Wetlands and people at risk

Edited by Claudio Baigún, Priscilla Minotti and Birguy Lamizana

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Foreword

Wetlands and people at risk seeks to bring awareness of important at-risk wetlands systems in different world regions by portraying their status, problems and conflicts related to human impacts as well as the effects of the loss of their ecosystem services on people's livelihoods.

Wetlands are among the world's most productive and valuable ecosystems. They are natural reservoirs of biodiversity, providing ecosystem services and critical livelihoods for many populations. However, their conservation has been threatened worldwide by accelerated changes in land and water use.

Because people use wetlands in different ways, it is important to highlight the direct relationship between a wetland's conservation status and local peoples' livelihood and well-being. Although wetland users easily perceive this link, it is not always clear to others how wetlands can provide high-quality benefits with the application of a few rational and sustainable management measures. However, pressure on wetlands has increased, particularly in densely populated freshwater and marine coastal areas, putting these unique ecosystems at high risk. While some damage to wetlands is obvious–development, pollution, and deforestation of mangroves leave scars–the worst damage can be insidious and invisible.

Because wetlands are created by complex hydrological systems, simply diverting water flow to agriculture, holding back water with a dam or siphoning it away through channels can starve and even eliminate wetlands.

To reverse the serious worldwide damage to wetlands, an updated diagnosis of the major threats is needed as well as prescriptions to implement sustainable management policies supported by appropriate legal frameworks. The conservation of wetlands is a challenging priority for the 21st century that must be addressed by initiatives such as those noted in this book. Instead of describing only problems and conflicts faced by wetlands in different regions of the world, the book proposes suitable management practices and solutions for the recovery and conservation of the different types of wetlands studied. Such solutions are presented to help environmental managers to restore and protect wetlands by integrating monitoring and assessment activities and sound restoration practices.

a. andrade

Angela Andrade

Chair, IUCN Commission on Ecosystem Management (CEM)

Executive summary

Wetlands are among the world's most productive and valuable ecosystems, covering 5–12 million km^2 of the Earth. Wetlands are an integral part of many ecosystems encompassing freshwater, tidal and brackish marshes, fens, bogs, swamps, mangroves, and many others. Water and hydrological processes largely determine wetlands structure and functioning while their hydrodynamics define wetland's characteristics.

Wetlands provide around 40% of the global ecosystem services critical to people's livelihoods. They regulate biogeochemical cycles, and provide habitats for species, goods such as food (fruit, fish), raw materials (timber, firewood, reed and peat), and genetic, medicinal, and ornamental biodiversity resources. Not surprisingly, wetlands have attracted human settlements and is the environment where most of the great cultures flourished throughout the history.

However, despite the undiscussed benefits, about 50% of the world's wetlands have been lost since the beginning the 19th century, with significant consequences for human well-being and the environment. In many of the industrialised countries but also in other parts of the world, wetlands have been severely degraded or drained by agriculture and urban expansion. This problem has been severe in large river systems where floodplains have been isolated and used for urban and agriculture purposes Intensive agriculture alone is responsible for the drainage and consequent loss of 56–65% of the wetlands in North America and Europe, and 27% in Asia. In low populated areas, major threats to wetlands include agro-industrial expansion, deforestation, soil erosion, urban and agricultural pollution, mining and large infrastructure development.

This book attempts to raise awareness on the relevance of wetland systems and their current impacts and existency threats in different regions of the world. The book aims at describing the status, challenges and loss of wetlands related to conflicts between anthropic activities and natural ecosystem services fundamental for people's livelihoods. The book compiles 14 case studies from different world regions in the world and wetlands typologies, including terrestrial, riverine, estuaries, marine coastal wetlands but also island wetlands. Independently from the typology, wetland ecosystems face common and peculiar issues in this context, and in the spirit of pushing for ecosystem resiliency management practices and ad hoc solutions for an effective recovery and conservation of wetlands are presented.

Many are the examples that could shed light on the reasons why wetlands should be preserved and restored. Terrestrial wetlands are known to encounter multiple risks hampering their existence and impacting their functionality. In The Tablas de Daimiel National Park, one of Spain's most at-risk wetlands, upstream dams have been constructed, rivers have been channeled and wetlands were transformed in dryland farming areas by increasing groundwater extraction for irrigation and contributing to rivers and wetlands drying.

In the area of Lake Ohrid in Macedonia and Albania, the oldest inland water in Europe, wetlands such as Studenchishte have been degraded and drained and large portions have been paved or converted to farmland. Iran's Gavkhouni Lake has dried up because of excessive water abstraction for agriculture, industry, and other uses. In the past, agriculture was seasonal and based on water availability, but rapid economic and industrial development, coupled with large-scale water infrastructure projects have reduced the size of this valuable wetland causing its degradation.

In Colombia, the Lake Fúquene basin was transformed to improve conditions for cattle raising. The catchment area suffered intensive deforestation, leaving only small fragments of native forest. Water contamination was caused primarily by untreated sewage outflows from the nearby towns, milk processing by-products, coal mining operations upstream and water drainage from cattle ranches. Interestingly, a peripheral channel, intended to address the contraction of the water body, was dredged around the littoral zone, causing a disruption of the hydraulic regime and limiting the natural interactions between the shore and the limnetic zone and constraining the wetland's area. This showed the importance of understanding the natural processes that govern wetlands functioning and their relationship with basin processes.
The Ciénaga La Palmita in Venezuela was affected by hydric restriction of the Aurare Rive. Other identified impacts corresponded to the presence of invasive Mozambique tilapia, forbidden fishing practices, clandestine hunting, extraction of wood and solid wastes organic matter, fishing, biodiversity, wood, recreation, and tourism. Finally, a wetlands complex located in Venezuela shows the effects of the combined impacts of fences, power lines, roads and highways, solid waste, buildings and homes, and cattle farming.

Riverine wetlands can be severely damaged by dams, as in the Massili River in Burkina Faso, where damming caused a drastic change in the flow regime with consequences such as upstream floods and downstream droughts. The severe alteration of the river flow had major repercussions on the poor, local population and revealed how local land-use decisions can result in environmental damages that impact people's livelihoods and lead to food insecurity. Another example is the Danube River in Austria, where river flow regulation increased the loss of endangered species by degrading wetland habitats, just like in the case of the water soldier. This case is paradigmatic as it shows how change in a species that played a key ecological role affects the riverscape and related ecosystem services.

In many estuaries, land uses in the adjacent ecosystems have degraded the physical, biological and socio-economic status of wetland ecosystems. For example, Sri Lanka's Negombo estuary and associated waters are rich in natural resources, such as mangroves, seagrass beds, coral reefs, salt marshes, sandy beaches and commercially important fish and shellfish. Land use patterns on adjacent ecosystems and natural and anthropogenic activities within and upstream from the estuary are degrading the physical, biological and socioeconomic status of this highly productive and extremely biologically diverse wetland ecosystem. Excessive damming has affected the Guadiana estuary between Spain and Portugal. Dams increase the estuary's salinity, reducing the amount of habitat available to freshwater species, and thus change the estuary's fish assemblages. Other activities with medium and high impact include the release of untreated household sewage and wastewater causing diffuse pollution to surface waters, and construction of dykes and embankments, which modify tidal and marine currents.

Marine coastal area wetlands, such as Laguna de Raya, Venezuela, face risks such as overfishing and extraction of the local sea urchin species, aggressive fishing techniques, pollution caused by residual wastes from boats and refrigeration trucks, and felling of mangroves trees. On the German Baltic Sea coast, the nature reserve 'Heiligensee and Hütelmoor', a peatland complex including coastal fens and a peat bog, attracts enough tourists to create a conflict between nature protection, management of the forest and touristic interests. Scientific activities also contribute to human disturbance of wildlife and coastal erosion is a continual natural threat to the area.

Island wetlands have similar problems. In the Virgin Islands, activities such as crop cultivation, cattle grazing and nutrient runoff from urban areas has had adverse impacts on a wetland. Another case is in Salmon Islands where overfishing and deforestation affected inland lagoons.

Aware of the fact that the examples here presented are few of the multiple impacts and threats that wetlands have to face, we are convinced that such examples chould serve to draw attention on the need of more effective strategies aiming at recovering and conserve

wetlands and at the maintenance of their associated livelihoods.
It is expected that *Wetlands and people at risk* will represent a useful initiative to bring awareness to stakeholders and social actors that manage and are affecting the quality and quantity of wetlands related ecosystem services. The mosaic of the examples will also show how the application of a sound management practices and solutions for wetland effective recovery and conservation could help avoiding irreversible ecosystems loss.

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Introduction

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Wetlands are among the world's most productive and valuable ecosystems and cover between 5.3 million km^2 to 12 million km^2 of the Earth (Matthews & Fung, 1987; Finlayson et al., 1999). The Ramsar Convention (Ramsar, 2020) defined wetlands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres." Wetlands present a wide array of characteristic defined by the environment such as freshwater, tidal and brackish marshes, fens, bogs, swamps, mangroves, and many others. The dominance of water and the hydrological regime are main factors that determine the wetlands structures, processes and their functioning, thus translating in diverse ecosystem (Mitsch & Gosselink, 2007; Maltby, 2009; Acreman & José, 2000). Hydro-geomorphology, such as the geomorphic setting, their water source (fresh or marine, surface or underground) and their hydrodynamics (such as unidirectional flow or reversing flow) define instead wetland's characteristics (Brinson, 1993).

Despite covering only 1.5% of the Earth's surface, wetlands provide around 40% of global ecosystem services (Zedler & Kercher, 2005) and the span of ecosystem services (Costanza et al., 1997) vary largely and can become a critical component for peoples' livelihoods as providers of material goods, food (fruit, fish), raw materials (timber, firewood, reed, and peat), as well as genetic, medicinal, and ornamental resources (De Groot et al., 2012). Wetlands are also essential systems for regulating biogeochemical cycles and maintaining biodiversity and habitats (MEA, 2005; Gardner et al., 2015).

Throughout the history of humankind, wetlands have been sites of great attraction where important cultures flourished due to the supply of water and abundance of natural resources. Evidence of wetland's occupation is still found in the so-called water civilizations that inhabited the Nile and the Tigris and Euphrates valleys (Viñals et al., 2002, p. 263). In Latin America, many of the great civilizations such as the Mayans, Incas and Aztecs also developed at the expense of resources extracted from wetlands and even today these systems are critical for much of the human population (Roggeri, 1995; Carpenter et al., 2009).

The consistent loss of wetlands has been estimated to be 50% of the global existing wetlands (Rijsberman & Silva, 2006; ICSU, 2008).

It has been widely reported that 50% of the world's wetlands have been lost (or lost since 1900 (Davidson 2017). In many industrialized countries, but also other parts of the world, wetlands have been severely degraded and drained and drained for agriculture and urban expansion. In low populated areas, major threats to wetlands include agro-industrial expansion, deforestation, soil erosion, pollution, mining, and large infrastructural projects such as dams and reservoirs constructed for hydropower, river channeling, road construction, and navigation infrastructure (Wittman et al., 2015). Intensive agriculture alone has been responsible for the drainage and consequent loss of 56–65% of wetlands in North America and Europe, and 27% in Asia (MEA, 2005). Coastal wetlands are also threatened by human expansion and sea-level rise due to climate change (Nicholls et al., 1999). Climate change is projected to alter runoff and water availability by 2050, increasing at high latitudes by 10–40% and decreasing in dry regions by 10–30%. It will also increase extremes of dry and wet periods (IPCC, 2007). The loss of wetlands therefore could decrease ecosystem service provision, with significant consequences for the human well-being (MEA, 2005).

Management of wetlands and associated conservation policies has unfortunately not received the deserved attention and this is true in particularly in large transboundary basins. Basin management is key factor in maintaining wetlands' ecological integrity (Maltby, 2006) and therefore wetlands' vulnerability should be highlighted at different scales. In particular, the construction of dams and their regulation of water flow have been identified as one of the main causes of wetlands deterioration (Dudgeon, 2000; Kingsford & Thomas, 2004) and the ecological integrity of wetlands located in floodplains is strongly associated with main river channel connectivity over time (Sparks et al., 1990; Junk et al., 1989).

The conservation of wetlands becomes thus a challenging priority goal for the 21st century. A paradigm shift in the way we perceive wetlands is needed. Awareness must be raised of the socio-economic relevance of their ecosystem services, the impact of wetland degradation on poverty alleviation initiatives, and the potential role of wetlands in sustainable development policy frameworks (Maltby, 2009).

This book attempts to raise awareness on wetlands services and wetlands systems at risk in different world regions by portraying their status, problems, and conflicts related to human impacts and threats and symptoms of people's livelihoods reduction due to the loss of ecosystem services provided by wetlands. This book aims also at highlighting how attempts to restore wetlands have caused major damage because the restoration did not take into account a holistic perspective of the system, thus encountering serious natural management problems. In addition, and no less important, are the sustainable management practices and solutions for an effective wetlands' recovery and conservation. In this context, the book offers a series of management tools as environmental flow management, implementation of policies, legal instruments and regulations, environmental educational programs for local communities and policy makers; economic appraisal of the value of environmental services; payment for ecosystem services, and increased scientific research and monitoring to monitor the health of the wetland.

Fourteen case studies from different world areas showcase terrestrial, riverine, estuarine, coastal, and island wetlands. Chapters are grouped into sections reflecting these types of wetlands because each one represents particular challenges and has different management solutions. Each chapter begins with a section that highlights risks and solutions common to specific wetland types. Within each section, the authors of the case study present a brief description of the physical-chemical, hydrological, geomorphological, and biotic characteristics of the wetland, including species. Wetland's threats are identified and management conflicts are described in detailing most of the cases, corrective measures evaluation have been analysed. Finally, for each case study, recommendations and tools for effective recovery and conservation and management directions are presented.

We hope *Wetlands and people at risk* can bring the attention of managers and social actors to the quality and quantity of ecosystem services that wetlands provide, and the need to apply sound management practices and solutions for their effective and long-term recovery and conservation.

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SECTION

1 Terrestrial wetlands

Wetlands depend on reliable sources of water to maintain their ecosystems. If the water supply is cut off, they can dry up and disappear. The most existential threat to wetlands around the world, and especially to terrestrial wetlands, is the diversion of surface or groundwater water before it enters the wetland.

In terrestrial wetlands, this water is usually diverted to irrigate agriculture and for urban and industrial uses. In the upper reaches of river basins, it can also be diverted by dams built for irrigation or hydropower (also see riverine wetlands). The diversion of water can be total (as in Iran's Lake Gavkhouni) or partial or seasonal, which can alter the hydrologic regime of wetlands causing possibly irreversible changes in species composition. An example of such effects is noted in the Tablas de Daimiel, Spain, where the over drafting of groundwater was so great that it triggered a disconnection between the surface water and groundwater so that the aquifer failed to overflow and contribute water to the rivers and wetlands. In the Andes, water diversions for irrigation around Lake Fúquene have caused severe alterations of its natural hydrological cycles, modifying its ability to capture water in the rainy season and release it gradually during the dry time.

Extreme water diversions can threaten the health and well-being of neighboring populations. For example, in Spain, peatland that had been generated over millennia caught fire due to spontaneous combustion, which caused land subsidence and the emission of toxic gases. In Iran, Lake Gavkhouni dried up, leaving dying fish scattered on the mud. Much of the soil was covered in salt crystals, which were turned into a corrosive, poisonous dust when combined with toxic chemicals from upstream industrial agriculture and industry. With no lake water, formerly cooling winds became deadly dust storms that increased in frequency and virulence, raising concerns over air quality, health, and quality of life for the 12,000 people of Varzaneh and the 5 million people of Isfahan Province.

Misguided attempts to restore degraded wetlands over the decades have often made matters worse. For example, a water regeneration plan to channel the Gigüela River in Spain actually drained the alluvial aquifer, causing a drop in river water levels, which changed the relationship between the river and the river-bank wetlands as well as the flood dynamics of the wetlands. These wetlands are now either dry or significantly degraded. In another effort, a peripheral channel was dredged around of Lake Fúquene intended to address the lake's contraction. However, it disrupted the hydraulic regime, affecting normal water circulation patterns by limiting the natural interactions between the shore and the limnetic zone and thus constraining the wetlands area. The channel also isolated the central body of the lake from the lakeside ecosystems, thus water level fluctuations and pulses now depend on the management of floodgates. In addition, near this lake an attempt was made at reforestation during the 1980s, but the exotic species chosen (Pinus patula, Cupressus lusitanica, Eucalyptus globulus and Acacia decurrens) damaged the soil, increasing erosion.

Large-scale supply-oriented water infrastructure, once the common solution to meet water needs, is now understood as a major cause of environmental degradation. Gradually, many water managers have begun to follow the 500-year-old advice of the 'Toomar-e-sheikh bahaei' a water allocation plan in Iran's Zaindeh Rud River. This system allocated a share of water for the Gavkhouni Wetland, rather than trying to take all the water for human uses. It is one of the oldest policies of its kind in the world, an outstanding example of holistic water use in traditional management.

S1

CHAPTER

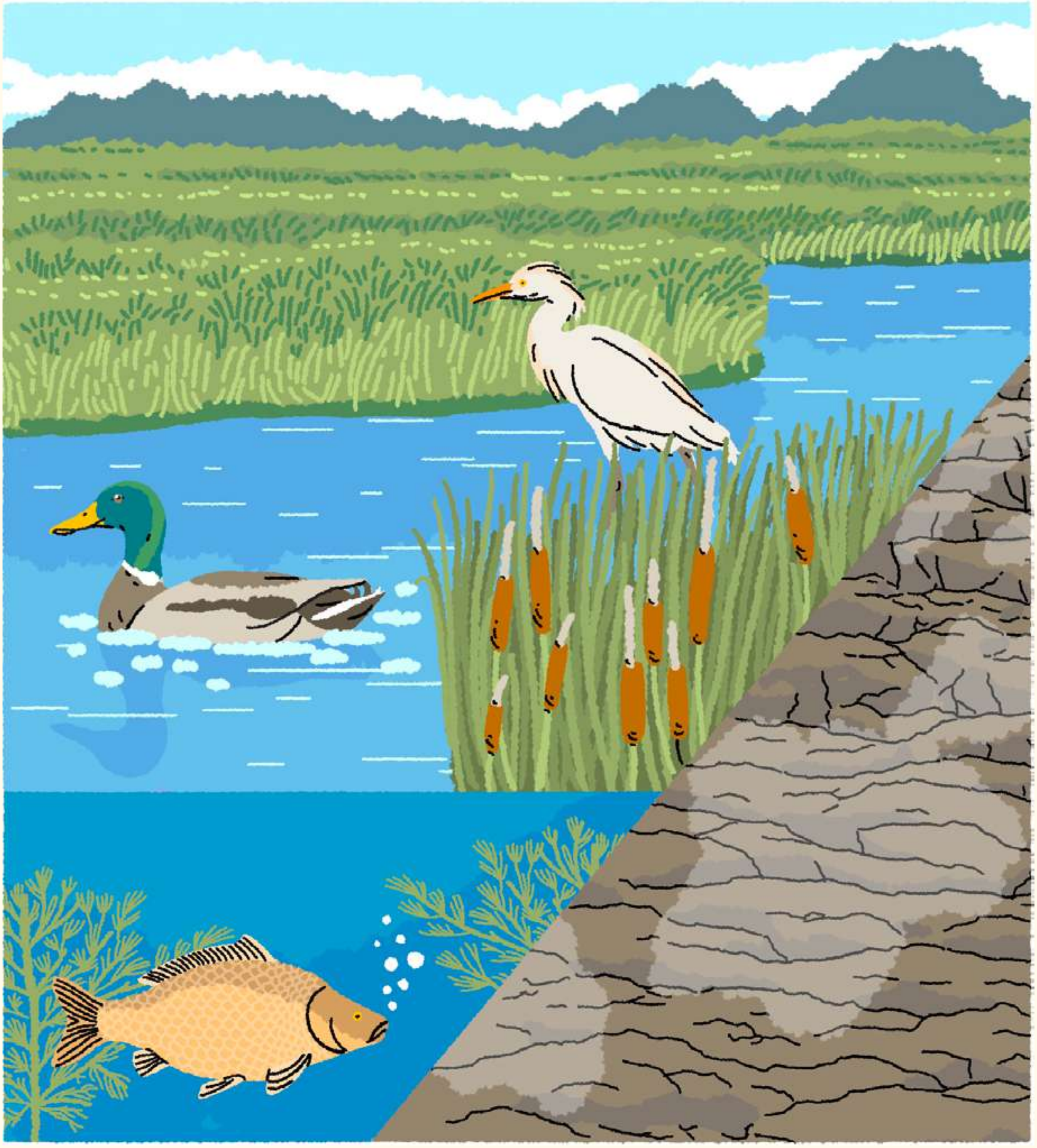
1

The Tablas de Daimiel National Park in Spain

By

África De la Hera-Portillo
Instituto Geológico y Minero de España (IGME-CSIC),
Madrid

Magdalena Bernués
Ministerio para la Transición Ecológica (MITECO)
Madrid



Abstract

The Tablas de Daimiel National Park is one of Spain's most at-risk wetlands. This wetland is a paradigmatic case because of its geographical situation, the history of its aquifer management, the stakeholders, and the aquifer's response to climate change and anthropic activity in recent years. This chapter summarizes the current status, problems, and conflicts of this wetland in an attempt to identify possible solutions for its recovery, conservation, and future management.

Keywords:

groundwater | hydrogeology | wetland | Tablas de Daimiel | Ramsar

Introduction

The Tablas de Daimiel National Park is part of a vast wetland plain in central Spain where groundwater bubbles up through *ojos* (eyes) to mix with river flood water and create marshy areas locally known as *tablas*. Saltwater, brackish, and freshwater rivers and lakes complete the setting. In the 1960s, as water was diverted for agriculture and as urban waste was allowed to flow in, the wetlands nearly dried up. Spontaneous peat fires burned and the ecosystem was thought to be irreversibly lost. By 2015, the hydrology was somewhat restored by an intra basin transfer of water, but because of farm and city pollution and differences in the water chemistry from the other basin, the original flora and fauna has not returned. Vigilance is needed to prevent activities outside the park from diverting its water again.

The Tablas de Daimiel National Park is the core of La Mancha Húmeda (25,000 ha), a UNESCO Biosphere Reserve designated in 1981. The park covers 3,030 ha, including the towns of Daimiel and Villarrubia de los Ojos, in the province of Ciudad Real, part of the Autonomous Community of Castilla-La Mancha (Figure 1). It is a floodplain wetland that also receives water from the groundwater discharge of a large aquifer. This part of Castilla-La Mancha region covered 25,000 ha when it was officially designated and was recently extended to 418,087 ha (BOE, 2014a) through the purchase of adjoining land that includes various lakes.

The water that forms the Tablas de Daimiel ecosystem comes from groundwater discharge from the Mancha Occidental aquifer; from the Guadiana River, which emerges in the Ojos del Guadiana, and also from the Gigüela River, which receives waters from the Riansares and Záncara Rivers before flowing into the national park from the north-east. The Gigüela River contribution is intermittent and is characterized by floods or severe droughts when the flow may drop to zero. The water from the Gigüela is brackish whereas the Guadiana contributes freshwater and the groundwater is of intermediate salinity.

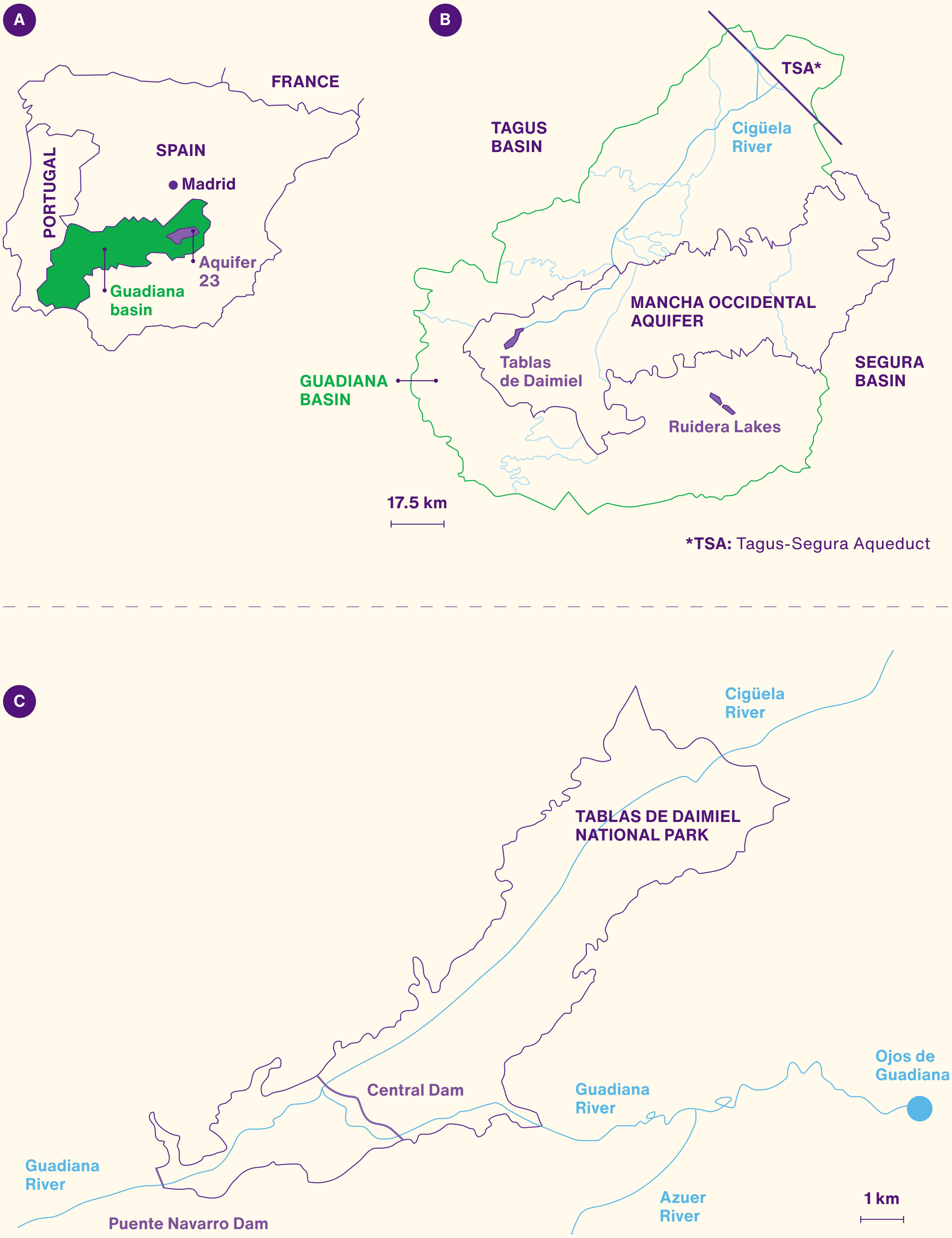


Figure 1. Tablas de Daimiel National Park.

(A) Location of the Guadiana River basin in Spain. (B) the Mancha Occidental aquifer (also called Aquifer 23) within the upper Guadiana basin.

Source: Map prepared by the authors.

The climate is semi-arid with irregularly distributed rainfall; the 1904–2014 mean was 405 mm per year, with a standard deviation of 118 mm (Martínez-Santos et al., 2018).

The Tablas de Daimiel are located on the wide Miocene plain of La Mancha, an area which is remarkably flat (with a continuous mean altitude of 610–630 m, exceeded only by occasional rises and isolated low hills). This extensive formation consists of limestone masses, limestone marls and Pontian limestone clays (Mejías, 2014).

Evolution of the Tablas de Daimiel

The Tablas de Daimiel are one of the best examples of efforts at wetlands management in southwestern Europe, both because of its status as an area protected by international, European and national legislation, and because of repeated attempts to stabilize the intensive groundwater use since pumping for irrigation began in the early 1970s.

For years (mainly in the 1960s), agricultural development channeled the rivers and the land dried out. This drainage of the wetlands led to a lower river level in the Guadiana from the Ojos to the Tablas de Daimiel, and the Tablas had dried up by 1971 (Serna & Gaviria, 1995). Because of protests by some environmental groups, these actions were halted and partly rectified (Llamas et al., 1996).

Five dams built in the upper basin of the Guadiana also reduced the river flow and its contribution to the wetlands (Serna & Gaviria, 1995). In particular, the El Vicario reservoir was built in the Mancha Occidental aquifer closing off the river basin, and the Puente Navarro Dam was built within the Tablas de Daimiel National Park to help flooding and to provide support to aquatic fauna.

The most important change was the conversion of dryland farming to irrigated farming, which since 1970 has included 100,000 of the 512,000 ha overlaying the aquifer (20% of its surface area). This was in addition to the 30,000 ha already under irrigation in 1970 (Serna & Gaviria, 1995). This change was accompanied by a considerable increase in groundwater extraction from the aquifer which exceeded the aquifer's recharge rate. Between 1960 and 1976 the pumping was estimated at 150 million m^3 per year. By the late 1980s, it increased to 600–700 million m^3 per year (4–5 times higher) and by 2006–2008 it was 300–400 million m^3 per year (2–3 times higher). These actions caused a drastic drop in flow contributions (both surface and groundwater) of 0.5–2 m per year from the mid-1970s (Martínez-Cortina, 2001; Martínez-Santos, 2007).

By the early 1980s, the over drafting of groundwater was so great that it triggered a disconnect between surface water and groundwater, so that the aquifer failed to overflow and contribute water to the rivers and wetlands (Mediavilla, 2013). This fall in the hydraulic head combined with an extreme drought during the early 1980s and the arrival of considerable pollutant loads from urban areas, significantly modified the hydrology and endangered the existence of the local ecosystem, the local biodiversity and the animal and plant populations. The biggest cause for alarm was the desiccation of the Ojos del Guadiana – the groundwater discharge area – in 1984.

The main problem of wetland conservation in general, and of the Tablas de Daimiel in particular, is that altering the water flows into the system can modify hydrological and ecological functions (Llamas et al., 1996), which can cause almost complete desiccation of the rivers and wetlands.

Because of the lost water flows, the wetland surface area in the Mancha Occidental aquifer for the Tablas de Daimiel has declined from nearly 25,000 ha to 3,030 ha, most of which is severely degraded (De la Hera et al., 2003). By 1985, the Tablas de Daimiel were practically dry (García, 2002). Without direct contributions from the aquifer, the only incoming water was from the brackish Gigüela River, which increased the water and soil salinity in the Tablas, increasing pollution and eutrophication, and changing the vegetation. This has resulted in a reduction in the number of life-giving species (García, 2002).

In 1987, the aquifer was declared provisionally overexploited, and in 1994, definitively overexploited. The 2sd cycle River Management Plan (2016–2021) report stated that the Mancha Occidental I, II and Rus-Valdelobos, as well as other groundwater bodies of the upper Guadiana basin, were at risk of not fulfilling the standards required by the European Water Framework Directive river basin management plan of 2000 (BOE, 2014b, 2014c, 2014d). The Mancha Occidental aquifer is included in the “nitrate vulnerable zone” within the European Nitrate Directive.

The situation became so serious that the decision was taken to implement a Water Regeneration Plan, (*Plan de Regeneración Hídrica*), approved in 1988. This plan, drawn up in 1984, proposed the adoption of a series of short-, medium- and long-term technical measures to ensure continuous surface flow contributions. It was essentially an interbasin transfer of water from the Tajo–Segura Aqueduct to the Tablas de Daimiel National Park. The park has received this transfer since 1988 to the present. In 1992 the flooded area was minimal (20 –200 ha). More urgent measures have since been implemented: the construction of pumping stations to the Tablas located within the National Park itself, and simultaneous comprehensive monitoring to ascertain the current status of the system and identify future guidelines for its evolution (OAPN, 2014).

One reason for the interbasin transfer was probably to deliver clean drinking water to urban areas since urban and agricultural activities had contaminated the groundwater with untreated urban wastewater and agricultural fertilizers and pesticides. Water pollution is one of the most important problems, with no easy solution (Zorrilla, 2009).

However, the transfer from the Tajo–Segura Aqueduct has had a negative effect on the Tablas de Daimiel National Park: certain plant communities have disappeared because the water pumped in from the other basin had different water chemistry and also allowed the crossover of endemic species from the Tajo to the Guadiana (ADENA, 1996).

Another action point in the Water Regeneration Plan was to channel the river Gigüela. However, this action drained the quaternary alluvial aquifer, causing a drop in river water levels, which changed the relationship between the river and river-bank wetlands, as well as the flood dynamics of the wetlands, which are now significantly degraded or dry.

Altering the ecological function of the wetlands caused other phenomena, such as the spontaneous combustion of the peatlands between the Ojos del Guadiana and the Tablas de Daimiel, which had been generated over millennia. This combustion, in turn, caused land subsidence and the emission of toxic gases.

In 2001, the fourth additional provision of the National Hydrological Plan (*Ley 10/2001 de 5 de Julio, Plan Hidrologico Nacional*) called for a series of actions for the upper Guadiana basin (*Plan Especial del Alto Guadiana*) to achieve the "sustainable" use of its aquifers (Martínez-Santos, 2007). This plan is currently inoperative, but its measures have taken effect.

Figure 2 shows the historical evolution of water levels in the Tablas de Daimiel using data from a piezometer located a few kilometers upstream, in the village of Villarrubia de los Ojos.

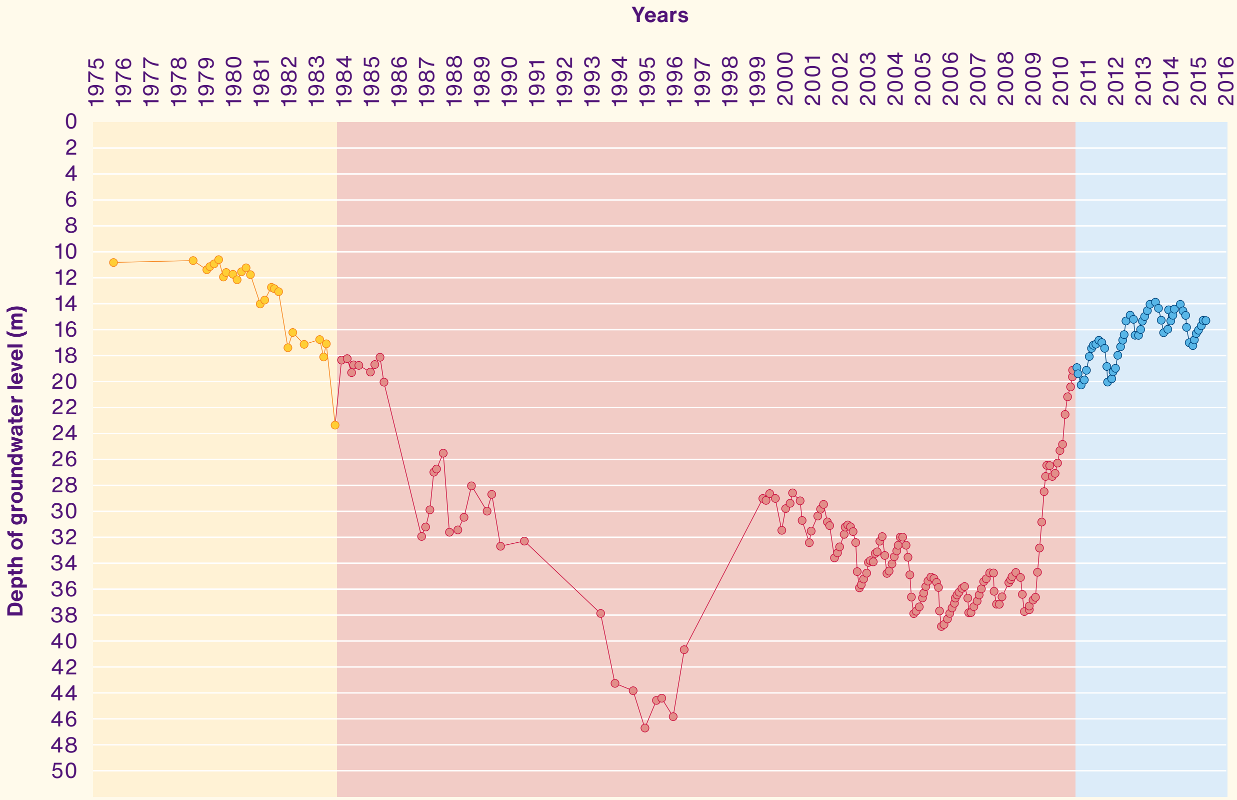


Figure 2. Groundwater levels in Tablas de Daimiel 1975–2016.

Piezometric evolution of a well in Villarrubia de los Ojos, a few kilometers upstream of the Tablas de Daimiel. The colours (also used in Figure 3) show different time periods: yellow – disturbances in the system (1960–1984); pink – investments to improve functioning of the system (1984–2010); blue – nearly undisturbed functioning of the Tablas de Daimiel (after 2010).

Source: Compiled by the authors.

In 2014, the boundaries of the Tablas de Daimiel National Park were extended (BOE, 2014a). Over the past eight years, investment has been unprecedented in the purchase of land rights adjoining the National Park and of water rights, and in sinking emergency wells for the artificial recharge of the aquifer (De la Hera et al., 2014). However, it should be noted that a complaint has been lodged by the European Commission because of Spain's noncompliance with its Habitats Directive (92/43/EEC).

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Current state of the Tablas de Daimiel

The increased rainfall between 2010 and 2015, together with the implementation of specific measures such as the installation of wells to artificially recharge the aquifer in 1997 and again in 2010, has allowed a significant recovery of groundwater levels. In 2015, groundwater welled up again in the Ojos del Guadiana despite flow models that projected a longer-term recovery. The recovery has re-established this aquifer as a hypogenic wetland, that is, one with groundwater discharge (Martínez-Santos et al., 2018).

Figure 3 summarizes the milestones and the four main stages identified in the evolution of the Tablas de Daimiel:

- Before 1960, the wetland functioned naturally.
- 1960–1984, disturbed function, when the intensive exploitation of groundwater in the aquifer began, with a sharp decline in water levels.
- 1984–2012, reversed function, when the system operated as a wetland recharging the aquifer.
- After 2012, following the heavy rainfall in 1997–1998 and later in 2009–2010, the wetland received the discharge of subsurface flows from stream beds adjacent to the river channel, but its functionality is still far from being fully recovered.

The water tables, which had risen to near ground level, fell again after the end of the rainfall period. Ensuring the full recovery of this wetland still presents many problems in the quantity and quality of water it receives, and in its flora and fauna. For example, the predominant emergent vegetation of the Tablas de Daimiel National Park was formerly heliophytic, mainly reeds and sedge. These emergent vegetation patterns have been replaced by the genus *Phragmites* or common reed, a perennial, aggressive wetland grass that outcompetes native plants and displaces native animals.

