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POND CONSERVATION

Restoring ponds for amphibians: a success story

R. Rannap · A. Lõhmus · L. Briggs

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Abstract Large-scale restoration of quality habitats is often considered essential for the recovery of threatened pond-breeding amphibians but only a few successful cases are documented, so far. We describe a landscape-scale restoration project targeted at two declining species—the crested newt (*Triturus cristatus* Laur.) and the common spadefoot toad (*Pelobates fuscus* Wagler)—in six protected areas in southern and southeastern Estonia. The ponds were restored or created in clusters to (i) increase the density and number of breeding sites at local and landscape levels; (ii) provide adjacent ponds with differing depths, hydroperiods and littoral zones and (iii) restore an array of wetlands connected to appropriate terrestrial habitat. In only 3 years, where 22 of the 405 existing ponds (5%) were restored and 208 new ponds (51%) created, the number of ponds occupied by the common spadefoot toad increased 6.5 times. Concerning the crested newt and the moor frog (*Rana arvalis* Nilsson), the increase was 2.3 and 2.5 times, respectively. The target species had breeding attempts in most of the colonised ponds—even more frequently than common species. Also, the amphibian species richness was higher in the restored than in the untreated ponds. The crested newt preferably colonised ponds that had some submerged vegetation and were surrounded by forest or a mosaic of forest and open habitats. The common spadefoot toad favoured ponds having clear and transparent water. Our study reveals that habitat restoration for threatened pond-breeding amphibians can rapidly increase their numbers if the restoration is implemented at the landscape scale, taking into account the habitat requirements of target species and the ecological connectivity of populations. When the remnant populations are strong enough, translocation of individuals may not be necessary.

Keywords Estonia · Aquatic habitat management · Threatened species · *Pelobates fuscus* · *Triturus cristatus*

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R. Rannap (✉) · A. Lõhmus
Institute of Ecology and Earth Sciences, University of Tartu, Vanemuise 46, 51014 Tartu, Estonia
e-mail: riinu.rannap@envir.ee

R. Rannap
Ministry of the Environment, Narva Road 7A, 15172 Tallinn, Estonia

L. Briggs
Amphi Consult, International Sciencepark Odense, Forskerparken 10, 5230 Odense M, Denmark

Introduction

Ponds—small, isolated freshwater bodies—are essential habitat supporting considerably more species, more unique species and more scarce species than rivers, ditches and streams, thus playing a central role in maintaining high regional biodiversity (Williams et al., 2003). Despite their significant ecological values, pond ecosystems are threatened by a number of human activities: infilling, stocking with fish, pollution, mismanagement, desiccation etc. (Brönmark & Hansson, 2005; Oertli et al., 2005); these are typically related to the loss of ponds' historical function and a changed land use. During the twentieth century, enormous numbers of ponds have vanished—in the European states often more than 50% and occasionally 90% (Hull, 1997)—and those remaining have often lost their quality and connectivity for biota.

Amphibians have the highest proportion of threatened species among higher taxa in the world (Stuart et al., 2004), and—together with dragonflies and aquatic plants—they represent a major pond-dependent taxon comprising numerous critically endangered species (Beebee, 1992; Oertli et al., 2005). Pond-breeding amphibians require both terrestrial and aquatic habitats during their life cycle, which makes them particularly vulnerable to a range of anthropogenic processes, such as landscape cultivation, intensification of agriculture, urban development and road building (Alford et al., 2001; Cushman, 2006). Fortunately, habitat alteration is potentially reversible. Thus, elucidating the factors critical for restoring or maintaining quality habitats (Semlitsch, 2002; Rannap et al., 2009) and, by necessity, large-scale restoration of both aquatic and terrestrial habitats (Fog, 1997; Stumpel & van der Voet, 1998), are essential for amphibian recovery efforts. The ultimate goal is to renew the ecological integrity of degraded wetlands and to create self-sustaining systems for long-term persistence of resident populations (Petranka & Holbrook, 2006), including their metapopulation structure (Semlitsch, 2002).

