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The Development of a Wetland Classification and Risk Assessment Index (WCRAI) for Non-Wetland Specialists for the Management of Natural Freshwater Wetland Ecosystems

P. J. Oberholster · P. McMillan · K. Durgapersad · A. M. Botha · A. R. de Klerk

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Abstract The Wetland Classification and Risk Assessment Index (WCRAI) is based on manifestations of ecological processes in natural wetland ecosystems. The index is hierarchical in structure and is designed to allow identification and rapid assessment at the broadest levels by non wetland experts in different disciplines to manage natural wetlands. From previous studies, landscape ecology has demonstrated the importance of considering landscape context in addition to local site attributes when explaining wetland ecological processes and ecological integrity. The pressures that land uses and activities exert on wetlands generate impacts that affect both the biotic and abiotic characteristics of the surface water column and the surrounding riparian zone. Therefore, human-altered land in a catchment and spatial patterns of surrounding wetlands provide a direct way to measure human impacts and can be correlated with indicators such as water chemistry and biotic variables. The objective of this study was to develop and test the WCRAI so that the index can be used to classify different types of wetlands and to assess their ecological condition (also known as "Eco-status") under different ecological conditions. The results obtained from the WCRAI were indicative of the integrity of these wetlands when compared to the status of the abiotic and biotic variables measured at each sampling site. From an economical perspective, the WCRAI can play a crucial role in preventing unnecessary degradation of wetlands, hence reducing financial loss through management, restoration, or rehabilitation efforts. The methodology can be applied very easily (due to its simplistic nature) by industry stakeholders to continually monitor these wetlands.

Keywords Wetland classification and risk assessment index · Wetlands · Management · Monitoring

P. J. Oberholster · P. McMillan · A. R. de Klerk (✉)
CSIR Natural Resources and the Environment,
Meiring Naude Road, Pretoria 0001, South Africa
e-mail: adklerk@csir.co.za

P. J. Oberholster
Department of Paraclinical Sciences, Faculty of Veterinary Science, University of Pretoria,
Onderstepoort 0110, South Africa

P. J. Oberholster (✉)
CSIR Natural Resources and the Environment,
Jan Cilliers Street, Stellenbosch 7599, South Africa
e-mail: poberholster@csir.co.za

K. Durgapersad
ESKOM, Research, Testing and Development,
Private Bag 40175, Cleveland 2022, South Africa

A. M. Botha · A. R. de Klerk
Department of Genetics, University of Stellenbosch,
Matieland 7601, South Africa

1 Introduction

Wetlands are also known as "green kidneys" and have diverse ecological attributes and provide important ecosystem services such as water storage, biogeochemical cycling and maintenance of biodiversity and biotic productivity (Stevenson et al. 2002; USEPA 2002). A wetland is defined as land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which under normal circumstances supports vegetation typically adapted to life in water saturated soil. As such, Wetland conservation forms a broader component of the protection of water resources (Winter 1992; Guntensergen et al. 2002).

According to DWAF (2004a), wetlands constitute approximately 6 % of land surface world-wide and they are found in every climate, from the tropics to the frozen tundra. In South Africa alone, as described by Swanepoel and Barnard (2007), 35–50 % of the wetlands was lost or severely destroyed due to unsustainable social and economic pressures where these ecosystems were viewed as excellent systems for water abstraction, drainage, grazing, sewage waste disposal, mining, and cultivation. These natural water resources have been affected by anthropogenic activities such as infrastructure development, industrial effluents, and urban sewage effluents (Oberholster et al. 2008, 2010). With a high rate of human population growth and its accompanying rapidly growing demands on the country's limited water resources, more than one third of South Africa's wetlands have already been destroyed; this figure is expected to increase rapidly in the near future (Breen and Begg 1989).

A commonly used wetland classification index developed by Cowardin and co-workers is comprised of five systems, with further divisions into subsystems that reflect different water regimes (Cowardin et al. 1979). Classes and subclasses were determined on the basis of vegetation and substrate characteristics. This classification scheme of 50 wetland types has been widely implemented and is the official classification scheme used by the United States Wildlife and Fisheries Service and is the basis for the United States National Wetlands Inventory maps. In South Africa, both Morant (1983) and Breen (1988) proposed that the Cowardin system for classifying wetlands can be used, subject to modification of the classification for the purpose of establishing a National Inventory of Wetlands in South Africa. Silberbauer and King (1991) based their classification of wetlands in the south-western Cape Province of South Africa on the Cowardin classification index. Rowntree (1993) also conducted a hydro-geomorphic classification of wetlands in the north-western Cape Province by using the Cowardin classification as a preliminary descriptor for the classification of the studied wetlands. However, later studies that used the Cowardin wetland classification system have noted that the system is difficult to use, particularly in the highly ephemeral wetland systems of the more semi-arid areas of South Africa (e.g., Dely et al. 1999). Therefore, an adaptation of the hydrogeomorphic classification system was proposed in later studies for the palustrine wetlands of South Africa (Jones and Day 2003; Kotze et al. 2005), and a hydrogeomorphic classification system has recently been proposed as the basis for all inland wetland classification in South Africa (Ewart-Smith et al. 2006). Hence, these proposed wetland classification systems need expert knowledge of wetland characteristics and taxonomic proficiency on, for example, aquatic plant species and is therefore not user friendly and difficult to interpret for non-experts from different disciplines (e.g., environmental officers). Furthermore, these proposed classification systems do not include rapid risk assessment features that can be used by non-experts to monitor degradation of wetlands over time and space.

Thus, the objective of the study was to develop a Wetland Classification and Risk Assessment Index (WCRAI) with the following in mind: (a) to determine the influence of various ecological processes in natural wetland ecosystems, for example surface morphology, hydro-chemical characteristics and biological communities; and (b) to design the index in such a way to allow for the rapid assessment of natural wetland ecosystems by non-wetland experts from different disciplines.

2 Materials and Methods

The study was divided into three phases which together aided in determining the characteristics and risk assessment of natural freshwater wetlands to the adverse effects of anthropogenic pollution. In the first phase the required data was obtained through collecting existing literature and used to develop the guidelines.

