

SPATIAL AND TEMPORAL DISTRIBUTION OF THREE AQUATIC BEETLES (DYTISCIDAE) IN MONEGROS ARID ZONE, NE SPAIN

Carmen BURGHELEA, Dragoș ZAHARESCU and Antonio PALANCA

Animal Anatomy Laboratory, Animal Biology and Ecology Department, Faculty of Biological Sciences, Vigo University, 36310, Spain.; bcarmen@uvigo.es; zaha_dragos@yahoo.com; apalanca@uvigo.es

Abstract. In arid regions, the artificial wetlands are temporary habitats supporting the regional biodiversity of many invertebrates. *Hydroglyphus pusillus* (Fabricius 1781), *Laccophilus minutus* (Linnaeus 1758) and *Rhantus suturalis* (Mc Leay 1825) are the dominant Dytiscidae beetles in the arid zone of Monegros, NE Spain. Spatial and temporal distribution of the three species was assessed in nine sampling sites covering three aquascape types: rice fields, reservoirs and temporary ponds, for the dry (non-irrigated) and wet (irrigated) period of 2003. We considered the relationship between the landscape variables (water depth, water coverage, vegetation coverage, altitude, landscape type, distance to the next water body), temporal data (season, sampling date), climate (solar radiation, precipitations), and population densities of the 3 species. Two types of landscape variables were found to be important for the species distribution: those related to microhabitat characteristics (water coverage, water depth, vegetation presence/absence) and the climatic variables (mean monthly precipitations and monthly solar UV-radiation). All three species reached the highest density in February-March (dry months), the critical month with lowest densities was May for *H. pusillus* and *R. suturalis* and August for *L. minutus* followed by a rapid population recovery for all species until September. This confirms the importance of scale and agricultural practices for aquatic beetles distribution; it demonstrates continuity between populations at small landscape scale but discontinuity, forced by climate at larger landscape scale.

Keywords: aquatic Coleoptera, arid area, rice paddies, spatial and temporal distribution, landscape species response.

Rezumat. Distribuția spațială și temporală a trei specii de coleoptere acvatice (Dytiscidae) în zona aridă Monegros, NE Spaniei. În zonele aride, bazinele acvatice artificiale sunt habitate temporare care susțin biodiversitatea regională a multor specii de nevertebrate. *Hydroglyphus pusillus* (Fabricius 1781), *Laccophilus minutus* (Linnaeus 1758) și *Rhantus suturalis* (Mc Leay 1825) sunt coleopterele Dytiscidae dominante în zona aridă Monegros, în NE Spaniei. Distribuția spațială și temporală a celor 3 specii menționate a fost evaluată în nouă situri, acoperind trei tipuri de umedale: orezării, rezervoare acvatice și bălți temporare, pentru perioada uscată (neirigată) și umedă (irigată) a anului 2003. Am luat în considerare relația existentă între variabilele de peisaj (adâncimea apei, gradul de acoperire cu apă, acoperirea cu vegetație, altitudine, tip de peisaj, distanța până la cel mai apropiat bazin acvatic), date temporale (sezon, data de colectare), climă (radiație solară, precipitații) și densitățile populaționale ale celor trei specii. Două tipuri de variabile peisagistice au fost găsite a fi importante pentru distribuția speciilor considerate: cele legate de caracteristicile de microhabitat (acoperirea cu apă, adâncimea apei, prezența/absența vegetației) și variabilele climatice (media lunară a precipitațiilor și media lunară a radiației solare globale ultraviolete). Toate cele trei specii au atins cel mai înalt nivel de densitate în februarie-martie (luni neirigate și acoperire cu apă minimă); luna critică cu cele mai joase niveluri de densitate a fost mai pentru *H. pusillus* și *R. suturalis* și august pentru *L. minutus*, urmată de o rapidă recuperare a populațiilor celor trei specii în septembrie. Aceasta confirmă importanța scării peisagistice și a practicilor agricole pentru distribuția speciilor de coleoptere acvatice; demonstrează continuitate între populații la scară peisagistică redusă, însă discontinuitate, forțată de climă, la scara peisagistică mai mare.

Cuvinte cheie: coleoptere acvatice, zonă aridă, umedale, distribuție spațială și temporală, răspunsul speciilor la variabile peisagistice.

Introduction

Over the last decade the significance of landscape, land use and species turnover between ponds have been given importance from both, pond wildlife conservation perspective and as a key factor in the ecology of pond biodiversity. The spatial and temporal scales of the landscape are important factors controlling invertebrate dynamics

as species and metacommunities show areal occupancy and movement and inter-annual turnover (Jeffries, 2005).