Despite the obvious necessity, only a few successful examples (Denton et al., 1997; Briggs, 1997, 2001; Petranka et al., 2007) are available for large-scale species-specific habitat restoration for threatened amphibians. Most special restoration has been small-scale and scattered (usually 1–3 ponds locally; Petranka & Holbrook, 2006; Petranka et al., 2007), while traditional approaches to create and restore wetlands may have even reduced regional amphibian diversity (Porej & Hetherington, 2005). Poor results often reflect inadequate planning and a failure to create wetlands suitable for amphibians (Petranka et al., 2007), for instance, due to inappropriate pond morphology, presence of fish or a lack of terrestrial habitat for juveniles and adults (Porej & Hetherington, 2005). For threatened species, it is important to identify particular areas and habitats where the restoration is expected to give the best results (Baker & Halliday, 1999; Nyström et al., 2007), but even then the species may not become established on their own (Pechmann et al., 2001). Thus, to successfully restore amphibian populations it is important to compile and implement biologically based management strategies (Semlitsch, 2002). Due to the complexity of the task and the lack of information, documenting the design and results of successful efforts (especially regarding rare and threatened species) is extremely valuable.

In this article, we describe a large-scale restoration project where 230 ponds were restored or created for two European-wide threatened species—the crested newt (*Triturus cristatus* Laur.) and the common spadefoot toad (*Pelobates fuscus* Wagler). In six protected areas in southern Estonia (Fig. 1), where the population density of these species is the highest in Estonia, we restored numerous clusters of ponds to halt the species' declines and to save from extinction the small and isolated populations of the common spadefoot toad at the northern edge of its distribution range. Most pond clusters comprised only a single remnant breeding pond of either species. We explored natural colonisation of the restored ponds by amphibians over 3 years to determine (1) the colonising species and (2) their speed of colonisation; (3) the efficacy of restoration (in terms of the total number and the number of new breeding ponds) and (4) the habitat characteristics influencing the probability of pond colonisation by target species.

Materials and methods

Study area

An extensive pre-restoration inventory in June 2005 and the following pond restoration were carried out in the two largest Landscape Protected Areas (LPA) of southern Estonia: the Haanja LPA (27°2′ E; 57°43′ N) and the Otepää LPA (26°25′ E; 58°5′ N). Additional ponds were restored/created in the same region in four smaller protected areas (Sadrametsa, 228 ha; Piusa, 53 ha; Hauka, 14 ha; Karste, 9 ha) where isolated

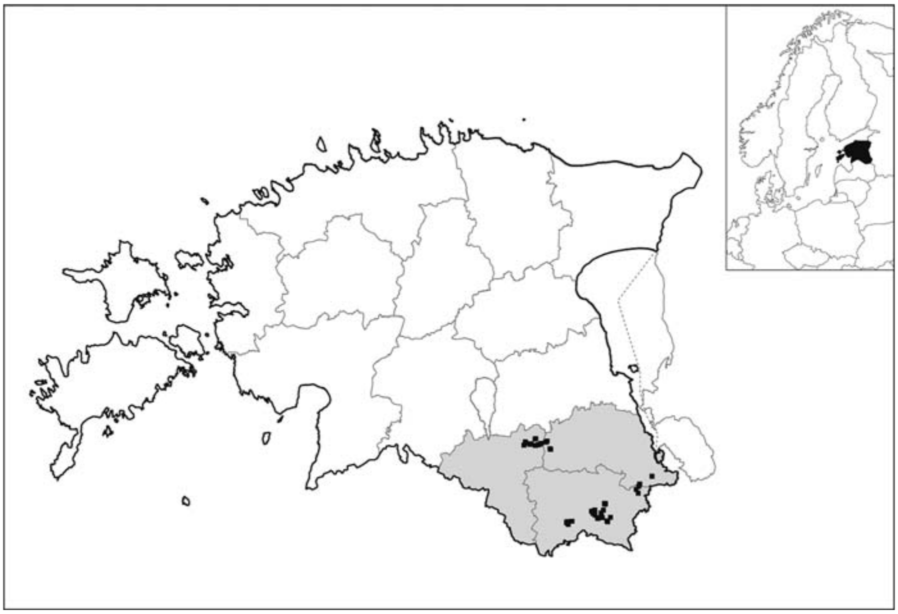

Fig. 1 The location of the study areas with constructed ponds in Estonia

populations of the crested newt and/or the spadefoot toad occurred in 2005. The hilly (altitudes 200–318 m a.s.l.) moraine landscape of the Haanja LPA (16,900 ha) represents a mosaic of forests (45%), grasslands (21%) and small extensively used fields and farmlands. Lakes, ponds, swamps and small bogs are situated in the depressions and valleys between the hills. The Otepää LPA (22,430 ha; 42% forest) also has a varied hilly relief that rises over 100 m above the surrounding plains, but the fields are generally larger than in Haanja though intensive farming practices are not in use (Evestus & Turb, 2002). Both areas have a great number of ponds of very diverse origin—created by natural processes (e.g. glaciation) or human activities (e.g. mineral extraction, cattle watering, water storage). The man-made ponds are situated mainly near human settlements.