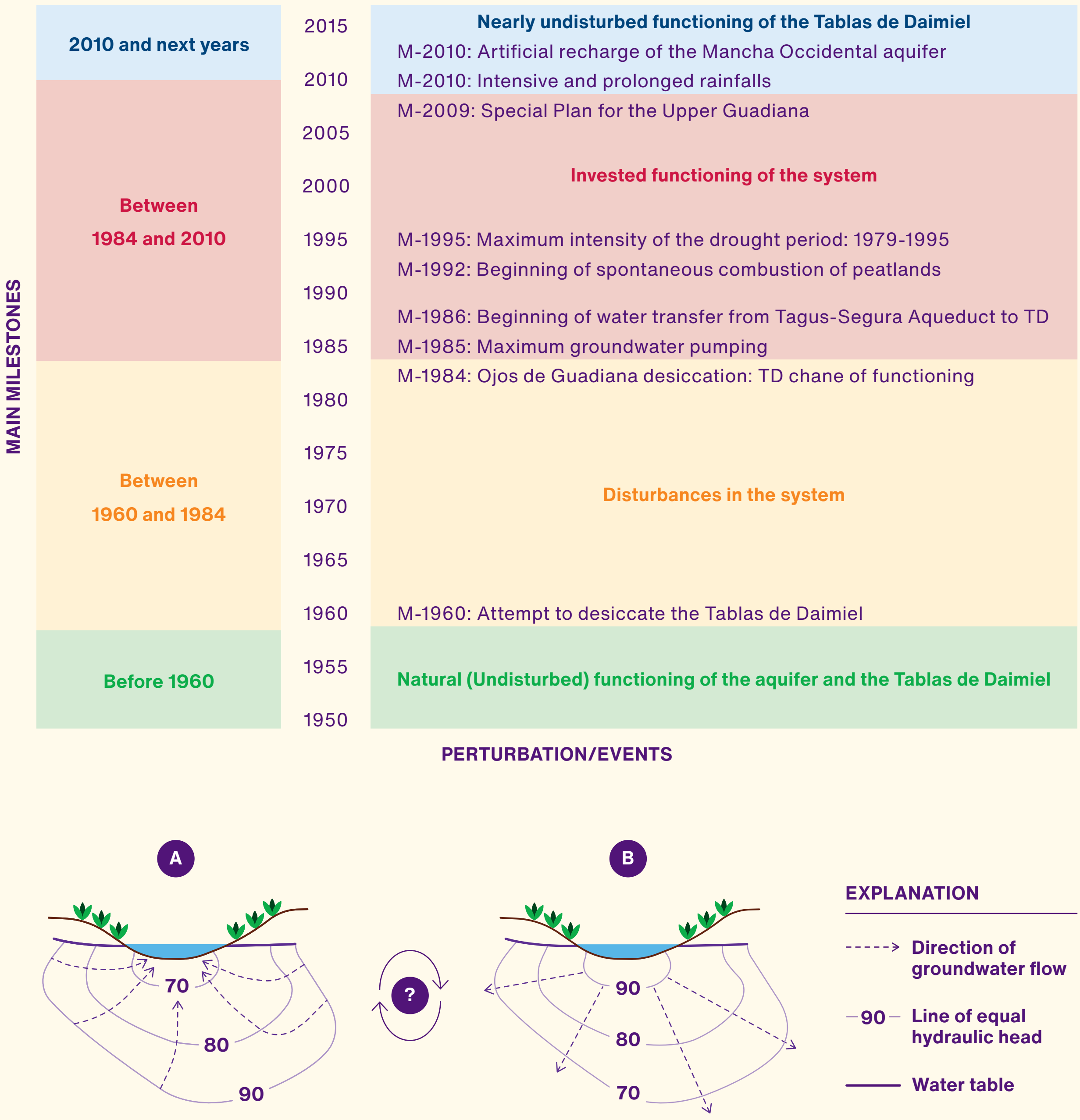

Figure 3. Chronology of the evolution of the Tablas de Daimiel from 1950–2015.

In the lower flow diagrams, (A) shows a gain-regime wetland and (B) shows a loss-regime wetland.

Source: Compiled by the authors.

Three changes have affected biodiversity: First, modifications to surface and groundwater flows changed the wetland’s water balance and its flooding periods (hydroperiod). Second, the change in water salinity affected the emergent and subaquatic vegetation, affecting the food chain. Third, what was previously periodic or seasonal flooding has become permanent flooding.

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Approval of the first master plan for the use and management of the Tablas de Daimiel National Park *(Plan Rector del Uso y Gestión del PNTD)* is currently underway. The master plan sets standards, objectives, action plans and general criteria for the next ten years.

Threats and conflicts

In terms of the ecosystem's biotic components, the major threat is how much the flora and fauna are affected by the loss of surface and groundwater flows. The current lack of groundwater contributions, which used to be permanent, has led to dependence on the contributions from the Gigüela River, an intermittent stream affected by climate variability, which dries up during periods of maximum drought.

Other major threats to the ecosystem are linked to the quantity and quality of groundwater available to enable the wetland to function properly and to the anthropogenic activities in its immediate environment. Regarding quantity, once the wet conditions that had helped the groundwater level reach almost ground level no longer pertained, the water table began falling as was expected. It will be difficult to maintain a high level of groundwater without reducing pumping for irrigation even further. The main problems with the groundwater quality are related to pollution; Recorded wastewater treatment and urban waste water discharges entering the Tablas de Daimiel have led to the disappearance of much of the vegetation and biomass. Species of the genus *Chara* including *Hispida* and *Canescens* have declined considerably, which are the food support for ducks.

When Gigüela River water is tested immediately before it enters the Tablas de Daimiel in drought periods, its chemical and isotopic composition show the results of the biological, evaporative and mixing processes that occur along the course of the river. It reveals the presence of treated wastewater, mainly contributing turbidity and nutrients, mixed with sulfate-rich waters draining the surface formations traversed by the river.

In March and April 2016, the Instituto Geológico y Minero de España (IGME) carried out two surveys to measure the physical-chemical parameters and to sample surface and groundwater in the immediate vicinity of Las Tablas de Daimiel. No significant levels of contaminants exceeding the standards in current regulations were detected. However, this does not eliminate the possible existence of some risks, such as the presence of nitrates in groundwater at concentrations higher than previous values, due to the use of agricultural fertilizers. Although this groundwater seems to remain disconnected from the wetland, in wet conditions it may again reach ground level, affecting the flooded area of the Tablas.

Peatlands suffer a double degradation process during drought: first, contraction with the consequent reduction in volume causes cracking, which may be associated with ground subsidence; and second, organic matter, which was underwater for thousands of years, oxidizes when it comes into contact with air in the unsaturated zone due to the falling water table. This chemical reaction increases the temperature of the material up to 220 °C, at which point spontaneous combustion occurs. This is a latent process, just like a covered brazier. This underground fire has no defined front, but advances according to air currents and shows up only in galleries where it can 'breathe', generating the characteristic fumaroles. The results of this process of peatland degradation are structural loss and a drastic reduction in water retention capacity, with an exponential increase in the water infiltration rate, seriously jeopardising the future of the wetland (OAPN, 2014). Both threats could cause irreversible damage to peatlands.

Biodiversity does not necessarily return in the same form and proportion as the waterlogged surface is restored. Although the flooding levels of the wetland are now optimal, the number of birds has significantly decreased. The presence of ova, the subaquatic vegetation much appreciated by ducks as food, remains the main indicator of water quality in the Tablas de Daimiel and its depletion is a cause for alarm. The overabundance of carp, together with water pollution, has caused the disappearance of submerged vegetation, according to research by Institute for hunting resources research Instituto de Investigación en Recursos Cinegéticos (IREC) and Spanish National Research Council (*Consejo Superior de Investigaciones Científicas; CSIC*).

Goods and services affected

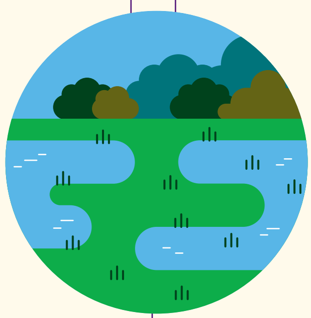
There are many classifications of the services provided by ecosystems to humans. In this chapter we follow the guidelines established by UNEP-MAP and UNESCO-IHP (2015) related to wetland groundwater. Three main groups of services are provisioning services, regulatory services and cultural services. Each group includes a number of different services (Figure 4).

Before the 1970s, the Tablas de Daimiel was a hypogenic-gain-regime wetland. This function supplied numerous provisioning benefits to humans. In undisturbed conditions, the wetland was mainly used as a water supply for hunting and fishing (including fish farms), and leisure activities due to the abundance of waterfowl. Furthermore, because of its water retention capacity, its regulatory functions included production of biological raw material, serving as a genetic reservoir, providing hydrological regimes, morphosedimentary regulation, acting as a carbon sink and regulating local climate. Its many cultural services included contributing to local knowledge, scientific knowledge, aesthetics, and cultural identity.

In the 1990s, when it became a hypogenic-loss-regime wetland, many of these services were affected. In fact, the wetland practically dried out in 1992, with the resulting disappearance of much of the flora and associated fauna (De la Hera & Villarroya, 2013). From 2015, the wetland appears to have regained its function as a hypogenic-gain-regime wetland. This means it regained part of the groundwater discharge flow it had in its previous undisturbed condition, but the quality of this groundwater is significantly deficient compared with the previous flow.

CULTURAL SERVICES

- Tourism
- Educational and scientific knowledge
- Local knowledge and good practices
- Landscape and aesthetic
- Cultural identity and sense of belonging
- Religious and spiritual



REGULATING SERVICES

- Hydrological regimes (Floods, droughts)
- Water purification
- Morpho-sedimentary regulation
- Biological control
- C sink and global regulation
- Air quality regulation
- Local climate regulation

PROVISIONING SERVICES

- Natural production of food:
  - Cropping
  - Livestock
  - Fishing
  - Fruit collection
  - Hunting
  - Other
- Artificial production of food:
  - Aquaculture
  - Agriculture
  - Other
- Supply of good-quality water
- Water supply for different uses
- Production of biological source materials
- Production of mineral source materials
- Genetic pool and biotechnology
- Energy production
- Natural species of medicinal interest

Figure 4. Groundwater-related ecosystem services provided by wetlands.

Source: Compiled by the authors.

The presence of nitrates from agricultural fertilizers and increased wastewater discharge, both in the riverbeds and at other uncontrolled points in the aquifer, has resulted in unacceptable concentrations of many chemical elements in the groundwater. This poor-quality groundwater, which is the predominant water supply to the wetland, affects trophic food chains to the detriment of the flora and fauna in the National Park. The services currently provided by the wetland are quite different from the original ones: for example, hunting is currently banned as a result of major changes in the flora and fauna. Although the groundwater flow supplying the wetland has somewhat recovered, the wetland-aquifer hydrogeological connection has not been re-established, nor is there any guarantee of an adequate qualitative or quantitative status of this connection, which is key to the recovery of the ecosystem.

Concluding remarks

The problems affecting the Tablas de Daimiel National Park always arise outside the protected area leaving park managers little or no room to maneuver. The solution for the Tablas de Daimiel can be found in the balance between the ecological demand for groundwater and the human demand for other uses. This equilibrium is not easy to achieve and should be carefully reviewed each year, depending mainly on meteorological conditions. The most adverse situations are related to periods of drought, and it will be in these times that extreme measures must be applied to maintain groundwater levels to prevent ecosystem degradation. The Mancha Occidental aquifer can be considered as recoverable, although some years ago it was considered to be irreversibly damaged. Clearly this is very good news. However, the crucial and substantial measures needed for the recuperation of Tablas de Daimiel National Park must be applied outside its boundaries.

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S1

CHAPTER

2

Studenchishte Wetland on the shores of Ohrid Lake

Republic of North Macedonia

By

Nadezda Apostolova
University of Valencia, Department of Pharmacology.
OHRID SOS, Citizens' Initiative,
Republic of North Macedonia

Daniel Scarry
OHRID SOS, Citizens' Initiative,
Republic of North Macedonia

Jos T.A. Verhoeven
Utrecht University, Ecology and Biodiversity, Utrecht,
The Netherlands

Abstract

Studenchishte is a wetland area with natural marshes, fens and seminatural wet meadows located on the shore of one of the world's most ancient lakes, Lake Ohrid, a UNESCO World Heritage Site in the Ohrid-Prespa region of the Republic of North Macedonia. It is the very last wetland of a previously extensive riparian fringe that has survived the gradual destruction of Macedonian wetlands over the past 100 years. Despite its significance, very few documents on this wetland exist. This fact is relevant because the wetland has been undergoing rapid degradation and its present state is not promising. This chapter describes the current status of Studenchishte's biodiversity and ecological characteristics in the wider context of the Ohrid-Prespa watershed system. It also describes the wetland's ecosystem services and reviews the imminent threats to the wetland's ecological characteristics posed by recent urban plans. Finally, it will suggest opportunities to develop the area further while leaving the wetland intact, or even enhancing its values by restoration of neighboring wetland areas that have been degraded. In the short run, several measures are needed to prevent further deterioration of the wetland: establishing a moratorium on all development plans in the Studenchishte area, setting limits on urbanization, providing adequate disposal of waste, removing the existing plant nursery, re-establishing or at least improving the natural connections of the wetland with the lake, and reweting parts of the wetland that were drained. A management plan is currently lacking and should be drafted to ensure the preservation of the integrity of the wetland.

Keywords:

Studenchishte | Ohrid | ancient lake | North Macedonia | biodiversity | wetland

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Introduction

Studenchishte Wetland is a complex of fens, marshes and moist grasslands along the shore of Lake Ohrid (Spirovska et al., 2012), the most ancient and deepest (in terms of average depth) European freshwater lake, located in between North Macedonia and Albania. This lake is a true natural gem with high biodiversity and numerous endemic species. Studenchishte is the last remaining wetland of a much larger extent of riparian wetlands along the lake. One of the major sources of freshwater feeding the lake passes through this wetland first; it has also its own characteristic flora and fauna, adding to the richness of the Ohrid-Prespa region. Despite its significance, very few documents on this wetland exist. The wetland has been undergoing rapid degradation and its present state is not promising. This case study describes the major ecological characteristics of the wetland, analyses its current state, and addresses the urgent need for its revitalization and conservation as well as providing an action plan for doing so.

The Ohrid-Prespa watershed system

Studenchishte Wetland is located in the Ohrid-Prespa region, which itself is in the southwest of the Balkan Peninsula and transboundary among North Macedonia, Albania and Greece (Figure 1). This region is one of the most ancient inland watershed systems in the world (Albrecht & Wilke, 2008). Aged between 2 million and 5 million years, Lake Ohrid is recognized as the oldest inland water in Europe, while Lake Macro Prespa, also called simply Prespa, is reported to have been more or less the same age (Albrecht & Wilke, 2008; Wagner & Wilke, 2011). The watershed covers a total of 3,921 km^2. Half of the water that feeds Ohrid Lake originates from several rivers, the largest of which are the Sateska and the Koselska (see Figure 1). The remaining inflow originates from the springs located in the southern and eastern part of the lake which is fed by water coming from Lake Prespa (located 150 m above Lake Ohrid) that is filtered through the porous karstic mountains in the east, particularly Mount Galichica. The water flows out of Ohrid Lake at the town of Struga into the Black Drim River, which runs into Lake Skadar and the Adriatic Sea. It takes 70 years to renew the total volume of water in Lake Ohrid.

The Ohrid-Prespa area belongs to the ecoregion “Southeast Adriatic Drainages” according to the Freshwater Ecoregions of the World (FEOW) classification developed by the World Wide Fund for Nature (WWF) to provide a global biogeographic regionalization of freshwater biodiversity

(Ecoregion ID: 420, Hales, 2015). It is one of the leading ecoregions on Earth for freshwater fish species density with more than eight taxa for every 104 km^2 (Abel et al., 2008), and displays remarkable endemism with more than 50% of its freshwater fish species.

Lake Ohrid has been a UNESCO World Heritage Site on Macedonian territory since 1979/80and on the Albanian side since 2019, one of just 39 locations worldwide designated for both nature and culture. In 2014, the 83,350-hectare site was then incorporated into a 446,244-hectare UNESCO Transboundary Biosphere Reserve together with Lake Prespa and its surrounds. Lake Prespa itself was designated as a Ramsar Site (18,920 ha) on the Macedonian side in 1995 and an IUCN Category III Monument of Nature (17,788) in 2011. It was joined as a Ramsar Site on the Albanian side in 2013, while Ezerani, a Prespa coastal wetland, was proclaimed an IUCN Category IV Nature Park (1,917 ha) in 2012. Mount Galichica is meanwhile an IUCN Category II National Park (22,750 ha) since 1958. Additionally, the Ohrid-Prespa area contains several Emerald sites. Both lakes are Important Bird Areas (IBAs) and several regions in the watershed are listed as Important Plant Areas (IPAs). National Park Galichica is designated as a Prime Butterfly Area (PBA). Parts of the Ohrid-Prespa area belong to the European Green Belt too. Ohrid Lake is a museum of living fossils as it contains numerous relict and 212 endemic species, many of which evolved in isolation over millions of years (Albrecht & Wilke, 2008).

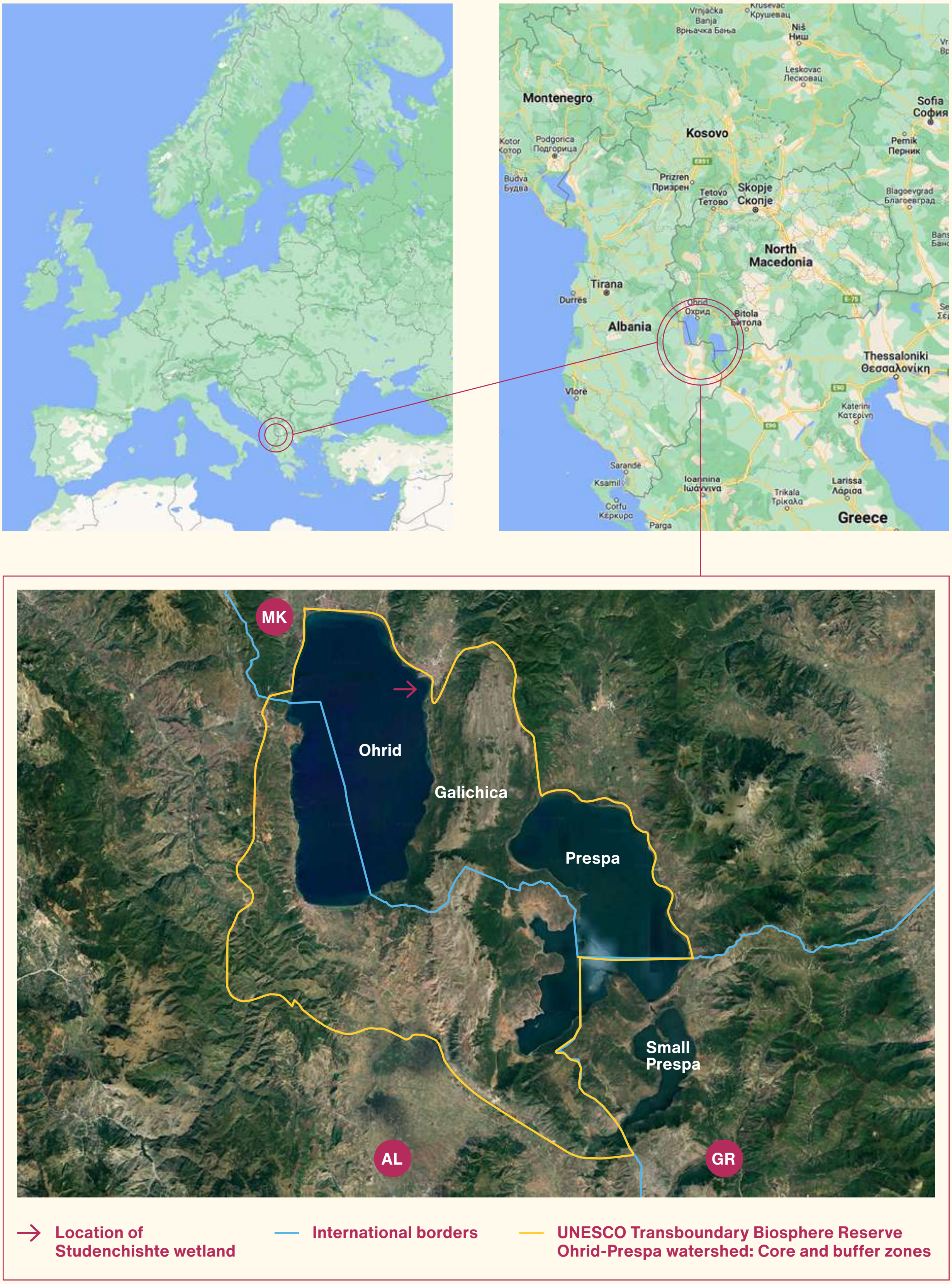

Figure 1. Geographical location of the Ohrid-Prespa area with Studenchishte Wetland.

Source: Google maps.

Table 1. Limnologic and geographical characteristics of Lake Ohrid

LOCATION, GEOLOGICAL AND HYDROLOGICAL CHARACTERISTICS			
LOCATION	41°05´ N; 20°45´ E. Transboundary (RA and RNM)	**AGE**	3-5 million years (recognized as ancient lake)
TYPE	Tectonic	**ELEVATION**	693.17 m asl
SIZE AND VOLUME	Shore line: 87.53 km (56.02 in RNM). Surface area: 358.18 km^2 (2/3 in RNM). Littoral zone width: 1-2 km in the southern and northern part and much narrower on the western and eastern shore (less than 10 m at some points). Max. width: 14.8 km; Max. length: 30.37 km. Max. depth: 288.7 m; Average depth: 163.7 m; Volume: 58.64 km^3.		
CLIMATE	Average air temperature registered 1951–2009: 11.3°C Average annual precipitation 1951–2009: 687.8 mm Insolation: Total number of daylight hours: 4,399 h/year, (2,257 h/year with sunshine) 56% of the maximal daylight duration) Cloud cover per annum: 4.9 tenths of the sky-dome Average air humidity: 70% Average wind speed per annum: B=1.8m/sec; Average wind frequency per annum expressed by promille is 297% o, and blows in a northerly direction with an average calmness C=138% o.		
CATCHMENT AREA	1,487 km^2 after it was artificially enlarged in 1962 by 460 km^2 when the river Sateska, previously a tributary of the river Black Drim, was diverted into the lake near the town of Struga. The effective size is substantially larger because several springs along the shores are supplied from Lake Prespa providing approximately 46% of the inflow of water to Lake Ohrid.		
WATER LEVEL	Regulated since 1963 (intergovernmental agreement between RA and the former Yugoslavia). Acceptable oscillations: minimal and maximal elevation of 693.10 m and 693.75 m asl respectively (water layer difference of 65cm).		
TROPHIC STATE AND BIODIVERSITY/ENDEMISM			
TROPHIC STATE	Oligotrophic according to the Carlson´s Trophic State index for lakes, based on water transparency (SD- Secchi depth), chlorophyll and total P). Average P content: 4.5 µg/L Presence of black spots: certain areas of the littoral zone, particularly where the rivers Sateska, Koselska, Velgoska and Cerava flow into the lake display increased water pollution and changes in the eutrophication status.		
ENDEMISM	A biodiversity hotspot. 212 endemic species* of which 182 are animal (34% of all animal species), 41% of its fish species, 89% of *Gastropoda*, 63% of *Ostracoda*, 90% of *Amphipoda*, 79% of *Tricladida*, and 54% of *Hirudinea*.		
RISKS AND THREATS			
POLLUTION FROM- HUMAN SEWAGE, AGRICULTURE, ETC.	Main source of pollution is untreated sewage. The primary collector and wastewater treatment plant on the Macedonian part of Lake Ohrid (since 1988), and the implementation of the bilateral Lake Ohrid Conservation Project with RA (1998) have not shown to be satisfactory. Lake Ohrid is particularly vulnerable to pollution because of its depth and the small number of connecting rivers. About 150 tons of dissolved P are estimated to enter the lake each year and the total P load may be 3–5 times greater than it should be to keep the lake in an oligotrophic state.		

URBANISATION AND TOURISM DEVELOPMENT	The resident lakeside population is estimated at 200,000 people. However, this number increases sixfold during the summer months. Massive development of tourism infrastructures and urbanization is supported by the local and national authorities.
OVERFISHING	Illegal fishing and introduction of nonindigenous fish species.

RA (Republic of Albania). **RNM** (Republic of North Macedonia). **asl** (above sea level). **P** (phosphorus).

* without taking into account *Diatomae*.

Sources: Avramoski et al., 2005; Spirovska et al., 2012; Schneider et al., 2014.

Studenchishte Wetland

Location, geophysical and hydrological characteristics

Studenchishte Wetland occupies 50–60 ha (Spirovska et al., 2012) of a flat area bordering the northeastern shore of Lake Ohrid (see Figure 1) (41°06'08"N, 20°48'49"E), some 3-5 km south of the UNESCO city of Ohrid (Figures 1 and 2). The total marsh expanse fluctuates depending on precipitation patterns and the level of Ohrid Lake. The altitudinal gradient feeding the wetland with water spans 965 m, between Gjafa Mountain and where Biljanini Springs flow into the lake (Figure 2). This gradient extends over 4.6 km and has a 21% slope (Spirovska et al., 2012).

The climate in the Ohrid region including Studenchishte is moderate-continental, modified by air currents from the Adriatic Sea via the River Black Drim, which, combined with the lake influence, induce a specific thermal and pluvio-metric regime characterized by small air-temperature amplitudes throughout the year and autumn/winter concentrations of heavier rain. Interestingly, the origin of the Studenchishte name itself suggests an area known to be chilly or fresh ('studen' meaning 'cold' in Macedonian).

Studenchishte contains materials belonging to the Paleozoic Neogene geological formation, mainly divided into three sediment series (basal, productive and upper layer) as well as quaternary sediment formations. The alluvial sediments along the lakeside, which are part of the loose quaternary sediments, display high water porosity. Under this layer, loosely-tied rock masses (clay, marley-clay and marley) have been found, which display low permeability and thus constitute impervious, confining beds. The subterranean aquifer at Studenchishte is unconfined with groundwater running relatively freely from northeast to southwest (Spirovska et al., 2012). The terrain abounds with water: The hydraulic head of the groundwater is high (above 10 m) and discharge is constant. Unbound materials make the terrain at Studenchishte particularly porous; hence, the filtration index is also quite high. The upper 20 m of sediments are loose, enabling rapid water filtration.

The hydrographic network of Studenchishte's surface catchment is poor, except for a little stream (Spirovska et al., 2012). Importantly, the wetland directly borders Biljanini Springs (Figure 2), one of the main springs that feed Ohrid Lake, which should be regarded as an integral part of the wetland. Providing 50–300 L/s of water, Biljanini Springs are of great significance as one of the few in Macedonia with a capacity above 100 L/s. Groundwater feeding Studenchishte mainly originates from atmospheric precipitation filtered through the highly porous, karstic Galichica massif. The Ohrid Lake water level is a major factor influencing Studenchishte's wetness. During high-water extremes such as in 1963 and 2010, the wetland fully merges with the lake. Notably, the contact of underground water in Studenchishte with Ohrid Lake and the dynamics of its discharge have not been adequately researched (Spirovska et al, 2012), even though they are assumed to be of strong interest for the survival of the wetland ecosystem.

Some of the most significant features of the wetland are its soils, which are mainly histosols (Filipovski, 1999). In Macedonia, this type of soil is not common, covering just 700ha or 0.03% of the country—a figure that includes the former Struga Marsh. Currently, the total area of histosols around Lake Ohrid is 90 ha, mainly in the proximity of the city of Ohrid (Filipovski, 1999). Studenchishte histosols are regarded as the largest and most representative remnant of lowland peat histosols in North Macedonia. Typically, lowland histosols in Macedonia have a relatively thin peat layer but, with a depth of 300 cm (average 220 cm), those in Studenchishte are an exception (Filipovski, 1999).

Biodiversity

Studenchishte Wetland's condition, ecology and biodiversity have not been comprehensively assessed. Major features are summarized in Table 2, but available data regarding certain animal or plant groups is either outdated or totally lacking. A 2012 assessment on the condition of the wetland by an interdisciplinary team of Macedonian experts, *Integrated Study on the State of the Remains of Studenchishte Marsh and Measures for its Revitalisation* (Spirovska et al., 2012), was an effort to consolidate all the available research regarding biodiversity, and additional screening of certain groups was performed. It describes a Studenchishte landscape mosaic ranging from natural habitats of swamp and alkaline fens through seminatural wet meadows to heavily managed areas of orchards and farms.

Numerous flora and fauna species are woven throughout these habitats. Adjacent to the marsh, 11 vascular hydrophytes and 6 fringe plant species are in evidence, while 11 of the 89 diatom species, including both marsh and oligotrophic taxa, identified for Studenchishte are endemic to Lake Ohrid and 4 are considered rare. For invertebrate fauna, Studenchishte differs fundamentally from Ohrid Lake, and, thus deserves recognition as a vital factor for overall biodiversity in the region. Meanwhile, Biljanini Springs adds 5 nonbiting midge species (*Chironomidae*) and 9 planarian taxa, the majority of which are endemic to either Ohrid Lake or its springs.

Even though Studenchishte's importance for nesting birds has greatly diminished, over 50 species still make use of the wetland for migration and foraging, including herons, ibises, godwits, harriers and ducks. Among those still raising young are several warblers, waterfowl and rare wetland species such as the little bittern (*Ixobrychus minutus*). The picture with fish is similar: Until some decades ago, several species used Studenchishte for breeding and shelter, but the current low water levels are unsuitable for dense fish populations. Nonetheless, Studenchishte Canal still hosts 17 taxa, 14 of which are native. Regarding mammals, consistent monitoring has not been undertaken. Herpetofauna is represented by 13 species – notably the Macedonian newt (*Triturus macedonicus*) (Spirovska et al., 2012).

Table 2. Significant features of Studenchishte Wetland regarding biodiversity and conservation status

HABITATS – EU CONSERVATION SIGNIFICANCE	Three natural and seminatural habitats: alkaline marshes, swamps, and wet meadows. Most important are those with the plant associations *Caricetum elatae* and *Cyperetum longi* (*Magnocaricion*), included in the EU Habitat Directive.
PLANT ASSOCIATIONS	*Alkaline fens* (7230). PAL.CLASS.: 54.2 Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition* - type vegetation (3150). PAL.CLASS.: 22.13 x (22.41 or 22.421) Class PHRAGMITEA. Order Phragmitetalia eurosibirica Alliance Phragmition 1. Association Scirpeto-Phragmitetu 2. Association Oenantheto-Roripetum Alliance Sparganio-Glycerion 3. Association Sparganio-Glycerietum fluitantis Alliance Magnocaricion 4. Association Caricetum elatae Subassociation lysimachietosum 5. Association Cyperetum longi SW includes 50% of the total diversity of marsh associations recorded in RNM. In RNM, the plant association *Caricetum elatae* is found only in SW and thus its protection is of particular importance. It could serve as a source for *Carex elata* individuals to repopulate other nearby sites, e.g., Struga Wetland.
	Wet meadow Class MOLINIO-ARRHENATHERETEA. Order Trifolio- Hordeetalia. Union Trifolion resupinati Association Trifolietum nigrescentis-subterranei
RARE PLANT SPECIES	Nine rare plant sp. (*Carex elata, Ceratophyllum submerse, Nymphaea alba, Nuphar lutea, Polygonum amphibiu, Leucojum aestivum, Senecio paludosus, Ranunculus lingua, Cyperus longus* and *Myosurus minimus*) which have disappeared or are in danger of extinction in SW[a]. Only 1 sp.—the yellow lotus—has been reintroduced in SW vicinity.
INVERTEBRATES	Thirty-four sp. of *Odonata*, some extremely rare: 15 sp. are included on the GRL-IUCN (13 of which are LC and 2 NT). In the EU HD, there is 1 sp. in Annex II (*Coenagrion mercurial*), also present in BC (NT). 39 sp. of Coleoptera (9 sp. are rare and exist nowhere else in RM: *Agonum lugens* and *A. piceum, Amara convexiuscula, Stenolophus skrimshiranus* and *S. proximus, Brachinus elegans, Pterostichus elongates, Oodes helopioides* and *O. gracilis*). 23 sp. of water insects.
VERTEBRATES	*Amphibians*: 9 sp. (all included in BC Annexes II and III, 6 are II and/or IV of EU HD). The most important at European level are the Macedonian crested newt (*Triturus macedonicus*) and the yellow-bellied toad (*Bombina variegata*). Reptiles: at least 4 snake sp. (*Emys orbicularis, Elaphe quatuorlineata* and *Natrix natrix, Natrix tessellata*), all included in BC Annexes II and III, 3 are II and/or IV of EU Habitat Directive. *Birds*: 15 sp. are of conservation significance for the EU (rare or endangered in Annex I of the Birds Directive). *Mammals*: otter (*Lutra lutra*), fox (*Vulpes vulpes*), European polecat (*Mustela putorius*), white-breasted marten (*Martes foina*) and several rodent sp.
ENDEMIC SPECIES	Eleven diatom sp. are endemic. The highest rate of endemism is found among planarians (most of the 9 known sp. are endemic for the springs by the lake)

BC (Bern Convention), **GRL-IUCN** (Global Red List of IUCN), **LC** (least concern), **NT** (near threatened), **RM** (Republic of Macedonia), sp. (species), **SW** (Studenchishte Wetland).

a Although, on a global level, the most threatened among these plant species are of least concern according to the IUCN Red List, such flora are rare at the national level, not least because of large-scale conversion of wetland ecosystems to arable land and other anthropogenic pressure.

Source: Spirovska et al., 2012.

The animal species listed in the EU Habitats Directive are classified under different annexes, each with its own level of protection. Annex II includes species that demand the highest protection – those whose conservation requires the designation of Special Areas of Conservation. Annex IV species are defined as those in need of strict protection.

Ecosystem services

Despite the lack of research to quantify ecosystem services from Studenchishte Wetland, the limited available information suggests numerous and varied functions and services (Table 3). Many need to be understood in the wider context of Lake Ohrid. Others are currently latent or require restoration.

Table 3: Ecosystem services provided by Studenchishte Wetland

ECOSYSTEM CATEGORY	STUDENCHISHTE ECOSYSTEM SERVICE
PROVISIONING	Food and related economic provision via direct habitat for four commercially important fish species, in particular *Cyrpinus carpio* and *Salmo Letnica* (H)(P)[a]
REGULATING	Climate mitigation due to peatland carbon storage (C)
	Water clarity and quality improvements via nutrient retention (C)[b]
SUPPORTING	Spawning, wintering and nesting sites for birds and fish (H)(C)(P)
	Habitat for locally endemic diatom and planarian taxa (C)(P)
	Refuge for relict species and nationally rare flora and fauna (H)(C)(P)
	Important component of national habitat and biological diversity as one of only seven[c] remaining small marshes in the Republic of North Macedonia (C)
CULTURAL	Research archive for palaeoecological, paleoenvironmental, and, together with Lake Ohrid, evolution studies due to stratified peat layers and species composition (P) and the human-wetland relationship (P)
	Education of the general public related to wetland functioning, biodiversity, and the human-wetland relationship (P)
	Provision of tourism infrastructure via landscape variety, biodiversity and regulating services for clear water (C)(P)

H (Historical ecosystem service whose contribution has now been lost); **C** (Current ecosystem service), **P** (Potential for future ecosystem service development). Where H and C appear concurrently, part but not all of the historical function has been lost. Simultaneous C and P indicate capacity for significant expansion of a current ecosystem service.
ES (Ecosystem Services)

a Requiring more study, Studenchishte Wetland's regulating functions for water purification may further contribute to food and related economic provisions indirectly by maintaining in-lake water quality.

b Regulating ecosystem services such as flood retention and pest control have not been researched in the context of Studenchishte, although the former is mentioned in the Society of Wetland Scientists' *Declaration on the Protection of the Lake Ohrid Ecosystem*, adopted at the organisation's 13th Europe Chapter meeting 1–3 May 2018.

c MoEPP 2014a.

d Apostolova, Scarry, & Verhoeven, 2016.

Source: Compiled by the authors

The relative stability of oligotrophic and ultra-oligotrophic conditions at Lake Ohrid over millions of years (Cvetkoska et al., 2016) has culminated in endemism at every level of the food chain and a rate of endemic biodiversity thought to be higher than any other lake by surface area (Albrecht & Wilke, 2008). Studenchishte Wetland, though small compared to the vast lake area and volume, still contributes to the quality and species richness of the area as a whole (Spirovska et al., 2012. If the wetland is considered in its pre-disturbance state (see Figure 3), a number of major features should be mentioned. The wetland's fen habitat is a peat-forming ecosystem with a carbon storage function and associated biodiversity. It contributes to the supply of clear water to the lake through its groundwater discharge and nutrient buffering capacity (Kovachevic et al., 2015). The stratified peat layer also provides a potential climate and paleo-ecological record for the Holocene, and peatlands with intact peat layers are rare in this part of the world.

Another important service that could be restored is the wetland's function as a nursing ground for fish species. Of six commercially valuable taxa, three were known to spawn in Studenchishte before recent degradation, while a fourth previously inhabited parts of the wetland (Spirovska et al., 2012). The endemic Ohrid trout (*Salmo letnica*) once sheltered there.

Studenchishte has added potential value for educating the public about wetland functioning, particularly as it is the final fully functional remnant of coastal wetland along Lake Ohrid containing post-glacial relict habitats with rare plant associations and endemic species and holding the deepest (3m), most representative histosols in North Macedonia (Spirovska et al, 2012). These conditions could easily be applied to both eco- and educational tourism due to Studenchishte Wetland's aesthetic lakeshore location and proximity to the sports-recreation centre Biljanini Springs, the Hydrobiological Institute of Ohrid, and several archaeological sites, most significantly the early Christian Studenchishta Basilica (5th to 6th century AD).

Contributed wetland services are also more broadly important for tourism, which as a whole accounted for 5% of Macedonian GDP in 2015 (WTTC, 2015) with a disproportionately sizeable share of overnight stays in the Ohrid region (Republic of Macedonia State Statistical Office, 2016). Such services have never been calculated for Studenchishte, but clear waters have been shown elsewhere to increase the number of visitors, and to inspire people to spend more time and to travel further (Keeler et al., 2015); biodiversity positively correlates with inbound tourism receipts (Freytag & Vietze, 2009); and the UNESCO status of the Lake Ohrid region rests on very high species richness including birdlife and oligotrophic conditions (UNESCO, 2009).

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Since eutrophication can have very serious consequences for recreation areas (Dodds et al., 2009), Studenchishte's aforementioned function as a nutrient retainer is all the more relevant to mitigate some of the potential effects on Macedonia's tourism industry in the era of climate change. As Matzinger et al. (2007) have warned, phosphorous inputs must decline 50% over coming years for Lake Ohrid to maintain oligotrophic conditions as temperatures warm.

Past actions and present consequences

In the past, Ohrid Lake had several adjacent wetlands, most of which have been drained and turned into agricultural and urban uses. The biggest wetland was Struga Marsh (500 ha) in the northwestern part of Ohrid Lake. It was drained almost entirely for agriculture in the 1940s. The only true wetland remaining is Studenchishte, the surface of which has been dramatically reduced over the past years (Figure 2). Ohrid Lake and Studenchishte were once directly connected by multiple channels of which there are now only remnants and many lake species visited Studenchishka River and its springs (Stankovic, 1960). A large number of Ohrid's fish used to spawn in the wetland which is no longer the case due to the diminished contact with the lake. Similarly, Studenchishte was previously considered one of the primary nesting sites for waterbirds along Lake Ohrid's shores.

Over the past 60 years, Studenchishte has been degraded and drained (Figures 2 and 3). Large portions have been converted to farmland or paved (buildings, a helipad and local roads). Meanwhile, the coastal area near the city of Ohrid has undergone swift urbanisation in line with the rapid development of tourism facilities. Several construction activities can be regarded as particularly detrimental: in the 1990s, a plant nursery, 'Rasadnik', destroyed large portions of the relict association *Caricetum elatae*—the only site for this community in Macedonia; the sports centre 'Biljanini Springs' (inaugurated in 1998) caused the disappearance of a large share of *Senecio paludosus and Ranunculus lingua*; and military and police facilities eliminated the rare plant *Myosurus minimus*. Anthropogenic pressure has likely led to the disappearance or danger of extinction of floating plants such as the white-water lily (*Nymphaea alba*), yellow pond lily (*Nuphar lutea*) and longroot smartweed (*Polygonum amphibium*), as well as the area's white willow, the reed-belt, and the association of *Cyperetum longi*. Recent plans for large-scale development now threaten to drain and urbanise the area almost entirely.

