Environmental Management (2015) 56:245–259
DOI 10.1007/s00267-015-0487-z

The Cultural Dimensions of Freshwater Wetland Assessments: Lessons Learned from the Application of US Rapid Assessment Methods in France

Stéphanie Gaucherand[1] · Eugénie Schwoertzig[2,3] · Jean-Christophe Clement[3] · Brad Johnson[4] · Fabien Quétier[5]

Received: 30 October 2014 / Accepted: 30 March 2015 / Published online: 7 April 2015

Abstract Given the recent strengthening of wetland restoration and protection policies in France, there is need to develop rapid assessment methods that provide a cost-effective way to assess losses and gains of wetland functions. Such methods have been developed in the US and we tested six of them on a selection of contrasting wetlands in the Isère watershed. We found that while the methods could discriminate sites, they did not always give consistent rankings, thereby revealing the different assumptions they explicitly or implicitly incorporate. The US assessment methods commonly use notions of "old-growth" or "pristine" to define the benchmark conditions against which to assess wetlands. Any reference-based assessment developed in the US would need adaptation to work in the French context. This could be quite straightforward for the evaluation of hydrologic variables as scoring appears to be consistent with the best professional judgment of hydrologic condition made by a panel of French local experts. Approaches to rating vegetation condition and landscape context, however, would require substantial reworking to reflect a novel view of reference standard. Reference standard in the European context must include acknowledgement that many of the best condition and biologically important wetland types in France are the product of intensive, centuries-long management (mowing, grazing, etc.). They must also explicitly incorporate the recent trend in ecological assessment to focus particularly on the wetland's role in landscape-level connectivity. These context-specific, socio-cultural dimensions must be acknowledged and adjusted for when adapting or developing wetland assessment methods in new cultural contexts.

Keywords Wetlands · Mitigation · France · Rapid assessment methods · Best professional judgment

✉ Stéphanie Gaucherand
stephanie.gaucherand@irstea.fr

1 IRSTEA, Unité de Recherche sur les Ecosystèmes Montagnards, BP 76, 38402 St-Martin d'Hères Cedex, France

2 Laboratoire Image, Ville, Environnement, UMR 7362 du CNRS, Université de Strasbourg, 3 rue de l'Argonne, 67083 Strasbourg, France

3 Laboratoire d'Ecologie Alpine CNRS UMR 5553, Université Grenoble Alpes, BP 53, 38041 Grenoble Cedex 09, France

4 Department of Biology, Colorado State University, Fort Collins, CO 80523-1878, USA

5 Biotope, 22 Boulevard Foch, BP 58, 34140 Mèze, France

Introduction

Wetlands provide numerous ecosystem services such as habitat provision for wildlife, mitigation of diffuse pollutants and water quality protection (Clement et al. 2002; Sabater et al. 2003), water and sediment flows regulation (Pinay et al. 2002; MEA 2005). The conservation and restoration of wetlands are increasingly justified to sustain the provision of these services (Maltby and Acreman 2011). Their delivery relies on specific wetland functions, which in turn depend on the wetland's ecological condition and on their surrounding watersheds. Wetland condition, which is commonly assessed in relation to pristine reference sites, indicates the range of function or services provided. Condition assessments are widely adopted in wetland management (Sutula et al. 2006; Fennessy et al. 2007; Stein et al. 2009b; McLaughlin and Cohen 2013). It is the case, in particular, for the implementation of environmental impact mitigation rules (Robertson 2009). There is an abundant literature on wetland impact mitigation in the US, where “not net loss of wetland function” has been set as a policy goal since 1990s (Hough and Robertson 2009) and numerous assessment methods have been developed in this context (Fennessy et al. 2007).

No net loss goals have gained interest in Europe in recent years under the impulse of government commitments under the Convention for Biological Diversity (Bull et al. 2013). The European Union, for example, is preparing a no net loss Initiative targeting ecosystems and ecosystem services (Tucker et al. 2014). In France, although the mitigation hierarchy of avoidance, reduction, and compensation of impacts to the environment has been in force since 1976, it is only very recently that a goal of achieving no net loss has been formulated in government guidance (Ministère de l'Ecologie, du Developpement Durable et de l'Energie-MEDDE 2012, 2013; Quétier et al. 2014). Offset requirements to address residual impacts on wetlands were laid out in the River Basin Management Plans established under the European Water Framework Directive (2000/60/EC) and known in France as *Schémas Directeur d'Aménagement et de Gestion des Eaux* (SDAGE). In 2009, these SDAGEs were reviewed and updated (Quétier et al. 2014) and area-based ratio, where 1.5–2 ha restored for 1 ha destroyed by development have been adopted in most river basins. For example, the SDAGE of the Rhône river basin requires either the construction or the restoration of twice the destroyed area, in the same catchment area, or measures that ensure equivalent function and biodiversity within the catchment (Comité de bassin Rhône-Méditerranée 2009). This second approach not only allows for loss–gain calculations and explicit no net loss goals, but also calls for assessment methods targeting wetland functions (Quétier and Lavorel 2011).

The legal definition of a wetland in France, established through Ministerial Order DEVO0813942A in 2008, is very broad and any habitat with a hydromorphic soil is considered a wetland, including recently drained agricultural soils. As a result, considerable offsetting requirements have been imposed on development projects in lowlands and river valleys. However, no shared methodological framework for the assessment of losses and gains when designing and sizing offsets has yet been developed in France, there is on-going work in this direction (MEDDE 2014). Currently, wetland functions are assessed on a case-by-case basis, typically through best professional judgment by trained and experienced professionals hired by developers. While some guidance is provided on how to proceed, there are no compulsory methods yet. This situation is forcing developers and regulators to innovate approaches on an *ad hoc* basis (Quétier et al. 2014).

One key innovation is the development of wetland assessment methods that are robust, easily applied, affordable, and which provide sufficient discrimination to guide management or regulatory decision making. The recent strengthening of wetland mitigation policies in France, including a pilot “banking” scheme, calls for improved methods to assess the suitability of proposed restoration approaches, determines the restoration size required to meet policy imperatives, and evaluates project success. Development of robust wetland assessment methods is a first step toward empowering wetland mitigation programs. Because of the long-standing work on rapid wetland assessment in the US, we tested whether US rapid assessment methods could be “imported” wholesale into France, or how the methods would have to be modified to work in the novel context.

Fennessy et al. (2007) analyzed 40 wetland assessment methodologies developed in the US and concluded that six of them met the study's criteria related to sufficiency in meeting the objectives of the US Clean Water Act programs, namely, (1) they are rapid taking less than half a day for two people to carry out an evaluation; (2) they gather information in the field; and (3) they are repeatable. These types of methods are called rapid assessment methodologies (RAMs). RAMs occupy the second level in the three-tiered wetland assessment hierarchy developed by the US Environmental Protection Agency (EPA) (EPA 2006), residing between remote landscape assessment (Level 1) and intensive site-level quantitative studies (Level 3).

We tested six methods (Table 1) on 13 depressional and riverine wetlands across a gradient of degradation in the Isère watershed of the Rhône-Alpes region. All the selected methods assessed wetland hydrology, biological structure (mainly through an assessment of the vegetation structure), and landscape setting, but they differed in their indicators and how these were combined. Fennessy et al. (2007) distinguish two types of indicators: first, “essential indicators” with broad, general applicability and second, “regionally refined indicators,” highlighting the importance of adapting some indicators to local conditions. The methods also differed in their choice of reference conditions. The latter can be “culturally unaltered,” which implies a state that existed prior to human management activities such as grazing, agriculture, fire suppression, land development, water resource management, and flood control. An alternative approach to defining reference conditions is termed “best attainable conditions.” It refers to the highest possible state that may exist given permanent or semi-permanent constraints on the landscape, such as major dams, urban centers, or flood control facilities (Sutula et al. 2006).

