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The classification of wetlands: integration of top-down and bottom-up approaches and their significance for ecosystem service determination

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Abstract The typology of wetlands provides important information for both water resource managers and conservation planners. One of the most important aims of allocating wetlands to a certain type or class is to provide information about the ecosystem services that the wetland provides. There are two main approaches towards wetland classification. Firstly, there are top-down approaches whereby wetlands are divided into several categories based on a conceptual understanding of how the wetland functions (mostly with regards to water flows). Secondly there are bottom-up approaches whereby the classification of wetlands is based on the collection of data in the wetland that is then subjected to various clustering techniques (mostly with regards to biodiversity). The most utilized system of top-down classification assigns wetlands into hydrogeomorphic units, which function as a single unit in terms of hydrology and geomorphology. This type of classification is most useful for water resource planning, as it provides information about how the wetland is connected to the drainage network and what are the water inflows, throughflows and outflows of the wetland. The bottom-up classification approach typically focusses on the classification of wetland habitats rather than complete wetlands, where wetland habitat represents a spatial unit delineated on the basis of vegetation, embedded within the (complete) hydrogeomorphic unit, and defined as an area of wetland that is homogeneous in terms of opportunities for plant growth. At a broad scale, most ecosystem services can be superficially derived from the hydrogeomorphic unit type and the way water moves through a wetland, but habitat units and the plant species that define them would have a specific effect on the delivery of ecosystem services, for example, with different assemblages providing different resistance to flow. Some types of ecosystem services are exclusively linked to specific wetland habitats, especially provisioning services. For this reason, it is proposed that a combined approach of hydrogeomorphic classification together with a vegetation map, offers the maximum information value for ecosystem service determination. In order to account for the potential pitfall of "double counting" when combining the top-down and bottom-up approaches, each service needs to be considered individually with reference to the degree to which a service is either: (a) primarily determined by HGM class/attributes and modified by

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the vegetation class/attributes; or (b) primarily determined by the vegetation class/attributes.

Introduction

Wetlands are considered among the most important ecosystems in terms of the delivery of ecosystem services (Van Andel and Aronson 2012; Mitsch and Gosselink 2000) and they are known to contain a rich and specialized biodiversity (Keddy 2004). Yet, they are also threatened by a wide range of human activities, ranging from drainage, cultivation, water pollution, lowering of water tables and alteration of flow regimes (Postel and Richter 2003; Kotze et al. 1995).

Due to their important role in the landscape, wetlands are considered in many management plans, including biodiversity and water resource management. However, not all wetlands play the same role in conservation and the delivery of ecosystems services, and therefore, different types of wetlands can have different levels of importance with regards to water resource management and biodiversity conservation (Kotze et al. 2008; Bullock and Acreman 2003). Wetland classifications are attempts to group wetlands with common characteristics or to identify the types of environments and biota they contain (Pressey and Adam 1995). Through classification systems that help to simplify complex ecosystems, it is possible to apply general rules to similar ecosystems at different locations (Froude and Beanland 1999; Adamus 2001). The foundation of a sound conservation and management plan for wetland ecosystems is the compilation of an inventory of wetlands in a region and such an inventory needs to be supported by a wetland classification system (Finlayson and Van der Valk 1995; Scott and Jones 1995; Tiner 1999).

The earlier classification systems based on habitat characterization (for example Cowardin et al. 1979) can be contrasted with later approaches that related more directly to processes and functions, focusing on Hydrogeomorphic Units (HGM) (Brinson 1993; Semeniuk and Semeniuk 1995). The HGM approach focuses on the flow of water through a wetland and the shape of the basin where water accumulates, as hydrology and geomorphic setting are the two most fundamental features that determine the occurrence of wetlands (Finlayson and Van der Valk 1995).

In South Africa, the inventory of wetlands is well underway as the South African government prioritizes wetlands in terms of water resource management and planning in anticipation of predicted water scarcity (Dini and Cowan 2000). A wetland classification system was devised to support a National Wetland Inventory, which, in turn, is geared towards supporting plans for water resource conservation and management as part of the National Freshwater Ecosystem Priority Areas project (Nel et al. 2011). For this reason, the South African Wetland Classification System (Ollis et al. 2013, 2015) utilizes an HGM approach on the premise that hydrogeomorphic characteristics play an important role when considering water resources. At the same time, there is a need for wetland classification that are more focused on the value that wetlands have for biodiversity (Rivers-Moore and Goodman 2010; Rivers-Moore et al. 2011).

In the absence of a national wetland vegetation framework, the National Freshwater Ecosystem Priority Areas project incorporated a regional framework, which made use of the terrestrial vegetation map (Mucina and Rutherford 2006) as this was the best available surrogate at the time for representing bioregional aspects including physiography, climate and soils. Since then, the national wetland vegetation project of Sieben et al. (2014) was undertaken.