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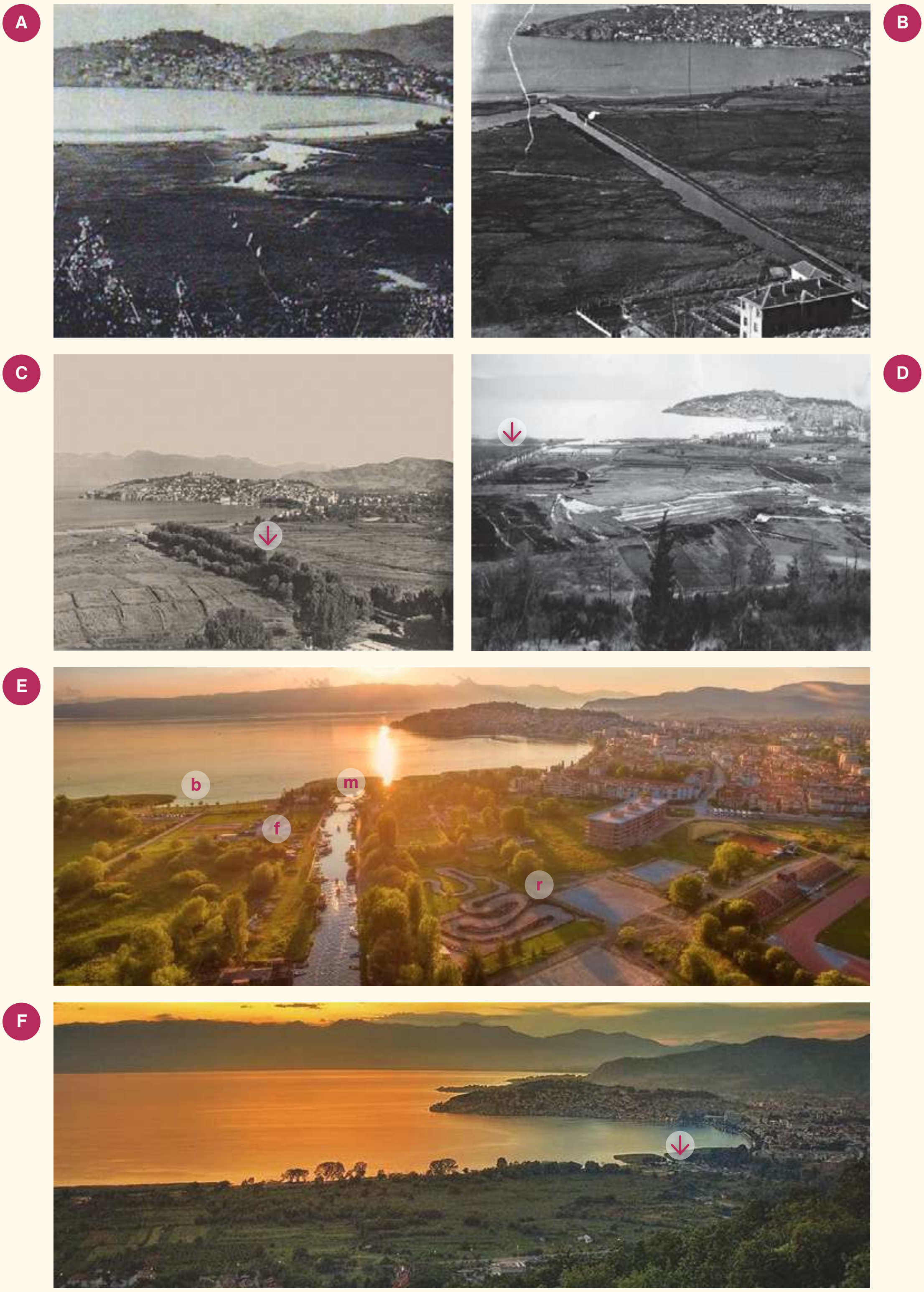

Figure 2. Photographs of the Studenchishte area over the years.

(A) Studenchishte Wetland in the first half of the 20th century; the water of Biljanini Springs flowed into the lake through Studenchishte River. (B) Studenchishte Canal and the Hydrobiological Institute Ohrid (built in 1935). (C) Studenchishte Canal and the surroundings in the 1950s when vast portions of the land were used for agricultural purposes. (D) Drying of the northern part of the wetland in the 1970s. (E) Studenchishte Canal and the surroundings in the present day. (F) Larger view of Studenchishte Wetland, present day. Studenchishte Canal is indicated with an arrow and Biljanini Springs with an asterisk; b (beach); f (army and police facilities); m (marina); r (recreation and sport facilities).

Photos: A to D - Ohrid-photos of the past; E © 2S Studio; F © Daniel Joveski.

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Threats by unemployment, politicisation and governance

Since 1991, Macedonia has endured unemployment rates between 24% and 38%. The poverty rate is assessed at one-third of the population (World Bank, 2016). These related pressures contribute to extended outward net migration (Bornarova & Janeska, 2012).

To alleviate employment problems, the government has increased the public sector to approximately 20% of the workforce (EC, 2015). Since many people depend on the government for salaried income against the backdrop of poverty, disagreement with official development proposals related to the environment is often inadvisable. Political pressure prevents regulatory, supervisory and advisory bodies from proper functioning (European Commission, 2016); misused appointment procedures and emigration cause an expertise short-fall; and obstacles to citizen engagement in environmental issues range from ineffective public consultations to interference with the judiciary (Freedom House, 2016; EC, 2016).

Residual unemployment leaves many people detached from direct economic benefits from natural environments, including wetlands; and contributes to poverty, which may act as a distortion to decision making (Shah et al., 2012; Schilbach et al., 2016). The population outflow hollows the country of educated citizens, who are more likely to be environmentally empowered (Rootes, 1997).

Governance is generally weak. Legislation such as the Law on Waters [2008], which theoretically prevents construction within 50 m of Lake Ohrid's highest water level, is regularly flouted (IUCN, 2017); illegal building is rife in the Ohrid region generally (IUCN, 2017); poorly defined legal terms such as for temporary buildings and urban equipment in the Law on Construction permit inappropriate activities in sensitive areas; and provisions in the criminal code have not deterred illegal disposal of waste (UNESCO, ICOMOS & IUCN, 2017). Environmental requirements are not adequately integrated into sectoral legislative frameworks such as for tourism (UNECE, 2019), and Macedonian law does not provide for tools such as *actio popularis* except in cases of discrimination, so third parties cannot bring actions on behalf of the public as a whole. National Biodiversity Strategy and Action Plan measures under the Convention on Biological Diversity from 2004, 2014 and 2018 to designate Lake Ohrid as a Ramsar Site have all expired without submission of the required paperwork (Ministry of Environment and Physical Planning 2004; 2014b; 2018), and secondary legislation for the implementation of the Ramsar Convention is absent even if nomination does one day proceed (Macedonian Ramsar Committee, 2018). Policy documents are not always adopted; national environmental action plans have been discontinued; wetland benefits have not been incorporated into poverty alleviation strategies, water resource management, or national tourism policies; and no national wetland strategy has been created (UNECE, 2019; Macedonian Ramsar Committee, 2018). Ministry of Environment and Physical Planning staff are not comprehensively trained, and the Ministry does not offer sufficient guidance or training to local municipalities to cascade environmental policy (UNECE, 2019).

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Figure 3. Studenchishte area according to the General Urban Plan for Ohrid and the urbanisation of the wetland over the past four decades.

(A) Map of the broader Studenchishte area (coloured and bordered with a red line), which contains four urban sections: 1 (70.53 ha), 2 (19.38 ha), 3 (17.30 ha) and 4 (4.45 ha). Some remnants of the wetland remain in sections 2 and 3 but the biggest wetland area is in section 1, bordered by Studenchishka River (now Studenchishte Canal, north), Racha River (south), the shore of Ohrid Lake (west) and a regional road (east). (B) Map of the Studenchishte area's section 1 showing its urbanisation over the past 40 years. Use of the land in 1970 (B) and in 2010 (C) is shown. Sc (Studenchishte Canal), rr (river Racha), h (Hydrobiological Institute Ohrid), r (road Ohrid-St. Naum), s (sport centre 'Biljanini Springs'), t (shaded in violet-village and tourist resort, Racha).

Source: Adapted from Spirovska. et al.,2012.

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Legal framework of regulations concerning the wetland

Over the past decades in Macedonia, several laws regarding nature conservation and protection particularly referring to the Ohrid region have come into force but none has been instrumental in conserving Studenchishte. There have also been several attempts, albeit ineffective, to provide specific legislation for its protection in local and national urban plans. The 1979 Basic Urban Plan of the city of Ohrid granted the wetland protected status as a special-purpose area, yet this was largely nominal and poorly defined. Studenchishte then became part of the city territory covered by the Master Urban Plan of 1987, and various categories of protection were proposed. The 2006 General Urban Plan (GUP) suggested categorising the wetland as a 'landscape with outstanding natural features' and establishment as a protected area (51.55 ha) to be used for basic education and specific kinds of recreation. Since 2004, the Spatial Plan for Macedonia has proposed the category of Special Nature Reserve.

The protection level in accordance with Macedonia's Law on Nature Protection has not been defined, however. Over recent years, Macedonian lawmakers have attempted to implement European legislation: The Law on Nature Protection regulates the designation of IUCN protected areas in specific categories, according to their management objectives. At present, North Macedonia contains 86 designated areas under the IUCN system, which cover 8.9% of the territory (230,083 ha). In accordance with a study on the protection of natural heritage elaborated by the Ministry of Environment, this figure was expected to reach 11.5% by 2020. Despite obvious ecological values, Studenchishte has not been recognised as an IUCN location. This is even less understandable given that the aforementioned expert-researched *Integrated Study* contains a detailed proposal for Studenchishte's designation as a natural monument (Spirovska et al., 2012), proposing a total area of 63.97 ha to be enshrined as IUCN category III, of which 24.47% would be designated as zone of strict protection. Defined by the IUCN, natural monuments "are generally quite small protected areas, with often a high visitor value, set aside to protect a specific natural monument which can be a landform, sea mount, submarine cavern, geological feature or even a living feature. Their primary objective is to protect specific outstanding natural features and their associated biodiversity and habitats." Category III areas are likely to hold sociocultural importance and are often of significant visitor value. There is overwhelming evidence that all these features apply to Studenchishte.

Despite this proposal, nothing has been done to adequately protect the wetland and the site's potential for Ramsar designation together with Lake Ohrid has not been fulfilled. On the contrary, recent amendments within the GUP for Ohrid (2002–2012) allow for part of the coastal strip along Studenchishte Canal and its estuary to be converted into a water sports centre with accompanying facilities (hotels, shops, restaurants) and the rest of the nearby coast used as an urban beach. There are also advanced plans to build a marina in this part of the lake. The latest GUP further includes measures to improve the supply of drinking water, which would inevitably affect the integrity and viability of the wetland.

The long-term lack of proper care and protection of Studenchishte has endangered its ecosystem, compromising some of the most important values of Ohrid Lake such as elevated rates of biodiversity in niche habitats, the maintenance of specific lacustrine conditions to which unique species have evolved, and the harboring of relict and locally endemic species. Overall, the series of legal documents and legislations aimed at protection and management for Studenchishte have clearly proven insufficient. Current plans and actions do not provide much hope for better status in the future and it is even unclear who manages the wetland.

While lakes in North Macedonia are managed in a complex way by several ministries (the Ministry of Agriculture, Forestry and Water Economy, the Ministry of Transport and Communication, and the Ministry of Environment and Physical Planning) depending on the aspect in question, wetlands such as marshes are managed by different entities including national parks or municipalities. Moreover, Studenchishte is located within the boundaries of the Ohrid Lake UNESCO World Heritage Site. Recent urbanization along the shoreline has already displayed negative impact, and a 2013 UNESCO mission concluded that the current draft management plan is inadequate to maintain the property's Outstanding Universal Value (OUV). UNESCO also recommended that Environmental and Heritage Impact Assessments should precede all development proposals that can potentially impact the OUV, and that these, along with project proposals, should be submitted to the World Heritage Centre for review prior to granting approval for implementation. Importantly, this has not been done for any of the developments in the Studenchishte area. Indeed, the cumulative raft of infrastructure and urbanization projects envisaged for the Ohrid Lake shore and watershed in the National Park Galichica have prompted the World Heritage Committee in 2016 to state its consideration for the "possible inscription of the property on the List of [World Heritage Sites] in Danger" (UNESCO, 2016).

What can be done?

Studenchishte is the very last wetland remaining on the shores of Lake Ohrid and it is urgently in need of protection and restoration to its less disturbed state of a couple of decades ago. This is all the more important as wetland services are increasingly recognised to be very valuable in ecological and economic terms. Restoration of previously drained wetlands is on the agenda of land use managers worldwide and could also become desirable in the catchment of Lake Ohrid. To be able to carry out restoration activities in the region, it is extremely important to have a reference wetland which is fully functioning and has the ecological characteristics, including biodiversity features.

Measures to ensure protection and partial restoration of the wetland

In the past 50 years, Studenchishte Wetland has become substantially smaller because parts were converted to roads, buildings, horticulture and agriculture. The remaining area urgently needs to be enlarged to protect the wetland's integrity. However, first, current land uses that threaten the wetland need to be stopped. Next, numerous measures need to be undertaken to, at least partially, convert damaged sections into restored wetland. Cancellation of all new plans for urbanization and development of mass tourism infrastructure is of imminent importance, because they would destroy the wetland altogether. Instead, a visionary plan is needed to convert Studenchishte Wetland into a nature park with strong facilities for the protection of wildlife, public access to enhance ecotourism, and a visitor centre for education about the marvels of nature in the wetland and Lake Ohrid as a whole.

Table 4: Action plan for the protection, rehabilitation and conservation of Studenchishte Wetland[a]

ACTION	ACTOR(S)	TIME	EXPECTED RESULTS
MORATORIUM ON ALL CONSTRUCTION WITHIN THE SW VICINITY (G) (B)	Local/ national authorities	Immediate	Cessation of new construction; revision of existing laws, regulations and systems related to building permits; analysis of legality and compatibility of existing structures with wetland conservation, rehabilitation and rewetting goals; increase in inspectorate capacity and amendment of criminal code to increase penalties and enforcement of law; drafting of secondary legislation to embed the Ramsar Convention in North Macedonian law more deeply.
AWARENESS CAMPAIGN (C) (B) (W)	Local and national authorities/ Local, national and international NGOs	Immediate- to long-term	Provision of online and offline materials in English, Macedonian and Albanian; observing social media trends and including educational tools for schools. Emphasis on ecosystem services and biodiversity. Incorporation of camera traps etc. and carefully designed citizen science. projects to bring people closer to wetland nature.
COMPLETION AND SUBMISSION OF RAMSAR INFORMATION SHEET TO THE RAMSAR SECRETARIAT, AND ESTABLISHMENT OF NATURAL MONUMENT ON A NATIONAL LEVEL (G)	National Ramsar Committee/ Ministry of Environment and Physical Planning/ Ohrid SOS	Immediate to short	Designation of SW together with the entire lake as a Wetland of International Importance under the Ramsar Convention. Proclamation of a SW Monument of Nature.
RESEARCH INTEGRATION (B) (E) (C)	Hydrobiological Institute Ohrid/ NGO Sector/ Local community	Immediate to short	Extension of regional research projects to include SW, encouraging citizen involvement with findings publicised in mainstream/ social media.
PRELIMINARY ASSESSMENT FOR REWETTING PROCESS (B)	Hydrobiological Institute Ohrid/ Municipality of Ohrid/ Panel of independent experts	Short	Identification of areas to rewet; carefully designed action plan for rewetting with the preliminary aim to achieve 1970s wetland area. Incorporation of rewetting action plan within below-mentioned urban, economic and tourism strategies as well as the SW Management Plan.

ACTION	ACTOR(S)	TIME	EXPECTED RESULTS
CREATION AND ENACTION OF THE FIRST SW MANAGEMENT PLAN (G)	Hydrobiological Institute Ohrid/ NGO Sector/ Municipality of Ohrid	Short	Clearly defined short, medium and long-term action plan to revitalise and repurpose SW for nature tourism, including sustainable budgetary mechanisms and detailed marketing strategy. Emphasis to be placed on maximisation of ecosystem services and habitat rehabilitation, both heavily publicised. Limits of acceptable change to be delineated. Reed-belt maintenance a special priority.
SUSTAINABLE REORIENTATION OF REGIONAL URBAN, ECONOMIC AND TOURISM PLANNING STRATEGIES (G) (E)	Municipality of Ohrid/ NGO sector	Short	Alignment of regional economic and urban strategy with both conservation aims and SW Management Plan to reduce loss/damage and optimise ecosystem services. Incorporation of a protected area at national level for the full extent of SW plus buffer zone provision within urban planning documents. Recognition and integration of a protected SW as key tourism infrastructure in a sustainable visitor attraction framework. Adherence to Society of Wetland Scientists' Declaration on the Protection of the Lake Ohrid Ecosystem. Training for local municipality and MoEPP staff.
ESTABLISHMENT AND IMPLEMENTATION OF EFFECTIVE WASTE MANAGEMENT PLAN FOR SURROUNDING VILLAGES AND COASTAL AREAS (G) (W)	Municipality of Ohrid/ Citizens/ Waste collection unit; Local wastewater management company	Short-medium	Increased regularity and scope of solid waste collection. Upgrade to wastewater systems, particularly related to the village of Racha. Fundraising and other initiatives for waste collection tied to the tourism industry. Removal of construction and other waste from the SW. Improved regulation for agricultural waste. Reformed agricultural processes. Heightened public contribution to environmental cleanliness.
RECONNECTION OF LAKE-WETLAND CHANNELS (B) (E)	Municipality of Ohrid/ Panel of independent experts	Short-medium	Functional connective channels allowing substantial ecological and hydrological communication between SW and Lake Ohrid to be established.
REMOVAL OR RELOCATION OF BUILDINGS/ STRUCTURES THAT ARE INCOMPATIBLE WITH SW RESTORATION (B) (W)	Municipality of Ohrid	Medium	Closure of the plant nursery. Removal of temporary, illegal and/or environmentally damaging buildings.

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ACTION	ACTOR(S)	TIME	EXPECTED RESULTS
IMPLEMENTATION OF REWETTING ACTION PLAN (B) (E) (W)	Municipality of Ohrid/ Panel of experts/ Hydrobiological Institute Ohrid	Medium	Wetland habitat to be regenerated with maximum publicity aimed at the local population and the tourism industry. Sanitisation and pollution removal in agricultural areas to be undertaken prior to raising the water level.
ESTABLISHMENT OF SW VISITOR CENTRE AND BOARDWALK (E) (C)	NGO Sector/ Municipality of Ohrid/ Hydrobiological Institute Ohrid	Long	Fulfilment of boardwalk attraction with visitor centre to include information panels, exhibitions and nature watching facilities, focusing on the unique, interconnected natural and human history of SW within the UNESCO Ohrid region and synthesising educative, research, conservation and tourism goals against the backdrop of both natural and cultural WH status. Monetisation of the project to facilitate wetland conservation. Emphasis on local employment and community involvement as well as visibility of activities.

(G) Governance measures; **(E)** Powering up of ecosystem services; **(B)** Biodiversity; **(W)** Waste Management; and **(C)** Recoupling of local communities to wetland values.

MoEPP (Ministry of Environment and Physical Planning), **SW** (Studenchishte Wetland).

a Sophisticated personnel techniques, international outreach and a robust social media strategy are an essential component of success to counterbalance potential politicisation in scientific institutions and freedom of speech restrictions.

Source: Compiled by the authors.

The potential of ecotourism in the context of the wetland natural and cultural surroundings

Another important added value to the potential tourism itinerary in the Studenchishte area is the archaeological site of Studenchishta located directly above the wetland. This site contains the ruins of the Studenchishta Basilica, a remarkable example of early-Christian sacral architecture dating from the 5th or 6th century AD. In addition to its complex architecture, the basilica is richly adorned with stone and marble reliefs, mosaic pavements of the highest quality craftsmanship, and ornamental patterns. The Studenchishta Basilica was erected on an older cultural site, possibly a temple, undoubtedly linked to pre-Christian worship of water as a life-providing force of nature, hence the choice of location in the near vicinity of one of the most abundant springs on the Ohrid Lake shoreline: Biljanini Springs.

These three sites together (Biljanini Springs, the wetland and the basilica), could very well be the highlights of a cultural-natural park complex. Biljanini Springs represent a fully functional natural spring phenomenon feeding the lake with crystal-clear water; the ruins of the Basilica testify to the importance of this water resource throughout 3,000 years of history; while the wetland, with its various services (water purification, carbon storage, food chain support through its nursery function for fish, and its contribution to the region's biodiversity), features the connection of water from land to lake. Such an original project can boost ecotourism in the area, and, if implemented sensitively, is a promising alternative to the planned, devastating, large-scale tourist developments that include a marina, urban beach, and amusement park.

Conclusions

Studenchishte remains an integral part of the Ohrid-Prespa UNESCO World Heritage Site, and by location, geology, biodiversity, ecological functioning, and ecosystem services, it is definitely a Wetland of International Importance. Studenchishte is under great anthropogenic pressure and has been gradually degraded over the years. Therefore, an in-depth management plan is required with various timescales. These actions, if undertaken properly, integrated with the tourism industry appropriately and publicized effectively, will deactivate current threats and ensure not only a more positive future for Studenchishte's biodiversity, but also that its numerous ecosystem services are maximized to the benefit of the local population so the wetland's economic contribution and awareness of that contribution can grow in parallel.

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CHAPTER

3

Iran's water crisis

Disaster unfolds in the drying of Gavkhouni Lake

By

Ania Grobicki
Deputy Secretary General,
Ramsar Convention Secretariat

Rob Cadmus
Consultant,
Ramsar Convention Secretariat

Sadegh Sadeghi Zadegan
Executive Director,
Ramsar Regional Centre in Central and West Asia

Maryam Omidi
Wildlife and Habitat Expert,
Department of Environment, Isfahan Province,
I R Iran

Lew Young
Deceased

In Memory of our dear friend and colleague Lew Young, who passed away in 2019. Lew was a dedicated conservationist who inspired many people through his work, and is sadly missed.

Abstract

Since 2000, the Zaindeh Rud River in the central part of the Islamic Republic of Iran has dried to a trickle, leaving a bare river bed under the historic covered bridges of the ancient city of Isfahan, and depriving the terminus of the river, the once expansive Gavkhouni Lake, of its water. Because of climate change, prolonged drought, high evaporation rates, and excessive water abstraction, demand for water has surpassed the amount available, leading to a challenging water crisis that is threatening the health and livelihoods of people. Good rainfall and a state crackdown on abstractions once again brought some water and life back to Gavkhouni Lake in 2016, but the long-term sustainability of the region and the unique ecology of this Wetland of International Importance are at risk. The tragedy of the Aral Sea is being repeated on a smaller scale. With increasing temperatures and frequent sandstorms, this environmental disaster exemplifies what continues to occur across Iran and many water-stressed countries of the region.

Keywords:

climate change | population pressure | pollution | water stress | water use | wetlands | infrastructure | agriculture | industry | water demand management | river basin management

Introduction

In the central plateau of the Islamic Republic of Iran, the importance of water is highlighted by the parched landscape. Rainfall is less than a third of the global average; hence the availability of water can make the difference between a fertile landscape and a barren environment (FAO 2009; Mirchi & Madani, 2016). Throughout the country, overuse of water has serious implications for the health and livelihoods of people and the environment. The Zaindeh Rud River, which ends in the ecologically valuable Gavkhouni Wetland, has cradled civilisation for thousands of years. The ancient city of Isfahan, now home to 4 million people, has long relied on the river's life-giving water for agriculture and human use.

Although Irrigation has been practiced here for generations, in modern times the scale of development has increased dramatically to include large interbasin water transfers. While one would expect such infrastructure to increase water security, an unsustainable approach to water use that prioritizes agriculture and supply-side solutions has led to increasing water vulnerability. As a result, for nine of the past ten years the Zaindeh Rud River has dried to a trickle and the once-fertile Gavkhouni Wetland is now largely dry (Figure 1). While designated as a Wetland of International Importance under the Ramsar Convention on Wetlands, the Gavkhouni Lake and marshes of the lower Zaindeh Rud are indisputably wetlands at risk.

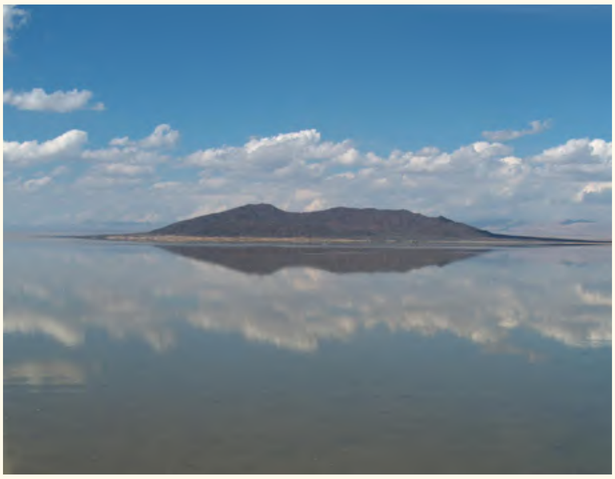

Figure 1. Then and now.

The famous "Gavkhouni smile," the reflection of Kouh-e-Siah (Black Mountain) in the waters of the lake (left), and a more recent picture of the exposed lake bed (right). This 43,000 hectare wetland has dried up because of excessive water abstraction for agriculture, industry, and other uses.

Photos: © Department of Environment, Isfahan Province, Iran

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Securing freshwater for people and the environment is one of the greatest environmental challenges of this century. With a changing climate and increasing population pressures, Iran's dramatic water shortages are predicted to worsen to extreme levels (Luo et al., 2015). The example of Gavkhouni Lake supports the growing calls for focusing on water and river basin management approaches that include demand-side solutions, including increasing water use efficiency and recycling to meet environmental flow requirements, rather than focusing mainly on supply-side infrastructure.

Geography of Gavkhouni Lake and marshes of the lower Zaindeh Rud

The Zaindeh Rud valley is a lush oasis compared with the surrounding drylands, with snowmelt from the Zagros Mountains feeding the east-flowing river (Figure 2). The city of Isfahan grew along its fertile banks as an agricultural centre, a commercial and administrative hub, and a stopping point along the famous Silk Road.

Figure 2. Map showing the Zaindeh Rud River.

The City of Isfahan is in the centre, with the inland delta and once expansive Gavkhouni Lake to the right. Location of Isfahan Province in Iran is upper right. Zaindeh Rud River in Isfahan Province is lower left.

Source: Google maps.

South-east of Isfahan, the lower Zaindeh Rud is made up of a chain of freshwater marshes and floodplains that end in inland delta marshes that cover about 1,000 ha when wet, and give way to the semi-saline Gavkhouni Lake (Figure 3) (Mansoori, 1997). The wetland is also fed by agricultural runoff and streams from nearby Kouh-e-Siah (Black Mountain), a striking volcanic massif to the north. These sources provide vital water when the Zaindeh Rud is dry. Sand dunes and drylands extend to the east, and the city of Varzaneh lies 20 km away.

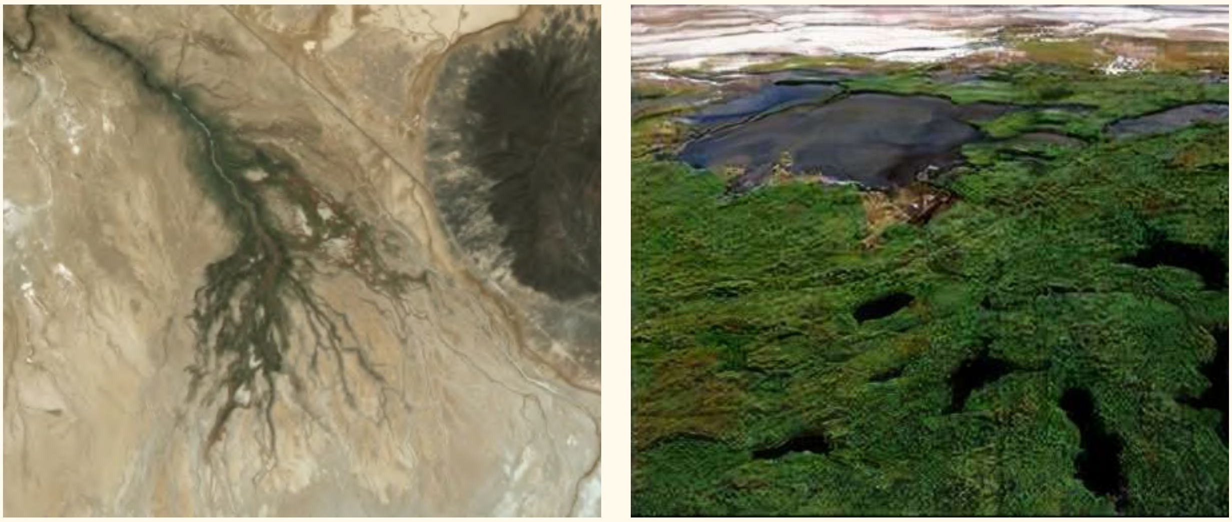

Figure 3. Lush marshes dry up and fall short of Gavkhouni Lake.

Left – A recent satellite photo of the vestigial Zaindeh Rud marshes (shown in green). The dry lake bed is white soil expanding south. In the past, the lake would have extended to the marshes and to the foot of Kouh-e-Siah Mountain, the black mountain shown as a dark semi-circle to the right of the image. Right – A closer look at the former lush green mashes of the lower Zaindeh Rud, an oasis in the desert.

During the 4th and 5th millennia BCE, Gavkhouni Lake was 10 times larger than it was in 1975, when it was designated a Wetland of International Importance. Objects recently found near the Gavkhouni marshes suggest that prehistoric people likely first settled in the area during the the Neolithic Age. The wetland is situated on a bird migration flyway, and is an important wintering area for birds (Mansoori, 1997). Many bird species breed at the site, with some annual variability. In recent years, numerous threats to the wetland have caused migratory birds to alter their flyway to other areas. Altogether 229 species of animals, including 49 species of mammals, 43 species of reptiles and amphibians, and 12 species of fishes, including the endemic fish *Aphanius isfahanensis*, were identified in the Ramsar Site at the time of designation in 1975 (Iran Aqua, 2016).

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In the Zaindeh Rud basin there are more than 910 species of plants, including endemics with genetic, herbal, decorative, edible, and industrial applications. The marshes at the mouth of the Zaindeh Rud are dominated by *Phragmites* with some *Tamarix scrub*; important plants include Tamarisk (*Tamarix mannifera*), Chicory (*Cichorium*), Wallflower (*Erysimum*), Camel's thorn (*Vachellia erioloba*), and many more. The adjacent land consists of degraded steppe and irrigated rice and wheat fields. The vegetation and water prevent the movement of sand towards the eastern part of Isfahan Province, helping combat desertification. The wetland naturally filters out pollutants, recharges groundwater, and controls flooding.

When wet and healthy, the wetland was one of the most visited tourist attractions for international sightseers, with the proximity of Isfahan and Varzaneh facilitating a growing ecotourism industry. Tourists come to see the Black Mountain and Gavkhouni Lake, cultural and historical attractions, and landmarks in the cities, along with magnificent congregations of birds.

Unique values and services

Gavkhouni Lake is a unique closed drainage basin and shallow lake wetland representative of the lowlands of Iran's central plateau. It provides important services such as habitat for wintering, migrating, and breeding waterfowl. The lake defends against desertification by increasing soil stability and sand/dust suppression through soil moisture and wetland vegetation. It controls flooding, recharges groundwater, and cools the harsh climate through evaporation and humidity, creating a pleasant and healthy microclimate.

The lake also provides provisioning and cultural services for humans. It is an ecotourism destination for its natural and sociohistorical values and biodiversity. It supports livelihoods (forage, salt extraction, ecotourism, and wetland handicrafts). And it is an ideal site for wetland education, management training, and research programs.

Biodiversity status

The wetland is recognized as an Important Bird Area and Wetland of International Importance under the Ramsar Convention on Wetlands (Mansoori, 1997). The 43,000 ha Ramsar Site (Site no.53) was designated on 23 June 1975, as a representative example of a shallow natural wetland of the lowlands of Iran's central plateau, and because

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the wetland used to support over 20,000 waterbirds, including flamingoes (*Phoenicopterus*), Graylag geese (*Anser anser*), ruddy shelduck (*Tadorna ferruginea*), and more. Wintering raptors included the white-tailed eagle (*Halieetus albicilla*), the eastern imperial eagle (*Aquila heliaca*), and the saker falcon (*Falco cherrug*). The rare Eurasian black vulture (*Aegypius monachus*) regularly occurred in the area.

Identified threats

Prior to 1950, most water abstraction was through small diversions in the central part of the valley, such as wells and 'qanats', a traditional irrigation system comprised of a complex series of tunnels and shafts (Murrey-Rust et al., 2000). Agriculture was seasonal and based on water availability. Fueled by rapid economic and industrial development, the past 50 years have seen large water infrastructure projects that have ushered in new agricultural and industrial uses, along with the threats summarized in Box 2. Diversions from the Kurang River basin and the large Chadegan storage reservoir have doubled the annual water supply flowing into the catchment, extending the growing seasons, allowing for additional lands to be irrigated, and encouraging urban and industrial development (Murrey-Rust et al., 2002). Today around 250,000 ha are farmed and Isfahan hosts the second largest industrial area in Iran (Molle et al., 2004).

Threats to the Gavkhouni Lake and marshes of the Zaindeh Rud include:

- Decreased water inflow, due to increasing water abstraction and water transfers.
- Decreased precipitation in recent years (possibly due to climate change).
- Development of agricultural lands upstream and use of inefficient irrigation methods.
- Pollution from urban and agricultural sources, including heavy metals, pesticides, herbicides, fertilizers, and waste water. These factors have affected the soil and vegetation to the extent that survival of living organisms is severely harmed and ecosystem processes are undermined.
- Degradation of vegetation in the watershed due to overgrazing and fire.
- Poaching.

As each new water infrastructure development increased supply, the demand increased to match nearly as soon as it was made available (Murrey-Rust et al., 2002). Experts with the International Water Management Institute and government agencies warned that "despite large investments in water resources development the basin remains just as vulnerable to drought as it always has been" (Murray-Rust et al., 2002). As in many other parts of the world, the management model in the Zaindeh Rud basin has focused on supply-side solutions, rather than controlling demand or subsidized efficiency. This has included subsidized water prices that eliminate economic incentives to prioritise uses and conserve water and the use of water-inefficient, outdated farming techniques (Schramm & Sattary, 2014).

With increasing demands and few options for additional water sources, the need for water has now outpaced its availability. Iran's population has more than doubled since the 1979 revolution, with nearly 80 million citizens (Rezaian, 2014). Water use is approximately twice the world standard, with an average of 66 gallons per person used each day (Rezaian, 2014). Most of Iran's water, 90% of withdrawals, goes to agriculture (FAO, 2009), and the efficiency of irrigation systems is generally low (Schramm & Sattary, 2014). Most countries in the world use less than 20% of their total renewable water resources, whereas in Iran, surface water and groundwater withdrawal are at approximately 68% (FAO, 2009).

Impacts on the environment and people

With uncontrolled water use and prolonged drought, groundwater levels around Isfahan have dropped as much as 270 meters (IMNA Broadcasting, 2014). Near Gavkhouni, after the last cotton crop was harvested 10 years ago, the farmers turned to food crops before gradually abandoning the land altogether. As the lake dried up, its microclimate and its moderating effect on local temperatures disappeared. Hot days became hotter, evaporation rates increased, and the water disappeared ever faster. The increasing temperature of the lake water dramatically affected the ecosystem until the water dried up, leaving dying fish scattered on the mud. Gavkhouni lost nearly all of its water by early 2015. Much of the soil was covered in salt crystals, along with which the toxic chemicals from upstream industrial agriculture and industry turned into a corrosive, poisonous dust. With no lake water, formerly cooling winds became deadly dust storms that increased in frequency and virulence, raising concerns over air quality, health, and quality of life for the 12,000 people of Varzaneh and the 5 million people

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of Isfahan Province. This environmental tragedy reflects the reality of population pressures and climate change.

Gavkhouni is not the only wetland facing this threat. In northwestern Iran, Lake Urmia was the sixth largest saline lake in the world, and a UNESCO Biosphere Reserve and a Ramsar Site. Due to unsustainable water use and diversions, it has shrunk to only 5% of its former expanse of 5,200 km^2 (Rezaian, 2014; Mirchi et al., 2015; Mirchi & Madani, 2016). Once a major tourist destination and an important migratory stop for waterfowl, the lake is now mostly dry. The wind spreads salt crystals that degrade the soil and the poor water and air quality cause health concerns. While some have tried to blame the changes of climate change, studies have shown that the lake has weathered worse droughts and have instead pointed the finger at unsustainable water use (Mirchi & Madani, 2016). The Hamoun Wetland on the Afghanistan border is faced with a similar challenge, as are Shadegan and Bakhtegan Wetlands.

Without serious action Iran may reach a tipping point, beyond which restoration of its waters and preservation of its people's livelihoods may become very difficult. The dire situation in the former Aral Sea of Central Asia serves as the worst-case scenario. Once the world's fourth largest lake, major water diversion systems installed in the 1960s resulted in the rapid loss of this inland sea. One of the world's worst environmental tragedies, the sequence of water scarcity, pollution, and the collapse of the fishing industry resulted in systemic economic and health hardships for local communities.

Restoration solutions

The fight to restore the Zaindeh Rud River and the life of the Gavkhouni Wetland began as farmers and communities in the lower catchments were forced to abandon their land because of lack of water and polluted soils. In 2013, riots over water rights broke out in Isfahan and later protests began in Isfahan and throughout Iran (Almonitor, 2013; 2014). Restoring the Gavkhouni Lake means balancing water use and the needs of the environment through integrated water resources management and a sound river basin plan. Some have argued for more large-scale inter-basin transfers to increase supply, such as a costly pipeline bringing desalinated water from the Caspian Sea. Many scientists called for demand-side management (Mirchi & Madani, 2016), and reducing urban and industrial water use as well as stopping water leakages from ageing pipes, especially in large cities such as Isfahan. The International Water Management Institute, Iranian Agricultural Engineering Research Institute, and others have collaborated on a series of research projects to foster integrated water resources management, with a particular focus on optimizing agricultural water use for sustainability (Murrey-Rust et al., 2000). Their efforts have shed light on the challenges and identified potential solutions, including water tariffs, water-efficient horticulture and irrigation techniques such as drip irrigation, reducing the area farmed, alternative crops that are less water-intensive, and balancing changes to agricultural and industry to minimise unemployment (Schramm & Sattary, 2014).

Water managers in the basin have begun to take action including upholding water rights and closing illegal wells. Treated urban wastewater is now released into the wetland, and there is a mandate for uninterrupted water flow during the farming season, ensuring that not all of the water in the Zaindeh Rud is taken by agriculture (Financial Tribune, 2016). As a result of the actions taken by water managers and a good rainfall, water once again reached the Gavkhouni Wetland in the spring of 2016, bringing back flamingoes, waterfowl, and wildlife (Financial Tribune, 2016). People not only benefited from the healthy environment, but this renewal of life-giving water has brought hope for a more sustainable future.

Establishing mandated water flows to maintain the ecological functions of the environment is a widely recognised best practice (Poff & Matthews, 2014). Large-scale supply-oriented water infrastructure that was once the common solution to meet water needs is now understood as a major cause of environmental degradation. Uncertainty about the changing climate and limited resources serves to undermine this approach further (Poff & Matthews, 2014). Integrated water resources management that includes improved demand management is supported by internationally agreed-upon standards, such as the goals and targets related to water in the UN Sustainable Development Goals (WWAP, 2015). Target 6.4, for example, outlines the need to ensure water use efficiency and sustainable withdrawals, Target 6.5 calls for integrated water resources management, while Target 6.6 calls for the protection and restoration of water-related ecosystems such as wetlands (UN General Assembly, 2015). Further, the UN Convention on Biological Diversity, UN Convention to Combat Desertification, Ramsar Convention on Wetlands, and other conventions have provided guidance through resolutions and technical briefings to help water managers.

Despite this widely recognized approach and the availability of scientific information, the high demand in water-stressed places like the Zaindeh Rud basin are undeniably challenging. With increasing population pressures and climate change, managers of the Zaindeh Rud basin must focus on balancing this key social-ecological system to become more robust against a wide range and variety of stressors, including changes in climate. This "managing for resilience" approach is the best way to ensure a healthy economy and environment (Allen et al., 2011).

A holistic approach to water management that values the multiple ecosystem services of wetlands is not a new idea. The historical water allocation agenda of the Zaindeh Rud, more than 500 years old and known as 'Toomar-e-sheikh bahaei', had a water share for the Gavkhouni Wetland. It is the oldest known policy to ensure environmental flows for a wetland in the country and likely one of the oldest policies of its kind in the world, an outstanding example of holistic water use in traditional management.

The landmark Convention on Wetlands was signed in Ramsar, Iran in 1971. This international agreement has fostered the wise use and conservation of wetlands throughout the world. Like the Ramsar Convention, the story of the Gavkhouni Wetland highlights the interconnectedness of people, water, climate and the environment. The interventions for the Zaindeh Rud River and Gavkhouni Lake prove that the wise use model can work, though more must be done to meet the growing and significant water challenges in the region and to ensure the long-term sustainability of this valuable place and the people who depend on it.

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CHAPTER

4

Lake Fúquene, Cundinamarca, Colombia

Ecological degradation and management mistakes in an Andean lake

By

María Pinilla-Vargas
Fundación Humedales,
Bogotá, Colombia

Mauricio Valderrama-Barco
Fundación Humedales,
Bogotá, Colombia

Abstract

Lake Fúquene (3260 ha) is one of the most important freshwater bodies of the high-elevation ecosystems in the northern Andes. It represents a local hotspot of biodiversity; 308 different species – including migratory birds – have been registered in the area around the lake. The lake provides freshwater to around 181,000 human inhabitants, who use it for direct consumption and agricultural activities. Management at Lake Fúquene has focused on maintaining pastures via an irrigation district, which has caused severe alterations of its natural hydrological cycles, modifying its ability to capture water surges in the rainy season and release it gradually during the dry time. Additionally, the lake faces threats such as water contamination from untreated sewage and small-scale coal mining operations, sedimentation, invasive species and extreme weather events triggered by climate change. Massive work is needed to reverse the degradation of the lake, combined with management strategies in the catchment as a whole to improve water quality and restore forest cover to prevent further soil erosion.

