The decline of Great Crested Newts in Switzerland – determining the important factors

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Abstract

1. The decline of species in the last decades affected many taxa, but no taxon was as highly affected as the amphibians. A victim of these declines is the Great Crested Newt (GCN) in Switzerland.

2. The reasons for the decline were under focus of several studies in the past and several factors were revealed. This study compares these known factors and zooplankton abundance as a new factor using a habitat selection approach.

3. The results showed that pH of the ponds is a vital important factor for the persistence of the GCN and its optimum lies around 8. Zooplankton abundance plays a major role, too, but the mechanisms are yet unclear and should be investigated in further studies.

4. A factor positively influencing the persistence of GCN is connectivity. This leads to the conclusion, that existing ponds in the Swiss landscape should be protected and even new ponds should be established to enhance metapopulation dynamics.

1. Introduction

Since the beginning of mankind, men tried to change the environment to their own good which was in very rare occasions a benefit for nature. In most cases nature got the bad end and a lot of species, animals and plants, got extinct due to the process of civilisation.

In the past 30 to 50 years those anthropogenic changes in the environment increased even more rapidly and led to a wave of threatening for a lot of species all over the world. According to the IUCN about 40% of the species assessed with the IUCN Red List Criteria are listed as threatened with extinction (which includes the three criteria “vulnerable”, “endangered” and “critically endangered”; IUCN 2006) A highly affected taxon are the amphibians as there is about one third of all amphibians considered to be threatened with extinction (Fig. 1, Houlahan *et al.* 2000, Stuart *et al.* 2004).Stuart *et al.* (2004) stated that the amphibians are now even more threatened than mammals and birds.

The Red List of Threatened Amphibians in Switzerland (Schmidt & Zumbach 2005) revealed a victim of these recent waves of declines: The largest Swiss newt species, the Great Crested Newt (*Triturus cristatus*). About 50% of the known GCN-sites could not be confirmed during the survey for the Red List in 2005 (Fig. 2). Due to this fact it is considered to be endangered in Switzerland according to the IUCN Red List Criteria.

What are the possible reasons for this decline? Several studies have been conducted to uncover factors influencing survival and persistence of populations of the GCN (Table 1).

This study will also test a new factor, which assumes that population persistence is affected by performance in the aquatic larval stage (as opposed to performance in the terrestrial habitat) I hypothesise that persistence of the Great Crested Newt may be related to abundance of food. This is based on observations made during an experiment conducted by Schmidt & Van Buskirk (2005) where performance of six newt species was assessed in a common garden experiment, amongst them the GCN. After 6 weeks in the ponds the GCN larvae had the largest size of the five Swiss newt species (Fig. 3) and furthermore was the only species that succeeded to completely erase the population of its main food source zooplankton (Schmidt & Van Buskirk 2005). These facts lead to the following novel hypothesis:

Growth of larval *T. cristatus* in natural ponds depends strongly on food resources and ponds where *T. cristatus* went extinct have lower zooplankton abundances than ponds where *T. cristatus* persisted.

Thus, the aims of this study are (1) to determine whether “food availability” hypothesis is true or not and (2) to assess the relative importance of various factors that have been proposed in the literature and the new hypothesis.

To reach these aims a habitat analysis approach is applied (MacKenzie *et al.* 2002) like it was done in several of the mentioned studies. This study differs in its basics from the former as it is trying to determine factors influencing local extinction, like Witte *et al.* in an unpublished paper, and not simply presence/absence. This means, that not only sites were tested where GCN occurs, but all suitable habitats or former GCN sites.

2. Material and methods

2.1. Field work

During the update of the Swiss Amphibian Red List 2003/04 50 randomly chosen ponds were surveyed to determine presence or absence of the GCN. In attempt to explain the occurrence of the GCN I measured habitat factors. Due to reasons like floods, dry-outs, insufficient depth for zooplankton sampling and so on, only 29 ponds could be sampled. During the Red List surveys, crested newts were detected in 16 ponds and no crested newts were observed in 13 ponds. (Fig. 4).

Each site was visited twice between mid-July and mid-September, whereas on a first visit zooplankton samples were collected with a Schindler-Patalas-trap along a transect through the centre of the pond on its broadest point, where every 1.5 m zooplankton was sampled. For smaller ponds at least 3 samples were taken at regular distances. If crossing of the pond was impossible (due to depth or deep mud) the accessible areas of the pond were sampled. Each sample was labelled with the number of the pond and the amount of water sampled to determine concentration later on. The samples were stored in ethanol with an additive of sugar to prevent zooplankton from deformation.

