Wetlands as early warning (eco)systems for water resource management

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Abstract

This paper describes a case study which investigated impacts of a change in catchment land use from natural grassland to commercial forestry on the hydrological regime and distribution of vegetation in a small hillslope seepage wetland near Nottingham Road in the KwaZulu-Natal Midlands. Hydrological modelling was used to estimate the reduction, following afforestation, in surface and subsurface stormflow runoff provided to the wetland by its catchment. Stormflow runoff was shown to have decreased substantially following afforestation, and since the wetland had no input association with a stream or river, its reliance upon surface and subsurface runoff derived from its catchment was considered to be high. Zones of wetness within the wetland were delineated based on edaphic characteristics. Wetland vegetation was classified, using TWINSPAN, into 7 communities. After comparing the edaphic-defined and floristic-defined boundaries of the permanent to semi-permanent wetland zone it was discovered that the area of permanent to semi-permanent wetland vegetation had decreased from its pre-disturbance (edaphic-defined) extent. Implications for water resources management are considered, with particular attention paid to determining the Ecological Reserve for wetlands, and the potential role that wetlands could play in providing an early warning of hydrological change in a catchment.

Keywords: wetland ecology, delineation, water resources management, Ecological Reserve

Introduction

Due to their dependence on water (Mitsch and Gosselink, 1993; Brinson, 1993), wetlands are highly susceptible to degradation by water-development (Bernaldez et al., 1993, Diederichs and Ellery, 2001), land-surface-development (Gibbs, 2000) and landscape-management (Kotze and Breen, 1994; Whitlow, 1992) practices that alter their hydrological regime (Winter and Llamas, 1993). The historical perception that wetlands were wastelands (Maltby, 1986) has led to the exploitation, alteration and in many cases complete destruction of these valuable ecosystems, with an accompanying loss of associated ecosystem goods and services (Begg, 1986). It is now acknowledged that wetlands perform functions that make these ecosystems invaluable to the management of both water quantity and quality, and wetlands are consequently recognised as integral components of catchment systems (Jewitt and Kotze, 2000; Dickens et al., 2003). As knowledge accumulates around the development, vulnerability and value of wetlands, the call for their increased recognition in water resource management policy and practices becomes ever more strident.

Wetlands are transitional ecosystems (Cowardin et al., 1979) that occur along a soil saturation continuum between the extremes of dry land and permanently flooded areas too deep for emergent plants to grow (Kotze et al., 1994). Consistent with this continuum, wetland ecosystems characteristically display zonation of floristic and edaphic characteristics. The primary driving force behind this zonation is variation in hydro-period; the frequency and duration of saturation (Mitsch and Gosselink, 1993) or degree of wetness (Kotze et al., 1994), over the area covered by the wetland. Three distinct zones that vary in their degree of wetness can be recognised in South African palustrine wetlands based upon edaphic and floristic characteristics: a zone in which saturation is temporary, one in which saturation is seasonal, and one in which saturation is permanent or semi-permanent (Table 1).

As transitional ecosystems, wetlands represent the aquatic edge for many terrestrial biota and the terrestrial edge for many aquatic biota (Mitsch and Gosselink, 1993). Thus, land-use practices that alter the balance between inputs and outputs of water to and from a wetland have the potential to shift the floristic characteristics of wetland zones along the continuum in a temporary/terrestrial or permanent/semi-permanent direction, in the event of water deprivation or addition respectively. While the response of floristic characteristics to a change in the local hydrological regime may be evident after one or two growing seasons, edaphic indicators of wetland environments are the result of many years of regular and prolonged saturation, and will reflect the former hydrological regime long after floristic characteristics have changed to reflect the current hydrological regime. Recognition of a mismatch between floristic and edaphic indicators can therefore be used as an early warning of wetland ecosystem abuse, and catchment water stress.

This paper describes a case of this nature near Nottingham Road in the KwaZulu-Natal Midlands where a small hillslope seepage wetland is located in a micro-catchment approximately 6 ha in extent that feeds a first order stream. Inspection of available aerial photography revealed that, at some point between 1989 and 2002, the landowner established a *Eucalyptus grandis* plantation that replaced all but a small island of the natural grassland that had previously characterised the vegetation of the upper catchment. The remaining island of grassland contained the wetland. Analysis of the floristic and edaphic characteristics of the wetland are used to illustrate how the impact of water deprivation on wetlands can be identified and used as an early warning of hydrological change in catchment management.