During the second phase, the index was applied to a set of selected wetlands to evaluate the applicability of the assessment index by selecting three different ecoregions in South Africa based on land use activities. The first ecoregion selected was within the Water Management Area (WMA) of the Olifants River catchment. A number of land and water use activities that take place in this catchment are of strategic importance to South Africa (e.g., mining, agriculture, power generation, industries, etc.). The Witbank coalfield in this ecoregion represent the largest conterminous area of active coal mining in South Africa with a permitted discharge of approximately 50 ML/d of acidic and partly saline mine water into the Olifants River catchment (Maree et al. 2004). A total of 56 % of South Africa's electricity is also produced in this catchment through the use of coal power stations. These activities rely heavily on a variety of goods and services that they derive from the aquatic ecosystems in the area to sustain their processes. The second ecoregion selected was the Waterberg region within the Limpopo Province. This area still contains a relatively high number of natural or near-natural ecosystems with game farming as the predominant land use activity. The third ecoregion was on the Highveld Region of Gauteng. This ecoregion is the industrial hub of South Africa and contributes 34 % to the national economy. These three distinct areas where chosen to show that the proposed index could be validated under different ecological conditions and land use activities, as well as the degree to which the wetlands are impacted.

During the third phase, the data obtained from the various case studies were used to further refine the index and enhance its applicability within different ecological and environmental conditions. The detailed processes that were followed during these three phases are described below.

2.1 Development of WCRAI using Selected Wetland Characteristics

Wetland characteristics used to develop the WCRAI are summarized in Table 1. These include: (a) *Wetland types*—were classified according to a method modified from DWAF (2007); (b) *Landform and hydrology*—are widely acknowledged as the two fundamental features that determine the existence of all types of wetlands since hydrological characteristics indicate the way that water flows into, through and out of a wetland system due to its landscape, terrain and form, whilst landform settings determine the size, shape, and potential depth of the wetlands (Ellery et al. 2005); (c) *Wetland size or scale*—was determined based on the categories, according to the geomorphic scale of Semeniuk (1987), using a 100-m measuring tape and 1: 50,000 map to estimate length and breadth of a wetland area; (d) *Wetland zones*—were used for the determination of the cross-section distances of a wetland (Mitsch and Gosselink 2000) as wetland boundaries may be distinguished by the occurrence of water, or waterlogged soils, or different vegetative types that are typical of water conditions, but it should be noted that the zones used in the selected wetlands do not include forest wetlands. The use of different wetland vegetative types to determine the different zones was done according to Gerber et al. (2004); (e) *Hydroperiod*—is a major component of wetlands and distinguishes the wetland habitat from other terrestrial habitats (Semeniuk and Semeniuk 1995). It is also the single most important factor which influences biological responses by its presence, depth, chemistry and movement. The time period of water availability in a wetland, is directly related to the rates and quantities of precipitation and evaporation, mechanisms of recharge and discharge, and the shape of the wetland. All data generated from the different wetland characteristics under study was incorporated into the proposed field sheet (Fig. 1).

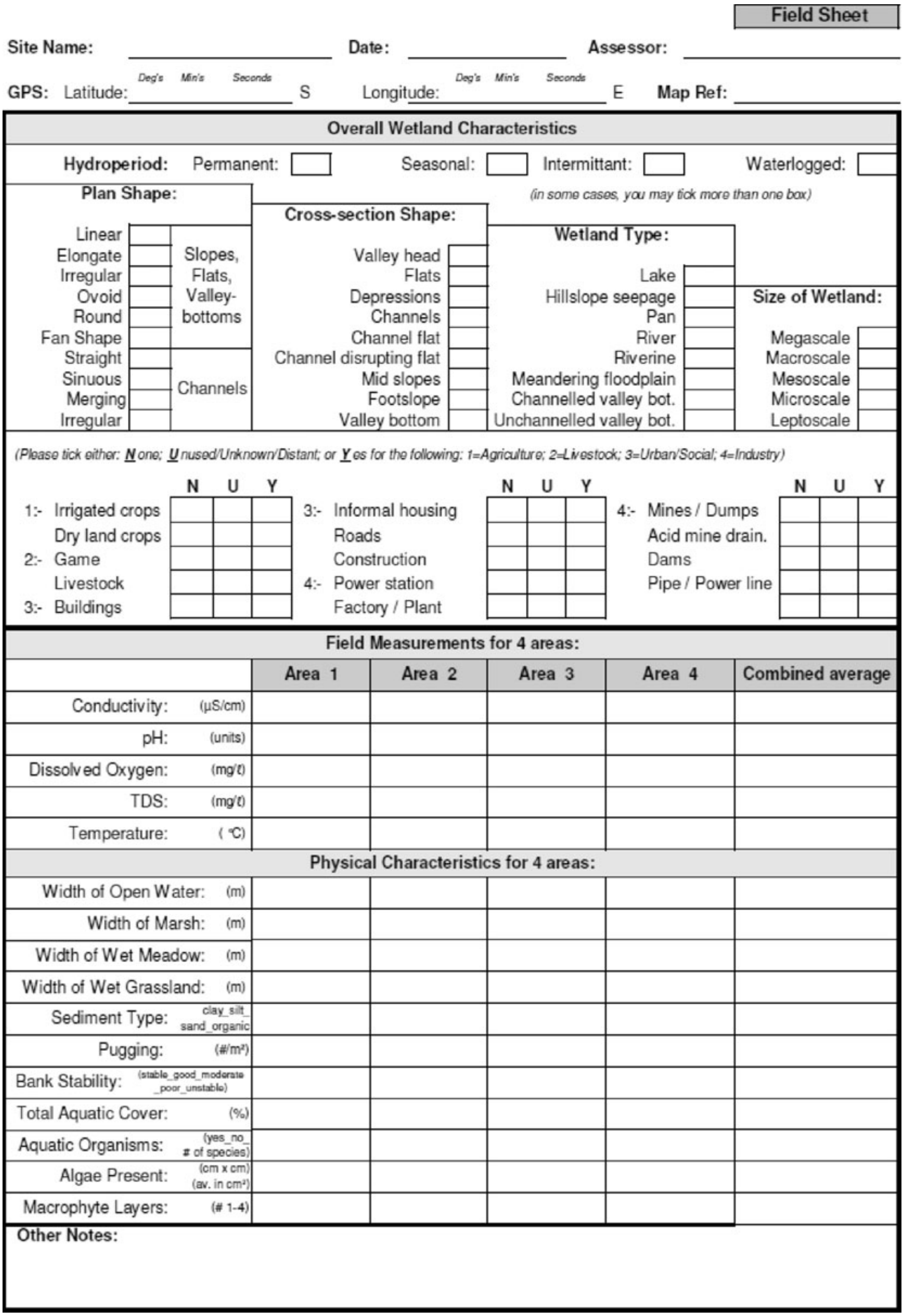
2.2 Rapid Risk Assessment Protocol to Determine the Ecostatus of a Wetland

