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Original Research Paper

Towards A Rapid and Repeatable Assessment Indicator System for Wetland Ecosystems: Example from the Poyang Lake National Nature Reserve, China

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ABSTRACT

Six wetland sites in the Poyang Lake, the largest freshwater lake in China, were sampled by two observers with different levels of experience following a two-day training workshop for a suite of scientifically defensible, rapid and repeatable indicator system that can serve as a blueprint to be used routinely in the area. A probabilistic random-stratified sampling design was used to select sites to be sampled. Field protocols consisted of different sections including scoring boundary forms, and quantitative ratings. Metric scores were assigned using the ratings for the current state of the wetland, without regard for what the wetland might have been in the past, or what it might become in the future. The variance in observer to observer scoring at each site was used to calculate pooled standard deviations, coefficients of variation, and signal-to-noise ratios for each survey. The results showed that the relationship between pairs of observer scores had little observer bias (rho = 0.845, $p < 0.01$) for all the sites in the surveyed. Training could have had a significant contribution to observer to observer repeatability. We are confident that, as developed, these indicators could be successfully applied for monitoring and assessing wetlands, recognizing that further field testing and verifications are still needed.

INTRODUCTION

Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. They are at least periodical, and the land supports predominantly hydrophytes; the substrate is predominantly undrained hydric soil; and the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season (Cowardin et al. 1979). They are not just valuable and sensitive ecosystems but are also very dynamic and adaptive systems. Because they occupy a transitional position between land and water, wetlands provide unique habitats for a wide variety of flora and fauna (Mitsch & Gosselink 1986). Their roles in providing a wide range of other ecological services are recognized by many workers (Ezcurra 2006, Millennium Ecosystem Assessment 2005, Dugan 1990). By providing these services, well-functioning wetlands can reduce the need for humans to construct alternative infrastructure necessary to provide those services, often at much higher cost (Finlayson et al. 2005, Euliss et al. 2008). The less healthy a wetland is, the less likely it can provide these services to its fullest abilities. Consequently, there has been a worldwide upsurge in efforts to conserve those wetlands that remain intact (Williams 1999, Mitsch & Gosselink 2007) and to remediate those that have been damaged by past human impacts.

Increasingly, it is being recognized that geomorphology (including flow, sediment transport and channel morphology) is an important natural driver of the biodiversity of floodplain wetlands (Kingsford 2006, Rowan et al. 2006). In China for example, the impoldering in the Poyang Lake region presents an important anthropogenic driver of the biodiversity of freshwater/floodplain wetlands, resulting in the decline of biodiversity and even the extinction of some endemic species (Zhao et al. 2005). In the 1990s, the amount of zonal vegetation around the lake decreased due to unregulated logging, construction of embankments and urban development. This directly led to severe water depletion and soil erosion in region (Hu 2001). The loss is a cause of concern to a balanced ecosystem (Schuyt 2005) as it implies that the capacity of the wetland to retain excessive nutrients from agricultural and industrial activities is greatly diminished (Simonit & Perrings 2005).

Nevertheless, wetlands can be sustainably exploited if the dynamics of the conditions and stressors contributing to their degradation are well understood and harnessed appropriately, monitored and assessed. Assessing wetland conditions is a management measure to ensure better conditions and integrity (Karr 1991, Angermeier & Karr 1994, U. S. EPA 2002) of the system. Wetland assessment is the gathering and analysis of information needed for wetland decision-making. Condition can be defined as the relative ability of a wetland to support and maintain its complexity and capacity for self-organization with respect to species composition, physico-chemical characteristics and functional processes as compared to wetlands of a similar class without human alterations.

Numerous methods have been developed to assess wetland condition or function at a variety of spatial scales. Methods best suited to measure condition reflect this by providing a quantitative measure describing where a wetland lies on the continuum ranging from full ecological integrity (or the least impacted condition) to highly impaired (poor condition). A single numeric score is the result. This score is not meant to measure absolute value or have intrinsic meaning, but allow comparisons between wetlands to be made. Assessing the current ecological condition or integrity of an ecosystem requires developing measures of the structure, composition, and function of an ecosystem as compared to reference or benchmark ecosystems operating within the bounds of natural or historic disturbance regimes (Lindenmayer & Franklin 2002, Young & Sanzone 2002). It is equally challenging to develop indices that can summarize the state of ecosystems, cost effective, precised and/or help guide mitigation success or failure. This challenge is part of a larger need to develop meaningful indices of terrestrial and wetland ecological integrity (Andreasen et al. 2001).

Methods that are designed to assess large areas (for example, the Synoptic Approach, Leibowitz et al. 1992), typically produce coarser and more general results than site specific methods, such as either the Hydrogeomorphic Method (HGM) (Smith et al. 1995) or the Index of Biotic Integrity (IBI) (Karr 1981). Methods such as the Wetland Rapid Assessment Procedure (WRAP) (Miller & Gunsalus 1999) and the Descriptive Approach (USACE 1995), are extremely rapid, whereas the Habitat Evaluation Procedure (HEP) (USFWS 1980), the New Jersey Watershed Method (Zampella et al. 1994), and the Watershed Science Approach (WSA, version 3.0) (Collins et al. 1998) are much more time intensive. These methods have been shown to be sensitive tools to assess anthropogenic impacts to wetland ecosystems (Fennessy et al. 1998, Mack et al. 2000).