We focused our analysis on three aspects of the RAMs: (1) their discriminatory power, i.e., the ability to discern poor versus good condition, (2) the consistency between RAMs, i.e., the degree of agreement between the different RAMs on which wetlands were in the best and in the poorest condition. Where inconsistencies were identified

Table 1 List of the six rapid assessment methods used for this study

Name and reference	Version used	Reference condition	Scoring	Time/expertise
Rapid Assessment Method Washington (WAFAM) (Hruby 2012)	2006	Best attainable condition (25 reference sites)	Vegetation Hydrology Landscape	0.5 days No specific expertise required
Uniform Mitigation Assessment Method Florida (UMAM 2004)	2004	Culturally unaltered reference	Overall score Vegetation Hydrology Landscape	1 day Expertise required
Montana Wetland assessment Method (MWAM) (Berglund and McEldowney 2008)	2008	Best attainable condition	Overall score Vegetation Hydrology	0.5 days Expertise required
Ohio Rapid Assessment Method (ORAM) (Mack 2001)	2001	Culturally unaltered reference	Overall score Vegetation Hydrology Landscape	0.5 days Expertise required
Delaware Rapid Assessment Procedure (DERAP) (Jacobs 2010)	v. 6.0 (2010)	Best attainable condition (calibrated with a statistical model)	Overall score Vegetation Hydrology Landscape	0.5 days No specific expertise required
California Rapid Assessment Method (CRAM) (CWMG 2012)	v. 5.0.2 (2008)	Best attainable condition	Overall score Vegetation Hydrology Landscape	0.5 days No specific expertise required

Most methods assess the vegetation, the hydrology, and the landscape setting of the wetlands, and give an overall score. If one of these four components is not assessed by a method, the missing component does not appear in the "scoring" column

we endeavored to identify the root cause, and (3) the consistency with best professional judgment of wetland condition made by panels of local wetland experts. This comparison was used to gage the congruence between evaluation scores and established best-management practices and local priorities.

Materials and Methods

Selection of Rapid Assessment Methods

Six rapid assessment methods were used (Table 1). We selected five of the six methods identified by Fennessy et al. (2007), dismissing the Massachusetts Coastal Zone Management Rapid Habitat Assessment (Hicks and Carlisle 1998) because it was too specific to coastal wetlands. Instead we added the California Rapid Assessment Method (CWMG 2012) which has seen wide use and for which abundant documentation was available (Hanson et al. 2008; Stein et al. 2009a).

All methods provided an identification key based on the Hydrogeomorphic (HGM) Classification (Brinson 1993) to help users determine the type of wetland being assessed. In all selected methods, the assessment was organized around the vegetation, the hydrology, and the landscape setting, except MWAM which does not directly evaluate the landscape context. The indicators used by the selected methods described the structure of wetland components (vegetation, geomorphology, etc.) and/or the disturbance factors (dams, levees, drains, management, etc.). However, the methods differed in the choice of indicators because they were designed in different biogeographic regions, posing different mitigation issues and in response to a variety of policies.

A fundamental characteristic that differentiates RAMs is whether they employ "relative" or "absolute" evaluation criteria. Most RAMs can be described as being the relative type; that is, ratings are based on the evaluation of functioning in comparison to a reference standard. In use, evaluators gage the departure of the observed condition of a variable from what is expected based on the normal range of variation exhibited by like-kinded reference standard wetlands. The rates or capacities of functions are merely implied based on the wetland's functional type (Johnson et al. 2013).

Fewer RAMs consider absolute functioning of a discrete number of functions in terms of capacity or the rate at which they are performed (e.g., cubic meters of surface water retained). To varying degrees, RAMs that rate variables in absolute terms step away from the assessment of pure condition and interject elements of societal value into the evaluation outcome. For example, the MWAM attributes a higher score to wetlands sheltering rare species regardless of wetland type or ecological condition ,and ORAM explicitly awards bonus points to certain wetland types, such as bogs, fens, old growth forests, etc. This is an important means for widely agreed upon conservation objectives to be interjected into the mitigation process. Likewise, WAFAM uses absolute measures of functions such as reducing water velocities and trapping sediment that describes an implied societal value ("removal of metals and toxic organic compounds"). DERAP is specific in that it focuses on stressors rather than measurable proxies of the target functions: the presence and intensity of stressors (habitat, hydrologic, and buffer stressors) lower the final score.

ORAM and UMAM use "culturally unaltered" reference standards, whereas the other 4 mainly refer to the "best attainable condition," though this may vary from one indicator to the other. CRAM and UMAM focus on wildlife habitat functions. CRAM was designed to assess condition based on the capacity of a wetland to support characteristic native flora and fauna. This means that hydrology and physical structure are assessed based on their contribution to supporting plant and animal habitat rather than on the ability of the wetland to provide services such as flood attenuation or water quality improvement (Stein et al. 2009b). Also, this method is not reference-based but scaled to a theoretical optimum condition. Like CRAM, UMAM focuses on the ability of the wetland to support wild and aquatic life but in this case the scoring is done according to best professional judgment (BPJ).

Selection of Study Sites and Field Data Collection

The RAMs are all based on the theory that as wetland ecological condition degrades along a disturbance gradient there is a corresponding impairment of functioning (Sutula et al. 2006; Fennessy et al. 2007). The sampling design aimed to cover gradients in vegetation structure, hydrological connectivity, and landscape context. Study sites were selected by cross-referencing information provided by the regional wetland inventory of 2006 (DREAL 2006), publicly available maps (e.g., through the www.geoportail.fr web portal), field visits, and expert recommendation. Thirteen sites were selected in the Romanche and Isere flood plains (Fig. 1). They encompassed the vegetation types (wet meadows, reed beds, and riverine forests), susceptibility to regular flooding, and landscape context that is more or less intensively cultivated or urbanized (Table 2; Fig. 2). Some sites were managed by local land trusts, and others were planted forests. Through a panel, local experts were asked to rank the sites on the basis of their quality and their importance in relation to local conservation priorities (Table 2).

The six methods were implemented by a single evaluator during spring 2011 after a trial period and extensive discussions on the interpretation of guidance manuals for each method, with involvement of the local expert panel. Scores for each method and study site are provided in Appendix.

Data Analysis

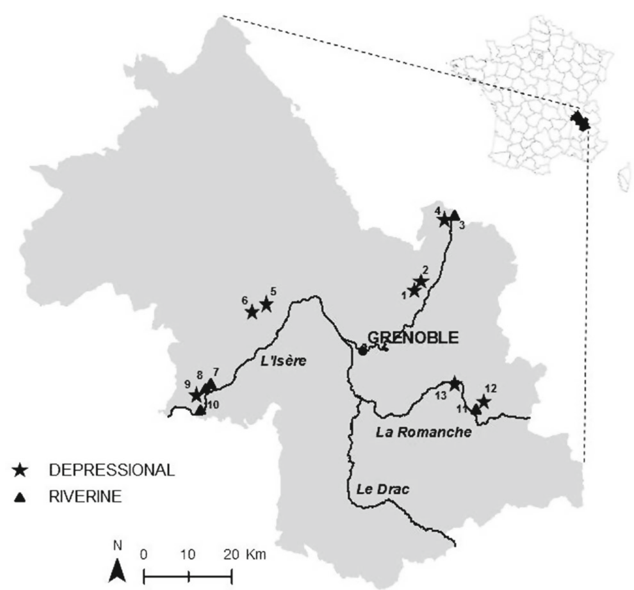
All scores were normalized by calculating, for each score and method, a percentage of the maximum total achievable score using the method. All analysis was done using *Statistica* (StatSoft Inc. 2004).

Discriminatory power is a measure of the ability of the method to differentiate between wetlands in poor versus good condition. For each method, we compared the minimum, average, and maximum scores obtained across the 13 wetlands, and distinguished overall score and scores for vegetation, hydrology, and landscape context. WAFAM does not attribute an overall score so this method was excluded from that comparison. A large spread of the scores across the broad range of site conditions sampled is interpreted as being indicative of high discriminatory power.

Consistency between methods was measured by comparing scores obtained for each wetland using different methods. A Principal Component Analysis (PCA) of assessment scores was used to measure and provide graphic illustration of the correlations between scores across methods and wetlands. This analysis was carried out on overall scores and on the scores obtained for vegetation, hydrology, and landscape context. Strong correlations across wetlands were interpreted as indicating consistency between methods.

The contribution of each component (vegetation, hydrology, and landscape context) to the overall score was explored for each RAM by running single and stepwise regression analyses. Correlations between the different components of the overall score were also measured.

Finally, we compared the scores obtained using each method with the ratings given by local experts in order to gage the relevance of rapid assessment methods in the local context. The relationship was tested for hydrology, landscape, and overall score by regressing the scores given by each rapid assessment method against the BPJ scores (no BPJ rating was done on vegetation).