All classification systems discussed up to here have been top-down classifications. A top-down classification uses a set of largely independent physical variables (such as landform, hydrology, vegetation structure and climate) as initial characteristics to group ecosystems in a conceptual model. The HGM classification is one of the most commonly used top-down classification types, because the hydrology and landform are the most obvious parameters that can be used to define wetlands and are accepted key drivers of wetland form and function (Ollis et al. 2013, 2015). The alternative, a bottom-up classification, would make use of data collected in existing wetlands (such as on water chemistry, soil properties or biota) and group the wetlands through statistical methods (O'Keeffe et al. 1994; Jones 2002). So, whereas a top-down classification is based on a conceptual model, a
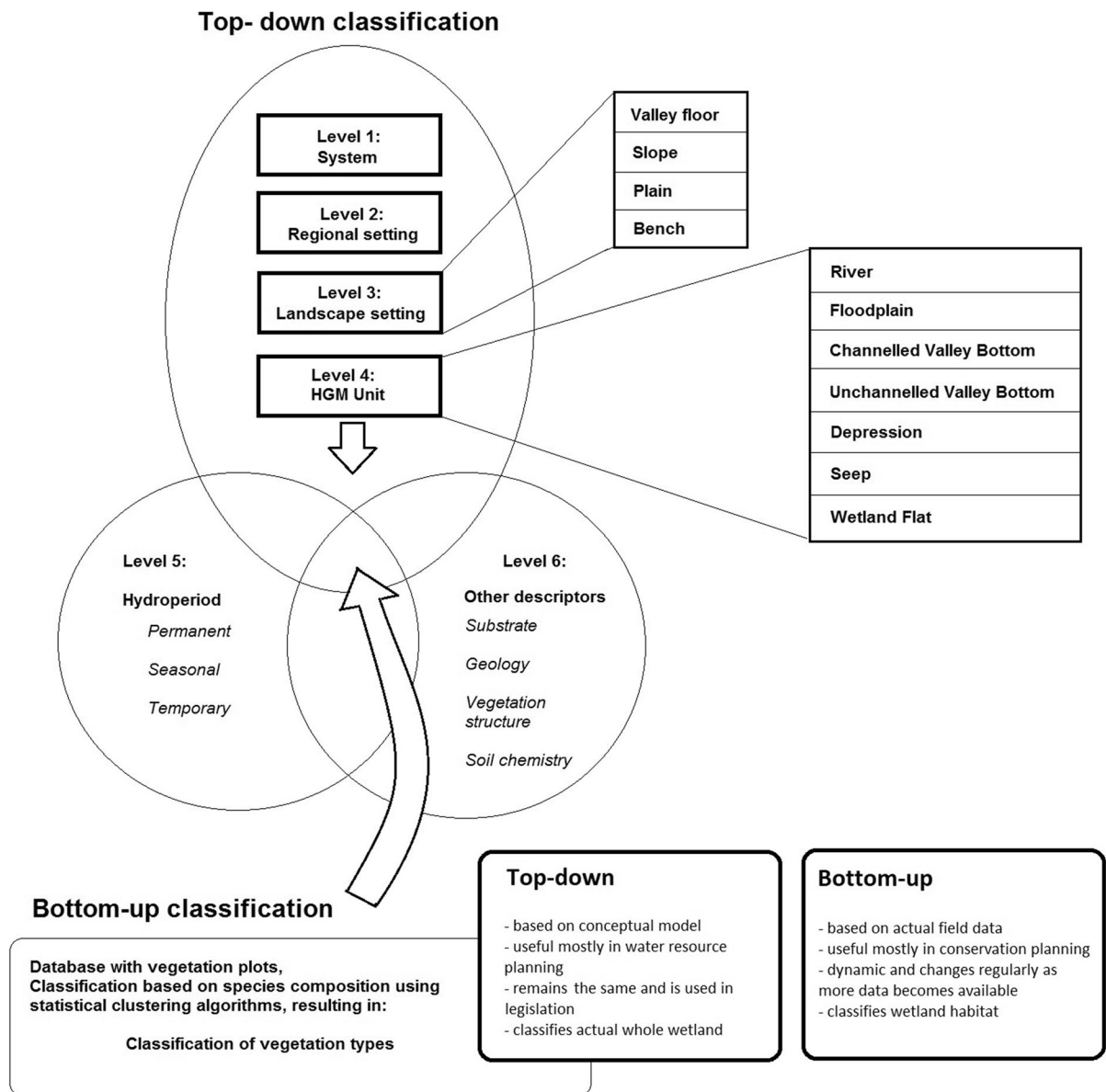
Top-down classification

Fig. 1 The connection between top-down classification and bottom up classification. Derived from Ollis et al. (2013)

bottom-up classification is based on actual data (on any aspect of the wetland environment; see Fig. 1). There are linkages between these two approaches, as data can be collected to confirm or refine a conceptual model.

In this paper, we demonstrate that the top-down and bottom-up approaches to classification are not mutually exclusive, but rather complement each other and, when combined, can lead to new insights about wetland ecosystem processes. We propose that the

combined approach to classification best reflects the organizing principles of wetlands as some processes in a wetland, such as water movement and sediment deposition, operate on the scale of the entire wetland and can best be understood when considering the wetland body as a whole. Because of their larger scale, they require more effort for measurement, are more variable in time and therefore more easily 'conceptualized' rather than measured. Other processes, however, operate from the bottom up, as many ecosystem

processes depend on the properties of individual plants, their physiological processes, and interactions with their direct environment. Because of their smaller scale, these processes are more easily and accurately measured, and provide data upon which classifications may be based. The ecosystem services ultimately delivered by a wetland are a result of both top-down processes (hydrological, geomorphological) and bottom-up processes (biological).

Top-down approach to classification

The hydrogeomorphic classifications are currently accepted as the most important type of top-down classifications of wetlands. The HGM classification reduces the classification of wetlands to first principles of wetland ecology by asking the question why water accumulates in certain places (Mitsch and Gosselink 2000). The understanding of wetland form and function benefits from a classification that first establishes the hydrogeomorphic context before introducing soil and vegetation factors, which are regarded as operating at a lower level (Maxwell et al. 1995). The classification of a wetland into an HGM unit will aid in the understanding of many ecosystem functions and services (Bullock and Acreman 2003). It will also provide a clear answer to the question what should be regarded as a single wetland, and when we are dealing with a 'wetland complex', as the HGM unit clearly describes a functional unit of a wetland and thereby makes the spatial scale explicit.

The HGM approach is a wetland assessment method comprising two main elements. The first element is to identify a wetland's hydrogeomorphic (HGM) type from a hydrogeomorphic classification system that classifies wetlands into groups based on geomorphic, water source, and hydrodynamic characteristics of a wetland. The second element is to assess wetland functions in relation to what are considered to be attainable conditions for wetlands with minimal anthropogenic impacts in the same HGM type and region as the wetland being assessed (Brinson and Rheinhardt 1996; Wardrop et al. 2007; Smith et al. 2013). Before the HGM approach can be applied, the second element takes extensive sampling and resources to set up, involving the description of many reference wetlands so as to represent the range of HGM types and regions encountered within the

geographical area to which the approach is to be applied (Brinson and Rheinhardt 1996; Smith et al. 2013).

In South Africa, the first element of the HGM approach has been adapted as a key component of the national wetland classification system (Ollis et al. 2013) for which HGM types have been identified, e.g. floodplain, depression, hillslope seepage. However, the second element of the HGM approach has not been adopted in South Africa given how onerous it would be to describe an adequate sample of reference wetlands across a country which has a considerable diversity of regions (e.g. from humid to arid) and hydrogeomorphic settings (Kotze et al. 2012). Nevertheless, the HGM classification (i.e. the first element of the HGM approach) forms the basis for identifying assessment units in both WET-Health (Macfarlane et al. 2008) for assessing wetland ecosystem condition and WET-EcoServices (Kotze et al. 2008) for assessing the provision of ecosystem services by wetlands.

If a wetland is classified according to the HGM classification system, this will give information about what type of ecosystem services are possible (Kotze et al. 2008; Table 1). However, it is important to recognize that Table 1 provides only a very course preliminary indication of possible ecosystem provision. The potential of a wetland to provide ecosystem services is also shaped by other specific features of the wetland and its geological and climatic setting. For example, in comparison with humid regions, wetlands in arid and semi-arid regions are generally characterized by: (1) more frequent and/or longer periods of desiccation; (2) higher levels of chemical sedimentation; and (3) more frequent fires that reduce the potential for thick organic accumulations and promote aeolian activity (Tooth and McCarthy 2007). These characteristics have important implications for the provision of ecosystem services.