Rapid assessment methods (RAM) are advantageous in monitoring programs because they require less time in the field and less taxonomic or other scientific expertise than more quantitative methods, leading to significant savings of time and money, and potentially allowing increased sample sizes (Fennessy et al. 2007). Several recent comprehensive reviews of these methods (Bartoldus 1999, Danielson & Hoskins 2003, Fennessy et al. 2004) serve as good starting points for the development of RAM metrics. The Delaware Rapid Assessment Protocol (DERAP, version 2.0, Jacobs 2005) has been identiûed as one of the methods with the potential to measure condition (Fennessy et al. 2007) from a review of forty existing rapid assessment methods. The methods have been identified to be useful for various purposes such as a means to evaluate best management practices, to assess restoration and mitigation projects, to prioritize wetland related resource management decisions, making regulatory decisions, evaluating mitigation compliance, and assessing ecological condition.

However, there is still paucity of literature with regard to a standardized, cost-effective indicator system to assess the status and trends in wetland ecosystems. Limited field testing of assessment methodologies has been cited (Adamus 1992, Lonard et al. 1981) among reasons for the shortcomings of many methodologies. Lack of money and staff time by agencies is the most common reason behind inadequate field testing. A statistically defensible rapid assessment methodology is inevitable to discern the magnitude of the condition and stressors, and, thus, reduce uncertainty about wetland systems. Repeatability testing quantifies the tendency of different people, using a standardized protocol, to independently select the same answers and arrive at the same score when assessing the same wetland. This paper contributes to ûll that gap, to evaluate the conditions and stressors, and propose a suite of scientifically defensible and repeatable indicator system - a Poyang Lake Rapid Assessment Indicator System (PRAIS) that can serve as a blueprint to be used routinely in Poyang Lake and other wetlands. Key questions include:

1. Which are the key stressors impacting the ecological in tegrity of wetlands in the Poyang area?
2. Which sub-lakes are under stress as a result of a combi nation of stressors?
3. What is the robustness (reproducibility and repeatability) of PRAIS and how does it vary with different levels of user experience?

Our approach is similar to the Nanticoke Watershed Wetland Study (Jacobs & Bleil 2007) in that we use metrics to document wetland conditions, but here we bring together biotic with abiotic metrics as part of an overall assessment of ecological condition. We assume that threats to the systems are as specific as possible, and ratings are appropriate for the ecological and biodiversity attributes to be measured, and discuss how our approach can assist the wetland mitigation process.

MATERIALS AND METHODS

Study area: Poyang Lake is the largest freshwater lake in China. It is located in the northern part of Jiangxi Province and lies south of the Yangtze River (latitude 28°222 -29°452 north, longitude 115°472 -116°452 east). The catchment area is 162,000 km^2. The coverage of the lake fluctuates from less than 1,000 km^2 in the dry season to approximately 4,000km^2 in the flood season (Shankman et al. 2006). Temperatures are low in winter (minimum of 5°C) and warm in summer (maximum of 29°C) in July (Wu & Ji 2002). Annual precipitation is 1528 mm with most of the rain falling in the wet season (April through June). It is recharged by five rivers, the largest in-flows being the, Gan and Xiu rivers, both connected to the Yangtse river. Grassland communities growing along the lakes have significant seasonal phenology (Guan 2007). The most common grass vegetation communities are *Carex* (a genus of plants in the family of Cyperaceae), *Miscanthus* and *Cynodon*. *Carex* spp. is the dominant species at lower elevation and has remarkable seasonal phenology, while *Miscanthus sacchariflorus* and *Cynodon dactylon* are at higher elevations (up to 15 m). The major threats to the lake include pollution, floods, erosion, degradation, and eutrophication. The entire watershed is inhabited by over 8-million people (Guan 2007) and the population is still growing.

Assessment area: We chose six wetland ecological systems, all freshwater lakes: the Banghu (7,300 ha), Dahuchi (3,000 ha), Shahu (1,400 ha), Zhonghuchi (600 ha), Xianghu (400 ha) and Zhushihu (200 ha), which partly make up the Poyang Lake National Nature Reserve (Fig. 1).

Visual change detection analysis (Wilkie & Finn 1996) was used as a basic form of change detection. Three satellite images (Path 121; Row 40) corresponding to the rainy season of 1989, a transition period between rainy and dry season, 1999, and dry season, 2005 were used.

Although the number of wetlands was small and represented only one geographical region, they were selected to encompass differences in water regime, land use, and vegetation and were typical of wetlands that will be assessed for regulatory purposes.

Field work and sampling: The field work took place in April of 2010, and was implemented in two phases. All observations at a specific site took place on the same day. Observers received two-day training. The first phase was exploratory; its objective was to observe general characteristics and changes in the entire Poyang wetland biosphere. With the assistance of experts from the Chinese Academy of Science, China University of Geosciences, and the Beijing Forestry University, visual change detection analysis (Wilkie & Finn 1996) was employed and sampling choice and points were unanimously adopted. All secondary data were obtained from the Poyang Lake Hydrogeological Station and the Poyang Lake Reserve. As data gathering and analysis become more sophisticated and complex, the types of information gathering and analysis including sampling assumptions become increasingly important. With this in mind, a probabilistic random – stratified sampling design based on a spatially balanced, generalized random sampling tessellation stratified (GRTS) (Stevens & Olsen 1999) was adopted. GRTS was chosen because it incorporates a hierarchical randomization process to ensure the sample is spatially balanced across the study region; it allows sites to be selected with unequal probability to satisfy the sample size requirements by wetland; it enables dynamic adjustment of sample size (imperfect sample frame formation, subpopulations of interest may change over time); and it accommodates variable inclusion probability (legacy sites, political, economic, scientific reasons affecting site selection). Because area and habitat heterogeneity affect species richness (Craig & Beal 1992), all sites were required to meet the following criteria: natural wetlands, with open water, and a partial or complete vegetation border. Two field observers accompanied by two guards carried out the final survey.