Wetlands in semi-arid regions are complex and fragile ecosystems that undergo extreme changes from the wet to dry periods and are particularly important because of their role in maintaining and controlling environmental quality and sustaining the biodiversity in the area (Schmid *et al.*, 2006). Providing ecosystem services for human communities, they are usually subject to harsh natural climatic cycles (mainly seasonal) but more frequently, to human-induced changes. These highly dynamic ecosystems often undergo shifts in temporal duration, area distribution and spatial complexity of their components (soils, vegetation, water, biodiversity). For this, there is a need to understand first how communities develop over time and move across land and waterscapes in these regions.

The rice fields in Monegros are dry landscapes in winter, while they are flooded up to 15–30 cm depth for summer cultures by irrigation from the Pyrenean dams. Thus they change into temporary ponds managed with a variable degree of intensity. These new created habitats are often affected by rapid and short-term disturbances such as draining, flooding and chemical inputs, contributing to a great variability in its resources and changes in its rich biota (Bambaradeniya *et al.*, 2004).

The temporal and spatial variation of macroinvertebrates in rice crops has been documented by many authors (Suhlinget *et al.*, 2000; Bambaradeniya *et al.*, 2004; Foote & Hornung, 2005; Leitão *et al.*, 2007). These communities show preference for field borders with submerged vegetation and show a spatial distribution along the paddies (Leitão *et al.*, 2007).

The diving beetles (Dytiscidae) inhabit both temporary and permanent habitats and are among the first large invertebrate predators to arrive in the newly formed wetlands (Layton & Voshell, 1991). They form a group with an active aerial dispersal strategy (Oertli *et al.*, 2005) and are generally good fliers that can cover several kilometers. This allows them to utilize resources fragmented in both, space and time (Bilton, 1994).

Migration is more prominent in the fauna of temporary habitats than permanent ones. However migration of dytiscids in relation to the landscape and different types of waters is not well studied (Lundkvist *et al.*, 2002).

Here we examine the spatial distribution of three Dytiscidae species: *Hydroglyphus pusillus*, *Laccophilus minutus*, *Rhantus suturalis*, predict their relationship with the landscape structure of pond environment and determine the short-term distribution patterns (temporal dynamics) across different pond types (aquascapes).

Hydroglyphus pusillus is a predator well adapted to rice field habitat in Italy, where forms the most abundant specie during the whole rice growing season (May–September) (Bellini *et al.*, 2000). *Laccophilus minutus* is a common specie of open water in lowland lakes and large ponds (Nelson, 1996) and is a quantitatively dominant Dytiscidae in the Italian rice fields (Moretti, 1932; Bellini *et al.*, 2001).

Bellini *et al.* (2001) recorded that seasonal dynamics in aquatic beetles in Italian rice paddies is largely dependent on rice fields and year.

Material and Methods

Los Monegros, with a total extension of 2700 km², is one of the most arid regions in Europe (Herrero & Snyder, 1997). It lies in the central part of the Ebro River basin (Aragón), NE Spain, between three mountain ranges: the Pyrenees at the north, the Iberian Chain at the south-west and the Catalanian Coastal Ranges at the south-east (Fig. 1a). This mountains isolating effect imprint the zone a semiarid climate. The average annual temperature is 14.5°C, with the extremes from -15°C to more than 40°C. The average rainfall is low, 400 mm yearly (Pedrocchi, 1998), but with a high interannual variability

(Comín & Williams, 1993) because of the mountains rain-shadow effect and the strong NW–SE winds. The altitude of the area ranges from 200–800 m.

An increase in the agricultural production in the last decades, has led to the introduction of a large-scale irrigation scheme in its northern part in the 70 s, with the subsequent rice crops production and the emergence of many temporal and permanent aquatic habitats. The area has been identified by Macklin *et al.* (1994) as being particularly vulnerable to human and climate-induced land degradation.

Currently, the intensive land management practices including water management, fertilization and pesticides input, crop rotations, inter-crop season land management and the extreme changes from the wet to dry period shape the ecological and life history strategies of the aquatic fauna colonizing these artificial aquascapes. Only the temporal rain-fed ponds are known to have a natural origin in the zone.

