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Factors influencing the distribution of *Hydrocharis morsus-ranae* L. and *Rumex hydrolapathum* Huds. in a mowed low-lying marshland, Réserve de Cheyres, lac de Neuchâtel, Switzerland

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Abstract

Using environmental parameters we studied the distribution of two endangered species, *Hydrocharis morsus-ranae* L. and *Rumex hydrolapathum* Huds., in a low-lying marshland of the Swiss Plateau, a region in which aquatic vegetation is particularly threatened. A large part of the study site is regularly mown by a machine for site management purposes. The caterpillar mower digs ruts, which are especially pronounced along the tracks used to reach the mown compartment. To assess the effects of site management on these species, we have tested six environmental parameters (vegetation unit, water conductivity, water supply indicated by altitude, time elapsed since the last cut, distance from major ruts and disturbance of major ruts) that can potentially influence plant distribution. All the plots of these two species have been found in mowed compartment, which seems to indicate a correlation between site management operations and occurrences. The other factors driving the distribution of these plants are vegetation unit, distance from major ruts and water supply.

Introduction

Many wetland plant and animal species are threatened with extinction at the regional, national or even European level. A total of 66% of the extinctions of continental species involve wetlands (Denny, 1994). On the Swiss Plateau the situation for aquatic vegetation is very grave, with more than 60% of the species on the Red List of threatened ferns and flowering plants of Switzerland (Moser et al., 2002). The principal reason for this is the destruction of habitats. In this context, remaining wetlands have to be protected. Maintenance operations are carried out to control invasion by shrubs and to prevent the degradation of these valuable natural environments. The open marshes of the study area are mown using a machine with caterpillar tracks. These tracks mark the ground with more or less major ruts, dependent on the frequency of passage and on the nature of the substrate. With a view to maintenance of the wetlands and conservation of rare species, our principal objective is to assess the impact of management on the presence and abundance of two endangered species: *Hydrocharis morsus-ranae* and *Rumex hydrolapathum*. This depends upon detailed prior knowledge on the occurrence sites of the two plants in the study area, and their status at each station. Many environmental parameters can potentially influence the distribution of the two species. We have tried to identify which factors are involved by using a geographical information

system (GIS) in conjunction with modelling tools, on a data set covering six environmental parameters: type of vegetation, type of water supply indicated by altitude, electric conductivity of water, time elapsed since the last cut, distance from major mowing ruts and disturbance frequency of the major ruts.

Description of the study site and of the management operations

The 0.98 km^2 study area is at an average altitude of 430 m, in a protected part of the Grande Cariçaie wetland, on the southern shore of Neuchâtel Lake (Switzerland), known as the Cheyres nature reserve. It includes a strip of 0.59 km^2 of open marshland approximately 2 km long and 300–500 m broad, which skirts the lake edge. This zone is above the level exposed to wave action and is out of its direct influence (Buttler et al., 1995). Water supply is primarily runoff from cliffs dominating the marsh and also surface streams and rainfall (Cuccudoro, 1990 in Buttler et al., 1995). The substrate is sand and silts, replaced locally by the underlying molassic bedrock.

Mowing of compartment of open marshes by the crawler-mounted machine Elbotel constitutes the principal management operation. The open marsh is cut in 15 adjacent compartments disposed along the banks, each of 0.02–0.05 km^2. They are mown in rotation, such that each is cut every third year, with 4–5 of them cut each year. One compartment is used as an uncut control. To access to compartment distant of one of the two service roads, the machine must pass trough adjacent compartment. This repeated passage digs major ruts with a higher disturbance frequency and often deeper than the lateral minor ruts let by a single moving passage per 3 year.

Materials and methods

The nomenclature employed here follows that of Aeschimann & Burdet (1994). The sites at which the two plants occurred were plotted and charted along parallel transect evenly space out each 5 m throughout the whole study area, between August 15 and October 25, 2000. The boundaries of the plot correspond to the limit of colonisation of the species. Inside each plot, the mean cover was estimated according to the Braun–Blanquet scale. The individual isolated were recorded in the class 1 (see Table 1).