In the second phase, on-site assessment of several wetland quality parameters were recorded using field data forms/field protocols previously designed. The entries consisted of major metrics defining the conditions of the wetland (Table 1).

As earlier indicated, office and field indicators/attributes/ stressors were identified first in the office, using satellite imageries and land-use maps.

1. Method for selecting metrics: Essentially based on secondary data sources including, literature on wetland ecology and function; other rapid assessment methods; peer-reviewed literature; conference proceedings; and monitoring studies.

2. Criteria for selecting ecological indicators: Building upon discussions by Landres et al. (1988), Kelly & Harwell (1990), Cairns et al. (1993) and Lorenz et al. (1999), we decided that our indicator system should meet the following criteria that are easily measured; sensitive to stresses on system; respond to stress in a predictable manner; anticipatory: signify an impending change in the ecological system; predict changes that can be averted by management actions; integrative: the full suite of indicators provides a measure of coverage of the key gradients across the ecological systems (soils, vegetation types, temperature, etc.); have a known response to natural disturbances, anthropogenic stresses, and changes over time; and have low variability in response.

Field assessment and data collection: Field equipments used included GPS, binoculars, camera, datasheets and pencils. A boat was used to facilitate movement from one assessment site/area to another. At each site, each member of the crew: walked at most 25% of the perimeter of each

Table 1: Prais attributes, metrics and stressors.

Habitat stressors	Hydrology stressors	Buffer/Landscape stressors
Pesticides or trace organics impaired (Point source or Non-Point source pollution)	Ditching & Draining	% of assessment area perimeter with 5 m buffer
Garbage/Dumping	Fill & Fragmentation	Average buffer width
Vertical biotic structure	Diking/Restriction	Surrounded developed
Adjacent land use (e.g., grazing, aquaculture, commercial fisheries in AA, etc.)	Point sources	250 m Landscape condition
Percent co-dominant invasive species	Hydrologic alterations	Barriers to landward migration
Percent invasives	Hydroperiod/Channel stability	Landscape connectivity
	Hydrological connectivity	

wetland site, information was recorded independently by the researchers, metric information on the wetland's hydrology, habitat/vegetation composition, buffer and landscape/ surrounding land use were assessed/collected to score variables that were responsive to disturbance. Habitat and hydrology stressors pertained to within the wetland site. Buffer stressors related to the habitat surrounding the wetland. The remainder of the perimeter not walked was visually inspected using satellite imageries and a set of binoculars.

Photos were taken in each cardinal direction and of prominent stressors. The photo number/ID, time and relevant comments were made, and GPS points (UTM coordinates), site name, and date and time were also recorded.

Metric information on the habitat/vegetative structure and species composition, hydrology and buffer/landscape (Table 1) were also collected to score variables that were responsive to disturbance. Disturbances such as grazing, cultivation, pesticides, nutrient loads and anoxia, etc. were also assessed.

DATA ANALYSIS

Scoring procedure: Site score was based on the presence of stressors in three categories: habitat/plant community (within site), hydrology (within site) and landscape buffer (around site). Metric scores were assigned using the ratings for the current state of the wetland, without regard for what the wetland might have been in the past, or what it might become in the future. Field protocols consisted of different sections including scoring boundary forms and quantitative ratings. The attribute scores for the ratings were 3, 6, 9 and 12 (Table 2).

Table 2: Sample rating scale used (ditching, AA only).

Alternative states	Rating (circle one)
No ditching	12
Low ditching	9
Moderate ditching	6
Severe ditching	3

An attribute score of 12 indicated an ''intact'' wetland, and a score of 3, a wetland with reduced functional capacity. For any attribute,

$$\text{Attribute Score} = \frac{\sum_{i=1}^{n} a_i}{12n}, \; i = 1, 2, 3\ldots n \qquad \ldots(1)$$

Where,

a_i is a sub-metric, and

n is the number of sub-metrics (sub-attributes).

The final score is given by:

$$\frac{\left(\left(\frac{(B_a + H_a + HT_a)}{3} * 100\right) - 25\right)}{75} \qquad \ldots(2)$$

Where,

B_a denotes the buffer attribute score, H_a, the hydrology attribute score, and HT_a, the habitat attribute score.

The final score formula is an average of the three (3) attribute scores adjusted to a 0-100 scale (thus the -25/75). Without the adjustment, the minimum score would be 25. Based on this, a final score below 0.5 (classified as poor) is equivalent to a rating of 3 (a wetland with reduced functional capacity), while a final score greater than 0.7 (classified as excellent) is equivalent to a rating of 12 (intact wetlands).

Mapping vulnerable sites: Wetland quality parameters/indicators data obtained from on-site measurement, were tabulated and checked for any errors and inconsistencies. An attribute table for site final scores was created. The satellite image of the assessment area was digitized into different shape files within a GIS framework (ArcGIS v9.3) in order to map and analyze the spatial distribution of wetland conditions.