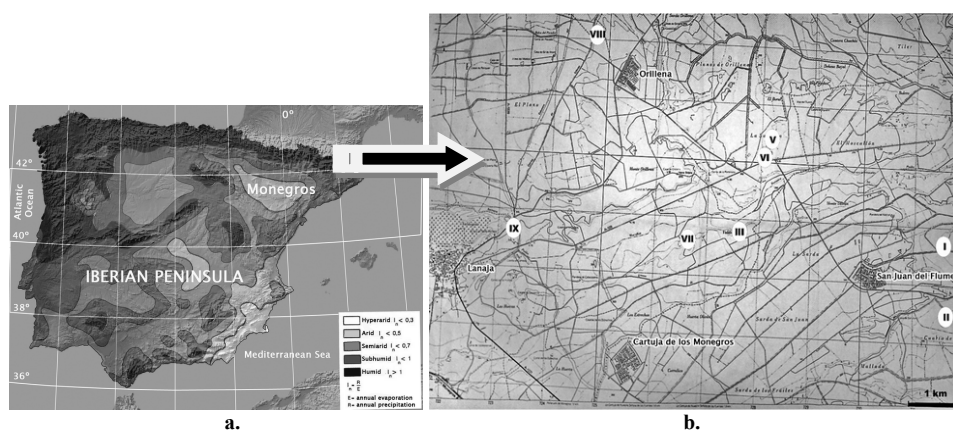


Figure 1. a. Climatic zones in the Iberian Peninsula with the location of the arid area of Monegros (after Thornthwaite arid index, 1948, and NASA-JPDL, Earth radar map- PIA03395). b. Location of study area with the sampling sites.

The sampling was performed by mean of a D-frame hand-net (Usinger, 1956a). It was intended to cover all major habitats in which the species were present and having in mind the possible importance of pond area for species colonization. However, in the ponds, including those of temporary nature, samples were collected at the sides, in vegetation and in the substrate. The number of samples was calculated from a relationship with pond area.

After a previous dytiscid beetles survey, three most abundant species were selected: *H. pusillus*, *L. minutus*, *R. suturalis*. The species considered dominant were those present in 50% or more of the captures in each environment and/or whose number was equal to or above the total number of other Dytiscidae species in the capture.

Monthly distribution of these species was assessed in nine heterogeneous sampling sites covering rice fields, reservoirs (supplying water for agriculture and farming in the area) and temporary ponds (resulting from past rains or water leaching from landfields), for the dry (intercrop season, from January to mid May) and wet (crop season, from mid May to September) periods of 2003 (Fig. 1b). However, water levels in temporary ponds fluctuated and a lack of water was observed at times in some habitats such as rice fields or rain pools.

We have chosen a variety of variables to cover the range of factors from those that are most closely related to species habitat (small landscape scale) to those at a larger

landscape scale. On this, we have considered the relationship between population densities of the three species and landscape setting [water depth, water coverage, vegetation coverage, vegetation presence/absence, altitude, landscape type, aerial connectivity (distance to the closest water body), presence of surrounding stress sources (road proximity and exposure risk to pollution)], temporal data (season, month), climate variables (temperatures, precipitations, UVB radiation). The pollution risk index was scored on a 1-3 scale, from low risk to severe risk, and based on a subjective assessment of the extent to which the ponds were exposed to pollution from known pollutant sources such as diverse farming practices: water management, pesticide treatment, intermittent flooding.

Prior to any statistical analysis, matrixes of species densities from each site were logarithm transformed [$y = \log y$] to prevent resultant distortions from the most abundant taxa. Environmental data were category standardized in order to centre and reduce the different ranges of variation among the variables. This procedure simultaneously quantified categorical variables while reducing the dimensionality of the data. The optimal-scaling approach allowed variables to be scaled at different levels.

Data normality was checked with the Kolmogorov-Smirnov test and the mean differences of the species density by Kruskal-Wallis one-way analysis of variance.

The environment gradients influencing the distribution of the three species in the dry and wet periods of 2003 were assessed by Categorical Principal Components Analysis (CATPCA) in SPSS 15 package, with the data previously treated.

The study was conducted at the metapopulation scale.

Results and Discussion

The mean water coverage of artificial ponds was 73.25% for the wet period and 56.37% for dry period, with a mean habitat depth of 9.23 and 8.26 cm for the wet, respectively dry period.

The water coverage registered the highest seasonal variation in rice fields: from 50% coverage in the dry period up to 75% for the wet period. Between landscape types the reservoirs had the highest mean water coverage (97.78%).

In the wet period (mid May to September) all species were found to inhabit field margins with shallow water in which submerged vegetation was abundant whereas in the inter-season time, corresponding to the dry period (January to mid May) they were inhabiting the water pools next to and in the wells on the irrigation channels and fields margins that preserved submerged dead vegetation. This is consistent with Smith and Smith (2001) who found that the edge effect is another key factor influencing macroinvertebrates distribution along the paddies, with densities higher at habitat borders.

With a Kruskal-Wallis non-parametric ANOVA we examined the differences between the environmental characteristics of ponds in the three landscape types. Only those differences significant at [$p < 0.01$] level were further considered (Table 1). Most ponds surveyed (75%) were categorized as temporary habitats (sometimes dry). The remaining 25% are reservoirs, permanent habitats (never drying out). There were significant differences [$p < 0.01$] between landscape types in mean wetland area, with temporary ponds significantly smaller than rice fields or reservoirs.

