Less Water in the Face of Climate Change Reduces Erosion Vulnerability of South Africa's Wetlands

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ABSTRACT

Given the fact that southern Africa is semi-arid and situated at an exceptionally high altitude for a region of the world that has not undergone plate collision for a half a billion years, wetlands are prone to degradation by gully erosion. This is because wetlands typically form an integrated component of fluvial systems and evolve a longitudinal slope that is appropriate for their discharge. Factors that increase discharge in fluvial systems, such as hardening of surfaces through urbanisation or overgrazing in wetland watersheds, lead to increased erosion as the longitudinal slope of wetlands is too steep for the available discharge. Given that decreased rainfall is predicted in southern Africa due to climate change scenarios, wetlands are less likely to be subjected to levels of erosion currently witnessed. Despite a reduction in water inputs due to lower rainfall, this is good news for many southern African wetlands.

INTRODUCTION

Wetland scientists generally think about the ecosystems in which they work as driven primarily by water. Flooding of the soil leads to anaerobic conditions and thus the radical alteration of soil biogeochemical characteristics, making life in this environment hostile to organisms not highly adapted to these conditions (Mitsch and Gosselink 2015). A key feature of wetland environments is the prolonged saturation near the surface, typically flooding of the wetland landform to a shallow depth, be it a floodplain, valley-bottom, depression, or mire. Such flooding requires the evolution of landforms with a very gentle slope and near-horizontal cross-section (Ellery et al. 2008). I have long been intrigued about how such landforms develop, particularly in the southern African context where two features make the formation of wetlands somewhat enigmatic:

1. The region is semi-arid with a mean annual rainfall across the subcontinent of about 500 mm per annum and potential evaporation of between 1000 and 4000 mm per annum. Nowhere is rainfall greater than potential evaporation.
2. The region is situated at an unusually high altitude for a region of the world that has not undergone mountain-building by tectonic plate collision for 500,000 years, and where erosion is thus the dominant geomorphic process.

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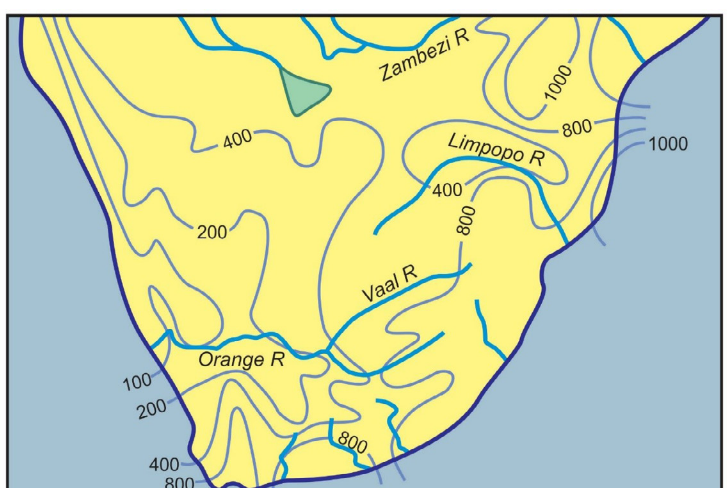
Erosion is viewed as the most serious threat to wetlands in the region, leading to degradation of these ecosystems across the subcontinent (Russell 2009). Erosion of wetlands is widely viewed as being caused by mismanagement of the land by humans, including overgrazing, wetland drainage, burning, removal of vegetation for crop production as well as urbanisation in wetland catchments (Russell 2009). There has been very limited research into the subject of wetland erosion, or of the geomorphic processes that contribute to wetland formation and dynamics. This brief analysis presents some new findings related to wetland erosion, and attempts to examine the implications of these for the vulnerability of wetlands to erosion in the face of predicted climate change in the region.

SOUTHERN AFRICA IS SEMI-ARID

The climate of southern Africa is generally dry (Schulze 1997). There is a gradient of decreasing rainfall from east to west and from south to north, such that the highest rainfall is experienced along the eastern and southern coastlines, and the lowest rainfall occurs along the west coast and the north-western interior of the subcontinent (Figure 1).