Study species

Of the 11 Estonian amphibian species, 8 are found in the southern and southeastern part of the country. The smooth newt (*Triturus vulgaris* L.), the crested newt, the pool frog (*R. lessonae* Camerano) and the edible frog (*R.* kl. *esculenta* L.) are mainly aquatic species, while the common spadefoot toad, the common toad (*Bufo bufo* L.), the common frog (*Rana temporaria* L.) and the moor frog (*R. arvalis* Nilsson) are largely terrestrial. The target species in our study were the crested newt and the common spadefoot toad, which are listed in the Annexes of the EU Habitats Directive (92/43/EEC) encouraging the Member States to achieve favourable conservation status of those species. Also, the moor frog is an Annex IV species of the Habitats Directive, and though it was monitored in this study, there was no necessity for special habitat restoration—the moor frog is one of the most widespread and numerous amphibians in Estonia (Pappel & Rannap, 2007).

Of the target species, the crested newt has declined in most of its range countries (Edgar & Bird, 2006), while the common spadefoot toad has decreased dramatically within its northern distribution range (Fog, 1997; Nyström et al., 2002, 2007), including the range edge in Estonia. Both species strongly depend on permanent fish-free ponds (Joly et al., 2001; Nyström et al., 2002, 2007; Skei et al., 2006) surrounded by suitable terrestrial habitat: for the crested newt—forest or mosaic of forest and (semi)natural grasslands (Joly et al., 2001; Skei et al., 2006; Danoël & Ficetola, 2008; Rannap et al., 2009), for the common spadefoot toad—natural or semi-natural grasslands, small-scale extensively managed vegetable fields or gardens on sandy soils (Nyström et al., 2002, 2007; Stumpel, 2004). The proposed factors for the declines are habitat-related: the loss of ponds, habitat fragmentation, decreased connectivity between ponds, lack of pond management, introduction of fish, changes in agricultural systems etc. (Joly et al., 2001; Nyström et al., 2002; Stumpel, 2004; Edgar & Bird, 2006; Skei et al., 2006). In a crested newt population in southeastern Sweden (climatically similar to Estonia), population modelling has highlighted the importance of pond restoration and increased pond density due to the crucial role of the early life-cycle stages (Karlsson et al., 2007). Yet, for the crested newt only limited conservation work has taken place, so far (Edgar & Bird, 2006). For the common spadefoot toad, pond restoration and creation have been carried out at different scales in Denmark (Fog, 1997; Briggs et al., 2008), Sweden (Nyström et al., 2007), and the Netherlands (Stumpel, 2004), but the toad's reproductive success (Nyström et al., 2007) or colonisation rate (Stumpel, 2004; Briggs et al., 2008) has remained low.

Field methods and habitat restoration techniques

During the pre-restoration inventory in June 2005, 12 herpetologists from seven European countries checked 405 natural and man-made ponds, including natural depressions, beaver ponds, cattle ponds, garden ponds, sauna ponds and ponds historically used for flax soaking. Data collection was carefully standardised and simplified: we used a standard dip-netting of larvae (Skei et al., 2006) as the main method for detecting amphibians, and the absence of a species was only concluded after 10 min of dip-netting. In each pond, the dip-net sweeps covered all important microhabitats for amphibians. In addition, eggs of newts and egg-clusters of the 'green frogs' (the pool frog and the edible frog) were searched for. Due to the single visit to each pond, random effects in the number of caught individuals were still probably large and we used only presence–absence for analyses (reminding that 'absence' may include undetected presence in some cases). For each pond, we estimated the presence of fish and the pond quality for amphibian breeding. A pond was considered of high-quality if no extensive negative effects were observed, such as overgrowing (complete cover of bushes or tall vegetation such as *Typha latifolia* L.), eutrophication or silting (water unclear and full of algae, a thick mud layer) or shade (more than 80% of the water table). The presence of fish was established using the combined data of visual observation, the dip-netting and information from local people.