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TABLE 1
Edaphic and floristic characteristics of wetland zones in South African palustrine wetlands (after Kotze et al., 1994). For a physical reference to soil colour, see *Munsell Soil Color Charts (2000).*

	Degree of wetness (wetland zone)		
Soil	**Temporary**	**Seasonal**	**Permanent/Semi-permanent**
Soil depth (0-10 cm)	Matrix chroma: 1-3 Few/no mottles Low/intermediate OM Non-sulphidic	Matrix chroma: 0-2 Many mottles Intermediate OM Seldom sulphidic	Matrix chroma: 0-1 Few/no mottles High OM Often sulphidic
Soil depth (40-50 cm)	Few/many mottles Matrix chroma: 0-2	Many mottles Matrix chroma: 0-2	No/few mottles Matrix chroma: 0-1
Vegetation	Predominantly grass species	Predominantly sedges and grasses	Predominantly reeds, sedges and/or bulrushes

OM: organic matter
High OM: soil organic carbon levels >5 %
Low OM: soil organic carbon levels <2 %
Note: Sulphidic soil material has sulphides present which give it a characteristic 'rotten egg' smell

Methodology

Aerial photographic interpretation and field observation were used to describe and classify the hydrogeomorphic setting of the wetland according to the system favoured by Kotze et al. (2005). A longitudinal profile of the valley in which the wetland was situated was plotted using an orthophotograph, to investigate possible geomorphic controls on the formation of the wetland and to add a third dimension to the description of hydrogeomorphic setting. The hydrogeomorphic setting of a wetland describes the geomorphic position the wetland occupies in the landscape (valley bottom, floodplain, hillslope), as well as the nature of flow into, through, and out of the wetland and the nature and connectivity of adjacent associated watercourses (Brinson, 1993; Kotze et al., 2005). The hydrological and geomorphic controls associated with the hydrogeomorphic setting of a wetland are largely responsible for maintaining many of the functional aspects of the wetland ecosystem (Brinson, 1993). In this study, interest in hydrogeomorphic setting was driven by a need to understand more about how afforestation has affected the nature of flow into, through and out of the wetland, and whether this hydrogeomorphic setting would have enhanced or mitigated any effects described.

Very few studies of wetland hydrology have been conducted in South Africa, but hydrological modelling makes it possible to crudely quantify changes in runoff associated with changes in land use. SCS-Based Design Runoff (Schmidt and Schulze, 1987) was used to model the impact of afforestation on water supply to the wetland from its catchment. This model was adapted for South African climate, soil and land use characteristics from the United States Department of Agriculture's Soil Conservation Service model (Schmidt and Schulze, 1987). Its use in this case was considered appropriate for the following reasons:

- The area and average slope of the catchment under investigation fell well within the model's upper limits of 8 km^2 and 30%, respectively.
- The model has been extensively tested in South Africa.
- The equations are relatively easily understood and applied.

Two catchment land-use scenarios were modelled: one that accounted for the land use of the catchment prior to afforestation (land use = grassland, area of grassland = 0.062 km^2), and one that accounted for the land use of the catchment at present (land use = grassland/forestry combination, area of grassland = 0.0096 km^2, area of forestry = 0.0524 km^2). Daily rainfall data supplied by the South African Weather Bureau for Station 02683594 (Cyprus/Mkamazi), approximately 25 km SW of the study site at a similar elevation, for the period 1981 to 2002, were used to calculate the most frequent 24 h rainfall event for the area over a time period spanning both land-use scenarios. This value was used to determine stormflow depth (quickflow or direct runoff response to the rainfall event consisting of both surface and subsurface runoff, but excluding baseflow, Schmidt and Schulze, 1987), given an index describing catchment runoff response characteristics (Schmidt and Schulze, 1987). Stormflow depths for each land-use scenario were calculated and converted to volumes by considering catchment area.

The vegetation of the wetland was sampled in 32 circular plots that were located along five transects, oriented perpendicular to the valley in which the wetland was situated. A plot radius of 2 m was chosen, based on the results of a species-area curve (Mueller-Dombois and Ellenberg, 1974) that was determined prior to the sampling process. Vegetation data were recorded as an estimate of percentage cover for each plant species within each plot. Voucher specimens were taken where *in situ* identification was not possible.

The methodology by which zones of wetness within the wetland were delineated derives its conceptual rationale from the work of Kotze et al. (1994). Delineation involved an assessment of the degree of mottling and measurement of soil matrix chroma using a *Munsell Soil Color Chart* at depths of 0 to 100 and 400 to 500 mm within each vegetation plot. A conventional soil auger was used to obtain samples for assessment. Additional sample holes were augered where plots were spaced too far apart to allow for accurate delineation of a zone of wetness. The relative elevation of each plot (and additional sample holes, where necessary) was surveyed using a dumpy level and staff. The plantation boundary comprised an additional set of survey points.