For the risk assessment and measurements of ecological end points in wetlands, it is necessary to place the risk assessment processes into an ecosystem context in order to identify the key linkages between stressors and wetland responses (DWAF 2004b). This requires an understanding of the three principal factors (ecology, hydrology and geomorphology) that determine the structural and functional characteristics of wetlands, and then using this information to identify the trigger points at which stressors operate to disrupt wetland processes and cause adverse effects. Therefore, one of the most important steps in the development of a rapid wetland assessment module is to identify and confirm clear trigger endpoints with their associated values to set the stage for future risk management efforts. At the wetland scale, the following trigger end points were employed within the different ecological zones and included into the proposed report sheet (Fig. 2).

The Wet Grassland and Meadow Zone (a) Bank stability: An assessment of the degree of bank erosion was followed according to Spencer (1998): 5=stable (the wetland banks are stable and well protected by vegetation cover); 4=good (some minor spot erosion occurring or areas of limited vegetation); 3=moderate (some erosion occurring, spot erosion points are often interlinked, and possibly minor structural and vegetation damage); 2=poor (significant areas of erosion

Table 1 Wetland characteristics used to develop the Wetland Classification and Risk Assessment Index (WCRAI)

Wetland types *Description*:	Landform and hydrology *Description*:	Wetland size *Description*:	Wetland boundary *Description*:	Hydroperiod *Description*:
Lake wetlands: Depressions in valley bottoms, which may be temporarily, seasonally, or permanently, inundated. Unlike pans, they have an outlet at the downstream end that links to a stream or river.	*Flats*—have a slope of <1 %, with little or no relief or diffuse margins.	*Megascale* : more than 10 km×10 km.	*The grassland zone*: is temporarily wet and is usually dominated by a mixture of plant species that may also occur in non-wetland areas, and hydrophyllic plant species that are usually restricted to temporarily and seasonally wet areas.	*Permanently inundated*—permanently flooded, water covers the land surface throughout the year.
Hillslope seepage wetland: Hillslope wetlands are located on the mid and foot-slopes of hillsides and originate w here groundwater emerges. Seepage wetlands are usually connected to valley bottom wetlands or rivers.	*Depressions*—are depressed basin-shaped areas in the landscape with no external drainage. Depressions may be shallow or deep and may have f lat or concave bottoms.	*Macroscale* : 1,000 m× 1,000 m up to 10 km× 10 km.		
Pan: Small depressions with an inward draining f low pattern, and no outflow.	*Channels*—refer to any incised water course. Channels may be shallow or deep but always	*Mesoscale* : 500 m×500 m up to 1,000 m×1,000 m.	*The wet meadow zone*: is seasonally wet and dominated by hydrophyllic plant species (usually sedges and grasses <1 m tall), which are usually restricted to seasonally or temporarily wet areas.	*Seasonally inundated*—surface water is present for extended periods, especially during the early part of the growing season, but is absent in the dry season.
River wetland: Linear, fluvial, eroded landforms that carry canalized f low on a permanent, seasonal, or episodic basis, and include wetland areas within the active channel.	*Channel flat*—comprised of a flat incised by a channel.			
Riverine wetland: Linear strips parallel to a river but are generally separated from the river channel by natural levees.	*Channel disrupting flats*—comprise a f lat that is fed and drained by a channel.	*Microscale* : 100 m×100 m up to 500 m×500 m.	*The marsh zone*: is usually dominated by tall emergent herbaceous plants such as reeds (e.g., *Phragmites australis*) (usually>1 m tall), and consists of permanently or semi-permanently w et areas.	*Intermittently inundated*—substrate is usually exposed but surface water is present at various times with no definite seasonal period.
Meandering Floodplain: Linear, fluvial river with a meandering channel. The meandering channel flows within an unconfined depositional valley, and ox-bow lakes or cut-off meanders are often visible.				
Unchannelled valley bottoms: Linear, fluvial, valley bottom surfaces that do not have any noticeable channels. The valley floor acts as a depositional environment composed of accumulated sediment.	*Slopes*—are areas with a gradient>1 %, which may be either concave or convex.	*Leptoscale* : less than 100 m×100 m.	*The open water zone*: is usually dominated by free-floating plants on the water surface, free floating beneath surface, emergent in substrate with floating leaves, and submerged (anchored in substrate).	*Seasonally waterlogged*—wetland soils that are saturated with water, but where the water does not inundate or cover the soil surface.
Channelled valley bottoms: Linear, fluvial, valley bottom surfaces that have a straight channel which carries water on a permanent, seasonal or episodic basis. No cut-off meanders or ox-bow s are visible.				



Field Sheet

Site Name: ______ Date: ______ Assessor: ______

GPS: Latitude: (Deg's Min's Seconds) ______ S Longitude: (Deg's Min's Seconds) ______ E Map Ref: ______

Overall Wetland Characteristics

Hydroperiod: Permanent: ☐ Seasonal: ☐ Intermittant: ☐ Waterlogged: ☐

(in some cases, you may tick more than one box)

Plan Shape:

Plan Shape		
Linear	☐	
Elongate	☐	Slopes, Flats, Valley-bottoms
Irregular	☐	
Ovoid	☐	
Round	☐	
Fan Shape	☐	
Straight	☐	Channels
Sinuous	☐	
Merging	☐	
Irregular	☐	

Cross-section Shape:

Valley head ☐
Flats ☐
Depressions ☐
Channels ☐
Channel flat ☐
Channel disrupting flat ☐
Mid slopes ☐
Footslope ☐
Valley bottom ☐

Wetland Type:

Lake ☐
Hillslope seepage ☐
Pan ☐
River ☐
Riverine ☐
Meandering floodplain ☐
Channelled valley bot. ☐
Unchannelled valley bot. ☐

Size of Wetland:

Megascale ☐
Macroscale ☐
Mesoscale ☐
Microscale ☐
Leptoscale ☐

*(Please tick either: **N**one; **U**nused/Unknown/Distant; or **Y**es for the following: 1=Agriculture; 2=Livestock; 3=Urban/Social; 4=Industry)*