Given the low rainfall that characterises the region, wetlands typically occur as features integrated within the drainage network. They typically receive groundwater inputs

FIGURE 1. Rainfall patterns in southern Africa showing the declining rainfall from the eastern and southern coastlines towards the west and north. (Note: Rainfall in mm per year). (Adapted from copyrighted figure from Ellery et al. 2008, permission received from Water Research Commission.)



where they occur in the upper regions of watersheds, or fluvial inputs where they occur in mid- and lower-positions of watersheds. Wherever they occur, they are characterised by a near-horizontal cross-section and very gentle longitudinal slope that is typically less than 1% (Ellery et al. 2008).

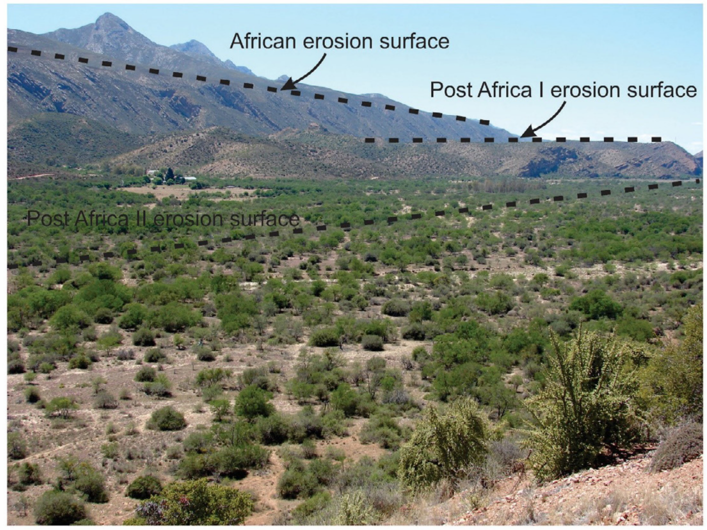
SOUTHERN AFRICA IS EROSIONAL DUE TO ITS GEOLOGICAL HISTORY

The high altitude of the subcontinent of southern and eastern Africa is anomalous on a global scale and results from two uplift events over the last 20 to 30 million years (Figure 2; Nyblade and Robinson 1994). The uplift events are thought to be the result of isostatic adjustment following the injection of heat into the crust by a hot mantle plume. Given that continental elevation results from a combination of the thickness of the crust and its density, the lowering of the density of the crust due to heating is proposed to explain the high elevation of a feature known as the "African Superswell." The first uplift event that happened 20 to 30 million years ago caused southern Africa to rise by about 150 m along the west coast and 250 to 300 m on the east coast. The second event caused the region to rise by approximately 150 m and 900 m on the west and east coasts, respectively. These events have led to the high elevation and gentle incline of the subcontinent from west to east (Figure 2).

It is worth stepping further back in time to appreciate what the surface of the subcontinent might have been like before these uplift events. The supercontinent of Gondwana, made up of India, Madagascar, Australia, Antarctica and South America (from east to west), broke apart around 150 million years ago. Following breakup, the African continent slowly eroded such that by about 30 million years ago the average elevation was approximately 300 to 400 m above sea level (Maud 2012). This land surface, known as the African Erosion Surface (Figure 2), was at an appropriate elevation for the available runoff such that erosion was negligible.

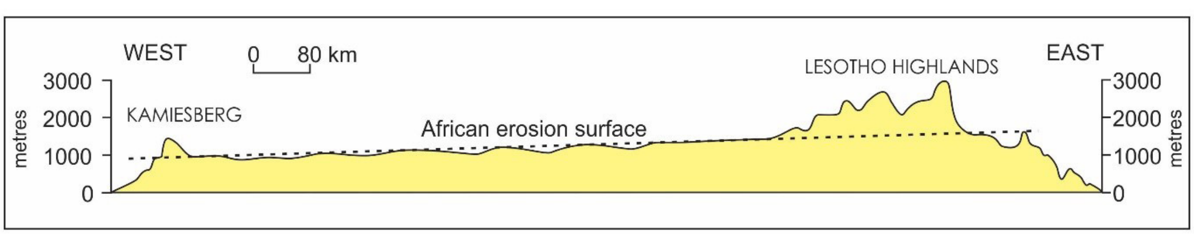
Following uplift and the associated lowering of sea level in relation to the southern African land mass, the subcontinent began eroding. Erosion was initially associated with streams incising into the pre-existing land surface, a process known as downcutting, which undoubtedly led to the loss of many wetlands that existed before the uplift events. Downcutting is followed by valley widening.