TWINSPAN, a FORTRAN program for **T**wo-**W**ay **IN**dicator **SP**ecies **An**alysis (Hill, 1979), was used to classify the vegetation into communities. TWINSPAN treats all plots (samples) as a single entity initially, and iteratively divides them into groups in an hierarchical manner (Kent and Coker, 1994). At the onset TWINSPAN performs a one-dimensional reciprocal averaging ordination, the axis of which is split at the centroid, dividing the samples into two groups (Kent and Coker, 1994). This procedure is repeated with the species quantities weighted in such a way as to emphasise the influence of diagnostic ('indicator') species identified in the first ordination (Kent and Coker, 1994). Eigenvalues indicate the statistical validity of each division.

The output of a TWINSPAN analysis is a sorted two-way table. A dendrogram can be plotted from this table, displaying the arrangement of samples in classification space and the eigenvalue of each division. An eigenvalue of 0.4 or greater was considered indicative of a useful division. The table and dendrogram formed the basis for community differentiation and the identification of indicator and preferential species. Indicator species were those present in 75% or greater of the samples on one side of a division, and 25% or less of the samples on the other side. Preferential species were those present in 50% or greater of the samples on one side of a division, and 25% or less of the samples on the other side.

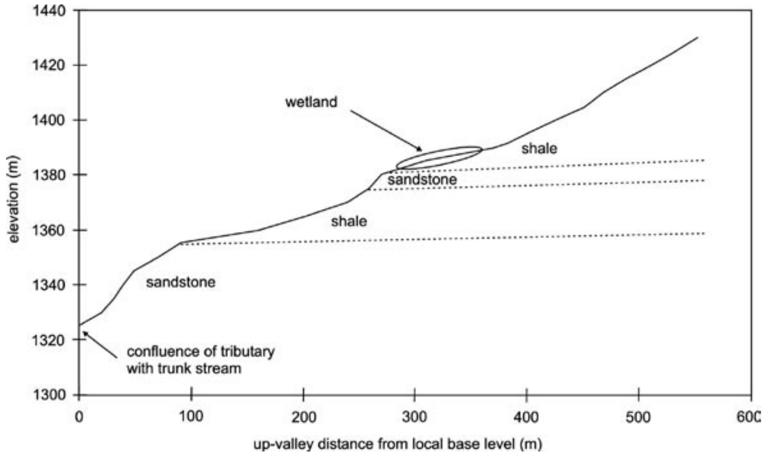

Figure 1
Longitudinal profile of the valley in which the wetland was situated, showing the location of the wetland and its relationship with underlying lithology

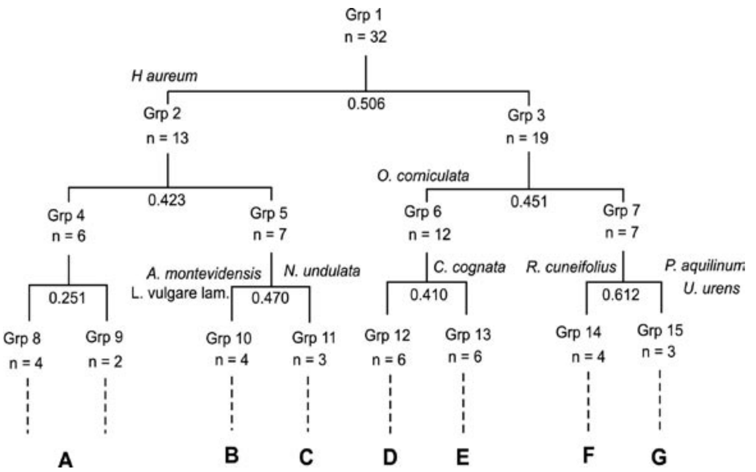

Figure 2
Dendrogram illustrating the arrangement of samples in classification space

Results

Wetland hydrogeomorphic setting

The wetland receives water inputs mainly from hillslope hydrological processes being located at the base of a hillslope and having no source of stream input. Outflow from the wetland is via a well defined channel connecting the area directly to a first order stream. These characteristics lend the wetland to the hydrogeomorphic classification: 'hillslope seepage wetland feeding a watercourse' (Kotze et al., 2005). Primarily groundwater discharge systems, the input and through-flow of water in hillslope seepage wetlands may be supplemented by surface water contributions (Kotze et al., 2005).

The longitudinal profile of the valley in which the wetland was situated (Fig. 1) displays two prominent regions of considerable over-steepening, above which the valley has attained a logarithmic profile. This profile owes its form to variations in geology over its length, with over-steepened regions resulting from strata of Estcourt Formation sandstone that are comparatively more resistant to erosion than the strata of Estcourt Formation shale enveloping them.