Keywords:

Lake Fúquene | Colombia | Andean lakes | invasive species | climate change

Introduction

Lake Fúquene is one of the most important freshwater bodies of the high-altitude ecosystems in the Northern Andes. Because of its uniqueness and the nature of the threats it faces, this lake is strategic for both the communities living around it and for biodiversity representing a regional hotspot.

Lake Fúquene is the second largest high-altitude lake in Colombia and it is very important for the survival and prosperity of the inhabitants of its catchment area. Additionally, Fúquene harbors endemic and threatened fauna and flora, and it is a key habitat for migratory bird species. This wetland supports fish stocks, provides water for human consumption, irrigation for agriculture, flow regulation and materials for handcrafts and has been subjected to years of unsustainable practices and inappropriate management policies (Franco-Vidal, 2015). Climate change poses a threat to the lake's ability to provide essential environmental services and therefore policies must assure measures towards adaptation and reduction of the vulnerability of the communities.

Although integrated management goals and biodiversity conservation objectives have been introduced in policy and action plans, management actions seek the continuous optimization of the lake's irrigation services, at the expenses of other ecosystem services (Andrade et al., 2012). The current state of the Fúquene Lake is the result of anthropic actions of territorial modification derived from policies and regulations for the drying out of the lake system that were, over the decades, changing towards the protection of wetlands and water sources. These processes must be analyzed in depth to understand the variables related to such environmental impacts such as changes in the water surface and land reclaimed from the lagoon, soil erosion, agricultural expansion, water pollution and the settlement of exotic species (Castro-Diaz and Natenzon 2020).

This study investigates the successes and failures of pursuing a sustainable management of the lake and raises a discussion into actions aimed to preserving the ecosystem. We identify main goods and ecosystem services provides by Lake Fúquene and describe major conflicts that this environment has faced and propose management measures to restore and preserve this valuable environment.

Physical environment

Lake Fúquene lies in the Ubaté River Basin in the Colombian Andes, on the border between the states Cundinamarca and Boyacá in the north-west of the country. The lake is 90 km north of the nation's capital, Bogotá at an altitude of 2,500 m above sea level (Figure 1). It extends over 3,260 ha, has a volume of 82.5 Mm^3 and a mean depth of 2.5 m (JICA, 2000). This lake is primarily fed by the Ubaté, Susa and Fúquene rivers as well as a couple of small streams and creeks. It ends in the Suarez River, which turns into the Sogamoso River and finally reaches the Magdalena River further north. The weather conditions are mostly stable with temperatures close to 18 °C, a rainfall of around 1,030 mm per year and a humidity variation of 70 –79% (JICA, 2000). The water quality tests indicate eutrophic conditions (Table 1.)

Table 1. Lake Fúquene's water quality

PARAMETERS	VALUE	UNIT OF MEASURE
TEMPERATURE	18.1	°C
NITRATES	0.21	mg/L
NITRITES	0.002	mg/L
PHOSPHATES	0.13	mg/L
TOTAL PHOSPHORUS IN SEDIMENTS	478	mg/kg
TOTAL DISSOLVED SOLIDS	47.5	Ppm
ORGANIC MATTER IN SEDIMENT	16.4	%
CONDUCTIVITY	98.5	us/cm
pH	6.78	
ALKALINITY	46.35	mg/L CaCO3
HARDNESS	77.1	mg/L CaCO4
DISSOLVED OXYGEN	4.8	mg/L
BOD (BIOLOGICAL OXYGEN DEMAND)	2.5	mg/l
COD (CHEMICAL OXYGEN DEMAND)	25.6	mg/L

Source: Adapted from JICA, 2000; Franco et al., 2011; Asociación de Pescadores los Fundadores and Fundación Humedales, 2011.

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Lake Fúquene is a local "hotspot" of freshwater biodiversity; 308 different species have been recorded at the lake and its surrounding area (Table 2), including the catfish (*Eremophilus mutisii*) and the river crab (*Neoestrengeria macropa*), both endangered endemic species (Amat-García et al., 2007; Mojica et al., 2012). The lake is also a key habitat in Colombia for globally threatened bird species due to its high proportion of migratory bird species (41 boreal, 2 austral) and local endemic and threatened species such as the Apolinar's wren (*Cistothorus apolinari*) and the Bogotá rail (*Rallus semiplumbeus*) (Birdlife International, 2012a; 2012b).

Table 2: Lake Fúquene's biodiversity

TAXA	NUMBER OF SPECIES	TAXA	NUMBER OF SPECIES
AQUATIC PLANTS	17	FISHES	6
PHYTOPLANKTON	27	MACRO CRUSTACEANS	2
COASTAL PLANTS	20	BIRDS	125
SURROUNDING FLORA	87	MAMMALS	12
REPTILES	5	AMPHIBIANS	7
TOTAL			**308**

Source: Adapted from Hilty &Brown, 1986; Olivares, 1969; JICA, 2000; Asociación de Pescadores los Fundadores & Fundación Humedales, 2011.

The lake's vegetation is mainly composed of emerging aquatic plants such as rush and cattail (*Scirpus californicus* and *Thypha angustifolia*), floating plants like duckweed (*Lemna minor*), and the invasive water hyacinth (*Eichiornia crassipes*), and Brazilian elodea (*Egeria densa*). The watershed is composed mainly of dry slopes, covered in sub xerophytic vegetation, with species such as the endemic Agave or Fique (*Agave cundinamarcensis*) and small relict stands of formerly extensive Neotropical oak forests (*Quercus humboldtii*) on wetter slopes to the east.

Lake Fúquene provides freshwater to around 181,000 inhabitants, which is used for human consumption and agricultural activities (e.g., dairy farming, cattle breeding, and crops). Plant material used for handcrafts and fish stocks provide local food. The lake offers other environmental services such as flow regulation and flood damping and habitat to endemic, migratory and threatened bird species. This region is dedicated to dairy production with an estimated 50 factories of different capacities producing dairy products and a growing number of cattle: around 146,218 cows in 2010 (Valderrama et al., 2013). Around 48 fishermen remain at Lake Fúquene from the 200 reported in 1996. Some derive their income solely from fishing and the rest fish to supplement other activities since the average monthly income deriving from fishing is only US$ 68, which represents less than one-third of the country's monthly minimum wage.

Legal status

Lake Fúquene was declared a regional protected area in 2017 by the regional environmental authority of Cundinamarca, Corporación Autónoma Regional (CAR). The legal authority used for this declaration is Regional Integral Management District (*Distrito Regional de Manejo Integral*), which allows for economic activities to take place in the area with some restrictions on mining and industrial farming among others. The lake was proposed as a Ramsar Site in the past but political will to make the designation has been lacking. It was then declared an Area of Importance for the Conservation of Birds as part of a global initiative led by Birdlife International, but this designation is not legally binding and therefore does not restrict land use and other activities in support of conservation.

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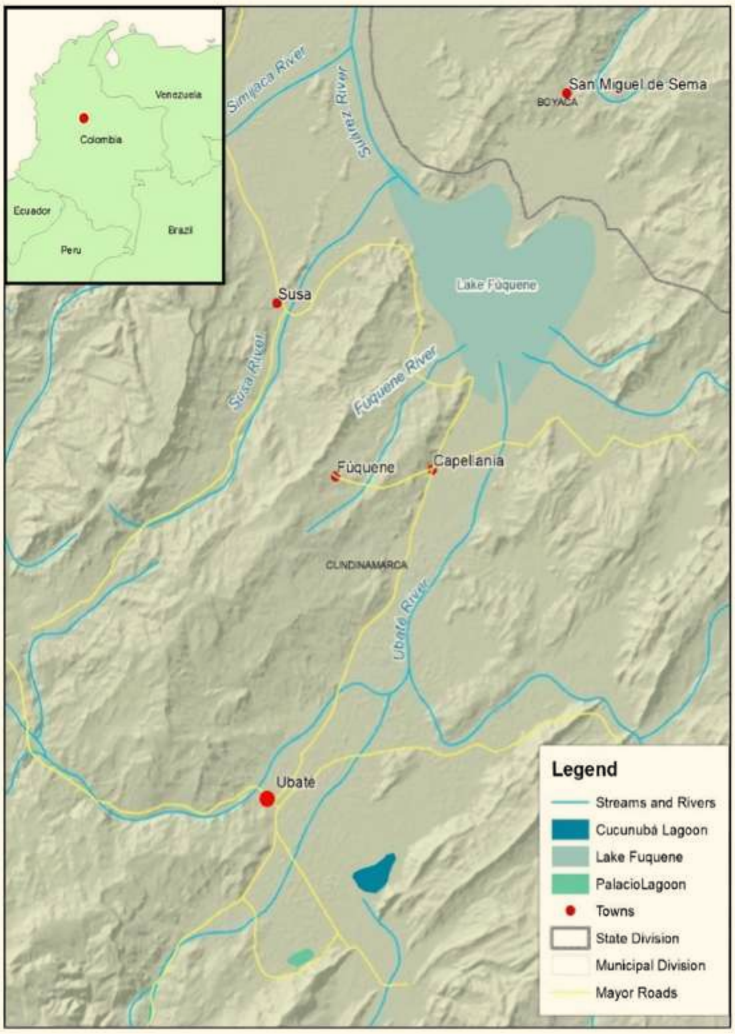

Figure 1. Map of Lake Fúquene and its catchment area with topographic relief.

Map was created in ArcGis 10.3 software.

Source: Compiled by the authors using publicly available data of the Instituto Geográfico Agustín Codazzi [June 2018] https://www.igac.gov.co/es/ide/datos-e-informacion/cartografia

Threats and management conflicts

More than 500 years of human intervention have changed the natural conditions (i.e., climate, hydrological pulses) of the lake and associated wetlands into a problematic human-regulated irrigation district (Andrade et al., 2012). The wetland system was transformed to improve conditions for cattle raising, focusing on maintaining the pastures and disregarding climate change adaptation measures. In consequence, the whole catchment area faces climatic stress, particularly during ´El Niño´ (Southern Oscillation) or ´La Niña´ years, with droughts and floods becoming commonplace. Government corruption and lack of political will have worsened the situation, leaving the environmental authorities without power to effectively enforce local environmental protection laws, and available are funds invested in dredging and other palliative measures instead of long-term solutions (Roldan, 2008; Murtinho et al., 2013).

The catchment area of Lake Fúquene has suffered an intensive process of deforestation, leaving only small fragments of native forest. Merely 5% of the land cover is primary and secondary forests and the rate of deforestation in the area reaches 5 ha per year (van der Hammen, 1998; JICA, 2000). The resulting erosion has increased the sedimentation rate of the lake, which in turn has caused a decrease of 2.5 m in its depth and a loss of 50% of its water storage capacity (Franco et al., 2011). Reforestation efforts were made during the 1980s, but the species chosen (*Pinus patula, Cupressus lusitanica, Eucalyptus globulus* and *Acacia decurrens*) were exotic and very damaging to the soil, increasing erosion.

The lake water's physicochemical conditions and biological indicators show poor water quality, and in several spots these indicators reach critical status and reveal a high level of eutrophication (Asociación de Pescadores los Fundadores & Fundación Humedales, 2011). Dissolved oxygen in the water has decreased and the levels of phosphorus and nitrogen are high, which has reduced water quality and increased treatment costs for the local watercourses. Water contamination is caused primarily by untreated sewage from the nearby towns, milk processing by-products, coal mining operations upstream and water drainage from cattle ranches. Further studies are needed to determine the relative contribution of each of these contamination sources.

A peripheral channel, intended to address the contraction of the water body was dredged around the littoral zone, causing a disruption of the hydraulic regime, affecting normal water circulation patterns by limiting the natural interactions between the shore and the limnetic zone and constraining the wetlands area (Useche, 2003). The channel also isolated the central body of the lake from the lakeside ecosystems thus water level fluctuations and pulses now depend on the management of floodgates.

In terms of invasive species, the water hyacinth, the elodea, the fish carp (*Cyprinus carpio*) and the red swamp crawfish (*Procambarus clarkii*) are widely present in the lake, competing for resources and space with the local flora and fauna. Two endangered native species, the crayfish and the catfish, are at risk and the expansion of invasive aquatic plants is reducing the extent of the open water, occupying about 64 new hectares per year. The combination of all of these factors over the long term predict a continual reduction of the lake´s open waters, and the transformation of the system into an extensive swamp with possible water shortages in El Niño years and floods in La Niña years.

Goods and services affected

Many people around the lake and downstream depend on the lake´s water supply (Chiquinquirá city, with around 56,000 inhabitants, also benefits from these services, via freshwater supplied to the municipal watercourse). The region's main economic activity is cattle raising for dairy production, with an estimated 50 dairy factories operating in the area in 2013, which benefit from the environmental services provided by the watershed. In terms of equality, big cattle ranchers hoard the most productive land, while smallholders are forced to the higher parts of the watershed, where water is scarce and the soil becomes easily eroded. To make ends meet, smallholders have expanded agricultural land into important ecosystems like *páramo* and forests, weakening the soil and its ability to retain water and nutrients (Valderrama et al., 2013).

The fish catches have decreased from 18.7 t in 2005 to 3.5 t in 2014, with a clear impact on food security. This trend is reflected in a 70% reduction of active lake fishermen, who now depend on other activities for their livelihoods. The number of local artisans has also dropped from 175 people in 2005 to 77 in 2012 (Pachón, 2016).

As a result, the environmental degradation, the social dynamics and the production practices, combined with the increase of extreme weather events, has affected the ability of the watershed to provide essential services like freshwater for human consumption and cattle raising and suitable soil for agriculture, resulting in losses of crops and animals and the migration of farmers to urban areas (Morales, 2016).

Recommended solutions

A more effective use of the soil in the catchment and the reduction of natural hazards will improve the livelihoods of local communities that depend on the lake for their survival and income. This in turn will slow the advance of widespread deterioration and loss of plant and animal life. Communities, landowners and environmental authorities should come together and agree on how to better adapt to the restrictions to land use that come with the declaration of the catchment as a Regional Integral Management District.

The importance of recovering the area's natural forest an adaptation strategy for climate change arose as a result of research projects that Fundación Humedales has conducted in the catchment area of Lake Fúquene. To ensure the resilience of the territory, the quality of the water supply and the sustainable management of soils under changing environmental conditions, it is necessary to have a forest cover on at least 36% of the basin area in the next 20 years (Franco et al., 2011). The recovery of these forests must be done in partnership with local landowners in order to restore forest cover in their properties by providing incentives like payments for environmental services or alternative economic activities. Planting new forests will enhance connectivity among forest remnants in the catchment area, allowing species to move freely and maintain the genetic integrity of their populations. We expect a transformation as landowners decide to use a portion of their land for conservation purposes and a change in the way local community and stakeholders support landowners to achieve a fairer distribution of the costs associated with sustainable management of the landscape.

Payment for ecosystem services (PES), is a scheme in which companies and cities that benefit from the services provided by the watershed, pay smallholders upstream an allowance to protect the vital ecosystem services (Milder et al., 2010). This scheme could provide the opportunity for retribution from the most productive areas to the less, creating an income opportunity for smallholders in key areas in the watershed, and discouraging further environmental degradation. This type of scheme has been successfully implemented in Colombia through partnerships between farmers, cattle ranchers, water users, and private and public organizations (Pagiola et al., 2004; Blanco et al., 2008; Calle et al., 2009; Zuluaga, 2014).

Nevertheless, the contamination of the lake's waters must be addressed. A thoughtful study of the relative contribution of each contaminant source in the catchment is needed to guide the enforcement of current pollution regulations. In the meantime, Fundación Humedales and the Global Nature Fund (GNF) constructed wetlands for the wastewater treatment of sewage effluents from small towns in the lake's basin. Three of these treatment systems are already operating in San Miguel de Sema, Susa and Fúquene.

However, treatment of sewage waters from larger towns like Ubaté is still lacking as well as an improvement of agricultural practices. To improve the lake's water quality, the amount of pesticides, fertilizers, and organic matter, derived from cattle and crops must be dramatically reduced. Silvopastoral systems and riparian buffers could be implemented to prevent excess nutrients and organic matter from reaching the lake (Collins et al., 2007;). Riparian buffers of at least 10 m around bodies of water are already required by the local law, but are rarely enforced.

Furthermore, invasive species problems like the red swamp crawfish must be addressed via an integral management strategy, which encourages the consumption of this species in order to keep its population under control and also improve the livelihoods of local fishermen by connecting them with potential markets. Likewise, there is a need to evaluate invasive species' impact on threatened endemic ones like the crayfish, the Bogotá Rail and the catfish, and implement conservation actions for their protection.

In conclusion, to achieve a successful and long-term adaptation to climate change and the provision of ecosystem services for future generations in Lake Fúquene's catchment area, it is important to ensure the management and protection of the territory as a whole, including strategies directed towards the variety of threats the lake faces. More work should be directed towards education and awareness regarding the protection of the lake and its importance for the region. Stakeholders should come together to make sure that authorities enforce existing environmental protection laws and guarantee that the declaration of Lake Fúquene as a protected area is not only true on paper.

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CHAPTER

5

Ciénaga de La Palmita, Zulia State, Venezuela

A wetland threatened by water restriction and anthropogenic activities

By

Antonio Vera

Laboratorio de Ecología, Centro de Investigaciones Biológicas, Facultad de Humanidades y Educación, Universidad del Zulia

Abstract

The Ciénaga de La Palmita, located in the Strait of Maracaibo Lake, Zulia State, Venezuela, is a Wildlife Fauna Reservoir. The biota contains amphibian species (3), mammals (6), invertebrates (8), reptiles (9), terrestrial and macrophyte plants (51), birds (57) and fish (59). The wetland faces threats such as the degraded flow of the Aurare River, presence of the invasive Mozambique tilapia (*Oreochromis mossambicus*), forbidden fishing practices, illegal hunting, extraction of wood and dumping of solid waste which alters the ecological character of the wetland impacting the goods and services. Management practices such as implementation of an ordinance plan and usage regulations, recovery of the flows of the Aurare River, vigilance and monitoring, environmental educational programs, and economic appraisal and scientific research for the conservation of the marshland are suggested. Threats to the swamp endanger the ecological stability and its goods and services and the habitats for its unique biological diversity.

Keywords:

anthropogenic action | conservation | mangrove | Maracaibo Lake | swamp | water restriction | Wildlife Fauna Reservoir | wise use

General characteristics, geographic location and climatic parameters

The Ciénaga de La Palmita is a wetland on the east coast of the strait between the Gulf of Venezuela and Lake Maracaibo opposite the city of Maracaibo, which is on the west bank of the strait. It is near the municipalities of Santa Rita and Miranda in Zulia State, Venezuela (10°35’12”-10°38’23” N and 71°26’41”-71°31’15” W) (Figure 1; Gaceta Oficial de la República Bolivariana de Venezuela, 2000).

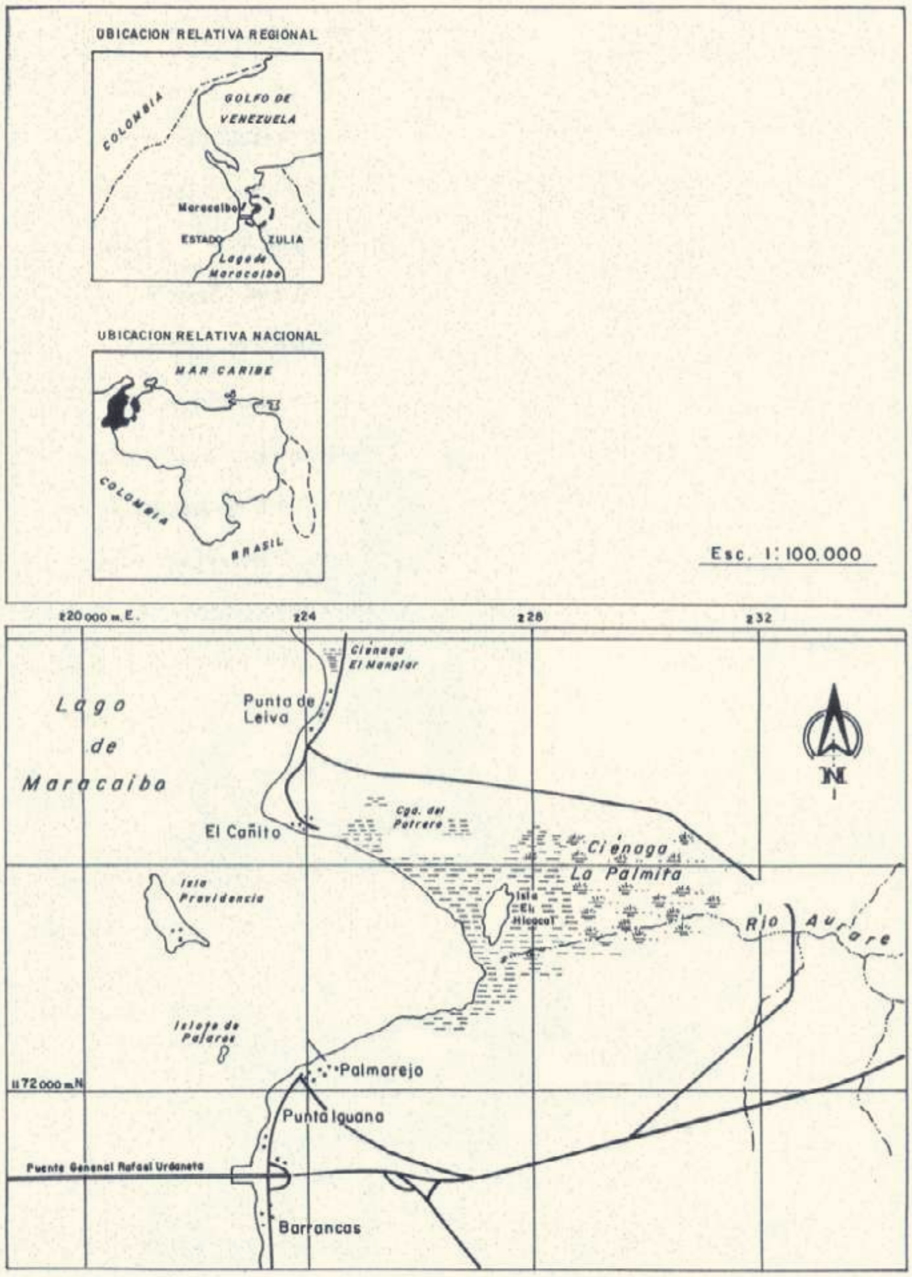

Figure 1. Ciénaga de La Palmita, Zulia State, Venezuela.

Source: Modified from Coty (1995) with permission.

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The Ciénaga de La Palmita is a transition area between the continental zone and Maracaibo Lake. From East to West there are three important biotic spaces: the swamp itself, the mangrove forest (mangle trees) and the inlet of the swamp. The swamp alone has an area of 855 ha and a slope lower than 1%; it receives fresh water from the Aurare River (De Olivares, 1988; Aguilera & Riveros, 1993).

The swamp makes way to a mangrove forest of 522 ha, dominated by red mangrove (*Rhizophora mangle*) (Vera et al., 2010). Finally, the mangrove forest communicates with the inlet of La Palmita, a formation of estuarine turbid and quiet waters of the Strait of Maracaibo Lake, (Figure 2; Vera et al., 2010). The average annual precipitation is of 400–500 mm, the annual evaporation is 2,500–3,000 mm and the annual average temperature varies from 27.8–28.3° C (Aguilera & Riveros, 1993).

Figure 2. Mangrove forest of *Rhizophora mangle* in direct contact with the estuarine waters of the inlet of Ciénaga de La Palmita, Maracaibo Lake, Western Venezuela.

Photo © Antonio Vera.

Physicochemical characteristics of the soil

The soils of the Ciénaga de La Palmita have a sandy clay loam texture with a predominance of clays; the area is flooded most of the year (De Olivares, 1988). The clay soil is blocky structure and hard consistency in a dry state and plastic in a humid state. The high content of kaolinite clay generates a low capacity for cationic exchange (9.6 meq/100 g) and low fertility for farming. The soils are also characterised by a low predominance of alkaline salts, making them slightly basic pH (7.55) with a moderate to high salinity (4–8 ppm) (De Olivares, 1988).

Biotic component

The avifauna of the Ciénaga de La Palmita is composed of 57 resident and migratory species found in fresh and seawater habitats, whose inventory has been taken in the swamp and in the mangrove forest (Coty, 1995). The mangrove offers adequate conditions for feeding, resting, protection and reproduction of the birds; the latter has been made evident by the presence of successful nests in the mangrove trees (De Olivares, 1988). Inventories in these environments have revealed three species of amphibians, six species of mammals and nine species of reptiles (Coty, 1995).

The floristic composition of the Ciénaga de La Palmita is made up of 51 species in the inlet, sand berms, mangrove forest, ecotones and the swamp itself (De Olivares, 1988; Vera et al., 2010). In the inlet, 12 non-halophyte species have been registered, such as coin vine (*Dalbergia ecastophyllum*), rope mangrove (*Hibiscus pernambucensis*), swamp bush (*Pavonia paludicola*) and portia tree (*Thespesia populnea*) (Vera et al., 2010). In the sand berms, 24 species have been registered, which fundamentally include halotolerant pioneer herbs. The mangrove forest is dominated by red mangrove; black mangrove (*Avicennia germinans*), buttonwood mangrove (*Conocarpus erectus*) and white mangrove (*Laguncularia racemosa*) are also present. In this forest, 28 species have been identified, which include leather fern (*Acrostichum aureum*) and dragonsblood tree (*Pterocarpus officinalis*) (Vera et al., 2010). In the ecotone, 22 species have been identified which comprise communities of halophyte herbs such as silver weed (*Gomphrena vermicularis*) and sea purslane (*Sesuvium portulacastrum*) (Vera et al., 2010).

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Regarding the aquatic plants (macrophytes), De Olivares (1988) have pointed out common duckweed (Lemna minor), brittle waternymph (Najas minor) and white nenuphar (Nymphaea alba) in the surface of the swamp.

The ichthyofauna of the Ciénaga de La Palmita is made up of 59 estuarine, freshwater, marine and marine-estuarine species (De Olivares, 1988; González-Bencomo & Borjas, 2003). This number of fish species is larger than that determined for other areas of the east coast and of the Strait of Maracaibo Lake; and supposedly, this number could be larger given the diversity of microhabitats which exist in this wetland for the larval and juvenile states (González-Bencomo & Borjas, 2003).

The inventories of invertebrates are scarce and information is available only for some arthropods and mollusks. Regarding the arthropods, outstanding are the crustaceans acorn barnacle (*Balanus* sp.), mangrove crab (*Metasesarma rubripes*), freshwater crab (*Pseudothelphusa* sp.) and fiddler crab (*Uca pugilator*), as well as the white shrimp (*Penaeus schmitti*). With regard to the mollusks, mangrove periwinkle (*Littorina angulifera*), marsh clam (*Polymesoda solida*) and marine shipworm (*Psiloteredo healdi*) have been pointed out (De Olivares, 1988).

The Ciénaga de La Palmita: A wetland protected as a Wildlife Fauna Reservoir

The Ciénaga de La Palmita was decreed on 9 March 2000, as a Wildlife Fauna Reservoir (*Reserva de Fauna Silvestre*; RFS) by the Venezuelan government. It conforms to the Areas under Rule of Special Administration (Areas Bajo Régimen de Administración Especial; ABRAE) and according to the Organic Law of Territorial Ordinance (*Ley Orgánica de Ordenamiento del Territorio*). The objective of creating a protected natural area is to conserve the habitat of numerous bird species, species of cynegenetic interest (of interest for hunting) and species in danger of extinction (Gaceta Oficial de la República Bolivariana de Venezuela, 2000).

The national executive power, according to decree 730, article 3°, designated the Ministry of Environment and of the Natural Resources (*Ministerio del Ambiente y de los Recursos Naturales*) as the agency in charge of the administration of the Wildlife Fauna Reservoir Ciénaga de La Palmita and Isla de Pájaros, as well as of everything relative to its vigilance, conservation and management (Gaceta Oficial de la República Bolivariana de Venezuela, 2000). In the same way, in article 4 of the same decree, the same Ministry is requested to prepare the Ordinance Plan and the Usage Regulation (*Plan de Ordenamiento y Reglamento de Uso*; PORU) within two years after the publication of the decree (Gaceta Oficial de la República Bolivariana de Venezuela, 2000).

However, even now, 21 years after decree 730, the Ordinance Plan and the Usage Regulation, the instruments that guide the administration and management of the reservoir, have not been prepared in accordance with the law. The Ordinance Plan and the Usage Regulation dictate the guidelines to implement the actions and activities that can be carried out in the reservoir, as well as the use of the natural resources available to this area under Rule of Special Administration (*Areas Bajo Régimen de Administración Especial*; ABRAE).

Another limit to the protection of the reservoir is that the baseline information on Ciénaga de La Palmita (published scientific articles, technical reports, scientific research projects and theses) is very scarce. These studies are needed as rationale for the preparation of the Ordinance Plan and the Usage Regulation. In addition, the scarce data that exists about reservoir is dispersed, is not readily available and its collection requires time, effort and dedication.

It has also been suggested that the lack of will and management (bureaucracy) by the relevant government agencies, generates obstacles and delay in administrative procedures for the implementation of Ciénaga de La Palmita as a Wildlife Fauna Reservoir. The Venezuelan state needs to take measures to execute practical, direct and concrete actions to guarantee the conservation, surveillance and management of this protected natural area.

Finally, the reservoir does not have personnel or a park ranger or National Guard posts to provide protection and surveillance. Lack of monitoring leaves the area exposed and vulnerable to free access without control or regulation. In addition, the Ministry of the Environment of Venezuela (Ministerio del Poder Popular para el Ecosocialismo) does not have an adequate budget to cover management and surveillance; however, some measures could be applied now.

The declaration of the Ciénaga de La Palmita as a Wildlife Fauna Reservoir declares an intent to preserve the habitat of numerous bird species, species of cynegetic interest and species in danger of extinction. Thus, laws could be applied through sanctions such as fines and detentions since field explorations have found both physical evidence (remains of animals and ammunition) and people engaged in poaching wildlife (birds and land mammals).

Another action could be to make greater use of Venezuela's legal environmental framework (Organic Law of the Environment, Organic Law of Territorial Ordinance, Law of Coastal Areas, among others) (*Ley Orgánica del Ambiente, Ley Orgánica para la Ordenación del Territorio, Ley de Zonas Costeras*) which can be used by the Ministerio del Poder Popular para el Ecosocialismo as a legal support to suggest, recommend, request and put into action measures that control the development of any human action or activity that constitutes a risk to the physicogeographic and biological integrity of the reservoir, causing damage to its ecosystem integrity and generate environmental deterioration.

The National Strategy for the Conservation of Biological Diversity 2010–2020 and its National Action Plan (*Estrategia Nacional para la Conservación de la Diversidad Biológica 2010-2020 y su Plan de Acción Nacional*) includes a set of actions taken by the national government to reduce the loss of biological diversity; its findings revealed that the destruction, degradation and fragmentation of ecosystems are the causes that directly affect the loss of biodiversity (Gobierno Bolivariano de Venezuela, 2013a).

Similarly, the Venezuelan government has indicated a set of measures in the Great Historical Objective Number 5 of the Plan de la Patria, Second Socialist Economic and Social Development Plan of the Nation 2013–2019 (*Gran Objetivo Histórico Número 5 del Plan de la Patria, Segundo Plan Socialista de Desarrollo Económico y Social de la Nación 2013-2019*) that could undoubtedly solve conflicts and threats that affect the Ciénaga de La Palmita reservoir, among which are: promoting actions at the national and international level for the protection, conservation, management and sustainable use of biological diversity, and preserving and managing strategic areas for conservation, such as the ABRAE (Gobierno Bolivariano de Venezuela, 2013b).

Therefore, the application of these plans could represent a viable alternative to addressing the problematic situation of the Wildlife Fauna Reservoir Ciénaga de La Palmita and Isla de Pájaros, which is a protected natural area subject to a series of natural and anthropogenic stressors, impacts and disturbances that threaten its biodiversity, stability and dynamics ecosystem.

Some Venezuelan public institutions state such as the Ministry of the Environment of Venezuela (*Ministerio del Poder Popular para el Ecosocialismo*), Institute for the Conservation of the Maracaibo Lake Basin (*Instituto para la Conservación de la Cuenca del Lago de*

Maracaibo; ICLAM) and the University of Zulia (LUZ) interact through agreements to address environmental issues.

Ad hoc commissions are made up of professionals specialized in environmental issues (biologists, environmental engineers, forestry engineers and environmental educators) who analyze, evaluate, deliberate, suggest, and prepare scientific-technical reports that could identify risk factors (tensioning or disturbing agents) of any third-party intervention in the area in or around the Wildlife Fauna Reservoir.

The work carried out by these ad hoc commissions represents a management mechanism to administer use of the reservoir, and their opinions are a valuable contribution that guides the Ministerio del Poder Popular para el Ecosocialismo in making the final decisions on the cases reviewed.

Threats and conflicts due to anthropogenic activities and climatic factors

The Wildlife Fauna Reservoir Ciénaga de La Palmita and Isla de Pájaros are disturbed by anthropogenic activities and climate factors, which affect its ecological processes and impact the goods and services the wetland provides. These ecosystem services are affected by threats that endanger the wetland's resilience and dynamic ecosystemic equilibrium.

At present, the swamp is being degraded by human influences that interfere with its general functioning. Among these threats is a drastic reduction in the discharge of fresh water from the Aurare River which feeds the swamp directly in an east–west direction. This water supply has been restricted to only seasonal intermittent contributions of very low volumes (Medina & Barboza, 2006). This reduction in flow is due mainly to the population settlements at the margins of the river and to the use of water for irrigation for agriculture, cattle farming and urban purposes.

The other flows to the wetland arise from the estuarine waters of the Strait of Maracaibo Lake through the inlet of the Ciénaga de La Palmita, via the mangrove forest, by means of two natural channels in a West-East direction, which does not supply the demand of the swamp.

The above aspects, in conjunction with a deficit of precipitation which characterizes the area as a bioclimatic zone of very dry tropical forest (Ewel & Madriz, 1968) as well as runoff reduction, jeopardize the functioning of this wetland.

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These freshwater limitations endanger the diverse habitats of the Ciénaga de La Palmita as natural physicochemical spaces that offer shelter to a diversity of species. In addition, the insufficient entry of water to the swamp could lead to the following problems:

> *A reduction in the hydric flow that drains and feeds the water pool of the swamp itself*, which lengthens the period of low water level, reaching desiccation levels, as it occurs during the dry season (Figure 3). Sheaffer-Novelli (1995) reported that water flow is important in wetlands and particularly in mangroves, because it guarantees the renewal of surface and interstitial waters and the transport of oxygen and dissolved organic matter and particulates to the ecosystem.

> *Limitations in the leaching of the salts and in the entry of sediments contributed by the Aurare River* as the main source of nutrients to the ecosystem. Also, flood levels and inflow and outflow (flow and reflux) of water could also be modified and interrupted. Barboza et al. (2006) have reported for the mangrove forest of Punta de Palmas, East Coast of Lake Maracaibo, Zulia State (wetland on a dry coast), that the salt transported by flood water evaporates rapidly during low tide in a semi-arid climate with features of high temperatures, high solar radiation, low rainfall, low runoff and high evapotranspiration (Ewel & Madriz, 1968). This finally generates greater accumulation of salts towards the area of maximum tidal range, which increases the appearance of hypersaline soils, increases osmotic stress in plants and gives the appearance of salt plains that may be totally devoid of vegetation (Medina & Francisco, 1997; Barboza et al., 2006).

A loss in the surface area covered by mangrove vegetation generates desiccation of the soil and an increase in the mortality of the mangrove trees due to sedimentation and reduction in the water contribution by the rush of torrent. New zones of high salinity appear and encourage the formation of areas of salt marsh or saltpetre beds, among other consequences (Figure 3). Barboza (1999) has reported dead *R. mangrove trees* in the Ciénaga La Tigra mangroves of the Limón-San Carlos river in Zulia State, due to the partial interruption of the water flow and salinity. This shows the importance of the amount and movement of water (hydrological regime) in mangroves as major factors in the ecophysiological aspects of these plants.

Figure 3. Reduction of the water flow of the Aurare River has generated soil desiccation, a decrease in water level and dead mangrove trees in the Ciénaga de La Palmita.

Photo © Antonio Vera.

Conversely, in the ecotone between the mangrove forest and semi-deciduous thorny xerophilous forest of the El Hicacal islet in the Wildlife Fauna Reservoir Ciénaga de La Palmita and Isla de Pájaros, Vera et al. (2010) recorded areas with desiccation due to the low entry of water from the tide (decrease in flood level). In this area are found salitral or salty areas occupied by communities of halophytic herbs such as *Gomphrena vermicularis, Sesuvium portulacastrum, Sporobolus virginicus*, and *Trianthema portulacastrum*, among others. Barboza et al. (2006) obtained similar results for the riparian mangrove in the semi-arid climate of Punta de Palmas, Miranda municipality, Zulia State, whose ecotones included communities of grass and succulent halophytes (*Sporobolus virginicus* and *Sesuvium portulacastrum*) in salty areas and in connection with the thorny coastal vegetation.

The ecological service of organic matter production (ecological productivity) in the mangrove areas could diminish as a result of insufficient hydric supply to the wetland, which would cause fewer nutrients to flow into the Ciénaga de La Palmita resulting in production of fewer litter fall, and in turn, less production of detritus from decomposition. Reduced detritus would create an unfavourable situation for the maintenance of the trophic networks which include species of invertebrates and fish of commercial importance, such as lebranche mullet (*Mugil liza*), parassi mullet (*Mugil incilis*), acoupa weakfish (*Cynoscion acoupa*), swordspine snook (*Centropomus ensiferus*), common snook (*Centropomus undecimalis*), armoured catfish (*Hypostomus watwata*) and striped mojarra (*Eugeres plumier*) (González-Bencomo & Borjas, 2003), resulting in a qualitative and quantitative reduction in their populations.

As a Wildlife Fauna Reservoir, the Ciénaga de La Palmita and Isla de Pájaros provides a sheltered environment for the reproduction, refuge and breeding of diverse fish species. The majority (82.6%) of these species has been recorded in their juvenile stage and 51% of them have economic importance (González-Bencomo & Borjas 2003).

These ecological attributes made the inlet of La Palmita a fishing site for the village people from the sectors El Rocío and Palmarejo of the Santa Rita municipality bordering the inlet; fishing is their source of income and social support.

Unfortunately, the ichthyofauna of the inlet is confronted with threats that endanger the ecological good of the fish and jeopardize the sustainable maintenance of the fishing in the zone. The main threats are introduced species and illegal fishing.

Introduced species. The presence of the introduced species Mozambique tilapia (*Oreochromis mossambicus*) an exotic species with a high degree of adaptation and competition with local species, could cause displacement and even disappearance (local extinction) of some native fish species (González-Bencomo & Borjas, 2003). Some local fishermen have confirmed that Mozambique tilapia feeds on the eggs and larvae of some native species of economic importance such as netted prochilod (*Prochilodus reticulatus*), which reveals the danger of its presence (González-Bencomo, personal communication).

Illegal fishing. In the inlet of La Palmita, legal authorities have detected and prohibited unauthorized fishing practices, such as trawling with nets ('chinchorros') of mesh size of 2–2.5 inches and the technique of producing loud noises with metals in the water so that the fish move into the nets to be captured. These techniques are used daily in the inlet waters and jeopardize sustainable fishing activity in the zone (González-Bencomo, personal communication).

The capture and extraction of undersized juvenile fish, that have not reached reproductive age, is harmful because can lead to a reduction in the fish population densities, causing severe negative consequences to the subsistence and economic and social support of the local village fishermen.

The biodiversity of the swamp is also exposed to disturbances such as illegal hunting, mangrove tree wood extraction and solid waste disposal:

- *Illegal hunting* has been observed for birds (De Olivares, 1988), though there is no official record of the impact caused by such practice. Certain species of birds, mammals and reptiles of great cynegetic interest both in the swamp itself and in the mangrove forest have been registered (Coty, 1995).
- *Overextraction of mangrove wood*. Wood, an ecological good of the mangrove forest, is used by the villagers in the construction of fences for cattle farming and pastures grounds as well as for the demarcation of their farm limits. The wood extraction from the mangrove ('twigs'or relatively thin stems) is common in the area, and should be addressed to prevent its overexploitation.
- *Dumping of solid wastes*, especially plastic containers and glass bottles, has been detected as an important threat in various areas neighboring the mangrove forest (Medina & Barboza, 2006).

