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An overview of methods

potentially suitable for pond biodiversity assessment

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Abstract

This study provides a general overview of existing methods potentially suitable for assessing pond biodiversity. A bibliographic review allowed to evaluate the number of papers and consequently the interest of scientific investigation allocated (i) to different freshwater assessment objectives such as biodiversity, water quality or hydrological functions, and (ii) to biodiversity assessment for each of four waterbody types (ponds, wetlands, rivers & streams, lakes). The review was conducted using ISI Web of Science and browsing grey literature (reports from environment agencies and research institutes). Both methods designed for fundamental research and site management were taken into account.

The results emphasize that biological assessment methods for routine monitoring have been developed mostly for streams and rivers during the last two decades, and that lentic freshwater habitats have been rather neglected. Ponds, in particular, have been widely ignored despite of their significant contribution to regional biodiversity. Freshwater assessment methods mainly focus on water quality and hydrological aspects, while biodiversity is underrepresented.

Keywords: small waterbodies, wetlands, species richness, monitoring, management

Résumé

Revue de méthodes potentiellement utilisables pour l'évaluation de la biodiversité des étangs

L'objectif de cet article est de présenter une vue d'ensemble des méthodes potentiellement utilisables pour l'évaluation de la biodiversité des étangs. Une recherche bibliographique a été réalisée afin d'estimer le nombre de publications et, par conséquent, l'intérêt porté (i) aux objectifs poursuivis par les différentes méthodes d'évaluation, tels que la qualité de l'eau, les fonctions hydrologiques et la biodiversité, et (ii) à l'évaluation de la biodiversité de quatre types de milieux aquatiques (étangs, zones humides, eaux courantes, lacs). Des rapports d'études provenant d'agences environnementales et d'instituts de recherche (littérature grise) ont également été pris en considération. Nous nous sommes intéressés autant aux méthodes destinées à la recherche fondamentale qu'à celles destinées aux gestionnaires des sites.

Les résultats montrent, que des méthodes consacrées à l'évaluation routinière de la qualité biologique ont été principalement développées pour les eaux courantes, et que les eaux stagnantes n'ont pas bénéficié d'autant d'intérêt. Plus particulièrement les mares et étangs ont été largement ignorés en dépit de leur contribution significative à la biodiversité régionale. Les méthodes d'évaluation s'intéressent principalement à la qualité de l'eau et aux aspects hydrologiques; à l'inverse elles se préoccupent moins de la biodiversité.

Mots-clés: petits plans d'eau, mares, zones humides, richesse spécifique, monitoring, gestion

Introduction

Until recent years, freshwater ecosystem assessment has focused primarily on pollution control (Resh and Jackson 1993; Verdonschot 2000). The EC Water Framework Directive (WFD: European Commission 2000) and its concept of *good ecological status* calls now for a shift from a classical bio-

geochemical approach to an ecological approach and requires advanced assessment techniques (Wasson et al. 2003). In addition, independently of the WFD, and according to the goals of the U. N. Convention on Biological Diversity (1992), the EC Environmental Action Programme (European Commission 2002) aims to stop the loss of biodiversity by 2010. Given this framework, and in order to prioritize areas for

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conservation, biologists and managers need accurate information on species diversity. It has been shown (Oertli et al. 2000; Williams et al. 2003) that ponds, compared to rivers and streams, contribute most to regional biodiversity. Yet methods to evaluate pond biodiversity are rare. As a matter of fact, the attention during the last decades has mainly been focused on rivers and streams, illustrated for example by a considerable number of biological assessment methods (e.g. AFNOR 1992; Wright 1995; Boon et al. 1997; Wright et al. 1998; Karr and Chu 2000; Oberdorff et al. 2002; AFNOR 2003; Hering et al. 2003). Regarding these facts, it seems that ponds have been rather ignored, even in the recent WFD they are not explicitly mentioned. The aim of this paper is therefore to provide a general overview of freshwater biodiversity assessment methods potentially suitable to ponds in order to summarize useful information for the development of future pond assessment programs.