Based on the results of the pond inventory, in autumns 2005–2007 (after the reproductive period of most water organisms), 27 clusters with a total of 230 ponds (120 in Haanja, 74 in Otepää and 36 in the four smaller protected areas) were constructed for the target species, including 22 ponds restored and 208 new ponds created (of these, 73 were created at the places of old, vanished ponds; Fig. 1). Nineteen pond clusters (153 ponds) were designed for both species; six clusters (46 ponds) for the crested newt in Piusa, Karste and Hauka areas, and in isolated sites in Otepää and Haanja; and two clusters (31 ponds) for the common spadefoot toad in Otepää and Haanja. The clusters were designed for one target species only if the other was absent at the site in 2005. Bulldozers (for large shallow water bodies) or excavators (in smaller or wetter areas to restore an old pond or to create a deeper one) were used for digging, sometimes combining their use.

For pond construction (restoration or creation), we followed four principles:

(1) to increase colonisation probabilities and preserve the existing populations (Semlitsch, 2000; Petranka & Holbrook, 2006; Petranka et al., 2007), we constructed ponds in clusters (4–26 ponds in each), with distances between ponds no more than 500 m (on average, 116 m ± 8.9 SE; range 6–479 m) and at least one constructed pond within 200 m of an existing breeding pond of a target species. Land cover within 50 m from any constructed pond was mainly to consist of a mosaic of forest and (semi)natural grassland (for the crested newt) and (semi)natural grasslands and small extensively used potato fields or vegetable gardens (for the common spadefoot toad);

(2) to assure different hydroperiods (Semlitsch, 2002; Petranka et al., 2003), improve the ponds' quality for amphibians and to fit them into the landscape various treatments were applied in each cluster. Notably, we constructed ponds of various depths (0.4–2.5 m), sizes (12–5000 m^2), slopes (3°–90°; the mean: 24°), shapes and widths of shallow littoral zone (0.2–10 m). In case of existing ponds, we cleaned the ponds

from bushes and high dense vegetation (*Typha latifolia*), extracted the mud down to the mineral soil (mostly clay), to assure the quality and transparency of water as well as to eliminate the fish (for that purpose, the ponds were also pumped dry) and enlarged very small ponds and levelled the banks to create shallow littoral zones with warm water;

(3) none of the constructed ponds was allowed a connection to running water (ditch, stream, river) to avoid fish introduction or sedimentation (Semlitsch, 2000, 2002); by necessity, existing ditches were blocked for that purpose;

(4) as each pond construction was unique (depending on the relief, soil, hydrology, presence of drainage system, surrounding habitats etc.), it was guided in the field by experienced amphibian experts.

After construction, the ponds filled with rainwater, and allowed colonisation and succession to take their course. The post-restoration monitoring took place over 3 years (2006–2008). Each pond was visited once and examined in 10 min using visual counting of adults, dip-netting of larvae and searching for eggs of the newts and 'green frogs'. Breeding attempt was ascertained by the presence of eggs and/or larvae. For each pond, seven aquatic and one terrestrial habitat features were described in the field in June 2008 (Table 1), and its distance from the nearest pond occupied by the target species (source pond) was measured from the Estonian base map.

Data analyses

In order to detect habitat determinants of the pond colonisation by target species (presence–absence in 2008), multiple logistic regression models were built according to the procedure of Hosmer & Lemeshow (1989): (1) performed univariate analyses for each of the eight independent variables, (2) built preliminary multivariate models, which included the potentially important variables according to the univariate analyses and (3) omitted non-significant and/or redundant variables from the multivariate model considering their biological meaning and large differences in univariate significance levels. In the first two steps, the significance level was set at $P < 0.15$ (to retain the variables that could gain significance while in combination with other variables); in the final step, $P < 0.05$ was used. Performance of the final multivariate models was assessed by comparing observed versus expected presence/absence using the breakpoint at 0.5 for the expected values. The analyses were performed using STATISTICA 7.0 software.