The strata of sandstone have impeded the incision of the drainage line and have formed bench-like structures, one of which has provided a low gradient depression within which water has accumulated in sufficient excess to create and sustain soil physiochemical conditions conducive to the formation of the wetland. Furthermore, it is likely that the stratum of sandstone has limited the loss of groundwater from the wetland through infiltration, thereby increasing the retention time of water in the wetland and prolonging saturation further.

Change in catchment land use and yield stormflow volume

The most frequent 24 h rainfall event for the area over the time period 1981 to 2002 was approximately 20 mm. Based on SCS-based design runoff calculations, under the former catchment land-use scenario (land use = grassland), following a 24 h rainfall event of 20 mm, the catchment would have yielded a stormflow volume of 16.62 m^3. Under the present land-use scenario (land use = grassland/forestry combination), the same rainfall event results in a catchment yield stormflow volume of only 2.33 m^3. Afforestation has therefore significantly reduced the magnitude of surface and subsurface runoff supplied to the wetland by its catchment.

Classification of plant communities

The first division of the dendrogram that was plotted from the TWINSPAN output table [Eig = 0.506] split the initial 32 plots (Group 1) into a negative (left) group comprising 13 plots (Group 2), and a positive (right) group comprising 19 plots (Group 3, Fig. 2). The indicator species associated with the negative group was *Helichrysum aureum* (erect herb). The second division [Eig = 0.423] split the 13 plots in Group 2 into a negative group comprising 6 plots (Group 4), and a positive group comprising 7 plots (Group 5). Group 4 was retained as one entity (Community A, Groups 8 and 9). The third division [Eig = 0.451] split the 19 plots in Group 3 into a negative group comprising 12 plots

TABLE 2 **Preferential and indicator species and their distribution in the plant communities classified**							
Species	**Community**						
	A (n=6)	**B (n=4)**	**C (n=3)**	**D (n=6)**	**E (n=6)**	**F (n=4)**	**G (n=3)**
Berkheya sp.	*4*	1			3	1	
Asparagus asparagoides	*3*	1					
Senecio polyanthemoides	5	2					
Pelargonium acraeum	*4*	1		1			
Urochloa mosambicensis	*4*						
Halleria lucida	3	1	2				
Agrostis montevidensis	3	***3***		1			
Leucanthemum vulgare lam.	2	***3***					
Plantago lanceolata		2					
Urochloa oligotricha		2				1	
Mohria caffrorum	*3*				2		
Nidorella undulata	3	1	***3***	4	3	2	2
Sporobolus fimbriatus	6	1	1	4	6		2
Rumex sagittatus	2		2	2	2	4	3
Rubus cuneifolius	1	3	1	1		***4***	
Pteridium aquilinum						1	***3***
Urtica urens			1	4	3	1	***3***
Conyza ulmifolia			2	3	3		
Cyathula sp.			2	6	3	1	1
Zantedeschia aethiopica					3		2
Typha capensis					3		
Carex cognata					***6***	1	
Ficinia cinnamomea					3		
Pupalia lappacea					3		

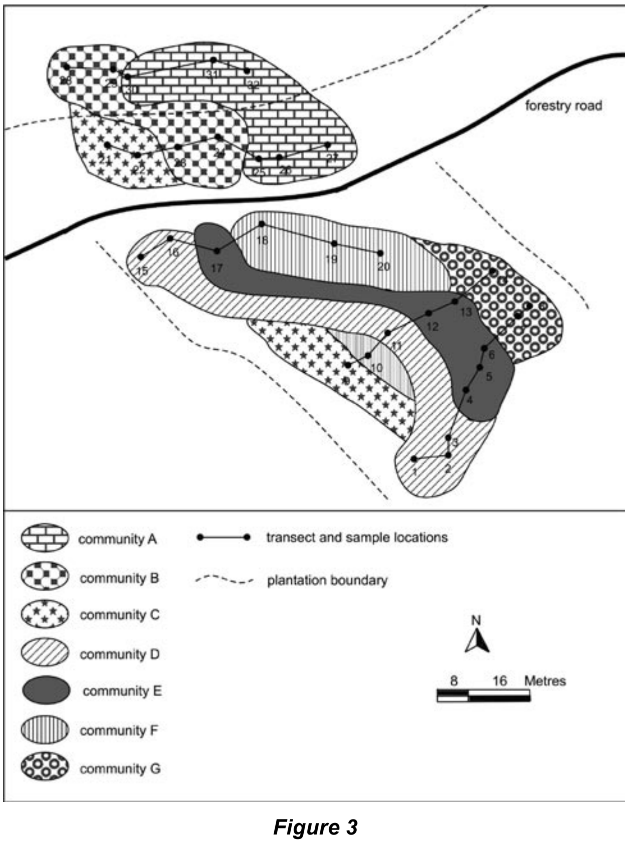

Figure 3
The distribution of plant communities at the site

(Group 6), and a positive group comprising 7 plots (Group 7). The indicator species associated with Group 6 was *Oxalis corniculata* (creeping herb).