The zooplankton in each sample was counted distinguishing between *Daphnia* sp., copepods, ostracods and insect larvae using a stereomicroscope. For each kind of zooplankton a simplified mean body volume was estimated. The zooplankton mass was then calculated using the count and the mean body volume. Afterwards zooplankton concentration (zooplankton mass divided by water volume sampled) and a mean of all samples within the same pond were calculated.

On a second visit different habitat variables were taken, that influence the GCN during its lifetime. Some influence the aquatic habitat (pH and water temperature), others contribute to the terrestrial habitat (forest cover and connectivity). And some factors directly affect development and survival of the larvae (predation, macrophytes cover and pond size). For predicted effects and references see table 1.

pH and temperature were measured with a combined pH and temperature meter on at least 4 points in the pond along the same transect as for the zooplankton and with the same alternative for ponds which could not be traversed. Area of the pond was estimated by eye, canopy and macrophyte cover were estimated as a percentage of pond area. To determine presence of fish 2 minnow traps were used during 20 minutes at each pond, as long as fishes were not simply visible. The way the different measurement contribute to the analysis is shown in Table 2.

The factors connectivity and forest cover were measured using GIS methods. Connectivity was determined using the connectivity formula often used in metapopulation biology (Hanski

$$\text{Connectivity}= \sum_{i \neq j} e^{-d_{ij}} A_j$$

et al. 1994) whereas d_{ij} is the distance between two patches and A_j is the maximal carrying capacity of the patch j, which was set to 1. Information on the nearby GCN populations were taken from the KARCH database. Percentage of forest cover was determined in two circular buffers around the pond with radii of 100 and 1000 metres using GIS with 1:25’000 vector maps.

2.2. Statistics

Prior to the site occupancy analysis, all factors underwent a correlation analysis (Spearman's r_s) to determine correlations between the different factors and no correlations were found. Another correlation analysis (Spearman's r_s) was done to reveal possible time effects. Most of the factors (except connectivity and both forest cover factors, as these values were taken from an existing database) were tested against the date and time of data collection. The only time effect was found for temperature (p= <0.001; Tab. 3). To correct for this time effect a linear regression was applied and the linear equation of the regression line was determined (in the form $y = ax + b$). In a next step, the date for each value was inserted and the resultant temperature value was subtracted from the originally measured value. This difference was then added to b. In this final formula x (i.e. date) was set to 0.5 and the corrected y (i.e. temperature) was calculated. All factors were standardised using z-transformation and then entered as factors influencing ψ (probability of species presence) of GCN into the program PRESENCE 2.0 (Hines J.E. 2006; http://www.mbr-pwrc.usgs.gov/software/presence.html). The "capture" history (in the form 0110, whereas 0 stands for no detection and 1 for detection) was taken from the data of the Red List survey 2003/04. Detection probability was set to be constant, as there was no data available. The basic procedure underlying this program is provided by MacKenzie *et al.* (2002).

In a first modelling step only simple single factor models were established with the exception of pH, as pH^2 was introduced to allow for an optimum. The models were then ranked according to the Akaike weight. Models (i.e. factors) better ranked than the null model were included in a further modelling step. In this second step all possible combinations of these factors were modelled and the factor pH^2 was introduced to allow for an optimum.

From the outputs the single ψ for each factor were extracted and in Excel 2003 multiplied with their according AIC weight and then summed up (i.e. model averaging; Buckland *et al.* 1997). To plot the different factors the inverse logit formula was applied.

3. Results

Older records of T. cristatus could be confirmed in 16 of 29 ponds during the survey 2003/2004. The differences in environmental characteristics between the two types of ponds are shown in Tab. 4.

For some variables the differences were relatively small (e.g., macrophyte cover) but for other differences were substantial (e.g., shade). In the first modelling step I evaluated the explanatory performance of models with only a single predictor variable. In this step pH, shade and connectivity and additionally, as hypothesised, zooplankton mass were the most relevant factors (i.e. better than the null model; Tab. 5). Other factors that differed greatly between pond types, such as pond area, ranked worse than the null model. However, no model had an Akaike weight > 0.32 which suggests that single-factor models generally do not describe the data well.