Results

During the pre-restoration inventory, we recorded seven amphibian species. The only regionally present species, not found, was the edible frog. However, this species and the pool frog form mixed populations in Estonia and their field identification by egg-clusters

Table 1 Univariate relationships (likelihood-ratio tests of logistic regression) between the incidence of the crested newt (*T. cri.*) and the common spadefoot toad (*P. fus.*) and the aquatic and terrestrial habitat variables of the 230 restored ponds in June 2008

Variable	*N* *T. cri.*	*N* *P. fus.*	Mean ± SD for occupied ponds		*P*	
			T. cri.	*P. fus.*	*T. cri.*	*P. fus.*
Pond area (m^2)	127	29	419.4 ± 606.2	556.0 ± 901.9	0.451	0.121
Maximum water depth (m)	117	28	1.3 ± 0.4	1.3 ± 0.4	0.006	0.416
Mean width of shallow (up to 30 cm) littoral zone in the pond (m) measured from four cardinal edges	107	24	1.0 ± 1.1	1.2 ± 0.6	0.302	0.723
Mean slope (°) of the four cardinal banks of the pond	111	24	23.6 ± 11.4	22.7 ± 9.7	0.360	0.469
Water colour or transparency (four types)	127	29	–	–	0.086	0.041
Main land cover within 50 m (seven types)	127	29	–	–	<0.001	0.470
% Pond area occupied by floating vegetation	118	28	10.0 ± 17.5	9.4 ± 14.4	0.157	0.782
% Pond area occupied by submerged vegetation	118	28	12.8 ± 18.5	12.6 ± 14.7	0.004	0.394

Table 2 The occurrence of amphibian species in the 405 existing ponds in Haanja LPA and Otepää LPA in June 2005; in the constructed ponds over 3 years after restoration; and the number of constructed ponds occupied by amphibians in 2008

Species	Ponds occupied in 2005		Post-restoration colonisation of constructed ponds (%)			Ponds occupied in 2008	
	N	%	I year $N = 230$	II year $N = 193$	III year $N = 111$	N	Breeding attempt (%)
T. vulgaris	149	36.8	35.7	65.8	82.0	156	68.7
T. cristatus	94	24.2	16.1	54.9	71.2	127	98.4
P. fuscus	8	2.0	5.2	15.0	15.3	29	96.6
B. bufo	86	21.2	23.9	30.1	41.4	76	65.8
R. temporaria	90	22.2	25.7	37.3	44.1	95	86.3
R. arvalis	62	15.3	17.8	22.8	40.5	85	87.1
'*Green frogs*'	236	58.3	19.1	55.4	82.0	144	54.2

Table 3 The occurrence of amphibians in ponds with ($N = 194$) and without fish ($N = 211$) in June 2005

Species	Presence (%) in ponds		The effect of fish presence	
	With fish	Without fish	χ^2	P
T. vulgaris	52	97	15.7	<0.001
T. cristatus	27	67	18	<0.001
P. fuscus	0	8	–	–
B. bufo	50	36	4.6	0.032
R. temporaria	30	60	9.5	0.002
R. arvalis	16	46	14.3	<0.001
'*Green frogs*'	119	117	1.4	0.23

or tadpoles is complicated. Collectively, these 'green frogs' were the most frequent amphibians in the area, while the rarest species was the common spadefoot toad (Table 2). Importantly, only 22% of the 405 ponds were of high-quality for amphibian breeding. Forty-eight percent of the examined ponds were stocked with fish, mainly with crucian carp (*Carassius auratus gibelio* Bloch), which is an alien species in Estonia. All amphibian species, except 'green frogs', avoided ponds with fish, and the common spadefoot toad was never found in such ponds (Table 3). Fifteen percent of the examined ponds were completely overgrown with dense vegetation and/or bushes, 10% were eutrophicated or silted up, and 5% were completely in shade.

During the first post-restoration survey (June 2006), all the seven amphibian species (and no fish) were detected in the constructed ponds already (Table 2). Presence of the edible frog remained uncertain (no adults or juveniles were found). The breeding attempts of the crested newt were detected in the constructed ponds of 5 clusters of the 13 restored (38.5%), and the common spadefoot toad in 3 of 10 clusters (30%). By 2008, the breeding attempts of the crested newt had been recorded in 23 of 25 clusters (92%), and of the common spadefoot toad in 17 of 21 clusters (81%).

Altogether, in only 3 years when 22 of the 405 existing ponds (5%) were restored and 208 new ponds (51%) created, the number of ponds occupied by the common spadefood increased 6.5 times (from 2 to 13%). Concerning the crested newt and the moor frog (another (non-target) species listed in the EU Habitats Directive), the number of occupied ponds increased 2.3 (from 24 to 55%) and 2.5 times (from 15 to 37%; Table 2). In 2008, the 230 ponds constructed for amphibians hosted, on average, 3.1 ± 0.1 SE amphibian species per pond, while the 383 non-restored ponds had 1.8 ± 0.07 SE amphibian species (*t*-test: $t = 11.2$; $P < 0.001$).