IMethods of the bibliographic study

To begin with, a quantitative search using Science Citation Index Expanded (ISI Web of Science, Institute for Scientific Information) was carried out in March 2004 to evaluate the number of papers on the subject of biodiversity assessment of four different waterbody types: ponds, wetlands, rivers & streams and lakes.

Secondly, to gather potentially suitable methods for pond biodiversity assessment, an extensive literature survey was conducted on SCI Expanded searching with the following keywords individually and in combinations: pond, wetland, river, stream, lake, bio-

diversity, assessment, evaluation, health and method. Additional papers were obtained by examining cited references and from browsing the web for relevant reports by environment agencies and research institutes (grey literature). Only documents relating to freshwater ecosystems (with particular emphasis on ponds and wetlands) were retained. For this overview, methods for fundamental research have been equally considered as those designed for site management.

Objectives of freshwater ecosystem assessment

An assessment is an integrated statement about a current situation and the factors that contribute to that situation (Innis et al. 2000). It can be focused on different objectives, such as water quality, ecosystem function, biodiversity or integrity. Our literature survey reflects the effort allocated to different assessment goals for several types of aquatic habitat (Fig. 1): only 12% of the papers focus on biodiversity, whereas 17% deal with functional aspects (e.g. sediment and nutrient retention, flood storage, water purification) and 71% with water quality.

Among the reviewed studies, the terms used to define the assessment objectives are diverse and sometimes confusing (eacosystem health, bioassessment, biological status, ecological status, biological integrity etc). Bioassessment, for example, does not necessarily equate with biodiversity assessment, but refers to a method using bioindicators. It is therefore important to clearly define the type of information a method provides. To facilitate the comprehension it might be convenient to use the terminology defined

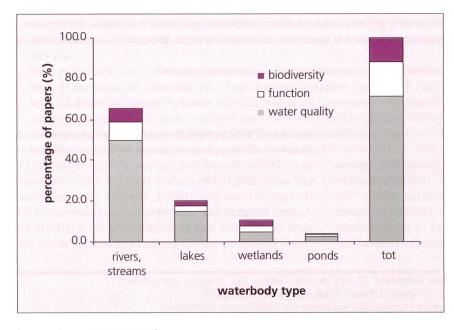


Fig. 1: Number of papers accorded to different assessment objectives (water quality, function, biodiversity) for four waterbody types (n = 1277). Browsed database: SCI Expanded (ISI Web of Science, March 2004).

in the WFD: "Ecological status" is an expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters, classified in accordance with Annex V of the Water Framework Directive (European Commission 2000).

Regarding the different waterbody types being assessed, it can easily be seen (Fig. 1) that running waters receive the most attention and that ponds, at the opposite, are poorly documented.

■Measurement of biodiversity

According to the Convention on Biological Diversity (1992), biological diversity means "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems". For the present overview, biodiversity is expressed in terms of species richness, which has become the common currency of much of the study of biodiversity assessment (Gaston and Spicer 2004). Two types of species richness metrics can be distinguished among the reviewed methods that focused on pond biodiversity: (i) the observed species richness (measured value), and (ii) the "real" species richness (estimated from the measured value). The observed species richness is the number of species observed during field investigations. As far as sampling is concerned, some authors highlight the fact that species richness recorded is vulnerable to variation in sampling effort (Lande et al. 2000; Magurran 2003) and to effects of abundance (Gotelli and Colwell 2001). To overcome these problems, i.e. to compensate for sampling bias, the use of "real" richness is recommended. To estimate "real" species richness from observed species richness, three main approaches are commonly used (see Magurran 2003): (i) extrapolations of species accumulation curves, (ii) fitting of species-abundance distributions and (iii) the use of non-parametric estimators. Non-parametric estimators, such as Chao (Chao 1984) and Jackknife (Burnham and Overton 1979), represent undoubtedly one of the most powerful tools (Colwell 1997; Foggo et al. 2003), as they are not based on a species abundance model that has been previously fitted to the data (Magurran 2003). To compute species accumulation curves or richness estimators, software packages can be used (e.g. EstimateS: Colwell 1997; Ws2m.exe: Turner et al. 2000).