In the second modelling step I evaluated models that combined the predictor variables pH, shade, connectivity and zooplankton. The models including pH and pH2 were notably better ranked than other models: the eight best models all included pH. The best model incorporated pH, pH2 and zooplankton mass. Models including pH had a summed Akaike weigth of 0.7319. Evidence for a pH optimum was strong, too. The best five models included pH2 and the summed Akaike weight for models with pH2 was 0.6045. Models including zooplankton had a summed Akaike weight of 0.5624. There was weaker evidence for a role of shade and connectivity. The summed Akaike weights of models including these two factors were 0.2785 and 0.3598, respectively (Tab. 7).

As shown in figure 5a pH tends to have an optimum around 8, which is slightly alkaline and differs from earlier studies in which a much lower optimum around 6.5 was found (Skei et al. 2006).

Zooplankton showed an unexpected negative effect (Fig. 5d), which would contradict the starting hypothesis. There will be further examinations and possible reasons explained in the discussion

Connectivity displayed an expected positive effect (Fig. 5b) as it is important for dispersal and colonisation.

Figure 5c shows, that shade (canopy cover) has a slight negative influence, but the slope is very flat and therefore the factor seems to be less influencing/important.

The slopes and standard errors of the factors after model averaging are shown in Table 7. Only pH showed a strongly positive slope, the other factors just reached a small slope.

4. Discussion

Models indicated the vital importance of pH for the occurrence of the GCN. This was also shown in a study of Skei *et al.* 2006, but with significantly different optimum of about 6.5 compared to about 8 in this study. The measurements of pH of ponds with GCN and without are highly overlapping (Fig. 6), but ponds with GCN present showed a smaller variation around the found optimum. This would lead to the conclusion, that the GCN only tolerates a very narrow range, which means any change in any direction away from the optimum could have disastrous effects. This would rise a huge concern for the future of the GCN. There is no study or database for small ponds and their development in pH values available at the current time, but most probably the pH is changing since the beginning of industrialisation and intensive farming. Naturally the pH in ponds and other water bodies is influenced by its basal rock structure. But it is also strongly affected by man. The main cause (among others like fertilisation) for changes in pH in our time is the so called acid rain, caused by combustion of fossil fuel and the following disposal of sulphur dioxide and nitrogen oxides. These air pollutants are also known to cause, along with carbon dioxide, global warming.

The models suggested zooplankton concentration to be an important factor, but the output showed some unexpected results. Zooplankton concentration negatively influences occurrence of *T. cristatus*, which is in a biological way kind of impossible, because zooplankton is the main food source for larvae. A possible explanation is that a delay in the field season played a role. Due to the delay, the GCN already reduced the zooplankton concentration that much, that the concentration in ponds with GCN was lower than in ponds without. This would support our hypothesis, but it has to be tested in a future study which should sample zooplankton over a whole season (i.e. when larvae of the GCN are present in the ponds) to determine natural and GCN induced effects. A direct comparison between larval growth and zooplankton concentration would also lead to a clearer view of the causalities between the occurrence of GCN and zooplankton abundance and their importance.

As the models show, connectivity is important, which supports the results of several earlier studies (Halley *et al.* 1996; Griffiths & Williams 2000). It has a positive effect which leads to the conclusion, that even more small ponds should be protected or re-established in the Swiss landscape, as it is done in some places. A possible step for the Swiss government could be to qualify ponds for direct payments as set-asides.

A bit surprising is that forest cover had – contrary to the study of Denoël & Ficetola 2007 – no (or only small) influence to the presence of GCN, although it is the main habitat for the adults out of the breeding season. As forest cover, many of the proposed factors of past studies, like pond size, macrophytes cover and predation, did not show an effect in this study. Although the slopes were very flat, some of these factors pointed in certain directions, so the GCN prefers warmer, bigger and less shady ponds. A reason for the insignificance of the factors of earlier studies might be, that those studies compared GCN habitat with GCN-free habitat to determine the most suitable habitat. But factors influencing habitat suitability are not necessarily influencing local extinction or persistence, as it is the focus of this study.

From a conservational viewpoint several things are revealed by this study. First of all pH plays a major role in the persistence of GCN. I would suggest starting a monitoring program to detect even small differences from the found optimum. Of course the probability exists, that pH is not changing. But then it never was optimal for persistence, but was good enough for colonisation in first place. Which underlines the difference between factors influencing occurrence and factors influencing extinction or persistence.