The three species populations are likely to be normal (Gaussian) distributed, following the Kolmogorov-Smirnov test (Table 2, Fig. 2).

Table 1. Kruskal-Wallis non-parametric ANOVA for differences between landscape types and pond characteristics.

Variable	Chi-Square	df	Asymp. Sig.
Pollutant risk	108.000	2	0.000
Altitude (m.a.s.l.)	33.080	2	0.000
Inter-site distance (m)	65.210	2	0.000
Roads proximities (Km)	14.150	2	0.001
Water depth (cm)	18.779	2	0.000
Water coverage (%)	12.617	2	0.002
Vegetation type	12.380	2	0.002

Table 2. Kolmogorov-Smirnov test for data normality.

		<i>H. pusillus</i> density	<i>L. minutus</i> density	<i>R. suturalis</i> density
Case N		75	43	21
Normal parameters	Mean	1.9946	1.5137	1.5277
	Standard Deviation	.80847	.62734	.58112
Most extreme differences	Absolute	.103	.178	.185
	Positive	.103	.178	.185
	Negative	-.057	-.114	-.106
Kolmogorov-Smirnov Z		.893	1.166	.849
Asymp.Sig. (2-tailed)		.403	.132	.467

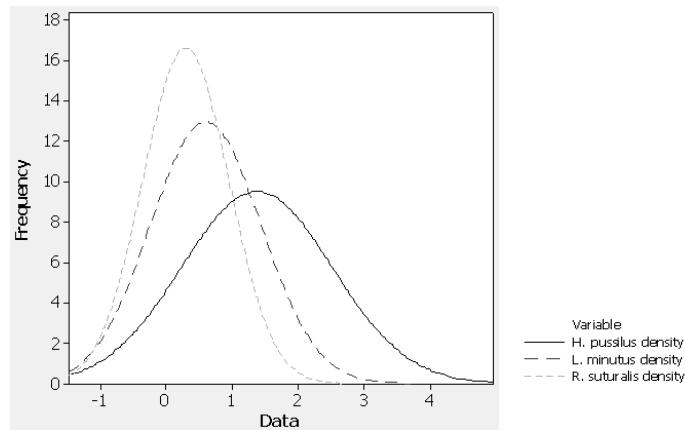


Figure 2. Kolmogorov-Smirnov test for normal distribution of the frequency of species densities.

On spatial scale, the non-parametric Kruskal-Wallis test revealed that except *R. suturalis* [$p < 0.01$], the densities of *H. pusillus* and *L. minutus* did not differ significantly between the three landscape types (Fig. 3).

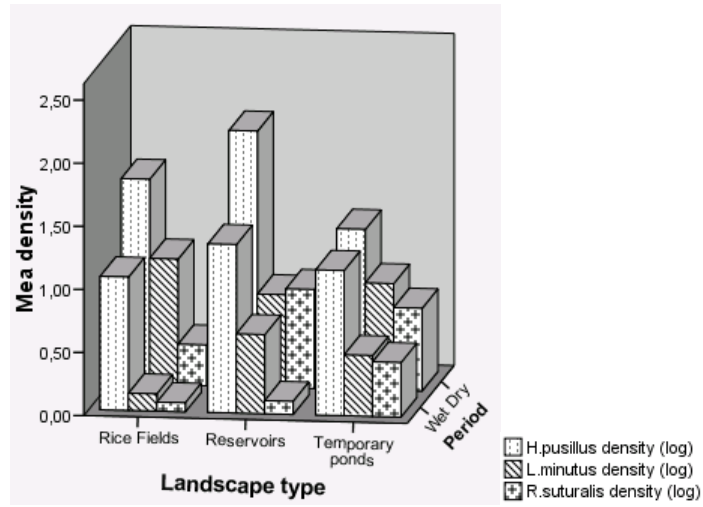


Figure 3. Differences in mean density of the three species across landscape types and the dry/wet periods.

On time scale, the same test revealed significant differences between the three species densities for the dry/ wet period (Table 3, Fig. 4).

Table 3. Kruskal-Wallis test for differences in mean densities of the three species between dry/wet periods.