	N	U	Y		N	U	Y		N	U	Y
1:- Irrigated crops				3:- Informal housing				4:- Mines / Dumps			
Dry land crops				Roads				Acid mine drain.			
2:- Game				Construction				Dams			
Livestock				4:- Power station				Pipe / Power line			
3:- Buildings				Factory / Plant							

Field Measurements for 4 areas:

	Area 1	Area 2	Area 3	Area 4	Combined average
Conductivity: (μS/cm)					
pH: (units)					
Dissolved Oxygen: (mg/ℓ)					
TDS: (mg/ℓ)					
Temperature: (°C)					

Physical Characteristics for 4 areas:

	Area 1	Area 2	Area 3	Area 4	Combined average
Width of Open Water: (m)					
Width of Marsh: (m)					
Width of Wet Meadow: (m)					
Width of Wet Grassland: (m)					
Sediment Type: (clay_silt_sand_organic)					
Pugging: (#/m²)					
Bank Stability: (stable_good_moderate_poor_unstable)					
Total Aquatic Cover: (%)					
Aquatic Organisms: (yes_no_# of species)					
Algae Present: (cm x cm) (av. in cm²)					
Macrophyte Layers: (# 1-4)					

Other Notes:

Fig. 1 The WCRAI fieldsheet used during the assessment of a wetland

Report Sheet

Site Name: ____________ Date: ____________ Assessor: ____________

GPS: Latitude: Deg's Min's Seconds ____________ S Longitude: Deg's Min's Seconds ____________ E Map Ref: ____________

Wetland Category:

Wetland Category Results

Field Measurements:		Field Average	Score Range 4	3	2	1	0	SCORE
Conductivity: (non-pans):	(µS/cm)		0 – 292	293 – 833	834 – 2500	2501 – 5833	> 5833	
Conductivity: (pans):	(µS/cm)		0 – 418	419 – 2450	2451 – 7832	7833 – 11600	> 11600	
pH:	(units)		7.01 – 7.5	6.61 – 7.0	6.21 – 6.6 7.51 – 8.0	6.0 – 6.2	< 6 or > 8	
Diss. Oxygen:	(mg/ℓ)		> 7	5.01 – 7.0	2.01 – 5.0	1.5 – 2.0	< 1.5	
Physical Characteristics:								
Buffer Zone:	(m)		> 30	8 – 30	3 – 7.9	0.5 – 2.9	< 0.5	
Pugging:	(#/m²)		0	1 – 6	7 – 12	13 – 19	> 19	
Bank Stability:	(rating)		Stable	Good	Moderate	Poor	Unstable	
Aquatic Cover:	(%)		41 – 65	26 – 40	5 – 25	> 65	< 5	
Algae Present:	(m²) (cm²)		0	0.01 – 0.1 1 - 1 000	0.11 – 0.5 1 001 - 5 000	0.51 – 1.0 5 001 - 10 000	> 1.0 > 10 000	
Macrophytes:	(# 1-4)		> 3	3	2	1	0	
							Total Score:	
							Percentage:	
							Wetland Category:	

Main land use stressor results

Category		Type	Condition	Score
1:-	Agriculture:	Irrigated crops:		
		Dry land crops:		
2:-	Livestock:	Game:		
		Livestock:		
3:-	Urban / Social:	Informal housing:		
		Buildings:		
		Roads:		
		Construction:		
4:-	Industry:	Power station:		
		Factory / Plant:		
		Mines / Dumps:		
		Acid mine drainage:		
		Dams:		
		Pipe / Power lines:		
Land-Use Impacts score:				

Wetland Classification

Hydroperiod:

Plan Shape:

Cross-section Shape:

Wetland Type:

Size of Wetland:

Fig. 2 The different variable scores obtained from the selected study sites at each wetland under investigation which were incorporated into the report sheet after completion of the field measurements occurring, little vegetation present); 1=unstable (extensive erosion occurring, bare banks, steep or undercut banks). (b) Degree of pugging: The pugging of surface soil by livestock was measured according to Bacon et al. (1994), by using the mean of the number of animal hoof marks in five quadrants (each of one m^2 in area) placed randomly on the sediment surface at the water's edge of a wetland under study. Pugging causes soil compaction, accelerates erosion, lowers water infiltration rates, and leads to a reduction in water storage capacity. (c) Width of fringing vegetation (buffer zone): The mean width of vegetation fringing the wetland was based on visual estimates of the riparian strip using ecological zones at four major cross-section points at each wetland (Bren 1993; Castelle et al. 1994). In the case of wetlands where the sides differed in their degree of steepness, the maximum flood height was used to distinguish between the wetland riparian strip and other floodplain flora. It appears that buffer strips that are less than 5 m wide provide minimal protection to aquatic resources under most environmental conditions; and buffer strips greater than 20 m in width are most frequently recommended as providing the best protection for the physical, chemical and biological components of wetlands (Barling and Moore (1994).

The Open Water and Marsh Zone (a) pH: The optimal water pH range was calculated according to Kalff (2001). The highest score was allocated to a wetland where the pH is neutral (±7). The loss of species richness commences when the pH of wetlands declines below 6.0, although not all taxonomic groups are equally affected. An increase in pH above 8 can cause the development of phytoplankton blooms, such as toxic blue-green algae. (b) Electrical conductivity: wetlands that are seasonally variable in salinity are categorized by the salinity state in which the wetland exists for the major part of the year. Conductivity ranges for this index were based on Hillman (1986) and Crabb (1997). With regard to depressional wetlands (pans), the conductivity categories were adjusted using information from de Klerk et al. (2012), Ferreira (2010), and Grundling et al. (2003). This is due to the fact that the conductivity values in any individual pan varies seasonally, but that real differences can be found between different pan types. Reed pans usually retain high water levels throughout the year due to a strong influence of groundwater; whereas other pan types are subjected to evaporation, evolve, and tend to become more saline. However, for this rapid index, these different pan types are not noted. (c) Dissolved oxygen: The categories for dissolved oxygen concentrations were based on Alabaster and Lloyd (1982), as well as Kalff (2001). (d) Aquatic vegetation cover: The percentage of water surface that is covered with aquatic vegetation including emergent, submerged and floating plants was based on Pressey (1987) and Mitchell (1990). A wetland which is almost or completely covered by aquatic vegetation (e.g., without any visible open water) may be caused by nutrient enrichment. Such wetlands were considered to be in a poor condition and are allocated a low score. An estimate of vegetation cover between 41 % and 65 % was allocated the highest score in this index. (e) Algae as indicator of progressive eutrophication and relative abundance of macroalgae were used to indicate the trophic status of wetlands according to Oberholster et al. (2010) and Oberholster (2011). The categories used for the index were (a) mats of macroalgae present >1.0 m^2=hypertrophic; (b) clumps or mats of drifting macroalgae present (0.51–1.0 m^2)=eutrophic; (c) clumps or mats of drifting macroalgae present (0.11–0.5 m^2)=mesotrophic; and (d) absence of algae mats=oligotrophic.