Group 5 was split [Eig = 0.470] to form Communities B (Group 10, n = 4) and C (Group 11, n = 3). The indicator species associated with Community B were *Agrostis montevidensis* (grass) and *Leucanthemum vulgare lam*. (erect herb). The indicator species associated with Community C was *Nidorella undulata* (erect herb). Group 6 was split [Eig = 0.410] to form Communities D (Group 12, n = 6) and E (Group 13, n = 6). The indicator species associated with Community E was *Carex cognata* (sedge). Group 7 was split [Eig = 0.612] to form Communities F (Group 14, n = 4) and G (Group 15, n = 3). The indicator species associated with Community F was *Rubus cuneifolius* (scrambling shrub). The indicator species associated with Community G were *Pteridium aquilinum* (fern) and *Urtica urens* (scrambling herb).

Plant community descriptions and distribution

Community A: The *Brachiaria* spp. disturbed moist grassland community contained five preferential species but no indicator species (Table 2). The species *Senecio polyanthemoides* and *Nidorella undulata* were indicators of disturbance, with the former being present at a high percentage cover in 5 of the 6 samples comprising the community. This community occupied a relatively low point in the wetland, occurring along the thalweg to an elevation of approximately 1.5 m above the thalweg, and matrix chroma values at 0 to 100 mm were lower than 3 (Table 3). Community A occurred only above the forestry road (Fig. 3).

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TABLE 3 Ranges of environmental variables in the plant communities classified			
Community	Sample ranges of measured environmental variables	Matrix Chroma (0-10 cm)	Matrix Chroma (40-50 cm)
	Elevation relative to the local Thalweg (m)		
A	0 to 1.52	2 to 3	1 to 6
B	0.51 to 2.65	2 to 4	1.5 to 6
C	1.76 to 2.96	3 to 4	2.5 to 4
D	1.12 to 2.66	1 to 4	1 to 3
E	0 to 0.81	1 to 2	1 to 2
F	0 to 1.36	1 to 3	1 to 6
G	1.3 to 2.4	1 to 3	2 to 4

Community B: The *Agrostis montevidensis*, *Leucanthemum vulgare lam*. disturbed moist grassland community contained two indicator and three preferential species (Table 2). None of the species had particularly high cover, but several were indicators of disturbance, including *Senecio polyanthemoides*, *Rubus cuneifolius* and *Plantego lanceolata*. This community occurred on the left flank of the valley above the road (Fig. 3), at elevations ranging from 0.51 to 2.65 m above the thalweg, and matrix chroma values at 0 to 100 mm were between 2 and 4 (Table 3).

Community C: The *Nidorella undulata* disturbed grassland community contained the indicator *Nidorella undulata, an indicator of disturbance,* and four preferential species (Table 2). The grass *Cymbopogon excavatus* was present at a high percentage cover in all of the samples comprising the community. This was the only community to occur both above and below the road (Fig.3). The community occupied higher ground, occurring at elevations of 1.76 to 2.96 m above the thalweg, and matrix chroma values at 0 to 100 mm were between 3 and 4 (Table 3).

Community D: The *Cymbopogon excavatus* moist grassland community contained no indicator or preferential species (Table 2). Grasses such as *Cymbopogon excavatus*, *Hyparrhenia cymbaria* and *Sporobolus fimbriatus* were present in most of the samples comprising the community at a high percentage cover. This community occurred on the left flank of the valley, below the road (Fig. 3). The community occurred at elevations of 1.12 to 2.66 m above the thalweg, and matrix chroma values at 0 to 100 mm were lower than 4 (Table 3). In four of the six samples comprising this community, parent material was encountered at a depth of approximately 150 mm.

Community E: The *Carex cognata* permanent to semi-permanent wetland community represented the only remaining stand of herbaceous permanent to semi-permanent wetland vegetation at the site. This community contained one indicator and four preferential species (Table 2). The obligate hydrophytes *Carex cognata* and *Typha capensis*, present exclusively in community E, indicated that this region of the wetland was permanently to semi-permanently waterlogged. The presence of *Urtica urens* in five of the six samples comprising the community was indicative of disturbance. Community E occupied the lowest point in the wetland, occurring below the road (Fig. 3) between thalweg elevation and 0.51 m above the thalweg, and matrix chroma values at both 0 to 100 and 400 to 500 mm were lower than 2 (Table 3).