Site code	Long.	Lat.
1	879562	2038628
2	879670	2038647
3	887221	2057248
4	886897	2057258
5	848014	2036430
6	847301	2035999
7	831115	2015860
8	831157	2015907
9	830794	2012742
10	830543	2010879
11	892847	2010714
12	893283	2011349
13	889733	2017772

Fig. 1 Code and location of the 13 study sites (latitude and longitude are given in the French geodetic system RGF93, Lambert 93 projection)

Results

Discriminatory Power

Normalized on a scale from 0 to 100, the overall scores assigned by different methods range from 24 (MWAM) to 41.6 (CRAM) for the most degraded sites, and 86 (ORAM) to 98 (DERAP) for the best sites. The mean score (all sites together) is 66 ± 18 SD. Figure 3 shows a spread of scores across the study sites for each method, which obviously discriminate different sites. Drained meadows received the lower scores with all methods and this result was confirmed in the PCA analysis on overall scores (Fig. 4).

Considering vegetation, hydrology, and landscape context separately, the discriminatory power of different methods varied. This was most evident in the case of CRAM's scoring of the landscape context. This method had little ability to discriminate between the variety of settings sampled, and scores were high compared to all other methods clustering within a narrow range between 66 and 93.

Consistency Between RAMs

The RAMs were projected on the first two axis of the four PCAs (Figs. 4b, 5, 6, 7b). The arrows indicate the direction of the highest scores given by the RAMs in the factor-plane. Axis 1 of the PCA on the vegetation, hydrology, or overall scores explains over 70 % of the variance (Figs. 4, 5, 6), whereas axis 1 of the PCA on the landscape scores only explains 47 % of the variance (Fig. 7). When projected on axis 1, all RAMs were located on the same side of the axis (left side, Figs. 4b, 5, 6, 7b). Axis 1 of all PCAs thus discriminates sites that received, overall, higher scores with all RAMs (left side of axis 1) against sites that received, overall, lower scores with all RAMs (right side of axis 1). This shows that the information provided by the RAMs on hydrology, vegetation, and the overall condition of the wetlands was very redundant (correlated). This is less clear for landscape assessment. Axis 2 of the PCAs explains a much lower part of the variance (around 15 %, for all PCAs except for the one on landscape scores, where axis 2 explains up to 30 % of the variance). This axis discriminates the least correlated RAMs, i.e., methods that gave the highest scores to different wetlands.

Indeed, all methods agreed on the sites to be considered "in poor condition" (Fig. 4a, sites 2, 13 and 6). The best sites, however, appeared to be different from one method to another. Meadows (sites 1; 2; 5; 6; 13) were generally discriminated against, receiving all the lowest scores (right side of the first PCA axis) and forests (sites 3; 4; 7; 10; 11; 12) mostly occupied the left side of the PCA (average to high scores). The second axis of the PCA separates sites that received high scores with different methods: only forested wetlands received the highest scores with CRAM, whereas MWAM gave high scores to a variety of wetland types, including a meadow (site 5). The PCA on vegetation scores confirmed the trend of all methods to discriminate against meadows (Fig. 5). It also showed that two methods, CRAM and WAFAM, clearly favored forested wetlands.

The overall scores obtained using different methods were significantly correlated (Table 3), except between

Table 2 Site description

Site code	Name	Type	AA (ha)	Vegetation type (Corine biotope Code)	Maintenance activities	BPJ rank
1	Montfort Marsh	DEP	6.5	Eutrophic wet meadow with *Juncus subnodulosus* colonized by *Phragmites* and *Solidago* (**37.2 × 54.2**)	Mowing (once every 2 years)	VII
2	Montfort Meadow	DEP	0.7	Wet meadow with *Filipendula ulmaria*, invaded by *Solidago* (**37.1**)	Grazing	VI
3	Chapareillan Riparian Forest—Isère side	RIV	2.8	Willow stands, dominated by *Salix alba* (**44.13**)	–	IV
4	Chapareillan Riparian Forest—Chartreuse side	DEP	1.7	Willow & Poplar stands with S*alix Alba, Populus alba*, *P. nigra* and *P. tremula* (**44.1**)	–	IV
5	Moïles Wet Meadow	DEP	6.2	Eutrophic wet meadow with *Juncus articulatus* and patrimonial species such as *Orchis palustris* and *Senecio paludosus* (**37.21**)	Mowing (once/year)	V
6	Moïles Meadow	DEP	2.2	Mesophile pastures with poaceae and semi-ruderal species (*Plantago major, Lampsane communis…*) (**38.11**)	Grazing	III
7	Loyes Riparian Forest	RIV	0.4	Willow stands (**44.1**)	–	VI
8	Loyes Reed bed	RIV	0.8	Reed bed (**53.1**)	–	V
9	Creux Reed bed	DEP	2.9	Reed bed (**53.1**)	–	V
10	Côte Chaude Riparian Forest	RIV	2.3	Ash and alder stands (**44.3**)	–	III
11	Buclet Riparian Forest—Left bank	RIV	1.3	Willow stands (**44.1**)	–	VII
12	Buclet Riparian Forest—Right bank	DEP	13	Ash and alder stands (**44.3**)	–	I
13	Bourg d'Oisans Meadow	DEP	0.2	Oligotrophic wet meadow with *Molinia caerulea* (**37.31**)	Mowing or grazing	II

The type of wetland is either depressional (DEP) or riverine (RIV). To describe the vegetation we used the Corine biotope code: a European typology for natural habitats (European Communities 1991). AA is for "Assessment Area." The best professional judgment rank (BPJ) was based on a general classification provided by a panel of local experts, from I (lowest quality) to VII (best quality). Different sites can have the same rank

CRAM and MWAM (which was consistent with the result of the PCA on overall scores, Fig. 4). Similar results were obtained for the vegetation scores: only CRAM and MWAM were inconsistent. For Hydrology, only DERAP gave significantly different scores; all other methods are well correlated. The PCA on hydrology scores reiterated this result (Fig. 6).

In contrast, scores for Landscape Context ranged widely among RAMs: only the scores given by CRAM and ORAM were well correlated ($r^2 = 0.67$, $P < 0.001$). The scores from UMAM and WAFAM were also correlated, but the relationship was weaker ($r^2 = 0.48$, $P = 0.09$). The scores obtained from DERAP were not consistent with any other methods, and MWAM did not give a score for landscape context. This is consistent with the result of the PCA on landscape scores (Fig. 6). While the methods do not agree on which sites should receive the best or the worst scores, the least degraded landscapes (wetlands surrounded by forests and meadows) are grouped on the left side of the first axis (sites 7; 11; 12; 13).

Contributions of Vegetation, Hydrology, and Landscape Context to Overall Scores

Simple regressions between overall scores and scores for vegetation, hydrology, or landscape context showed that for all methods, vegetation and hydrology explained most of the variance of the overall score (Table 4; the results for WAFAM were not presented because this method had no overall score). The exception was DERAP, where hydrology had no significant relationship with the overall score. Only DERAP and UMAM show a significant relationship between landscape scores and the overall scores.

Results from the stepwise regressions showed that, for all methods except UMAM, vegetation alone explained 87 % or more of the variance of the overall score (Table 4). In the case of UMAM, hydrology explained 92 % of the variance of the overall score. As a consequence, adding another component of the overall score explained only slightly better its variance. Indeed, scores given to hydrology and vegetation are correlated in all methods except DERAP (Table 5).