	<i>H. pusillus</i> density	<i>L. minutus</i> density	<i>R. suturalis</i> density
Chi-Square	5.454	14.974	5.698
df	1	1	1
Asymp. Sig.	.020	.000	.017

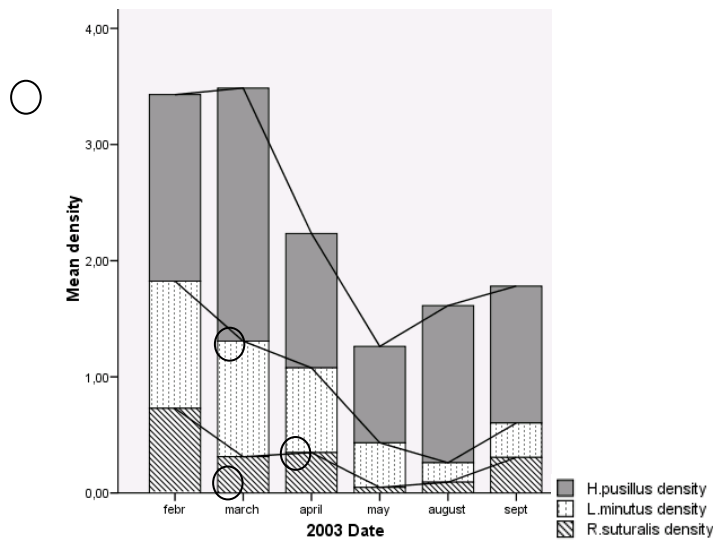


Figure 4. Monthly distribution of the three species density (log transformed). The inflexion points are marked with small circles.

A faunal succession of organisms was observed across the whole period in the studied water bodies. All three species reached the highest density in February-March (dry months), even if there was under 60% water coverage in the remained ponds, most probably because species overwinter in adult stage and crowd together in the few available ponds and pools. The edge of the rice paddies, with consistent aquatic vegetation (algae and dead vegetation), made up the refuge and suitable wintering places for the species of aquatic beetles in the dry season, although there was very little water in the paddies.

The critical month with lowest densities was May for *H. pusillus* and *R. suturalis* and August for *L. minutus*. The first inflexion point may be explained by the starting of farming practices with fields irrigation (by flooding) in May, therefore providing a good opportunity for migration, colonization and in general level off of densities. This is also supported by Batzer and Wissinger (1996) which have found that for beetles inhabiting temporary waters, long-lived adults typically overwinter in permanent habitats and then fly to newly inundated fields in spring. Fairchild *et al.* (2003) also found that the rates of macroinvertebrate species accrual relative to the number of individuals sampled increased late in the spring season, reflecting in part the timing of dispersal among ponds.

All species showed a rapid population recovery until September. *H. pusillus* has a bivoltine life cycle, with the first generation emerging in March and the second most probably in September. The other 2 species are univoltine, overwintering in adult stage and have a unique generation per year that emerges in autumn (September). Lake *et al.* (1989), Layton & Voshell (1991), Walton *et al.* (1990) have found that after inundation, species richness and overall density of the invertebrate community steadily increase for one to six months and then level off for that year. Densities can continue to increase during a second year of continuous flooding (Maher, 1984; Maher & Carpenter, 1984).

The importance of cyclic colonization for the maintenance of beetle populations in temporary habitats is emphasized by Svensson (1992), who suggests that their absence in those habitats near the edges of geographical ranges is related to the relatively low density of source populations.

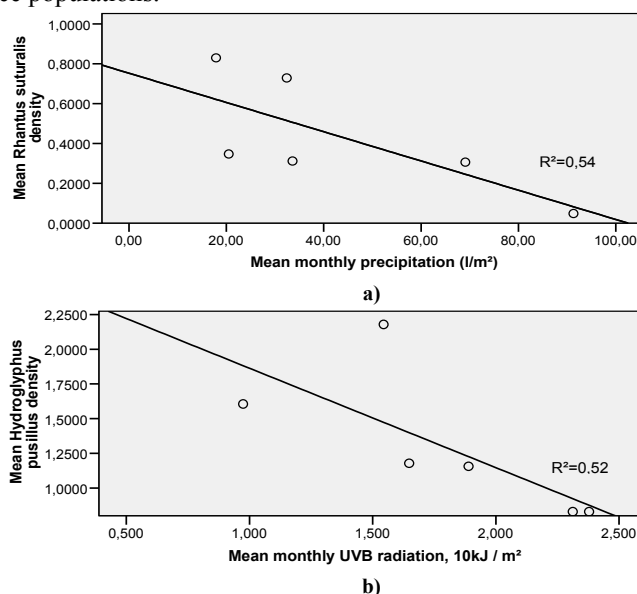


Figure 5. Linear regression supporting **a)** the relationship between mean monthly precipitation and *R. suturalis* density (log) and **b)** mean monthly solar radiation and *H. pusillus* density (log).

By recounting the climatic variables we have found negative significant Spearman correlations [$p < 0.01$] between *R. suturalis* density and the mean monthly precipitations ($r = -0.94$) and between the density of *H. pusillus* and monthly solar (UVB) radiation ($r = -0.92$); see Fig. 5a, b. *R. suturalis* is a highly mobile specie (Nelson, 1996) therefore in the arid conditions of Monegros these populations are not favored by precipitations in their dispersal and colonization although the other way round expected.

