HABITAT REQUIREMENTS OF *PELOBATES FUSCUS* AND *LEUCORRHINIA PECTORALIS*

PROJECT REPORT

"Securing *Leucorrhinia pectoralis* and *Pelobates fuscus* in the northern distribution area in Estonia and Denmark"

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INTRODUCTION

Pelobates fuscus is widely distributed amphibian species in Europe, having an overall decreasing population trend with particularly dramatic declines within its northern distribution range (Fog, 1997; Nyström et al., 2002; 2007), including the range edge in Estonia and in Denmark (Briggs et al., 2008). Thus the species is listed in the Annex IV of the EU Habitats Directive (92/43/EEC). Such status requires conservation efforts and explicit understanding of species' habitat requirements, to achieve favourable conservation status. However, due to its low abundance, fossorial and secretive way of living, still little is known about the species, especially the use of different habitats and the key habitat requirements across its distribution range (Eggert, 2002; Nyström et al., 2007).

Leucorrhinia pectoralis is a semi-aquatic dragonfly species, depending not only on aquatic, but also on the surrounding terrestrial habitats. During the 20th century *L. pectoralis* has dwindled dramatically mainly because of the destruction of freshwater habitats (Sahlén et al., 2004). Currently the populations of the species are small and isolated, depending often on small freshwater ponds and lakes. Thus the species is listed in the Annexes II and IV of the EU Habitats Directive (92/43/EEC). Despite of the declining population trend and the ongoing habitat destruction, the species has had a little attention from nature conservationists so far and large-scale habitat restoration for this species has not been carried out in Europe yet.
In this report we determine the exact aquatic and terrestrial habitat requirements of *L. pectoralis* and *P. fuscus* at the northern range of those species.

MATERIALS AND METHODS

In order to explore the habitat characteristics essential for *P. fuscus* and *L. pectoralis* both aquatic and terrestrial habitats of those species were included to the study. We use data from breeding ponds' evaluation, carried out in 2010 in Estonian and Danish project sites (all Natura 2000 sites). In addition, similar inventory was also carried out in the Netherlands, where *P. fuscus* is in decline as well, in order to find out the similarities and differences of the species habitat demands along its northern range. Contrary to Estonia and Denmark, where all small freshwater bodies were studied during the inventory, the water bodies inventoried in the Netherlands were potential breeding sites for *P. fuscus* (calling males were recorded at least once during the last 5 years there).

Altogether 407 water bodies and their surroundings were analysed for *P. fuscus*, including 170 water bodies in Estonia, 191 in Denmark and 46 in the Netherlands. As adult toads spend most of their terrestrial life in the vicinity of the breeding pond and rarely disperse over 500 m from it (Nöllert, 1990; Hels 2002) this distance was taken to study the landscape characteristics vital for the toad.

To explore the habitat requirements of *L. pectoralis* only data from Estonian project sites was used (in total 91 water bodies), because in Denmark the species was found in less than five water bodies (Fig. 1).

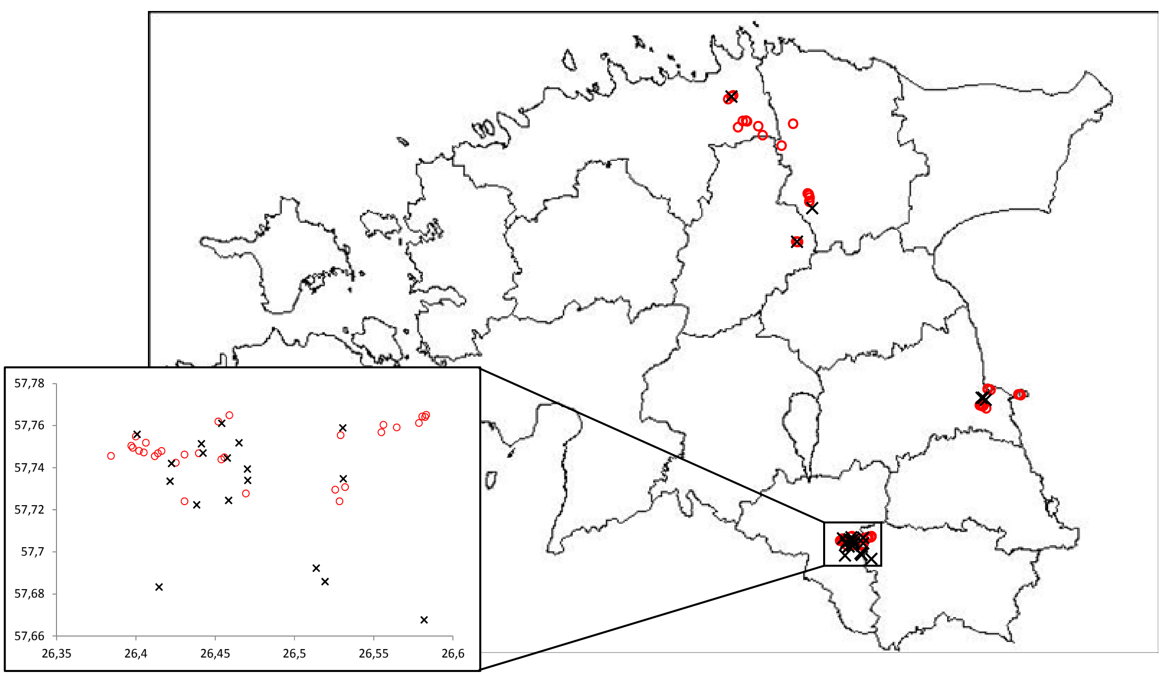

Figure 1. Distribution of inventoried water bodies. Red circles – water bodies without larvae/exuvia of *L .pectoralis*; black crosses –water bodies with larvae/exuvia of *L. pectoralis* (Karula NR is zoomed in).