The constructed ponds situated close to the source pond were colonised more quickly than ponds that were further away both in the case of the crested newt: (Kruskal–Wallis ANOVA: $\chi^2 = 17.6$; df = 3; $P < 0.001$) and the common spadefoot toad ($\chi^2 = 10.6$; df = 3; $P = 0.014$; Fig. 2). In terms of pond characteristics, the crested newt presence in the 230 constructed ponds in 2008 was explained (model log-likelihood = −129.0; $\chi^2 = 26.0$; $P = < 0.001$) by the land cover within 50 m (log-likelihood = −138.0; $\chi^2 = 18.1$; $P = 0.006$) and a higher percentage of submerged vegetation in the pond (estimate: 0.03 ± 0.01; SE; log-likelihood = −131.4; $\chi^2 = 4.8$; $P = 0.028$). The most favourable land cover type around the pond was forest (all six forest ponds being colonised), while the

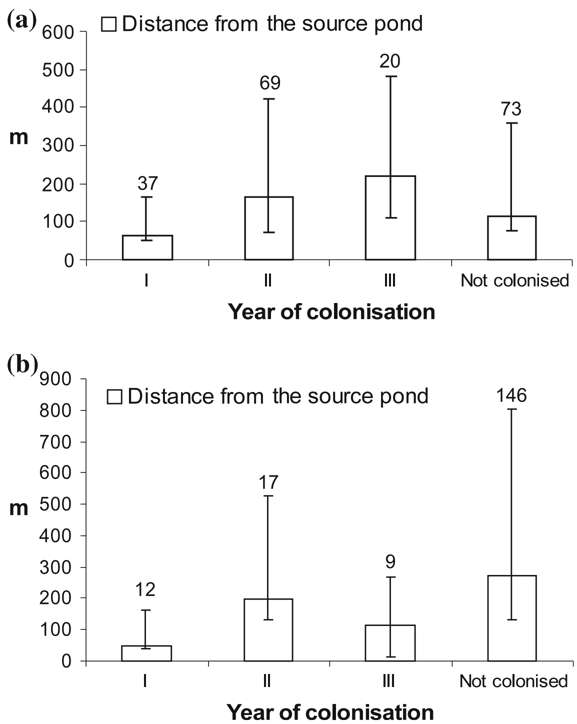

Fig. 2 Relationship between the year of colonisation and the distance (median and quartiles) of the constructed pond from the source pond in the crested newt (**a**) and the common spadefoot toad (**b**). The numbers above bars are sample sizes

29 ponds on meadows had the lowest colonisation rate (44.4%). The presence of forest, in combinations with meadows and farms, increased the suitability of the pond (70.4%; $N = 115$). Altogether, the multivariate model correctly classified 67% of the observations (81% for the presence, 49% for the absence of the species). At the univariate stage also depth of the pond appeared significant ($P = 0.005$; Table 3), but lost its significance in the final model. Pond colonisation by the common spadefoot toad was explained by the transparency and colour of water only (log-likelihood = −77.9; $\chi^2 = 8.3$; $P = 0.04$): transparent or clear but brownish water were favoured (96.6% of such ponds being colonised) and the unclear and muddy or algae-green water were avoided.

Discussion

The amphibian conservation management described in this study provides one of the rare success stories of its kind—given the rapid spontaneous colonisation of the constructed ponds and overall population increases of the two specifically targeted threatened species as well as the general increase in local amphibian diversity. Most of the previous pond restoration for amphibians has attempted to improve the local breeding conditions for amphibians, in general, with common species having benefited most (Lehtinen & Galatowitsch, 2001; Pechmann et al., 2001; Stumpel, 2004; Petranka et al., 2007). The success for threatened species has often remained low (Pechmann et al., 2001; Stumpel, 2004), even when these have been specifically targeted (Nyström et al., 2007; Briggs et al., 2008). Importantly, the few successful cases of habitat restoration for declining amphibians have always been carried out at the landscape scale, taking into account the particular terrestrial and aquatic habitat requirements of the target species (Denton et al., 1997; Briggs, 1997, 2001).