The shape of the containing body where water accumulates determines to a large extent how water enters and exits the system and how it flows in between. These physical properties can translate into ecosystem services through, for example, considering how much water can be stored or retained in a basin, thereby preventing excess flow and eventual flooding damage. For the quantification of these ecosystem services, however, it is still necessary to obtain more detailed data on topography, soil depth, physical properties of the soil, flow regime etc. For example,

Table 1 Potential ecosystem services supplied from the various HGM types. Modified from Kotze et al. (2008)

HGM type	Flood attenuation	Erosion control	Enhancement of water quality			
			Sediment trapping	Phosphate assimilation	Nitrate assimilation	Toxicant assimilation[a]
1. Floodplain	■	■	■	■	■	■
2. Valley bottom, channelled	■	■	■	■	■	■
3. Valley bottom, unchannelled	■	■	■	■	■	■
4. Hillslope seepage	■	■	0	0	■	■
5. Depression	■	0	0	0	■	■

Carbon sequestration is omitted from the table as it appears not to be linked to particular HGM types but has been related better to other factors such as climate and geology (Grundling and Grobler 2005)

[a]Toxicants are taken to include heavy metals and biocides

Rating: 0 Service unlikely to be supplied, or if supplied then at a low level

■Service likely to be supplied at least to some degree

■Service very likely to be supplied, and often to a high level

the contrast in water inputs and outputs between the various Hydrogeomorphic types is highlighted in Fig. 2. This figure illustrates how the HGM classification can be made more robust by quantifying the parameters that are used to allocate a wetland to a certain HGM type, by considering the relative proportion of different sources of water. Some wetlands may superficially seem very similar, but are actually functionally very different from each other, because of 'invisible' inputs of water such as deep groundwater discharge, and actual measurements of field characteristics may help allocate a wetland to the correct HGM type. This has important implications in terms of how the wetlands function and the ecosystem services which they provide. Attempts are ongoing to provide more evidence-based support to aid in diagnostic tools to differentiate between the HGM types (Ollis et al. 2013, 2015).

Bottom-up approaches to classification

A bottom-up classification classifies a wetland on the basis of fine scale field data collected at various singular sites within a wetland. It represents the classification of wetland habitat types usually by classifying vegetation into types on the basis of plant species composition. It is possible to use other types of data for a bottom-up classification, such as soils, water quality, or other biota such as invertebrates, fish or planktonic organisms, but since plants are the primary producers and are also the most easily observed components of an ecosystem, ecosystems are often classified on the basis of the communities of vascular plants (Kent 2012). This can be done by defining representative vegetation plots where all species are recorded together with an index of their abundance (Westhoff and Van der Maarel 1978; Kent 2012). The presence and abundance of each plant species in such a vegetation plot represents a 'character' of that plot that it can have in common with another plot in the same or another wetland. Therefore, a classification can only emerge after a large database of vegetation plots has been built. Numerical statistical techniques can then be used to make the classification scientifically tenable and based on evidence (Wildi 2010; Legendre and Legendre 2013).

A particular combination of species in a wetland emerges as the outcome of biotic and abiotic filters, and with the use of canonical ordination techniques, particular species can be correlated to particular environmental conditions. For this reason, vegetation types provide a window into the environmental and soil conditions that could otherwise not directly be detected without extensive measurements in the wetland. For example, nitrogen-poor conditions can be easily recognized by very distinct plant communities (Kent 2012; Wildi 2010).

In South Africa, a bottom-up habitat classification has been constructed on the basis of a national
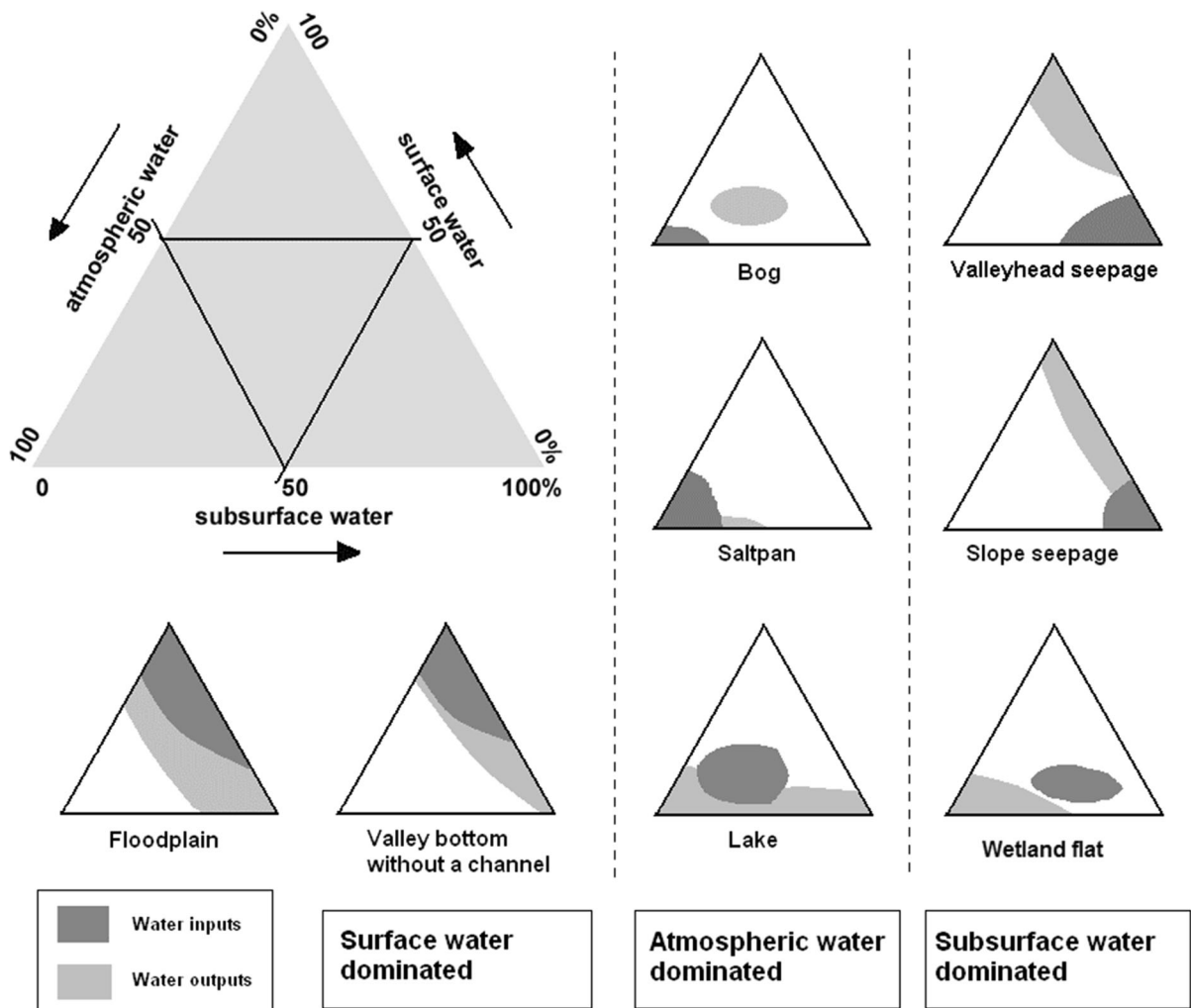
Fig. 2 Water inputs and outputs of the various HGM units, illustrating how measured data can help in identifying wetlands

wetlands vegetation database (Sieben et al. 2014). There have been 275 vegetation types described in wetlands in the country and these fall into nine major groups, summarized in Table 2. Each of the 275 vegetation types has an identity that can be given a number by using the number of the main group (first column in Table 2) and the number of the community within that main group. For example, the community that consists of a monoculture of Common reed (*Phragmites australis*), which is common and widespread within South Africa, is part of Main Group 6 (Temperate grassy wetlands) and there it is community number 25, so it is referred to as Community 6.25 *Phragmites australis* community.