FIGURE 3. Evidence of uplift events recorded in many modern landscapes such as the Baviaanskloof valley in the Cape Fold Mountains of the Eastern Cape, South Africa. (Photo: Fred Ellery.)



These uplift events are written into the landscape that we see today. The Baviaanskloof valley in the Cape Fold Mountains of the Eastern Cape clearly shows the geomorphic history of the subcontinent as a result of the way that streams respond to uplift events (Figure 3). Before the first uplift event, the floor of the valley would have been at an elevation appropriate for sea level at the time. This surface, which is preserved in the landscape, is the African Erosion Surface. There is strong evidence on this erosion surface in the form of siliceous root casts preserved in sediments that a wetland existed here prior to the first uplift event. At an elevation about 150 m lower than the African Erosion Surface is a second erosion surface that formed between the first and second uplift events, known as the Post-Africa I Erosion Surface. The current valley floor (Post-Africa II Erosion Surface), which is about 100 m lower, is at an elevation that allows it to slope very gently (0.7 %) towards the Indian Ocean.

FIGURE 2. Cross-section of South Africa showing the gently-sloping interior plateau of the subcontinent that occurs at an average elevation greater than 1 000 m above sea level. (Adapted from copyrighted figure from Partridge and Maud 1987, permission received from Geological Society of South Africa.)



Given that erosion is the dominant geomorphic process in southern Africa and that downcutting generally leads to wetland degradation in the short- to medium-term, it is surprising that southern Africa supports a wide diversity of wetlands in regions at altitudes of 1000 m or more. Examples include the Nyl River floodplain, the Klip River floodplain, and floodplains in the foothills of the Drakensberg Mountains (Rogers 1997).

LEARINING ABOUT WETLAND GEOMORPHIC PROCESSES FROM THE WETLAND LONGITUDINAL SLOPE

Given that streams work through erosion and deposition to achieve a longitudinal slope that is appropriate for their discharge (Ellery et al. 2008), it is useful to plot the longitudinal slope of valley-bottom wetlands in relation to their size (Figure 4). There is a clear negative relationship between longitudinal slope and wetland size such that small wetlands typically have a high slope and larger ones have less slope. It is not difficult to argue that wetland size is a surrogate for mean annual discharge, such that large wetlands are likely to require a large amount of water to flood, but small ones are inundated by a small discharge. Valley-bottom wetlands varied from about 10 ha and reached a size up to about 1 000 ha.

Figures 5 and 6 show examples of valley-bottom wetlands that had either been incised by gully erosion (Figure 5) or that had not been incised (Figure 6). In many cases, gullying had been very recent, while in others, gullies had been present from the time of the earliest aerial photography in about the 1930s. While the formation of gullies is generally attributed to human impacts, in most cases in this study, it was not possible to attribute gully formation to human activities in the catchment or the wetland, with any degree of certainty.

It is clear from Figure 4 that those wetlands with a high slope for their size were gullied, while those wetlands with a low slope for their size were not gullied. The line on the figure separating gullied and non-gullied wetlands represents a threshold slope, such that steepening of a valley through processes such as deposition, can lead to the initiation of erosion. Given that wetland size is a surrogate for runoff, it also suggests that hardening of surfaces in a catchment such as through urban development, may lead to the initiation of gullies.

A recent study in the Krom River wetland in the Cape Fold Mountains near Joubertina in the Eastern Cape Province, attempted to explain the reason for the presence of a broad wetland with a near-horizontal cross section and very gentle longitudinal slope (<1 %), nestled within the Cape Fold Mountains (Figure 7). The wetland is dominated by *Prionium seratum* (Figure 8), which is a robust perennial palm-like plant named "palmiet" by early Dutch settlers in the Western Cape as they were not sure whether it was a palm or a reed (Dutch = "riet").

FIGURE 4. The relationship between the longitudinal slope of valley-bottom wetlands in South Africa. The red circles represent wetlands that have erosion gullies present, while the wetlands that do not have erosion gullies are indicated by green circles. (Adapted from copyrighted figure from Ellery et al. 2008, permission received from Water Research Commission.)