Second is that zooplankton is an important factor too, although the mechanisms in which way it contributes to extinction or persistence are unclear and should be elaborated in future studies. It is important to understand the mechanistic reasons why and how zooplankton abundance affects the distribution of the GCN.

The third but not less important factor is connectivity which implies that the conservation of even the smallest ponds in the landscape is important for the GCN and most probably for all amphibians, as an enhanced connectivity leads to better metapopulation dynamics (Halley *et al.* 1996).

5. Acknowledgments

Special thanks to Dr. Benedikt Schmidt and Prof. Dr. Raphaël Arlettaz for supervision, Fabien Fivaz for help with GIS and my father for field assistance. Additional thanks go to the different federal authorities for the authorisation of the pond sampling.

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Tables

Tab. 1: Factors influencing survival and persistence of the GCN identified by former studies

Factor	Effect	References
Pond size	(–) on larval developement	Sztatecsny *et al. 2004*; Pearman 1993; Van Buskirk 2005
Predation	(–) mainly fish	Schmidt & Van Buskirk 2005; Skei *et al.* 2006; Denoël *et al.* 2005
Shade	(–)	Sztatecsny et al. 2004; Skelly *et al.* 1999
pH of pond	optimum ~6.5	Skei *et al.* 2006; Langton *et al.* 2001
Macrophyte cover	(+) egg laying	Gustafson *et al.* 2006
Forest	(+) as habitat for adults	Denoël & Ficetola 2007
Connectivity	(+)	Halley *et al.* 1996; Griffiths & Williams 2000)

Tab. 2: Measured factors and their measurements

Factor	Measurement
Pond area	estimated value in m^2
Predation	presence (1) or absence (0) of fish
Shade	canopy cover in % of pond area
pH	pH value
Macrophytes cover	cover in % of pond area
Percentage of forest cover in two circles centred on pond with radii 100 and 1000 metres	% of forest cover
Connectivity	connectivity index acoording to formula
Concentration of zooplankton	in mg per litre

Tab. 3: p-values of Spearman's r_s test to determine time effects. Bold writing represents significance. (a = not tested, as these factors were taken from an existing database)

Factor	Date	Time
pH	0.896	0.082
Temperature	**<0.001**	0.139
Shade	0.853	0.445
Makrophytes	0.154	0.124
Fish	0.100	0.594
Area	0.694	0.276
Zooplankton	0.343	0.490
Connectivity	a	a
Forest100	a	a
Forest1000	a	a

Tab. 4: Means and standard deviations of ponds with and without GCN

	with GCN (N=16)		without GCN (N=13)	
	mean	standard dev.	mean	standard dev.
pH	7.66	0.36	7.41	0.75
Temperature [°C]	19.01	2.10	17.95	3.05
Area [m^2]	5323.69	11835.68	3857.42	10394.83
Shade [%]	0.12	0.22	0.26	0.33
Makrophytes [%]	0.34	0.33	0.39	0.27
Fish	0.38	0.50	0.15	0.38
Connectivity	2.25	1.50	1.61	0.52
Forest100	0.26	0.36	0.24	0.34
Forest1000	0.24	0.19	0.32	0.23
Zooplankton	1.52	2.12	3.74	4.95

Tab. 5: Results of the first modelling step, AIC and AIC weight for single factor model (N=29)

Model	AIC	AIC weight
psi(pH,pH2),p(.)	103.19	0.3279
psi(pH),p(.)	105.12	0.1249
psi(zoo),p(.)	105.61	0.0978
psi(connect),p(.)	106.12	0.0758
psi(shade),p(.)	106.32	0.0686
psi(.),p(.)	106.36	0.0672
psi(fish),p(.)	106.37	0.0671
psi(temp),p(.)	106.72	0.0561
psi(forest1000),p(.)	107.53	0.0374
psi(makro),p(.)	108.22	0.0265
psi(area),p(.)	108.29	0.0256
psi(forest100),p(.)	108.33	0.0251

Tab. 6: Established models during the second modelling step with AIC and AIC weight (N=29)

