Changes in Carbon Storage in Wetlands of the United States: 2011-2016

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Wetland soils contain some of the densest stores of carbon in the biosphere. However, there is little understanding of the quantity and distribution of carbon stored in US wetlands, or how these stocks change over time. Soil carbon was measured using the same protocol to a maximum depth ranging from 90 to 120 cm at approximately 1000 probabilistically selected wetland sites in each of the 2011 and 2016 National Wetland Condition Assessment (NWCA); 205 of the same sites were sampled in both survey years. Preliminary analyses of carbon density from the resampled sites show a median increase of 6.0% in the top 10 cm, while lower in the soil profile (30–60 cm and 60–90 cm), median carbon density decreased (-14.4 and -9.1%, respectively). Significant decreases in soil carbon density over time (i.e., 5 years) deeper in the soil profile parallel results from the 2011 NWCA data, where human disturbance was correlated to lower carbon densities in the deepest (60–90 cm and 90–120 cm) soil layers (Nahlik & Fennessy, 2016, NatComm:13835). We explore human disturbance and other mechanisms that may be impacting carbon stores over time. These data provide the first empirical, unbiased estimates of change in soil carbon for wetlands of the United States, and demonstrate the power of probabilistic surveys for upscaling data collected at a limited number of sites to regional and national scales. Understanding wetland carbon storage at large scales provides critical insight for the effective management of carbon stocks for climate regulation.

Human Impacts to Northern Wetlands - Scaling GHG Fluxes for Canada's National GHG Inventory

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There is increasing need for better reporting of carbon and GHG fluxes resulting from wetland disturbance in national inventory reports. In Canada, development in the North and in the Alberta oil and gas region impacts areas with high proportion of wetlands. The consolidation of knowledge and development of tools is an important first step in the quantification of the net GHG impact of these complex disturbances on wetlands in these areas. Long-term monitoring data, with broad spatial coverage are lacking to parameterize models. Default methodologies proposed by the Intergovernmental Panel on Climate Change for calculating GHG emissions and removals from wetland disturbance have limited application to the types of complex disturbances observed in these regions. To lower uncertainty of estimates, it is important to develop country-specific methodologies that reflect the wide regional landscape variability existing in Canada. We present an analysis of knowledge for up-scaling wetland models, as well as novel approaches and lessons learned to resolve data gaps. One such approach is the Delphi consultation, a quantitative technique used to generate consensus among experts on driver-based measures when adequate empirical data are not available. Further we discuss two examples of national-scale tools (the Northern Land-Use Change model and The Canadian Model for Peatland) currently being developed to address the need to better account for GHG emissions resulting from wetland disturbance. Using the development of these tools as examples, we look at pros and cons in methodologies to parameterize large-scale GHG models.

Modeling tidal wetland carbon cycling in the USA using data from a range of spatiotemporal scales

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We developed a model of carbon cycling in tidal wetlands of the coterminous USA with the objectives of 1) assessing baseline carbon pools and fluxes in coastal wetlands and 2) projecting scenarios of climate and land use change impacts on carbon sequestration in coastal wetlands. We adapted the Land Use and Carbon Scenario Simulator (LUCAS) model for use in tidal wetland ecosystems using both site-level carbon cycle data and remotely-sensed land use and land cover (LULC) data. LUCAS combines a state-and-transition simulation model (STSM) to predict land change with a stock and flow model to simulate carbon dynamics, within a scenario-based framework to assess major controlling processes, characterize uncertainties, and develop future scenarios. As a test case, we calibrated LUCAS for the tidal wetlands of the Mississippi River Alluvial Plain (MRAP), using measurements of carbon pools and fluxes across 24 sites, covering a range of salinity. We then assessed tidal zone carbon sequestration under current conditions with static LULC and with historic LULC changes. Our results highlight that estimates of carbon sequestration in this region are extremely sensitive to assumptions about the fate of soil carbon when coastal wetlands transition to open water with relative sea level rise. We further show how empirical distributions from calibration data can be used to estimate projection uncertainties using a stochastic Monte Carlo modeling approach. The modeling approach developed for the test case ecoregion was then extended to assess the effects of land use change on tidal zone carbon sequestration across the coterminous USA.