When a wetland is delineated, this delineation should be accompanied by a delineation of the various

habitats within the wetland, if the purpose is to understand how the wetland functions and what ecosystem services it may deliver. This means first and foremost that zones of similar hydroperiod will be identified within the wetland: permanently wet zones, seasonally wet zones that are inundated/saturated for most of the wet season and temporarily wet zones that are inundated/saturated for mostly a few weeks every year. Often the relative abundance of each of these zones can be assessed, especially when they align well with the vegetation types in the wetland (Kotze et al. 1996). Within the wetland there may be several communities of wetland plants and each of these indicates specific habitat conditions. Therefore, the wetland map can be subdivided further into habitat units and each of these mapping units can either be

Table 2 Main classification into habitat units in South African wetlands. Based on Sieben et al. (2014)

Main group	Number of communities	Main structural description	Widespread examples
1. Sclerophyllous wetland vegetation	22	Medium to tall restio-land	Palmiet vegetation
		Mixed medium shrubland	Belskruie vegetation
			Mountain fynbos wetland vegetation
2. Swamp Forest	7	Mixed closed forest	Waterberry swamp forest
3. Subtropical wetland vegetation	49	Closed medium short to tall sedgelands	Papyrus vegetation
		Closed medium short to medium grasslands	Ikhwane vegetation
			Pondo coastal wetland vegetation
4. Estuarine wetland vegetation	23	Closed short grasslands	Incema vegetation
		Closed to open medium succulent shrubland	Saltbush vegetation
5. Montane grassy wetland vegetation	32	Closed medium grasslands	Misbelt wetland vegetation
		Mixed very short medium grasslands	Summit plateau wetland vegetation
		Medium short sedgelands	River pumpkin vegetation
6. Temperate grassy wetland vegetation	25	Closed medium to all grasslands	common reed vegetation
		Closed tall sedgelands	common bullrush vegetation
			Rooivleigrass vegetation
7. Grass lawn wetland vegetation	37	Open very short to closed medium short grasslands	Kweek grass vegetation
		Medium short shrublands	Buffalo grass vegetation
		Closed medium short herblands	Renosterveid wetland vegetation
8. Submerged vegetation	20	Submerged aquatic vegetation	Waterlily vegetation
			Pondweed vegetation
9. Inland saline wetland vegetation	29	Open shrubland	Saltwort vegetation
		Open short grasslands	Kalahari sedge vegetation
		Medium short sedgelands	

allocated to a vegetation unit that fits within the bottom-up vegetation classification system of Sieben et al. (2014) or a local classification of vegetation can be constructed, based on vegetation plots made in the area. Each of these mapping units represents a specific type of wetland habitat, and can be characterized by environmental factors that exert their influence in the rooting zone or the direct environment of the plants. The mapping units in turn have certain vegetation properties depending on the characteristics and the requirements of the dominant species and these properties are helpful in understanding how vegetation contributes towards ecosystem functioning and ecosystem services.

Wetland classification and the link with ecosystem services

If we use a typology to classify wetlands, one of the implicit goals of such an exercise is to be able to determine the role of this wetland in the broader landscape, and to determine the ecological services of the wetland. There are a wide range of ecosystem services known from wetlands and most of these arise from links to the hydrological cycle. Table 3 shows an overview of these ecosystem services and its determinants within the wetland ecosystem.

The HGM type of a wetland has important implications for the delivery of ecosystem services. This is best viewed in terms of the three main components of

Table 3 Some key features of a wetland potentially influencing the effectiveness of the wetland in providing a range of different ecosystem services. Adapted from Kotze et al. (2008)

Ecosystem services		Some key features of a wetland contributing to services provision
Regulating and supporting benefits	Flood attenuation	Surface roughness (which is strongly influenced by the robustness and density of the vegetation); gentleness of the wetland's longitudinal slope and depression storage in the wetland
	Streamflow regulation	Influence of the vegetation over evapotranspirative loss from the wetland (e.g. vegetation which dies back during the dry season reduces evaporation from the wetland); sub-surface water movement through the wetland
	Water quality enhancement benefits	
	Sediment trapping	Features contributing to flood attenuation, given that the greater the extent to which runoff is slowed down, the greater will be the deposition of the sediment carried by the runoff
	Phosphate assimilation	Phosphates are generally adsorbed to sediments, and thus the greater the extent to which wetlands trap new sediment, the greater will be the extent to which the wetland removes phosphates
	Nitrate assimilation	Presence of vegetation, which provides: (1) an important supply of soil organic matter required by the microbiota in order to assimilate nutrients and toxicants; and (2) habitat for the microbes in the soil immediately surrounding the roots
	Toxicant assimilation	Factors contributing to sediment trapping given that many toxicants are generally adsorbed to sediments. Presence of vegetation (see above)
	Erosion control	Vegetation cover, which plays a central role in controlling erosion by binding the soil with its roots and protecting the soil surface with its leaves and stems
	Carbon storage	Permanence of saturation given the influence this has on impeding organic matter decomposition; vegetation growth providing the source of organic material
Provisioning benefits	Provision of water for human use	Contribution to water storage and streamflow regulation
	Provision of harvestable resources	The presence and abundance of natural resources from the wetland, including livestock grazing, craft plants, fish, etc
	Provision of cultivated foods	The provision of fertile areas in the wetland favourable for the cultivation of crops
Cultural benefits	Cultural heritage	The presence of places of special cultural significance in the wetland, e.g., for baptisms or gathering of culturally significant plants
	Tourism and recreation	The presence of sites of value for tourism and recreation in the wetland, often associated with scenic beauty and abundant birdlife
	Education and research	The presence of sites of value in the wetland for education or research

the HGM classification. (1) The geomorphic setting, encompassing the wetland's landform and landscape position and how it evolved, has a key influence over clastic sedimentation, i.e. whether the site is inherently degradational (with a net loss of sediment) or aggradational (and therefore accumulating sediment). This, in turn, has an important influence over the services which the wetland delivers in terms of the trapping of sediment and elements adsorbed to the sediment, notably phosphorus. (2) The water source maintaining the wetland has an important influence over which component/s of the hydrological cycle the wetland is best positioned to influence in terms of water quality, e.g. if the wetland is maintained primarily by sub-surface water inputs, it is potentially well positioned to influence this water, e.g. by assimilating dissolved nitrates. (3) The hydrodynamics of a wetland, which refers to how water moves through the wetland, has a profound influence over the level of contact between this water, the sediment and vegetation. In unchannelled valley bottoms, for example, even the low flows are spread diffusely across the wetland, resulting in high levels of contact, which in turn potentially result in high levels of influence over water quality

throughout the year. This contrasts with floodplains, where most of the flows are confined within the channel and only during major flood events do flows spread out across the wetland.