Model	AIC	AIC weight
psi(ph,ph2,zoo),p(.)	102.17	0.1496
psi(ph,ph2,zoo,connect),p(.)	102.75	0.1119
psi(ph,ph2),p(.)	103.19	0.0898
psi(ph,ph2,zoo,shade),p(.)	103.60	0.0732
psi(ph,ph2,connect),p(.)	104.15	0.0556
psi(ph,zoo),p(.)	104.31	0.0513
psi(ph,ph2,zoo,connect,shade),p(.)	104.38	0.0495
psi(ph,ph2,shade),p(.)	104.49	0.0469
psi(connect,zoo),p(.)	104.91	0.0380
psi(ph),p(.)	105.12	0.0342
psi(zoo,shade.connect),p(.)	105.20	0.0329
psi(zoo,shade),p(.)	105.44	0.0292
psi(ph,ph2,shade,connect),p(.)	105.52	0.0280
psi(zoo),p(.)	105.61	0.0268
psi(ph,connect),p(.)	105.91	0.0231
psi(connect),p(.)	106.12	0.0208
psi(ph,shade),p(.)	106.32	0.0188
psi(shade),p(.)	106.32	0.0188

Tab. 7: Slopes and SE of the of the factors after model averaging

Factor	Slope	SE
pH	14.555	2.741
pH2	-13.769	6.798
Zooplankton mass	-0.546	0.653
Connectivity	0.263	0.560
Shade	-0.143	0.441

Figure captions

Figure 1: IUCN Red List Assessment for all 5918 amphibian species, the three emphasized slices represent the percentage which is threatened with extinction ; data from the 2006 IUCN Red List of Threatened Species. (http://www.iucnredlist.org)

Figure 2: Map of GCN-sites. Grey areas represent all known sites of *T.cristatus*, circles are ponds surveyed during the monitoring of the Red List of Amphibians, whereas black circles represent confirmed site, white circles unconfirmed. Schmidt & Zumbach 2005

Fig. 3: Life history, behaviour, and morphology of six species of Triturus newt larvae in the absence (open symbols, mean ± SE) and presence of predators (closed symbols). Mass (g) was measured once after 6 weeks; (vul = Triturus vulgaris, hel = T. helveticus, alp = T. alpestris, mar = T. marmoratus, car = T. carnifex, cri = T. cristatus). Schmidt & Van Buskirk 2005

Figure 4: Map of the 29 tested ponds across the Swiss Mittelland.

Figure 5 a-d: Output of the habitat analysis. After model averaging, ψ(*T.cristatus*) is plotted against each factor (N=29).

Figure 6: Comparison of pH in ponds with and without GCN. pH was grouped in 9 bins (5.75-6.24, 6.25-6.75 and so on). Occupancy graphic equal to Fig. 5a.