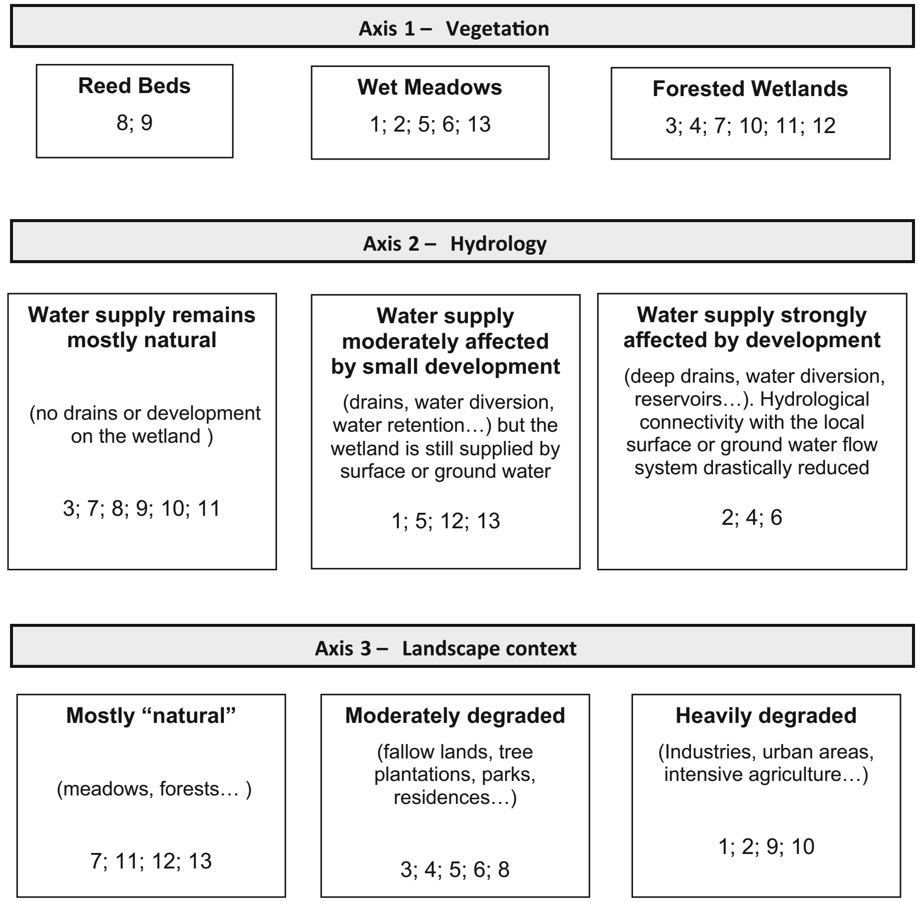


Fig. 2 The study sites have been selected among three types of habitats and along two gradients of degradation: Landscape and Hydrology. The *numbers* are the sample site identification codes (cf. Fig. 1)

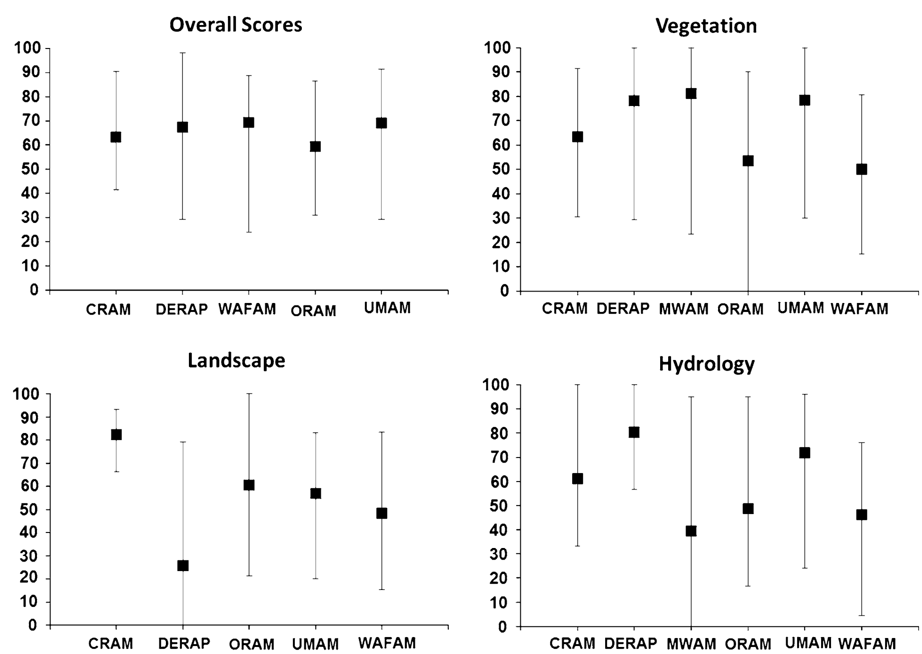


Fig. 3 Mean score attributed by different RAMs to vegetation, hydrology, landscape, and overall score. The *square* represents the mean score; *whiskers* represent the minimum and maximum scores

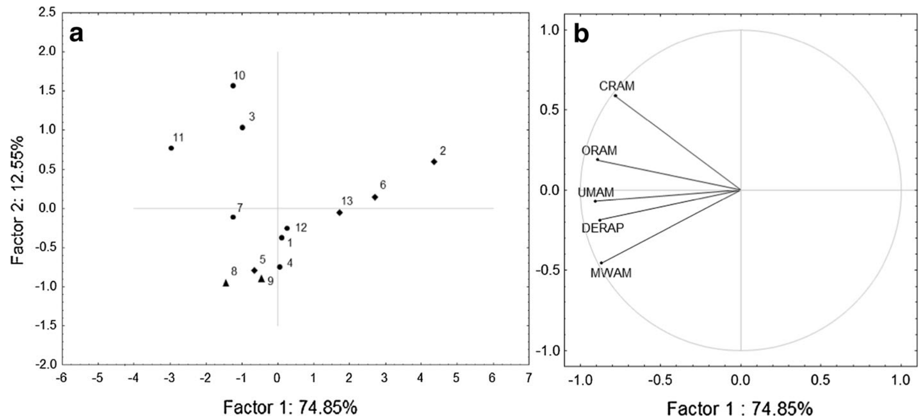


Fig. 4 PCA on overall scores obtained for 13 sites using five different rapid assessment methods (RAMs). **a** Projection of the wetlands on the first two axis of the PCA, *dots* are forested wetlands, *diamonds* are wet meadows, *and triangles* are reed beds. **b** Projection of the RAMs on first two axis of the PCA

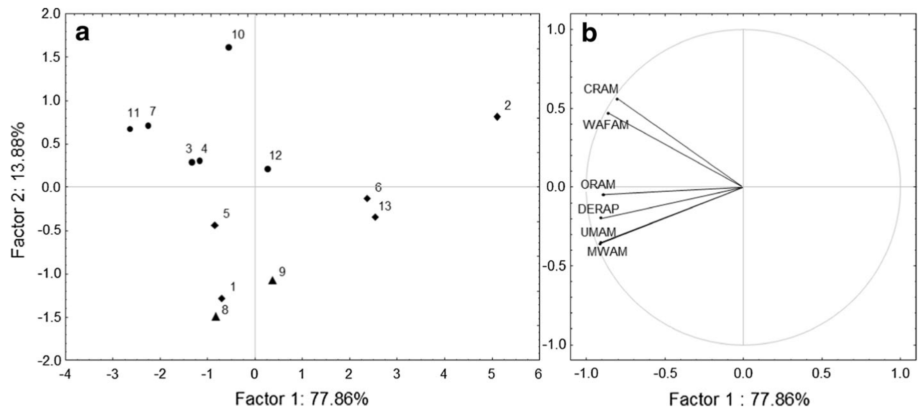


Fig. 5 PCA on vegetation scores obtained for 13 sites using 6 different rapid assessment methods (RAMs). **a** Projection of the wetlands on the first two axis of the PCA, *dots* are forested wetlands, *diamonds* are wet meadows, *triangles* are reed beds. **b** Projection of the RAMs on first two axis of the PCA

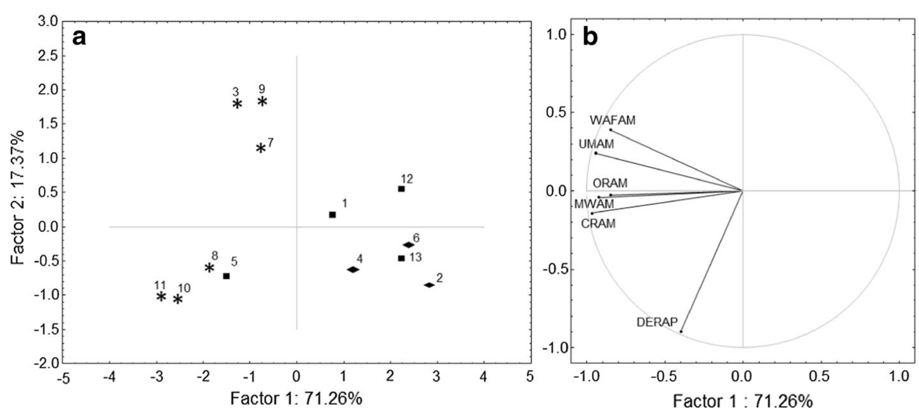


Fig. 6 PCA on hydrology scores obtained for 13 sites using 6 different rapid assessment methods (RAMs). **a** Projection of the wetlands on the first two axis of the PCA. The *marker's shape* indicates the BPJ classification of the site regarding hydrology: *stars* are wetlands with mostly natural water supply, *squares* are wetlands where the water supply was moderately affected by small development, and *diamonds* are wetlands where the water supply was heavily affected by development. **b** Projection of the RAMs on first two axis of the PCA

Consistency Between Scores and Local Ranking of Wetlands

A panel of local experts was consulted to position 13 wetlands on a gradient of hydrological and landscape conditions (Fig. 1), and to rank them from "best quality" to "poorest condition" (Table 2). The PCA on hydrology scores showed that the gradient identified by local experts was consistent with the gradient detected using the tested methods (Fig. 6). Indeed, all the sites considered in good hydrological condition by local experts also have higher RAM scores (left side of the first axis of the PCA), and all