However, wetlands can offer many ecosystem services that are not directly associated with water itself, such as carbon sequestration, or provisioning services by means of the species present in the wetland. For this reason, classifying a wetland into hydrogeomorphic types does not capture all potential ecosystem services from a wetland, but a vegetation map of the wetland provides additional information that can aid in the assessment of ecosystem services in a more detailed manner. Additionally, even though most hydrological ecosystem services emerge due to the flow of water through the wetland and therefore by the hydrogeomorphic type, these flows can sometimes be modified by the occurrence of a specific type of vegetation.

A vegetation map can indicate how hydrological functions may be affected by vegetation processes: the dominant presence of a dense and tall vegetation type, e.g. tall reeds or shrubby vegetation, will result in more resistance to flow than short grassland vegetation (O'Hare et al. 2015). Other ecosystem services emerge from processes that occur locally at the scale of an individual plant (e.g. transpiration, primary productivity) and can be scaled up to the level of the ecosystem (Chapin et al. 2009; Denny and Benedetti-Cecchi 2012). Many of such ecosystem functions can be derived from functional characteristics of the plants themselves and are driven by the dominant species in the ecosystem (Kinzig et al. 2002; Díaz and Cabido 2001; Vile et al. 2006). It could be argued that, for the purpose of providing information on ecosystem services, a coarse 'structural' vegetation classification may be sufficient. However, it has become clear that ecosystem properties are often overwhelmingly determined by a single dominant species (Zhang et al. 2015) and wetlands often have a clear dominant species, due to the clonal growth forms that predominate (Sosnová et al. 2010). Therefore, if the vegetation type that includes the dominant species is known, the properties of this dominant species can be expected to have an overwhelming impact on ecosystem functioning. For example, species with different traits can have an impact on the nitrogen cycling in riparian wetlands (Sutton-Grier et al. 2013), on hydrological flow resistance (O'Hare et al. 2015) or in the response

towards global warming (Moor et al. 2015). The fact that many wetland plants are specifically adapted to transfer oxygen down into their roots, and some of this diffuses into the soil, increasing the contrast between aerobic and anaerobic soils within the wetland, which has an impact on nutrient cycles, for example by denitrification (Hemond and Benoit 1988). In some cases, the functional characteristics of a single dominant species are so overwhelming that the species is known as an 'ecosystem engineer', which means that the development of the ecosystem is guided into an entirely new direction due to the impacts that a single species has on large-scale ecosystem processes and associated services (Jones et al. 2010).

In order to understand the link between plant community types and ecosystem services it is necessary to know the functional traits of plants that play a role and to understand the effects that these traits have on ecosystem services (Violle et al. 2007; Moor et al. 2017). Functional traits of constituent plants have two roles in the ecosystem: they determine the way a plant responds to the physical environment in a wetland (response traits), and they also determine the cumulative effects of all those plants present on the ecosystem itself (effect traits) (Lavorel and Garnier 2002). Although the determination of functional traits of wetland plants has not happened on a large scale yet in South Africa (Sieben 2012), this approach is useful towards ecosystem service determination (see case studies below). Some examples of how traits mediate ecosystem functions are given in Table 4. In some cases, plants may enhance or modify hydrological functions that are largely determined by the HGM type, but in other cases, for example in terms of carbon sequestration, the plants play the main role in the overall ecosystem functioning and associated services because they are the primary producers (Naeem et al. 2009). Listing the presence of vegetation with traits that have an impact on these ecosystem services is therefore particularly important as they would be missed out if only a top-down classification of wetlands is carried out.

Provisioning services are another category of ecosystem services that is largely determined by species identity of the dominant plant species rather than structural types, since different plants have different properties that can be regarded as useful by people (Kotze and Traynor 2011). For example, the high fibre content and tensile strength in some

Table 4 Some ecosystem services linked to ecosystem processes that are mediated by plant traits

Ecosystem services which plants potentially influence	Plant traits that mediate these services	Plants enhance/modify ES from HGM type	Plants are the primary determinant of ES	Some situations where these traits are important to consider
Regulatory services				
Flood attenuation	Plant height, aboveground biomass, robustness of plant architecture	X		Where depression storage is lacking and slope is not very gentle; floodable property downstream
Water retention	Stomatal conductance, rooting depth, wood density	X		Where depression storage is high
Carbon sequestration	Relative growth rate, aboveground biomass, specific leaf area		X[a]	Where permanent saturation is extensive in the wetland
Erosion control	Aerial and basal cover, rooting depth, belowground biomass, clonal connections		X	Wetlands subject to high discharge; slope is steep
Enhancement of water quality	Nutrient foraging, aerenchyma in stem, allocation to leaves, rooting depth	X[b]	X[b]	Where flow is diffuse through the vegetation; upstream pollution sources
Provisioning services				
Livestock grazing	Leaf nitrogen content, fibre content		X	In an agricultural context, especially where grazing is limited over the dry season
Medicinal plants	Resistance against fungi and bacteria		X	In communal/traditional use areas
Crafts/construction	Quality and quantity of fibre, wood density		X	
Aesthetic beauty	Flower colour, flowering time and duration, architecture of the plants	X[c]	X[c]	In touristic areas

[a]The carbon accumulating in wetlands is derived primarily from the plants growing in the wetland, but it is also recognized that the carbon which ultimately accumulates in a wetland is strongly affected by several environmental factors at the site including geology, climate and HGM type

[b]In so far as the HGM is strongly depositional and nutrients/toxicants are predominantly associated with sediment or the HGM unit is inherently characterized by diffuse flow, the HGM type is likely to play a primary role. Otherwise, the plants are likely to be the primary determinant

[c]In so far as the HGM unit has a low level of visual contrast with the surrounding landscape (e.g. a concave hillslope seepage surrounded by slightly less concave dryland hillslope) then the plants are likely to be the primary determinant. However, if the HGM represents a medium to strong visual contrast with the surrounding landscape then the HGM type is likely to play a primary role

helophytic sedges confers value on these plants as material for woven crafts.

Case studies

A combined approach where both bottom-up classification and top-down classification takes place in parallel, will be illustrated in two different case studies. In these case studies, wetlands are mapped and divided into their component Hydrogeomorphic Units, as well as their habitat units. The first case study represents Goukou wetland in the Western Cape and the second case study represents the Pongola River floodplain in northern KwaZulu-Natal. In both cases, an assessment of ecosystem services will be derived from the combined classifications.

Case study 1: Goukou wetland

The Goukou wetland is an approximately 700 ha wetland in the foothills of the Langeberg Mountains in the Western Cape of South Africa (Fig. 3). In terms of the top-down (HGM) classification of Ollis et al. (2013), this wetland has been identified as an unchannelled valley-bottom wetland, due to its location on a valley floor and the absence of a continuous river channel through the wetland. Valley-bottom wetlands provide many important regulating ecosystem services to society; perhaps most importantly water purification, retaining water in the landscape and influencing water quality through for example denitrification, should nitrates be present in the landscape, because of extended retention times and presence of soil organic material.