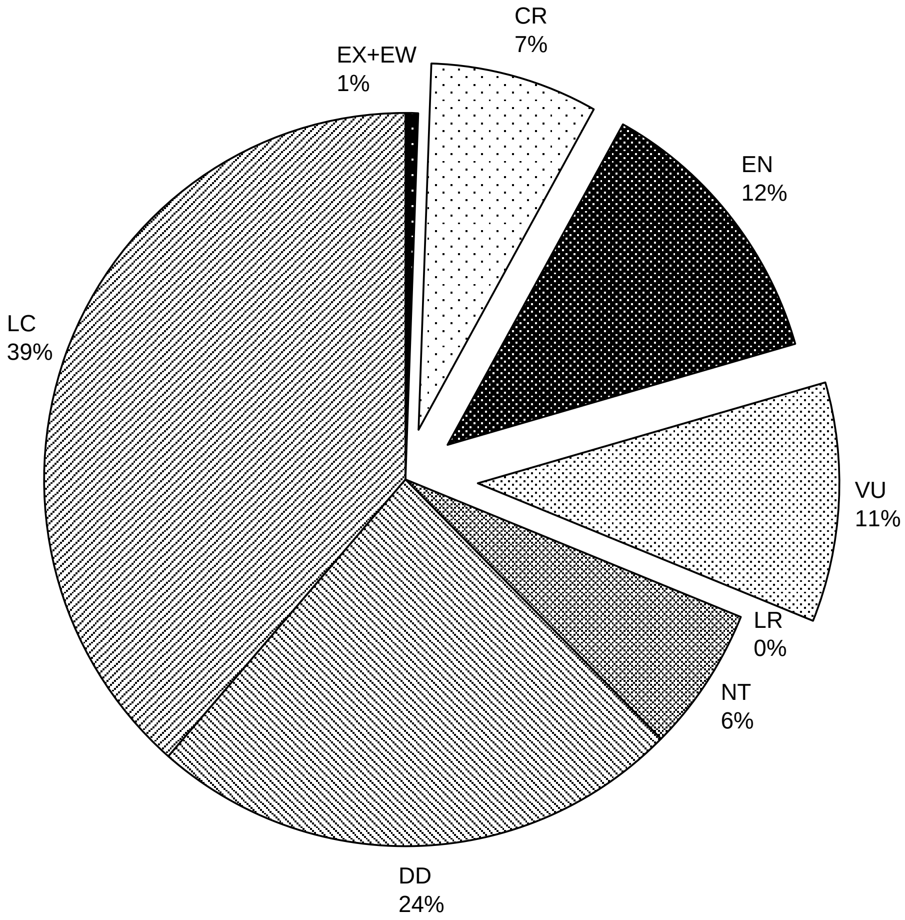


Figure 1

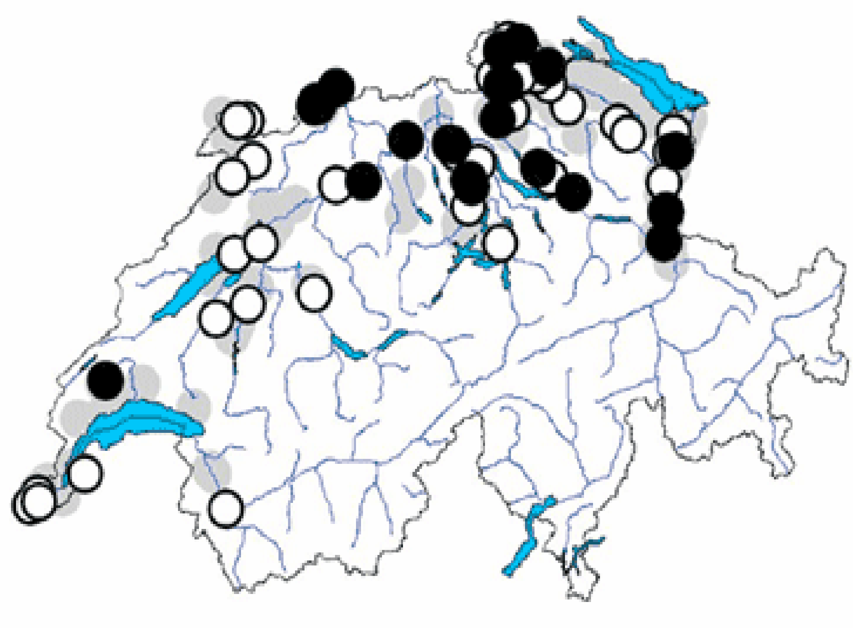
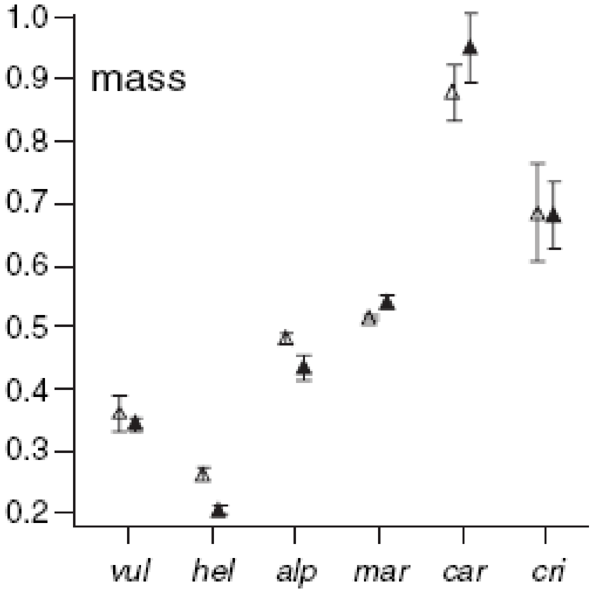