Importance and proposed management of the Wildlife Fauna Reservoir

The Wildlife Fauna Reservoir Ciénaga de La Palmita is a special biotic space for recreational and tourist activities because it comprises a freshwater wetland, the swamp and another estuary represented by the mangrove forest and the vegetation of the inlet.

These hydrological features allow abundant shelter with heterogeneous biodiversity adapted to these contrasting environments.

Areas of potential tourism

The mangrove forest is the most extensive in the Strait of Maracaibo Lake (approximately 522 ha) and according to Coty (1995), it is relatively less degraded and polluted here than in other areas. It contains red mangrove trees averaging about 18 m, has a closed canopy and has channels (canales) that allow navigation to its interior in small vessels. These physiognomic and structural features of this mangrove area lend itself well to recreational tourism experiences. The mangrove forest along with the inlet could show to national and foreign visiting tourists relatively undisturbed natural scenarios of the valuable and abundant biological diversity that characterize this wetland, including outstanding vegetation at the edge of the inlet, plant species of the mangrove community, and resident and migratory birds as well as amphibians, invertebrates, mammals and reptiles.

The inlet of La Palmita is of potential importance for sport and recreational fishing. The development of these activities must be contained in the Ordinance Plan and Usage Regulation (*Plan de Ordenamiento y Reglamento de Uso*; PORU) of that protected area in order to protect the biotic potential of the species of invertebrates and fish of the area.

It is important to note that the threats, disturbances, pressures, impacts and conflicts to which the Ciénaga de La Palmita is subjected are urgent and alarming because they threaten the ecological stability of its goods and services, cause an unfavorable impact in the maintenance and preservation of its biodiversity and lead to the loss of unknown and possibly unique biological information of this great wetland.

Management of the recovery and the conservation of the Ciénaga de La Palmita

In the Wildlife Fauna Reservoir Ciénaga de La Palmita and Isla de Pájaros no concrete actions have been taken to transact, maintain, recover or preserve its biological, geomorphological, physiographical and structural attributes. The Ministry of the Environment of Venezuela (*Ministerio del Poder Popular para el Ecosocialismo*) should design, elaborate and implement the Ordinance Plan and Usage Regulation (*Plan de Ordenamiento y Reglamento de Uso*; PORU) of the reservoir with the participation of the residents (villagers) of the zone whose activities have generated threats and conflicts in this natural protected area.

The following actions are also suggested:

Restore the water flow of the Aurare River, which drains into the swamp. This action could be accomplished through a change in the use of the land by the farmers of the zone who use the water for irrigation and cattle farming purposes.

Implement governmental policies (at all scales) for greater vigilance and monitoring of the zone by the competent official organizations to reduce to a minimum the activities of illegal hunting, felling of trees and wood extraction. This measure must include the active and direct participation of the municipal authorities and of the communities that inhabit the surroundings of the swamp.

Conduct environmental education workshops for villagers and provide them with knowledge of the practical functioning of the swamp; highlighting, for example, making fishermen aware of the ecological damage generated by the use of overly exploitive fishing practices.

Conduct an economic appraisal of the Ciénaga de La Palmita to establish programs for conservation and sustainable use of its natural resources, while maintaining the ecological processes that support them.

Develop scientific research that can generate information to strengthen the management and conservation of this ecosystem, given the current scarcity of baseline investigations (scarce inventories, sampling and field explorations) relative to this wetland.

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CHAPTER

6

The vegetation in a wetland complex in Miranda State, Venezuela (Bolivarian Republic of Venezuela)

By

Lourdes M. Suárez-Villasmil
Laboratorio de Ecología de Plantas Acuáticas. Instituto de Zoología y Ecología Tropical, Facultad de Ciencias, Universidad Central de Venezuela (UCV).
Caracas, Venezuela

Eduardo M. Barreto-Pittol
Laboratorio de Ecología de la Vegetación. Instituto de Zoología y Ecología Tropical, Facultad de Ciencias, UCV.
Caracas, Venezuela

Elizabeth Gordon
Laboratorio. de Ecología de Plantas Acuáticas. Instituto de Zoología y Ecología Tropical, Facultad de Ciencias, UCV.
Caracas, Venezuela

Irene Carolina Fedón
Instituto Experimental Jardín Botánico Dr. Tobías Lasser, UCV.
Caracas,Venezuela

Deiby García
Laboratorio de Ecología de la Vegetación. Instituto de Zoología y Ecología Tropical, Facultad de Ciencias, UCV.
Caracas, Venezuela

Yamilex Avendaño
Laboratorio de Ecología de Plantas Acuáticas. Instituto de Zoología y Ecología Tropical, Facultad de Ciencias, UCV.
Caracas, Venezuela

María Beatriz Barreto
Laboratorio de Ecología de la Vegetación. Instituto de Zoología y Ecología Tropical, Facultad de Ciencias, UCV.
Caracas, Venezuela

Abstract:

The research reported here was carried out in 2013 in Barlovento, in Miranda State, Bolivarian Republic of Venezuela, an extensive coastal plain drained by numerous rivers, where the influence of the tide allows the development of a variety of salt-tolerance (halophytic) and freshwater wetlands. We sampled 18 wetlands near areas impacted by humans to evaluate their physical and chemical characteristics and plant richness, their ability to deliver goods and services, and the threats they face. We propose viable solutions for sustainable development of these and other wetlands.

The herbaceous wetlands studied are mainly freshwater ecosystems, with pH close to neutrality and dissolved oxygen between 0.93 to 5.80 mg/L. They have more than 70 herbaceous species, mainly graminoids, and dominated by Cyperaceae and Poaceae families. Some protected areas are in the neighborhood of the study space; however, the development of residential, crop, cattle, tourism, and recreational areas are threatening these wetlands and complicate their conservation. Viable solutions for safeguarding them consist of education and sensitization of local communities about the importance of these ecosystems, and proposals for coordinated actions that guarantee their management and conservation as reservoirs of biodiversity.

Keywords:

Cyperaceae | environmental goods and services | freshwater wetlands | Poaceae | wetlands threats

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Introduction

The area known as Barlovento in Miranda State, Venezuela, is a wide sedimentary plain dominated by flat and low landscapes inundated by rain and river overflows. Under those conditions it is common the existence of seasonal or permanent wetlands, associated to an environment showing urban and agricultural extend. One of those wetlands, Tacarigua Lagoon, is well known, studied and protected; in fact, it is one of the five Ramsar sites of Venezuela (Ramsar 2014). However, we though that there would be some other sites, probably unknown or unstudied, whose resources and vegetation might be affected by the advance of economic and tourist growth in the entire region.

This situation encouraged us to develop the research which supports the present chapter, a project performed between 2010 and 2013 with the main objective of defining the location of representative wetlands in the plain, and characterizing their vegetation and physicochemical characteristics. These wetlands were the result of a review on previous researches (Feo, 2002; Gordon et al., 2007; Suárez-Villasmil, 2010), cartographic and remote sensing evaluation through SPOT images from 2009, and field expeditions as well, identifying them by flooding or overflow sign and hydrophytic vegetation (Marrero 2009). As a result of this work, we will be able to have a reference point for the environmental valuation of these spaces, or for future research and conservation projects.

Physical-chemical, hydrological and geomorphologic description

Barlovento Plain (4,610 km^2) represents 58% of the eastern area of Miranda State, between parallels 10°11° N and meridians 65°–67° W (Ramirez, 1996; CEOTEBM, 2010). The annual average temperature is 26 °C (range: 24.8–27.5 °C) (Conde, 1996; Ramirez, 1996) and it receives 1300–1500 mm of rain per year (CEOTEBM, 2010); its topography is highly varied and includes mountain areas and a vast plain, where this study was done. This extensive sedimentary plain is dominated by flat, low landscapes (valleys, plains, and marine coast), and subjected to the constant deposition of sediments from the sea and the rivers that descend from the coastal mountain range, which runs parallel to the shore in an east–west line (Vila, 1967). The most important rivers are Tuy and Guapo (Vila, 1967), along with smaller permanent rivers: Curiepe, Cúpira, Capaya, San José and Rio Chico (IGVSB, 2016). There are also lagoons such as La Reina, Loma del Viento, Moreno, La Unión, El Pailón, Grande, Lagunón, Encantada, La Islita, Monte Oscuro, La Draga, El Silencio, Cerritos, El Continuo, and Tacarigua (IGVSB, 2016).

This chapter shows the results of a study of 18 wetlands located in the Barlovento Plain, an area of approximately 1,000 km^2. Despite their geographical proximity, these wetlands differ in relief, geomorphological conditions, hydrography, edaphic characteristics and human activities; therefore, we have denoted them as a complex of wetlands. Figure 1 gives the names and locations of the 18 wetlands.

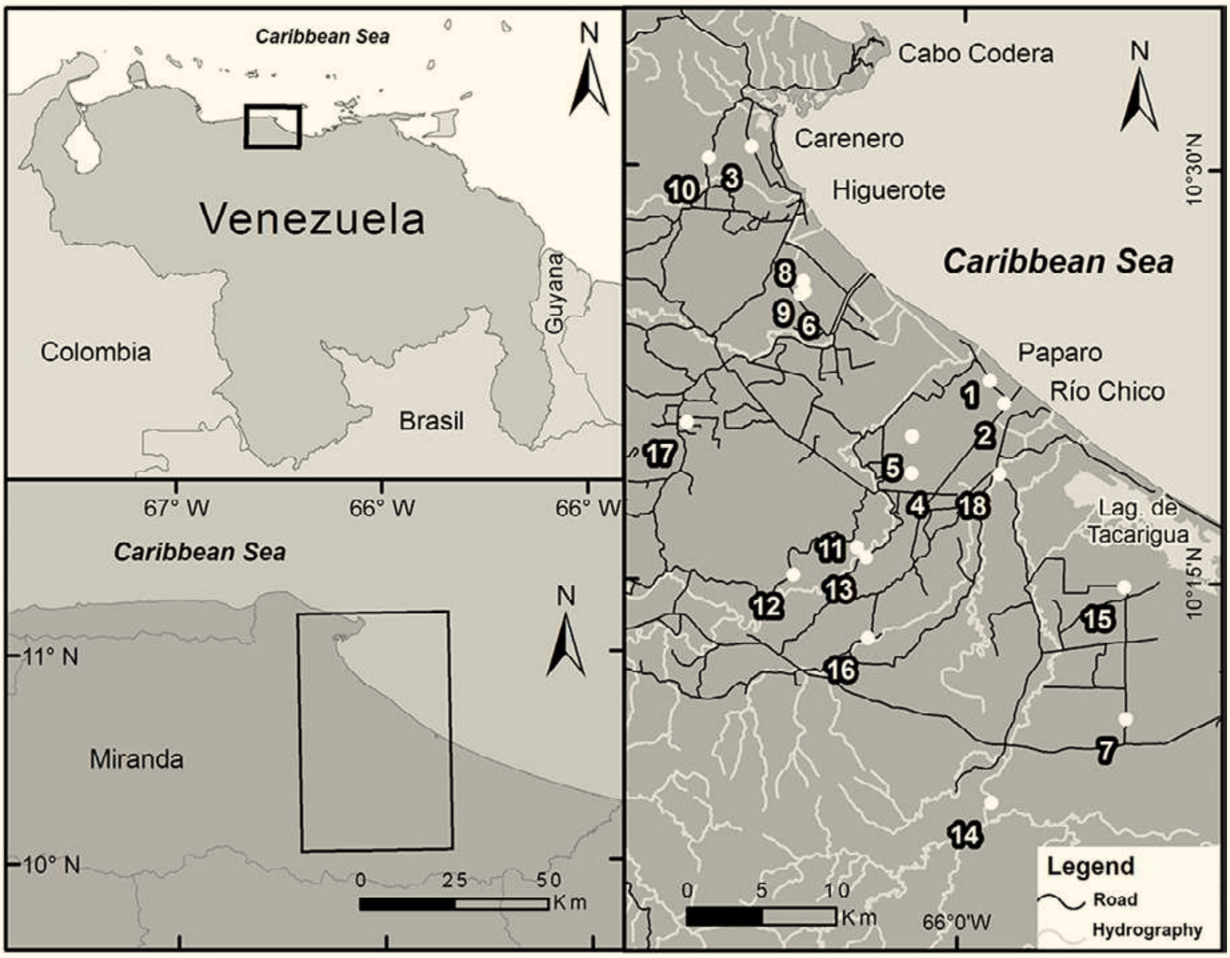

Figure 1. Study area: Map of Venezuela and Barlovento Plain, with the studied wetlands represented by a number that indicates the order in which the wetlands were sampled.

The 18 wetlands are located in the vicinity of numerous rivers and lagoons that influence their hydrological dynamics. The 18 wetlands are known as: 1-Paparo canals; 2-Road to Paparo; 3- Loma del Viento Lagoon; 4-Madre Vieja; 5-Bajos de Manatí; 6, 8 and 9-Sabana de Oro, 7-Arenita, 10-Los Flores, 11-Los Hernández; 12-El Colorado; 13-El Tesoro; 14- Guapo River in La Esmeralda; 15-Las Lapas; 16- El Olimpo bridge; 17- Tacarigua-San José de Río Chico road; 18- San José de Río Chico.

Source: Suárez-Villasmil et al., 2015.

The physical and chemical soil and water parameters were measured and discussed by Suárez-Villasmil et al. (2015) and are presented in Table 1.

Table 1. Chemical water parameters and soil texture in 18 wetlands

WETLAND	pH	DISSOLVED OXYGEN (mg/L)	CONDUCTIVITY (µS/cm)	SALINITY (‰)	TOTAL NITROGEN (mg/L)	AVAILAB LE NITROGEN (*((mg/L)	TOTAL PHOSPHORUS (mg/L)	AVAILAB LE PHOSPHORUS	% SAND	% CLAY	% SILT
1	7.3	3.6	35350.	20.8	6.1	3.0	0.05	<0.001	86.0	4.0	10.0
2	7.6	4.8	1154.0	0.6	9.1	3.0	0.05	0.001	92.0	4.8	3.2
3	8.0	0.9	0.5	0.0	6.1	3.0	0.02	0.010	76.0	6.8	17.2
4	7.9	1.9	400.4	0.2	6.1	3.0	0.09	0.033	53.2	26.0	20.8
5	7.5	1.9	1271.5	0.6	12.2	6.1	0.21	0.042	62.0	4.8	33.2
6	*	1.5	1308.0	0.7	9.1	3.0	0.14	0.126	72.0	8.0	20.0
7	7.8	4.6	22.8	0.0	9.1	3.0	0.26	0.137	49.2	24.8	26.0
8	6.8	2.4	488.0	0.2	6.8	3.4	2.60	<0.001	80.8	10.0	9.2
9	6.7	3.4	319.7	0.2	13.5	3.4	1.92	<0.001	74.8	12.0	13.2
10	6.9	2.4	330.5	0.2	6.8	3.4	1.38	<0.001	52.8	18.0	29.2
11	6.2	5.8	16.0	0.0	10.1	3.4	4.56	0.087	80.8	8.0	11.2
12	6.3	1.2	193.1	0.1	6.8	3.4	4.33	<0.001	46.8	16.0	37.2
13	6.7	1.5	186.2	0.1	10.1	3.4	3.16	0.051	50.0	22.0	28.0
14	6.8	2.5	230.2	0.1	3.4	1.7	1.73	0.123	46.0	24.0	30.0
15	6.2	1.7	228.4	0.1	6.8	1.7	2.66	<0.001	42.0	34.4	23.6
16	7.6	5.2	162.7	0.1	10.1	3.4	1.43	<0.001	68.0	12.0	20.0
17	6.3	1.1	172.3	0.1	10.1	1.7	1.72	<0.001	60.0	24.0	16.0
18	6.3	2.1	216.7	0.1	6.8	3.4	3.09	<0.001	72.0	10.0	18.0

* Field problems with the pH-meter prevented the recording of the pH in wetland 6.

Source: From Suárez-Villasmil et al. (2015) with permission.

In Table 1, the mean pH is 7.0 (range: 6.2-8.0), and the dissolved oxygen concentration is 2.70 mg/L (range: 0.9-5.8 mg/L) with most below 3 mg/L. The total amount of nitrogen in water is 8.3 mg/L (range: 3.4-13.5 mg/L), available nitrogen is 3.1 mg/L (range 1.7–6.1 mg/L), total phosphorus is 1.6 mg/L (range 0.02–4.56 mg/L) and available phosphorus is 0.07 mg/L (range: 0.00-0.14 mg/L). The specific conductivity of wetland 1 is 35,350.0 μS/cm, while the remaining wetlands are between 200 and 1,308 μS/cm. The soil composition is sand (42–92%), silt (3–37%) and clay (4–34%). The amount of sand is high, so the soils are mostly sandy loam, sandy clay loam or loam. Wetlands 5, 7, 9, 10–18, in Rio Chico, Curiepe, Tacarigua and El Guapo, show higher phosphorus content, lower conductivity, and less sandy soils than wetlands 1–4 and 8. Wetlands 5, 9 and 16, located in Rio Chico and Higuerote, have higher concentration of total nitrogen.

These values reflect the different ionic contributions related to the proximity to saline water bodies, as well as the effect of nutrients and fertilizers (Suárez-Villasmil et al., 2015). All the physical and chemical values were within the limits reported for other Venezuelan continental wetlands (Feo, 2002; Rial, 2006; Suárez-Villasmil, 2010) and show the variety of conditions and processes in these ecosystems; for example, wetland 1 has higher conductivity and salinity due to it nearness to the coast; wetlands 5 and 9 have higher total nitrogen, probably because of cattle farming (in 5) and solid waste around them (Table 2).

Vegetation structure

The wetlands comprise dominant emergent plants (Figure 2), woody plants (nondominant) and occasional floating plants. The predominant plants are herbs (73%), along with shrubs (10%), trees (9%), climbers (6%) and subshrubs (3%). The dominant growth form is emergent plants (83%) (Cronk and Fennessy, 2001) although there are also floating species (10%) and floating-leaved species (7%). The greater richness of emergent species over other growth forms is attributed to the shallow depth of the water and to seasonal changes in precipitation, which facilitate the colonization and establishment of emergent species (Suárez-Villasmil et al., 2015). In the different periods in which we visited these wetlands, we observed the temporal variation in the composition of free-floating and floating-leaved species, as well as the variations in the coverage of emergent species. During drought periods, most of the floating component dries out.

Plant diversity

Suárez-Villasmil et al. (2015) reported 70 species with an average of 8.2 species per wetland. Of these species, 8% were shared among the wetlands, whereas 56% were present in only a single wetland and 73% were present in one or two wetlands. These results show a high turnover rate in response to environmental conditions, high spatial heterogeneity, and temporal changes in flooding (hydro-edaphic) conditions.
This occurs because the abundance and distribution of plants that grow in the wetlands depend on specific environmental conditions (Mitsch & Gosselink, 2007).

The most frequent species are *Cyperus articulatus and Hymenachne amplexicaulis* (in 8 wetlands each), *Pistia stratiotes* (in 6 wetlands), and *Cyperus ligularis, Ludwigia decurrens, L. peruviana* and *Nymphaea micrantha* (in 5 wetlands each). The most frequent families are: Cyperaceae (11 species), Fabaceae (6 species), Poaceae (5 species) and Amaranthaceae (4 species).

Figure 2. A wetland representative of the study area.

Wetland 3, one of the sampled sites, has both emergent and floating herbaceous plants. In the surroundings of this wetland, woody plants were found.

Photo © E. Barreto-Pittol.

Status of the wetlands

Commercial tourism development began in the 1960s with the construction of hotels and recreational complexes (Parkswatch, 2006) and later reached a high state of development. Commercial fishing and agricultural also developed in the area (Ramirez, 1996; Malaver et al., 2014). This unplanned development has degraded the environment due to soil, water, and air pollution affecting the loss of green areas and the generation of unhealthy and high-risk overcrowded communities (Ramírez-Treviño & Sánchez-Núñez, 2009).

The sites studied are outside the most restrictive regimes of the national system of protected areas. However, they are on a floodplain near the Tacarigua Lagoon (9,200 ha; 10°12'N, 65°56'W), a coastal lagoon with mangroves forming dense vegetation islands scattered in open water spaces. Because of its high ecological and landscape value and its social and economic importance to local communities, Tacarigua Lagoon was included in the list of protected wetlands by the Ramsar Convention in 1996 (Ramsar site number 858). This lagoon is separated from the Caribbean Sea by a barrier coast with a mouth (10°15'53"N, 65°49'16"W) that allows a natural water balance in the lagoon, where many species and subspecies of rare, threatened or vulnerable plants and animals are protected (Parkswatch, 2006; Ramsar 2016).

Identified threats

Within less than 1 km away from the studied wetlands, Suárez-Villasmil et al. (2015) identified five situations that could degrade them: fences or power lines (frequency: 89% of studied wetlands), roads and highways (frequency: 72%), solid waste (frequency: 33%, Figure 3a), buildings or homes (frequency: 28%), and cattle farming (frequency: 17%, Figure 3b). The presence of these activities was evaluated in all wetlands (Table 2), with the frequency of threats as a measure of disturbance. Wetlands highly disturbed (3 to 4 threats) were in Paparo (sites 1 and 2), Rio Chico and Higuerote (sites 4 to 6, 8, 11, 17 and 18), which are the most visited places in the zone during vacation time. Less disturbed wetlands (1 to 2 threats), were in El Guapo, Curiepe, and Tacarigua zone, which are less touristic places.

Table 2. Frequency of five threats to the coastal wetlands studied

WETLAND	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
FENCES OR POWERLINES	x	x	x	x	x	x	x	x	x	x	x	x		x	x		x	x
ROADS AND HIGHWAYS	x	x		x	x	x	x				x	x	x	x		x	x	x
SOLID WASTE	x							x	x	x	x						x	
BUILDINGS OR HOMES	x	x				x		x										x
CATTLE FARMING		x		x	x													
FREQUENCY OF THREATS (DISTURBANCE LEVEL)	4	4	1	3	3	3	2	3	2	2	3	2	1	2	1	1	3	3

Presence of situations that degrade each wetland is marked with x. Frequency of threats (disturbance level) is the total of threats in each wetland.

Source: Modified from Suárez-Villasmil et al. (2015) with permission.

Observed sources of contamination were wastewater and solid waste, such as plastic, coming from domestic sources (Malaver, 2014) and high levels of fertilizer and pesticides from agricultural activities and cattle farming. Mangrove degradation in nearby areas (García, 2017; Quintero, 2017) will reduce the oxygen concentrations of water and soils, which can restrict organic matter decomposition. If these conditions continue, the ecosystems will degrade, with the consequent loss of habitats and biodiversity. Government assistance will likely be needed to protect these environments.

In summary, the identified threats, management conflicts and main stakeholders involved in the Miranda wetland complex are:

- Sedimentation to basins where these wetlands are located,
- Fragmentation by roads, highways, fences and powerlines,
- Landscape degradation by inadequate management of solid waste (Figure 3a),
- Buildings and homes located in areas naturally affected by flooding,
- Agricultural activities near the river basins where the wetlands are located, and
- Cattle farming, near the river basins where the wetlands are located (Figure 3b).

Agricultural activities and cattle farming together probably discharge an excess of nutrients to nearby water. If human activities such as domestic discharges and solid waste, are not controlled through planning that takes into account the value and importance of these ecosystems, the intensity of current activities will undoubtedly lead to the destruction of these wetlands through increased changes in hydric dynamics and species loss. Wetlands are very important to water quality regulation, and they are carbon sinks among other functions, as we will see in the next section.

Figure 3. Two of the five threats observed in the wetland complex:

(A) Inadequate management of solid waste causes its accumulation near the wetlands; and (B) cattle farming in areas adjacent to wetlands.

Photos © E. Barreto-Pittol.

Goods and services

The list of goods and services provided by these wetlands to the environment (Table 3) is in agreement with the goods and services described by De Groot et al. (2007), Mitsch and Gosselink (2007) and Osmond et al. (1995). The 2005 Millennium Ecosystem Assessment (MEA 2005) classifies the benefits people obtain from ecosystems into four groups: provisioning services (the products obtained from ecosystems), regulating services (benefits obtained from regulation of ecosystem processes), cultural services (nonmaterial benefits) and supporting services (those necessary for the production of all other ecosystem services). Table 3 follows this classification system. The first four goods and services are tangible and the rest are intangible. Some wetlands offer opportunities for tourism, recreation and navigation (wetland 1), and for guided tours and fishery. The 78% of the wetlands that provide aquarium and ornamental species, and 56% of all wetlands, are associated with peat and forage production.

Wetlands regulate the global and local climate by being carbon sinks. All the studied wetlands fulfill several regulating functions, such as, retaining water, regulating the air quality, charging and discharging groundwater, accumulating organic matter, storing and recycling nutrients, retaining sediment, preventing structural changes in soil and helping to control floods and erosion. They are also a genetic and biodiversity reservoir; have an important role in the spirituality of human communities; provide storm protection for human structures, and serve as formal and informal training in biology, ecology, geology, and other science fields. This benefits, mostly intangible, are extremely important to people and their communities, even if they do not use them consciously.

Table 3. Goods and services provided by the studied wetlands

SERVICE PROVIDED (TYPE OF SERVICE)	WETLAND NUMBER (SEE FIGURE 1 FOR LOCATION)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
OPPORTUNITIES FOR TOURISM AND RECREATION (CS)	×		×			×		×			×	×	×		×			×
FISHERY (PS)	×										×							×
PEAT AND FORAGE PRODUCTION (PS, SS)		×	×	×	×				×	×	×			×	×			×
AQUARIUM PLANT PRODUCTION (PS)		×	×	×	×	×	×	×	×	×	×			×	×	×		×
CLIMATE REGULATION (RS)	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
WATER STORAGE RETENTION (PS, SS)	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
AIR QUALITY REGULATION (RS)	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×

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← TC

SERVICE PROVIDED (TYPE OF SERVICE)	WETLAND NUMBER (SEE FIGURE 1 FOR LOCATION)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
CHARGE AND DISCHARGE OF GROUNDWATER (RS)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ACCUMULATION OF ORGANIC MATTER (RS, SS)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
STORAGE AND RECYCLING OF NUTRIENTS (SS)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SEDIMENT RETENTION (RS, SS)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PREVENTION OF STRUCTURAL CHANGES SOILS (RS, SS)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FLOOD AND EROSION CONTROL (RS, SS)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
GENETIC RESERVOIR (PS)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SPIRITUALITY OF COMMUNITIES (CS)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
STORM PROTECTION (RS)	X																	
FORMAL AND INFORMAL TRAINING (CS)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

The services were classified according to Millennium Ecosystem Assessment (2005) into: Provisioning services (**PS**), Regulating services (**RS**) Cultural services (**CS**) and Supporting services (**SS**).

Source: Compiled by the authors.

Freshwater ecosystems are severely affected by invasive species, alterations in land use, habitat degradation and climate change (Sala et al., 2000). The deterioration of these environments, or even the mismanagement of them, can lead to human and economic losses because of flooding, and can also affect human health because many wetlands can be sources of food (fish, rice, and others) and sustain the growth of plants that are used for medicines.

In a wetland complex, given its location and geomorphological characteristics, there is a hydrological interconnection regardless of whether its waters are sweet, brackish or salty. The destruction of any of these environments by sedimentation, fragmentation, landscape degradation, construction, agricultural activities or cattle farming, in an unplanned manner like the one that has occurred in some of these and other nearby areas, may produce negative effects, losing the goods and services that the wetlands bring to people, and affecting the ecosystems that depend on them. As an example, the villages of Higuerote located in the same basin as these wetlands, have suffered from floods with high economic losses for its inhabitants. These floods had their origin in 1884, when farmers diverted water from the Capaya River before it entered the Tuy River. Currently, the Capaya River is no longer a tributary to the Tuy River, but feeds the Aguasal basin, which overflows into the Curiepe River and floods Higuerote (González, 2005). This situation worsens with El Niño events, whose intensity has increased in the last 120 years (CVG, 1997; Null, 2016).

Climate change will have a major impact on the global hydrological cycle and could have significant impacts on regional water resources (Yospin et al., 2015). Climate change may cause variations in the regional distribution of wetlands (Bergkamp & Orlando, 1999). In the Barlovento Plain, mangrove ecosystems could be indicators of this condition. The deterioration and mortality of mangrove areas have also been recorded in the Barlovento zone, likely due to the modification of hydroperiod and the increase of the sediment load (Barreto, 2008) caused by the high rate of deforestation and degradation of the forests in the upper river basins that drain to the wetlands. Modification of the hydroperiod has been related to an increase in soil salinity (Cintron et al., 1978). That was evident in some areas of La Reina Lagoon, adjacent to Loma del Viento Lagoon, where we observed the mortality of the mangrove fern *Acrostichum* sp., a species sensitive to hydrologic changes and higher soil salinity (Sharpe, 2010).

It is important to remember that wetlands are associated with tangible resources (fishery, water, and food, place for recreation) and with intangible benefits (climate, air and flood regulation, charge and discharge of groundwater, nutrient recycling, and as a biodiversity reservoir). In all connected systems, any alteration has an impact on other components of the system in unpredictable ways; in this case alterations affect the functioning of the biological systems and the biodiversity of species and processes.

Recommended solutions and tools for an effective recovery

Planned tourism development does not necessarily lead to environmental degradation; Rossi & Molinari (2012) show how sustainable ecotourism strategies can allow for planned, fair, respectful and viable development, with the participation of local communities aware of the value of their resources. However, it is necessary that stakeholders know in depth the system and its variations, to adequately manage resources.

Wetlands are identified by the presence of characteristic species, hydric soils or a water surface (Osmond et al., 2016). All the wetlands presented in this study were sampled between August and December 2011 in the presence of a water surface. However, the presence of the water had a major side effect, namely the mortality of species less tolerant to flooding and the colonization of floating species. In the absence of water, the physical and chemical substrate conditions change (Keddy, 1984; Mitsch & Gosselink, 2007) and the colonization of other species is limited by their flooding tolerance, which may produce changes in the dominance pattern of the species (Gordon, 2003; Neiff et al., 2008). For this reason, wetland monitoring at different times of the year, including dry periods, when the availability of nutrients is higher due to organic matter decomposition, allows a more accurate estimate of biodiversity.

Climate change could cause variations in the structures of species composition in many environments. Therefore, it is important to develop monitoring and research plans to evaluate these changes. In general, aquatic environments and wetlands associated with them are currently under pressure due to the presence of invasive species, alterations in land use and habitat degradation, which makes them more vulnerable to climate change.

The growing urban, tourist and agricultural expansion in Barlovento will be sustained over time because Miranda State has an industrial, commercial and tourism-based economy (Lemus & Perez, 2011). Therefore, it is unlikely to propose conservation alternatives that involve the creation of more protected areas. However, environmental education plans together with adequate monitoring of environmental sustainability adopted by the authorities and owners of hotels and tourist establishments would help. It is necessary to encourage research in areas such as ecology, ecological economics, fisheries, agronomy, tourism, and sustainable development in adjacent areas (Parkswatch, 2006) as well as adopt patterns for sustainable use of wetland resources. These environments should be administered by public and private organizations working with updated policies in accordance with the latest global trends to ensure their conservation.

The services these ecosystems provide make them worth preserving in a changing world. Taking into account the value of these ecosystems and their current problems, as well as some proposals to avoid sedimentation (Gleason & Euliss, 1998) and ideas for avoiding the degradation of areas susceptible to erosion by human activities (Packer & Christensen, 2014), we propose the following conservation measures:

- **Support wetland research** to understand their dynamics and evaluate the biodiversity of species to identify its general patterns of distribution at various times of the year. This will become a baseline for preserving the planet's biodiversity as much as possible, with emphasis on environments that are most critically threatened.
- **Generate permanent education plans** for schools and tourist centers to highlight the value of wetlands and to sensitize the population on their conservation.
- **Monitor the sedimentation processes** on the rivers that descend from the coastal mountains and evaluate alternatives if accelerated increases in sedimentation are detected. These alternatives could encompass control of sediments emission as well as the restoration of wetlands.
- **Work with the communities** that live nearby and identify the problems of wetlands with them to seek conservation alternatives together.
- **Work with authorities** to prevent or reduce the uncontrolled discharge of wastewater, solid waste and toxic waste.
- **Restrict extraction of plants or animals from their natural habitat** or, as far as possible, to avoid disturbances of the environment and the uncontrolled extraction of flora and fauna that feed and reproduce in those places.
- **Raise awareness of the dynamics of wetland flooding.** Housing construction on wetland sites is not recommended.
- **Avoid the introduction of plant or animal species** from other ecosystems, whose effect or impact is unknown.
- **Use modern tools** such as marine spatial planning and ecosystem base management approaches to make better decisions about these ecosystems.
- **Organise** public awareness campaigns in addition to formal and normal permanent education plans.

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SECTION

2 Riverine wetlands

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Natural rivers twist and bend, have periods of flood and drought and change over time. Early Egyptians first took advantage of river cycles by planting on fields newly enriched by the flood of the Nile. But humans soon found ways to engineer rivers into new shapes to serve their purposes. They built dams to prevent floods and to form reservoirs for irrigation and power generation. They straightened and dredged rivers for better navigation. This worldwide diverting, straightening, unbending, drying, and managing of rivers has had some disastrous effects on riverine wetlands and sometimes on human populations as well.

Of the two cases studies in this section, one describes how damming a river led to a drastic change in the river's flow regime in Burkina Faso, with consequences such as floods upstream and droughts downstream of the dam, and has deprived the local villages of their food and livelihoods. The other case shows how floodplains of the Danube River in Austria were nearly wiped out because straightening the river cut off the backwater habitat of the water soldier (*Stratiotes aloides L.*) and its ecological community.

Solutions to these unintended effects rest mainly in foresight and prevention – in thoughtfully preparing environmental and social impact statements on new projects that may damage ecosystems and harm human populations dependent on them. In the Danube, a valiant effort was made to re-water a population of water soldiers, but more sustainable solutions involve working with other stakeholders such as swimmers and fishers to relocate some of the water soldier populations to more suitable areas where they can thrive.

After many ecosystems and human populations experienced catastrophic effects from dam building, environmental managers figured out ways to calculate how much water needs to flow through to maintain the river and surrounding ecosystem. These calculations must be part of any interference with river flow. In the Burkina Faso case, it was calculated that a flow rate greater than 10 m^3/s could have helped preserve its water quality, but unfortunately, no flow rate was implemented or monitored.

S2

CHAPTER

1

The Massili River in Burkina Faso

The impact of halting natural river flows on ecosystems and the livelihoods of riparian people

By

Birguy Lamizana-Diallo
Member
Steering Committee for the Commission of Ecosystem Management and Programme Officer at United Nations Environment Programme

Riccardo Zennaro
Associate Programme Officer
United Nations Environment Programme

Abstract:

The rehabilitation of the national road (RN22), linking Ouagadougou to Kongoussi and Djibo in the northern central region of Burkina Faso, has caused serious environmental and socio-economic problems. This area is in the Sahel region, which is prone to water scarcity and droughts. This road rehabilitation project was launched without conducting an environmental impact assessment (EIA). As part of the project, the Massili River was temporarily dammed above a road crossing to allow for construction of the new Dapelogo bridge near the community of Dapelogo. This dam led to a drastic change in the river's flow regime with consequences such as floods upstream and droughts downstream of the dam. The severe alteration of the flow regime also had major repercussions on the local population that showed how local land-use decisions can result in environmental damage that can impact people's livelihoods and lead to food insecurity. The nearsighted decisions made for the rehabilitation of RN22 demonstrates how poor, rural communities, who are highly dependent on the functions and services of natural ecosystems, particularly the wetlands, for their livelihoods, and can easily be disrupted by infrastructure projects.

Keywords:

Massili River | environmental impact assessment (EIA) | flooding | damming | impacts | ecosystems | livelihoods

Introduction

Over the years, natural flows shape river basins. Any modifications to the quantity and quality of the water that is required to maintain ecosystems and their functions and services – usually referred to as environmental flow – affect the associated aquatic ecosystems with varying degrees of severity. These changes can individually or collectively create complex impacts on aquatic wildlife as well as on the use of river goods and services and modes of river ecosystem management by the riparian populations. Therefore, it is important that actions affecting the natural flow of watercourses, such as the construction of dams and water withdrawals for agricultural or domestic uses, account for these risks and include adequate mechanisms to prevent or mitigate the impacts on biodiversity and the other functions of the affected aquatic ecosystems. It was also established that maintaining a flow rate of more than 10 m^3/s in the river could help preserve its water quality Paliwal et al., 2006).

Around the middle of the 20th century, people started noticing negative impacts on water resources resulting from development. In North America, for example, some game fish disappeared (King et al., 1999). Around the world, the construction of large dams was found to lead to significant social and environmental impacts downstream (WCD, 2000; Baxter, 2003; Schmutz & Moog, 2018).

People living along rivers depend on them and on nearby wetlands and their ecosystem services to different degrees for their livelihoods. Since river flow is widely acknowledged as an important to the functioning of river ecosystems and wetlands, communities are affected by the changes in the river flow regime (Hollis et al., 1993; Barbier et al., 1997; Sene et al., 2006; Lamizana-Diallo, 2009). Nowhere is this truer than in Burkina Faso, where low rainfall and droughts regularly occur. Here, wetlands collect and redistribute water, offer natural rest areas for wildlife and provide a large number of ecosystem and human services, including water supply for agriculture and aquaculture, and for the regeneration of grazing areas. Overall, when used rationally and sustainably, wetlands can be instrumental in improving economic and social conditions for the poorest populations in their vicinity. However, immediate survival problems are paramount in people's minds, and concerns such as nature conservation are often neglected even though rapidly growing populations rely on wetlands for food production (Lamizana-Diallo, 2009).

The rehabilitation of the national road RN22 (12°63 N, 1°70 W), connecting Ouagadougou to Kongoussi and Djibo, shows how poor rural people's production systems can be highly dependent on the functions and services of natural ecosystems, specifically wetlands. In this instance, the change in the river's environmental flow regime caused by damming the river, has led to the loss of all their crops and sources of livelihood. This is shown in pictures and discussed in this article. Further, the alteration of the Massili River's flow regime shows how local land-use decisions can result in environmental damages impacting the lives of people other than those making the decisions.

For sure, the decision to pave the road in question was more than welcomed by all Burkinabe because the road was bumpy and dusty with big trucks making it impracticable during the rainy season from June to September. Indeed, it was one of the few remaining unpaved roads in Burkina Faso, making travel and transport over the 203 km between Ouagadougou and Djibo, very difficult. Road construction in general boosts development, but due to the lack of an environment impact assessment (EIA) and because of the inextricable linkage between ecosystems and rural communities' livelihoods, this project had major impacts on the communities of Dapelogo.

This case study shows the impact of river flow regimes on ecosystems: it describes the repercussions of the alteration of the flow on the livelihoods of people living alongside a river, and the importance of maintaining the natural flow. The following section presents the Massili River basin, its geographical location, and the socioenvironmental context. The next section discusses the initial situation in the study area, and the last section describes the situation after the damming of the river and the consequent impacts.

Description of the study site

The Massili River basin, which covers an area of about 4,500 km^2, has a high population density varying from 61.7 persons/km^2 in the province of Ganzourgou, to 335.8 persons/km^2 in the province of Kadiogo, six times higher than the national average of 48 persons/km^2. It is recognized as one of the most urbanized basins in the country and hosts the Loumbila reservoir with a capacity of 42 million m^3 that supplies drinking water to the over 1 million people living in the capital Ouagadougou and its surroundings. The Massili River is a major water source for the entire population of the basin. It is also a main tributary of the Nakambé River, formerly the White Volta River, a major transnational river whose basin encompasses over 400,000 km^2 and is shared by six countries: Benin, Côte d'Ivoire, Ghana, Togo, Mali, and Burkina Faso.

The Massili River basin occupies the central part of Burkina Faso and is home to its capital city, Ouagadougou. The Massili River receives all municipal and industrial wastewater from the city which are discharged downstream of the Loumbila dam. The river and its resources are the main means by which most people living near it sustain their livelihoods. In a context of poverty and total dependence of the population on the watercourse, numerous users rely almost exclusively on the Massili River. The endemic poverty faced by the basin's population is a catalyst for environmental degradation (KYBP, 2006). The various human activities, together with climate change and climate variability, coupled with the socio-economic changes in the Sahel region since the 1970s, all contribute to the precarious state of the Massili watercourse.