To describe the vegetation, we used the vegetation map of the southern shore of Neuchâtel Lake (Clerc, 2003), merging categories as necessary, according to the standardised typology of Delarze et al. (1998). Water conductivity characterises water bodies by their content of dissolved salts and gives indirect information on nutrient content, conductivity being positively correlated with concentration of phosphorus (Wang & Yin, 1997). We measured conductivity two time in 3 days at 120 randomly chosen points, following Jenness (2001), but with 50% of the sample points located at sites where species occurred (30 points each). Variations in altitude, which indicates the discharge direction and persistence of water in the marsh, were given using a series of 608 points determined by photogrammetry and distributed in a zone projecting the study area. Series of measurement points have been interpolated in the GIS to generate a continuous layer of information from the point measurements. Results derived from interpolation were assembled into four classes. The mowing cycle indicates the number of years since the last mowing operation. The distance to major ruts allows quantification of the proportion of plots located in these ruts and their range of influence in the lateral minor ruts. The disturbance of major ruts gives the frequency of passage of the mower during a complete management cycle (3 years). This value increases with the proximity of a service road because the rut is more often use to deserve remote compartment. An information field has been created in the GIS

Table 1. Braun–Blanquet cover scale

Braun–Blanquet cover scale	Interval of covering (%)	Class
+	<1	1
1	1–5	2
2	6–25	3
3	26–50	4
4	51–75	5
5	<75	6

for each of the six environmental parameter, the classifications are given in Table 2.

We model the distribution of plots where the target species occurred with generalised additive models (GAM). Characteristics of GAM are explained in Hastie & Tibshirani (1990), Bio et al. (1998) and Lehmann (1998). Regression is mainly data-driven and explanatory variables are smoothed by a spline function instead of depending on a with-priori model. Three parameter diagnoses are used to evaluate quality of models (Hosmer & Lemeshow, 1989): proportion of deviance explained by the model (D^2), coefficient of correlation (val) and coefficient of correlation between the values predicted and observed, obtained by cross validation (cross-val), the model being calculated on 5/6th of the data and tested on the remaining 1/6th. This modelling was carried out with the software GRASP (Generalised Regression Analysis and Spatial Prediction) developed by Lehmann et al. (2002). The table of explanatory variables used for modelling was extracted from the GIS. It is composed of 197 lines, each corresponding to either the centroid of a plot of occurrence of one of the species or to a point from which the species were absent and at which water conductivity has been measured. Its composition is shown in Table 3.

Results and discussion

The complete cartography of the occurrences of the two species for the whole study site allow us to enumerate 68 plots of *Hydrocharis morsus-ranae* (sized from 2 to 680 m^2) and 65 plots of *Rumex hydrolapathum* (sized from 1 to 328 m^2). The two species only occur in the mowed area.

The incidence of *Hydrocharis morsus-ranae* is associated with mainly two vegetation unit (Fig. 1): Phragmition (class 1, Table 2) in particular its variant with *Typha* sp., and Magnocaricion (class 3, Table 2), more specifically meadows with *Carex elata* and *C. panicea*, mixed with *Cladium mariscus*. This preferential localisation is related to the persistence of water throughout the growing season in this particular environment. For the same reason, occurrences of *Hydrocharis* are more frequent than absences in the lowest part of the marsh, which is most frequently inundated (altitude classes 1 and 2, Table 2). This plant is preferentially localised in water with a high nutrient content, indicated here by a high conductivity (classes 3 and 4, Table 2). Because of the digging action caused by the repeated passage of the mower, the major ruts are depressed and accumulate water. For this reason occurrences in major ruts are more frequent than absences. The major ruts provide the larger surfaces colonised by *H. morsus-ranae*, 65.5% of the colonised surface (determined from the complete cartography) representing 38% of the plots are located in major ruts and their direct neighbourhood (classes 1 and 2 in Table 2). Interpretation of the influence of the mowing cycle is more difficult. It would require data from the complete rotation cycle of 3 years, rather than from 1 year as available to this study. For interpreting the effects of the disturbance of major ruts, the situation is different,

Table 2. Unit, interval and frequency classes of the six environmental parameters