The fieldwork was carried out in June and July 2010 for both species in all Estonian and Danish project sites, as well as in the Netherlands. However, concerning *P. fuscus*, data from Lahemaa NP, Lasila NPA and Neeruti NPA was omitted from the analysis, because those sites were situated outside the distribution range of the species. The main method to detect the species was dip-netting of larvae. Additionally, exuvias of *L. pectoralis* were also searched in the shoreline vegetation of every water body. The abundance of larvae of both species was estimated in each breeding pond. During the inventory each water body was visited once and dip-netted for a maximum one hour by one herpetologist and one entomologist. Altogether 18 aquatic and 16 terrestrial features were assessed for every water body and its surroundings. Spearman rank correlations were used to analyse the data.

RESULTS

Pelobates fuscus

The species bred in 11.2% of Estonian, 11.5% of Danish and 28.3% of Dutch water bodies (Fig. 2).

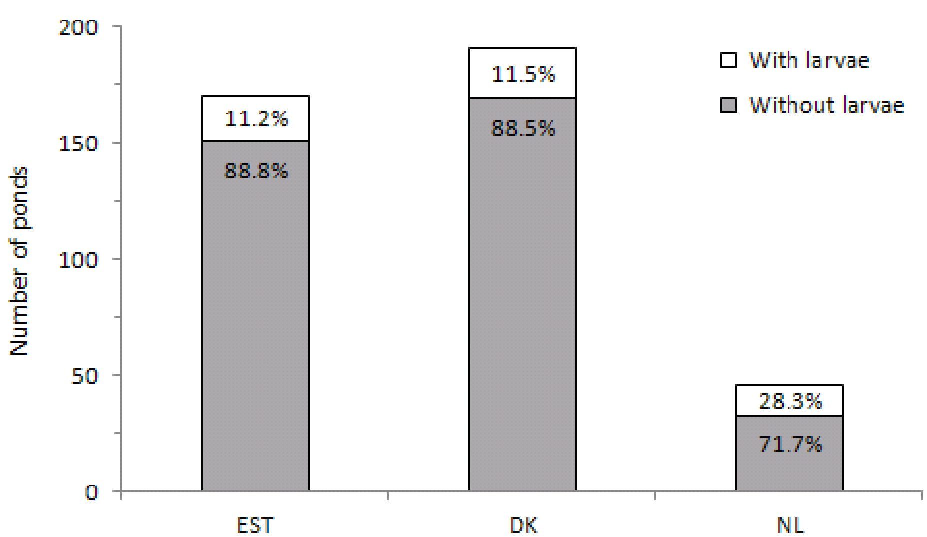

Figure 2. Number and percentage of studied ponds according to the occurrence of *P. fuscus'* larvae.

Type of water body

Slightly more than a half of Estonian potential breeding waters were man made ponds, followed by lakes and natural depressions (Fig. 3). In Denmark and in the Netherlands the majority of studied water bodies consisted also of man made ponds, followed by natural depressions in Denmark and meanders in the Netherlands (Fig. 3). Man made ponds, in our study sites, represented ponds which were created by local people for fish, cattle watering, sauna or garden.

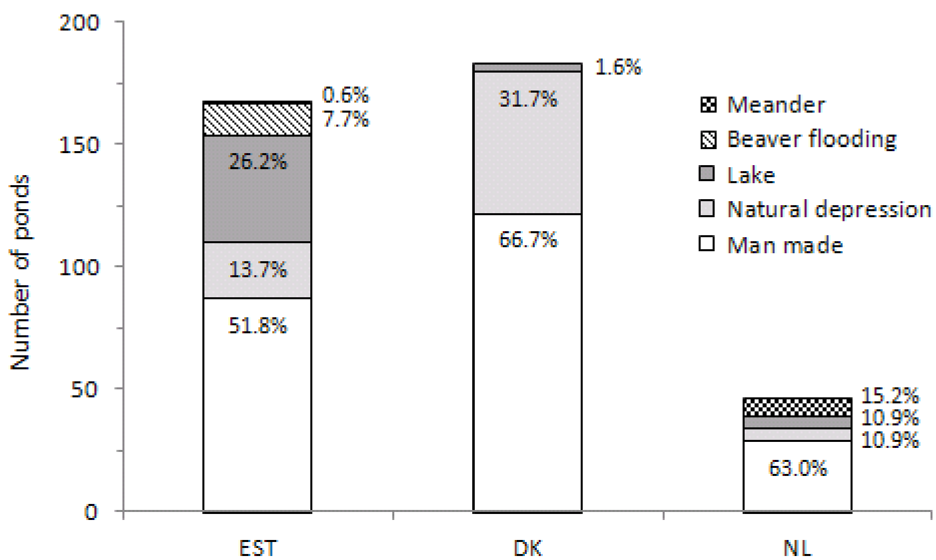

Figure 3. Number and percentage of studied ponds according to their type.

The type of water body, used for breeding by *P. fuscus*, differed remarkably between three countries. In Estonia *P. fuscus* bred significantly more often in beaver floods (30.8 %), than in other type of water bodies and lakes were generally avoided as breeding sites (Fig. 3; 4). In Denmark *P. fuscus* used natural depressions (15.5 %) and man made ponds (9.8 %) for breeding (Fig. 3). Importantly, natural depressions were favoured over the artificial ponds (Fig. 4). Contrary to Estonia and Denmark, lakes were most preferred reproduction sites for *P. fuscus* in the Netherlands, where 60 % of those were used for breeding (Fig. 3). However, many lakes in the Netherlands, used for breeding by *P. fuscus,* used to be natural depressions or meanders before their transformation to small lakes after deepening. Moreover, the lakes in Estonia were at lest 10 times larger than those in the Netherlands and Denmark. Thus, water body with an area of 1000 m^2 can be identified as a lake in the Netherlands and Denmark, but not in Estonia. In addition, fish was present in the majority of Estonian lakes, while missing in the Dutch and Danish lakes.