Community F: The *Rubus cuneifolius* disturbed wetland community bordered community E to the right (Fig.3). This community contained one indicator species, *Rubus cuneifolius* (Table 2), present in all the samples comprising the community at a high percentage cover. This aggressively invasive species is commonly associated with disturbed watercourses. The community occurred at a similar elevation to Community E, and matrix chroma values at 0 to 100 mm were lower than 3 (Table 3).

Community G: The *Pteridium aquilinum*, *Urtica urens* disturbed moist grassland community contained two indicator and two preferential species (Table 2). The fern *Pteridium aquilinum* was dominant in terms of abundance in all samples comprising this community, having even out-competed *Urtica urens* and *Nidorella undulata*, more common indicators of disturbance at the site that were present at low percentage covers in some of the samples comprising the community. This community bordered the plantation, occupying higher ground on the right flank of the valley below the road (Fig. 3). The community occurred at elevations of 1.3 to 2.4 m above the thalweg, and matrix chroma values at 0 to 100 mm were lower than 3 (Table 3).

Discussion

The origin and hydrogeomorphology of the wetland and impacts of afforestation at the site

The origin of the wetland at this position in the landscape may be explained by the effect that a stratum of sandstone has had on the longitudinal development of the valley in which the wetland is situated, and the effect that this stratum has had on promoting the discharge of groundwater into the wetland and ensuring that it was retained within the wetland for a prolonged period of time. Hydrological modelling demonstrated that afforestation within the wetland's catchment had significantly reduced the catchment's yield stormflow volume, and hence the supply of surface and subsurface runoff to the wetland. This presents a significant threat to the persistence of the wetland because, having no stream input source, a wetland in this hydrogeomorphic setting relies solely on hillslope-derived surface and subsurface inputs from its catchment. Thus, through canopy interception and evapotranspiration (Schulze et al., 1995; Kotze, 2004), the *Eucalyptus grandis* plantation has reduced the primary sources of water input to the wetland and hence the store of water available to hydrophytic vegetation.

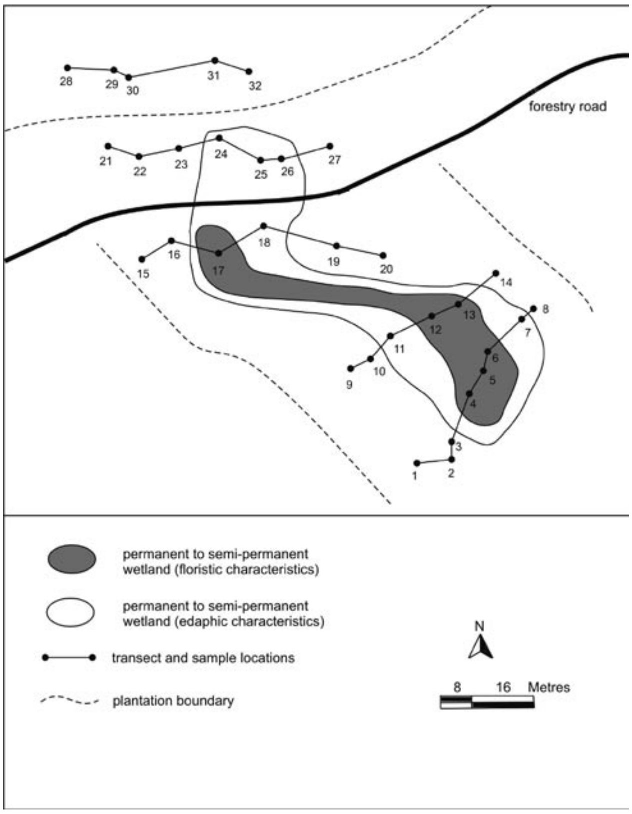

Figure 4
The result of water deprivation: a marked reduction in the area of permanent to semi-permanent wetland

The former boundary of permanent to semi-permanent wetland, delineated based on edaphic characteristics, and the present boundary of permanent to semi-permanent wetland, the zone of permanent to semi-permanent hydrophytic vegetation (Community E), were overlaid to produce Fig. 4. The edaphic-defined boundaries of the temporary and seasonal wetland zones would lie outside that of the permanent/semi-permanent zone, but are not mapped in Fig.4 to avoid clutter.