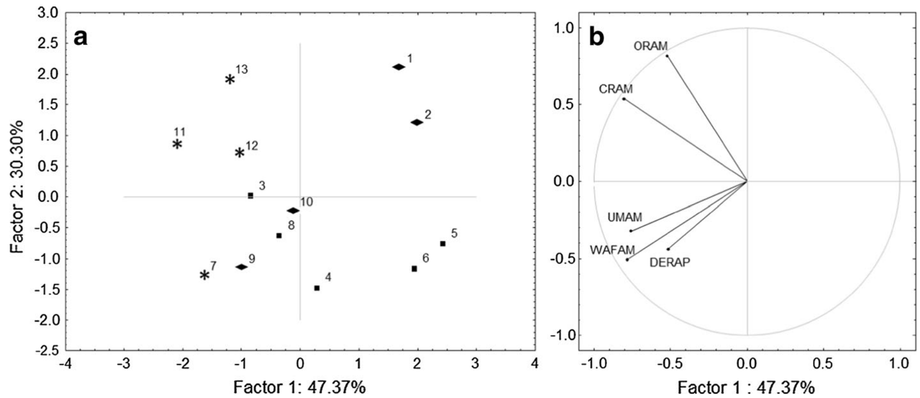


Fig. 7 PCA on landscape scores obtained for 13 sites using 5 different rapid assessment methods (RAMs). **a** Projection of the wetlands on the first two axis of the PCA. The *marker's shape* indicates the BPJ classification of the site regarding the landscape context: *stars* for wetlands surrounded by mostly "natural" ecosystems (forests, meadows), *squares* are wetland surrounded by moderately disturbed landscape (fallow lands, tree plantation, residences…), and *diamonds* are wetland surrounded by urban areas, industries, or intensive agriculture. **b** Projection of the RAMs on first two axis of the PCA

Table 3 Correlation matrix of the scores obtained using different methods

	CRAM				ORAM				UMAM				DERAP				MWAM			
	OS	H	L	V	OS	H	L	V	OS	H	L	V	OS	H	L	V	OS	H	L	V
ORAM	*	**	*	*																
UMAM	*	**	ns	*	*	*	ns	*												
DERAP	*	ns	ns	*	*	ns	ns	*	*	ns	ns	**								
MWAM	ns	**	–	ns	*	*	–	*	*	**	–	**	*	ns	–	**				
WAFAM	–	*	ns	**	–	*	–	*	–	**	*	*	–	ns	ns	*	–	*	–	*

Correlation was measured on Overall score (OS), Hydrology (H), Landscape (L), and Vegetation (V). * when $P < 0.05$, ** when $P < 0.01$, ns when correlation is not significant. MWAM does not measure Landscape. WAFAM gives no Overall score

Table 4 Results of the forward stepwise regression analysis done to analyze the effect of the different components evaluated (vegetation, hydrology, and landscape) on the overall score of the wetlands for each RAM

Predictive variable	Step	Multiple *R* stepwise	Multiple *R* square stepwise (simple regression)	*R* square change	*F*	*P*
CRAM Veg	1	0.87	0.76 (0.76**)	0.76	34.25	0.0001
CRAM Hydro	2	0.94	0.89 (0.64**)	0.13	11.98	0.0061
CRAM Landscape	3	0.97	0.94 (0.17^{ns})	0.05	7.99	0.0198
ORAM Veg	1	0.86	0.74 (0.74**)	0.74	31.68	0.0002
ORAM Landscape	2	0.96	0.93 (0.14^{ns})	0.19	26.23	0.0004
ORAM Hydro	3	0.98	0.97 (0.64**)	0.04	11.25	0.0085
UMAM Hydro	1	0.96	0.92 (0.92**)	0.92	126.02	0.0000
UMAM Landscape	2	0.98	0.96 (0.56**)	0.04	10.58	0.0087
UMAM Veg	3	1.00	1.00 (0.63**)	0.04	2910	0.0000
DERAP Veg	1	0.87	0.76 (0.76**)	0.76	34.57	0.0001
DERAP Hydro	2	0.96	0.91 (0.11^{ns})	0.16	18.26	0.0016
DERAP Landscape	3	0.98	0.96 (0.38*)	0.04	9.26	0.0139
MWAM Veg	1	0.96	0.93 (0.93**)	0.93	138.70	0.0000
MWAM Hydro	2	0.98	0.95 (0.47*)	0.03	5.87	0.0359

The results of simple regressions (r^2) between the components and the overall score are also indicated between brackets, * Level of *P* values (* $P < 0.05$, ** $P < 0.01$)

Table 5 Correlation between scores of the RAM components (veg: vegetation structure, hydro: hydrology and landscape)

Method	Scores significantly correlated	r	r^2	P
CRAM	Veg–hydro	0.58	0.33	0.038
ORAM	Veg–hydro	0.63	0.39	0.021
UMAM	Veg–hydro	0.77	0.60	0.002
	Hydro–landscape	0.61	0.37	0.026
DERAP	Veg–landscape	0.69	0.48	0.009
MWAM	Veg–hydro	0.57	0.32	0.043
WAFAM	Veg–hydro	0.65	0.42	0.016
	Veg–landscape	0.70	0.49	0.007

Only significant correlations ($P < 0.05$) are shown

the sites considered in poor hydrological condition by local expert had lower RAM scores. The regression showed that BPJ rating and RAM Hydrology scores were correlated for all methods except DERAP (Table 6).

For the Landscape Context, only one method, WAFAM, showed a significant correlation with BPJ ratings (Table 6) and that relationship was not strong ($r^2 = 0.25$). The only congruence between RAM and BPJ Landscape Context ratings was that they tended to agree on the least disturbed landscapes (sites 7; 11; 12; 13; Fig. 1).

Finally, and importantly, there was no significant correlation between the overall scores provided by RAMs and the overall condition ratings provided by local experts (Table 6). This lack of correlation is because expert opinion favored meadow sites over forested ones. Indeed, focusing on the 3 lowest overall scores, only ORAM and UMAM included a forest among them (site 4), whereas 2 forests (sites 10 and 12) and 1 meadow (site 13) are considered as low quality wetlands by local experts. At the other end of the gradient, two meadows (sites 1; 2) and one forest (site 11) were considered as the highest quality by local experts, when only MWAM included a meadow in the best scores (site 5). One site in particular (site 2) was classified as the most degraded by all rapid assessment methods yet received one of the highest ranks from local experts as 2nd best wetland. These results reveal a real challenge in "importing" these US methods to the French context, which we discuss below.

Discussion

The methods tested in this study were developed in specific geographical areas, in response to local socio-economic, ecological, and regulatory circumstances in the US. They were not developed for the type of wetlands sampled in this study. Moreover, although the reproducibility of the scoring was assessed through repeated multi-assessor trials (unpublished), the methods were tested by a single evaluator who was not formally trained by an agreed institution in the use of these methods (we used the manual provided by each method). Despite these limits, applying six US rapid assessment methods in a novel situation, in France, provided a means of exposing the underlying assumptions and workings of each. It has generated several results which we discuss below.

Selected Rapid Assessment Methods were Consistent in Their Overall Ranking

The different RAMs enabled study sites to be ranked. Meadows disconnected from the natural water flow system had the lowest scores with all methods. Highest scores, however, depended on the method used: CRAM clearly favored forested habitats (the highest overall scores were attributed to 3 forested wetlands), while MWAM gave high overall scores to very different vegetation types. In fact, MWAM was the only method that gave a high overall score to a meadow (site 5). A closer look at the way vegetation was scored by these different methods provided insights on these differences. In both CRAM and MWAM, the number of plant layers was one of the indicators used to score vegetation. However, in CRAM (for riverine and for depressional wetlands), a higher number of plant layers led automatically to a higher score, whereas in MWAM the number of plant layers was considered relative to the potential of the wetland. Nevertheless, wetlands where the number of plant layers was artificially maintained low through management practices, such as tree cutting or mowing to prevent shrub encroachment or spontaneous afforestation, received a lower score from both methods.