Although man made ponds consisted the majority (nearly 60 %) of all breeding waters used by *P. fuscus* in three study countries, the species still preferred natural water bodies for breeding: beaver floods in Estonia, natural depressions in Denmark and lakes in the Netherlands (Fig. 4).

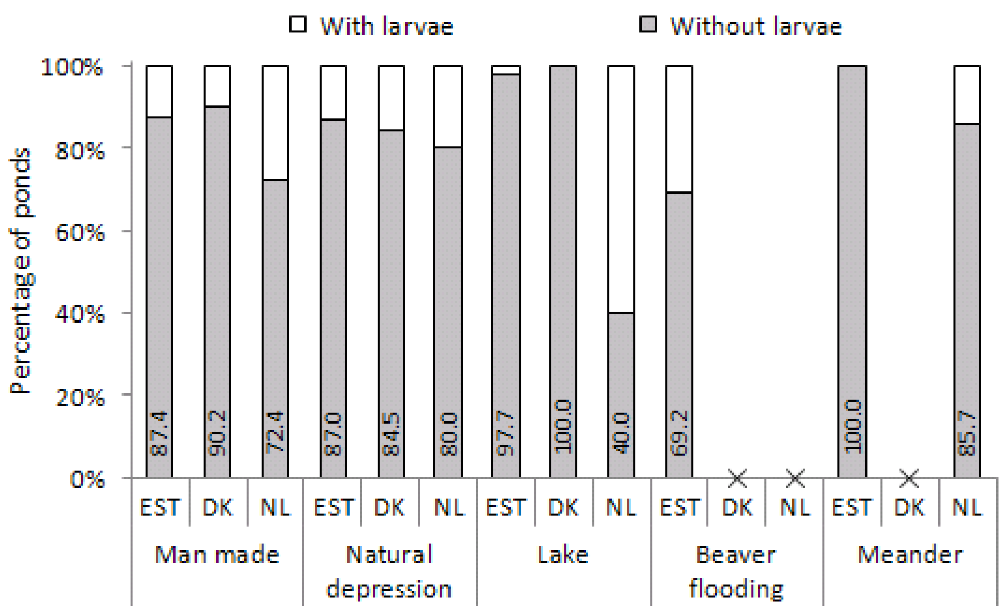

Figure 4. Proportion of ponds with and without *P. fuscus'* larvae, depending on the pond's type and country (the numbers denote the percentage of ponds without *P. fuscus'* larvae).

Characteristics of aquatic habitat

In general the breeding habitat characteristics of *P. fuscus* were similar in all three countries. Larger, fish free water bodies with extensive zone of shallow water were favoured by toads in Estonia, Denmark and in the Netherlands (Fig. 5).