Repeatability evaluation of indicator system: For many rapid assessment methods, it is likely that observer to observer differences are the major source of variability because

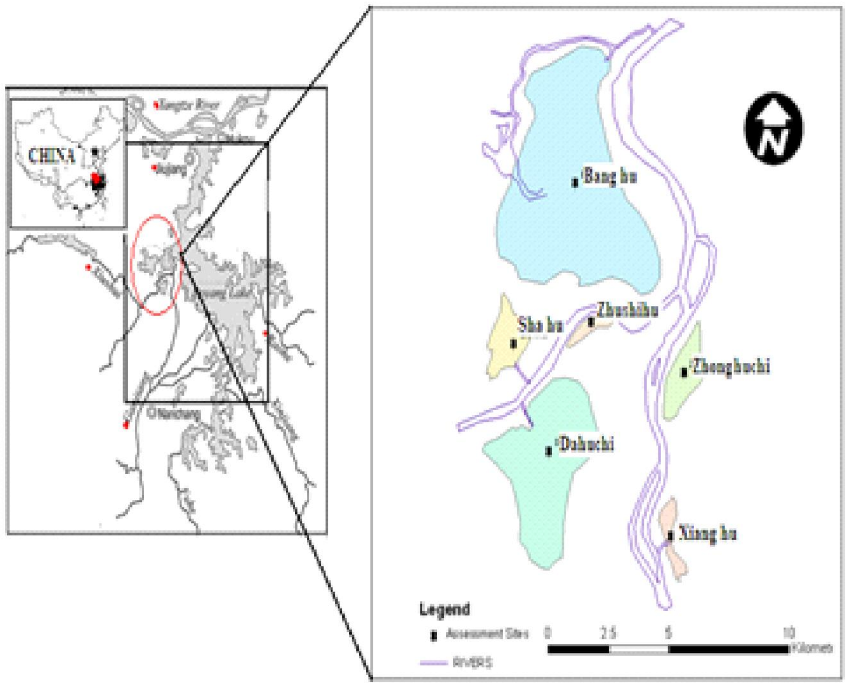

Fig. 1: Study/assessment areas/sites of Poyang Lake Nature Reserve.

many of the metrics in these methods are not affected by temporal changes, e.g., presence of roads. Various factors may affect the repeatability of a rapid method such as temporal changes in site condition during the sampling window or observer to observer variability. However, experience level of observer has little impact on the repeatability of the final rapid assessment score. The two-day seminar/training workshop organized by the staff of the Chinese Academy of Science, Beijing and some university Professors was in part, to improve on the repeatability of our results. The following models were used for repeatability evaluation:

The Spearman's Rank Correlation Coefficient was used to discover the strength of a link between two sets of data/scores for site stressors by each observer. Mathematically, Spearman rank correlation coefficient is denoted and defined as:

$$\rho = 1 - \frac{6\sum d^2}{n(n^2-1)};\ -1 \le \rho \le 1 \qquad ...(3)$$

Where,

$\sum d^2$ is the sum of squares of the differences between scores, 6 is a constant, and n is the number of scores/samples.

A correlation coefficient of closer or equal to +1 means a perfect positive correlation; if 0, then there is no correlation, and if closer to, or equal to -1, it means a perfect negative correlation.

To evaluate repeatability of our indicator system, combined means, pooled standard deviations, coefficient of variations (CV) and signal to noise ratios (S/N or SNR) were calculated for each survey site:

$$\bar{X}_c = \frac{\sum_{i=1}^{k} n_i \bar{x}_i}{\sum_{i=1}^{k} n_i}; \quad S_p = \sqrt{\frac{\sum_{i=1}^{k}(n_i-1)s_i^2}{\sum_{i=1}^{k}(n_i-1)}} \qquad ...(4)$$

Where:

s_p is the pooled variance,
$\bar{X}_C$ is the combined mean,
$\bar{X}_i$ is the mean for the *i*th sample,
n_i is the sample size of the i^{th} sample,
s_i^2 is the variance of the i^{th} sample,
k is the number of samples being combined, and
$n-1$, the Bessel's correction.

The coefficient of variation/relative variability (for non-zero mean) was calculated as:

$$CV = \frac{S_p}{\bar{X}_c} * 100\% \qquad ...(5)$$

The lower the CV, the smaller the residuals relative to the predicted value. This is suggestive of a good model fit.

The Signal-to-noise ratio (SNR or S/N) is a measure often used in science and engineering to quantify how much a signal has been corrupted by noise. It is used here based on the concept that it will be able to correctly determine the differences that exist among sites in a survey, the variance due to performing the assessment (i.e., the noise) must be smaller than the variance across the sites (i.e., the signal). S/N is as the reciprocal of the coefficient of variation (Schroeder 1999). The higher the S/N, the greater the ability to discern differences among sites. In our analysis, the signal was deûned as the variance in total rapid assessment score across all sites. The noise was deûned as the variance (among observer variance) in total rapid assessment score within each site. An S/N ratio equal to 1 indicates that the variance among sites is the same as the variance among observers within a site. Indicators with an S/N ratio less than 1 are not very useful for assessing spatial patterns in site condition.