Table 6 Correlation between scores given by RAMs and BPJ rating

Method	Hydrology			Landscape			Overall score		
	r	r^2	P	r	r^2	P	R	r^2	P
CRAM	**0.72**	**0.52**	**0.0057**	0.19	0.11	0.1412	0.01	−0.08	0.7434
ORAM	**0.77**	**0.60**	**0.0020**	0.13	0.05	0.2311	0.08	−0.00	0.3456
UMAM	**0.87**	**0.75**	**0.0001**	0.15	0.08	0.1873	0.06	−0.02	0.4065
DERAP	0.02	0.00	0.9576	0.03	−0.06	0.5600	0.04	−0.05	0.5022
MWAM	**0.69**	**0.47**	**0.0095**	–	–	–	0.05	−0.03	0.4524
WAFAM	**0.81**	**0.66**	**0.0007**	**0.31**	**0.25**	**0.0490**	–	–	–

Bold is used for significant correlations ($P < 0.05$)

Hydrology scores were very consistent across RAMs, except DERAP, which was based on the identification of stressors and how these impaired the functioning of the wetland. The same stressor could have little or large impact depending on the type of wetland. The lack of correlation between DERAP scores and other RAMs for hydrology was mainly due to the attribution of a low score to sites 9 and 3 using DERAP, while other methods considered these sites to be in average or good condition. Site 9 was difficult to classify as depressional or riverine due to limited available information. Because of the way the score was calculated, a misclassification could have an important impact on the final score. If site 9 had been classified riverine instead of depressional, its score with DERAP would have been substantially higher and more consistent with other methods. Misclassification problems are a key issue in developing and using rapid assessment methods and our application to wetlands in the Isère watershed clearly illustrated its potential effects on site condition scores.

The scores obtained for landscape context were quite inconsistent across methods, with significant correlations only existing between CRAM and ORAM and UMAM and WAFAM scores. The disparities in scores could be explained by the way landscape context was considered in the methods. Assessment of wetland buffer condition is important to all methods and, in fact, DERAP, CRAM, and ORAM limit landscape assessment to consideration of the surrounding buffer area. On the other hand, WAFAM and UMAM also consider connections and corridors connecting the assessed wetland to other similar habitats. Another distinction among methods is that CRAM and ORAM evaluate the ability of the buffer to protect the wetland from human activity, whereas DERAP lists the stressors (road, development, etc.) that could affect the buffer as well as the wetland. Although the width of buffer considered differs between CRAM (250 m) and ORAM (50 m), the ratings were generally in concurrence. DERAP, with a 100-m wide buffer, gave very different results from the other methods, probably because of different indicators ("stressors") used to describe the buffer. Here again, the choice of indicators was a key determinant of how wetlands were assessed, ranked, and therefore valued in development and mitigation decisions.

Combining Vegetation, Hydrology, and Landscape Context into an Integrated Assessment

Most of the tested RAMs generated consistent scores for vegetation and hydrology, but not for the landscape context. Regressions between the overall scores and the scores obtained for vegetation, hydrology, and the landscape context showed that vegetation and hydrology explained most of the variance in overall scores. The role that landscape factors actually played in these methods was called into question, and this would certainly have to be considered in detail since land-use planning regulations increasingly consider landscape-level connectivity in France (under French law 2009-967 of 03 August 2009). Stepwise regression results showed that scores obtained for either vegetation or hydrology were enough to explain most of the overall score variance. Because changes in hydrology lead to changes in vegetation, a correlation between these scores is inevitable (they were especially strong with UMAM). However, methods should be constructed in a way that each component of the overall score brings in as much unrelated information, to be as comprehensive as possible and to limit redundancies.

Another key finding from this study is that most of the evaluated methods favor sites with vertical vegetation structure, particularly forest vegetation. Moreover, all methods discriminated against wetlands where the number of plant layers was artificially maintained low through management practices. This finding reveals fundamental differences between Europe and the US in terms of both landscape ecology and socio-cultural views of wetlands. In the US, RAM scores are usually somehow tied to a notion of "natural" functioning, with most references alluding to passive maintenance of ecosystem processes in a way that would mirror pre-European settlement conditions. The methodological preference for multiple canopy layers and vertical structure is a reflection of the foundation of US references. Use of a naturalistic-type reference is problematic in France, however, because many highly desirable and valuable wetland habitat types are sustained solely through active maintenance. This is particularly the case with meadows that are regularly mowed to avoid invasion by trees, for fodder or, in a conservation context, to favor animal and plant species associated with herbaceous vegetation. If assessment methods assign higher scores to "pristine" or "old growth" vegetation types, then most maintained meadows are automatically downgraded.

The case of site 2 (Montfort Meadow) illustrates the conundrum of using naturalistic references in the assessment of wetlands in France. At this site, invasive plants dominated the vegetation, it has been drained and separated from the river by levees, and it is set in an unfavorable landscape context. For all these reasons, the site was ranked as degraded by all the RAMs tested. Local experts, however, classified it as the second best site. They valued this wetland for its cultural heritage value: it was a rare reminder of past land-use systems from the ninetieth and early twentieth century called "*chantournes*." Moreover, in spite of invasive species, the site was included in a larger group of wetlands that sheltered protected butterfly species (*Coenonympha oedippus*, *Maculinea teleius and Lycaena dispar;* Seigne-Martin et al. 2007). The conjunction of a protected species and cultural value "boosted" the score of the site, locally, despite it being dysfunctional. Thus, we conclude that wetland assessments developed for use in France, and likely other European settings, need to incorporate elements societal value in the site scores in addition to evaluation of ecological integrity or natural functioning.

Applicability of Rapid Assessment Methods to French Wetland Management

The case of the Montfort Meadow (site 2) raises the question of how to consider managed semi-natural ecosystems in assessing wetland condition. The answer to this question is crucial in intensively used landscapes where few wetlands are unmanaged, as this is the case in France where historical practices are often maintained on "protected" ecosystems in order to keep historical landscapes and habitats that would otherwise change (Prins 1998; Fischer and Wipf 2002; Muller 2002; Middleton et al. 2006). Using "pristine" or "old growth" reference conditions is consistent with frequent references to wildness in North America that find less echo in Europe or France (Arnould and Glon 2006; Carrière and Bidaud 2012; Nash 2014). Given the longer land-use history in France, and the different objectives with regard to which functions and which land covers are considered of higher value, the development of wetland assessment methods in France (or Europe) should include careful statements of intent and objectives. It appears that the variables in the set of assessment methods evaluated could be reconfigured to design an appropriate set of metrics that score the field observations to reflect preferences. Not only scientists and managers but also citizens should be consulted to fully comprehend which ecological functions and ecosystem services are valued by the collective populace.

Reference conditions against which to assess wetlands are key elements in the design of assessment methods. For the reasons discussed previously, the "best attainable conditions approach" should be preferred to make up for the lack of pristine wetlands (Smith et al. 1995; Brooks et al. 2013). Another is the reference against which losses and gains are assessed to design and size mitigation and offsets and the set of indicators or proxies used. The capacity of wetland offsets to achieve no net loss has been questioned repeatedly (e.g., Matthews and Endress 2008; Hossler et al. 2011; McLaughlin and Cohen 2013; Strain et al. 2014; Yepsen et al. 2014). Our capacity to restore their complex structure and function has also been questioned (Mitsch and Wilson 1996; Moreno-Mateos et al. 2012). All of these topics should be addressed in the development of a rapid assessment method for wetland functions in France (Quétier and Lavorel 2011; Lavoux et al. 2013; MEDDE. 2014).

Interestingly, none of the rapid assessment methods used in this study focused on the importance of the wetland for the surrounding landscape's value (rather than the opposite), except in the more recent (2012) version of WAFAM. Yet, when a wetland is filled or damaged because of a new development, the consequence of this loss for surrounding similar habitat, and even the possible loss of connectivity between natural habitats at larger spatial scales, should be taken into account (Bruggeman et al. 2005, Bruggeman et al. 2009; Hartig and Drechsler 2009). Also, the size of the buffer and the indicators used varied a lot among methods, leading to different assessments of a same wetland landscape. A possible explanation for this situation could be historic and cultural. Historic because land-use policy and regulations in the US have their origin in local (state or municipal) government. Local regulation (and assessment) of wetlands can still be more stringent than state and national level regulations. Cultural because there is a strong support in the US for protection of the rights of individual landowners, preventing precise delineation of a legal boundary of an individual wetland. These issues probably influenced the details of many US wetland assessment methodologies. This should be kept in mind when developing landscape assessment indicators for a French (or European) method.

In conclusion, this study has shown that American rapid assessment methods cannot be directly transferred to the French context. Some adaptation will be necessary. This would be quite straightforward for assessments of hydrology as these specific indicators are widely shared and scoring appeared to be consistent with current best professional judgment (revealed here by a panel of local experts). Vegetation and landscape context, however, would require substantial reworking to reflect conservation priorities tagged to historical reference conditions that involve intensive management (mowing, grazing, etc.) and a recent focus away from site-based approaches to landscape-level connectivity.