It is immediately apparent from Fig. 4 that the boundary of permanent to semi-permanent wetland indicated by floristic characteristics does not overlie that indicated by edaphic characteristics. Under a pre-disturbance hydrological regime, the boundary of Community E would have more accurately conformed to the boundary delineated based on edaphic characteristics. Thus, the disparity between boundaries is indicative of alteration to the hydrological regime of the wetland. Afforestation at the site has been planned with no apparent regard for buffer conservation initiatives (Pereira, 1973; Begg, 1990): the plantation is within 10m of the boundary of the permanent to semi-permanent wetland zone above the forestry road (Fig. 4), and it is in this area that the disparity between the floristic-related and edaphic-related boundaries is most pronounced. This is possibly a result of the cumulative impact of plantation proximity and dissection of the wetland by the forestry road.

When a wetland is deprived of water, vegetation adapted to drier wetland or even terrestrial zones is able to encroach on zones that were formerly seasonally or permanently to semi-permanently saturated. Plant species indicative of disturbance were present in virtually all of the communities identified. The similarity in environmental characteristics between the *Carex cognata* permanent to semi-permanent wetland community (Community E) and the *Rubus cuneifolius* disturbed wetland community (Community F) suggests that *Rubus cuneifolius* is out-competing and replacing indigenous herbaceous wetland vegetation within this region of the wetland. Although this species is moisture-loving, it cannot tolerate prolonged saturation, and its encroachment on the permanent to semi-permanent wetland community provides further confirmation that the hydrological regime of the wetland has been altered.

Implications for water resource management

Wetlands reflect the presence of water in the landscape. Their dependence upon water, and particularly the relationship between hydrology and the distribution of vegetation demonstrated by this study, makes wetlands effective indicators of hydrological change at the catchment scale. Measuring the relationship between edaphic and floristic indicators of wetness provides catchment managers with a tool that may be used to improve the efficacy of water resources management, and a means of measuring water resource use and distribution equity. By monitoring wetlands in a catchment, managers will at the very least be provided with an early warning of impending water resource disputes, and may attempt to pre-emptively resolve disputes brought by down-slope water users. Further applications of such a tool could include monitoring the success of rehabilitation interventions and assessing both individual wetland and overall catchment health or integrity.

Given the recent provision for integrated catchment management (ICM) principles in South African policy and law that require catchment managers to recognise the needs of all users of a catchments water resources (Burton, 1995; DWAF, 1996), the water requirements of wetlands must be considered in the decision making process. Inherent to the National Water Act 36 of 1998 in particular, is the responsibility of catchment managers to ensure the protection of "aquatic and associated ecosystems and their biological diversity" (Section 2 (g)). One of the proposed methods of achieving such protection is through determining, implementing and monitoring the Ecological Reserve; the quantity and quality of water required to protect the aquatic ecosystems of a particular water resource (Ch 3, Part 3). The relationship between edaphic and floristic characteristics of wetlands provides a starting point from which methods to determine, implement and monitor the Ecological Reserve for these ecosystems may be developed. Disparity between edaphic-defined and floristic-defined boundaries indicates that a wetland has not been provided the quantity and/or quality of water required to ensure its persistence and optimal provision of ecosystem services.

The water requirements of wetland ecosystems must be balanced with the requirements of all water users in a catchment. Because trade-offs between water resource use and protection are inevitable, it is important for society to inform the setting of any limits that dictate what level of biodiversity and ecosystem service loss is acceptable, and what reduction in water supply or water use is acceptable. After all, it is society at large that suffers the consequences of poorly managed resources. Integrated catchment management, as suggested in the National Water Act 36 of 1998, provides an effective vehicle by which such limits may be decided, and water use compromise achieved.

Conclusion

Land-use practices that interfere with hydrological and ecological balances that sustain wetlands need to be understood if water resource management is to be effective. In this case study the reduction in water input to the wetland is shown to alter plant community structure and allow the encroachment of alien and invasive plant species within most of the identified plant communities. Analyses of the origin and hydrogeomorphic setting of wetlands can provide valuable insight into the manner in which these systems are likely to be affected by changes in land use. Given that wetland vegetation responds to changes in water supply, measurement of a change in vegetation distribution and species composition can provide managers with a means of determining, implementing and monitoring the Ecological Reserve for wetlands, an indicator of catchment management efficacy and water resource use and distribution equity, an early warning of pending water disputes, a means of judging the success of a rehabilitation intervention, and a means of measuring the health or integrity of wetlands and their catchments.

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References

BEGG G (1986) The Wetlands of Natal (Part 1). An Overview of their Extent, Role, and Present Status. Natal Town and Regional Planning Commission, Pietermaritzburg, Report 68, 114 pp.

BEGG G (1990) The Wetlands of Natal (Part 4). Policy Proposals for the Wetlands of Natal and KwaZulu. Natal Town and Regional Planning Commission, Pietermaritzburg, Report 75, 86 pp.

BERNALDEZ FG, BENAYAS JM and MARTINEZ A (1993) Ecological impact of groundwater abstraction on wetlands (Douro Basin, Spain). *J. Hydrol.* **141** 219-238.