However, wetlands impacted by acid mine drainage (AMD), as in the case of our study, may have large mats of low pH tolerant filamentous algae at very low water column nutrient levels. A study by Niyogi et al. (1999) showed a strong inverse relationship between deposition of metal oxides caused by AMD and algal biomass. They further observed that algal biomass was undetectable at high levels of hydroxide deposition from AMD, while the chlorophyll *a* concentration reached 80 mg m^{-2} at the lowest levels of ferric hydroxide precipitation. Therefore, in AMD impacted wetlands with low pH values, association needs to be rather made between low pH values and algae mats, than nutrient enrichment. (f) Spatial heterogeneity of macrophytes—the numbers of layers of aquatic vegetation occurring was noted according to Williams (1983) and Oberholster et al. (2010) and included the following five layers of aquatic vegetation: (a) free-floating at surface, (b) free floating beneath surface, (c) in substrate with floating leaves, and (d) submerged (anchored in substrate).

2.3 The Rapid Risk Assessment Matrix

The appropriate steps/instructions to be applied when employing the WCRAI on selected wetlands are summarized in Fig. 3.

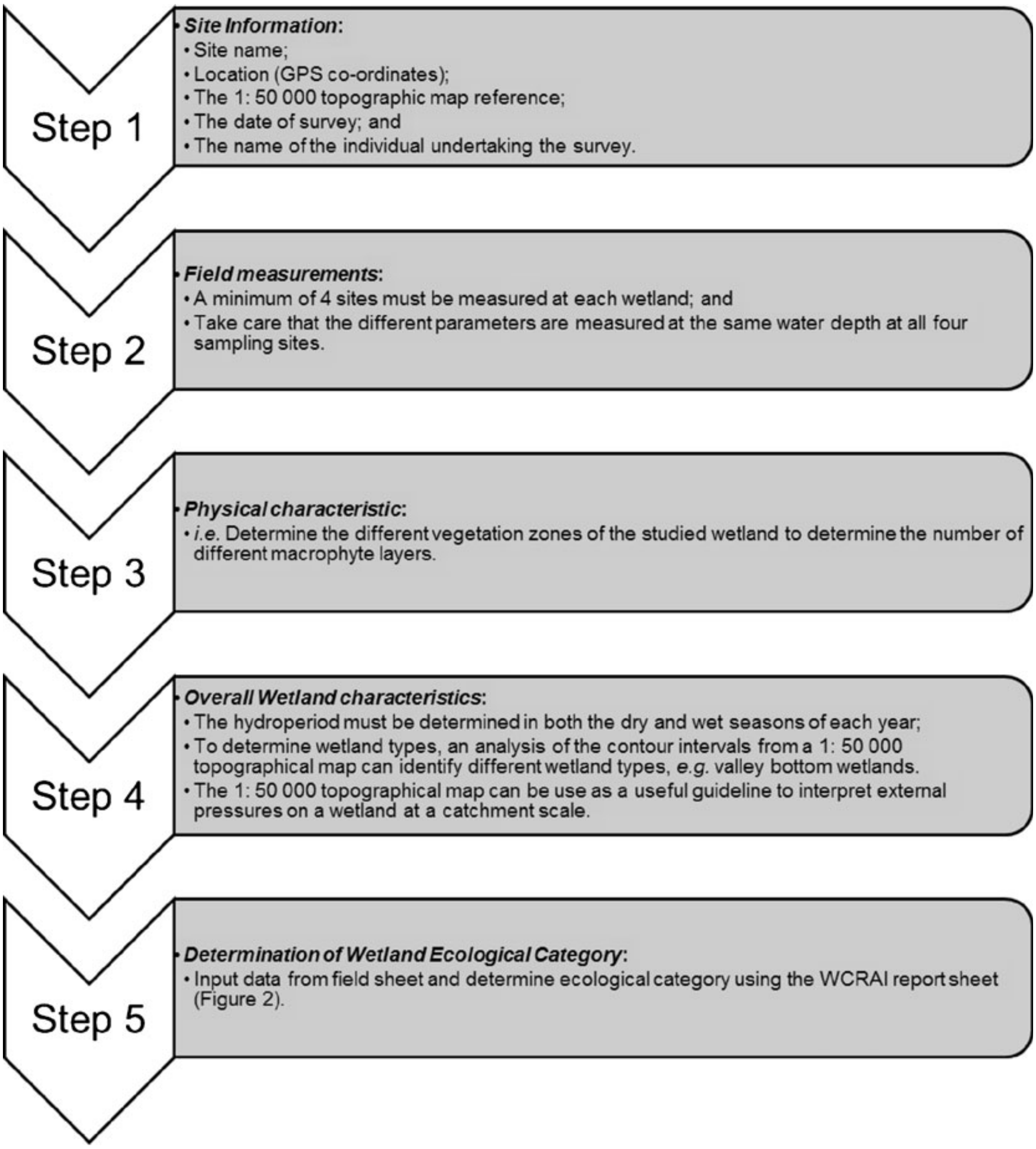


Fig. 3 The appropriate steps/instructions to be applied, or the important information to be gathered when using the WCRAI on selected wetlands

2.3.1 Wetland Variable Scores

The different variable scores obtained from the selected study sites at each wetland under investigation were incorporated into the report sheet after completion of the field measurements (Fig. 2) where an average for each variable of the four selected wetland sites were generated. The sum of the averages of each variable (with a maximum possible total score of 36) was then transformed to a percentage. The percentage outputs were expressed as the standard South African Department of Water Affairs' A–F ecological categories (Kleynhans 1996, 1999; Table 2) and provide a score of the present ecological state or the habitat integrity of each wetland system being examined.