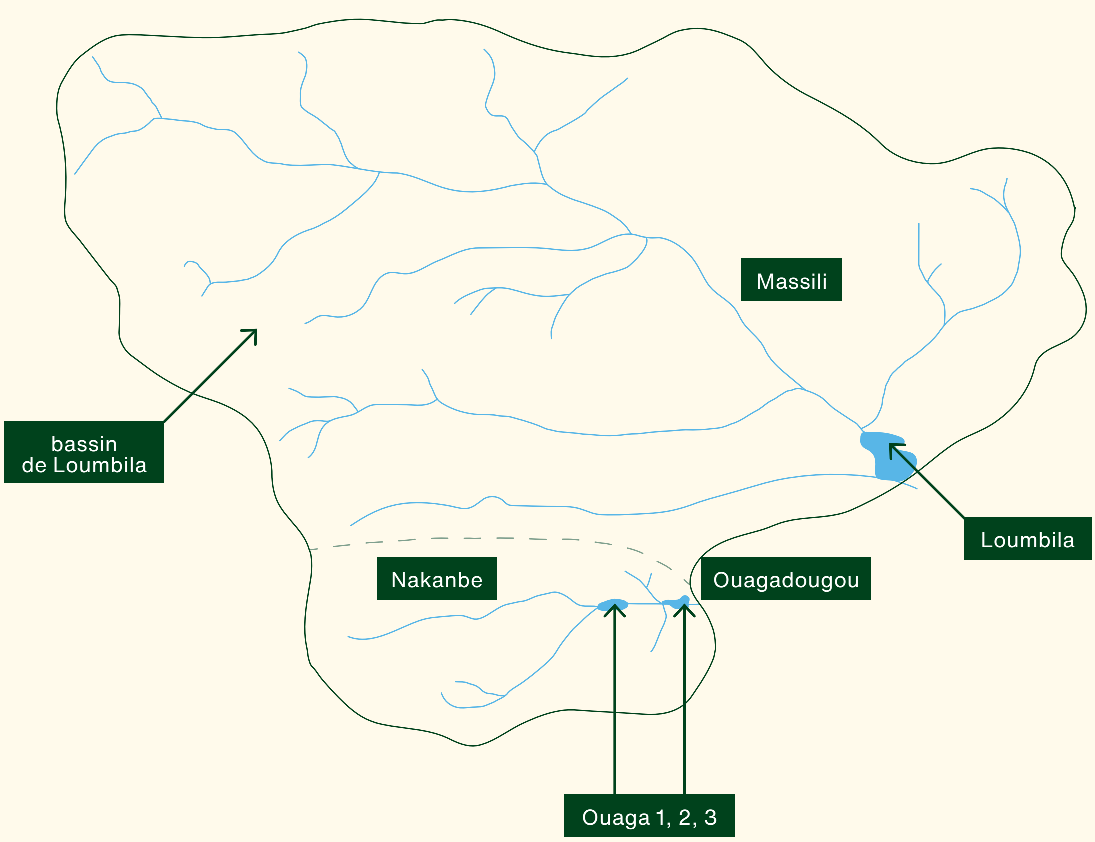

Figure 1: Massili watershed.

Source: Adapted from Lo et al., 1991.

Figure 2: Massili River basin.

Source: Lamizana-Diallo, 2005.

Methodology

Regular field visits to the site were undertaken from 2004 to 2008, allowing observation not only of the changes to the river ecosystems but also of the activities which took place on the riverbank and on the water itself. A socio-economic survey of villages around Dapelogo (Figure 2: 12˚39 N, 01˚32 W), comprising focus group discussions, semi structured interviews, and mapping was used to collect data. The method comprised a series of open meetings using the key tenets of the participatory rural appraisal (PRA) method, including participation, teamwork, flexibility, optimal ignorance, and triangulation (Lamizana-Diallo, 2005).

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Figure 3: Map of the district of Burkina Faso with the survey area highlighted in green.

Source: Lamizana-Diallo, 2005.

The PRA was conducted with 33 individual interviews and five focus groups. The community selection criteria included proximity to the river and the estimated number of people in the community. The selected communities included villages very close to the river, less than 1 km from the river, and more than 1 km away, but still relying on river resources as their main means of livelihood. The communities living closest to the river tended to be more dependent on the river resources.

Five focus groups were determined: herders, fishermen, horticulturists, leaders, and traditional plant users. Each group consisted of a minimum of five people who directly used the river resources for their livelihood. All interviews were conducted in the field. The study also gathered information from key informants, including village leaders and field extension workers.

The data collected was analyzed and presented using simple descriptive statistics, mostly percentages. Graphs, pictures, and tabulations were used to present the results. The interviews were analyzed using Epidata and the Statistical Package for Social Science (SPSS).

Results and discussion

The interviewed population is relatively young, 70% being less than 30 years old, and 30% were immigrants from other parts of the country and region. The literacy rate is low, under 50%. The population has a cultural and spiritual connection to the Massili River and uses its waters as the main source for its livelihood and income generation. Ritual ceremonies are performed in the river and along its banks. When asked who owns the river, 45% of the interviewees said the river belongs to the State, while 23% said it belongs to the local community. Most (84%) of the population uses water from the river for various activities: horticulture (62%), breeding (25%), fisheries (5%), and others (8%).

Figure 4 illustrates how local communities depend on the Massili River for food production. Around Dapelogo, all 33 people interviewed used river water for horticulture, which was the main source of their income (Table 1).

Figure 4: Main river livelihood activities in different villages.

Source: Lamizana-Diallo, 2005.

Table 1 shows that horticulture is the main source of income for the population of Dapelogo. This activity is undertaken during the dry season, from October to May, near water bodies, including rivers, ponds, and lagoons. The main crops are cabbage, tomatoes, lettuce, carrots, and onions, which are sold in the local market as well as in the capital, Ouagadougou. The income is mainly used to purchase food (31%), to pay for health care (31%), for education fees (23%), as well as for professional investment and leisure. 10% of the interviewees estimate that the expenses covered by this means amount € 200 or higher. Therefore, any influence on the river's flow regime and water availability has a drastic impact on the inhabitants' livelihoods.

Table 1. Income sources of the people in Dapelogo.

INCOME SOURCE	ANNUAL GAIN (EUROS)	EXPENSES PURPOSE USE OF PROCEEDS	SALE CENTRE
RAINFED AGRICULTURE	0		
CATTLE GRAZING	0	To be sold only under extreme necessity conditions	
HORTICULTURE	230	Food, motorbike, wedding, funeral, health, education, cattle	The market in Dapelogo and Ouagadougou
FISHING	80	Material, investment in horticulture	Market in Dapelogo

Source: Compiled by the authors.

Initial situation

Most of the people in Dapelogo are unskilled, small-scale farmers who depend on seasonal crops like millet and maize. Among them are some who have mango and guava plantations and cultivate cabbage, carrots, tomatoes and onions during the dry season.

Upstream of the Dapelogo Bridge: The Massili River is very wide at the Dapelogo bridge. During the dry season from October to May, the river banks on both sides were used for socio-economic activities such as cattle grazing (Figure 5), horticulture, including cultivation of onions, zucchini, lettuce, and other vegetables, and material extraction for house construction, the latter undertaken from October to early May (Figure 6). During the rainy season, from June to September, the population would cultivate rice, maise, and millet within 30 m of the river. Fishing was also an important activity.

Vitellaria paradoxa. Permanent wells and boreholes very close to the river provided drinking water to the population. The people living near the Massili River earned income from the river's ecosystem services for their livelihoods.

Figure 5. Cattle grazing area upstream from the Dapelogo bridge, May 2004.

Photo © B. Lamizana.

Figure 6. Housing construction material made (a) and harvested (b) along the Massili River banks at Dapelogo.

Photos © B. Lamizana.

Downstream from the bridge: The population downstream from the bridge engaged primarily in horticulture and the collection of construction materials during the dry season. These activities usually took place from the end of the harvesting period in October until March. During the rainy season, the population would also fish and cultivate rainy season products, mainly cereals, on the riverbank.

Situation after damming the river

National road RN22 passes over the Massili River via the Dapelogo bridge. To use water from the river to help rehabilitate the road, the project initiator constructed a temporary dam in the river near the bridge without conducting an environmental impact assessment. A preliminary study regarding this road was undertaken in 1979. However, in 2006, when the decision to implement the project was made, and after securing the necessary funds, no new EIA was conducted despite the long time between 1979 and 2006.

The damming work began in July 2006 during the rainy season. The dam was not completed and, a small sluice allowed water to flow downstream to avoid destruction of the unfinished dam. In October 2006, the dam was completed and the river was completely blocked, with no water subsequently allowed to flow downstream. This led to flooding upstream and to a dry riverbed downstream.

Impacts upstream: After construction of the dam, the area upstream of the bridge was flooded for up to 14 km from the bridge. All crops, including millet, sorghum, rice, fruit trees, as well as wells and boreholes in the area were flooded. This event destroyed all the crops and led to the unavailability of drinking water. The local population was unable to harvest any agricultural products. In addition, the flooding led to the loss of wells and boreholes and the inundation of the remaining trees, causing all guava and mango plantation trees to die (Figure 7).

After the shock of having lost everything, the local people tried to gain benefit from the situation. The presence of water due to the dam was an opportunity, so many people rushed to engage in horticulture. Whereas before the dam was installed about 4,000 persons engaged in dry season cultivation, after the dam formed a reservoir more than 10,000 people engaged in this activity. Many people from surrounding communities, including Tanghin, Napalgue, came to the area for the same purpose. Deforestation was widespread with large numbers of shea trees (*Vittelaria paradoxa*) and *Parkia biglobosa* removed to make space for horticulture (Figures 7, 8, 9, 10 and 11). People invested heavily in pesticides, using four sacks per hectare, with each sack costing about US$ 30. Each horticultural plot was 1–2 ha.

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Figure 7: Flooding upstream and extraction of water for horticulture.

Photos © B. Lamizana.

Figure 8. Cutting trees (*Parkia biglobosa*) to make space for horticulture.

Photo © B. Lamizana.

Figure 9: Stump of a shea tree (*Vittelaria paradoxa*) cut to make space for horticulture.

Photo © B. Lamizana.

Figure 10. Preparing land for horticulture.

Photo © B. Lamizana.

Figure 11. Horticulture upstream of the dam.

Photo © B. Lamizana.

Unfortunately, competition for water, including abstraction for construction of the road and horticulture, coupled with evaporation, was so intense that the riverbed was dry before the community was able to make its first harvest (Figures 12 and 13).

Figure 12. The dry riverbed upstream of the dam.

Photo © B. Lamizana.

Figure 13. The dry riverbed downstream of the dam.

Photo © B. Lamizana.

In October 2007, after this portion of the road was completed, the dam was removed (Figure 14). The positive side is that now the RN22 is paved, making the connection between Ouagadougou, Kongoussi, and Djibo easier (Figure 15). Nonetheless, all the above-mentioned negative impacts could have been avoided with proper planning and an EIA.

Figure 14. Opening the dam in the riverbed, October 2007.

Photo ©B. Lamizana.

Figure 15. The newly paved road RN22.

Photo ©B. Lamizana.

Impacts downstream of the bridge: There was no significant impact downstream of the bridge during the rainy season. The only notable effect was a decreased catch of fish, according to some interviewees. Indeed, the dam's interruption of natural seasonal flooding led to a reduction of ordinary activities during the dry season. The population resumed its dry season vegetation farming, extraction of material for house construction, harvesting of wild fruit, and more. However, the dry season vegetation, which formerly occurred from October to March, lasted two months less due to the lack of water.

Lessons learnt

A free-flowing river generally has benefits attached to it, and it is a mistake to assume the opportunity costs of altering the natural flow of a river are zero. Ecosystem needs (restoration of pre-dam flow patterns) must be synchronized with the needs of poor people whose livelihoods are largely based on water-dependent activities such as fishing, livestock rearing, and farming. Based on this knowledge, opportunities for building a coalition between environmental advocates and local communities exist.

An EIA is a must be undertaken before any construction, or alteration of river flow. Such a study may indeed prevent or mitigate the negative impact of these modifications on biodiversity and the livelihoods of local communities.

Conclusion

In a dry country like Burkina Faso, any water point is an opportunity for income generation. Hence, youths migrate towards these water bodies to do horticulture, fishing, or other activities. The money gained from these activities usually helps them to face their expenses such as health care, education fees, and food supply.

The experience of the people living around the Massili River has clearly shown the key role that water bodies play with regards to food security, including agriculture, vegetable production, grazing and fishing. It also demonstrated the importance of conducting an EIA before implementing any project to avoid the negative impacts on the people and the environment. Ultimately, this experience clearly shows the importance of maintaining the natural flow of the river for the benefit of humans and the environment too. If this is not ensured, human activities and livelihoods might be compromised or affected, such as in this case, and biodiversity particularly threatened by environmental degradation, which is often caused by a combination of wrong policies, market failure, and widespread poverty.

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CHAPTER

2

The Water Soldier (*Stratiotes aloides*)

An indicator for the conservation and management of riparian ecosystems

By

Katharina Lapin
University of Natural Resources and Life Sciences, Institute of Botany, Department of Integrative Biology and Biodiversity Research
Vienna, Austria

Austrian Federal Research Centre for Forests, Natural Hazards and Landscape
Vienna, Austria.

Karl-Georg Bernhardt
University of Natural Resources and Life Sciences, Institute of Botany, Department of Integrative Biology and Biodiversity Research
Vienna, Austria

Karoline Zsak
Nationalpark Donau-Auen GmbH
Orth an der Donau, Austria

Patrick McClatchy
Austrian Federal Research Centre for Forests, Natural Hazards and Landscape
Vienna, Austria.

Abstract:

The regulation of the Danube River has caused a decline in species diversity in riparian habitats throughout Europe. Aquatic macrophytes adapted to the ecology of backwaters are particularly affected by this decline. One such macrophyte is the water soldier (*Stratiotes aloides L.*) The water soldier, a suitable indicator for assessing the development of riparian ecosystems, could be found in only six locations of the eastern Danube floodplains in Austria in surveys from 2014 to 2017. While primarily endangered by gradual siltation due to a lack of regular flooding events, a large number of anthropogenic disturbing factors were also found to significantly compromise the habitats of water soldiers. The most desirable conservation approach would be to create or promote natural backwater dynamics for water soldiers' habitats. In the short term, however, less extensive local measures are also suitable for delaying the succession process.

Keywords:

Stratiotes aloides | aquatic macrophyte | endangered plant species | Danube floodplains | Austria

Introduction

A hundred years ago, visitors described huge expanses of water densely covered in white water soldiers' flowers (Sauberer, 1942; Hübl, 1952). But regulation of the Danube River eventually led to a loss of species diversity in the riparian habitats: backwaters were cut off from the main trunk, the dynamism of the river was restricted and areas with stagnant water gradually began to silt up. Besides direct anthropogenic interferences, various indirect influences like the introduction of certain nutrients and contaminants contributed to changes in fluvial landscapes (Jungwirth et al., 2014; Schratt-Ehrendorfer, 1999). Modern agricultural processes, in particular, have a massive ecological impact on rivers, lakes and backwaters as areas of high species diversity undergo eutrophication. European freshwater bodies are, therefore, among the most endangered landscapes (Harabiš et al., 2013) with progressive ecological impact as a result of increasing anthropogenic influences (Relyea, 2005; Richards et al., 1996; Oťaheľová & Valachovič, 2006).

Water plants are well-adapted to their aquatic habitats and represent an important element in river ecologies (Chaves et al., 2002). Their evolution has provided them with strategies to cope with the natural changing dynamics of rivers (Gurnell et al., 2012). Anthropogenic influences heavily affect macrophytes in riparian habitats. Knowledge of these plants and their ecology allow pressures from human interference to be assessed, and areas of particular ecological significance and value determined (Munné et al., 2003). In recent years, comprehensive management concepts for maintaining populations of water soldiers as a key species for ecologically valuable backwaters have been tested (Hudler et al., 2015).

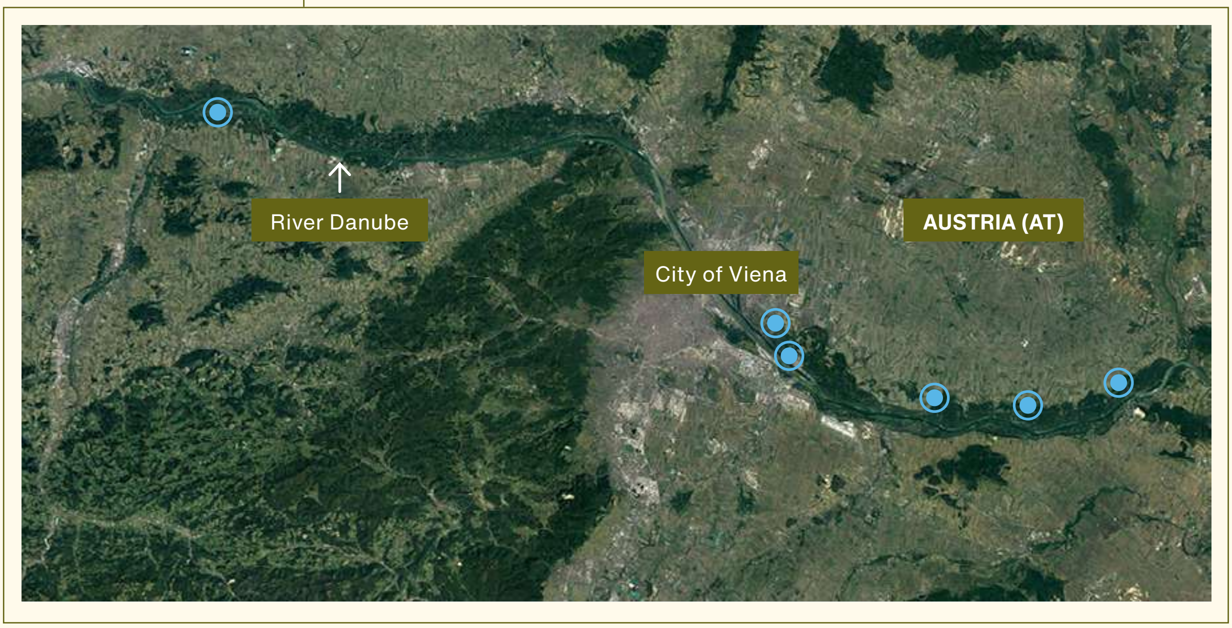

Figure 1. Location of the six remaining populations of water soldiers (*Stratiotes aloides L.*) in the riparian forests along the Danube in eastern Austria.

Map data: Google, Terrametrics

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The water soldier

The water soldier is a perennial aquatic macrophyte that grows as a rosette of serrated leaves. Most specimens alternate between an emerged state in the winter and a submersed state in the summer, but a perennially submersed variant also exists (Hegi, 1981; Cook & Urmi-König, 1983). Its natural range extends across most of northern and eastern Central Europe and all the way to the Baltics and Siberia. The populations along the Danube are among the southernmost known occurrences (Cook & Urmi-König, 1983).

The water soldier is a typical representative of riparian forest flora, preferring slow-moving or stagnant bodies of water. Although it is a dioecious species, vegetative reproduction by way of offsets and turions is far more common than generative reproduction. Owing to its fast growth under ideal conditions (De Geus-Kruyt & Segal, 1973), the species plays an important part in siltation succession (Segal, 1971). The water soldier is a free-floating macrophyte whose life cycle (see Figure 2) requires water with high concentrations of carbon dioxide, typical of ponds, creeks and reed areas (Nielsen & Borum, 2008). The water soldier is noted for its close connections to other species such as the green hawker dragonfly (*Aeshna viridis*), which is listed as an Annex IV species in the 1992 EU 'Habitats Directive' (Rantala et al., 2004).

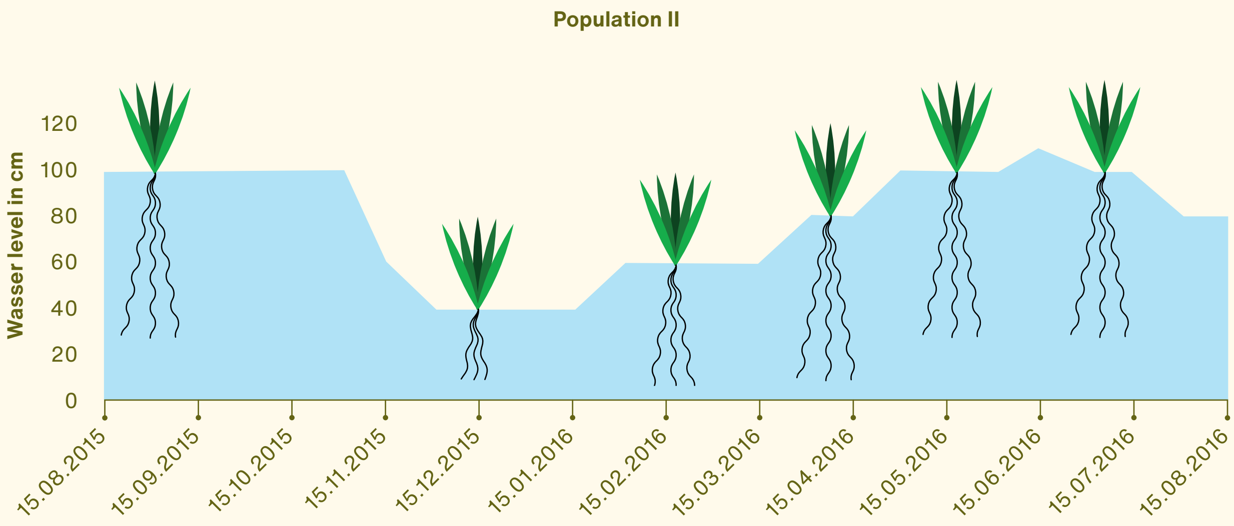

Figure 2: Ideal annual life cycle of water soldiers in a water body with water level fluctuation in centimetres.

Source: K. Lapin.

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Current situation

The last remaining Austrian populations of water soldiers can be found in two conservation areas: the Natura 2000 area Tullnerfelder Donau-Auen and the Donau-Auen National Park (Bernhardt & Naumer-Bernhardt, 2010; Hudler et al., 2015). These populations were monitored over one year (July 2015 to August 2016 at intervals of 14 days). All locations are between 150 and 320 m above sea level, and all are subject to seasonal fluctuations in pH and oxygen partial pressure (Table 1). Factors like water depth and water quality (conductivity, pH value and oxygen partial pressure) also differ among the locations (see Figure 3).

Figure 3: Pictures (2015) of the water bodies where the last remaining Austrian populations of water soldiers can be found in two conservation areas: Natura 2000 Tullnerfelder Donau-Auen (Zwentendorf) and in the Donau-Auen National Park (Tischwasser, Öllager, Ortzonau, Eckartsau and Stopfenreuth).

Source: K. Lapin.

The depths fluctuate significantly depending on precipitation and groundwater levels. Furthermore, large amounts of deadwood are present in the water. Siltation of the inhabited waters appears advanced and extensive reed beds are present in three of them.

Table 1. Hydrological description of the waters with populations of water soldiers, 2015

CONSERVATION AREA	NATURA 2000	DONAU-AUEN NATIONAL PARK				
	ZWENTENDORF	TISCHWASSER	ÖLLAGER	ORTH/DONAU	ECKERTSAU	STOPFENREUTH
COORDINATE N	N 48° 22´	N 48° 11´	N 48° 10´	N 48° 08´	N 48° 08’	N 48° 11’
COORDINATE O	E 15° 47´ 03.80˝	E 16° 28´ 54.84˝	E 16° 29´ 47.30˝	E 16° 41´ 00.30˝	E 16° 46’ 52.8”	E 16° 28’ 56.6”
NATURAL BACKWATER	×	×		×	×	×
POPULATION	250 m^2	100 m^2	890	232	150	1 m^2
INDIVIDUALS/m^2	12	4	12	9	7	1
INDIVIDUALS TOTAL	3,050	15	11,760	2,552	800	1
SEX	Female	male	male	?	male	?
OFFSETS AND TURIONS	3,00	2,18	10,8	nn	8,4	0
pH	7,3	7,78	7,03	nn	8,4	7,36
WATER LEVEL (cm)	30	150	100	100	130	20
CONDUCTIVITY µS/cm	405	699	627	784	694	445
O^2 LEVEL mg/L	4,02	6,45	3,84	6,14	5,1	6,3
INFLUENCED BY FLOODING	No	no	no	yes	yes	no
LIGHT CONDITION	Shady	sunny	semi-sunny	sunny	semi-lit	shady
STREAMING	No	no	no	yes	yes	no
ACCOMPANYING SPECIES (N)	21	16	17	15	20	10
THREATS AND CONFLICTS						
VITAL POPULATION			×	×	×	
ENDANGERED BY SILTATION	×		×	×		×

CONSERVATION AREA	NATURA 2000	DONAU-AUEN NATIONAL PARK				
	ZWENTENDORF	TISCHWASSER	ÖLLAGER	ORTH/DONAU	ECKERTSAU	STOPFENREUTH
AFFECTED BY DROUGHT EVENTS	⊗			⊗		⊗
LACK OF FLOODING EVENTS	⊗		⊗	⊗		⊗
LIMITED BY SHADED LOCATIONS	⊗				⊗	⊗
NO GENERATIVE REPRODUCTION	⊗	⊗	⊗	⊗	⊗	⊗
DIRECT HUMAN INTERFERENCE		⊗				
PLASTIC WASTE		⊗	⊗			

Note: Measurements were taken in September 2015 during the monitoring period of August 2015 to August 2016.

Source: Bernhardt et al., 2016.

Identified threats and conflicts

Habitat loss

The phytosociological analysis shows that backwaters with populations of water soldiers are extremely rich in species. Many species found in the backwaters are red-listed and extremely endangered (see Table 1). What these species have in common is the loss of their backwater habitats, which are natural parts of riparian areas. Backwaters are an individual habitat type with particular flora and fauna, while at the same time providing partial habitat for other animals. Anthropogenic influences, however, have caused a significant decline in the incidence of backwater habitats (Lange et al., 2000).

Natural backwaters are created by the dynamics of watercourses, which cause seasonal variance in water levels and temporary regional flooding. However, this dynamic is barely present today. To allow human settlement of former vast (temporary) floodplains, rivers were engineered into permanent channels to protect against flooding, thereby preventing the natural creation of backwaters.

As revealed by the phytosociological analysis, backwaters are a rich and important habitat for water soldiers, but also for many other species, for example, European water-plantain (*Alisma plantago-aquatica*), broadleaf cattail (*Typha latifolia*) and bladderworts (*Utricularia australis*). Where other aquatic vegetation occurs extensively covering much of the water surface, water soldiers' surface emersion and submersion cycles can be inhibited. Furthermore, different vegetation units compete in terms of light absorption and encroachment can increase the succession pressure on various species, promoting the decline of certain populations.

Siltation succession

Water soldiers play an important role in siltation succession (Segal, 1971), not least because the species' high biomass production contributes significantly to the siltation of the water bodies it inhabits. It grows in naturally occurring oxbow lakes and backwaters – habitats cut off from the dynamics of the main river that tend to experience an acceleration in succession processes leading to siltation (Hudler et al., 2015). Thus, water soldier populations like the one in Orth an der Donau are heavily affected by droughts (Figure 4). The low precipitation between June and September further promotes this effect. Low water levels during periods with little precipitation influence the vitality of water soldiers' populations because rosettes frequently drift off and wither at the water's edge. All populations face the dangers of siltation in the long term and this risk is mainly a result of the lack of flooding events.

Besides water levels, the amount of sunlight is also important to water soldiers' survival. Various vegetation – especially overhanging trees – can influence the intensity of light reaching ground level. Locations with current or detectably recent populations of water soldiers can be described as semi-shady or semi-lit. However, populations in less shaded locations showed noticeably more vital development.

Figure 4. Drought in Orth an der Donau in September 2015 with water levels at 0 cm.

Source: K. Lapin.

Endangerment of genetic variance

Generative reproduction is an important factor for the vitality of water soldier populations (Orsenigo et al., 2017). Despite large numbers of flowers in two locations, generative reproduction was limited in all examined populations because the male populations in the Donau-Auen National Park are too far away from the only female population in the Natura 2000 area Tullnerfelder Donau-Auen to allow successful pollination. Proliferation through drifting and introduction of new specimens from other populations, which could potentially alter the gender distribution and thus result in generative reproduction, do not occur (Hameister et al., 2013; Bernhardt et al., 2014).

Recreational use

Water soldiers were affected by direct human interference in two of the examined waterbodies. Swimmers (people or dogs) can easily cause rosettes to be mechanically damaged or overturned, causing their growth to be stunted because their leaves are no longer oriented towards the sun and their bases dry out because they are no longer submerged. In locations with biking or hiking trails near a waterbody inhabited by water soldiers, as is the case for the Öllager population, plastic refuse can frequently be found stuck to the plants' leaves (Figure 5).

Figure 5. Plastic refuse on water soldiers.

Source: K. Lapin.

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Recreational fishing

The population of water soldiers covering the largest area can be found at the Öllager location near the OMV oil depot site Lobau. The depot is located immediately to the east of the waterbody housing the population. Originally situated in the nearby Panozzalacke, an easily accessible and flat-shored lake frequented by bathers and recreational fishermen, the water soldier plants were moved to the artificial lake close to the OMV oil depot in the 1970s by anglers seeking to increase the attractiveness of their fishing site (Schratt-Ehrendorfer, 1988). This population has since grown to be the largest in Austria, with more than 11.100 individuals per m^2. No new occurrence of water soldiers has been recorded in Panozzalacke.

Agricultural resource use

For three of the six examined populations, nutrients may come from nearby low-intensity farming plots and more distant but intensively farmed areas connected to the sites via small channels. The water levels at Eckartsau were particularly affected by a period of drought, with water levels dropping by more than a meter during the vegetation period. This development is most likely attributable to the drying up of the Fadenbach brook. Water usage for agricultural irrigation likely accentuated the low water levels (Smolders et al., 2003).

Management conflicts

Management to protect and preserve water soldier populations will have to deal with conflicting interests for water use (Hudler et al., 2015). Many of these conflicts are the result of the backwaters fulfilling multiple functions simultaneously. The main ecosystem functions of the affected habitats are recreational use, water use for agricultural irrigation, resource production (fishing), resource protection (water) and wildlife conservation.

Perceptions of the management of water soldiers differ. In the Natura 2000 area, the selection of substitute habitat locations was discussed. Four water bodies in the study area fulfilled all the requirements for substitute habitats for the endangered populations. However, massive resistance by the landowners and fishermen was encountered, as the establishment of water soldier populations would entail significant changes to the structure and usability of these bodies of water.

In order to protect the water soldier populations and the ecologically valuable habitats characterized by them, many regions have recently commenced comprehensive conservation measures. Conservation areas have been established and re-population projects undertaken. Despite these efforts, the decline in water soldiers' numbers has continued. Water soldiers are also endangered in many other European countries, requiring a more extensive international effort to protect the species.

Solutions

Reconnection of cut offs

Reconnection of cut-offs and backwaters to the Danube promotes the formation of a dynamic river system and enlarges habitat for the water soldiers. The restoration of the shorelines of water body ecosystems, reconnection of separated waterbodies, optimization of low-water regulation, and granulometric improvement and stabilization of the riverbed is the declared goals of the Water Management Authority of the city of Vienna and the Donau-Auen National Park. Many projects have already been successful. Over the long term, the intent is to ensure continuous water exchange with the main stem of the Danube.

Visitor monitoring

Use of riparian forests and waterbodies for recreation by the Viennese population has a long tradition and requires consideration in the establishment of plans for water soldiers' conservation. Awareness about the species in well-frequented waterbodies needs to be raised and measures need to be taken against its mechanical disturbance and removal for transfer to private ponds. Removal of water soldiers is already forbidden in the Donau-Auen National Park area (Nationalpark Donau-Auen GmbH, 2015).

Projects undertaken in the national park have shown that visitor information campaigns and visitor monitoring are effective. A further solution for usage conflicts is to offer alternatives. Tischwasser Lake, for example, has been used for bathing, with a concrete pier available to bathers entering the backwater. Influences on the ecology of this lake due to this activity are to be expected. By creating more accessible and attractive public bathing opportunities in the vicinity, managers could reduce the use of Tischwasser Lake with an expected reduction of pressures on the aquatic ecosystem.

Creation of substitute biotopes

Human-made substitute biotopes can serve as safe habitats for many rare plant species. Naturally, environmental influences like intensively cultivated and heavily fertilized agricultural plots in the vicinity need to be taken into consideration for the choice of location for such sanctuaries. Selected locations could be settled with water soldiers to compensate for the loss of their existing habitat due to the siltation. The new locations should provide opportunities for the plants for natural propagation through flood drifting,

Monitoring conditions

Especially in months with little precipitation, it is necessary to protect the populations of water soldiers in shallow, cut-off waterbodies from desiccation. The population in the Natura 2000 area was preserved thanks to active monitoring in a critical phase during 2014 when the waterbody felt dry for an extended period and was regularly refilled with external water to ensure the survival of the plants. To protect water soldiers' populations in the short term, supplying endangered locations with external surface water to maintain water levels during periods of drought is an urgent need.

A further important measure is improving light conditions. The removal of single trees overhanging the shoreline and water surface could allow water soldiers to receive more light. This measure, however, needs to be evaluated in regards to conservation targets to avoid unwanted habitat disturbances. Furthermore, the increasing thicknesses of the soil, hydro-chemical aging of the water bodies, and associated eutrophication can likewise significantly alter the living conditions in the examined habitats.

Conclusion

Loss of habitat, changes in water chemistry and the immediate destruction of individual plants and entire populations (Schratt-Ehrendorfer, 1999) have caused water soldiers to become endangered in Austria (Niklfeld & Shratt-Ehrendorfer, 1999; Fischer et al., 2008). The important role of wildlife conservation areas is exemplified by the case of this species. However, without clear goals and strict measures for wildlife preservation, macrophytes like water soldiers face the risk of extinction. Therefore, we propose recording the water soldier as a threatened species in eastern Austria and including the species in future conservation management activities.

The majority of selective local protection measures are cost-intensive and not viable in the long term. It is, therefore, all the more important to ensure the reconnection of dissociated riparian water networks, thereby allowing natural dynamics to contribute to wildlife conservation. River restoration is an important element of such processes and measures to revitalize riparian backwaters are necessary for preserving them as habitats in the mid and long term. The entire extent of the Danube backwater network likely cannot be comprehensively restored to its original state, but small-scale and large-scale projects like the river bed stabilization efforts along the Danube (Nationalpark Donau-Auen GmbH, 2015) can contribute significantly to preserving riparian landscapes and their waterbodies.

The aquatic macrophyte *Stratiotes aloides*, commonly known as the water soldier, is an excellent indicator for the assessment of the situation of species in riparian areas. The development of water soldiers' populations is affected not only by the degradation of its habitats in the vicinity of and affected by rivers on a larger temporal and spatial scale, but also by more immediate small-scale interferences. It is therefore a key species to illustrate the many-facetted challenges of wildlife conservation in riparian landscapes.

Acknowledgements

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SECTION

3 Estuaries and coastal wetlands

Estuaries are wetlands that interface with the tidal flows of the sea. The flow of salt water in and out with the tides as well as the input from a freshwater source that may change due to wet and dry periods, make estuaries a chemically complex habitat constantly in flux. Because of this complex chemistry, estuaries tend to have many species highly evolved to thrive in different niches. Thus, estuaries teem with life and diversity, but are also fragile to disruption and degradation.

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The first case, related to the Negombo estuary, is considered one of the most productive brackish water bodies in Sri Lanka. Its narrow opening to the sea, distribution pattern of mangrove vegetation, sea grasses and salinity have resulted in a patchwork of diversified niches leading to high species diversity. Its tidal and freshwater exchange mechanisms maintain the salinity levels, the siltation rates, the pollution transport and the biological productivity within the estuary. The Guadiana River estuary shared by Portugal and Spain, described in the next case, forms a natural border between Spain and Portugal. Its ecosystems are considered natural habitats of community importance within the European Union" and have received a high level of protection under national and international laws. The third case describes an unusual peatland on the Baltic coast where the flora and fauna represent a rare mixture of typical fen and mire associations with species indicating brackish conditions. These elements are found in a mosaic pattern, while more mobile species travel through both intertwined.

Estuaries also face different, and perhaps more, threats than freshwater wetlands, which are prominently threatened by being cut off from their source of freshwater or polluted from nearby land. Because of their coastal location, estuaries are often near urban areas, fisheries, and other industries. These uses can be productively and sustainable managed, or they can seriously damage the resources they depend on threats to estuaries include pollution from human and animal waste, solid waste, oil from fishing boats, industrial wastes including heavy metals; encroachment by housing and industry; degradation of mangrove habitats and seagrass beds, which provide protection to many species, and illegal fishing and overfishing especially of shrimp and other valuable species. All these threats can damage the delicate balance and amazing productivity of estuaries and authors recognize that human uses must be incorporated into the estuary's management.

In Sri Lanka's Negombo estuary, a centuries-old form of self-management by shrimp fishermen has kept the lucrative fishery viable and sustainable. The author recommends that government managers incorporate these fishermen and their systems into larger aspects of environmental management. In the Guardiana estuary author recommends that reviving artisanal saltworks – and upgrading their product to *Fleur de sel*, a specialty form of table salt – may stabilize the socio-economic and ecological aspects of the area. Along with sustainable tourism, it may enable economic use of the estuary without degrading it. Conversely, in the Baltic coast's Hütelmoor peatland, managers decided to abandon management practices that had allowed some economic uses and allow the sea to flow into the marsh during storms as it had in the distant past striving for a re-dynamization of this section of the shallow coast. This represents a pilot project to investigate interactions involved in rewetting a coastal peatland.

S3

CHAPTER

1

Negombo Estuary, Sri Lanka

Threats and management plans

By

D.D.G.L. Dahanayaka

Department of Zoology, Faculty of Natural Sciences, The Open University of Sri Lanka

Abstract

Negombo estuary and associated waters of Sri Lanka are rich in natural resources, such as mangroves, seagrass beds, coral reefs, salt marshes, sandy beaches and commercially important fish and shellfish. However, studies have revealed that land-use patterns on adjacent ecosystems, including natural and anthropogenic activities within and upstream of the estuary, are continuously degrading the physical, biological and socio-economic status of this highly productive and extremely biologically diverse wetland ecosystem. This case study reviews the information on current threats and management plans including who is legally responsible for managing the estuary, legal obligations, institutional arrangements, regulations and laws affecting the fishery. Available data are used to address the environmental problems in the water pollution and fisheries sectors and make recommendations for successful rational management. In addition, it attempts to identify the immediate actions needed for improved management.

Keywords:

fisheries management | mangroves | Muthurajawela | remote sensing

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Introduction

Sri Lanka's Negombo estuary is a highly studied, productive, diverse, and intensively used ecosystem that is home to many people who rely directly on its abundant resources for their livelihoods. Commercial small-scale shrimp fishermen's associations have worked out a mutual system of resource management over centuries, which is seen as a possible model for stakeholder resource management in larger areas. The estuary has been challenged by at least two decades of increasing degradation, and must find a balance between development and conservation to achieve a sustainable future.

Physical description

The Negombo estuary (7°6' – 7°12' N; 79°40' – 79°53' E) is a shallow basin estuary in the western coastal region of Sri Lanka (Figure 1). Its surface area is around 35 km^2; it is approximately 10 km long and 3.5 km at its widest point. It has a mean depth of about 1.2 m (Samarakoon & van Zon, 1991) with 70% of its area at less than 1 m deep at low tide. The estuary has a perennial connection with the sea by a single narrow opening of the channel segment at its northern end. The basin segment has a large freshwater supply and restricted water exchange with the open sea (CEA & Euroconsult, 1994).