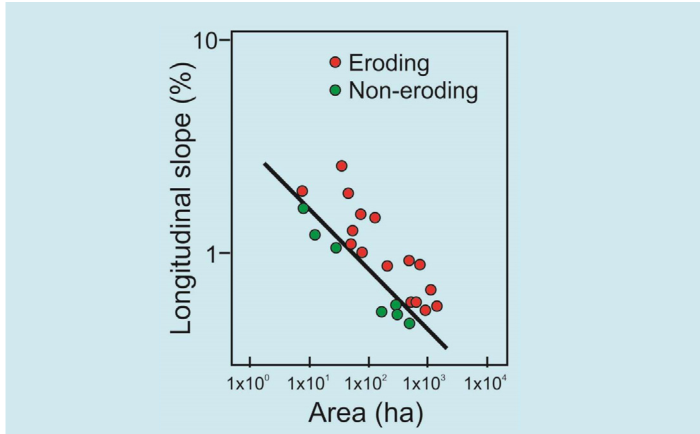


FIGURE 5. A recently formed erosion gully in a tributary of the Goukou wetland near Riversdal in the Western Cape Province, South Africa. A person standing in the image (center) provides a sense of the scale of the erosion of this remarkable peatland. (Photo: Fred Ellery.)

FIGURE 6. An aerial image of the head of the Goukou wetland, an unchannelled valley-bottom peatland immediately south of the Cape Fold Mountains in the Western Cape Province. (Photo: Japie Buckle.)

Cores were taken through valley-fill sediments (Figure 9a) in order to examine stratigraphy and the cross-sectional form of bedrock across the valley floor. Many cores could not reach bedrock due to the presence of a sand layer that collapsed and limited coring depth (Figure 9a, yellow dots). These cores contained clastic and organic sediments to the depth of the sand layer (Figure 9b). A limited number of cores located gullies that were overgrown by floating entangled stems of palmiet (Figure 9a, red dots). These overgrown gullies were not visible from the ground or in high resolution aerial photography. Beneath the mat of palmiet, which could easily be penetrated by coring, water was found to occur to a depth just above bedrock (Figure 9c). Based on dating of organic sediment at the base of these cores, it is clear that they started filling with sediment as far back as about 7060 years BP, with several subsequent cycles of cutting and filling having been identified at 4770, 1290, and 470 BP (Pulley et al. 2018). These dates long precede settlement of the valley by European settlers, and demonstrate natural cycles of erosion that have led to valley widening and the creation of a valley with a gentle longitudinal slope of about 1%.