Vegetation unit		Conductivity		Altitude		Mowing cycle		Distance to major ruts		Disturbance of major ruts	
Unit	Class	Interval (μS/cm)	Class	Interval (m)	Class	Years elapsed	Class	Interval (m)	Class	Passage/3 years	Class
Phragmition	1	≤300	1	428–429.7	1	Pilot zone	0	0	1	0 (minor ruts)	1
Phalaridion	2	301–500	2	>429.7–429.9	2	2 years	1	0–5	2	2	2
Magnocaricion	3	501–600	3	>429.9–430.4	3	1 year	2	>5–15	3	4	3
Caricion davallianae	4	>600	4	>430.4	4	0 year	3	>15–30	4	6	4
Glycerio-Sparganion	5							>30–50	5	8	5
								>50	6	10	6

Table 3. Description of the table of explanatory parameters (legend of classes see Table 2)

Vegetation unit			Conductivity			Altitude			Mowing cycle			Distance to major ruts			Disturbance of major ruts		
Class	*n*	%	Class	*n*	%	Class	*n*	%	Class	*n*	%	Class	*n*	%	Class	*n*	%
1	43	21.8	1	8	4	1	37	18.8	0	3	1.5	1	37	18.8	1	160	81.2
2	49	24.9	2	45	23	2	69	35.0	1	58	29.4	2	26	13.2	2	5	2.5
3	77	39.1	3	86	44	3	71	36.0	2	73	37.1	3	26	13.2	3	11	5.6
4	17	8.6	4	58	29	4	20	10.2	3	63	32.0	4	23	11.7	4	5	2.5
5	11	5.6										5	23	11.7	5	12	6.1
												6	62	31.5	6	4	2.0
n=	197			197			197			197			197			197	

because frequency of disturbance is constant through the 3-year management cycle. Nevertheless, the real effect of this parameter is difficult to assess, because it must be dissociated from under-representation of particular frequency of disturbance. It shows essentially that occurrence of the plant is possible at every level of disturbance. The Generalised Additive Models (GAM) of presence/absence as well as GAM of abundance are driven by three explanatory parameters which explain more than 60% of the distribution: the distance to the major ruts, the vegetation unit and the altitude. The contribution of each variable is described in Table 4 and response curves are given in Figure 2. The two models predict a positive correlation between occurrences and a buffer area of 30 m

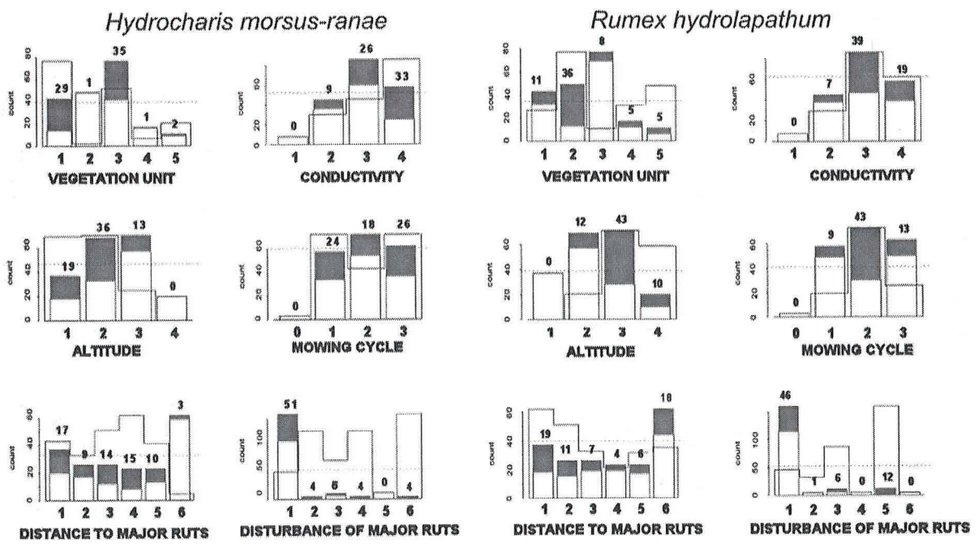

Figure 1. Histogram of the presences/absences (n = 197). (On the left *Hydrocharis morsus-ranae*; on the right *Rumex hydrolapathum*.) The legends of the classes are given in Table 1. White portion of histograms indicates absences. The black portion, as well as the number printed above the column, indicates the number of plots where the species is present. The continuous line indicates proportion of presence, compared to the whole of the plots: when it passes above the dotted line, the ratio of this attribute for the particular species is higher than in the whole sample.