Scaling-up spatially-explicit to regionally-relevant estimates of wetland carbon accounting for prairie potholes

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Wetlands are a characteristic feature of agricultural landscapes in Canada. There is growing interest in preventing wetland loss and restoring wetlands to serve as biological sinks for carbon. Here, we present the results of a project that will improve understanding of wetlands as bioreactors of carbon, sequestering carbon dioxide and emitting methane. Compiling data from hundreds of studies, we improve the understanding of ecologically driven spatial heterogeneity in estimates of wetland carbon and greenhouse gas (GHG) fluxes throughout the Prairie Pothole Region of North America. We use a combination of on-the-ground and remote sensing approaches to scale estimates from sites to the entire region, and to produce a 50-year time series of these estimates based on empirical models that relate key environmental factors (i.e., climate, hydrology and soil properties) to wetland carbon and GHG fluxes. By comparing the spatially-explicit estimates of intact wetlands to drained or restored wetlands, we show the influence of agricultural intensification on the wetland carbon accounts of the region. The project will also use and refine process models, so that the relative importance of wetland contributions to carbon and GHG fluxes in agricultural landscapes can be forecasted under different climate change scenarios. This information will be used to inform a methodology compatible with methodological standards established by the Intergovernmental Panel on Climate Change for use in Canada's national GHG gas inventory. Quantifying the contribution of the human management of wetlands drainage and restoration is an important step towards carbon credits and Canada's emission reduction objectives

Spatially-explicit model of methane emissions from prairie pothole wetlands

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Almost half of all biogenically-produced methane emitted to the atmosphere is emitted by small lakes and wetlands. The Prairie Pothole Region (PPR) of central North America contains 5–8 million wetlands, which can influence continental and global methane budgets. However, there is considerable uncertainty of current and future emissions of methane from PPR wetlands due to a lack of landscape-scale models based on robust, empirical data. We used a bottom-up approach to develop a spatially-explicit, temporally-dynamic model of wetland methane emissions from PPR wetlands. Using a dataset of >20,000 static-chamber flux measurements, we developed a chamber-based model of methane flux and then upscaled to the landscape using GIS and remotely sensed proxies. Covariates in the chamber-based model included water-filled pore space, soil temperature, wetland size, land cover, and normalized difference vegetation index (NDVI). Proxies for upscaling included the Dynamic Surface Water Extent based on Landsat, ClimateNA, and the North American Land Change Monitoring System. Total emissions from the PPR ranged from 0.1 to 1 Tg CH_4 per year during historic dry and wet years. Future warm temperature scenarios (RCP 8.5) indicate methane emissions from the PPR could increase significantly, although wetland extent is the primary driver of regional emissions.

HOW IN THE WORLD DO WE GET PEOPLE "INTO" WETLANDS? CEPA ENGAGEMENT CASE STUDIES FROM AROUND THE GLOBE.

Karen Denyer[1], Chris Rostron[2], Christine Prietto[3]

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We benefit in so many ways from wetland ecosystems, yet many people remain unaware of the vital role they play in sustaining our lives: purifying water, protecting life and property from storm surges, tsunamis, floods, and droughts, and permanently storing carbon. Wetlands are of great cultural and spiritual significance to indigenous communities and are often biodiversity hotspots. Despite these values some 64% of the world's wetlands have disappeared in the last century, including 90% from New Zealand.

Access to and interaction with nature has been shown to contribute to both mental and physical well-being, and awareness-raising is an effective way to increase appreciation and understanding of wetland values, and ultimately better protection and restoration of wetlands.

The Ramsar Convention promotes the application of CEPA (communication, capacity building, education, participation and awareness) programmes to engage people in wetland protection, restoration and wise use. Effective use of CEPA requires a planned systematic approach which reflects the interests of stakeholders and beneficiaries. Approaches need to be tailored to the local context, culture and traditions. International experiences can guide the formation and implementation of national and regional CEPA plans and programmes.

In this symposium we will explore a wide range of CEPA initiatives from around the world via a live panel session and a series of rapid-fire case study presentations.