Figure 2



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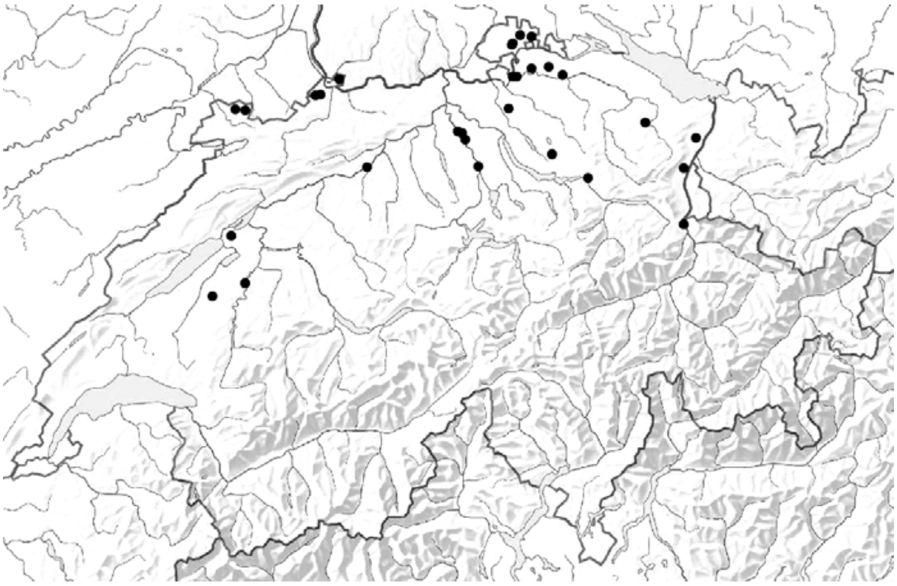

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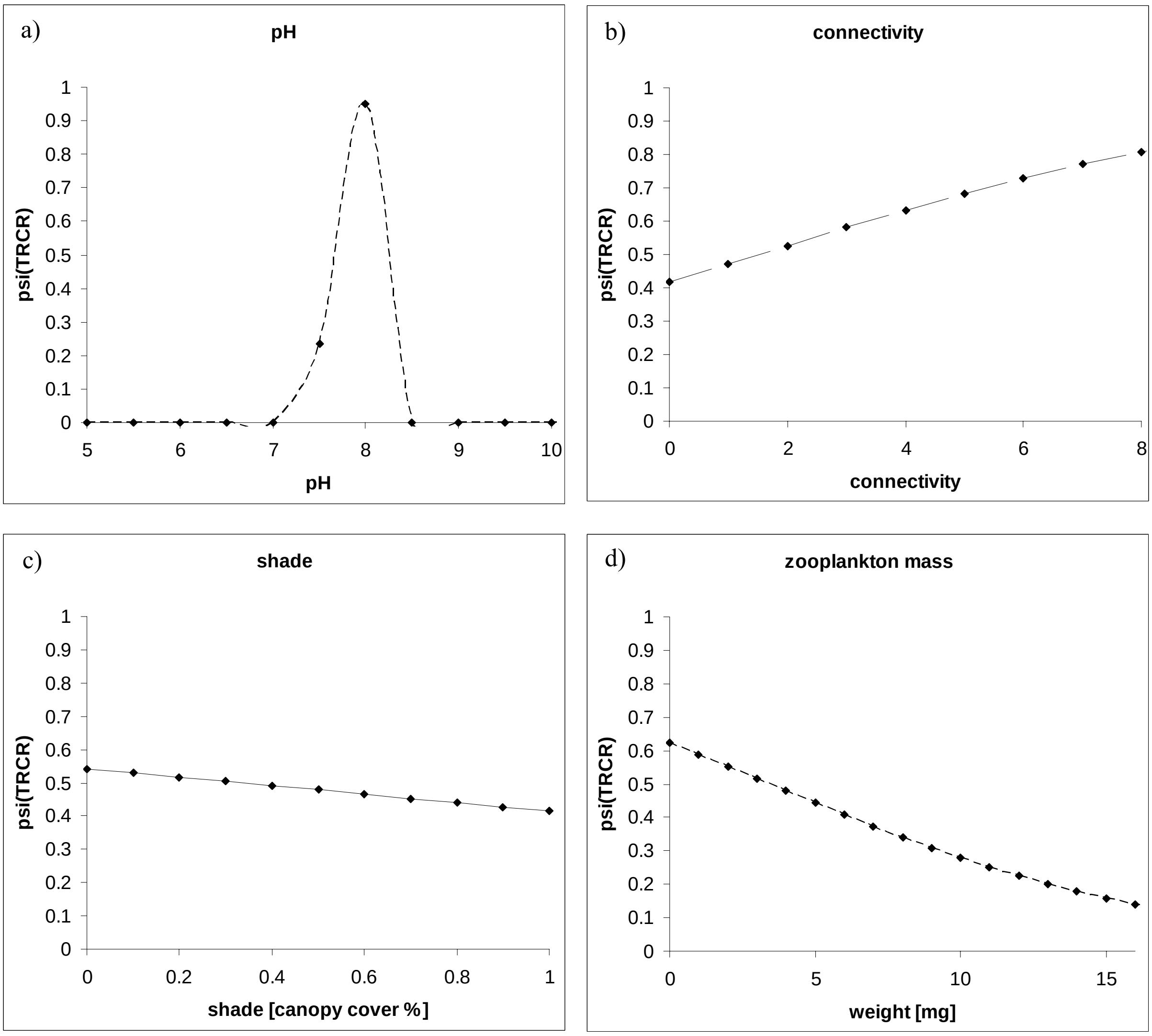
a)
pH
psi(TRCR)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5
6
7
8
9
10
pH
b)
connectivity
psi(TRCR)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
connectivity
c)
shade
psi(TRCR)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1
shade [canopy cover %]
d)
zooplankton mass
psi(TRCR)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
weight [mg]