RESULTS

Overview of the ecological environment in some of the assessment sites: Nonpoint source pollution (NSP) and the dumping of wastes of dead chicken remains from poultry farms by poultry industries are a major risk to the ecological environment. Located at an elevation of 5-15 m, when rain waters wash over such land surfaces, it picks up environmental contaminants that are ultimately deposited in surface water in adjacent lakes and rivers. A consequence is algal blooms. When the algae develop and later dies off, bacteria proliferate with the increase in organic material, using up dissolved oxygen in the water. Low oxygen levels cause further plant and fish deaths, creating an acidic environment unable to support life.

Road construction and biomass accumulation on surfaces of some ponds, but also cattle grazing, fishing, dredging, etc., were common in the assessment area. Road can cause the upland side of a wetland to flood and the downland side to drain, diverting the surface water flow in the process and causing the biological characteristics to change. On the other hand, biomass accumulation of algae often leads to anoxia, which can cause damage to ecosystems and fisheries resources.

Wetland assessment scores: Final average attribute scores for the wetland ecological systems ranged from 0.40 to 1.00 (Fig. 2).

From these scores, a range-based system was used to classify and map the individual systems from Poor (final average attribute score: $R = 0 \leq R < 0.5$ to Excellent (final average attribute score: $R = 0 \leq 0.7$) (Table 3).

Based on our ranking system, the Zhushihu and Xianghu are in Poor ecological conditions while the Dahuchi and Banghu are in Good and Excellent conditions respectively (Fig. 3).

Table 3: Metric rating criteria (vulnerability status of AAS).

Final average attribute score (R)	$0 \leq R < 0.5$	$0.5 \leq R < 0.6$	$0.6 \leq R \leq 0.7$	$0 \geq 0.7$
Rating	Poor	Fair	Good	Excellent

Table 4: Observer variability and signal: Noise ratio (S/N) in rapid wetland assessment scores by stressor category for the six lakes.

	Combined mean	Sp	CV (%)	S/N
Buffer/Landscape	8	1.8	22	4.4 (0.044)
Hydrology	12	2.3	19	5.3 (0.053)
Plant community/Habitat	10	2.1	21	4.9 (0.049)

Repeatability evaluation of indicator system: The relationship between pairs of observer scores was fairly tight and showed little observer bias for all sites in the survey (*rho* = 0.845, p< 0.01-two-tailed).

Among the six lakes surveyed, the Dahuchi Lake had the lowest repeatability (Sp = 3.15 points; S/N = 0.23<1). This indicates that the observer-to-observer difference in the Dahuchi Lake were greater than the differences between sites.

When the total rapid score is broken down into the three individual stressor categories, there was little difference in repeatability between categories. Individual category scores range from 3 to 12 and 1<Sp<2.5 for all three categories (Table 4).

Most of the individual stressors had over 90% between-observer agreement. The stressor associated with the most disagreement between observers (15%) was percent of co-dominant invasive species in the habitat/physical structure category (Table 5).

The presence/absence of garbage/dumping, ditching, fill and fragmentation, and the buffer stressors, all had over 95% agreement between observer pairs at a site.

DISCUSSION

Managers of wetlands would like to know "how their wetlands are doing, where wetlands might be under stress as a result of a combination of factors (abiotic and biotic), and what precautions can be taken to avoid further degradation of the system. In the particular case of the wetland systems assessed in the Poyang lake biosphere nature reserve, it is time management begin taking urgent measures to ensure the security of the Xianghu and the Zhushihu, whose ecological conditions are highly threatened during the dry periods of the year. These ecological systems suffer from human activities resulting from diking and dredging, point

Table 5: Concordance between pairs of observers at each site for individual stressor presence/absence.

	% both observers agree present	% both observers agree absent	% with observer disagree ment
	Buffer/Landscape		
B1: % of AA Perimeter with 5 m Buffer	23	75	2
B2: Average buffer width	15	81	4
B3: Surrounded developed	28	67	5
B4: 250 m Landscape condition	31	67	2
B5: Barriers to landward migration	22	76	2
B6: Landscape connectivity	100	0	0
	Hydrology stressors		
H1: Ditching & Draining	17	79	4
H2: Fill & Fragmentation	23	74	3
H3: Diking/Restriction	37	57	6
H4: Point sources	32	58	10
H5: Hydrologic alterations	19	71	10
H6: Hydroperiod	100	0	0
H7: Hydrologic connectivity	23	65	12
	Habitat/Physical structure		
HA1: Pesticides or trace organics impaired (PS or Non-PS pollution)	17	75	8
HA2: Garbage/Dumping	21	77	2
HA3: Vertical biotic structure	23	65	12
HA4: Grazing in AA	19	68	13
HA5: Percent co-dominant invasive species	20	65	15
HA6: Percent invasives	17	73	10

source pollution, road networks, and human settlement around the lakes. Buildings, roads, and road ditches alter the timing of runoff entering wetlands, and may shift the wetland's predominant source from groundwater to surface water. Even when sewered, residential areas contribute and accelerate inputs of nutrients and contaminants. As human population grows, there is the likelihood of more pressure on the system which may outweigh its carrying capacity.