Acknowledgments The authors are very grateful to the local experts consulted as part of this study: Jean-Christophe Clément, Christian Gay, Jacky Girel, Olivier Manneville, and Roger Marciau. We also wish to thank the reviewers for their very helpful comments, some of them now included in the text. This study was funded by the Conseil Général de l'Isère through the Pôle départemental de Recherches sur la biodiversité en Isère. Subsequent analysis was partly funded by the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement 308393 "OPERAs." We also acknowledge funding by the Mission Biodiversité of the Caisse des Dépots et Consignations, the Cluster Recherche Rhône Alpes, and the PIR IngECOTech "Ingénierie et equivalence." LECA and IRSTEA Grenoble are part of Labex OSUG@2020 (ANR10 LABX56).

Appendix

See Tables 7 and 8.

Table 7 Overall scores

Site code	Site	Category	CRAM	ORAM	UMAM	DERAP	MWAM
1	Montfort Marsh	DEP	55.8	66.0	63.3	64.6	75.0
2	Montfort Meadow	DEP	41.6	32.0	29.3	29.3	24.0
3	Chapareillan Riparian Forest—Isère side	RIV	80.2	74.5	80.0	58.2	71.2
4	Chapareillan Riparian Forest—Chartreuse side	DEP	63.8	41.0	58.8	90.2	78.3
5	Moïles Wet Meadow	DEP	56.8	69.0	73.3	68.6	88.3
6	Moïles Meadow	DEP	51.7	31.0	55.0	39.0	46.0
7	Loyes Riparian Forest	RIV	70.3	68.0	86.3	70.3	85.0
8	Loyes Reed bed	RIV/Flat	59.4	67.0	91.3	81.7	88.6
9	Creux Reed bed	DEP	54.5	56.0	82.9	79.1	76.2
10	Côte Chaude Riparian Forest	RIV	90.5	69.5	78.3	79.1	60.0
11	Buclet Riparian Forest—Left bank	RIV	89.7	86.5	86.9	98.4	83.8
12	Buclet Riparian Forest—Right bank	DEP	59.5	61.0	54.7	69.9	74.0
13	Bourg d'Oisans Meadow	DEP	48.3	52.0	59.0	47.6	53.0

Table 8 Hydrology, Landscape, and vegetation scores

Site code	Site	CRAM	ORAM	UMAM	DERAP	MWAM	WAFAM
Vegetation							
1	Montfort Marsh	61.1	60.0	100.0	87.9	96.7	34.6
2	Montfort Meadow	30.5	0.0	30.0	29.3	23.3	15.4
3	Chapareillan Riparian Forest—Isère side	80.5	65.0	90.0	90.9	90.0	65.4
4	Chapareillan Riparian Forest—Chartreuse side	86.1	40.0	86.0	100.0	93.3	61.5
5	Moïles Wet Meadow	59.7	85.0	85.0	76.3	96.7	53.8
6	Moïles Meadow	44.4	15.0	70.0	46.6	63.3	30.8
7	Loyes Riparian Forest	91.6	90.0	91.0	90.9	96.7	76.9
8	Loyes Reed bed	44.5	85.0	95.0	87.7	100.0	42.3
9	Creux Reed bed	41.6	45.0	81.0	94.0	80.0	38.5
10	Côte Chaude Riparian Forest	91.6	70.0	75.0	70.9	66.7	69.2
11	Buclet Riparian Forest—Left bank	91.6	85.0	92.0	100.0	100.0	80.8
12	Buclet Riparian Forest—Right bank	66.7	40.0	68.0	82.8	83.3	50.0
13	Bourg d'Oisans Meadow	33.3	15.0	57.0	58.6	66.7	30.8
Hydro							
1	Montfort Marsh	52.8	46.7	70.0	76.7	10.0	40.0
2	Montfort Meadow	33.3	20.0	24.0	83.3	0.0	20.0
3	Chapareillan Riparian Forest—Isère side	75.0	75.0	92.0	57.5	40.0	69.6
4	Chapareillan Riparian Forest—Chartreuse side	41.6	26.7	53.0	86.7	40.0	35.6
5	Moïles Wet Meadow	84.5	56.7	90.0	93.3	70.0	51.1
6	Moïles Meadow	41.6	16.7	50.0	76.7	0.0	17.8
7	Loyes Riparian Forest	66.7	40.0	85.0	71.2	50.0	76.1
8	Loyes Reed bed	75.0	50.0	96.0	100.0	80.0	73.3
9	Creux Reed bed	58.3	53.3	90.0	56.7	70.0	65.2
10	Côte Chaude Riparian Forest	100.0	95.0	92.0	100.0	60.0	56.5
11	Buclet Riparian Forest—Left bank	100.0	81.7	92.0	100.0	95.0	60.9
12	Buclet Riparian Forest—Right bank	33.3	26.7	48.0	66.7	0.0	30.4
13	Bourg d'Oisans Meadow	33.3	46.7	52.0	76.7	0.0	4.4

Table 8 continued

Site code	Site	CRAM	ORAM	UMAM	DERAP	WAFAM
Landscape						
1	Montfort Marsh	84.3	78.6	20.0	0.0	15.4
2	Montfort Meadow	77.7	64.3	33.0	0.0	15.4
3	Chapareillan Riparian Forest—Isère side	90.2	57.1	58.0	33.3	58.3
4	Chapareillan Riparian Forest—Chartreuse side	77.7	35.7	37.0	66.7	61.5
5	Moïles Wet Meadow	66.2	35.7	45.0	16.7	23.1
6	Moïles Meadow	70.8	21.4	45.0	0.0	46.2
7	Loyes Riparian Forest	85.3	50.0	83.0	33.3	83.3
8	Loyes Reed bed	80.8	50.0	83.0	11.1	53.8
9	Creux Reed bed	80.6	57.1	77.0	79.2	50.0
10	Côte Chaude Riparian Forest	82.9	50.0	66.0	0.0	58.3
11	Buclet Riparian Forest—Left bank	92.9	100.0	75.0	50.0	58.3
12	Buclet Riparian Forest—Right bank	88.1	85.7	48.0	44.2	58.3
13	Bourg d'Oisans Meadow	93.3	100.0	68.0	0.0	46.2

References

Arnould P, Glon E (2006) Wilderness, usages et perceptions de la nature en Amérique du Nord. Annales de géographie 115: 227–238

Berglund J, McEldowney R (2008) MDT Montana wetland assessment method. Prepared for: Montana Department of Transportation Post, Buckley, Schuh & Jernigan, Montana

Brinson MM (1993) A hydrogeomorphic classification for wetlands. Wetlands Research Program TR-WRP-DE-4. US Army Waterways Exp. Station, Vicksburg, MS

Brooks RP, Brinson MM, Wardrop DH, Bishop JA (2013) Hydrogeomorphic (HGM) classification, inventory, and reference wetlands. In: Brooks RP, Wardrop DH (eds) Mid-atlantic freshwater wetlands: advances in wetlands science, management, policy, and practice. Springer, New York, pp 39–59

Bruggeman D, Jones M, Lupi F, Scribner K (2005) Landscape equivalency analysis: methodology for estimating spatially explicit biodiversity credits. Environ Manage 36:518–534

Bruggeman D, Jones M, Scribner K, Lupi F (2009) Relating tradable credits for biodiversity to sustainability criteria in a dynamic landscape. Landsc Ecol 24:775–790

Bull JW, Suttle KB, Gordon A, Singh NJ, Milner-Gulland E (2013) Biodiversity offsets in theory and practice. Oryx 47:369–380

Carrière SM, Bidaud C (2012) En quête de naturalité: Représentations scientifiques de la nature et conservation de la biodiversité. In: Ramiarantsoa HR, Blanc-Pamard C, Pinton F (eds) Géopolitique et environnement: les leçons de l'expérience malgache. IRD Marseille, France, pp 43–71

Clement JC, Pinay G, Marmonier P (2002) Seasonal dynamics of denitrification along topohydrosequences in three different riparian wetlands. J Environ Qual 31:1025–1037

Comité de Bassin Rhône-Méditerranée (2009) Programme de mesures. Le SDAGE 2010-2015 du bassin Rhône-Méditerranée. Vers le bon état des milieux aquatiques, directive cadre européenne sur l'eau. Agence de l'eau Rhône-Méditerranée DR-A, Office national de l'eau et des milieux aquatiques, Délégation régionale Rhône-Alpes, Bassin Rhône-Méditerranée