Strategies for connecting people with wetlands

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The Ramsar Convention introduced its first education programme in 1999 at COP 7 in Costa Rica. The Ramsar Outreach Programme encouraged member countries to develop programmes to promote and educate people about wetlands. Three years later it was introduced at COP 8 as the Ramsar Communication Education and Public Awareness programme and the acronym "CEPA" came into being. Over the years CEPA has frequently come to be used as a word on its own. Useful or not as that may be, it's use is widespread.
In 2008 at COP 10 in Korea, the Ramsar CEPA Programme was re-introduced as the Communication, education, participation and awareness programme.
If one unpacks the acronym, each of these four words represent different audiences, different threats and different tools. Across the 171 countries that are members of the Ramsar Convention there are many wonderful examples of how CEPA initiatives have been developed and applied. In my presentation I would like to focus on participation. I will use the story of Shortland Wetlands Centre, now Hunter Wetlands Centre to showcase how direct participation in wetland management can help people understand wetlands, love wetlands and want to conserve wetlands. I will include what has worked or not worked at site level, challenges faced and also how the site level achievements have impacted on broader conservation status for the whole of the Hunter Estuary, NSW.

Wetland centres as CEPA delivery tools

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Wetland Link International (WLI) is a network of over 300 wetland centres across the globe. It forms part of the delivery mechanism for Ramsar's CEPA programme (communication, capacity building, education, participation and awareness). Wetland centres support a range of CEPA activities on site, leading to increased knowledge and awareness, and ultimately to behaviour change and action for wetlands. The presentation will include:

- The definition of wetland centres, their structure and common concepts (mix of conservation, education and recreation; zoned sites to enhance visitor/wildlife interaction; trained staff to deliver positive experience; wildlife-sensitive built infrastructure)
- Positive outcomes of wetland centres (raised awareness; informal and formal learning; positive action for wetlands; limit impact on wildlife).
- Challenges of wetland centres (preaching to the converted; superficial experience of wetlands with no long term benefits; negative impact on the wetland resource; exclusion of locals in 'pay to enter' wetlands; long term funding sources)
- Recommendations for a good wetland centre (do good master plans at the start; build in flexibility of design; avoid captive animal collections unless you really know what you're doing; change the offer regularly; low tech versus high tech)

Automated elevation corrections using GPS/GNSS to measure water levels in a subsiding Louisiana estuary, USA

James Fountain[1], Christopher Swarzenski[1]
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In coastal Louisiana, where downwards VLM (vertical land movement) can exceed 1 cm per year, USGS routinely collects water-level data spanning periods of 40 or more years. Maintaining water elevations to an absolute datum considering GPS/GNSS solution variability requires innovative approaches. Staffing to collect the large number of observations traditionally needed to reconcile these VLM differences is cost-prohibitive. Instead, autonomous data collection using a minimally labor-intensive processing solution is required. To this end, low cost dual-frequency GPS/GNSS receivers were permanently deployed at data collection platforms. Data collection from these receivers consists of a twelve-hour observation, synchronized between all deployed receivers, once every seven days. The resulting data is then telemetered for further processing and evaluation. Data processing is handled through submission of observations to the US National Geodetic Society (NGS) Online Positioning User Service (OPUS). Standardized protocols continue to evolve but initial results indicate that with proper grouping of one to three months of data, relative accuracy of +/- 0.01 to 0.02 meters with 99% confidence can reliably be expected. These data can be used to correct in near real time water levels to an absolute datum that can be tracked over long periods and updated as new and improved GEOID models are developed. These data can also be adapted to develop regional subsidence models. By adapting the techniques to the rSET protocol (rod Surface Elevation Table to measure marsh elevations, an understanding of how entire coastal areas experience VLM in surface waters and adjacent wetlands may be obtained.

Estimating wetland relative sea-level rise using 20 years of SET-MH, GNSS, and tide gage data