An ecological condition assessment with a score sheet provides a strong tool for assessment and monitoring, provided that the underlying ecological description/model and threats analyses are well developed, metrics are carefully chosen, data are well-collected, and indicator system simple and repeatable. The indicator system developed for the Poyang Lake can be helpful in encouraging collection of similar data, even when users may need to pick and choose among the metrics provided for each system. Our method, though not too detailed in classification, is relatively simple and can serve a cross section of wetland areas where sophisticated technology is still a liability. Fennessy et al. (2004) are concerned that too detailed a classification will hinder the ability to develop a comprehensive set of metrics for all wetland types, thereby preventing rapid-based assessments from being completed.

Rapid assessment indicator system: The set of indicators specifically developed here are to give rapid and cost effective information to evaluate the potential functioning of natural wetlands in the Poyang Lake biosphere. Using these indicators to assess the functioning of wetlands enabled us to examine how robust the method was across wetland types. These indicators are considered good for rapid assessment of wetlands because, the overall process is indeed rapid, evaluates condition and/or stressors, easy to follow, flexible scoring, provides an overall rating, and easy to calculate the final score. A probable weakness could be that it includes some "value-based" metrics such as presence of rare species which may score wetland higher, but is not necessarily an indicator of condition.

The results show that some of the wetlands are in poor condition as a result of a combination of a number of stressors:

High-density dredging projects are common in the entire wetland. The practice has lead to habitat destruction and can contribute to suspended sediments into waters adjacent to wetlands. Intense boating activity can also increase turbidity and degradation of wetlands. Wetlands can be adversely affected by pollutants released from boats and marinas. Pollutants such as hydrocarbons, heavy metals, toxic chemicals from paints, cleaners, and solvents, which are common in the Poyang wetlands, may gradually build up in high quantities, leading to the death of the local wildlife population.

Dumping of wastes from fish cleaning and discharge of human waste from boats, which are common phenomena, especially in the Zhushihu ecological milieu, can increase the amount of nutrients and organic matter in a wetland. The increased organic matter and nutrients can lead to eutrophication. The wastes from poultry farms could in the nearest future build up unbearable nitrogen pollution. Ammonia emitted from agricultural sources has been implicated in forest decline (McLeod et al. 1990) and species changes in the heathlands of Europe (Van Hove et al. 1987).

Road construction is also another source of stressor. A road can cause the upland side of a wetland to flood and the downland side to drain, diverting the surface water flow in the process and causing the biological characteristics to change. A road can also critically impact the subsurface water flow in a wetland, depressing the water table and affecting the amount of groundwater available (Darnell 1976). This depression can affect many water-dependent fauna and plants. Roads facilitate the alteration of the chemical environment. Highways can introduce oil and heavy metals, such as lead, aluminium and cadmium, which can contaminate a wetland (Adamus & Stockwell 1983). In aquatic environments

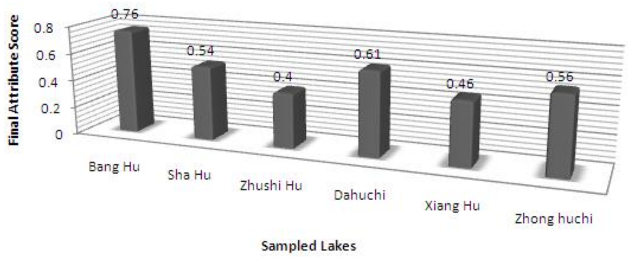

Fig. 2: Final average attributes scores for the different assessment sites.

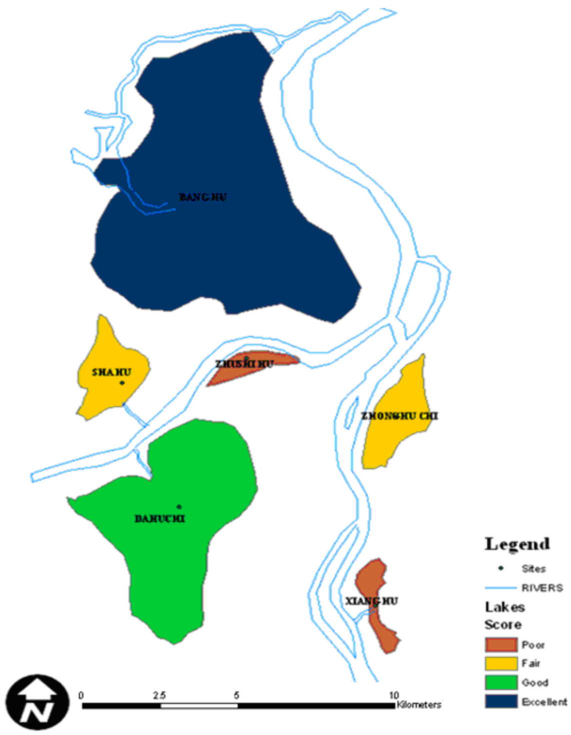

Fig. 3: Vulnerability status of the assessment areas at Poyang Lake.

especially, these contaminants can travel far and fast. Such contamination can have adverse impacts on wildlife.

Non point source pollutants could be seen floating on the surface of most of the lakes. The chicken wastes with foul smell (H_2S) were freshly deposited in the Dahuchi Lake during our investigations. Hydrogen sulphide is not merely a smelly nuisance from stink bombs or rotten eggs, it is a highly toxic gas which interferes with cellular respiration just like carbon monoxide and hydrogen cyanide. It is a potent chemical asphyxiant, combining with haemoglobin in red blood cells and with intracellular cytochromes and thus rapidly stopping oxygen from access to cellular metabolism. The literature on toxic effects of hydrogen sulphide to fish has been reviewed by Adelman & Smith (1970). Smith & Oseid (1972) reported the reduced swimming endurance of bluegill sunfish (*Lepomis macrochirus*) after exposing to 0.04 mg/L H_2S. Even very low concentrations of H_2S are shown to be detrimental to fish eggs, fry and juveniles (Adelman & Smith 1970, Smith & Oseid 1972). Long term exposure of fish to sub-lethal levels can cause slower growth, increase in mortality and reduction in fecundity.