In terms of the bottom-up (vegetation) classification and vegetation mapping, the wetland is dominated by a dense network of Palmiet vegetation (Community 1.22 of Sieben et al. 2014). This habitat type is very widespread over the entire wetland, particularly in its upper reaches, although in the lower reaches it is replaced by *Phragmites australis* vegetation (Community 7.25), *Calopsis paniculata* vegetation (Community 1.1), *Cliffortia strobilifera* vegetation (Community 1.2) and *Pennisetum macrourum* vegetation (Community 1.23) (None of these are shown in the limited section of the vegetation map in Fig. 3). In the upper reaches of the wetland, the entire wetland is dominated by Palmiet vegetation, with only the fringes of the wetland covered by other vegetation types, consisting either of tall leafless vegetation (*Cyperus textilis* Community) or short sedge vegetation (*Juncus capensis* Community).

The plant Palmiet (*Prionium serratum*) has unique functional traits that have an important effect on the functioning of unchannelled valley bottom wetlands. The main characteristic of Palmiet is that, unlike most wetland plants, it is a robust woody plant, clonal in nature, with a very large belowground biomass, and it can grow to several metres in height. It is therefore very effective at creating a dense wall of stems, rhizomes and roots, trapping sediment, slowing flows and remaining rooted in place, despite the high energy flows that regularly flow through these wetlands.

Diffuse flows prevail throughout the wetland. This can be attributed to the change in gradient from steep mountain stream to low gradient valley floor, but mostly to the dense vegetation present in the wetland which dampens water flow (Job 2014). This is relevant for the protection of downstream properties and agricultural land, where erosion is prevented. The robust plant is also attributed to playing a significant role in facilitating peat accumulation, which is important for carbon sequestration. Once it is fully established across a river channel it is able to slow flows and trap sediment, leading to permanently flooded, quiet waters that are low in sediment, conditions that are conducive to peat formation (Job 2014).

Palmiet can be regarded as an ecosystem engineer as it keeps the wetland in place in an area with an overall slope that would otherwise be too steep for a wetland to exist (Sieben 2012). This is particularly relevant as Palmiet occurs in areas at the foothills of the Cape Fold Mountains where flash flooding occurs regularly and peak storm flows often exceed the infiltration capacity of the wetland (Job 2014). When comparing intact Palmiet wetlands to damaged wetland systems such as the Duiwenhoks River and several of the tributaries to the Goukou, it becomes clear that the unique properties of Palmiet and its high rooting depth are crucial in protecting the wetland from erosion during such flash floods (Barclay 2016). In areas where palmiet has been cleared for cultivation or for creating ditches to concentrate water flows into irrigation channels, severe erosion and loss of the peat has followed, leaving behind a rocky, cobbled river bed. Where palmiet is in place, the large peat deposits (up to eight meters deep) are protected and can continue to grow. Palmiet contributes to the creation of conditions conducive to water retention and the accumulation of fertile, highly organic soils but they are very vulnerable to human impacts (Job and Ellery 2013). Therefore, within the Goukou wetland, the presence of Palmiet vegetation directly modifies the ecosystem services ordinarily delivered by the HGM wetland type, and disregarding the vegetation types in the wetland would have underestimated the ecosystem services delivered by the wetland.

Case study 2: The Pongola River floodplain

The floodplain of the Pongola river forms an extensive wetland on the Maputaland Coastal Plain, towards the Northern border of KwaZulu-Natal, at the Eastern foot of the Lebombo Mountain Range (Fig. 4). Part of this
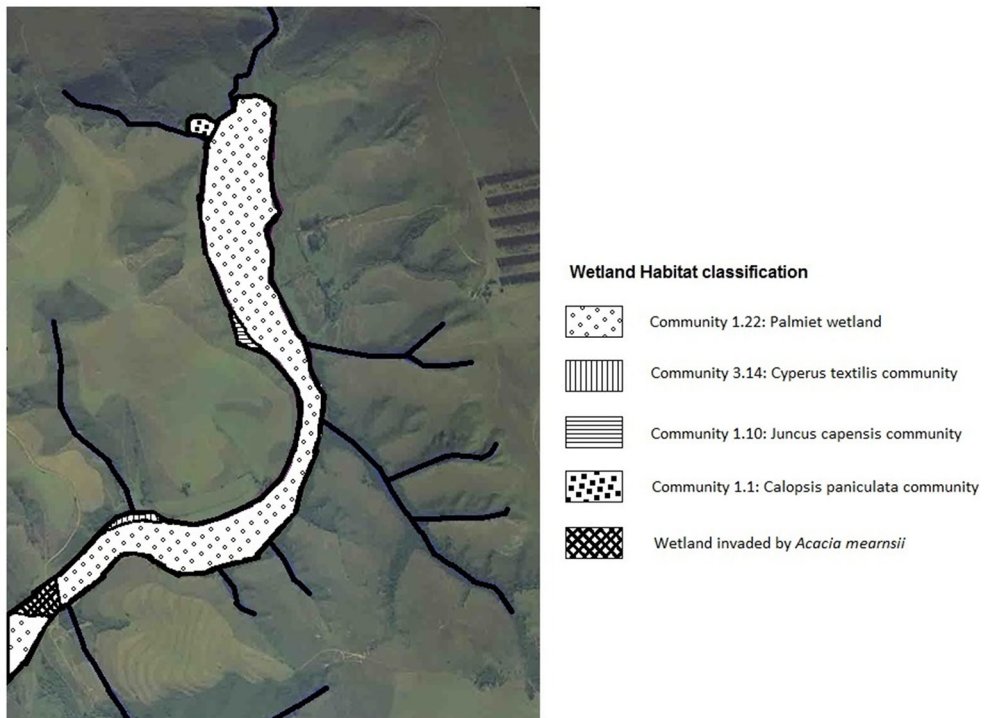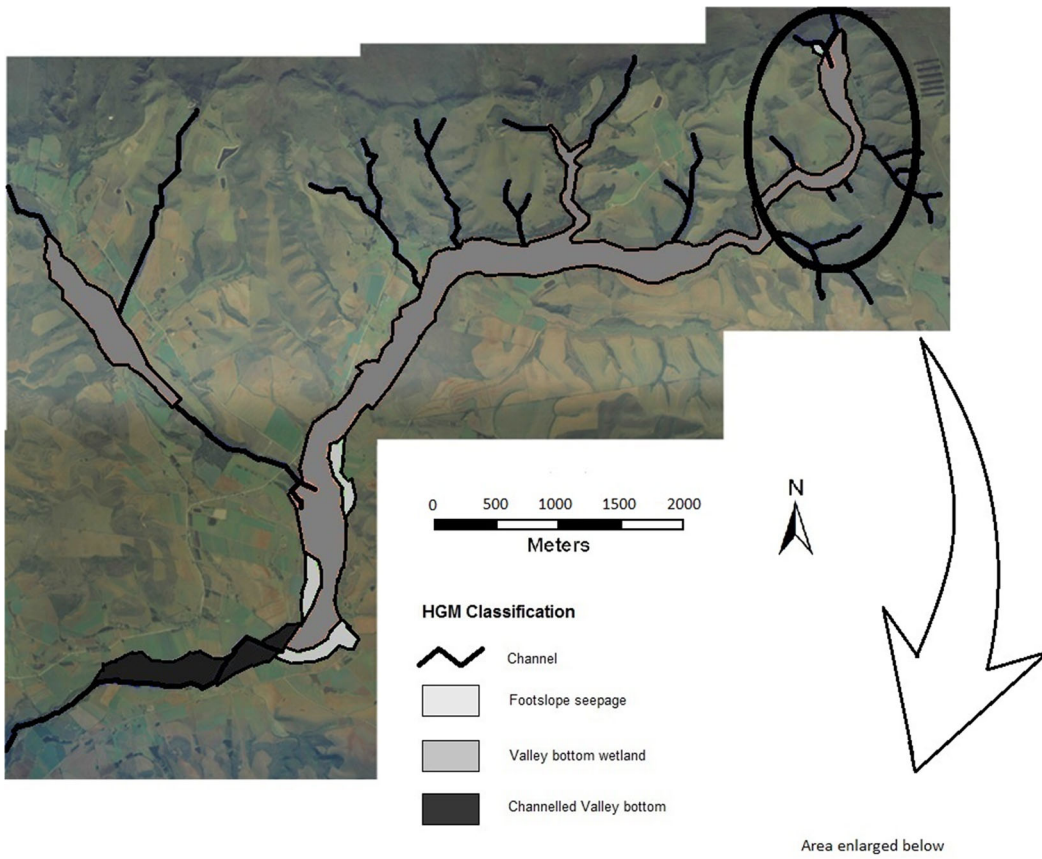
◀ **Fig. 3** Case study 1: Goukou wetland where the entire wetland is shown mapped and classified into a number of HGM units as well as a section of the wetland that is further subdivided into a number of habitat types