Dr Camille Stagg[1], Dr. Christopher Swarzenski[2], Mr. Richard Day[1], Dr. Brian Perez[3]
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The persistence of coastal wetlands during periods of sea-level rise is an indicator of ecosystem resilience. As sea levels rise, resilient wetlands increase surface elevation through hydrogeomorphic mechanisms to maintain acceptable flooding conditions. Thus, the ability to accurately measure sea-level rise, and the elevation of the wetland relative to changing sea level, is critically important to assessing the resilience and persistence of coastal wetlands.
Over the last 25 years, scientists have introduced several methods for improving these estimates. The surface elevation table-marker horizon method (SET-MH) measures movement of the wetland surface relative to a stable benchmark. Further progress was made with the introduction of wetland relative sea-level rise (RSLRwet), which specifies the movement of the wetland relative to local relative sea-level rise and requires the co-location of SETs with tide gages.
Nonetheless, in coastal wetlands where vertical land movement (VLM) dominates, acquiring accurate estimates of RSLRwet is especially difficult because the benchmark itself may be moving. In this case, the use of global navigation satellite systems (GNSS) in conjunction with SET-MH and tide gage data may provide a more accurate estimate of RSLRwet. Our dataset incorporates multiple acute disturbance events including hurricanes, sudden vegetation dieback events, and major river flood events, in the high-VLM setting of the Mississippi River Deltaic Plain. We compare RSLRwet from four coastal salt marshes along a gradient of mineral supply and elevation collected using SET-MH, GNSS, and tide gages over the last 20 years at duplicate stations in each marsh.

The Implication of Vertical Land Motion on Coastal Wetlands:

Subsidence and Uplift along the Plate Boundary in New Zealand

Dr Paul Denys[1], Dr Andrew Swales[2]

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Vertical land motion (VLM) affects coastal sedimentary environments and can be, as in New Zealand, a major driver of change. The fate of coastal wetlands depends on substrate elevation keeping pace with relative sea-level rise (RSLR). Increasing sea levels due to processes such as subsidence, sediment compaction or climate warming will dictate the RSLR trend at any given location.

Continuous and campaign Global Navigation Satellite Systems (GPS/GNSS) technology have been used to measure VLM to accuracies in the order of ±4-6 mm (rms). Measuring VLM is technically challenging. Compared to horizontal deformation, vertical deformation signals are typically an order of magnitude smaller as well as being 2–4 times less precise. The challenges include biases that are difficult to either control or model including atmospheric delays, antenna-phase centre errors and ocean loading.

Here we present three case studies that demonstrate how VLM has influenced development of coastal environments. Firstly, the impact of the Mw 7.8 Kaikoura 2016 earthquake that caused uplift and subsidence of the lower North Island and upper South Island at the centimetre level; secondly how the 2010-11 Christchurch earthquakes have induced ongoing post-seismic subsidence of the Heathcoate-Avon estuary , and; lastly monitoring the subsidence of a mangrove forest (Firth of Thames) observed at Rod Surface Elevation Table benchmarks (~8mm/yr) that is consistent with sedimentary records.

While major earthquakes create an immediate and obvious impact, more gradual and less obvious slow slip events and VLM processes have a major influence on the development and fate of coastal wetlands.

Twenty years of Saltmarsh Elevation Dynamics Measured using GPS/GNSS and Water Levels

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Coastal wetland sustainability requires maintaining elevation relative to long-term water level trends. The rSET (rod Surface Elevation Table) is a standard approach to clarify these relations. In areas with rapid VLM (vertical land movement), the elevation of the rod may move vertically, and other methods may be needed. In coastal Louisiana, VLM results in 0.3 to over 1 cm of subsidence per year. The US Geological Survey has tracked changes in marsh elevation at four replicated salt marshes since 2000 using repeat GPS (Global Positioning System) surveys of concreted benchmarks, laser-level surveys of marsh elevation relative to the benchmarks, and local tide gage records. The sites align along a gradient in mineral sediment availability. Accretion rates using Cs-137 dating ranged from 0.49 cm/y to 0.99 cm/yr. GPS surveys did not resolve absolute and relative changes in benchmark and marsh elevations over the 20-year study. Instead, bracketing marsh elevations to averaged daily high water and daily water levels in 2002 and again in 2020 was enough to evaluate relative marsh elevation changes. The efficacy of local water levels in assessing marsh surface elevation change over time at these delta plain salt marshes, separated by over 45 miles, is explained by the uniform water level regime. The development of low-cost pressure transducers to measure water levels needing few servicing trips as well as improved low-cost GPS receivers are tools that can complement rSET techniques, especially in areas experiencing significant VLM.

Managed Realignment – Experience from the UK

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Managed realignment - creating space for natural dynamic processes along the coast - is now a widespread measure employed in the UK and an important component of green infrastructure. More than 70 managed realignment projects have been completed since 1991, the most of any European country.

Managed realignment projects in the UK are driven by the need to address an historic loss of internationally important intertidal habitat caused by coastal squeeze – when coastal habitats are trapped between a fixed landward boundary, such as a sea wall and rising sea levels and/or increased storminess. The UK government has set a target to create 3,000 ha of saltmarsh in next 100 years.