Pesticides: Farmers and gardeners use pesticides and fertilizers to increase production and improve plant growth in the Poyang area. However, their use carries serious environmental risks for wetlands. Pesticides harm wetlands directly by causing immediate plant and fish kill. The effects can linger as increasing bacteria levels from decomposition of dead organic matter rob water resources of dissolved oxygen. Soon, the wetlands become ecological dead zones, unable to support any life, plant or animal.

Hydrologic connectivity between wetlands (for example, Banghu and the Xiu River) and adjacent uplands supports ecological function by promoting exchange of water, sediment, nutrients and organic carbon. Inputs of organic carbon are of great importance to ecosystem function. Litter and allochthonous input from adjacent uplands provide energy that subsidize the aquatic food web (Roth et al. 1996). Similarly, connections with adjacent or upstream/downstream water bodies promote the import and export of water-borne materials, including nutrients. Surface and subsurface hydrologic connections, including connections with shallow aquifers and hyporheic zones, influence most wetland functions. Plant and animal communities are affected by these hydrologic connections. Plant diversity tends to be positively correlated with connectivity between wetlands and natural uplands and negatively correlated with increasing inter-wetland distances (Lopez et al. 2002). Similarly, diversity of amphibian communities is directly correlated with connectivity between streams and their floodplains (Amoros & Bornette 2002). Linkages between aquatic and terrestrial habitats allow wetland-dependent species to move between habitats to complete life cycle requirements. As shown in Fig. 1, these wetlands are recharged by two main rivers. It is, therefore, necessary for management to increase efforts in linking these wetlands, especially those.

Vertical biotic structure: Land managers can use native plants to maintain and restore wildlife habitat.~For instance, on land managed for upland game animals, native warm season grasses (switch grass, coastal panic grass, gamma grass), and other native forbs (butterfly weed) offer good sources of nutrition without the ecological threats associated with non-native forage plants. Dramatic increases in nesting success of both game birds and songbirds have been observed in fields planted with native grasses, which also offer superior winter cover.

The results from this work can be used as a baseline to measure future trends in wetland condition in the Poyang Lake watershed. Changes in wetland condition can be evaluated using landscape assessment methods or repeating an intensive field survey of wetland condition. Landscape models could be used to determine if changes in wetland condition are occurring on the watershed scale based on changes in land use patterns surrounding wetlands (Weller et al. 2007). If landscape changes are found, a more detailed assessment of wetland condition by performing another probabilistic survey using field assessment methods would determine if dominant stressors that are impacting wetlands have changed from previous surveys. Wetland restoration projects should continue to be monitored to determine the functions that they are performing and how these change over time.

Approach to evaluating assessment method: One of the objectives of this study was to examine the utility of the various statistical tools in evaluating the repeatability of our indicator system, PRAIS. The tools we employed, i.e., Sp, CV, and S/N, measure different aspects of repeatability, which was useful in our evaluation of PRAIS.

Sp is an absolute measure of the variation between observers in the same measurement units as the rapid assessment. CV and S/N are relative measures. Both CV and S/N can be misleading as indicators of survey repeatability due to their dependence on the magnitude of the survey mean or amount of variance among sample sites (signal). An indicator can be measured very precisely (low Sp) but if the survey mean is very low you will have a large CV. Similarly, a very precise indicator in a study where all sites have virtually the same value (no signal) will have very low S/N. For example, two observations of Sp and different combined means will obviously have different S/N ratios. Thus, it is important to look at both absolute and relative measures of repeatability when evaluating indicators. Small sample sizes can inûuence the S/N ratio, because the signal may be fairly small due to a restricted sample range.

Kaufmann et al. (1999) reported on the effect of varying S/N on correlations and population statistics on physical habitat indicators in wadeable streams. They note that two perfectly correlated variables (*r* /*rho* = 1.0) will not be perfectly correlated if there is any measurement variability. If both variables have S/N = 10, the theoretical maximum observed correlation coefûcient between them would be 0.91. Similarly, if both have S/N of 2, the maximum (*rho)* would be 0.67 and for S/N of 1, the maximum (*rho*) would be 0.5. Kaufmann et al. (1999) also reported that while varying S/N had no bias on measures of population means and medians from survey data, it did cause increasing bias in other population percentiles with decreasing S/N. S/N>10 had insigniûcant bias on percentiles whereas S/N=1 could overestimate the proportion of sites exceeding criteria values by a factor of 1.5. They believed that metrics or measurements with an S/N<2 were too imprecise to use in surveys designed to quantify proportions of sites within various criteria ranges. In the case of PRAIS, 4<S/N<5 and indicated that it would be a near robust indicator for spatial surveys if both observers were of the same experience level.