To assess the collected data, different methods are used in the reviewed papers. Once the species richness has been measured, it can be assessed by a comparison either with the richness of a set of other sites, or with the richness for an unimpaired reference site.

The richness of this reference site can be calculated by means of predictive models based on the relation between species richness and environmental variables. This approach is also suggested in the WFD (European Commission 2000), as an alternative of hindcasting methods. For building those predictive models, the influence of environmental variables on species richness has to be evaluated. This can be achieved by a classical regression analysis (Gee et al. 1997; Biggs et al. 2000). A non-parametric alternative to this technique is provided by Generalized Linear Models (McCullagh and Nelder 1997) or Generalized Additive Models (Hastie and Tibshirani 1990), which are used in the PLOCH method (Oertli et al. 2005). The strength of the GAM models is their flexibility: the relationship between two variables can take any curved form and does not depend on the implicit shape of a standard parametric regression. Finally, a promising nonlinear approach, not yet applied to still waters, is the use of artificial neural networks (Lek and Guegan 1999; Giraudel and Lek 2001; Céréghino et al. 2003). All these analyses enable the baseline prediction of the species richness of a site that is to be assessed and the comparison of predicted values with observed ones.

Methods suitable to ponds

A list of methods used in still waters and potentially suitable for assessing pond biodiversity is given in Table 1. The reviewed papers measure diversity at one (or more) of three different spatial scales: (i) regional diversity, i.e. the overall diversity within a large region (landscape or biogeographic province), (ii) local diversity, i.e. the diversity in one ecosystem (e.g. pond or wetland), and (iii) point diversity (sample diversity), i.e. the diversity in a sample. It appears that all the methods in Table 1 measure local diversity, 22 % assess also point diversity, but only one method addresses regional diversity.

Concerning the selection of taxonomic groups, only a third of the methods use more than two groups (Table 1). Most of the methods use invertebrates because of their qualities as indicators, such as being representative of the assessed habitat, and having well understood taxonomy, life history and ecology (see New 1995). Nevertheless, besides their quality as bioindicators, the use of invertebrates as surrogate for the diversity of other taxonomic groups is questionable. Indeed, the relationship between the richness of invertebrates and the richness of the whole biotic community is not clearly established (Gee et al. 1997; Heino et al. 2003).

The choice of the taxonomic level is a trade-off between an increased information content and the cost of obtaining it. Even though family or genus level data could be effective for assessing overall quality

Table 1: Selected stillwater assessment methods potentially suitable to ponds. Only methods including measurement of biodiversity have been retail

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Scale of diversity	point, local		local	local			local		local								local			استا	local		point, local						local				local	point, local						local	
Nb of sites	-		157	42			51		142								19			212	313		96						71				57	80						47	
Sampler type	Pond net, 1mm mesh, artificial substrate		Pond net, 1mm mesh	Pond net			Pond net, 300 µm mesh		Pond net	species	Pond net						Pond net, 0.5 mm mesh	Pond net 0 5 mm mesh	Pond net 0.5 mm mesh	+ + + + + + + + + + + + + + + + + + +	Pond net		Core sampler	Core sampler	64 µm mesh.	Pond net, 500 µm mesh	Gill nets, fyke nets		80 µm mesh net		Gill nets				Pond net 0 5 mm mash	Perdiet, 0.5 mm mesh	Pond net, U.5 mm mesn			Hess-type sampler,	0.5 mm mesh Fkman dredae
Taxonomic level	species	species	species	species*	species	species	species*	species	family	Macrophytes	genus	species	species	species	species	species	species	spacies	species	formill.	Tamıly	sbecies	species	species	species##	species	species	species	species	species	species	species	species	species	chaciae	species	sbecies	species	species	genus	
Studied taxa	Macroinvertebrates	Crustacea Amphibia	Coleoptera	Macroinvertebrates	Amphibia	Macrophytes	Macroinvertebrates	Macrophytes	Macroinvertebrates		Macroinvertebrates	Amphibia	Fish	Birds	Algae	Macrophytes	Coleoptera	Mollusca	Odonata		Macroinvertebrates	Macrophytes	Bacterioplankton	Protists	Zooplankton	Macroinvertebrates	Fish	Macrophytes	Zooplankton	Phytoplankton	Fish	Macrophytes	Macrophytes	Odonata (adults)	Gasteronoda	Gasteropoua	Coleoptera	Amphibia	Macrophytes	Macroinvertebrates	
Objectives	Species monitoring		Conservation value	Conservation value			Biodiversity		Ecological integrity		Water quality	Ecosystem health					Biodiversity			7	Ecological quality		Biodiversity						Biodiversity				Conservation value	Biodiversity						Biological integrity	
Country	nk		UK (Wash)	UK (Scotland)			UK (Wales)		N.	(England & Wales)	USA						UK (Wicken Fen)			<u> </u>		(England & Wales)	B, DK, NL, E						DK				UK (East Yorkshire)	H)						USA (Utah)	
Target habitat	spuod		Arable fenland	Forestry ponds			Ponds		Ponds, canals		Wetlands,	running waters					Ditches				Ponds, small lakes		Shallow lakes						Shallow lakes				Ponds	Ponds, small lakes						Wetlands,	mountain lakes
Author (method)	Macan 1977		Foster et al. 1990	Jeffries et al. 1991			Gee et al. 1997		Williams et al. 1998	(PSYM)	U. S. EPA 1998, 2002	(IBI)					Painter 1999			0000 1-1-1-10	Biggs et al. 2000	(PSYM)	BIOMAN 2000						Jeppesen et al. 2000				Linton and Goulder	Oertli et al. 2000,	2005 (PLOCH)	2002 (FLUCH)				Hawkins et al. 2001	