wetland is found within the borders of the Ndumo Nature Reserve. In terms of the top-down (HGM) classification of Ollis et al. (2013), this wetland would be classified as a floodplain and therefore the main ecosystem services it provides are water retention and flood attenuation, thereby protecting downstream properties from flood damage. Floodplains are also very fertile areas and due to the high productivity of the ecosystem depending on the summer floods, the subsistence economy of the amaThonga culture can thrive on the Pongola river banks (Lankford et al. 2010). Therefore, the function of flood protection serves a large community of people, both in South Africa and in neighboring (downstream) Mozambique.

The flooding of the Pongola River floodplain is dependent to the catchment west of the Lebombo Mountains where the Pongolapoort Dam was built. Since the building of this dam, the floodplain hydrology has changed considerably from its natural state. The Pongola River floodplain has specific relevance for scientific knowledge on floodplain ecosystems in South Africa as it was the first system in South Africa where water requirements were determined for sustaining environmental flows (Heath and Plater 2010).

In terms of the bottom-up (vegetation) classification, Furness and Breen (1980) recognised six plant communities which they grouped according to their relative periods of exposure and inundation. Four of these communities are found in the northern part of the floodplain, in the Southern part of Ndumo Nature Reserve, as displayed in Fig. 4. The hydrological functions of the floodplain are mediated only to a small extent by the hydraulic properties of the various vegetation types, which are low in stature, in contrast to the first case study of Goukou wetland. As the water slows down in the floodplain, the wetlands in a floodplain also provide functions for the retention of nutrients, particularly phosphates, which make the amaThonga subsistence economy viable (for example by small-scale agriculture and livestock grazing). The extent to which certain vegetation types slow down the water has an impact on how effective the wetland is in

terms of nutrient retention and flood attenuation. The vegetation types that have the highest hydraulic roughness from the ones shown on Fig. 4 (dense vegetation, high biomass) are the Riverine forests and possibly the reed marshes. In the figure it can be clearly seen that these vegetation types are much more common inside the Nature Reserve than outside of it, where vegetation has been cleared and damaged to a greater extent, so having some parts of the floodplain in a pristine state would benefit the people living downstream (in this case the people living along the Pongola river in Mozambique).

The reedbeds dominated by *Phragmites australis* play a significant role in natural wastewater management (Tamene 2000). This is particularly relevant for the Pongola floodplain as it is situated downstream of the large Jozini Dam where eutrophication has taken place. The reeds and the microfauna associated with its root zone remove pollutants, sediments and other material. The clonal properties of *Phragmites australis* also help towards preventing erosion on river and channel banks which is useful during floods (Bonham 1980).

Some of the dominant plant species in the riverine forest also offer additional services, for example in terms of medicinal properties in a rural area where health services are limited. For example, the leaves of the *Ficus sycomorus* are known to treat snakebites and jaundice and its latex found is effective in treating chest diseases, colds and dysentery (Tamene 2000). The fever tree (*Acacia xanthophloea*) is known for several medicinal uses, for example for treating malaria, fever, eye complaints and sore throats. Its timber has value for making furniture and carvings. The root nodules of the fever tree help to enrich soils with nitrogen and enhance the growth of other plants in its vicinity due to the presence of nitrogen-fixing bacteria. This contributes to the overall productivity of the area which is covered by *Cynodon dactylon* grasslands that provide many benefits for livestock grazing.