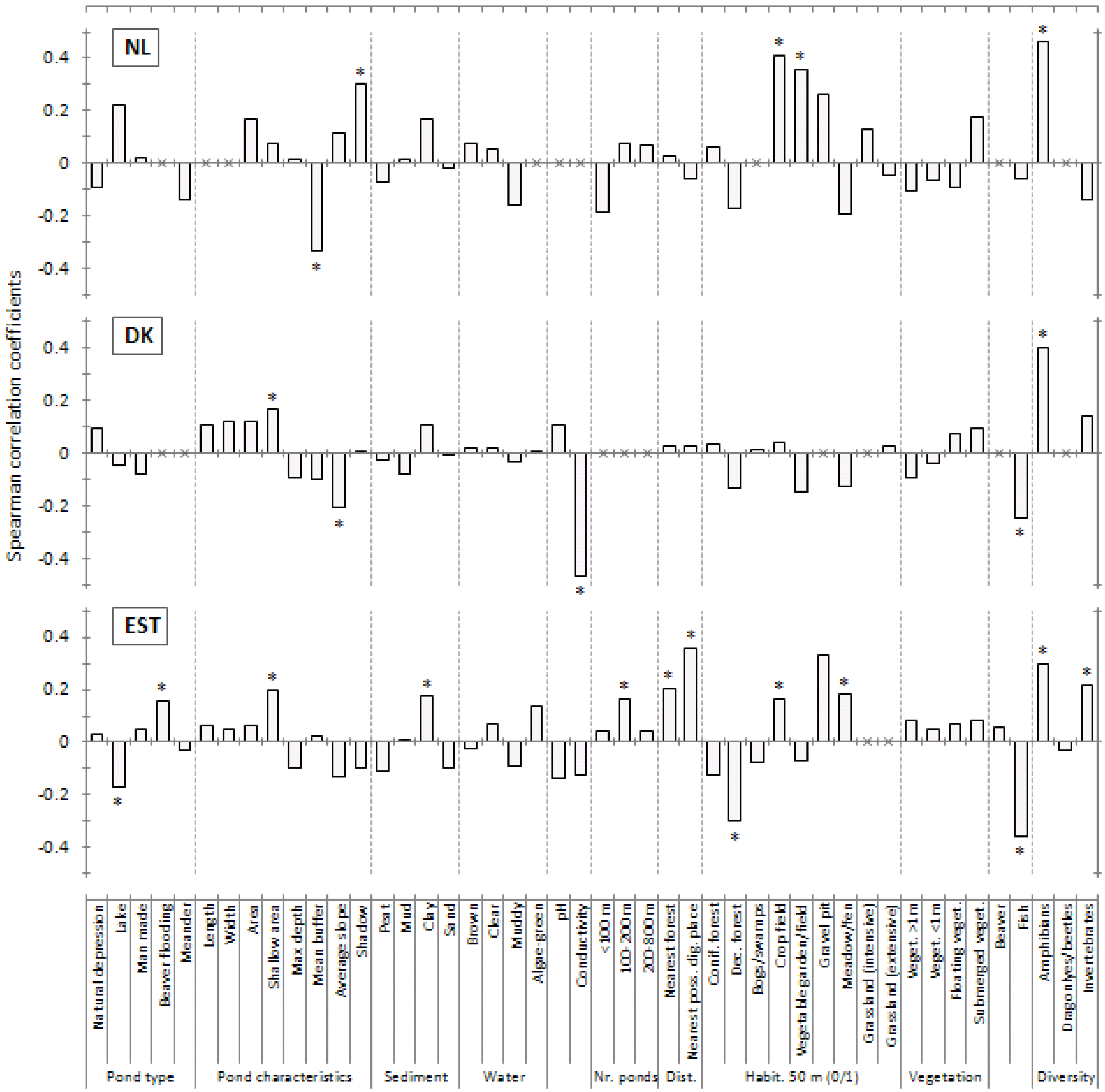

Figure 5. Spearman rank correlations between larval abundance of *P. fuscus* and pond's and surrounding landscape characteristics by country (EST – Estonia, DK – Denmark, NL – the Netherlands); stars denote the statistically significant ($p < 0.05$) relationships and "×" marks the characteristics not observed or not variable in corresponding country.

However, some aquatic characteristics still differed between the countries. For instance, in Denmark water bodies used for breeding by *P. fuscus* had significantly less shelving slopes than those used for breeding in the Netherlands. Interestingly, shadow of water body had a positive effect on breeding habitat selection in the Netherlands, while the effect was negative in Estonia (Fig. 5).

The preferred sediment type for *P. fuscus* in all three countries was clay. Peaty and muddy waters were avoided by the toads (Fig. 5). Importantly, *P. fuscus* favoured breeding ponds with low conductivity, especially in Denmark (Fig. 5). Interestingly the amount of water vegetation did not have any significant influence to the species.

When looking dissimilarities and their extent between different water body types in all three countries, one could see that artificial man made ponds were in general smaller with steeper banks and narrower shallow littoral zone, than natural water bodies (depressions, beaver floods and lakes) in all studied countries. Also the water conductivity was higher in man made ponds than in natural water bodies (Table 1).

Table 1. Average ± standard deviation ponds' characteristics depending on the presence of *P. fuscus'* larvae, pond type and country; if feasible, the mean values of ponds with and without *P. fuscus'* larvae were compared with Wilcoxon rank-sum test (p-values ≤ 0.05 are presented in bold).

Country	Pondtype	*P. fuscus* larvae	n	Area, m^2	Shallow area, m	Max depth, m	Mean buffer zone, m	Average slope °	pH	Conductivity, S/m
EST	Man made	No	76	1,977±4,540	118.1±311.7	1.80±0.36	141.5±126.7	53.4±25.1	7.63±0.95	0.38±0.17
		Yes	11	3,696±8,766	429.8±997.8	1.50±0.45	120.4±86.1	36.1±29.6	7.52±1.12	0.28±0.10
		p-value		0.726	**0.007**	**0.014**	0.931	0.056	0.100	0.083
	Natural depression	No	20	6,525±15,208	695.2±911.2	1.20±0.64	169.7±223.0	22.0±18.3	7.16±0.53	0.33±0.16
		Yes	3	17,510±12,920	787.1±125.3	1.83±0.29	173.4±186.3	18.8±7.0	7.58±0.51	0.34±0.19
		p-value		0.062	0.353	0.151	0.585	0.704	0.347	1
	Lake	No	43	77,799±164,568	6,625.1±17,785.7	1.79±0.50	152.7±153.0	35.7±31.9	7.21±0.66	0.22±0.10
		Yes	1	14,450	-	2.00	500.0	-	6.88	-
	Meander	No	1	5,750	-	1.00	5.0	5.0	7.70	-
	Beaver flooding	No	9	13,285±11,013	1,772.4±3,721.9	1.25±0.71	106.2±83.0	38.3±33.1	7.32±0.22	0.30±0.06
		Yes	4	32,406±28,314	1,218.0±1,675.9	1.63±0.48	38.5±41.3	22.8±7.4	7.07±0.16	0.19±0.01
		p-value		0.301	0.607	0.440	0.288	0.820	0.154	0.074
DK	Man made	No	110	1,225±1,592	286.9±1,237.9	1.68±0.52	71.9±112.7	45.4±28.0	7.26±0.48	0.57±0.17
		Yes	12	1,248±1,649	256.7±287.1	1.58±0.51	44.3±65.9	30.5±26.8	7.57±0.75	0.29±0.14
		p-value		0.721	0.219	0.395	0.486	0.056	0.298	**0.026**
	Natural depression	No	49	1,812±2,623	448.4±637.9	1.54±0.64	109.5±109.1	21.7±16.4	7.01±0.51	0.34±0.23
		Yes	9	4,483±4,670	2437.8±2,701.0	1.48±0.70	89.8±101.7	15.4±9.0	7.21±0.58	0.30±0.20
		p-value		**0.036**	0.166	0.806	0.393	0.262	0.498	0.787
	Lake	No	3	4,000±1,732	178.0±106.5	2.00±0.00	154.2±79.4	26.7±17.6	7.00±0.00	-
NL	Man made	No	21	1,393±3,465	295.8±579.9	1.36±0.55	607.1±946.2	33.2±18.2	-	-
		Yes	8	672±488	151.3±137.2	1.31±0.65	163.5±196.2	46.3±20.7	-	-
		p-value		0.156	0.646	0.920	0.119	0.122		
	Natural depression	No	4	1,425±287	562.5±634.3	1.25±0.29	88.5±66.6	21.3±11.1	-	-
		Yes	1	1,600	200.0	0.50	62.5	10.0	-	-