It should be recalled that this assessment was carried out without thorough training on the use of the indicator system. However, our indicators were quite simple and easy to understand. This probably explains the reason for the low variability in our results (observer-to-observer) despite the different levels of understandings of wetland ecological systems. We agree with Herlihy et al. (2009) that the experience level of the observer has little impact on the repeatability of the final rapid assessment score, provided effective training and design is undertaken. Information about repeatability can be used in power analysis to detect differences between sites and in trend detection. Additionally, quantiûcation of the repeatability of the method is needed to fully understand and interpret survey results.

Metzeling et al. (2003) have also noted that untrained/ inexperienced/novices can conduct rapid macroinvertebrate assessments and obtain results similar to experts in terms of assemblage ordinations. They also noted that thorough training of crews was essential. In our review of the literature, we found very few studies that quantiûed the observer variability in rapid assessment scoring. This is somewhat surprising, because conûdence in any rapid method requires some system to insure that different users get repeatable and comparable results.

Management implications: When a functional assessment methodology such as PRAIS provides a single score for wetland function, important information could be missed. Two wetlands could easily have the same PRAIS score but for quite different reasons. Understanding why a wetland has a particular score is important from a number of perspectives including resource management, assessing restoration potential, or evaluating temporal trends in wetland function. Each of the variables that are used to derive a single PRAIS score provides important information and insights to wetland function. The importance of paying attention to these variables individually cannot be overstated. Wetlands do not perform all functions equally. Understanding what functions are lacking or have low potential for a wetland certainly provide important information for potential restoration strategies. Low PRAIS scores for these wetlands could mask the success in achieving the desired goals while attention to the individual variables would provide a better indication of whether the wetland had the potential to achieve the desired function. No indication of what factors need to be better managed to improve wetland condition-how would you expect a manager to use the information on wetland condition?

CONCLUSION

This research highlights where wetlands are vulnerable as a result of a combination of a number of key stressors in the Poyang lake biosphere, China and suggests that these stressors are both natural and highly related to human activities. The Xianghu and the Zhushihu are the most highly affected. On the whole, one of the lakes in the assessment area (the Banghu) is in excellent condition, one (the Dahuchi), in good condition, two (Shahu and Zhonghuchi) in fairly good conditions, and two (Zhushihu and Xianghu) in poor condition. This information serves as early warning signs to management, especially as population growth may increase the intensity of stressors on the already degrading systems. There is, therefore, need for a monitoring system to be put in place in order to mitigate probable adverse ecological health situations discussed in this paper. Repeatability was similar across sites. When the total rapid score is broken down into the three individual stressor categories, there was little difference in repeatability between categories.

Information from multiple aspects of the environment is included because of the use of a combination of metrics, it can be used to determine the condition of similar wetlands in that region, the ability to determine which sites are degraded and then conduct further assessments to determine actual causes of degradation, the outcome is quantitative and easy for policy makers and the general public to understand, the method is based on actual attributes of the assemblage evaluated. However, certain challenges remain:

1. The hydrologic and ecological requirements (depth of water, water temperature, salinity, sediment tolerances, vegetative needs, etc.) of many wetland species are poorly understood. Many biological, chemical and physical processes are also only partly understood.
2. There is a need for further field testing of metrics and evaluation of the ability to generalize these results across broad categories of wetlands. The use of more than two trained field investigators (though may not be necessary as they are already trained) could reduce the standard error of the mean likely to be associated with this activity.
3. Because it is difficult to develop real (ratio) numbers in assessing wetlands, our rapid assessment technique utilize non ratio numbers to help assess wetland functions or conditions (e.g., nominal scale 3-12). Though scientifically meaningful, such numbers cannot ordinarily be validly added or subtracted. They are also subject to manipulations and maybe misleading in calculating compensation needs.
4. The numeric estimates PRAIS intends to provide of wetland functions, values, and other attributes are not actual direct measures of those attributes, nor the products of validated mechanistic models of ecosystem processes. Rather, they are estimates of those attributes arrived at by using standardized scoring models that systematically combine well-accepted indicators. Scoring models have not been validated in the sense of comparing their outputs with those from long-term direct measurement of wetland processes. That is the case because the time and cost of making the measurements necessary to fully determine model accuracy would be exorbitant. Nonetheless, the lack of validation is not, by itself, sufficient to avoid use of any standardized rapid method, because the only practical alternative relying entirely on non-systematic judgments or best professional judgment is not demonstrably better in many cases. When properly applied, PRAIS's scoring models and their indicators are believed to adequately describe the relative effectiveness in performing the function.
5. Assessment of many onsite and offsite factors which determine functions and values including overall hydrologic, ecological, social contexts is time consuming, expensive and requires multi-disciplinary expertise. The Poyang wetlands and related resources are complex and large amounts of information are needed to describe relevant plants, animals, soils, geology, hydrology and other features. For example, efforts to assess biodiversity are complicated by the broad range of hydrological niches within a single wetland related to the depth of water, saturation, flooding, soils and plant and animal species. And, these niches shift somewhat throughout a single year and over a period of years as water levels change. This prevents simple characterization of a wetland as a whole without analysis of more specific sub zones within a wetland over time.

Water level fluctuations in the Poyang area also mean that it is difficult to use a single observation of wetland hydrology, plants, and animals to describe or characterize a wetland. Time-series information is needed. Evaluation is also difficult because most wetlands are altered (e.g., partial drainage) and further changes are occurring in water regimes due to manipulation of those regimes (e.g., dredging, dyking) or watershed development). Finally, evaluation of value is difficult because different segments of society feel differently about various functions and attribute change over time.

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