																		point, local, regional								911									_		
	local		local	local		local			local	local		point, local		local				point, loca		point, local					local										point, local	local	
	sh, 44		10	38		traps 18			130	35		m		corer66				80		8 ر			- us		408	1			hesh		•				th 119	71	
Ekman dredge	Pond net, 600 µm mesh,	activity traps	Pond net, 0.5 mm mesh	Kicknet, 0.5 mm mesh		Funnel traps, blacklight traps 18	Fyke nets		Pond net	64 µm mesh net		Pond net, 1 mm mesh		Stem tube, soft bottom corer66	Nylon nets, fyke nets	50 µm mesh net		Pond net, 1mm mesh		Pond net, 250 µm mesh	10 µm mesh net		Pond net, 250 µm mesh			Pond net	Various nets		Plankton net, 64 µm mesh		100 - 200 µm nets				Kicknet, 0.25 mm mesh	Pond net, 1mm mesh	
	genus	species	subfamily / tribe	genus		genus	species	species	species	species		species		species	species	species	species	species**	species	species	species	species	genus***	genus	species	species	species	species	species	species	species	species	species	species	species	species	species
	Macroinvertebrates	Macrophytes	Macroinvertebrates	Macroinvertebrates		Macroinvertebrates	Fish	Macrophytes	Macroinvertebrates	Cladocera		Macroinvertebrates	(except Diptera)	Macroinvertebrates	Fish	Plancton	Macrophytes	Macroinvertebrates	Macrophytes	Macroinvertebrates	Zooplankton	Macrophytes	Microcrustacea	Insecta	Odonata	Macroinvertebrates	Fish	Amphibia	Plankton	Macrophytes	Macrocrustacea	Macroinvertebrates	Amphibia	Macrophytes	EPT Taxa	Macroinvertebrates	Macrophytes
The second secon	Wetland health		Bioassessment	Bioassessment	Biological integrity	Water quality	Biological integrity		Biodiversity	Biodiversity		Biodiversity		Ecological status				Biodiversity		Biodiversity			Water quality		Ecological status	Monitoring					Conservation				Biodiversity	Biodiversity	
	USA (Minnesota)		USA (Florida)	USA (Utah)		USA (Great Lakes)			UK (Oxfordshire)	B (De Maten)		UK (SW England)		EU				UK (Oxfordshire)		L.	(Causses du Quercy)		ш		A (Danube floodplain)	USA					ш				CH, I	Ϋ́Ω	(England & Wales)
	Wetlands		River oxbows	Wetlands		Wetlands			Ponds	Shallow ponds		Ponds		Shallow lakes				Rivers, streams,	ditches, ponds	Ponds			Ponds		Floodplain areas	Mountain	ponds and lakes				Temporary ponds				Parafluvial ponds	Temporary ponds	
	Gernes and Helgen	2002	Merritt et al. 2002	Vinson et al. 2002		Wilcox et al. 2002			Briers and Biggs 2003 Ponds	Cottenie and	De Meester 2003	Foggo et al. 2003		Moss et al. 2003				Williams et al. 2003		Angélibert et al. 2004			Boix and Quintana	2004 (QAELS)	Chovanec et al. 2004	Hoffmann et al. 2004					Grillas et al. 2004				Karaus 2004	Nicolet 2004	