Lake	No	2	7,000±4,243	1,100.0±1,272.8	2.00±0.00	768.8±631.1	45.0±0.0	-	-
	Yes	3	5,833±6,658	3,466.7±5,766.6	1.67±0.58	130±124.3	28.3±16.1	-	-
	p-value		0.787	1	0.704	0.222	0.213		
Meander	No	6	1,312±1,458	298.3±246.3	1.25±0.42	255.3±250.3	31.0±15.5	-	-
	Yes	1	1,500	1,350.0	2.00	55.0	25.0	-	-

Landscape features in the vicinity of breeding pond

The number of water bodies in the vicinity of breeding sites was recorded in Estonia and in the Netherlands only. In both countries the higher number of water bodies, especially within 100-200 m of the study pond, had a positive effect on *P. fuscus*.

Presence of forest, especially deciduous forest, in the close vicinity of breeding site had a negative effect on toad's breeding in all three countries. In addition, the shorter distance to the nearest forest edge had a negative effect on the toads in Estonia – the further the breeding site situated from the forest edge, the more favourable for larval abundance and reproduction success (Fig. 5). The preferred longer distance to the nearest suitable digging place by the toad in Estonia, was quite a surprising result. It could be explained by lack of data on this landscape feature for Estonia (it was available only for 1/5 of inventoried sites). For example, in Denmark and in the Netherlands, where this data was available for most of the study sites, distance to the nearest digging site was not significantly important to the breeding site selection for the toad (Fig. 5).

While forest in the vicinity of breeding pond had a negative effect on the species, the presence of crop field and gravel/sand pit influenced positively breeding site selection of *P. fuscus*. Interestingly, vegetable gardens in the surroundings of the breeding site had a significantly positive effect on the toads in the Netherlands, while this effect was negative in Estonia and Denmark. At the same time presence of meadow/fen had a positive effect on the toad in Estonia and negative in Denmark and in the Netherlands.

Biodiversity in the breeding site

The number of other amphibian species breeding in the same water body with *P. fuscus* affected positively larval abundance of the species in all three study countries. In Estonia toads preferred to breed in water bodies with high invertebrate diversity. The same tendency was also observed in Denmark, but not in the Netherlands.

Leucorrhinia pectoralis

The larvae/exuviae of the species were found in 26 % of studied ponds in Estonia (N = 91; Fig. 6).

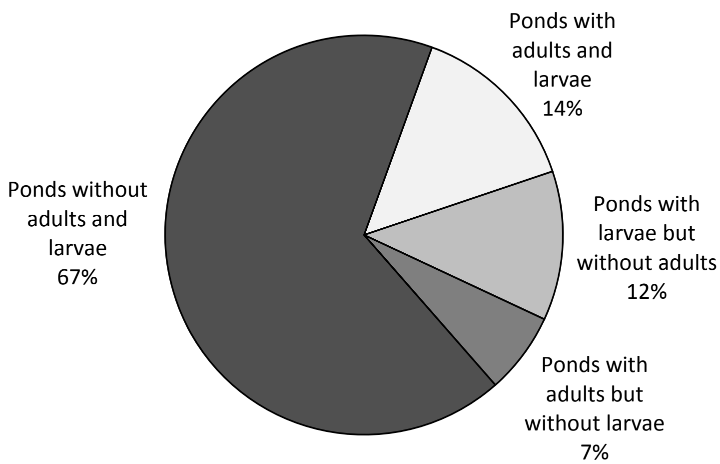

Figure 6. The percentage of visited ponds according to the occurrence of *L. pectoralis'* larvae(exuviae) and/or adults.

Type of water body and aquatic characteristics

Our study demonstrated that *L. pectoralis* preferred to breed in lakes and avoided man made ponds as reproduction sites (Fig. 7; 8). Lakes were larger, deeper and with extensive area of shallow littoral zone – features which associated positively with the abundance of larvae. At the same time the steepness of the slopes and shade were negatively related to the breeding site selection (Fig. 8).

The breeding site selection depended significantly also on the sediment type of the water body – peaty bottom was preferred and muddy bottom was avoided by dragonflies. Additionally, water bodies with clear brownish water and low conductivity were favoured and those with muddy water and high conductivity were evaded for breeding (Fig. 8). Similarly to *P. fuscus*, also *L. pectoralis* prevented shady water bodies for breeding.

The larval abundance of *L. pectoralis* was positively associated with vegetation cover (<1 m tall) in water body ($r = 0.36$, $p < 0.001$). Also the presence of water mosses

(*Sphagnopsida* and *Bryopsida*) had a positive effect (r = 0.47, $p < 0.0001$ and r = 0.39; $p < 0.001$ respectively) for *L. pectoralis'* breeding habitat selection.

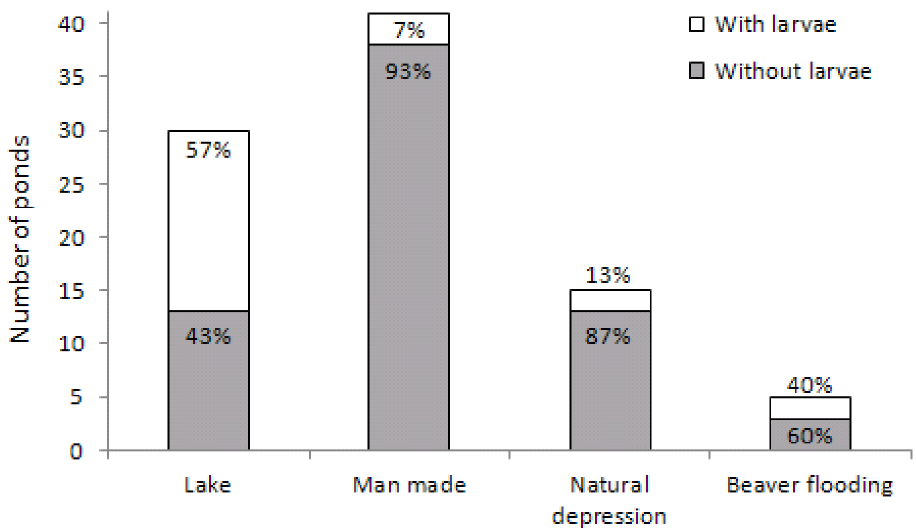

Figure 7. Distribution of different water body types according to the presence of *L. pectoralis'* larvae.