This suggests that climate itself is an important driver of invertebrate dynamics. If climate is an important factor determining species distributions, then change in its patterns over time should trigger changes in species metapopulations dynamics, therefore a limited selection of sites for conservation of local biodiversity may become unviable as when local climate alters the species change the distribution area.

These spatial and temporal dynamics are mediated locally by species-specific responses to environmental conditions such as ponds drying or variation in the habitat.

Categorical Principal Components Analysis (CATPCA)

This analysis allowed us to search for connections between species and landscape constituents at different scales.

The first 2 components explained 59.32% of total variance (Table 4). The results of the CATPCA for all assessed variables have been depicted on a two-dimensional plot (Table 5, Fig. 6).

Table 4. Categorical Principal Components Analysis of the three species densities and surrounding landscape variables. (a) The Total Cronbach's Alfa is calculated based on the total eigenvalues.

Component	Cronbach's Alfa	Explained variance	
	Total (Autovalores)	% of the variance	Total Eigenvalues
1	.842	4.263	38.755
2	.614	2.263	20.575
Total	.931(a)	6.526	59.329

Table 5. Correlations of the environmental variables with the canonical axes of CATPCA (higher correlations in bold).

Landscape variables	Principal Components	
	1	2
Pollutant_Risk	-.010	.847
Altitude	.343	.664
Inter-site distance (m)	.260	.479
Roads proximities	-.189	.803
Water depth (cm)	.909	-.098
Water Coverage	.606	-.167
Water Vegetation	.923	-.149
Vegetation Type	-.919	.153
<i>H. pusillus</i> density	.786	.044
<i>L. minutus</i> density	.587	.148
<i>R. suturalis</i> density	.439	.352

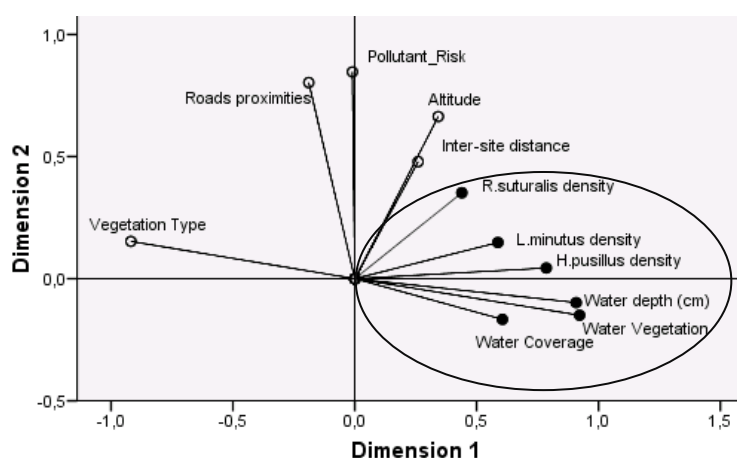


Figure 6. Categorical Principal Components Analysis for landscape variables and the density of the three species.

The PC1 (Dimension 1) explains 38.75% of the total variance in the data. The negative segment of the plot for PC1 is related to vegetation type, while the positive segment is related to water depth, water vegetation, water coverage and species density. Aquatic vegetation was structured in emerged macrophytes (*Typha*, *Phragmites*, *Carex*, *Rhiza*, *Scirpus*), submerged vegetation (dominated by *Lemna*, *Chara*, *Potamogeton*), decomposed vegetation and algae (Zoosteraceae). Vegetation presence proved to play an important role in our species distribution. Apart from providing food resources, wetland plants also serve as structural microhabitat where species can shelter of direct solar radiation and winds of Monegros or hide of other big predators as the ever-present *Rana perezi* frogs. In permanent and temporal wetlands Fairchild *et al.* (2003) observed strong microhabitat affinities, with ~85% of all individuals found along pond margins and ~40% of all taxa associated with particular substrate types. These are small scale landscape variables meaning that the three species respond better to the measures of local habitat but may not travel over long distances during recolonisations. Aquatic beetles often have been regarded as mobile transients among water bodies, but recent studies suggest strong environmental influences on distribution and thus the potential for using beetles as indicators of habitat quality (see Fairchild *et al.*, 2003).

The PC2 is basically related to pollutant risk, road proximities, altitude and inter-site distance, the relationships yielding a positive coefficient. Road proximities and pollutant risk are very close located on the PC2, suggesting that there is a clear evidence that human interventions alter the landscape. This second principal component proved no important correlation with any of the biological variables.

The eigenvectors are relatively long, indicating again that the first two dimensions account for most of the variance of all quantified variables.