2.4 Land Use Evaluation Criteria

A rapid risk assessment method for scoring land use disturbances on the selected wetlands was formulated as

Table 2 Description of the A–F ecological categories (adapted from Kleynhans 1996, 1999)

Ecological category	Score in percentage (%)	Description
A	90–100	Unmodified, natural
B	80–90	Largely natural with few modifications. A few small-scale changes in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.
C	60–80	Moderately modified. Loss and changes of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
D	40–60	Largely modified. A large loss of natural habitat, biota and basic ecosystem function has occurred.
E	20–40	Seriously modified. The loss of natural habitat, biota, and basic ecosystem functions is extensive.
F	0–20	Critically modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota.

part of this study to prioritize wetland classification in terms of land use impacts (Figs. 1 and 3). The trigger end points with their associated ranking values vary from 0 to 2. The different ranking values were as follows: 0—no direct impacts of land use activities observed in the immediate surroundings of the wetland under study; 1—indirect impacts of land use activities upstream of the wetland's catchment or sub catchment (e.g., possible atmospheric deposition of coal-fired power stations); and 2—direct impact of land use activities in the immediate surroundings of the wetland (e.g., effluent from a wastewater treatment plant). Basic environmental information on the immediate surrounding or catchment and subcatchment of each wetland under study was obtained from current land-use cartography (1: 50,000). We quantified land cover through observations of the immediate area surrounding the wetland as well as on catchment and sub catchment level. Importantly, the ranking values used to determine possible trigger end points or impacts cannot be correlated to the habitat integrity of the wetland under study, but rather give an indicative value of alterations that are occurring in the immediate surrounding or on catchment level. The higher the score, the more likely is the chance that these alterations will have a direct and indirect impact on a wetland under study.

2.4.1 The Validation of the WCRAI

To validate the WCRAI, selected water quality variables were measured and used as indicators of ecosystem integrity within the wetlands selected for the case study so as to compare the spatial results obtained from the WCRAI with those of the water quality parameters from a scientific perspective. The key environmental stressors occurring in the immediate catchment or sub catchment of the selected wetlands varied from untreated sewage outflows from sewage treatment plants, acid rain from industries and coal power plants, acid mine drainage from decanting or abandoned mines, residue from smelters and slime dams, agriculture, and livestock.

3 Results

3.1 Case Studies of Selected Wetlands

The WCRAI data generated from the survey of 29 wetlands conducted from 2008 to 2012 in three different eco-regions with different land use activities indicated that the eco-status of these wetlands ranged from unmodified to largely modified. The results of these assessments are summarized in Table 3. Wetlands in the Mpumalanga and Gauteng regions were categorized as either "Class C" (moderately modified) or "Class D" (largely modified) and their surrounding catchments revealed a wide range of external stressors on the selected wetlands. The single largest stressor impacting these wetlands was salinity, as reflected in the measurement of above average electrical conductivity values (Fig. 4). The increased salinity values have triggered a chain of events that were characterized by an increase in the growth of reed beds to the point where these reed beds dominate the open water zone of many of the selected wetlands. The overgrowth of reed beds in the sampled wetlands affected environmental attributes and biogeochemical processes in a variety of ways, including reduced light availablity to submersed macrophytes, reduced water temperatures due to shading, reduced circulation of the water column with resultant changes to

Table 3 Summary of the ecostatus scores for the 29 wetlands evaluated during the case study period

Wetland no.	Latitude	Longitude	Wetland type	Main landuse stressor	Total wetland category score	Percentage (of maximum possible score; %)	Wetland ecostatus category
1	25° 57′ 32.2″ S	29° 46′ 27.96″ E	River	Power station	26	72	C
2	26° 37′ 13.53″ S	30° 6′ 29.4″ E	Channelled valley bottom	Road	25	69	C
3	26° 46′ 2.88″ S	28° 30′ 22.9″ E	Channelled valley bottom	Slimes	dam	21	58
4	26° 3′ 5.32″ S	29° 35′ 46.96″ E	Hillslope seepage	Road	28	78	C
5	26° 2′ 59.08″ S	29° 36′ 28.44″ E	Channelled valley bottom	Pipeline	19	53	D
6	26° 2′ 42.2″ S	29° 36′ 35.63″ E	Hillslope seepage	Slimes dam	21	58	D
7	26° 1′ 51.39″ S	29° 25′ 15.21″ E	Hillslope seepage	Treatment plant	29	81	C
8	26° 5′ 51.08″ S	28° 57′ 38.59″ E	Channelled valley bottom	Power station	22	61	C
9	26° 14′ 59.44″ S	29° 12′ 9.23″ E	Pan	Power station	18	50	D
10	27° 6′ 13.34″ S	29° 45′ 49.37″ E	Unchannelled valley bottom	Ash dam	22	61	C
11	27° 6′ 41.21″ S	29° 45′ 30.77″ E	Meandering floodplain	Ash dam	24	67	C
12	27° 6′ 26.77″ S	29° 44′ 15.63″ E	Hillslope seepage	Road	26	72	C
13	27° 6′ 47.79″ S	29° 47′ 1301″ E	Hillslope seepage	Railway lines	26	72	C
14	26° 16′ 59.2″ S	29° 9′ 26.5″ E	Pan	Power Lines	22	61	C
15	25° 58′ 15.17″ S	28° 58′ 57.87″ E	Channelled valley bottom	Agriculture	24	67	C
16	25° 51′ 22.58″ S	29° 8′ 4.95″ E	Channelled valley bottom	Acid mine drainage	10	28	E
17	26° 11′ 12.96″ S	27° 41′ 6.92″ E	Lake	Industrial inflow	26	72	C
18	26° 16′ 14.00″ S	30° 8′ 14.05″ E	Pan	Agriculture and livestock	21	58	D
19	26° 12′ 28.44″ S	30°1 2′ 16.98″ E	Pan	Agriculture	29	81	B
20	26° 12′ 49.04″ S	30° 13′ 9.76″ E	Pan	Agriculture	28	78	C
21	25° 46′ 32.56″ S	29° 1′ 23.50″ E	Channelled valley bottom	Acid mine drainage	17	47	D
22	26° 7′ 26.7″ S	27° 40′ 59.8″ E	Hillslope seepage	Acid mine drainage	15	42	D
23	25° 46′ 11.88″ S	29° 28′ 55.29″ E	Channelled valley bottom	Industrial inflow	20	56	D
24	24° 30′ 28.4″ S	27° 52′ 00.0″ E	Hillslope seepage	Game farming	33	92	A
25	25° 53′ 11.36″ S	28° 18′ 20.47″ E	Channelled valley bottom	Waste water treatment plant	20	56	D
26	25° 52′ 21.71″ S	29° 0′ 36.70″ E	Channelled valley bottom	Agriculture	16	44	D
27	26° 16′ 14.94″ S	30° 14′ 31.68″ E	Pan	Livestock	33	92	A
28	26° 10′ 5.50″ S	27° 7′ 22.31″ E	Riverine	Acid mine drainage	19	53	D
29	23° 39′ 13.78″ S	27° 45′ 47.08″ E	River	Sand mining	28	78	C