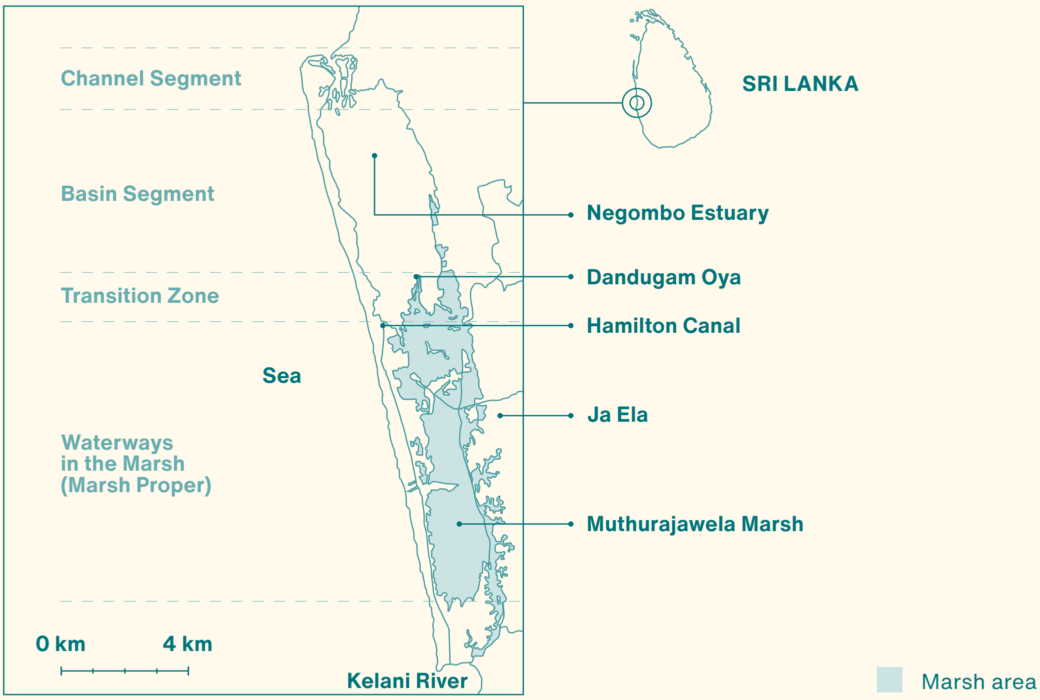

Figure 1. Map of Negombo estuary and Muthurajawela marsh, Sri Lanka.

Source: Jayakody & Dahanayaka, 2005.

The estuary is situated at the boundary of the intermediate and wet zones of the country and receives rain during both monsoons. Rajapaksha (1997) estimated a total annual rainfall of 1,993–2,040 mm and evaporation of 1,440 mm. The estuary entrance, a narrow inlet, acts as a low-pass filter, which is considerably choked during tidal amplitudes. The estuary's tidal range varies between 0.05 m at neap tide to 0.13 m at spring tide, which is about 30% of the open ocean tide (Rydberg & Wickbom, 1996; Rajapaksha, 1997). The volume of water stored and released varies between 2.5 million m^3 and 7 million m^3 per tide with an average of about 4.5 million m^3 (Samarakoon & van Zon, 1991). The exchange mechanisms maintain the salinity levels, the siltation rates, the pollution transport and the biological productivity within the estuary.

At high freshwater discharge (i.e., at more than 100 m^3s^{-1}), the freshwater input is similar to the tidal flux at the entrance. Thus, freshwater dominates the water exchange during such periods, whereas during low-discharge periods, the tide dominates. Rydberg and Wickbom (1996) estimated the water residence time at between four days at maximum freshwater supply (100 m^3s^{-1}) and two weeks at low freshwater supply and neap tide. Rajapaksha (1997) indicated that a very low mean freshwater supply of 20 m^3s^{-1} results in a residence time of more than 10 days while the highest mean supply of 160 m^3s^{-1} gives about 2 days of residence time. Rajapaksha (1997) also studied the relation between estuary salinity and freshwater supply in detail.

The catchment area of the rivers, namely the Dandugam Oya and Ja Ela rivers, entering Negombo estuary is 775 km^2 (Amarasinghe et al., 1999). The average annual discharge from these rivers is approximately 50 m^3s^{-1} and varies from 10 m^3s^{-1} during the dry season to more than 200 m^3s^{-1} during rainy periods. Rajapaksha (1997) reported a monthly freshwater discharge of 25–225 m^3s^{-1} in 1993, of which 72% was from the Dandugam Oya and 28% from the Ja Ela. The estuary experiences a highly variable freshwater discharge pattern (Rydberg & Wickbom, 1996). Evaporation and evapotranspiration remove about 0.15 km^3 of water annually. The balance flows to the sea, mainly via the sea opening at the north of the estuary as well as through the Hamilton Canal (see Figure 1) which opens to the Kelani River.

The inflow of saline water from the sea is estimated at 1.1 km^3 per year through the sea opening in the north of the estuary with a considerably lower quantity through the Hamilton Canal (Samarakoon & van Zon, 1991). The salinity varies from 5 to 30 g/kg (De Silva & Silva, 1979a; Rydberg & Wickbom, 1996; Rajapaksha, 1997; Arulananthan, 2004; Dahanayaka & Wijeyaratne, 2006). Total nitrogen content in the surface sediments of Negombo estuary varies from 0.03% to 0.22% with an average of 14% (Ratnayake, 1999).

Mangroves and biodiversity

The estuary is surrounded by mangroves and mangrove associates which cover 350 ha (Figure 2). Mangrove forests extend over a narrow intertidal area on the edges of the estuary, at a width not exceeding 100 m (Amarasinghe, 1988). Twenty-three species of plants (true and associates) have been recorded in the area (Dahanayaka & Sumanadasa, 2005; Dahanayaka et al., 2015). Loop-root mangrove (*Rhizophora mucronata*), Rhizophora apiculata, Grey mangrove (*Avicennia marina*), white-flowered black mangrove (*Lumnitzera racemosa*), Milky Mangrove (*Excoecaria agallocha*) are the most widely distributed species (Pinto & Wignarajah, 1980). Seagrasses cover approximately 20% of the total estuary with *Halodule pinifolia* the most dominant of the five major species.

Figure 2. Dense mangrove patches along Negombo estuary.

Photos © D.D.G.L. Dahanayaka.

Negombo estuary is considered one of the most productive brackish water bodies in Sri Lanka. Its narrow opening to the sea, distribution pattern of mangrove vegetation, sea grasses and salinity have resulted in a patchwork of diversified niches leading to high species diversity. A total of 62 species of fish belonging to 36 families were recorded from the fishery by De Silva and Silva (1979b), 62 species belonging to 39 families were recorded in seagrass and mangrove areas by Pinto and Punchihewa (1996), while Wijeyaratne and Perera (1996) recorded 82 species belonging to 41 families from catch data.

The estuary is a nutrient-rich ecosystem, which provides many sheltered places for fish. Many fish species that inhabit the estuary are important as food fish and some are important as aquarium fish (Wijeyaratne & Perera, 1996). Negombo estuary is a habitat where fish live in mixed schools showing low and moderate dietary overlap. Certain amounts of ecological segregation are evident among most of the co-occurring species in the Negombo estuary (Edirisinghe & Wijeyaratne, 1986).

Seventy-six species of invertebrates belonging to 41 families were recorded in the benthic samples of the estuary which included 23 species of polychaetes, 24 species of gastropods, 16 species of bivalves and 13 species of crustaceans (Dahanayaka & Wijeyaratne, 2006).

The fishery

To harvest the estuary's resources, local fishermen employ 34 types of fishing gear, with 7 gear types used for 70% of the resources. This high gear diversity is attributed to the high biodiversity (Jayakody & Dahanayaka, 2005). Of these 34 types of fishing gear, 16 target juvenile penaeid shrimp. A stake seine net fishery, in operation for centuries, targets subadult penaeid shrimp at the mouth of the estuary on their migration from the estuary to the sea (Wimalasena, 2005).

Fishing is the most important economic activity in the estuary. Shrimps, in the penaeid family of large commercial species are the staple income-generating resource of the estuary (Jayakody & Dahanayaka, 2005). According to Atapattu (1987), about 27,000 people lived in nine fishing villages around the estuary, of whom 6,302 are engaged in fishing. A 1991 study (Samarakoon & van Zon, 1991) found the total number of fishermen in Negombo estuary was about 3,000. In 2005, Jayakody and Dahanayaka (2005), reported over 10,000 people directly or indirectly dependent on fishing for their livelihood. The fishing populations are not well recorded except in the dominant stake seine fishery.

Threats and their impacts

Land use changes

The channel segment in the northern region of the estuary is very important for the continuation of estuarine functions through the exchange of water between the sea and the estuary. On the seaward side, the channel bed is sandy, but on the estuary side, the bottom is muddy (CEA & Euroconsult, 1994). During the past few decades, the channel segment has been disturbed due to poor water exchange, illegal land reclamation, ad-hoc mangrove planting, wastewater discharge, and siltation. Further, the channel segment serves as an anchorage for several hundred fiberglass boats with outboard motors and about 300 boats with inboard engines (CEA & Euroconsult, 1994; Dahanayaka et al., 2012). Disposal of waste oil from these boats has resulted in oil pollution of the water and sediments (CEA & Euroconsult, 1994). Since the early 1980s, haphazard expansion of piers and landing points altered the flow patterns and sedimentation in the channel segment. As a result, new sand shoals have formed obstructing fishable and navigable areas. Unauthorized houses have also been built on the intertidal sand shoals in the channel segment causing serious impacts on hydrology. Functional seagrass beds have been smothered by sediments resulting in their rapid depletion (CEA & Euroconsult, 1994).

Changes over two decades

Long-term monitoring by Dahanayaka et al. (2012) of the land-use changes in the channel segment using multi-temporal, multi-satellite data concluded that some parts of the channel segment decreased significantly between 1987 and 2009 (Figure 3) resulting in changes in water circulation which has probably affected the biological productivity through changes of chlorophyll a (Chl-a). Chl-a concentration is an indicator of phytoplankton abundance and biomass in coastal and estuarine waters. Accurate Chl-a data are critical for determining the magnitude and variability of estuarine primary production, the effect of biological processes on carbon dioxide drawdown in surface waters and for improving our understanding of phytoplankton dynamics in lagoons and estuaries. Significant increase in Chl-a especially in stagnant-water areas of the estuary can lead to localized eutrophication. This information will useful to describe and mitigate sudden fish kills that frequently occur in these areas (Dahanayaka et al., 2012).

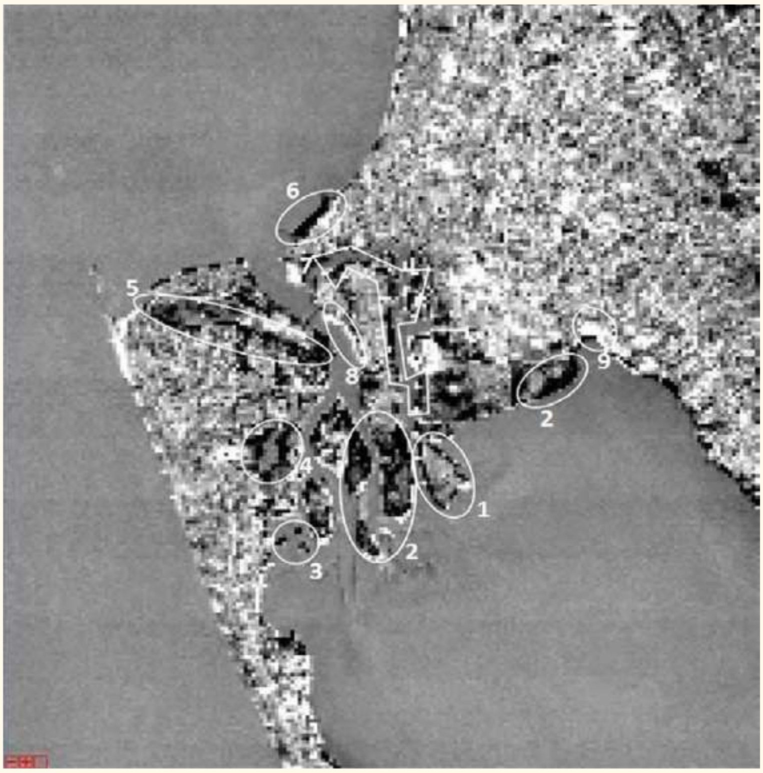

Figure 3 compares a Landsat TM 19 February 1987 image with an ASTER 16 February 2009 image using Multivariate Change Detection Technique.

Maximum change areas are shown as white and black pixels. Grey pixels indicate no change. Significantly changed areas are indicated as circles and the causes given below.

1. **Expansion of the islet area due to mangrove vegetation**
2. **Increased density and area of mangrove vegetation**
3. **Formation of new islets**
4. **Decrease of water area due to increase of land area and vegetation**
5. **Narrowing of outlets and decrease of area of Kuda Ela**
6. **Sand depositions (seasonally change)**
7. **Narrowing of east channel due to increased land area and vegetation**
8. **Soil erosion and vegetation area converted to land**
9. **Vegetation area converted to land**

Figure 3. Two decades of changes of the channel segment of Negombo estuary are shown.

Source: Dahanayaka et al., 2012.

The Muthurajawela marsh and the adjoining Negombo estuary were studied using remote sensing by Rebelo et al. (2009), to detect trends in land uses. In this study, multi-spectral Landsat satellite imageries from 1992 to 2002 have been used to spatially capture changes in the land cover and land use in the wetland and adjacent lands.

The estuary's sedimentation rate is estimated at about 50,000 mt per year, which causes the depth to decrease by about 1.5 mm per year. At the present rate of sedimentation, the filling in time for Negombo estuary exceeds 400 years. The rate of sea level rise compensates for sedimentation and the anticipated sea level rise will ensure existence of the estuary for the next 1,000 years (Samarakoon & van Zon, 1991).

Over 11 years (1981–1992), the extent of true mangroves decreased by about 10% (Samarakoon & van Zon, 1991), causing a loss of about 30 ha of the true mangrove area. Mangroves still occur on the small islands in the northern part of the estuary. Some residents of these

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islands replant mangroves (Samarakoon & van Zon, 1991). People living in and around this area depend on the products and environment of these mangroves. About 1,050 brush piles (*mas athu*) are maintained for fish habitat in the Negombo estuary mostly in the northern area. A brush pile consists of mangrove brushwood placed in shallow water and pegged down with sticks. A single brush pile is maintained in place for a long time. Residents visit the brush piles regularly to collect fish or shrimp by encircling the brush pile with a net fixed to sticks. The twigs in the brush pile are removed manually and the trapped fish or shrimp harvested. Due to limited availability of twigs and branches around the Negombo estuary, brush pile fishing has led to the cultivation of mangroves. At present, there is no scientific information to determine how many hectares of mangroves are required to maintain the estuary function, fishing resources and human needs.

Other threats

The system is under severe stress caused by destructive fishing, encroachment, expanding housing areas, water pollution and social disparity, mainly due to lack of effective management of the resource base by those concerned. Managing the estuary fishery involves regulating the behavior of the fishermen whose activities affect that resource (Jayakody & Dahanayaka, 2005).

Seagrass is decreasing: algae increasing

Anthropogenic activities such as pollutant inputs, sedimentation and conversion of wetlands for other development activities have increased and it resulted in a significant decrease of seagrass bed areas. Seagrass ecosystems in the northern, eastern and western parts of the estuary recorded a significant decrease of 96% within the six-year period 1997–2004. Seagrass growth has been affected by dense algal proliferation caused by high nutrient loading from wastewater discharge from shrimp farms.

Nutrient loading in the water column has fostered the proliferation of macro algal on seagrass beds; this algae blocks needed sunlight to the seagrasses, which may be a cause of seagrass bed decline. Further, some fishing methods, such as encircling nets, push nets and drag nets, threaten the survival of the seagrass communities and also contribute to the distribution of benthic invertebrates. According to Dahanayaka and Wijeyaratne (2006), there is a significant difference in spatial variation and distribution in the macrobenthic community structure due to the resource use patterns, such as use of encircling nets and the disposal of sewage and other wastes in the area.

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Water pollution

Water pollution of the Negombo estuary is a direct result of the following:

- Wastewater and storm water canals entering into the estuary
- Industrial wastewater and domestic sewage entering the estuary through Dandugam Oya and other channels and runoff
- Solid waste carried into the estuary by the Dandugam Oya and other channels and from the periphery of the estuary

Pollutants are mainly nutrients, fecal matter, oil and heavy metals:

Nutrient pollution has contributed to entropic conditions within the estuary. Dahanayaka et al., (2013), who evaluated the chlorophyll trends over two decades using satellite imagery, suggested that the in some parts of the estuary, increased eutrophication between 1987 and 2011 has significantly affected the water quality, the fishery and biodiversity.

Further, excessive nutrients caused proliferation of dense filamentous algae, with *Chaetomorpha* the most dominant. This algae is reducing the amount of sun light that can filter through to seagrass beds, which is one cause attributed to the decline of seagrass beds in the estuary. Increased macro algal blooms 70–100 m away from the shore could reduce the available light to below the minimum required for seagrass survival. Research has revealed that this taxonomic group of algae is a significant factor for light interception (Pahalawattaarachchi & Bjork, 2004) and the algae mats cover 80% of the surface of the seagrass area. The percentage of light penetrating this 42cm deep macro algal canopy was reduced by 96%.

Oil pollution of the water and sediments resulted from the disposal of waste oil from boats at anchorage in the channel segment of the estuary (CEA & Euroconsult, 1994).

Fecal pollution in the estuary and its neighborhood leads to water-related diseases and poor hygienic conditions. It occurs mainly due to low-income settlements near the estuary mouth as well as freshwater inputs such as the Dandugam Oya and Ja Ela rivers and Hamilton Canal (Joseph, 2011). Figures 4 and 5 show human and animal fecal matter being discharged directly into the estuary.

Heavy metal levels of the estuarine water were studied by Chandrasekara et al. (2014) and Sivanantha et al. (2016). Findings revealed that relatively large amounts of heavy metal concentrations indicate lagoon pollution and are probably linked to anthropogenic activities.

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Figure 4. Pipes discharge faecal material directly into the estuary.

Photos © D.D.G.L. Dahanayaka.

Figure 5. Poultry and pig farm waste outlets to the estuary.

Photos © D.D.G.L. Dahanayaka.

During high tides, solid wastes from the back yards of residents are brought to the estuary with the tidal flows and deposited in mangroves creating severe environmental problems. Unauthorized development, land reclamation and unplanned solid waste dumping into the estuary reservation were identified as the main causes of pollution (Figure 6).

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Figure 6. Unauthorized waste dumping site at the catchment area of Negombo estuary.

Photo © D.D.G.L. Dahanayaka.

Estuary management plans

Negombo estuary is close to the greater Colombo urban area and adjacent to the Negombo municipal area, thus it has been subjected to severe environmental and social stresses due to development activities over the past three decades (Dahanayaka et al., 2015). The importance of conserving the Negombo estuary and the Muthurajawela marsh gained momentum in the late 1980s. Accordingly, in 1991, the Greater Colombo Economic Commission prepared a Master Plan for Muthurajawela marsh and the Negombo estuary.

The major environmental issues in the Negombo estuary environment are degradation of mangrove habitats and seagrass beds, surface water pollution by domestic and industrial wastes, and illegal fishing methods. However, the issues are becoming more complex. Poor water circulation within the estuary is causing health issues and a decline in the daily income of the communities in surrounding areas. Several factors contribute to the degradation of this coastal wetland system.

Several extensive studies in Negombo estuary have brought out the environmental and fisheries related issues in the recent past (Dahanayaka et al., 2012). Major studies were initiated during preparation of the Master Plan for Muthurajawela marsh and the Negombo estuary and a profile under the Greater Colombo Economic Commission in 1991.

Conservation and management plans for Muthurajawela marsh and the Negombo estuary were prepared by a wetlands project under the Central Environmental Authority and Euroconsult in 1994. The Special Area Management (SAM) concept for Negombo estuary was introduced by the Coast Conservation Department (CCD) in 1997 under its SAM program. It includes key focus areas such as ecosystem management, fishery management, pollution control and waste management, community development and institutional strengthening. A Community Coordinating Committee (CCC) was established to coordinate the implementation of the SAM Plan for Negombo estuary. The SAM plan sought integrated management of the ecosystem, including fishery management, pollution control and waste management, community development and improved socio-economic conditions and strengthened institutional capabilities and mechanisms.

An evaluation found that the SAM process has taken too long (over two decades during which several policy changes occurred), programmes were project and development oriented rather than participatory and focused on co-management, the CCC was dominated by state actors, lead agency participation was inadequate, political involvement was very high and the major issues of the area have been neglected (Joseph, 2011; DFAR, 2012).

The conservation and management plans have focused on resolving these environmental and social issues:

- Pollution including nutrient, oil and fecal sources
- Habitat degradation from various activities including destruction of seagrass beds and mangroves
- Poor water circulation within the estuary and sedimentation
- Encroachments into the estuary
- Eutrophication
- Loss of fishing areas
- Ad-hoc mangrove plantations
- Institutional issues including lack of coordination, lack of boundary demarcation, and no implementation of regulations and laws
- Social problems including insufficient land, land ownership issues, loss of traditional estuary access, continuous spreading of various diseases

Fisheries management plans

Fishing has been one of the most important economic activities in the coastal areas around Negombo for generations (Figures 7 and 8). The fishing pressure, particularly in the coastal waters, is still increasing and the coastal resources are believed to be exploited beyond their sustainable levels. Apart from the overexploitation, environmental degradation has significantly contributed to the depletion of estuarine and coastal fisheries resources.

Successful co-management

The best example for a successful fisheries management in Sri Lanka is the stake seine net fishery conducted in the Negombo estuary. A stake seine net is a cone-shaped net having four components: two wings, a mouth and mouth opening, the body of the net and the cod end. It is set close to the estuary mouth with the onset of the low tide so that fish and crustaceans moving with the tide from the lagoon to the sea are caught in the net. It is especially effective in estuaries with bottle-neck type openings where most of the fish are funneled through a narrow passage where fast water currents move them into the net.

Amarasinghe et al. (1997) reported on this centuries-old community-based fisheries management (co-management) system, where three communities of fishers share fishing days and members of each community share fishing sites using a lottery system. However, community laws do not remain static and often come under the pressures of modernization. Market expansion and technological change could have serious impacts on community laws, while causing heavy pressure on fish resources (Amarasinghe et al., 1997). State intervention in fisheries management coincides with evidence of overexploitation and degradation of resources. State rules (which are generally "written" laws) mostly aim at resource conservation to achieve sustainability. But they are formulated without much concern for human development needs. One exception is in the stake seine fishery of Negombo estuary, where the traditional co-management system has been reinforced by the regulations published in Gazette No. 11, 579 of 7 November 1958. These regulations are called the Stake Seine Net Fishing Regulations of 1958. Unfortunately, only a few such success stories are reported from the Negombo estuary and the associated coastal waters.

The stake seine net fishing system involves self-regulation of the use of fishing gear on a rotational basis. Each of the 300 fishermen gets an opportunity to fish in the estuary once every six days. In practice, they usually form groups of two per craft thus each can fish once every three days subject to sharing the catch. However, because there has been an increase in the number of fishers eligible for this category over the past few years, many have been compelled to fish on a part-time basis as the competition has grown.

Observing this self-management system can help government managers design more effective management plans for the estuary as a whole. Co-management in fisheries allows fishers to fully participate in a shared decision-making process with fishery agencies for the sustainable management of fisheries resources. It focuses on establishing and empowering local institutions with minor support from the government. It also involves establishing partnerships between government and the local community and resource users. Co-management brings together relevant levels of government and the users in pursuing a common set of goals to improve resources conditions and socio-economic conditions of the community. It allows the community to develop a management strategy with a high probability of meeting local needs and conditions. It is more legitimate in their eyes because the community members understand their problems, needs and opportunities better than outsiders do. In integrating environmental conservation into fisheries management, there is a need to bring other stakeholder agencies mandated with natural resources management and environment conservation into the co-management process and partnerships.

Figure 7. Brush park fishery activities of Negombo estuary.

Photos © D.D.G.L. Dahanayaka.

Figure 8. Cast-net fishing in the estuary.

Photo © D.D.G.L. Dahanayaka.

Fisheries legislation, institutional settings and management practices

The Minister of Fisheries and Aquatic Resources Development declared the Negombo segment of the master plan as the Negombo Estuary Fishery Management Area (see Gazette No. 947/13 of 31 October 1998, which is based on the Cabinet decision, taken on 20 October 1995 with the result of the implementation of the Master Plan of Muthurajawela and Negombo estuary).

The Negombo Estuary Fisheries Management Authority (NLMA) was established in 1999 with selected members of the following ten fisheries committees (according to regulations Gazette 14 March 1997):

- Kattu del (Stake seine) Committee – Wella Weediya, Maha Weediya, Duwa, Pitipana Weediya
- City II Committee – Kurana, KadolKale, Thaladuwa
- City III Committee – Mankuliya, Munnakkaraya, Siriwardena Place
- Pitipana North, Meda Pitipana Committee

- Pitipana South Committee
- Aluthkuruwa, Basiyawatta, Thalahena Committee
- Dungalpitiya, Kepungoda, Settapaduwa Committee
- Dandugama, Tudella, Wewala, KalaEliya, Delathura, Leenuswella Committee
- Keendigoda, Ambalanmulla, Liyanagemulla, Katunayake, Kurana-Katunayake Committee
- Serakkuwa, Elenegoda, Bopitiya, Pamunugama Committee

According to the 1996 Fisheries and Aquatic Resources Act No. 2, a Fishery Management Authority may make recommendations to the minister on:

- the conduct of fishing operations and the use of different types of fishing gear in that fisheries management area,
- the establishment of closed seasons for fishing or closed seasons for the taking of specified species of fish in the fisheries management area, and
- the times during which fish may be taken.

It is imperative to seek scientific and technical advice for regulatory provisions through government agencies such as the National Aquatic Resources Research and Development Agency (NARA) and the Department of Fisheries and Aquatic Resources for which additional clauses in the revised bill need to be introduced. It is also important to consider revising the composition of the Fisheries Management Authority to include relevant representatives of these government agencies to strengthen their input to decision making and to enhance their legal recognition.

Local fisheries committees

The membership of the NLMA has been restricted to nominees from the ten fisheries committees covering specific areas within Negombo Estuary Fisheries Management Area who are registered fishermen in the area and those engaged in migratory fishing activities. A fisheries committee can by formed with a minimum of 10% of the fishermen in a given area.

The objectives of the fisheries committees are as follows:

- actively contribute to the resource management, conservation and development of resources,
- commit to the development of socio-economic status and cultural values among the membership,
- protect the fishing rights among the members.

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The functions of the fisheries committees include:

- formulating a fisheries program for its area and implementing that program,
- assisting its members to obtain boats, gear and equipment to be used in fishing operations, and
- engaging in any other activities as may be approved by the Director General which are beneficial to the fishing community of the area.

The ten fisheries committees established for Negombo estuary, covering 33 fishing villages, must prepare individual fisheries program that are compatible with other resource users and should have combined program to avoid conflicts under the direction of the NLMA.

At present, there is a conflict between the Stake Seine Net Fisheries Committee and other fishermen who are competing for the same resources using other types of fishing gear that had reduced the catch rates of the stake seine net fishers. No solution has been found as yet (see “Successful co-management” above).

Members of the fisheries committees as well as the NLMA could be a valuable informant group to support regulatory actions by the relevant government agencies: Department of Fisheries and Aquatic Resources (DFAR), CCD, Central Environmental Authority (CEA), Urban Development Authority (UDA) and Negombo Municipal Council (NMC).

As many of the activities required for co-management of Negombo estuary resources have been identified in the SAM plan, it is important to strengthen the process of implementation of the plan using the resources to be provided.

The Muthurajawela Wetland Sanctuary

The Muthurajawela Wetland Sanctuary (declared by a 1996 Gazette notification No. 947/13 dated 31.10.1996 issued under the FFPO as amended), covers 1,285 ha in the northern portion of the Muthurajawela wetland. It is a cradle of biodiversity, housing several endemic and nationally threatened species, and provides an important area for migratory birds, in addition to offering a number of ecological and hydrological services. However, owing to its location as a ‘conservation island’ in the midst of intense urban and industrial development, the sanctuary is an extremely vulnerable ecosystem.

In response to a decision made by the Muthurajawela Management Committee in 1999, a subcommittee for Negombo estuary management was formed in January 2000 under the Chairmanship of the Director General of The Department of Fisheries and. Aquatic Resources (DFAR) with the following membership:

- Director, Department of Wildlife and Conservation (DWLC)
- Conservator, Forest Department (FD)
- Director, Coast Conservation Department (CCD)
- Chairman, Ceylon Fishery Harbours Corporation (CFHC)
- Chairman, Sri Lanka Land Reclamation and Development Authority (SLRDC)
- Chairman, Central Environmental Authority (CEA)
- Divisional Secretaries, Negombo, Katana, Ja ela and Wattala
- Commissioner, Negombo Municipal Council (NMC)
- Chairman, Negombo estuary Management Authority (NLMA)

Its management options and proposed activities are to:

- Increase awareness among the general public, identify existing gaps and give strong solutions targeting sustainable use and conservation.
- Establish alternative livelihood development mechanisms among surrounding communities.
- Improve the water circulation and drainage systems and identification of pollution sources.
- Empower a committee for Negombo estuary management to long-term conservation of the estuarine system in collaboration with all stakeholder institutes and implementation of the existing laws, regulations and rules.
- Demarcate the boundaries of the estuary and establish a buffer zone and conservation areas that will lead to reduction of encroachment and filling of land.
- Conduct the necessary research and identify and prepare zoning systems within the estuary such as boat anchorage and fish landing sites, breeding sites for fish and other faunal groups, sites to develop ecotourism activities, areas for the development activities and conservation.
- Establish a regular monitoring system for water quality, biodiversity of estuarine system and empower NARA's Kadolkele Regional Research Centre as an educational and recreational center within the system.
- Recommend appropriate fishing gear and prevent the use of destructive fishing gear.
- Strengthen existing community-based fishery management systems of the estuary.

Research needs

Negombo estuary is one of the most studied estuarine systems in Sri Lanka. Its resources and uses, dynamics and ecology have been studied over the past century. These studies, conducted by research institutes, universities, International and domestic non-governmental organizations focused on the physicochemical parameters of water quality, pollution, hydrodynamic modelling, primary productivity, biodiversity, distribution of fauna and flora, distribution and abundance of sensitive habitats such as mangroves, seagrass beds, fishery biology and ecology of both estuary and adjacent coastal waters. Special emphasis has been given to the studies of recruitment patterns of prawns because both estuary and sea components are vital in the life cycle of penaeid prawns. Socio-economics studies have focused on both resources and user conflicts.

However, the studies are discrete, isolated and usually limited to the estuary only. Thus, they have two deficiencies:

- *Lack of multidisciplinary and an integrated approach*. Conducted at different point in time, the studies focused on one or another component of the ecosystem, thus do not provide insight into the inter¬relation between the different components of the ecosystem.
- *Lack of holistic ecosystem approach*. The studies focused on a part of the ecosystem only, usually limited to either estuary or coastal waters. Thus, they are not sufficient to assess and evaluate the influence of inter linked ecosystems on the estuary.

According to Dahanayaka and Wijeyaratne (2006) most of the macrobenthos species of the estuary have been identified only to the family level. Therefore, there may be unidentified species. Some species were recorded only at one sample site throughout the entire study. Therefore, these rare species may be threatened with extinction due to local pollution. Taxonomic identification of benthic fauna is important to study their biology. One of the major constraints faced by those studies was the lack of reliable taxonomic keys for species identification. Therefore, preparation of a taxonomic guide for the benthic fauna is important.

This case study makes a valiant attempt to synchronise the studies conducted at different times to address a single issue or discipline to evolve an understanding on the interactions of the ecosystem components. Still it fails to include the other vital components of the ecosystem, such as the river catchments, the Muthurajawela wetlands and the open sea, in its scope.

The following aspects have either not been studied or the studies are limited. Thus, it is recommended that the future research focus on them:

- Geomorphological changes of the estuary ecosystem due to siltation
- Coastal sediment dynamics and its impact on the ecosystem
- Impact of near-shore development such as sand extraction on the estuary ecosystem
- Impact of sea-level changes and climate change on the estuarine system

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S3

CHAPTER

2

The Guadiana River lower estuary

Is nature protection working well?

By

Noa Sainz-López
Universidad de Cádiz,
Campus de Puerto Real,
Polígono San Pedro
Cádiz, Spain

Centro de Investigação
Marinha e Ambiental,
Universidade do Algarve
Portugal

Abstract

The Guadiana River estuary is a natural border between Spain and Portugal. Both sides of the river mouth are protected under national and international nature protection laws, but its situation is not ideal. The over-damming of the river has increased the estuary's salinity, but the artisanal salt harvesting that would profit local people has been abandoned. Saltworks abandonment has led to loss of bird diversity, degradation of the cultural landscape and waterscape and a decrease in work opportunities. Urbanization, which increased during the late 20th century and early 21st century, has stopped due to economic crises in both countries which has led to high rates of unemployment. Currently, beach tourism is an important source of income, but diversification is needed, especially towards the nature protection areas. Some Guadiana estuary ecosystem services are endangered and protected sites do not seem to be the only solution.

Keywords:

Transboundary ecosystem services | coastal protected area | traditional saltworks | Guadiana River estuary

Introduction

The Guadiana River flows into the Gulf of Cádiz forming the Southern Spanish-Portuguese border. Tourism represents one of the most important activities in the river mouth, in the towns of both sides of the river: Vila Real de Santo Antonio (Portugal), and Ayamonte (Spain).

Within the Guadiana River estuary, several sites are designated nationally and internationally for their populations of waterfowl and other wildlife. However, the estuary is still under several threats and pressures, such as the multiple dams along the river length and the urbanization causing habitat loss. A possible solution to the estuary degradation may lie in the sustainable management of the revitalization of old artisan saltworks that will make the area more economically stable without harm to the environment.

Climatological, hydrological and geomorphological description

The Guadiana River estuary, a natural border between Portugal and Spain in southwestern Europe, is approximately 70 km long and discharges into the Atlantic Ocean west of the Strait of Gibraltar (Figure 1). Its basin is in the Mediterranean climate zone, experiencing very dry summer months and with 80% of the precipitation occurring during autumn and winter with a mean annual rainfall of 400–600 mm (Chícharo et al., 2001; Morais, 2008). The natural river flow is highly variable on interseasonal and interannual scales due to the North Atlantic Oscillation. The annual average air temperature varies from 14 to 18 °C. Tidal amplitudes in the estuary range from 1.3 to 3.5 m and it is considered a mesotidal estuary (Morais, 2008). The estuary is in the terminal stage of sediment infilling of the paleo valley which was incised down to an 80 m depth during the glacial low stands; tidal currents carry material back into the channels´ system, contributing to progressive shoaling. To preserve wetland habitats, water circulation is enhanced through occasional dredging (Boski et al., 2008).

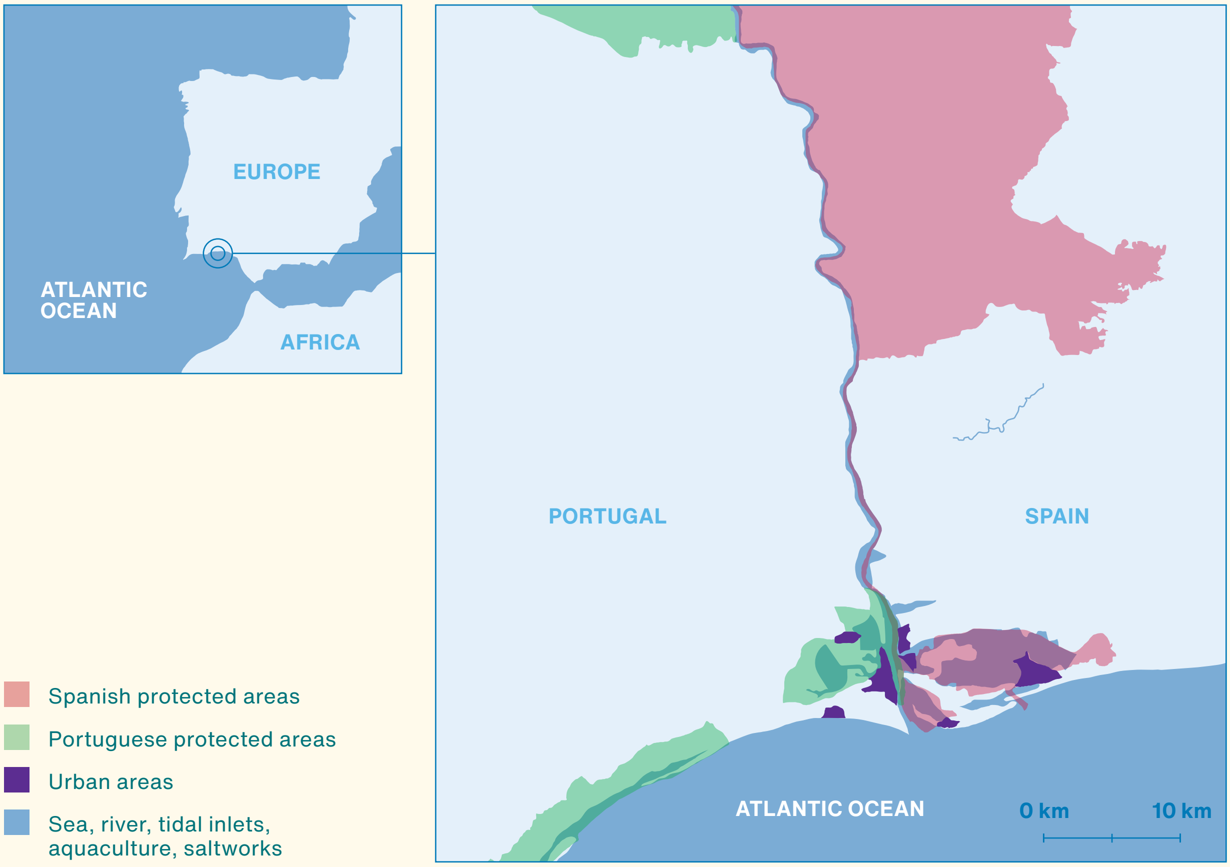

Figure 1. Guadiana River estuary: Location and protected and urban areas.

Source: Noa Sainz-López

Main biotic components

The extensive salt marshes, which developed on the accreted sediments of the estuary, are covered by halophytic plants: dense-flowered cordgrass (*Spartina densiflora*), small cordgrass (*Spartina maritima*), saltbush (*Atriplex spp.*) and glassworts (*Salicornia patula*) (Boski et al., 2008).

On the Portuguese side of the lower estuary, according to the European Environmental Agency (EEA) (2016a), species classified as 'vulnerable' in the IUCN Red List of Threatened Species™ are the fish *Tropidophoxinellus alburnoides* and the following birds: oystercatcher (*Haematopus ostralegus*), black-tailed godwit (*Limosa limosa*), curlew (*Numenius arquata*), kingfisher (*Alcedo atthis*), lapwing (*Vanellus vanellus*), little bustard (*Tetrax tetrax*), curlew sandpiper (*Calidris ferruginea*), and pochard (*Aythya farina*). On the Spanish side, species classified as vulnerable in the IUCN Red List are the same although the bird pochard and the fish *Tropidophoxinellus alburnoides* are not present (EEA, 2016a).

Stakeholders

Guadiana river mouth wetland is a natural border between Spain and Portugal. The main traditional landscapes on both sides of the river are saltworks and fruit tree plantations, although on the Spanish side urbanization and transformation of saltworks into aquaculture are more pronounced (Figure 2). Hence, a mix of stakeholders (decisionmakers, technicians, scientists, and local citizens) should be involved in the management and development of a shared view of opportunities, problems, pressures, and impacts characterizing the river basin.
As an example, a consultation for water planning and management which took place in the area included the national water authority, the protected areas authorities, local municipalities, regional development associations, environmental associations, producers' associations, research institutes, tourism developers, and the regional directorates for the environment, agriculture, and economics (Videira et al., 2009).

Figure 2. Guadiana River estuary general perspective.

Aerial photograph © CIMA – Centre for Marine and Environmental Research, 1996.

Status of the wetlands

A Portuguese nature reserve of 2,312 ha was declared in 1975 (Dec. Nº162/75), belonging to two municipalities: Castro Marim and Vila Real de Santo Antonio. Moreover, 2,111 ha of Castro Marim Municipality and 1,309 ha of Vila Real de Santo Antonio Municipality are part of Natura 2000, an ecological network for the conservation of wild animals and plant species and natural habitats of community importance within the European Union (EU) where sites are classified under the EU Habitats Directive and Birds Directive. Since 1996, 2,235 ha have been included in the Convention on Wetlands of International Importance (Ramsar, 1971).

On the eastern side of the river mouth, since 1989, 2,145 ha of wetlands have been designated as the Nature Site of Isla Cristina Wetlands (*Paraje Natural de las Marismas de Isla Cristina*, as the conservation category is expressed in Spanish, a regional protection category). Application of the EU Habitats Directive and Birds Directive gave 2,498 ha of this wetland the status of Special Protection Area in 2002 and Site of Community Importance in 2006 (Aranda& Otero, 2014; EEA, 2016a).

