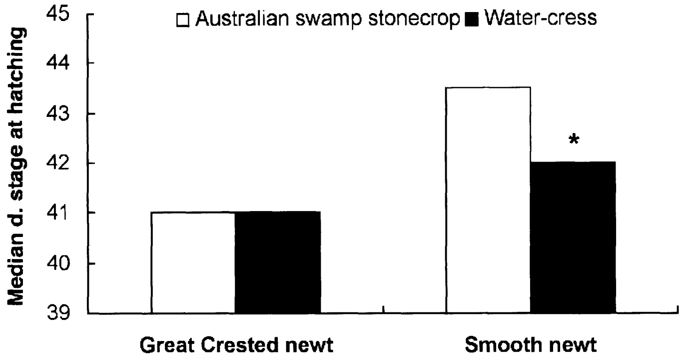

Figure 2. Developmental stage at hatching of great crested and smooth newt eggs laid on two substrates: Australian swamp stonecrop and watercress. * Indicates significantly different medians. Note: scale used is not comparable between species because species-specific developmental stage differences exist.

highly variable, making detection of effects difficult. Gross effects on communities have been searched for but have not been found. It is interesting to note that although Australian swamp stonecrop is reputed to have a large effect on plant communities it invades, these effects are not necessarily detectable through field investigation. Currently, this could be purely because of limited time since colonization at the sites under investigation, resulting in no detectable effects. There may also be other factors, not measured in this study, which could be preventing Australian swamp stonecrop exhibiting its "normal" suppressive growth patterns in these ponds. These factors could include the preinvasion diversity of the systems, climatic conditions, and the presence of more invasive or better adapted weeds already established at the sites (for example, broad-leaved pondweed). Without detailed preinvasion histories of each site invaded by the weed, it is very difficult to determine the exact effects on plant communities. The wider literature is lacking in laboratory investigations into the effects of Australian swamp stonecrop and other nonnative invasives. However, from these investigations, it can be seen that laboratory investigations have an important role to play in picking up initial effects and the mechanisms of effect. Conclusions thus far are that Australian swamp stonecrop is likely to reduce germination of seeds from neighboring plants. Some of these plant species may be of importance to newt breeding. Eggs of smooth newts are also influenced somehow during their development by the substrate they are laid on. Whether these effects could be the cause of the reduced breeding success in great crested newts reported by Watson (1999) is still uncertain, but they are possibly two contributing factors. More laboratory and field investigations are required to determine the true nature of the effects caused by the weed.

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