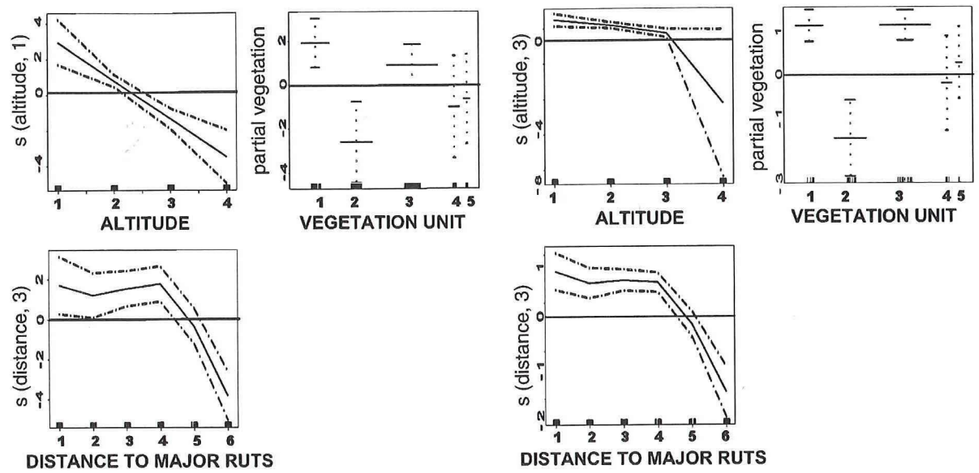

Figure 2. Response curves for the variables incorporated in presence/absence GAM (left) and in abundance GAM (right) for *Hydrocharis morsus-ranae*. On *X*-axes the classes and on *Y*-axes the response of the model. Unities of *Y*-axis are smoothed function of order gave in the parenthesis. Response curves are given by the black lines and intervals of confidence by the dot lines. The horizontal continuous black lines indicate the limit between negative effect (below) and positive effect (above) on the species occurrence.

around the major ruts. This relation can be partly explained by the colonisation of the minor lateral ruts from the large plots located in major ruts. Colonisation of the minor ruts is limited by the persistence of water, which increase with the proximity of the major ruts. There is also a positive correlation between occurrence and the two preferential vegetation unit cited above. On the other hand there is a negative correlation between occurrences and altitude, which is related to the water supply.

Our results relate the occurrence of *Rumex hydrolapathum* to the presence of two plant associations (Fig. 1): principally the Phalaridion (class 2, Table 2) and in less importance the Glycerio Sparganion (class 5, Table 2). *R. hydrolapathum* can colonise ground subjected to various hydrological regimes (Landolt, 1977), and for this reason, it is present in the upper, less regularly flooded part of the study area (altitude classes 3 and 4, Table 2). Its plots are recorded primarily in water with a conductivity higher than 500 μS/cm (Fig. 1). As in the case of *H. morsus-ranae*, assessment of the influence of the mowing cycle requires field information for a complete 3-year cycle. Concerning distance from ruts, the species is more frequently recorded within a radius of 5 m from the ruts (Fig. 1). Interpretation of the disturbance frequency data suffers from the same limitation as identified in considering *H. morsus-ranae*, but the rut of class disturbance 5 (containing only plots where the plant was present) nevertheless support a particular type of Phalaridion, pioneer vegetation with *Alisma plantago-aquatica* favoured by a high disturbance frequency. This class of disturbance is correlated positively with the abundance of *R. hydrolapathum* at the sites. The general additive model of presence/absence is driven by five explanatory parameters: vegetation unit, mowing cycle, water conductivity, altitude and distance to major ruts. Approximately 40% of the distribution is explained by this model. Individual contributions are given in Table 4 and response curves are plotted in Figure 3. The model predicts a positive correlation of the occurrences of *R. hydrolapathum* with the two vegetation unit cited above and also with conductivity and altitude. Because of its large confidence interval, the model predicts possible occurrence at every distance from the major ruts. The abundance model also shows a poor level of explained deviation. It retains altitude and the same vegetation unit as the presence/absence GAM, as positively correlated with abundance

Table 4. Characteristics of the GAM models (PA – presence/absence; REC – covering; hydroch – *Hydrocharis morsus-ranae*; rumex – *Rumex hydrolapathum*) $n = 197$. Values for each parameter quantify the drop contribution (correspond to the loss of significance of the model without this parameter). D^2, validation and cross-validation are the diagnostic parameters of model. Variables without drop contribution were not retained in the model