processes of gas exchange (between water, atmosphere, sediments and plants), material transport (especially particulate material), and increased inputs of detrital carbon.

The spatial variation of the selected water quality parameters are presented in Fig. 4. From these results, it was evident that the conductivity of wetlands 5, 6, and 9 were relatively higher than in the rest of the tested wetlands. pH values also showed an increase at wetlands 5, 9, and 14 relative to pH values measured at wetlands 8, 16, 21, 22, and 28. The low pH ranges were possibly caused by acid rain from the Coal Power Station in the vicinity of wetland 8 and AMD from abundant mines upstream of wetlands 16, 21, 22, and 28. These wetlands impacted by AMD had large mats of green filamentous algae in relationship with low water pH ranges while algae mats were observed in wetland 25 with a pH above 7.8. The latter was possibly due to nutrient enrichment from a sewage treatment plant upstream. Algae mats in wetlands 8, 16, 21, 22, and 28 may be associated to filamentous algae tolerant to low pH values and not due to nutrient enrichment. The dissolved oxygen levels were relatively similar at the respective wetland, while a clear decrease in pH values was noticed at wetland 3. From the results in Fig. 4 it was evident that most of the main variations noticed at the respective wetlands, namely wetlands 3, 5, 6, 9, 16, 21, 22, and 28, with regard to water quality parameters corresponded to a lower eco-status category shown by the WCRAI (Table 3).

During high flow regimes in the summer months, floating macrophytes were removed from some of the selected wetlands, excluding Pan wetlands. Furthermore, higher water levels in the summer months—due to rainfall—caused fringing scores of the selected wetlands to vary as well as water conductivity, especially in the case of Pan wetlands. Higher pugging scores were also observed during the winter months in comparison to the summer months and can possibly be related to more water scarcity for animals in the drier winter months.

4 Discussion

Most of the wetlands sampled in this study can be described as channel reed bed marshes due to the lack of open water zones. The vegetation of the reed bed marshes in this study was dominated by perennial,

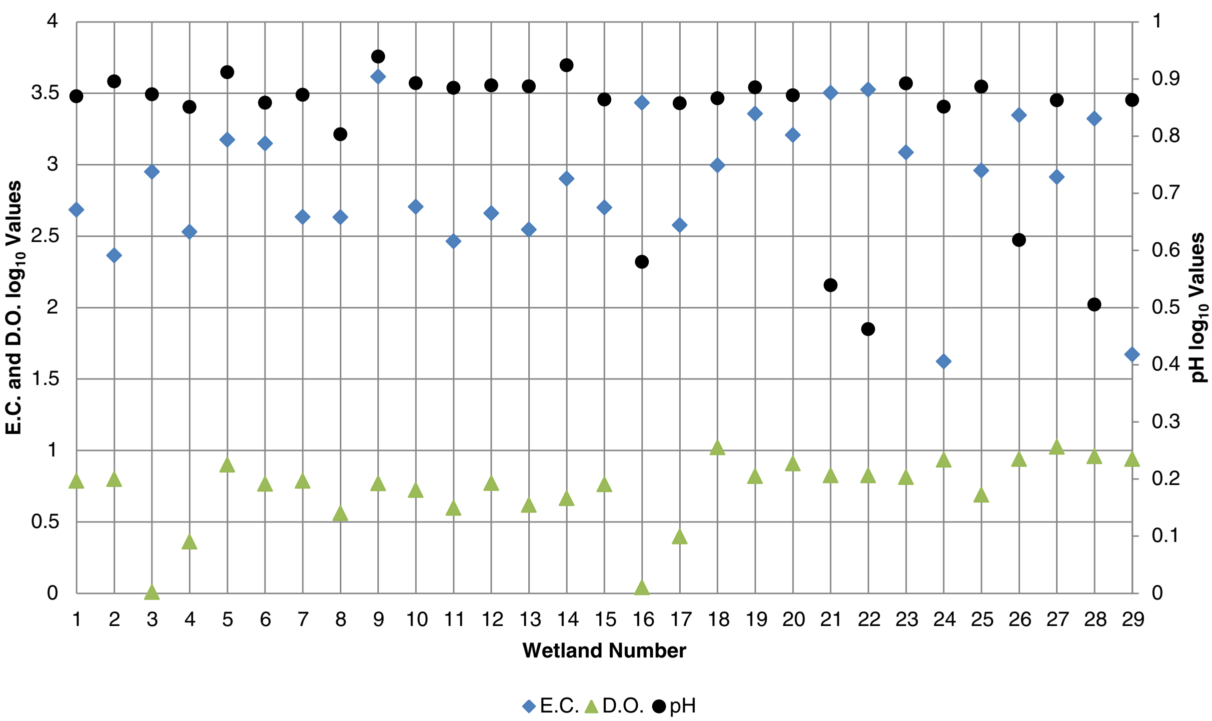


Fig. 4 Spatial changes in selected water quality parameters, namely electrical conductivity (E.C.), dissolved oxygen (D.O.), and pH. Values have been log^{10} transformed

emergent, salt-tolerant aquatic plants (Chambers 1997). Water quality is one of the most important factors which influence an aquatic ecosystem's integrity, as the distribution of aquatic freshwater organisms is controlled mainly by water quality characteristics, including dissolved oxygen and acidity (Dallas and Day 1993). Thus, by using these water quality parameters as indicators of ecosystem integrity one would be able to validate the ecological categories obtained from the WCRAI for a specific wetland. Changes in pH levels of water in unimpacted aquatic ecosystems may impact upon associated biota, whilst changes in electrical conductivity is a useful indicator of changes in dissolved salt loads within a system.