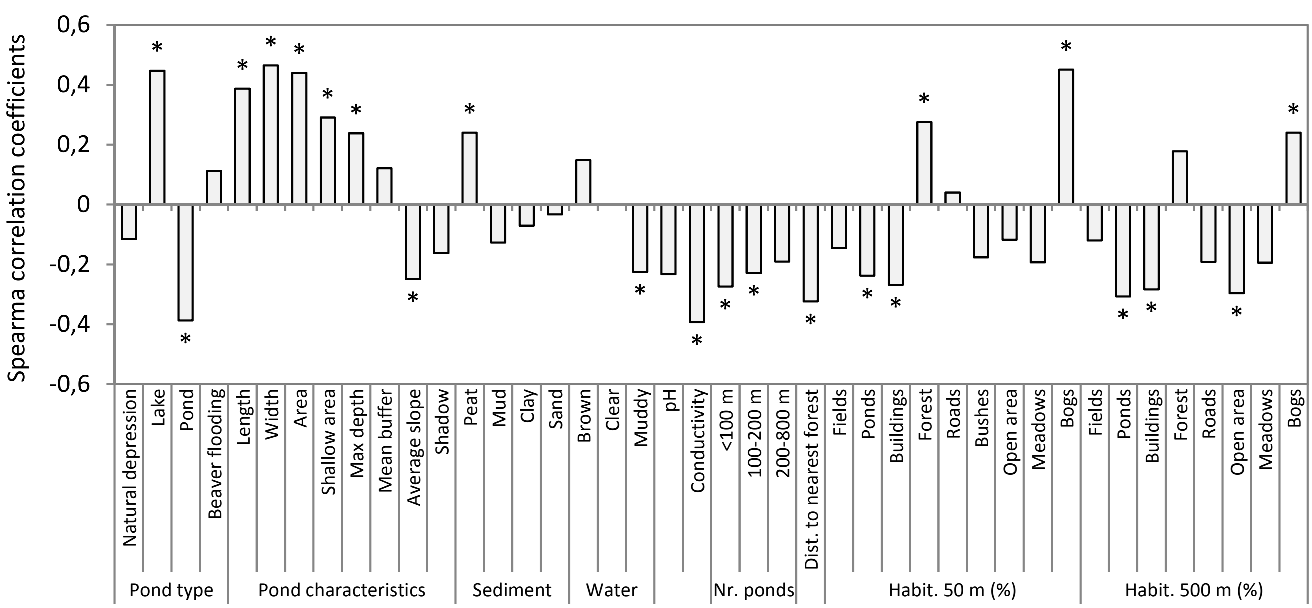

Figure 8. Spearman rank correlations between larval abundance of *L. pectoralis* and pond's characteristics; stars denote the statistically significant ($p < 0.05$) relationships.

Landscape features in the vicinity of breeding pond

The number of other water bodies in the vicinity of breeding site affected breeding habitat selection and larval abundance positively. Thus, tense network of water bodies is essential for *L. pectoralis*. Larger lakes and bogs have to be included to the wetland network.

The presence of bogs and forest in close vicinity of breeding ponds was vital for the dragonflies and shorter distance to the forest was also favoured (Fig. 8). At the same time, buildings and large open areas, such as meadows and fields had a negative impact on dragonflies.

DISCUSSION AND CONCLUSIONS

Pelobates fuscus

Our results indicate that *P. fuscus* has specific habitat requirements, associated with land cover type and conditions of the reproduction site. This is in accordance with several earlier studies, demonstrating that many other European amphibian species select breeding habitats based also on characteristics of the terrestrial and aquatic environments (Beebee 1985, Loman 1988, Marnell 1998, Rannap et al. 2009).

The general habitat demands of *P. fuscus* were rather similar in all three countries. This species preferred large, fish free water bodies with extensive zone of shallow water for breeding. The shallow littoral zone can provide suitable egg laying sites for the toads and foraging and hiding place for their larvae. In all three countries those requirements were met in natural water bodies (beaver floods in Estonia, natural depressions in Denmark and lakes in the Netherlands), which were also the preferred breeding sites in these countries respectively. Importantly, despite of high number of artificial man made ponds available, natural water bodies were favored in all study countries. Contrarily to natural water bodies, man made ponds were smaller, having steeper slopes and consisted often fish. The avoidance of fish and preference of large water bodies with extensive shallow littoral zone by *P. fuscus* have also been demonstrated in Sweden (Nyström et al. 2002, 2007).

Additionally, clayish sediment of water body and low water conductivity were essential breeding habitat characteristics for the toad in all study countries. In water bodies with clay sediment, oxygen level is relatively high, compared to water bodies with peaty or muddy sediment (Brönmark and Hansson 2005). The preference of breeding sites with high oxygen level by *P. fuscus*, have been demonstrated also in the Netherlands and Sweden (Strijbosch 1979, Nyström et al. 2002). Interestingly, in all study countries water conductivity in man made ponds was generally higher than in natural water bodies.