Conclusion

The top-down approach to classification has demonstrated its usefulness around the world. This approach is particularly valuable in a data-poor environment such as sub-Saharan Africa and for particular aims, such as water resource planning. However, when
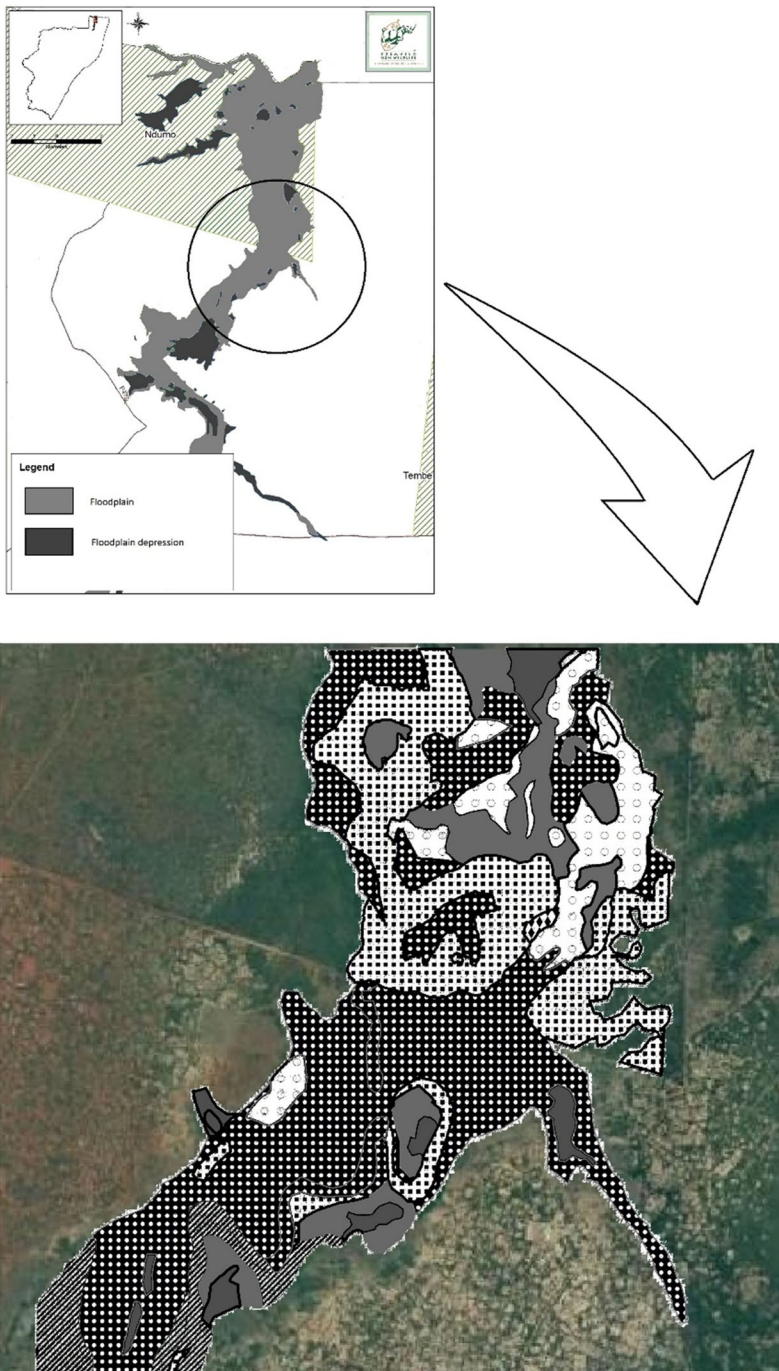
Fig. 4 Case study 2: Pongola River floodplain. The HGM classification of the wetland as a whole is relatively simple because all of it falls under the Floodplain, but in terms of habitat there are some structurally very distinct vegetation types which may impact local ecosystem service delivery

wetland classification proceeds only up to this point, a large part of the information on ecosystem services that wetlands provide will be missed and therefore, when possible, data collection should be encouraged to do a bottom-up classification of patches of similar habitats within wetlands as well.

When a complete understanding of wetland ecosystem services is targeted, it is appropriate to conduct two classifications on a wetland ecosystem that complement each other. One of those is the classification of the wetland (which is seen as synonymous with a Hydrogeomorphic Unit) whereas the other classification focuses on the wetland habitat (which refers to any land unit within the wetland with similar vegetation, soil and inundation patterns). One wetland often consists of several wetland habitats, but this does not always need to be the case, and even some large wetlands can be homogenous in terms of wetland habitats. The classification of wetland habitats happens in a spatial context within the wetland but some of the processes that happen at the level of the wetland habitat have a cascading effect on the larger scale, the entire wetland system. In general, the top-down approach is more useful for water resource managers while the bottom-up approach is more useful for conservation managers.

The main confusion about wetland classification in the past arose because of different stakeholders in wetland conservation emphasizing different aspects of wetland ecosystem functioning. The HGM classification in most cases addresses many questions about the role the wetland plays in the overall regional water cycle (Bullock and Acreman 2003). On the other hand, an over-emphasis on the hydrogeomorphic characteristics of a wetland neglects the role of that wetland in regional conservation planning as the information on wetland biodiversity provided by this approach is poor and insufficient (Nel et al. 2011).

We would like to argue that making the differentiation between hydrogeomorphic characteristics and vegetation aspects is very useful but that the classifications based upon them should occur complementary to each other as both classifications provide their own useful information needed to understand the wetland ecosystem. A wetland (or hydrogeomorphic unit) can consist of different habitats and therefore these two classifications are not actually classifying the same objects.

Many wetland classification systems have used a single classification that use a mixture of characteristics from hydrogeomorphic and biodiversity aspects (Cowardin et al. 1979; Rivers-Moore et al. 2010), but this is bound to confuse matters as both approaches to classification and mapping provide different kinds of information. The habitat classification describes

spatial units that are embedded within HGM units. Vegetation has its own effects on ecosystem services or in some cases, vegetation enhances or moderates services that are determined by HGM units at a higher spatial scale. The exercise of combining both approaches will highlight the ecosystem services that emerge either through top-down or bottom-up processes and shows them in their spatial context.

It is recognized that a potential problem with combining the top-down and bottom-up approaches is that of "double counting" of ecosystem services. In order to account for this potential pitfall, the approach advocated is not simply to add together the services revealed from the top-down and bottom-up approaches. Instead, each service needs to be considered individually with reference to Table 4 to see the degree to which: (a) a service is primarily determined by HGM class/attributes and adjusted by the vegetation class/attributes; or (b) a service is primarily determined by the vegetation class/attributes. An example of the former situation would be a floodplain with a very gentle longitudinal gradient, extensive depression storage and a readily over-topping stream channel, which are key HGM-related factors conferring a high effectiveness on the wetland for flood attenuation and sediment trapping. In such an example, which is represented by the Pongola Floodplain, the vegetation occurring on the floodplain would have a modifying effect on the HGM-related factors through the potential resistance offered by vegetation to water flow, depending on the robustness, density and height of the dominant plant species growing on the floodplain. However, this effect of the vegetation should nonetheless be secondary to the combined effect of the HGM-related factors. An example of the latter situation would be a wetland with a high abundance of plant species well recognized locally and regionally for having suitable quantity and quality of fibre for craft production, thereby conferring a high effectiveness on the wetland for the provisioning of raw material for craft production. In this latter situation, the HGM-related factors contribute indirectly to the provisioning of fibre for craft production through the influence that they have over the accumulated moisture and soil nutrients required by the specific plant species, but other factors such as the fire regime and grazing regime may also profoundly affect the occurrence and abundance of these suitable species (Kotze and Traynor 2011). Thus, when assessing the

effectiveness of the wetland for craft production, the primary focus should be on the direct presence and abundance of the plant species themselves.

The main strength of the approach of combining bottom-up and top-down classification systems on wetlands is that these two classifications reflect different types of ecosystem processes that emerge either because large scale processes take place that influence the entire ecosystem from the top down or because small scale processes occur across the area and have a large scale 'mass' effect due to their predominance. In general, the top down classification into hydrogeomorphic types reveals which types of ecosystem services may be expected, but for a more complete assessment of these ecosystem services, a starting point would be a map of the various vegetation types, the relative frequency of each of the vegetation types present, combined with the functional traits of the dominant plant species.

An additional benefit of incorporating a bottom-up vegetation classification into a national wetland classification is that this can aid the identification of wetlands by use of remote sensing technology by differentiating vegetation types on the basis of the spectral signature of its dominant plant species. Vegetation is the most visible aspect of a wetland from aerial photography and it is possible to differentiate different species or even functional types by means of satellite imagery (Adam and Mutanga 2009; Schmidtlein et al. 2012). For this reason, a bottom-up classification supports the long-term monitoring of environmental changes in wetlands, which have important impacts on ecosystem services (Chapin et al. 2009; Sutton-Grier et al. 2013).

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