Leitão *et al.* (2007) has found that macroinvertebrate assemblages (71 taxa belonged to Insecta, among which *Hydroglyphus* sp. and *Laccophilus* sp.) inhabiting the rice paddies in Portugal tend to prefer field margins with aquatic, submerged vegetation, revealing a spatial distribution along the paddies and their richness and abundance depending on the paddy sediment and water physical characteristics (temperature, ph, conductivity). The macroinvertebrates were observed to follow a succession during the rice cycle.

Conclusions

This study confirms the importance of scale for aquatic beetles dispersion and present evidence for the landscape metrics determining their distribution.

It demonstrates continuity between populations at small landscape scale but discontinuity within metapopulation, forced by climate at larger landscape scale. This is consistent with the principle of island biogeography (MacArthur & Wilson, 2001) in which the populations within the metapopulation are separated by low degree gene flow. The connectivity and therefore genes flow in this case seems to be assured only through short distance aerial corridors of dispersion such as pond-to-pond movements.

Drivers and patterns of species distributions are noted and discussed briefly here. These are related to the local, low landscape scale variables. Low scale characteristics (water level, water coverage, aquatic vegetation presence) are therefore critical factors for these opportunistic species, preparing an ideal environment for habitat colonization.

In terms of ecosystem services, habitat disturbances through agricultural practices are the main drivers of temporal and spatial patterning in populations distribution. Thus, the aquatic Coleoptera in the arid zone of Monegros have found the strategy to use the unstable network of temporary and permanent ponds by restricting their area to the permanent reservoirs in the dry periods and move to develop their cycles to more resource rich rice fields and temporary ponds in the warm and irrigated period. As such, the spatial and temporal dynamics are mediated locally by life cycle species-specific responses to local environment conditions such as ponds drying or habitat successions.

This is a condition expected for arid zones but not for irrigated land where species are expected to use the artificial aquatic corridors for long range movements. The good negative relationship to climatic variables highlights that these are limiting factors that border populations distributions on local basis and frame patterns of local, island-type populations and do not allow much mobility of individuals across the landscape. These are the high precipitations and high UVB radiation. This is a clear example of metapopulation fragmented in island type populations conditioned by climate patterns.

Local management can provide the variety of habitats and ponds, but wildlife must have the freedom to exploit this opportunity, which in this area is a limited factor. This has significant ecological and policy implications for future management of the new aquascapes as further development in Monegros and in the light of global climate change must be considered in terms of a sustainable ecosystem services approach consistent with the Water Framework Directive and in terms of halting biodiversity loss conventions. Failure to do this will lead to a continuation of under-achievements in land remediation, biodiversity protection and sustainable water management in this intensive farming area. The future vision needs to incorporate large-scale as well as small-scale view to wetlands in arid zones. Farming diversification and intensification can provide economic drivers, but there needs to be a strategic holistic vision with effective sustainable approach.

Acknowledgments

Special thanks to Animal Anatomy Laboratory Foundation teamwork and its field station in San Juan del Flumen (Huesca) for allowing the year long study, to Diputación Provincial de Huesca for the financial support through the Felix de Azara award, as well as to the farmers from Monegros (villages of San Juan del Flumen, Sarinena, Cartuja de los Monegros, Orillena and Lanaja), for allowing and helping in their land survey.