General amphibian diversity in water bodies (number of breeding species) was positively associated with the larval abundances of *P. fuscus* in three study countries. Thus, water bodies favored for breeding by *P. fuscus* were also preferred breeding sites for other amphibians in the area. Therefore, aquatic habitat management targeted to *P. fuscus* could also benefit other amphibian species. Additionally, the toad's preference to breed in natural water bodies indicates the necessity for maintenance and restoration of natural depressions and other type of large water bodies with shallow margins.

The only terrestrial habitat feature affecting the toad in a similar way in all three countries was presence of forest, especially deciduous forest in close vicinity of the breeding pond. The impact of forest on breeding site selection was negative in all countries. Thus, toads avoided forest and preferred open landscape around their aquatic habitat.

Despite of several similarities, our study also revealed many differences on habitat requirements of *P. fuscus* in study countries. Below we discuss those differences in details.

Estonia

Pelobates fuscus preferred to breed in beaver floods in Estonia, although man made ponds formed a majority of all water bodies available in the study sites. Beaver flood is a specific aquatic habitat type for Estonia, because not existing in Denmark neither in the Netherlands. Conditions in beaver floods were often in accordance with aquatic habitat demands essential for the toad. They were usually large with extensive areas of shallow water and low water conductivity. Apparently in times when waste number of natural depressions and floods were destroyed by ditching and amelioration, the growing beaver populations secured the survival of *P. fuscus* in some parts of Estonia by creating suitable breeding habitats for the toads.

Lakes were in general avoided as breeding sites by the toad in Estonia, probably due to the presence of fish in those. However, in Porkuni LPA, where majority of lakes have karstic nature, being large temporary fish free water bodies, *P. fuscus* uses those for breeding.

Among the terrestrial habitat characteristics, presence of crop fields and meadows/fens in the surroundings of the breeding site had a significantly positive effect on *P. fuscus*. When crop fields in general affecting negatively breeding site quality of amphibians, due to the nutrient influx (Hansen 2002, Ficetola and Bernardi 2004), fields in Estonian study sites were extensively used. Our results illustrate the importance of having high quality open landscapes in the surroundings of breeding sites. Today the forest cover is more than 50 % in Estonian project sites. Historically (ca 60-70 years ago) the forest cover in those sites was only about 20 %. However, in some areas (e.g. Porkuni LPA, Mõdriku-Roela LPA) *P. fuscus* occurs also in coniferous old growth forest, where at the same time high quality aquatic habitats are available. Deciduous forest around the breeding site had significantly negative impact on the toad, probably due to its scrubby nature, because majority of deciduous forest in Estonian project sites is rather young and also appears often after clear cutting. The avoidance of scrubland by *P. fuscus*, has been demonstrated by Eggert (2002).

Denmark

In Denmark natural depressions were preferred breeding sites for *P. fuscus*. Those water bodies met the criteria essential for the toad. They were large, with shallow slopes and extensive littoral zone and no fish. At the same time high water conductivity (eutrophicated water) influenced negatively breeding site selection by toads. Importantly, in Estonian study sites the conductivity of water did not play significant role for breeding site selection of toads. It could be due to the natural nature of water bodies, as well as lack of pollution in Estonian study sites. Thus, the high quality of breeding sites is probably one of the limiting factors of Danish *P. fuscus'* populations. Breeding site management and restoration should therefore be a priority and taken as an essential, first step conservation tool, to save the species in Denmark.

None of the terrestrial habitat features had significant effect on *P. fuscus* in Danish study sites. Most of the investigated water bodies situated in Natura 2000 sites there, thus, the serious negative impact from the surroundings (influx from intensively used farms and agricultural fields) probably did not emerged in this study.

<u>The Netherlands</u>

Contrary to Estonia and Denmark *P. fuscus* preferred to breed in lakes in the Netherlands. However, lakes in the Netherlands were in general fish free and 10 times smaller than those in Estonia. Also the positive effect of shadow on the breeding habitat selection was specific to the Netherlands, which could be explained by the southernmost location of the country compare to Estonia and Denmark. Thus, temperate shadow over the breeding waters might avoid early evaporation of water bodies in the Netherlands. In addition, trees shading the water could protect it at the same time against agricultural pollution having thou indirect positive influence.

The positive effect of vegetable gardens and crop fields and the negative effect of buffer zone around the water body on breeding site selection were, in first glance quite surprising results. However, contrary to Estonia and Denmark, large scale conservation work has been carried out in the Dutch study sites already. Ecological vegetable gardens and extensively used crop fields were established in the vicinity of *P. fuscus'* breeding ponds by nature conservation authorities, offering high quality terrestrial habitat for the toads. At the same time uncultivated areas around the breeding sites (indicated as buffer zones in our study) consisted often in tense scrub and tall vegetation, heavily permeable by the toad.

Suggestions for habitat management

Our data demonstrated that the basic habitat features, essential for breeding habitat selection of *P. fuscus* were in general similar in all three study countries. Those habitat requirements are:

- no fish in water body;

- naturally clean water (low conductivity);
- clayish bottom of water body;
- large water table;
- extensive zone of shallow water;
- no forest, especially deciduous forest, around the breeding site;
- presence of open landscapes around breeding site (e.g. extensive fields and vegetable gardens, but also dunes, gravel/sand pits – habitats with loose sandy soils where the toads can dig in and forage around).

Our results suggest that aquatic habitat management is important for *P. fuscus* in all three countries. In addition, as breeding success of *P. fuscus* was related to general amphibian diversity in the breeding sites in study countries, water body management targeted to *P. fuscus* would also benefit the reproduction success of other amphibian species.