At 550 hectares, Steart Marshes on the north Somerset coast, is the UK's largest managed realignment project. The marsh is built on low lying improved pasture/cultivated land create the 2.9 km creek network, flood defences and habitats. 320 ha of saltmarsh was created, 80ha of freshwater and 50ha of 'transitional' brackish habitat.

Steart Marshes has become a site that demonstrates best practice in public engagement; is an exemplar of landscape and over one million tonnes of material had to be excavated to wetland design; and provides benefit to people and wildlife. The estimated ecosystem service benefit is £490k - £950k each year and the quantified benefits for carbon sequestration are emerging.

We will provide detail on the design, planning, construction and operation of Steart Marshes and the multiple green infrastructure benefits it provides.

Opportunities for Integrating Prairie Pothole Wetlands into Urban Communities

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Urban environments provide a unique opportunity to bring wetlands and people together in a very accessible way. When done sustainably, urban wetlands can provide a catalyst for growing public support for wetland protection initiatives and show people that wetlands are home to a diverse array of wonderful plants and animals, and not just mosquitoes. The natural functions of wetlands can also be harnessed to improve stormwater treatment while creating valuable amenities for residents.

This presentation will explore ways urban prairie pothole wetlands have been successfully brought into the urban fabric of Calgary, Alberta, Canada. We'll also discuss some of the considerations and challenges that come with incorporating wetlands into urban settings.

The 4G Ranch Wetlands: The Wetland Solution to Groundwater Recharge, Improved Water Quality, and Habitat Creation

Ms Allison Lewis[1], Mr. Rafael Vazquez-Burney[1], Mr. Jeff Harris[2]
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In 2017, the largest groundwater recharge wetland in the world, known as the 4G Ranch Wetlands, was constructed in Florida. Groundwater recharge wetlands are constructed wetlands that do not have a surface water outflow and water is applied at the rate of infiltration to the underlying aquifer. The 4G Ranch Wetlands serve as a wet-weather management solution for Pasco County's reuse system and recharge 19 Ml on annual average to the aquifer system. Located in an area suffering prolonged drawdown by regional wellfields, the 4G Ranch Wetlands also restore nearby hydrologically-altered lakes and wetlands.

Through a public-private partnership, the 4G Ranch was identified as a suitable site for the infiltration wetland. The 70-hectare 4G Ranch Wetlands are comprised of 15 individual cells that are operated via water level measurements and flow control valves. Driven by the 4G Ranch's desire to use the system for recreation, the wetland system includes several ecological design features and a mosaic of wetland habitats with transitional, shallow, and deep-water zones.

The wetlands have been in operation since 2017 and water levels of each wetland cell are adjusted seasonally to achieve healthy wetland hydroperiods and encourage the growth of desirable wetland species. Since operation, the 4G Ranch wetlands have been monitored for the success of the planted wetland vegetation establishment, the rate of infiltration, nitrate reduction, and presence and diversity of wildlife.

This presentation presents the wetland design, construction methods, and an update on the success of the overall wetland system following three years of operation.

Emerging studies on the structure and function of coastal urban wetland ecosystems in Miami FL, USA

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Wetlands are a unique type of urban ecological infrastructure (UEI) because they have ecological structures and functions that are both terrestrial and aquatic, and in human-dominated landscapes may confer ecosystem services at levels of wetlands found in “natural” environments. In South Florida, these ecosystem services can be based on high levels of productivity given the sub-tropical climate and low-lying elevation, providing unique places and opportunities for both remnant natural wetland and natural-built types of urban ecological infrastructure to emerge and persist. Mangrove wetlands are among those ecosystems with often high rates of productivity and relatively large rates of organic carbon sequestration, in addition to their potential for providing water quality regulation, storm surge protection and fisheries habitat services. The potential for natural, restored and created wetlands in urban environments to confer ecosystem services are not well understood, and cannot necessarily be inferred from natural systems in more pristine environments. To further our understanding of mangrove UEI, we are undertaking studies characterize their ecosystem structure and function in Miami, Florida. Studies include estimation of carbon stocks and sequestration between natural and restored urban mangrove wetlands, assessment of vertical accretion relative to local rates of sea level rise in natural mangrove wetlands of urban environments, and emerging studies on the role of hybrid and created mangrove shorelines in sequestering urban contaminants. These types of studies will further our understanding of the role of UEI and the ecosystem services they contribute in coastal urban environments.