Figure 5

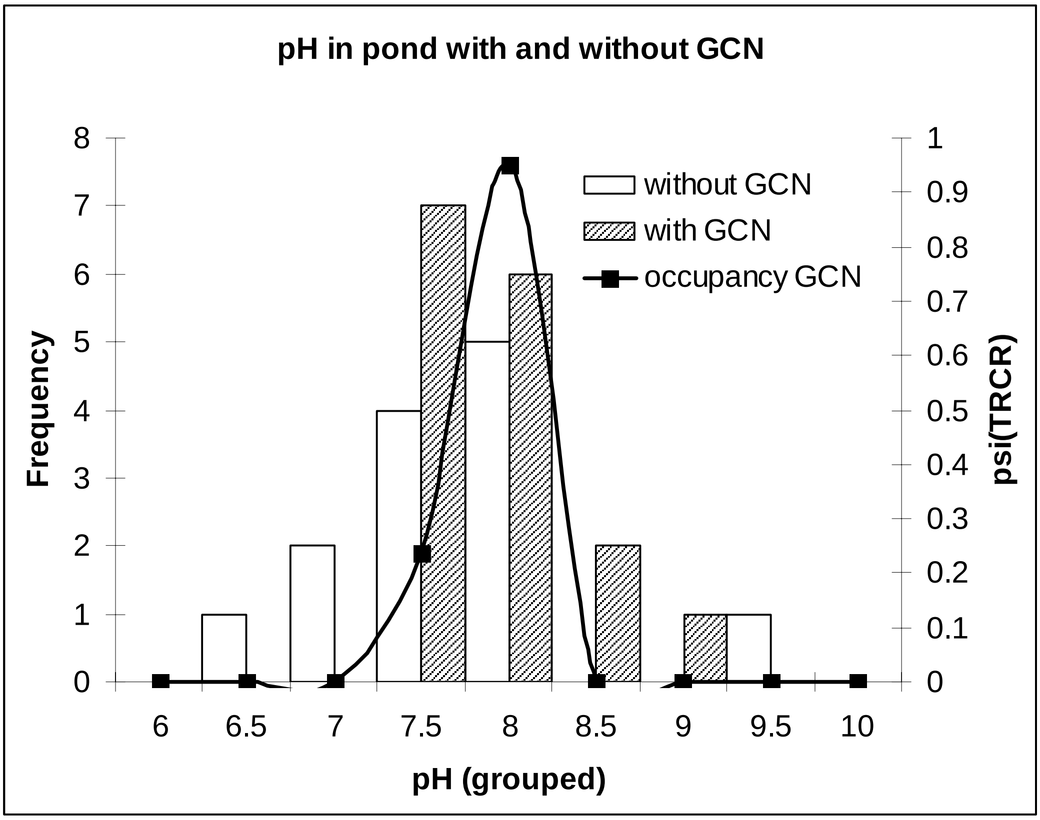
pH in pond with and without GCN
8
7
6
5
4
3
2
1
0
Frequency
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
psi(TRCR)
without GCN
with GCN
occupancy GCN
6
6.5
7
7.5
8
8.5
9
9.5
10
pH (grouped)

Figure 6