In addition to breeding habitat management (restoration and creation of natural depressions and other type of large water bodies with shallow margins) the vicinity of reproduction site has also to be taken into account while planning habitat management actions. Extensively used fields and vegetable gardens could favor the species, while intensive agricultural fields should be avoided in the vicinity of *P. fuscus* breeding sites. The pollution from intensively used fields and farms will spoil the water quality of breeding ponds, so that the reproduction could fail in about 50 % of water bodies, as demonstrated in Denmark (Hansen 2002). Thus, organic farming should be promoted, as well as maintenance and creation of extensively used fields and small vegetable gardens in the vicinity of *P. fuscus* breeding sites.

In Estonia, in addition to aquatic habitat management, avoidance of further encroachment of deciduous forest and scrub over the open landscapes (fields and grasslands) would also be vital. It is important to allow the beaver populations thrive and let them create new aquatic habitats for the toads. Also the negative impact on expansion of intensive agriculture to the areas with *P. fuscus'* populations should be avoided in Estonia. The general negative consequences of intensive farming to amphibian populations have already been demonstrated in many countries (e.g. Semlitsch 2000, Cushman 2006, Ficetola and Bernardi 2004).

In Denmark the avoidance of eutrofication of breeding sites by cleaning water bodies and creating new ones could be essential tool for species management.

In the Netherlands both aquatic and terrestrial habitats of the species should be maintained by creating new breeding sites and providing high quality terrestrial habitats (organic fields, vegetable gardens) around them. In addition, originally shallow temporary and thus fish free breeding sites should not be deepened, but stay temporary as they are. The temporary nature of the water body allows using natural pond drying to prevent and eliminate fish predation (Semlitsch, 2000). Deepening may create permanent water body with steep banks and narrow zone of shallow water. It is also difficult to keep such ponds fish free.

Overall conclusions

Active management measures	**Estonia**	**Denmark**	**Netherlands**
Maintain existing breeding sites with active management	very important	very important	very important
Create and restore new natural depressions (fish free, clean water) with large shallow margins.	very important	very important	very important
Create loose soil habitats near the breeding ponds	in some sites	very important	very important
Preventive measures			
Avoid intensive agricultural activities in close vicinity of breeding sites	very important	very important	very important
Avoid planting deciduous forest near breeding sites and in the foraging areas	important	important	important
Avoid natural succession with scrub and deciduous bushes and trees	very important	in some sites	in some sites
Let beaver population thrive and make new ponds	very important	important to start in some areas	

Leucorrhinia pectoralis

To determine habitat requirements of *L. pectoralis* only data from Estonia was used, because in Denmark just three sites with *L. pectoralis'* larvae were found during the inventory in 2010. This dragonfly species has declined sharply in the westernmost parts of its range and its present distribution is very patchy (Sahlén et al., 2004). Thus, knowledge on habitat demands of *L. pectoralis*, gained from Estonia, would be very useful for active habitat management planning in Denmark and in other Western and Central European countries (e.g. Germany, France, the Netherlands, Belgium, etc.) as well.

In Estonia *L. pectoralis* preferred larger natural lakes with extensive shallow littoral zones and large swampy edges of moor vegetation for breeding. At the same time artificial man made ponds with generally small size and steep banks were avoided as reproduction sites for *L. pectoralis*. In many areas in Europe natural lakes surrounded by bogs and swamps have completely vanished or their number has decreased rapidly. If such sites still exist, it would be important to preserve those in a state as close to natural as possible. In the other hand, while planning actions of habitat management for *L. pectoralis* creation of large wetlands and restoration of large permanent depressions with depth variation and extensive littoral zones should be considered. In addition, tense network of natural water bodies (lakes, bogs, beaver floods, river flood plains etc) is essential to harbour a vital population of *L. pectoralis*. Therefore aquatic habitats should be created and restored in clusters.

Leucorhhinia pectoralis favoured to reproduce in water bodies with peaty sediment and avoided water bodies with mud. The sediment type turned out essential for the species probably due to its influence to the water chemistry and macrophytes' community. Sediment type also indicates the species' preference to natural clean water bodies and avoidance of eutrophicated waters. Thus, when restoring or creating breeding sites for this species, sediment type should be taken into account and agricultural pollution as well as nutrient influx should be prevented.

In accordance to earlier studies, breeding site selection of *L. pectoralis* was strongly associated with presence of macrophytes in the water body (Schindler et al. 2003, Sahlén et al., 2004). Less than 1 m tall vegetation cover, as well as presence of

Sphagnopsida and *Bryopsida* mosses associated positively with larval abundance of *L. pectoralis*. Water vegetation has various important functions for adults and larvae, which include concealment from predators (Askew 1982), substrate for egg deposition, larval habitat, as well as for mating and feeding perches (Buchwald 1992, Schindler et al. 2003).

Presence of forest and bogs in the close vicinity of breeding site was essential for *L. pectoralis* and the shorter distance to the forest was favoured. Forest provides shelter for the adults. At the same time open areas and buildings had significantly negative influence on breeding site selection. As demonstrated by Chin and Taylor (2009) the dispersal ability in the genus *Leucorrhinia* was limited by open areas, particularly in short distances, whereas forest shelters acted as dispersal routes for the adults. Thus, breeding sites should be created near the woodlands and large open areas as well as urban areas should be avoided.

Overall conclusions

Active management measures	**Estonia**	**Denmark**
Manage existing and previous breeding sites	important if the sites are partly destroyed by drainage	very important if these sites are partly destroyed by drainage
Create and restore new large lake like water bodies and large wetlands with extensive shallow littoral zone and peaty sediment.	important as stepping stones between natural lakes and beaver floods	Very important
Create shelter and sitting places for adults (plant trees, bushes)	Not relevant	very important in many places
Preventive measures		
Avoid general drainage of natural lakes and moors	very important	very important
Avoid eutrophication of the landscape from agriculture	very important	very important
Let beaver population thrive and create new ponds and wetlands.	important	important to start in some areas

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