Changes in the various salt concentrations can impact aquatic biota either individually or the entire community structure, whilst microbial and other ecological processes may also be affected. This is especially true for depressional wetlands, namely pans, due to these systems having no outlets, for example, chemicals entering a pan become trapped and can accumulate over time. Pans are also subjected to evaporation and tend to become more saline. Hence, the proper management of these systems is very important (de Klerk et al. 2012). Anoxic conditions can also be lethal to aerobic organisms and many organisms are sensitive to changing dissolved oxygen levels which may result in lethal effects in a short space of time (DWAF 1996). Thus, using these variables one could establish a relative water quality signature of the different wetlands and therefore differentiate between different wetlands based on their respective water qualities. From the results (Fig. 4), it was evident that wetlands 3, 5, 6, 9, 16, 21, 22, and 28 had the worst measured water qualities when comparing all three selected water quality variables to the rest of the selected wetlands. The rest of the wetlands studied were very similar with regard to changes in water quality variables, with only one of the three water quality variables showing some form of impact on certain wetlands. When these results were compared with the ecological categories obtained from the WCRAI, it was evident that wetlands 3, 5, 6, 9, 16, 21, 22, and 28 rated the lowest in terms of ecological categories in comparison to the other selected wetlands. This suggests from a scientific perspective that the ecological categories produced by the WCRAI using the selected input variables produce valid and reproducible results.

A wetland that was totally covered by a reed bed and without an open water zone was likely to be receiving nutrient enrichment and water with high salinity from the surrounding catchment. In order to employ the WCRAI effectively in the field, we recommend that both the chemical and physical attributes of wetland surface water, as well as the biological aspects should be monitored. According to Oberholster et al. (2008), the monitoring of chemical and physical attributes of wetland water is insufficient to assess the health of a wetland ecosystem alone. The main reason for this is our relatively limited knowledge of the specific effects of individual compounds and mixtures of toxic and non-toxic substances on aquatic biota. In addition, chemical monitoring does not account for the variety of man-induced perturbations that influence wetland integrity; these include flow alterations, habitat degradation and removal (destruction) of wetlands, all of which can impair the biological health of a wetland (Roux et al. 1993). Furthermore, although certain previous wetland bioassessment studies have only concentrated on correlation coefficients (r), coefficients of determination (r^2), and statistical significance (p) of correlations, Gernes and Helgen (2002) and Bird (2010) suggested that these values do not provide the full wetland picture for bioassessment purposes and that emphasis should rather be placed on the visual analysis of a site.

The concept of biological monitoring, or biomonitoring, is a product of the assumption that the measurement of the condition (e.g., an increase of filamentous algae which is an indicator of progressive eutrophication in wetlands) can be used to assess the health of an ecosystem (Herricks and Cairns 1982). A large number of substances can contribute to problems in freshwater wetlands, and therefore only monitoring for numerous substances that may produce a toxic risk using traditional physical and chemical analytical methods are not only costly and impractical, but very often ineffective in the detection of the ecological risks. Furthermore, chemical and physical data are biased towards the momentary conditions that exist at the time the sample was collected and many short-term events that may be critical to ecosystem health remain undetected. In contrast, biological monitoring can detect changes in organisms (e.g., the expansion of reed beds) and relate these changes to the effects on environmental conditions. These results help to identify point or diffuse sources of pollution as well as natural causes that may have been responsible for the environmental changes over a period of time (Ten Brink and Woudstra 1991).

Although the present study is designed to allow for the identification and rapid assessment of wetlands at the broadest level by non-wetland experts, it is acknowledged that other more specialized approaches may add value to the results obtained from the WCRAI. Thus, for a more in-depth assessment of the wetland being studied, certain biotoxicity assays and remote sensing techniques can provide useful additional lines of evidence to support the results obtained using the WCRAI. This is because it is well known that measuring only the physical and chemical attributes of water cannot provide the complete assessment of an aquatic system (Oberholster et al. 2008). This is mainly due to our limited knowledge of the effects of various pollutants on aquatic biota. On the other hand, biota is known as accurate indicators of overall environmental conditions, since they are exposed to the totality of adverse effects of chemical and physical influences within the system.

Amphibians, in particular, are sensitive to low pH values and a range of other chemicals and physical stressors in wetlands. Studies by Birge et al. (2000) have also revealed that amphibians as bioindicator organisms are more sensitive than fish that is commonly used in bioassay tests and certain pollutants are known to produce specific malformations in amphibians using biotoxicity assays (Dresser et al. 1992). Wetland vegetation exposed to contaminated water or contaminated soil have also been proven to show certain signs of leaf pigment stress, reduction of nutrients, and growth inhibition (Kooistra et al. 2004; Gardea-Torresdey et al. 2005; Peralta-Videa et al. 2009). Changes in the foliar chemistry of certain vegetation can be correlated with changes in absorption features in the electromagnetic spectrum (Curran 1989). Results from such a field spectroscopy approach and derived spectral vegetation indices may provide another, more in-depth, means of determining vegetation conditions and indirectly wetland condition, but needs specialist expertise (Wu et al. 2007). Both *Phragmites australis* and *Typha capensis* species are capable of growing in polluted water and soil (Bonanno 2011; Rufo et al. 2011; Klink et al. 2013). Globally, these species are known for their potential for bio-indication (Gazea et al. 1996; Tian et al. 2009) and thus may also provide a useful additional line of evidence for the results generated from the WCRAI and can be plotted using a geographic information system.

5 Conclusion

By using water quality parameters and biological indicators of ecosystem integrity, we were able to validate the ecological categories obtained from the WCRAI for a specific wetland. In order to employ the WCRAI effectively in the field, we recommend that both the chemical and physical attributes of wetland surface water, as well as the biological aspects should be monitored. Changes in pH levels of water in impacted aquatic ecosystems may impact associated biota, whilst changes in electrical conductivity was a useful indicator of changes in dissolved salt loads within the different wetland systems. From the information gained through the use of these assessment techniques, compared to those obtained during field surveys, it appears that the WCRAI gave an accurate reflection of the environmental status of the selected wetlands. Furthermore, due to the simplicity of the WCRAI, it can easily be employed by nonwetland specialists (e.g., environmental officers and farmers) to manage wetlands sustainability.

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