Before discussing the key factors for the success, two major limitations of the study need to be considered. First, only the short-term efficacy of habitat restoration (colonisation) was considered, while long-term monitoring will be needed to understand the viability of the populations (see also Petranka et al., 2003), which most likely depends on the succession in the restored ponds and the effects of annual fluctuations on the recovering, but small, populations of the threatened species. According to the management schemes in our project, the state of each of the 230 ponds will be monitored at 2- to 3-year intervals by local site managers. The emphasis is on the necessary management actions (bush cutting on the banks, removal of dense aquatic vegetation, mowing or grazing in the vicinity, fish elimination etc.), some of which (together with the restrictions for fish release) are included in special contracts with land owners. The potentially high risks for local extinctions from demographic or environmental stochasticity (Marsh, 2001) was addressed by selecting the areas where population densities of the two target species were the highest in Estonia and by restoring a variety of ponds in each cluster; however, the local populations were initially small and isolated (often a single extant breeding pond) and the long-term effects of fluctuations cannot be predicted. Second, the main effort was directed to aquatic habitats, although terrestrial habitats were also considered (and these appeared highly relevant for the crested newt). In degraded land areas, also a specific terrestrial habitat restoration may have to be considered as in successful population recovery cases of the fire-bellied toad (*Bombina bombina* L.) in Denmark (Briggs, 1997) and the natterjack toad (*Bufo calamita* Laur.) in England (Denton et al., 1997).

There were probably five general factors that contributed most to the success of the project. First, the restoration areas and habitats were carefully selected, as suggested by Nyström et al. (2007). The areas hosted the strongest, not the weakest, remnant populations in the region and protected areas with a high forest cover and a low-intensity agriculture were chosen to improve the long-term perspectives. Second, we restored ponds in clusters, taking into account the relatively limited dispersal abilities of the target species (Jehle, 2000; Kupfer & Kneitz, 2000; Nyström et al., 2002) and the preference of breeding adults to return to natal ponds (Berven & Grudzien, 1990). Indeed, the constructed ponds were significantly more rapidly colonised, when closer to source ponds, and the actual distances observed in the crested newt resemble the 400-m upper limit reported by Baker and Halliday (1999) for this species. Therefore, the clustering was apparently an effective way to increase the density and number of breeding sites both at the local population and at the landscape level. Third, pond quality was considered to be at least as important as pond availability (Danoël & Ficetola, 2008) and, as the exact requirements of the species are not precisely known and pond quality may fluctuate (e.g. depending on rainfall), a variety of ponds were created in each cluster. This also allows using natural pond drying to prevent and eliminate fish predation (Semlitsch, 2000), which was the fourth key consideration. In accordance with similar findings in many amphibian species, both our target species avoided ponds with fish (see also Joly et al., 2001; Skei et al., 2006; Nyström et al., 2007). Finally, we suggest that the participation of experienced experts in the field was essential for achieving good results.

The important technical details of pond reconstruction were species-specific. The shallow littoral zone of submerged vegetation, which can provide suitable egg laying, foraging and refugium sites for amphibians (Semlitsch, 2002; Porej & Hetherington, 2005), influenced colonisation of restored ponds by the crested newt. In addition to the habitat model, this was apparent in the increase of the colonisation rate after the submerged vegetation was established (Table 2). For the common spadefoot toad, the transparency of water was essential, which may indicate a high concentration of oxygen as favoured by this species (Nyström et al., 2002). Surprisingly, the presence of vegetation lacked significant effects to the common spadefoot toad, although other studies (Hels, 2002; Nyström et al., 2002) have reported its preference for ponds in late successional or eutrophic stages.

Conclusion

Habitat restoration for pond-breeding amphibians, especially for threatened species, can be successful if it is biologically based, implemented at the landscape scale, taking into account the habitat requirements of target species and the ecological connectivity of populations. The key considerations for short-term (colonisation) success highlighted by the study were: (i) at least some of the constructed (restored or created) ponds should be located in the close vicinity of existing source ponds; (ii) the ponds should be constructed in clusters, and each cluster should include a variety of ponds; (iii) the constructed ponds should be separated from running water to avoid fish introduction, sedimentation or pollution; (iv) the ponds have to be surrounded with terrestrial habitats suitable for target species; (v) the field guidance by experienced experts in the restoration is strongly advisable. In addition, long-term monitoring of the constructed ponds is necessary to assess the viability of the target populations and for adaptive management in the future.

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