Assessing The Conservation Value of Farmland Ponds: Use of Predictive Techniques to Identify Surrogate Groups

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Freshwater biodiversity - Ponds

- Ponds (i.e. water bodies comprised between 25 m² to 2 ha) are among the most diverse and yet threatened freshwater ecosystems
- More species, more uncommon, rare, and threatened species compared to lakes, rivers and streams (ditches)
- Biodiversity hotspots
- Pond conservation = cost-effective opportunity to maintain and enhance biodiversity
 - Small size catchment area
 - Large number
- Model systems in biology and ecology

Effective pond conservation

Effective pond conservation requires:

1. The conduction of large-scale pond biodiversity inventories
2. The development of long-term monitoring programmes aimed at assessing changes in pond distribution and biodiversity associated with socio-economic and environmental changes
3. Identifying the drivers of pond biodiversity
4. A classification system for ponds based on the biotic communities they support and on environmental and management variables

Surrogate groups

- Limited resources to undertake biodiversity surveys
- Increasing interest in identifying surrogate taxa to be used as indicators of biodiversity
- Cross-taxon congruence = relationship between (among) taxonomic groups
- More effective than environmental surrogates

Cross-taxon congruence analysis - 1

- Def = relationship between (among) taxonomic groups
- Consistent correlation (spatial scale)
- Similar response to environmental variables
- 3 main mechanisms to explain congruence between pairs of taxa (Gaston & Williams, 1996) :
 - 1) trophic, competitive, or mutualistic interactions between taxa;
 - 2) common determinants of community patterns;
 - 3) random draw of taxa from a larger pool of available colonists

Cross-taxon congruence analysis – 2

- If there was a strong and consistent correlation between two or more taxonomic groups
→
- We could use of one taxonomic groups to predict community patterns for other groups
- This would allow:
 - Rapid pond biodiversity assessments
 - Identify ponds of high conservation value (hotspots)
 - Monitoring programs

Pond biodiversity indicators

- Wetland plants
 - Taxonomy and ecology well-known
 - Sensitive to environmental changes
- Water beetles
 - Speciose (244 species in Ireland)
 - Predaceous diving beetles: multispecies assemblages
 - Ubiquitous

Objectives

- Quantify the relationship between the vegetation and water beetles
- Evaluate the power of vegetation data in predicting patterns in patterns in water beetle assemblages
- Biotic-abiotic relationships for both plant and beetle assemblages

Biotic and environmental data

- 54 ponds (June/July 2008 and 2009)
 - Water beetle data (counts)
 - Wetland plant data (% cover)
- Environmental variables
 - Size (surface area, max depth, max depth of sampling)
 - Permanency (T/P) *
 - Grazing intensity (U, G, F) *
 - Substratum (Gv, M) *
 - Pond age (2-10; >10 years) *
 - Physico-chemical variables
 - NO₃-N, PO₄-P, NH₃-N, pH, alkalinity, DO, conductivity

Data analysis

- Cross-taxon congruence (community concordance or correspondence)
 - Species richness
 - Species composition
- Biotic-abiotic relationships
 - Species richness
 - Species composition

Cross-taxon congruence

- Species richness
 - simple regression analysis (Pearson correlation)
- Species composition (counts - % cover):
 - Mantel tests
 - Procrustes analysis – PROTEST (Gower 1971, Jackson 1995): 1) original data; 2) NMDS
 - Co-correspondence analysis (Co-CA; ter Braak & Schaffers 2004)
 - ✦ Predictive – symmetric
 - Similarity percentages analysis (SIMPER, Clarke 1993)

Mantel tests

Commonly used in ecology to evaluate the correlation between two data matrices

- 1) Standard parametric approach (Pearson correlation)
 - assesses the degree of correspondence between two distance/dissimilarity matrices calculated for the plant and beetle datasets;
 - the significance of the relationship between the plant and beetle distance matrices was tested using 10,000 Monte Carlo randomizations (Jackson 1995; Manly 1997)
- 2) A non-parametric Mantel approach based on the Spearman rank correlation (Clarke 1993; 10,000 permutations)

Procrustes analysis - 1

- This is a multivariate ordination technique (Gower 1971)
- It uses a rotational-fit algorithm to maximize the sum-of-square distances between corresponding points of two data matrices
- Procrustes analysis fits one matrix to another by rotating, translating, and rescaling one matrix to minimise the sum-of-squared residuals between two matrices
- The goodness of fit measure between these matrices is the m^2 sum-of-squared deviation statistic (Gower 1971)
- m^2 is a measure of concordance when two matrices
- The Procrustes approach can be performed using either raw data matrices or the results of direct or indirect gradient analyses

Procrustes analysis – 2

- The significance of the Procrustean fit (m^2) → randomization or bootstrapping tests (Jackson 1993; Husson et al. 2009)
- Advantage:
 - Based on the original matrices or ordination
 - Higher power than Mantel tests (Pere-Neto & Jackson 2001)
 - Consistent – Pearson correlation
- The use of the results of multivariate analyses (CA, NMDS - PCA) of the original dataset is useful to reduce the data dimensionality
- PROTEST (software)- R ('shapes', 'FactoMineR',)

Co-correspondence analysis

- ter Braak & Schaffers (2004); Schaffers et al. (2008)
- Direct approach – 2 biological matrices
- Predictive version
 - Weighted averages
 - Partial least square regression
- Cross-validated fit percentage (>0)
 - Can be compared directly to that of predictive CCA (CCA-PLS)
- Randomization tests (MATLAB, R)