References

- Bambaradeniya, C. N. B., Edirisinghe, J. P., De Silva, D. N., Guanatileke, C. V. S., Ranawana, K. B., Wijekoon, S., 2004. Biodiversity associated with an irrigated rice agro-ecosystem in Sri Lanka. *Biodivers. Conserv.*, **13**: 1715–1753.
- Batzer, D. P., Wissinger, S. A., 1996. Ecology of insect communities in nontidal wetlands. *Annu. Rev. Entomol.*, **19** (41): 75-100.
- Bellini, R., Pederzani, F., Pilani, R., Veronesi, R., Maini, S. 2001. *Hydroglyphus pusillus* (Fabricius) (Coleoptera Dytiscidae): Its Role as a Mosquito Larvae Predator in Rice Fields. *Boll. Ist. Ent. "G. Grandi" Univ. Bologna*, **54**: 155-163.
- Biggs, J., Bilton, D., Williams, P., Nicolet, P., Briggs, L., Eeles, B., Whitfield, M., 2004. Temporary ponds of eastern Poland: an initial assessment of their importance for nature conservation. *Archives des Science*, **57**: 73-84.
- Bilton, D., 1994. The flight apparatus and flying ability of *Hydroporus glabriusculus* (Coleoptera, Dytiscidae), with a brief review of structural modifications in flightless beetles. *Ent. Tidskr.*, **115**: 23-32.
- Comin, F. A., Williams, W. D., 1993. Parched Continents: Our Common Future? A Paradigm of Planetary Problems. In Margalef, R. (ed.), *Elsevier*, Dordrecht: 473–527.
- Fairchild, G. W., Cruz, J., Faulds, A. M., Short, A. E. Z., Matta, J. F., 2003. Microhabitat and landscape influences on aquatic beetle assemblages in a cluster of temporary and permanent ponds. *Journal of the North American Benthological Society*, **22** (2): 224-240.
- Foote, A. L., Hornung, C. R., 2005. Odonates as biological indicators of grazing effects on Canadian prairie wetlands. *Ecol. Entomol.*, **30**: 273–283.
- Herrero, J., Snyder, R. L., 1997. Aridity and irrigation in Aragón, Spain. *Journal of Arid Environments*, **35**: 55–547.
- Jeffries, M., 2005. Small ponds and big landscapes: the challenge of invertebrate spatial and temporal dynamics for European pond conservation. *Aquatic Conserv: Mar. Freshw. Ecosyst.*, **15**: 541–547.
- Lake, P. S., Bayly, I. A. E., Morton, D. W., 1989. The phenology of a temporary pond in western Victoria, Australia, with special reference to invertebrate succession. *Arch. Hydrobiol.*, **115**: 171-202.
- Layton, R. J., Voshell, J. R., 1991. Colonization of new experimental ponds by benthic macroinvertebrates. *Environ. Entomol.*, **20**(1): 10-17.
- Leitão, S., Pinto, P., Pereira, T., Brito, M. F., 2007. Spatial and temporal variability of macroinvertebrate communities in two farmed Mediterranean rice fields. *Aquatic Ecology*, **41**(3): 373-386.
- Lundkvist, E., Landin, J., Karlsson, F., 2002. Dispersing diving beetles (Dytiscidae) in agricultural and urban landscapes in south-eastern Sweden. *Ann. Zool. Fennici*, **39**: 109-123.
- Mac Arthur, Robert, H., Wilson, E. O., 2001. *The Theory of Island Biogeography*. Princeton University Press.
- Macklin, M. G., Passmore, D. G., Stevenson, A. C., Davis, B. A., Benavente, J. A., 1994. Response of rivers and lakes to Holocene environmental change in the Alcaniz region, Teruel, North-East Spain. In Millington, A., Pye K. (eds), *Environmental Change in Drylands* (Chichester: Wiley): 113–130.
- Maher, M., 1984. Benthic studies of waterfowl breeding habitat in south-western New South Wales. *I. The fauna. Austr. J. Mar. Freshw. Res.*, **35**: 85-96.
- Maher, M., Carpenter, S. M., 1984. Benthic studies of waterfowl breeding habitat in Southwestern New South Wales. 11. Chironomid populations. *Ausi. J. Mar. Freshwater Res.*, **35**: 97-110.
- Moretti, G. P., 1932. Note sulla fauna entomologica delle risaie. *Atti Soc. Ital. Sci.nat.*, **71**: 61-85.
- Nelson, B., 1996. Species Inventory for Northern Ireland Aquatic Coleoptera. Department of Zoology, Ulster Museum BELFAST.
- Oertli B., Auderset, J. D., Castella, E., Juge, R., Lehmann, A., Lachavanne, J. B., 2005. PLOCH: a standardized method for sampling and assessing the biodiversity in ponds. *Aquatic Conserv: Mar. Freshw. Ecosyst.*, **15**: 665–679.
- Pedrocchi, C., 1998. *Ecología de los Monegros*. Ed. Instituto de Estudios Altoaragoneses and, Centro de Desarrollo de Monegros, Huesca, Spain.
- Schmid, T., Gumuzzio, J., Magaly Koch, M., Mathe,r P., 2006. Semi-arid Wetlands: Assessment of their Degradation Status and Monitoring by Multi-Sensor Remote Sensing. *4th ESA CHRIS PROBA Workshop ESA-ESRIN*, Frascati, 19-21 Sept. 2006.
- Smith, R.,L., Smith, T.,M., 2001. *Ecology and field biology*. Ed. Benjamin Cummings, San Francisco.
- Suhling, F., Befeld, S., Hausler, M., Katur, K., Lepkojus, S., Mesleard, F., 2000. Effects of pesticide applications on macroinvertebrate density and biomass in ricefields in Rhone-delta, France. *Hydrobiologia*, **431**: 69–79.
- Svensson, B. W., 1992. Changes in occupancy, niche breadth and abundance of three *Gyrinus* species as their respective range limits are approached. *Oikos*, **63**: 147-56.
- Usinger, R. L., 1956. Aquatic Hemiptera. In Usinger, R. L. (ed.), *Aquatic insects of California: Berkeley*, University of California Press: 182-228.
- Walton, W. E., Tietze, N. S., Mulla, M. S., 1990. Ecology of *Culex iarsalis* (Diptera: Culicidae): factors influencing larval abundance in mesocosms in Southern California. *J. Med. Entomol.*, **27**: 57-67.