Model	PA hydroch	REC hydroch	PA rumex	REC rumex
p	< 0.004	< 0.004	< 0.004	< 0.004
Vegetation	36	69.56	25.91	26.89
Conductivity			10.36	
Altitude	38.45	41.32	9.29	52.33
Mowing cycle			24.05	
Distance to major ruts	79.45	110.88	6.28	
Disturbance of major ruts				11.54
D^2	0.63	0.65	0.45	0.42
val	0.96	0.8	0.92	0.61
cross-val	0.94	0.77	0.86	0.5

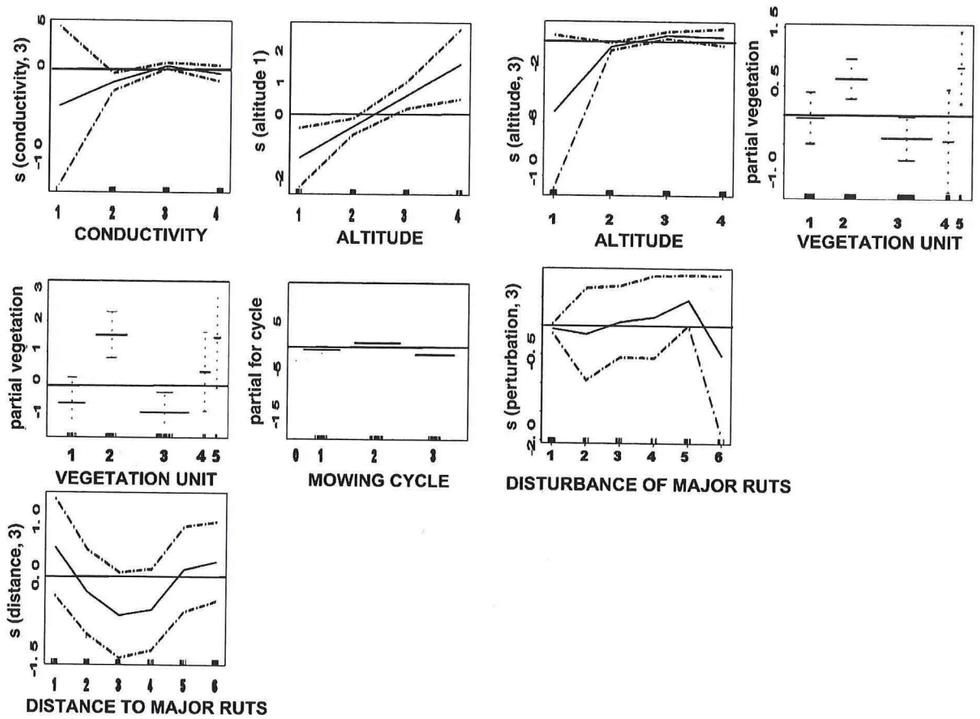

Figure 3. Response curves for the variables incorporated in presence/absence GAM (left) and in abundance GAM (right) for *Rumex hydrolapathum*. On *X*-axes the classes and on *Y*-axes the response of the model. Unities of *Y*-axis are smoothed function of order gave in the parenthesis. Response curves are given by the black lines and intervals of confidence by the dot lines. The horizontal continuous black lines indicate the limit between negative effect (below) and positive effect (above) on the species occurrence.

(Fig. 3). For modelling the distribution of *Rumex hydrolapathum* more accurately explanatory parameters, like soil chemistry or sediment structure, probably require to be brought into play.

The fact that neither of the occurrence plots of one of the two species were observed in the unmowed pilot zone suggest that the survival of the two species at the site may be dependent upon maintenance of open areas of marsh.

Conclusions

The results of this work show up that the mowing of the marshes does not seem to have a negative impact on *Hydrocharis morsus-ranae* and *Rumex hydrolapathum*, the two species are able to colonise the ruts and occur even at the most recently mowed plots. The repeated rutting of the major track servicing the compartments has even a positive impact on the target species. With the management programme currently operated, it appears that the populations of *Hydrocharis morsus-ranae* and *Rumex hydrolapathum* are not threatened with disappearance in the short-term.

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