Additional methods

- A number of indirect approaches have been applied to evaluate cross-taxon congruence
- indirect gradient analysis and calculate pair-wise correlations of the resulting ordination axes (Hájek et al. 2002; ter Braak and Schaffers 2004)
- Bilton et al. (2006) used second stage NMDS (see Clarke et al. 2006) based on the Spearman rank correlation to calculate the similarity among different taxa in ponds
- Sætersdal et al. (2003):
 - detrended correspondence analysis (DCA) on community data
 - correlation of the results with a set of environmental variables using the Kendal rank correlation index

Biotic-abiotic relationships - 1

- Species richness
 - Generalized linear models (GLM, Poisson, log-link)
 - Multiple regression model (FP; forward procedure described by Blanchet et al. 2008)
 - Distance-based linear models (DISTLM, Anderson 2006)
 - Multicollinearity:
 - ✦ Pearson coefficient (0.60)
 - ✦ Variance inflation factor (never >10)

Forward Procedure (FP)

- This procedure is based on two stopping criteria:
 - 1) the significance level α (here set at 0.05)
 - 2) an adjusted coefficient of determination (maximum R^2_{adj}), calculated by constructing a full model inclusive of all explanatory variables
- This forward procedure performs a forward selection by permutation of residuals under the reduced model
- Advantages:
 - 1) avoids the overestimation of the explained variance
 - 2) an inflated Type I Error

Biotic-abiotic relationships - 2

- Species composition
 - FP
 - Predictive CCA (CCA-PLS; ter Braak & Schaffers 2004)
 - Predictors:
 - 1) plant species composition
 - 2) environmental variables
 - Explanatory CCA
 - DISTLM (distance-based linear model)
 - Procrustes analysis (using the results of non-multidimensional scaling for biotic communities, and principal components analysis for environmental data, NMDS-PCA)

Plant and beetle assemblages

- **Plant: 67 species**
 - Alpha diversity: 2-26
- **Beetle: 76 species**
 - Alpha diversity: 5-33

Cross-taxon congruence

- Species richness: $r^2 = \mathbf{0.3102}$
- Mantel test: ($r = \mathbf{0.302}$, $P = 0.001$)
- Permutational Mantel test (Spearman rank correlation rho = $\mathbf{0.337}$)
- Procrustes analysis - PROTEST
 - Original data: correlation (m): $\mathbf{0.717}$, $P = 0.001$
 - NMDS (3 axes): correlation (m): $\mathbf{0.568}$, $P = 0.001$
 - Advantage: being based on the original matrices and not the distance matrix
 - Higher power than Mantel tests

NMDS

Fig. 1. Results of NMDS performed on plant and beetle community data collected from two regions from 54 farmland ponds

Procrustes analysis

Fig. 2. Results of Procrustes analyses performed to evaluate the degree of correlation between plant (predictive) and beetle (response) assemblages collected from 54 farmland ponds

Predictive Co-CA and CCA-PLS

- Predictive Co-CA (Gioria et al. 2010, *Biol Conserv.*)
 - 1. Plant species composition (67): **5.34%** variance (2*)
 - 2. Environmental variables (12): 7.53% variance (2*)
 - 3. Env. variables + Plant diversity (J): 7.69% variance (2*)
 - 4. Plant community type: 3.36% variance (2*)
 - No statistical difference between plant species composition and environmental variables (Model 1 and 2)
- Symmetric Co-CA: **28.1%** explained variance

Predictive Co-CA

Fig. 3. Results of Co-correspondence analysis performed to evaluate the degree of correlation between plant (predictive) and beetle (response) assemblages collected from 54 farmland ponds

Biotic-abiotic relationships

- Both plants and beetles responded in a similar way to the same set of environmental variables (depth, substratum)
- Identified a common set of environmental variables
 - Selected a different number of variables (CCA)
 - Different variables
 - Contribution of each variable differed
 - Transformation
 - Measure of dissimilarity
 - Model selection criterion (AIC vs. BIC)
 - Parametric vs. non-parametric
 - Species richness vs species composition (Gioria et al., *Community Ecology*)

Results biotic-abiotic relationships

- **GLM**

- Beetle species richness AIC, $D^2_{adj} = 0.727$; BIC, $D^2_{adj} = 0.697$
- Plant species richness AIC, $D^2_{adj} = 0.565$; BIC, $D^2_{adj} = 0.538$

- **DISTLM**

- Beetle species richness: $R^2 = 0.730$; Beetle species composition: $R^2 = 0.408$ (0.305)
- Plant species richness: $R^2 = 0.588$; Plant species composition: $R^2 = 0.305$ (0.215)

- **Forward Procedure**

- Beetle species richness: $R^2 = 0.634$; Beetle species composition: $R^2 = 0.332$
- Plant species richness: $R^2 = 0.478$; Plant species composition: $R^2 = 0.184$

- **CCA**

- Beetle species composition: $\chi^2 = 0.469$
- Plant species composition: $\chi^2 = 0.193$

Issues

- Approach used substantially affect the results
- Species richness *vs* community composition (abundance)
- Parametric *vs* non-parametric
- Which method to measure cross-taxon congruence?
- Which method to model biotic-abiotic relationships?
- Use of multiple approaches
- Parametric *vs* non parametric
- Abundance data should be used

Recommendations

- Experimental studies
- Balanced designs – use of categorical variables
- Protocol or analytical framework:
- → Meta-analysis studies

Biological conclusions

- Plant were a good surrogate group for water beetles in pond biodiversity assessments
- Plant species composition – good predictor of water beetle assemblages patterns
- Plants and water beetles respond in a similar way to the same environmental gradients (based on a range of ecological models)

Biological conclusions

- Synthesize information on the biotic and abiotic conditions at a site
- Plant diversity – predictive value minimal – no suitable to predict community patterns
- Plant species composition – similar contribution than plant community type
- ? Redundant information – microhabitat provided, food, shelter, oviposition site
- Information at the species level only important for host-specific species or genera

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