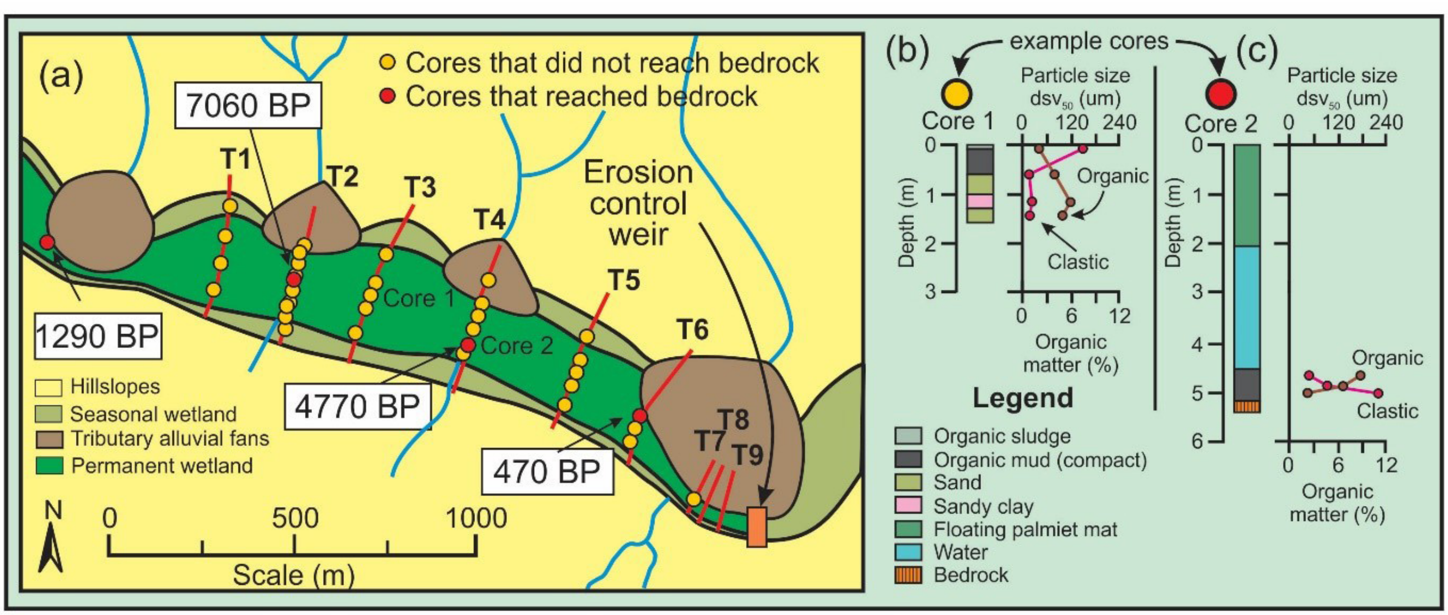
WETLAND VULNERABILITY TO EROSION IN RELATION TO PAST CLIMATE VARIABILITY

The Dome C Ice Core, taken by an international group of scientists working in Antarctica, reveals climate variability

FIGURE 7. The Krom River wetland with a near-horizontal cross-section and gentle longitudinal slope, situated in the Cape Fold Mountains of the Eastern Cape Province. (Photo: Fred Ellery.)

FIGURE 8. The Krom River wetland is dominated by the robust plant palmiet, (Prionium seratum) which has stems with a diameter of about 100 mm and grows to a height of 3.5 m. (Photo: Nancy Job.)

FIGURE 9. A series of cores taken to bedrock (red dots) and to a sand layer above bedrock (yellow dots) in a basin of the Krom River unchannelled valley-bottom wetland, Eastern Cape, South Africa. Core locations (a) and typical sedimentary fill are shown for cores that did not reach bedrock (b) and for those that did reach bedrock (c). The age of sediment (years before present) at the base of cores that reached bedrock is shown (a). (Adapted from copyrighted figure from Pulley et al. (2018), permission received from John Wiley and Sons.)



as indicated by variation in the concentration of deuterium (δD), a stable isotope of the hydrogen atom in water (EPICA community members 2004). A higher concentration of deuterium in the ice is related to higher ambient temperatures in the southern hemisphere. The core shows that the last 10,000 years have been very warm, but that over the last 800,000 years, temperatures were generally cooler than today (Figure 10a). The dust concentration in the ice is related to rainfall in the southern continents such that a high dust concentration suggests arid conditions (Figure 10b; Lambert et al. 2008). Temperature and dust concentration are inversely related suggesting that during warm periods the climate of southern continents appears wet, but during cool periods the climate appears dry. Consequently, we are currently experiencing a warm and wet phase of the Earth's climatic history.

Given that the prevailing climate from about 100,000 to about 10,000 years ago was cooler and drier than presently, we might expect wetlands to develop geomorphologically to a higher slope than the threshold slope that currently prevails in southern Africa. Increased rainfall and runoff associated with the warmer modern climate may be the reason that wetlands in the region are eroding to the extent that we currently witness (Ellery et al. 2008). Of the restoration work undertaken by the South African statutory agency Working for Wetlands, about 80-90% of the expenditure is on gully stabilisation and restoration. The geomorphic understanding that we have of wetland formation in South Africa suggests that this erosion may have been natural given long-term climate cycles.

HOW MIGHT WETLAND VULNERABILITY TO EROSION RESPOND TO PREDICTED CLIMATE CHANGE?