BRINSON MM (1993) A Hydrogeomorphic Classification for Wetlands. US Army Corps of Engineers Technical Report WRP-DE-4.

BURTON J (1995) A framework for integrated river basin management. *Proc. Int. Spec. Conf.: River Basin Management for Sustainable Development.* Kruger National Park, South Africa.

COWARDIN LM, CARTER V, GOLET FC and LAROE ET (1979) Classification of Wetlands and Deepwater Habitats of the United States. US Department of Interior, Fish and Wildlife Services. Report FWS/UBS 79-31, Washington, DC.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF), SOUTH AFRICA (1996) The Philosophy and Practice of Integrated Catchment Management: Implications for Water Resource Management in South Africa. Water Research Commission, Pretoria, Report TT 81/96.

DICKENS C, KOTZE DC, MASHIGO S, MACKAY H and GRAHAM, M (2003) Guidelines for Integrating the Protection, Conservation and Management of Wetlands into Catchment Management Planning. Water Research Commission, Pretoria, Report TT 220/03.

DIEDERICHS NJ and ELLERY WN (2001) An analysis of plant species distributions on the floodplain of the Okavango River, Namibia, with respect to impacts of possible water abstraction. *Afr. J. Aqu. Sci.* **26** 121-129.

GIBBS JP (2000) Wetland loss and biodiversity conservation. *Cons. Biol.* **14** 314-317.

HILL MO (1979) TWINSPAN - a FORTRAN Program for Arranging Multivariate Data in an Ordered Two Way Table by Classification of the Individuals and the Attributes. Department of Ecology and Systematics, Cornell University, New York.

JEWITT GPW and KOTZE DC (2000) Wetland Conservation and Rehabilitation as Components of Integrated Catchment Management in the Mgeni Catchment, KwaZulu-Natal, South Africa. In: Bergkamp G, Pirot JY and Hostettler S (eds.) *Integrated Wetlands and Water Resources Management. Proc. Workshop held at the 2nd Int. Conf. on Wetlands and Development*. November 1998, Dakar, Senegal.

KENT M and COKER P (1994) *Vegetation Description and Analysis. A Practical Approach*. Wiley, West Sussex. 363 pp.

KOTZE DC and BREEN CM (1994) Agricultural Land-Use Impacts on Wetland Functional Values. Water Research Commission, Pretoria, Report No 501/3/94.

KOTZE DC, HUGHS JC, BREEN CM and KLUG JR (1994) *The Development of a Wetland Soils Classification System for KwaZulu-Natal*. Water Research Commission, Pretoria, Report No 501/4/94.

KOTZE DC (2004) Guidelines for Managing Wetlands in Forestry Areas. Mondi Wetlands Project.

KOTZE DC, MARNEWECK GC, BATCHELOR AL, LINDLEY DS and COLLINS NB (2005) WET Ecoservices: A Technique for Rapidly Assessing Ecosystem Services Supplied by Wetlands. Report submitted to the Water Research Commission, Pretoria, for publication.

MALTBY E (1986) *Waterlogged Wealth: Why Waste the Worlds Wet Places?* Earthscan, London. 200 pp.

MITSCH WJ and GOSSELINK JG (1993) *Wetlands* (2nd edn.) Van Nostrand Reinhold, New York. 722 pp.

MUELLER-DOMBOIS D and ELLENBERG H (1974) *Aims and Methods of Vegetation Ecology*. Wiley, New York. 547 pp.

MUNSELL SOIL COLOR CHARTS (2000) (Revised edition) Munsell Color, New Windsor, New York.

PEREIRA HC (1973) *Land Use and Water Resources in Temperate and Tropical Climates*, Cambridge University Press, London. 246 pp.

SCHMIDT EJ and SCHULZE RE (1987) Flood Volume and Peak Discharge from Small Catchments in Southern Africa, based on the SCS Technique. Water Research Commission, Pretoria, Report TT 31/87.

SCHULZE RE, JEWITT GPW and LEENHARDT D (1995) Forestry Related Responses: Hydrological Impacts of Afforestation and a Timber Yield Model. In: Schulze RE (ed.) *Hydrology and Agrohydrology: A Text to Accompany the ACRU 3.00 Agrohydrological Modelling System*. Water Research Commission, Pretoria, Report TT 69/95, AT20-1 - AT20-26.

WHITLOW R (1992) Gullying within wetlands in Zimbabwe: An examination of conservation history and spatial patterns. *S. Afr. Geog. J.* **74** 54-62.

WINTER TC and LLAMAS MR (1993) Hydrogeology of wetlands. *J. Hydrol.* **141** 1-269.