#genus for Chironomidae, small Arthropoda, juvenile Hemiptera & juvenile Coleoptera

^{##}except Rotifera: mainly genus

family for Diptera

^{**} genus for Diptera and Oligochaeta

^{***} species for Daphnia and Moina

(e.g. Balmford et al. 1996), species level datasets are more relevant and are used in most of the methods dealing with biodiversity.

Besides species richness, some methods also assess the *conservation value*, an important criterion for taking into account the degree of threat faced by the species (Eyre and Rushton 1989; Foster et al. 1989; Painter 1999; Linton and Goulder 2000; Oertli et al. 2002; Nicolet et al. 2004).

Regarding the range of existing sampling methods and sampler types, various techniques are used, including net sampling, core sampling or use of artificial substrate (Table 1). Mesh size for macroinvertebrate sampling, for example, varies from 0.25 to 1.5 mm; as differences in mesh size generate different retention probabilities of the invertebrates (see Bachelet 1990, Schlacher and Wooldridge 1996, Morin et al. 2004), standardization of the mesh size would be useful. The diversity of sampling methods indicates the importance of using standardized protocols and acknowledging the sampling biases (e.g. Muzzaffar and Colbo 2001). Some recent methods include standardized sampling (pond net sweeping for a given time): Williams et al. (1998), Biggs et al. (2000), Nicolet et al. (2004) and Oertli et al. (2005).

■Methods used in wetlands

In addition to the methods potentially suitable to ponds (listed in Table 1), there are a certain number of assessment procedures available for wetlands, which have been developed for purposes such as hydrogeomorphic (Brinson et al. 1995) or biological assessment (U.S. EPA. 2002). Some of these procedures could also be suitable to ponds, as large wetlands often include one or more small lentic waterbodies. Many of these methods, mostly rapid assessments, rely on the use of metrics and provide a single score as an overall estimation of the ecological status of a site (e.g. Resh and Jackson 1993; Barbour et al. 1999; Miller and Gunsalus 1999; Mack 2001; Collins et al. 2003; Stapanian et al. 2004). Instead of standardized sampling they are often based on expert field investigations. Nevertheless, if rapid assessment methods are useful and attractive economic tools to assess anthropogenic impacts on aquatic ecosystems, they are not in all cases a substitute for biodiversity studies. Consequently, there is growing interest, illustrated for example by Alonso et al. (2002), in improving the accuracy of the rapid methods and adapting them for biodiversity assessment.

I Conclusions

Ecological assessment methods for ponds are rare compared to methods designed for running waters. Even though a certain number of procedures are now available for measuring pond biodiversity, there is a need to strengthen the development of pond-specific methods for fundamental research on one hand, and for site managers on the other hand (rapid assessments). Concerning the estimation of species richness, the use of non-parametric techniques might be a powerful tool in reducing sampling bias.

Often a restricted number of taxonomic groups is used as a surrogate for diversity of the whole biotic community. Nevertheless, further studies need to be carried out in this field of species richness indicator taxa and flagship species to validate this approach (see for example Andelman and Fagan 2000). Taxa richness is often the unique metric used for the assessment of biodiversity; however, future methods should also take into account the species's degree of rarity (conservation value). Regarding the scale of measured biodiversity, most methods specifically address local or point biodiversity; it should now be evaluated how these methods could be designed to assess also regional biodiversity. Finally, according to Magurran's textbook on measuring biodiversity (2003), standardization should be recognized as a main element of any assessment method.

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