Long-term trajectory of constructed (treatment) wetlands towards urban sustainability and the simplicity (or not) of it: from functions to services, from ecologists to urban planners

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The majority of wetlands on Earth have been depleted for human purposes over a few centuries. Today, as the landscape has dramatically changed and half of the world population is about to become urban, wetlands and their anthropic constructed counterparts are reconsidered anew. From the very ecological functioning of these turquoise urban ecological infrastructures, ecosystem services are retrieved by society to achieve urban sustainability. From fieldwork achieved in the city of Strasbourg since 2012, we will discuss the significance of wetlands in the field of urban storm- and wastewater management. We will especially focus on i) the shift from ecological functions to ecosystem services and the subsequent trade-offs, ii) the transfer and adoption from scientists to urban planners and iii) the simplicity of the implemented wetlands. We will try and provide elements for a larger discussion on what makes wetland UEI useful and what still needs to be done to make the best out of it. We will thus introduce simplicity as a way to measure the gap still to be bridged towards sustainability, and long-term thinking as a way to more integrated and relevant knowledge about wetland UEI.

Nine years of long-term research on a “working” constructed treatment wetland in Phoenix, AZ, USA: An example of turquoise Urban Ecological Infrastructure

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Urban ecological infrastructure (UEI) is a recently revived term for “nature in cities”. As a concept, UEI is fully inclusive of the myriad ecological structures and functions found in cities. We have been quantifying a number of ecosystem-level parameters in the City of Phoenix’ Tres Rios constructed treatment wetland (CTW) since July 2011. The wetland vegetation and soils are sequestering large amounts of nitrogen. Our whole-system nutrient budgets also show considerable nitrogen uptake, but rates are not as dramatic as within the marsh proper. Plant transpiration and water budget measurements show large water deficits, particularly during the hot summer months.

Peak summer plant biomass is typically 1.5 - 3 kg dw m-2 for the five dominant species (2 species of Typha and 3 species of Schoenoplectus); Typha biomass makes up 80-90% of this. Evaporation and transpiration rates are highest during the hot summer months, with high temperatures exceeding 45°C and humidity as low as 2%. During this time, evaporation and transpiration account for roughly 90% of the water deficit; up to 75% of that is transpiration. Transpiration-driven water losses equate to a residence time of 5 – 8 days for the water overlying the marsh. We used controlled tracer studies to confirm that plant transpiration is driving a lateral “tide” that brings new water and nitrogen into the vegetated marsh, making this CTW more effective at nutrient removal than similar UEI in cooler or mesic cities. This is the first evidence of biological control of surface hydrology in a wetland.

Restoration of the Kafue Flats, Zambia, as a Working Wetland for all

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The Kafue Flats is among Africa' premier wetlands, home to the global population of endangered Kafue Lechwe antelope, 30% of all endangered Wattled Cranes, diverse large mammals and bird species, and a wealth of ecosystem services. For millennia, the ecological health of the flats was maintained by communities that used the flats for livestock, fisheries, and subsistence hunting. In recent decades, however, the breakdown of traditional management structures and weak government regulation have resulted in the near collapse of the flats, with unsustainable levels of poaching, grazing, fishing, hydrological degradation, and invasive species. These changes are exacerbated by climate change, with more prolonged droughts and water scarcity. Kafue lechwe are in dramatic decline, and waterbird breeding conditions are rapidly deteriorating. Through a new 20-year agreement with Zambia to co-manage the Kafue Flats, we are creating a new protected area model for Zambia based on the concept that a "working wetland," with the right balance of government protection and community empowerment, can sustain a rich biodiversity, local livelihoods, economic growth, and improve climate-resiliency of the local population. We are improving law enforcement, while concurrently empowering the communities around the flats to adopt land use conservation strategies linked to their traditional management structures for wildlife, livestock, and fisheries. Our approach builds on a successful invasive species control project underway, in which communities have been hired to clear more than 3000 ha. of invasive mimosa shrubs while earning scarce income used for school fees, livestock production, home repairs, food security, and other purposes.