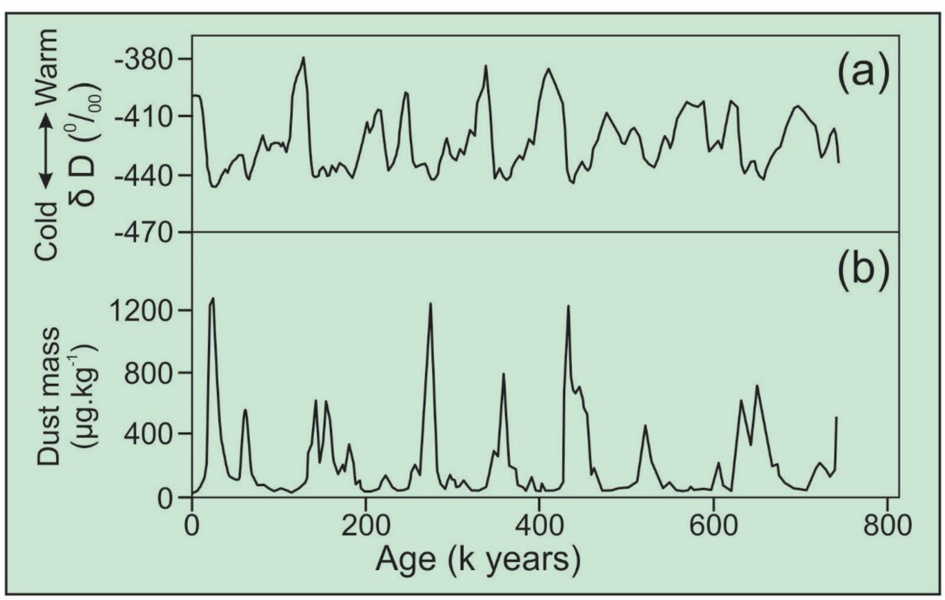
In contrast to what the past climate record shows, predictions for future climate in South Africa suggest a warmer and drier climate (Engelbrecht et al. 2015; Maúre et al. 2018). If this is the case, we might expect runoff to decline and therefore wetlands to be less vulnerable to erosion than is presently the case. The key factor is that the relationships described above are nonlinear because a drier climate will reduce the extent of wetlands, which might be viewed as a threat to wetland security. However, erosion is a much greater threat as it often leads to complete wetland destruction. Based on a better understanding of the geomorphology of South African wetlands, it is clear that predictions for future climate change in the region suggest a reduced risk of wetland erosion and therefore lower the impact of what is viewed as the single greatest threat to these ecosystems. While the extent of wetlands will be reduced as a result of declining water inputs, they are less likely to be completely destroyed through erosion. Therefore, although the extent of wetlands will decline in the face of reduced water inputs due to likely scenarios of climate change, wetlands are less likely to be destroyed through gully erosion than they are at present.

THE SIGNIFICANCE OF THIS UNDERSTANDING FOR CATCHMENT MANAGEMENT

An understanding of the role of geomorphology in wetland structure and functioning highlights the importance of improved catchment management in order to enhance wetland protection. Given that in Figure 4, area is a surrogate for runoff, land use changes in catchments that increase runoff may shift a wetland with a slope below the threshold of erosion to above the threshold, thereby resulting in gully erosion in the wetland that radically alters wetland hydrology due to lowering of the water table and widespread desiccation of the wetland.

In contrast to this scenario, if climate change decreases runoff from the catchment into the wetland, wetlands that are at risk of erosion or that have eroded under present climate conditions, may be restored naturally through reduced ability of the stream to transport sediment. Climate change may therefore reduce the risk of erosion in wetlands and promote increased sediment trapping, thus

FIGURE 10. The climate record of the last 750,000 years as shown by variation in the concentration of the stable hydrogen isotope, deuterium, in the Dome C ice core from Antarctica (a). Dust concentration (b) is inversely related to rainfall given that vegetation cover is related to rainfall and reduces aeolian dust transport. (Adapted from copyrighted figure from Lambert et al. 2008, permission received from Springer Nature.)



leading to wetland restoration through processes that are consistent with what wetland restoration efforts in South Africa attempt to achieve artificially. Understanding geomorphic processes in wetlands under different flow conditions thus supports wetland restoration efforts in South Africa. Given climate change predictions for the region, it is likely that wetland restoration efforts nationally will be more sustainable than at present.

CONCLUSION

It is also evident from our work that we need to better understand the geomorphology of wetlands if we are to answer questions about what might happen next under certain scenarios of change. A key issue is that wetlands have evolved geomorphologically to develop slopes that are very close to the geomorphic threshold slope for the current or past climate. We therefore need to think of the water that enters and flows through a wetland as shaping the morphology of the basin that hosts the wetland, as well as modifying soil biogeochemistry and therefore the biota that we find in a wetland. This seems a relatively unexplored frontier in our science, and it seems there are many opportunities for novel insights that allow us to better manage wetlands in the future. ■

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