CWMG (California Wetlands Monitoring Workgroup) (2012) California Rapid Assessment Method (CRAM) for Wetlands and Riparian Areas. Version 5:2

DREAL (2006) Inventaires départementaux des zones humides de Rhônes-Alpes. http://www.zoneshumides-rhonealpes.fr/index.php/linventaire

EPA (2006) Application of elements of a state water monitoring and assessment program for wetlands. U.S. Environmental Protection Agency. Wetlands Division OoW, Oceans and Watersheds), Washington. http://www.epa.gov/owow/wetlands/monitor/

European Communities (1991) CORINE Biotopes: the design, compilation and use of an inventory of sites of major importance for nature conservation in the European Community. Report and Manual. Office for Official Publications of the European Communities, Luxembourg

Fennessy MS, Jacobs AD, Kentula ME (2007) An evaluation of rapid methods for assessing the ecological condition of wetlands. Wetlands 27:543–560

Fischer M, Wipf S (2002) Effect of low-intensity grazing on the species-rich vegetation of traditionally mown subalpine meadows. Biol Conserv 104:1–11

Hanson AR, Swanson L, Ewing D, Grabas G, Meyer S, Ross L, Watmough M, Kirkby J (2008) Aperçu des méthodes d'évaluation des fonctions écologiques des terres humides. Série de Rapports techniques no 497. Service canadien de la faune, Sackville, Canada

Hartig F, Drechsler M (2009) Smart spatial incentives for market-based conservation. Biol Conserv 142:779–788

Hicks A, Carlisle B (1998) Rapid habitat assessment of wetlands, macro-invertebrate survey version: brief description and methodology. Massachusetts Coastal Zone Management Wetland Assessment Program, Amherst

Hossler K, Bouchard V, Fennessy MS, Frey SD, Anemaet E, Herbert E (2011) No-net-loss not met for nutrient function in freshwater marshes: recommendations for wetland mitigation policies. Ecosphere 2:art82

Hough P, Robertson M (2009) Mitigation under Section 404 of the Clean Water Act: where it comes from, what it means. Wetl Ecol Manage 17:15–33

Hruby T (2012) Calculating credits and debits for compensatory mitigation in wetlands of Western Washington, Final Report, March 2012. Washington State Department of Ecology Publication

Jacobs AD (2010) Delaware Rapid Assessment Procedure Version 6.0. Delaware Department of Natural Resources and Environmental Control. Dover, Delaware

Johnson BJ, Beardsley M, Doran J (2013) The Functional Assessment of Colorado Wetlands (FACWet) Methodology—Version 3.0. Colorado Department of Transportation. https://www.codot.gov/programs/environmental/resources/environmental-cards/wetlands/01-0010-11.pdf

Lavoux T, Barrey G, Perret B, Rathouis P (2013) Evaluation du Plan national d'action pour les zones humides 2010-2013 (PNZH). Rapport no 008343-01 au Conseil Général de l'Environnement et du Développement Durable (CGEDD), Ministère en charge de l'environnement. Paris, France

Mack JJ (2001) Ohio rapid assessment method for wetlands, manual for using version 5.0. Ohio EPA Technical Bulletin Wetland/2001-1-1. Ohio Environmental Protection Agency, Division of Surface Water, 401 Wetland Ecology Unit, Columbus, Ohio

Maltby E, Acreman MC (2011) Ecosystem services of wetlands: pathfinder for a new paradigm. Hydrol Sci J 56:1341–1359

Matthews JW, Endress AG (2008) Performance criteria, compliance success, and vegetation development in compensatory mitigation wetlands. Environ Manage 41:130–141

McLaughlin DL, Cohen MJ (2013) Realizing ecosystem services: wetland hydrologic function along a gradient of ecosystem condition. Ecol Appl 23:1619–1631

MEA (2005) Millennium ecosystem assessment, ecosystems and human well-being: synthesis. (ed. Press I) Washington

MEDDE (2012) Doctrine relative a la séquence éviter, réduire et compenser les impacts sur le milieu naturel. Ministère de l'Ecologie, du Développement Durable et de l'Energie. Paris, France

MEDDE (2013) Lignes directrices nationales sur la séquence éviter, réduire et compenser les impacts sur les milieux naturels. Ministère de l'Ecologie, du Développement Durable et de l'Energie. Paris, France

MEDDE (2014) 3ème plan national d'action en faveur des milieux humides (2014-2018). Ministère en charge de l'environnement, Paris

Middleton BA, Holsten B, van Diggelen R (2006) Biodiversity management of fens and fen meadows by grazing, cutting and burning. Appl Veg Sci 9:307–316

Mitsch WJ, Wilson RF (1996) Improving the success of wetland creation and restoration with know-how, time, and self-design. Ecol Appl 6:77–83

Moreno-Mateos D, Power ME, Comín FA, Yockteng R (2012) Structural and functional loss in restored wetland ecosystems. PLoS Biol. doi:10.1371/journal.pbio.1001247

Muller S (2002) Diversity of management practices required to ensure conservation of rare and locally threatened plant species in grasslands: a case study at a regional scale (Lorraine, France). Biodivers Conserv 11(1173):1184

Nash RF (2014) Wilderness and the American mind. Yale University Press, New Haven

Pinay G, Clement JC, Naiman RJ (2002) Basic principles and ecological consequences of changing water regimes on nitrogen cycling in fluvial systems. Environ Manage 30:481–491

Prins HH (1998) Origins and development of grassland communities in northwestern Europe. In: WallisdeVries MF, Bakker JP, Van Wieren SE (eds) Grazing and conservation management. Springer, Berlin, pp 55–105

Quétier F, Lavorel S (2011) Assessing ecological equivalence in biodiversity offset schemes: key issues and solutions. Biol Conserv 144:2991–2999

Quétier F, Regnery B, Levrel H (2014) No net loss of biodiversity or paper offsets? A critical review of the French no net loss policy. Environ Sci Policy 38:120–131

Robertson M (2009) The work of wetland credit markets: two cases in entrepreneurial wetland banking. Wetl Ecol Manage 17:35–51

Sabater S, Butturini A, Clement JC, Burt T, Dowrick D, Hefting M, Maitre V, Pinay G, Postolache C, Rzepecki M, Sabater F (2003) Nitrogen removal by riparian buffers along a European climatic gradient: patterns and factors of variation. Ecosystems 6:20–30

Seigne-Martin A, Bernard M, Marciau R (2007) Plan de préservation et d'interprétation du Marais de Montfort 2007–2011 (Commune de Crolles). AVENIR - CREN, Grenoble

Smith RD, Ammann A, Bartoldus C, Brinson MM (1995) An approach for assessing wetland functions using hydrogeomorphic classification, reference wetlands, and functional indices. Wetlands Research Program Technical Report WRP-DE-9. U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS

StatSoft Inc (2004) STATISTICA (data analysis software system), version 7. www.statsoft.com

Stein ED, Brinson M, Rains MC, Kleindl W, Hauer FR (2009a) Wetland assessment debate: wetland assessment alphabet soup: how to choose (or not choose) the right assessment method. Soc Wetl Sci Bull 26:20–24

Stein ED, Fetscher AE, Clark RP, Wiskind A, Grenier JL, Sutula M, Collins JN, Grosso C (2009b) Validation of a wetland rapid assessment method: use of EPA's level 1-2-3 framework for method testing and refinement. Wetlands 29:648–665

Strain GF, Turk PJ, Anderson JT (2014) Functional equivalency of created and natural wetlands: diet composition of red-spotted newts (*Notophthalmus viridescens viridescens*). Wetlands Ecol Manage. doi:10.1007/s11273-014-9362-6

Sutula MA, Stein ED, Collins JN, Fetscher AE, Clark R (2006) A practical guide for the development of a wetland assessment method: the californian experience. JAWRA 42:157–175

Tucker G, Allen B, Conway M, Dickie I, Hart K, Rayment M, Schulp C, van Teeffelen A (2014) Policy options for an EU No Net Loss initiative. Report to the European Commission. Institute for European Environmental Policy, London

UMAM (2004) Uniform Wetland Assessment Method (UMAM) rule. Chapter 62-345, Florida Statutes (F.S.) Florida Department of Environmental Protection

Yepsen M, Baldwin AH, Whigham DF, McFarland E, LaForgia M, Lang M (2014) Agricultural wetland restorations on the USA Atlantic Coastal Plain achieve diverse native wetland plant communities but differ from natural wetlands. Agric Ecosyst Environ 197:11–20