Threats and pressures

The whole estuary is under similar threats and pressures. **Excess damming** can be considered a threat to the ecosystem and its stakeholders. The closure of the Alqueva dam in 2002, 60 km from the estuary head and with a 4,150 hm^3 storage capacity (Garel et al., 2009), has diminished the river inflow. The resulting freshwater deficit in the Guadiana estuary has resulted in increased salinities which reduced the amount of habitat available to freshwater species, affecting the fish assemblages in the estuary (Chícharo et al., 2006). However, salinization can help the recovery of abandoned saltworks. More salt deposition means less time will be required for salt harvesting (Sainz & Boski, 2015). The former, would create jobs and preserve biodiversity because artisanal salt production is one of the few economic activities permitted in the lower estuary and it illustrates a sustainable use of resources, diversifying natural habitats for birds and other species of flora and fauna (Sainz & Boski, 2017).

River discharge is critical for sustaining saltmarsh habitats in the estuary because fine-grained sediment is mainly derived from fluvial sources (Sampath et al., 2016). The salt marshes will also experience the effects of **climate change** and flooding risks because they are highly vulnerable to both lack of sediment supply and sea-level rise (Sampath et al., 2011). The Spanish margin will suffer more due to the construction of jetties at the mouth of the Guadiana River, which have interrupted the dominant eastward-directed longshore drift (Sampath et al., 2015). Both sides are under pressure due to urbanization, intensive tourism and agriculture (Ménanteau et al., 2006) (Figure 3). They have experienced **land speculation** for development, such tourism infrastructure, especially on the Spanish side (i.e., golf courses), although due to the 2008 financial crisis, development stopped abruptly, together with employment.

Figure 3. View of urbanisation, salt ponds, and agriculture in the Castro Marim and Vila Real de Santo Antonio Saltmarshes Nature Reserve, Castro Marim Municipality, Portugal.

Photo © Noa Sainz-López.

Invasive species: The threat of alien species proliferation is represented by the presence of the invasive exotic species dense-flowered cordgrass in the western margins of the river, reported by the Portuguese non-governmental organization (NGO) Quercus in 2014. It occupies poorly drained soils or disturbed biotopes where changes in drainage conditions or patterns of sediment accumulation have occurred (ICNB, 2018).

Aquaculture: The single fish aquaculture company in the Portuguese nature reserve carries out semi-intensive activity in former saltworks, occupying 32 ha. The Spanish marshland experienced a quick transformation into aquaculture ponds in the 1980s before the area acquired a protection category. In 1991, aquaculture occupied 700 ha of marshland, which modified microtopography, hydrologic regime, biodiversity and represented a pollution risk to the nearby saltworks and its users (Ménanteau et al., 2006).

Other threats: Other activities with medium and high impact are diffuse pollution to surface waters due to treated and untreated household sewage and wastewaters (Guimarães et al., 2012; SNIRH, 2018); and, natural system modifications, such as tidal and marine currents with dykes and embankments. In the Portuguese protected area there are conflicts originating from trapping, poisoning, poaching of terrestrial animals and illegal removal of marine fauna; and interspecific faunal relations due to the presence of domestic animals (EEA, 2016a; EEA, 2016b).

Conflicts

Management conflicts arise in both countries because different government agencies represent different sectors (water, agriculture, tourism, urban, fishing and industry) and levels of government: local (e.g. Castro Marim Municipality in charge of urban planning); regional (e.g., Algarve Regional Coordination and Development Commission (CCDR-Alg), engaged in land management and development); national (e.g., Portuguese Institute for Nature Conservation and Forests, involved in nature conservation); and, international (e.g., Andalucía-Algarve-Alentejo Euroregion to promote cross-border cooperation). Nevertheless, both countries are Member States of the EU and they must comply with the same basic environmental legislation, such as the Natura 2000 directives on habitats and birds. Moreover, both countries have a Guadiana River Basin Management Plan, which is mandatory in the EU Water Framework Directive, which aims for the protection of inland surface waters, transitional waters, coastal water, and groundwater. Regarding coastal waters, the European Marine Strategy Framework Directive requires EU Member States to take the necessary measures to achieve a good coastal and oceanic environmental status by 2020, and the Maritime Spatial Planning (MSP) Directive requires both countries to establish maritime spatial plans by 2021. The previous might mean even more intricate management for Guadiana River estuary, although one of the benefits of MSP should be to increase cross-border cooperation to develop coherent networks of protected areas.

Management plans

The following management plans exist in the Spanish margin: Wetland Inventory of Andalusia - Decree 98/2004 of 9 March (*Inventário de Humedales de Andalucía*); and, the Master Plan of Use and Management, and the Plan for Natural Resources to comply with the Law of Natural Heritage and Biodiversity (42/2007 of 13 December). In the Portuguese margin, the National Ecologic Reserve of Castro Marim was approved in 2015 (under the Law Decreto-Ley nº 93/90), it is a public utility constraint that determines the occupation, use and transformation of land uses and activities consistent with the goal of protecting areas with ecological value and/or exposed sensitivity and susceptibility to natural hazards. Both countries have plans for the urban areas in the nature protected sites, as well as national legislation related to the coastal area. Among these regulations, some prevail over the others and this can lead to overlapping; the former generates conflicts between local, regional and central administrations increasing the technical, legal and administrative complexity.

Stakeholders

The main stakeholders are artisanal and industrial salt makers, fishers, farmers and the tourism companies. Some view the Portuguese nature reserve as a limitation on economic activities and development (Videira et al., 2009) but the reserve draws nature tourism and should be promoted by local government, the nature reserve management institution and local enterprises (Guimarães et al., 2014). In 2015, tourist activities related to salt making started in the nature reserve, including a health-treatment tourist spa using the traditional saltworks (Sainz-López, 2017). Moreover, artisanal salt makers have recently focused production on *Fleur de sel* (or ‘Flower of salt’) which is produced by a process that involves collecting the thin layer of salt at the surface of shallow pools of brine. *Fleur de sel* is a profitable commodity that is driving the rehabilitation of abandoned saltworks.

Goods and services affected or disturbed by impacts and expected problems and conflicts

The main environmental goods and services of the Guadiana River lower estuary are listed in Table 1 along with a rating of their disturbances and problems.

Table 1. Goods and services of the Guadiana River estuary, grade of disturbance, and conflicts.

GOODS AND SERVICES	GRADE OF DISTURBANCE (1: low | 2: medium | 3: high)	PROBLEMS AND CONFLICT
EMPLOYMENT	2	Unemployment and youth
RECREATION OR TOURIST INDUSTRY: BIRDWATCHING AND BATHING WATERS	2	Loss of habitats and bad water quality
TRADITIONAL LANDSCAPE	2	Cultural geo-heritage and identity degradation/loss
WATER QUALITY	2	Salinisation, other pollution
FLOOD REGULATION	3	Less sediments, estuary less resilient to climate change
RESEARCH OR EDUCATION	1	None
CARBON SEQUESTRATION	2	Capacity loss
FISHERIES AND AGRICULTURE	3	Bad water quality

Note: Goods and services are related to the grade of disturbance created by the main impacts and the problems and conflicts caused.

Source: data compiled by the author.

The services shown in Table 1 can also be arranged by the Common International Classification of Ecosystem Services (CICES) (Haines-Young & Potschin, 2018):

- *Provisioning services*, include raw material as halite, fishing, and genetic resources;
- *Regulating services*, comprise air purification, regulation of water flow and ecosystem resilience (birds and fish habitats); and
- *Cultural services*, cover recreation and leisure (e.g., birdwatching), aesthetic and inspiration for art and design (e.g., saltscape), information for cognitive development (e.g., education, research), and cultural heritage.

The ecosystem services are interlinked. For instance, employment growth can be promoted by good environmental quality. Improved coastal water quality can improve recreational and commercial fishing conditions and increase possibilities for nautical activities such as sailing, rowing, canoeing (Guimarães et al., 2011). Water quality improvement can increase tourism and ultimately attract investments (Guimarães et al., 2012).

Services and its disturbances are also interlinked. For example, construction or expansion of aquaculture, urban areas, or golf courses can put the achievement of nature conservation goals at risk; but unemployment can lead to local population decline (Videira et al., 2009). Another example is how salinization and flood regulation can help the recovery and preservation of traditional saltworks. As mentioned earlier, improvements in salt harvesting would help biodiversity conservation, create jobs, preserve the traditional landscape, and even allow research on new commercial products, such as *Fleur de sel* (Sainz & Boski, 2019).

Therefore, a multidisciplinary approach should be adopted to mitigate the consequences of the ecosystem services degradation of the Guadiana River estuary.

Recommended solutions and tools for an effective recovery

As Morais (2008) stated, the creation of a Portuguese–Spanish Basin Management Council for the lower Guadiana is essential to produce ecological and sustainable management decisions. This council should involve people interested in the sustainable development of the Guadiana, such as local residents and civil society organizations, private stakeholders (dam managers, tourism entrepreneurs, farmers, and fishers), non-governmental organizations (NGOs), academia, and local, regional and national authorities. They should engage in dialogue and an exchange of best practices, including from third countries, with the goals of enhancing sectoral and cross-sectoral cooperation and promotion of culture and public use of the area.

Conservation can be attained by reconnecting socio-economic development to a sustainable use of natural resources and by promoting the traditional practices of the local natural resources. The former could entail the revitalization of traditional solar saltworks which are a fundamental part of these coastal territories and whose modern exploitation could increase the competitiveness of the region, as shown by Sainz-López (2017) in an economic study of this artisanal activity specializing in *Fleur de sel* production in the Portuguese nature reserve. The promotion of sustainable development using renewable energy, such as solar and wind energy for salt production, can also be enhanced with respect to other sectors based within the natural protected areas.

At the same time, research and innovation should be promoted to look for other sustainable socioeconomic practices (e.g. commercializing salt production by-products), and tourism should be planned more strategically (i.e. diversification, infrastructure improvement, seasonality).

A property tax policy would assure that rising property taxes do not force conversion of the ponds and other wetlands to urban development.

It is crucial to maintain the conservation of the hydrological system and water quality of the Guadiana River estuary and its ecology. The current conservation status of the protected areas should be defined and administrative burdens should be avoided either by harmonization among administrations or by improving collaboration and integration of disciplines.

The 2012 Limassol Declaration is a Marine and Maritime Agenda for growth and jobs which is set to be a milestone for future development of the EU Integrated Maritime Policy. It suggests two specific measures that could be undertaken in the estuary:

Implement suitable management, prevention and adaptation practices to enhance the resilience of the protected areas and the activities carried out in them to the impacts of climate change. For example, simulating *Fleur de sel* production in traditional solar salt ponds as proposed by Sainz-López et al. (2019) has shown significant potential as a novel management approach for making better-informed decisions (such as exact dates or times for harvest) based on accurate forecasts, and for evaluating different climate change or land-use planning scenarios.

Improve planning transparency for investments and a balanced approach between relevant sectors and stakeholders to ensure coherence with environmental and socio-economic objectives.
For instance, a study like the one carried out by Teixeira et al. (2018) identifying priority areas for aquaculture in saltscapes to manage space competition could be developed in the Guadiana River estuary.

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S3

CHAPTER

3

Heiligensee and Hütelmoor

A threatened coastal peatland in transition

By

Katharina Romoth
Leibniz Institute for Baltic Sea Research Warnemünde, Biological Oceanography

Lennart Gosch
University of Rostock, Soil Physics and Resources Conservation

Hanna Schade
University of Rostock, Biosciences

Iris Schaub
University of Rostock, Biosciences

Manon Janssen
University of Rostock, Soil Physics and Resources Conservation

Gerald Jurasinski
University of Rostock, Landscape Ecology

Hendrik Schubert
University of Rostock, Biosciences

Abstract

The nature reserve 'Heiligensee and Hütelmoor', located on the German Baltic Sea coast, protects a peatland complex including coastal fens and a peat bog. It is a part of a national biodiversity hotspot area and protected by a number of regulations. In the past, the area has undergone drastic changes, caused by natural processes as well as by anthropogenic impacts. Sea level rise in combination with flooding events caused a continuous reduction of the fen area. As a result, part of the fen became overlain by beach and dune systems, while the sea-exposed peat is today providing a unique kind of hard substrate for macrophyte growth. Irrespective of its protection status, the fen was drained for use as a grassland in the 1970s, which impacted its hydrology and the species composition. The loss of threatened species, as well as political changes, initiated restoration measures, including rewetting the area. These measures, in turn, induced another series of changes, which are discussed in this chapter in the context of the societal demands for ecosystem services provided by this wetland. Returning the area to its natural cycles may actually reduce the amount of some productive habitats.

Keywords:

peatland | rewetting | seawater intrusions | redynamization | nature protection | coastal management

Introduction

Heiligensee and Hütelmoor is a large nature reserve located on the German Baltic Sea coast with a peatland complex including coastal fens and a peat bog. It is a part of a national biodiversity hotspot area and protected by a number of regulations. Drained and used as grazing land first in the 19th century and more intensively in the 1970s, the area is now being managed to return it to its original pattern of being occasionally flooded by the sea. Although this may reduce biodiversity, it is seen as a pilot project to study the original processes of the ecosystem.

Site description

The coastal peatland in the nature reserve 'Heiligensee and Hütelmoor' consists of different fen areas, Lake Heiligensee and a small peat bog called the Hütelmoor. Because many locals refer to the entire area as the Hütelmoor, we will do so here. The area is located at the southern stretch of the German Baltic Sea coast (N 54°12', E 12°10'), an area characterised by a pattern of active cliffs feeding sand deposition areas between them (Figure 1). The area was ice-covered during the last glaciation, which shaped the landscape by depositing massive till layers on top of the Eocene sediments.

The peatland started to develop around 7000 BP (Kreuzburg et al., 2018), when a rising sea level caused a back-up of the landside groundwater. From a hydrological perspective, the fen in the nature reserve represents a coastal paludification fen (Hahn et al., 2015), that is, the previously dry surface turned wet, allowing peat accumulation. The sand layers between the peat horizons could have been deposited during periods of saltwater flooding due to isostatic land subsidence and eustatic water level rise, frequently interrupting the development of the fen (Ikels, 2011) or they could have been caused by anthropogenic activities.

The Hütelmoor is managed by the city of Rostock, a university town that owns about 95% of the reserve area. The 'Forstamt Rostock' (authority of forest management) – responsible for all the forests owned by the City – manages all maintenance and is responsible for planning and controlling the strategic development of the nature reserve. As there is no annual budgeting, financing as well as personnel deployment is carried out on actual demand.

The nature reserve covers about 490 ha (UMV, 2003). In addition to the peatland complex, it consists of a beach and a large area of surrounding forest (see Figure 1). The surface catchment comprises an area of about 900 ha, mainly consisting of woodland. However, water from the catchment area reaches the fen only at extreme water levels as a result of hydrological regulation measures (Miegel et al., 2016). The Hütelmoor area is streaked with draining ditches. The main ditch, Prahmgraben, crosses the fen in the middle and drains into the estuary of the river Warnow. Seawater intrusion via this outflow has been recorded repeatedly (Bohne & Bohne, 2008), most recently after a flood in the autumn of 2016. The Hütelmoor is almost at sea level, with topographic elevations ranging between -0.4 m in the central part to 1 m above mean sea level in the bog part.

Today, an artificial dune dyke protects the area from being flooded by the Baltic Sea. In case of a flood, this dune may break in the northeastern part, close to Lake Heiligensee, where it is approximately 1 m high, allowing a direct saltwater intrusion of brackish Baltic Sea water. The dune was partly destroyed in a major storm surge in 1995. However, the dune dyke was restored in 1996 to protect the lowland area behind it, closing off the Hütelmoor from the sea again (UMV, 2003). Afterwards, the responsible authorities decided to not retain coastal protection measures in this area so as to reach a redynamisation of coastal processes, meaning that in flooding events, the dune dyke would not be restored again. A groyne system in front of the beach protects the waterfront against coastal erosion.

There are clear signs of an earlier loss of fen area because peat layers can be found along the beach up to approximately 2 m of water depth on the coasts of the area, especially in the northeast close to the Lake Heiligensee (Figure 2). The fact that peat banks can be found in the shallow coastal waters may illustrate the dynamics of the coastline. However, it is not understood yet how fast the coastlines are receding in front of the Hütelmoor, especially as the rates of coastline retreat vary strongly from the Warnow River mouth to the Darß-Zingst peninsula (Kolp, 1957). The thickness of the peat body increases from the edge of the forest to the dunes up to a maximum of 3 m. It overlies a sandy aquifer with variable thickness between 1 m and more than 7 m, which is limited downwards by the glacial till. In some parts (especially near the freshened Lake Heiligensee), mud deposits can be found below the peat.

The peat mainly consists of small decomposed plant materials from reed and sedges as well as of wood at greater depths. Due to the intense drainage between the late 1960s and 1992, the upper parts of the peat layer are highly degraded, whereas less decomposed peat can be found in the deeper parts (Hahn et al., 2015; Miegel et al., 2016). The investigation of the exact stratification is the objective of an ongoing interdisciplinary research project, which is mainly focusing on the water and matter fluxes in and between the coastal peatland and the adjacent Baltic Sea (www.baltic-transcoast.uni-rostock.de).

The climate is typical for the transition zone between the Atlantic maritime climate from the western part of the German coastline to the more continental climate prevailing at the easternmost part of the German Baltic coast (Voigtländer et al., 1996). Mean annual precipitation is 645 mm and the mean annual air temperature is 9.2°C (1987–2010) (Koebsch et al., 2013).

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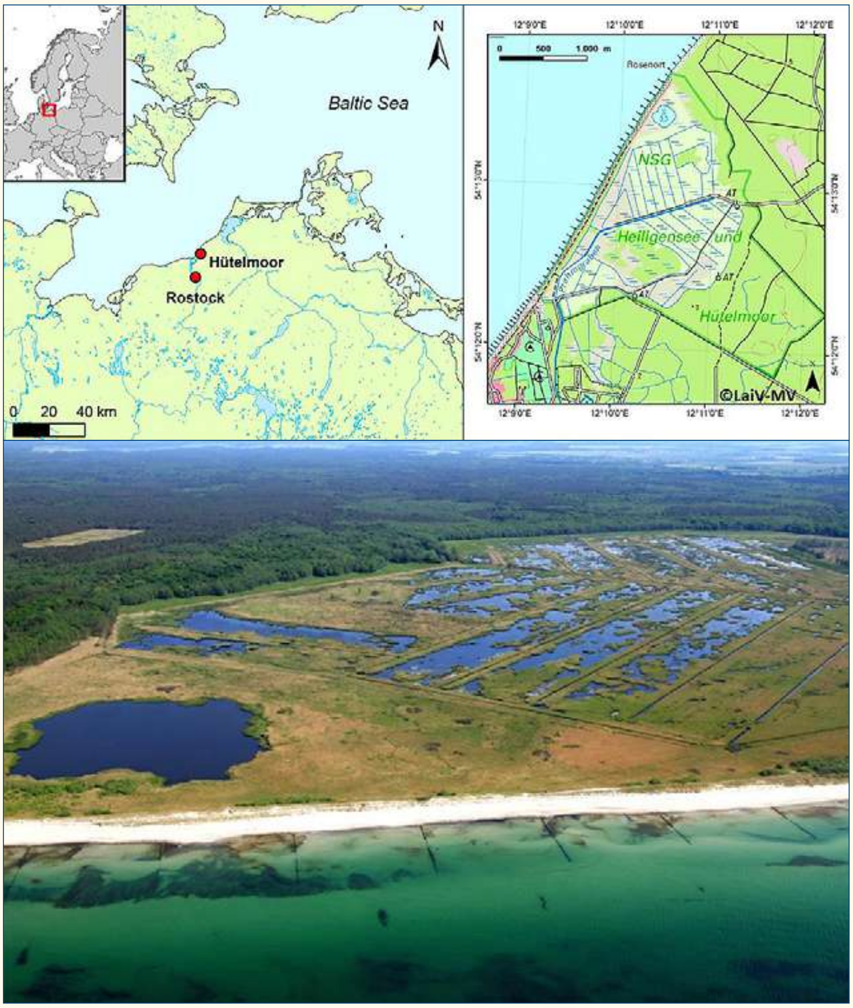
B



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A. **The fen is situated at the German Baltic Sea coast, north of the city of Rostock and the river Warnow.**

B. **In the northern part, Lake Heiligensee is located. The area is streaked with draining ditches; the main ditch, Prahmgraben, crosses the fen in the middle and is already visible in early maps of the area from 1786.**

C. **View from northeast of the coastal peatland and the surrounding beach and forest in May 2014.**

Figure 1. Nature reserve Heiligensee and Hütelmoor.

Map A: administrative areas, GADM https://gadm.org/data.html.
Map B: Landesamt für innere Verwaltung- Mecklenburg Vorpommern.
Photo © Dr Lars Tiepolt.

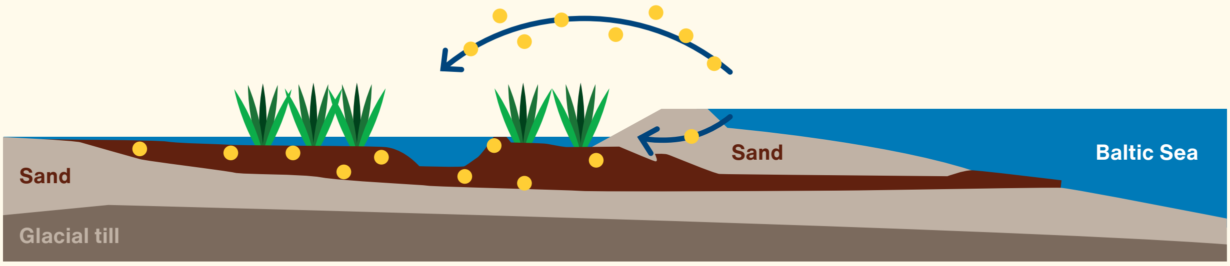

Figure 2. Schematic of transactional structure of the area, showing that the peat extends into the shallow water at some sections of the beach.

Source: Jurasinski et al., 2018.

To improve the climate footprint of regions, the renaturation of peatlands has become increasingly important over the past few decades. In the German state of Mecklenburg-Western Pomerania, the Hütelmoor is a pilot for the process of rewetting drained peatlands, to observe the influence of anthropogenic intervention and renaturation processes.

Biodiversity

The flora and fauna of the Hütelmoor represent a rare mixture of typical fen and mire associations with species indicating brackish conditions. These elements are found in a mosaic pattern, while more mobile species travel through both intertwined habitats. Examples are multiflowered buttercup (*Ranunculus polyanthemos*), marsh spurge (*Euphorbia palustris*), viper's grass (*Scorzonera humilis*), Baltic rush (*Juncus balticus*) and saltmarsh flat-sedge (*Blysmus rufus*) (UMV, 2003). Low-lying, salt influenced parts of the fen are covered by brackish reed communities, in which common reed (*Phragmites australis*) is accompanied by, for example, soft stem bulrush (*Schoenoplectus tabernaemontani*) and saltmarsh bulrush (*Bolboschoenus maritimus*).

With increasing elevation, *Holcus* communities show decreasing salt influence. The highest parts are formed by a bog area, the Hütelmoor itself, located in the west of the reserve, where a rare Scots pine (*Pinus sylvestris*) and bayberry (*Myrica gale*) association prevails. Here, in the moor grass meadows, many of the especially protected species of the reserve can be found, including, for instance, marsh gentian (*Gentiana pneumonanthe*), northern bedstraw (*Galium boreale*), Prussian sermountain (*Laserpitium prutencium*), lousewort (*Pedicularis sylvatica*), and royal fern (*Osmunda regalis*).

Lake Heiligensee is the locality of the charophyte green algae *Chara aspera* and the recent record of *Chara connivens*, an endangered species on both the regional as well as the national level, which underpins the importance of this wetland for conservation (Teppke et al., 2015).

Faunal elements of special interest are the moor frog (*Rana arvalis*), the European tree frog (*Hyla arborea*), as well as highly specialised animal species like the ground beetles *Agonum monachum, Bembidion tenellum, Dyschirius chalceus* and *Harpalus melancholicus*. The common lizard (*Zootoca vivipara*) and the common European viper (*Vipera berus*), which is categorized as highly endangered in Germany (UMV, 2003), are also found.

The permanent inundation of the fen since 2010 has led to significant changes in the species composition. The observed expansion of common reed stands is usually accompanied by a shift to a species-poorer vegetation (Koch et al., 2014; Koch et al., 2017). Furthermore, the avifaunal species inventory has also changed. For instance, during the 1990s, the avifauna was dominated by typical meadow-breeding birds like the northern lapwing (*Vanellus vanellus*) and the common snipe (*Gallinago gallinago*). In 2012 these species were no longer found, and the most abundant avifaunal species are now the Eurasian bittern (*Botaurus stellaris*), Savi's warbler (*Locustella luscinioides*) and the common reed bunting (*Emberiza schoeniclus*) (Leipe & Leipe, 2013).

Land use changes

The Hütelmoor, as well as the catchment, are part of the ‘Rostocker Heide’, a large forest that has belonged to the city of Rostock since medieval times. Irrespective of the dense population along the German Baltic coastline, the small catchment of the fen is almost completely forested and does not include any settlements. In the 18th century, a channel (the Prahmgraben) was installed for the transport of wood from the surrounding forest to the river Warnow. Drainage of the fen, allowing large parts to be used as meadow, started in the 19th century (UMV, 2003). Irrespective of its protected status as a nature reserve, the area was intensively drained in 1970. A pumping station at the outlet of the Prahmgraben ensured the retention of low water levels in the fen. This drainage, partly accompanied by ploughing, allowed use as an intensively managed grassland that was continued until 1992 when the pumping station was shut off (Krischer, 1977). From then on, the area was still used for extensive horse and cattle grazing until the fen became flooded due to a severe dune break in a storm surge in 1995.

To prevent further degradation of the peat, the water level in the fen was permanently increased by installing a ground sill in the outflow of the catchment in the winter of 2009/2010 (Hahn et al., 2015). Since then, large parts of the fen are inundated most of the year.

Status of the wetland

Since 1961 the Hütelmoor with Lake Heiligensee is a nature reserve by national law. As part of the Rostocker Heide, it is since 1995 also a protected landscape area. Additionally, in 1999, it was suggested that the Rostocker Heide be designated as a flora-fauna-habitat (FFH) area (according to the European Flora-Fauna-Habitat-Guideline) by the state of Mecklenburg Vorpommern. In 2004, the European Commission added the area to the list of Areas of Community Importance. The protective purpose of the FFH area Rostocker Heide is the preservation and development of the last large contiguous forest area of the region with broadleaf forest, heath species and adjacent lake, dune and peatland habitats, all of which is influenced by coastal dynamic processes.
The main requirements for the preservation of the state of the FFH area Rostocker Heide are undisturbed groundwater conditions and dynamic coastal influences, reduced nutrient inputs and an adapted utilization and fostering of the habitat types – forest and open country. The main protection components of the FFH area Heiligensee and Hütelmoor are Lake Heiligensee, the Atlantic salt meadows (*Glauco-Puccinelli et alia*), the white dunes with beach grass (*Ammophila arenaria*), dune bushes (*Hippophae rhamnoides*), the peatland area with the adjacent wood rush – beech forest (*Luzulo Fagetum*), oak forest (*Quercus robur*) and peatland forest (*Pinus sylvestris – Betula pubescens*). Animal species with special protection status are the hermit beetle (*Osmoderma eremita*), the warty newt (*Triturus cristatus*) and the harbour porpoise (*Phoecoena phocoena*).

At 490 ha, this nature reserve represents a rather small conservation site. Because other sites in the same state (such as Boddengewässer Ostufer Zingst and Westküste Rügen- Hiddensee with 25 800 ha) showed higher numbers of water birds (more than 20 000), the nature reserve Heiligensee and Hütelmoor was not designated as a Ramsar site.

The preservation goals for the FFH area Heiligensee and Hütelmoor are the preservation and development of Lake Heiligensee by allowing regular saltwater inflows. To reach this goal, the maintenance of the coastal protection dune along the seaward boundary of the FFH area was ceased in 2005 (Hahn et al., 2015). Further preservation goals for the FFH area are the protection and development of the white dune by following aggradation dynamics and the protection and development of the degraded coastal fen peatland by maintaining water levels close to or above ground level (UMV, 2006).

Identified threats, management conflicts and main stakeholders

Despite the modes of protection described, the coastal peatland complex still faces a number of potential threats. Because it is in transition from a meadow to a lowland fen, one of the main uncertainties is the development of the peat layer. During the period of intensive drainage, the peat underwent severe degradation, and it may have degraded to the extent that restoration of the hydrological conditions necessary for re-establishing it a functional fen is not possible (Schumann & Joosten, 2008). The peat properties can thus be decisive for the prognosis of recent restoration efforts.

Natural management

Irrespective of whether global climate change may increase the intensity and frequency of storm surges, coastal erosion is a continual natural threat to the area. The dune dyke that protects the reserve from the forces of the sea is not tall enough to prevent direct intrusions of brackish water. On one hand, coastal protection by groynes typically reduces sediment loss, thus helps stabilise the dune dykes. On the other hand, coastal protection by a dune dyke is clearly in direct conflict with the nature conservation targets. Coastal erosion is regarded as a natural process in the area. The coastal retreat, as seen by the subsurface peat layers in front of the Hütelmoor, has been going on for centuries at least. As a result, the regional state agency for agriculture and environment (Stalu-MM) agreed to remove the groynes (Sommermeier, pers. comm., 2016[1]) and accept the increased risk of the dune dykes being breeched and subsequent flooding of the considerable parts of the area (Kreutzberg et al., 1994).

In this case the wildlife of the fen that is not adapted to brackish conditions will be heavily impacted, and in the worst-case scenario, a part of the forest may die off. Nevertheless, such a process must

1 Personal Communication (15.11.2016, Rostock): Sommermeier,K., Staatliches Amt für Landwirtschaft und Umwelt Mittleres Mecklenburg (StALU MM), Dezernatsgruppe Küste.

be seen as natural. The recent protection targets are in agreement with this, even though some of the protected species may disappear. Furthermore, a possible inflow of brackish water from the backside of the fen must be taken into account. The outflow channel is connected to the Warnow estuary, which is brackish. During storm surges the water level in the estuary can increase sufficiently to overcome the ground sill, resulting in inundation of at least the drainage system of the fen with brackish water. Since this occurs already at water levels much lower than needed for breaking the dunes, the removal of the groynes becomes an even more reasonable option.

Tourism

The close distance to the city of Rostock in the west and other recreational cities in the east, as well as the close proximity to the Baltic Sea and the national park 'Vorpommersche Boddenlandschaft', put the region under high touristic pressure, resulting in conflict between nature protection, forest management, and touristic interests. Tourism within the fen is a potential threat, but seems to be managed well at the moment. The fen is accessible to interested visitors through pathways but is closed for motorized vehicles. Visitors interested in the fen itself, mainly bird-watchers, are guided to viewpoints allowing excellent conditions for the observation of wildlife. Water levels stay well above ground level for major parts of the year, preventing locals and tourists from entering the inner parts of the reserve. Walkers and cyclists are channeled to the few accessible footpaths. Beyond the destined paths, walking is almost impossible and not attractive to tourists, even in periods of drought, since the still existing drainage net cuts the area into island-like stretches of about 100 m width. Most of the protected species live in the inaccessible inner parts of the peatland; even the lake is protected by a large surrounding swamp area. Thus, the vegetation of the beach and the dunes are the areas most negatively influenced by tourism. The beach in the nature reserve is still a popular bathing spot, however, due to the protection status, the influence of tourists has lessened in the past years (Voigtländer et al., 1996).

Research

Scientific activities can also contribute to human disturbance of wildlife. Being located close to the university city of Rostock, the coastal fen system has been investigated for its hydrological behaviour, trace gas release and many other subjects of scientific interest since the early 2000s (Koebsch et al., 2013; Glatzel et al., 2014; Miegel et al., 2016). These investigations required sampling and installation of measurement devices, the latter at least in parts of the fen lying beyond the official footpaths. Sampling itself causes negative impacts on biota, an aspect more and more regarded as a potential threat and tackled in the context of the recent debate about fieldwork ethics (Costello et al., 2016). Breeding bird populations may be disturbed by sampling activities, while vegetation cover is influenced by repeated access to the installed logging equipment, which needs to be maintained throughout the year. In this context, the presence of people outside of public access areas encourages copying by curious passers. Consequently, scientific activities are strongly regulated. Each planned investigation is supposed to supply a detailed scheme of sampling activities beforehand; permission is granted only in cases where expected disturbances are minimised as much as possible and the expected outcome of the research is of such high interest for the conservation targets that it outbalances any possible negative impact.

Goods and services

The recent status as a nature reserve prevents provisioning services like peat extraction, reed harvest, and agriculture in the fen. This also applies to the forest area belonging to the nature reserve, which has a potential for timber production, including valuable tree species like pedunculate oak (*Quercus robur*). Also, recreational services are restricted mainly to wildlife observation, while all kinds of physical activities like walking and cycling are limited to the few paths made accessible to the public. The parking lot was closed in 1989 in order to limit the number of visitors (Voigtländer et al., 1996). Rewetting the area by the installation of a ground sill reduced the accessibility even of the public paths. At least one of these paths connects the neighbouring settlements of Markgrafenheide and Graal-Müritz for pedestrians and cyclists. Public protests led to the elevation of the path up to 90 cm to improve the accessibility during floods. Wild game such as boars, deer and geese feed in the area, cannot be hunted in the fen area itself, but contributes to the total hunting prey in the surrounding forests.

Expected ecosystem services after rewetting are most prominently decreased CO_2 emissions and an intensified carbon sequestration (Wilson et al., 2016) as well as an improved balance of thewater regime (Menberu et al., 2018). The development of the exchange of carbon dioxide and methane of the fen after the rewetting is still subject to research (Koch et al., 2014; Koebsch et al., 2013). Directly after flooding, methane emission increased strongly (Hahn et al., 2015), but seem to have decreased slowly since then (Koebsch et al., 2013).

Species conservation is another example of an ecosystem service that can be better fulfilled by the current use of the fen. The dune dyke in

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front of the reserve contributes to the coastal protection of a large low-lying area. In the past, this dune dyke was reconstructed whenever storm surges lead to damages, the last time in 1996 after the storm surge of 1995. The decision to stop maintaining the dune dyke may result in partial loss of forest area and even in the loss of salt-sensitive protected species in the fen itself, representing a conflict within the field of nature protection. However, the main objective of the nature reserve, as well as of the FFH reserve, is the redynamisation of the coastal landscape.

Creating improved knowledge by scientific investigations might be regarded as a part of cultural services. As already mentioned, this service is in conflict with the use as a nature reserve. Even though priority is given to conservation, restricting the potential scientific study, scientific research is granted if it is compatible with the protection goals.

Following the protection targets, the rewetting of the Hütelmoor results in some restrictions for tourism and research activities, but is not excluding them. Other ecosystem services, like an intensified carbon sequestration, an improved balance of the water regime and the redynamisation of coastal processes, are enhanced.

Recommended solutions and tools for an effective recovery, conservation and management directions

Management of the degraded and in part eutrophic peatland is difficult. The effect of nutrient pollution caused by past fertilization may be reduced stepwise by mowing and removal of the plant material. However, having reached stage-three degradation, pedogenesis (soil formation) took place in the period of agricultural use. This kind of degradation has been reported in a change from percolation mires to surface flow mires (Schumann & Joosten, 2008). Consequently, effective restoration might even require the removal of the uppermost peat layers – which is in strong contrast to the development targets, which include the preservation and development of the peatland habitats with their special protected plant and animal species. Any solution of this problem will raise conflicts. Hence, the definition of clear conservation targets, taking their risks and consequences into account and finally accepting them in a broad agreement, is a prerequisite of a sustainable management plan.

Keeping or filling in the drainage ditches, for example, is such a decision with strong consequences. Keeping these ditches does not only allow water level regulation and, in combination with the ground sill, may balance the water regime effectively – it also influences accessibility.

A similar conflict area represents species protection versus process protection. A clear decision towards the prioritization of one aspect prevents continuous re-adjustment, being not only expensive but also inefficient because none of the targets can be achieved sustainably. For these reasons, the first step should be a comprehensive analysis of the consequences of process protection versus species protection and, based on this, a decision about priority. Such a decision must be agreed upon with full knowledge of the negative consequences for the non prioritised target, allowing clear communication of the pros and cons as a prerequisite of public acceptance.

Furthermore, as it is the case for all kinds of protected areas, raising public acceptance for access restrictions is a key element for achieving conservation targets. A clear and understandable description of the conservation targets and an explanation of the measures taken can enhance the acceptance of restrictions and should be provided at the entrance to the protected area.

At the same time, visitors should be helped to profit from the protected goods without disturbing them. Accessible viewpoints and explanatory tables depicting the regional features of the area help to increase recreational value. Signposted footpaths and orientation maps prevent visitors from wandering around in sensitive parts of the area. These measures have been realised already in the nature reserve Heiligensee and Hütelmoor. Additionally, guided hikes through the wetland are offered occasionally by the forest authority of the city of Rostock and the local advisory council of Markgrafenheide. These measures are implemented in management directives of natural reserves and applied as well in other countries (see e.g., Parks and Trees Act in SSO, 2005). They are based on public acceptance analysis of natural protection demands (e.g., Thede et al., 2014; Lawton, 2001) and have been proven effective for wetland management (Lim & Mcaleer, 2005).

The responsible authorities for the nature reserve Heiligensee and Hütelmoor agreed on renaturation management plans striving for a redynamisation of this section of the Baltic shallow coast. The restoration of the natural conditions represents a pilot project that is highly suitable for showing and investigating the changes and interactions happening in the course of rewetting a coastal peatland.

Acknowledgement

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SECTION

4 Island wetlands

In this section, three lagoons on St. Croix, U.S. Virgin Island; Margarita Island, Venezuela, and Malaita, Solomon Islands are analyzed. These island wetlands face the same threats as coastal lagoon systems on the mainland as they are impacted, overfishing, and deforestation of mangroves due to commercial interests, encroachment of roads or resorts, resulting in loss of species and environmental and cultural services, pollution from agriculture and navigation, waste from fishing boats, and impacts from climate change such as devastating storms, flooding, and salinization. The small tropical islands are affected by under-resourced governments without the capacity for the cross-departmental cooperation required for sustainable development and the widespread damage from hurricanes and rising sea levels that can impact the whole island.

Wetlands conservation in islands faces complex challenges as tradition runs deep in small multigenerational communities. Some traditions embody rules for sustainable resource management. But growing populations and outside influences have resulted in unsustainable practices. Setting up integrated, ongoing, evidence-based, monitored program with agreed goals requires sophisticated planning that is becoming essential for sustainable resource management. For this fragile wetlands, main recommendations included (a) collect data on use patterns, use intensity, and levels of resource extraction; (b) establish an ecological baseline, a baseline for site use, and improve data capture and management capacity; (c) determine the value of the ecosystem services provided by the lagoon to inform policy making and encourage increased engagement by the community; (d) create an appropriate policy framework for management including environmental and commercial interests; (e) support a sustainable management and enforcement regulation of the fisheries; (f) prevent the discharge of wastes in the lagoon; (g) Involve local communities in decision management policies.

S4

CHAPTER

1

Great Pond, U.S. Virgin Islands

Protecting a wetland through complementary regulatory frameworks

By

Lloyd Gardner
Foundation for Development Planning, Inc.
St. Thomas,
U. S. Virgin Islands

Stevie Henry
Eastern Caribbean Center, University of the Virgin Islands
St. Thomas,
U.S. Virgin Islands

Abstract

Great Pond is an important asset in the conservation and development strategies of the U.S. Virgin Islands, with territorial and national regulatory frameworks to support management of the wetland. Although acknowledged as a significant natural area, the wetland is not subject to targeted management intervention. In the absence of a management regime, threats continue to the integrity of the wetland, degradation of which would reduce the flow of goods and services to the local community. However, the wetland is located within an area of particular concern, which is a landscape planning framework established within the coastal zone management program.
To date, this framework has been the most effective policy tool to prevent loss of the wetland to development projects.

Keywords:

wetland | coastal zone management | conservation policy | landscape planning | Great Pond | St. Croix | United States Virgin Islands

Site description

Great Pond is a coastal wetland located on the south shore of St. Croix, U.S. Virgin Islands, at latitude 17°43.30' N, longitude 64°39.30' W (Figure 1). The 49-hectare wetland is separated from the sea by a sand bar that is partially covered by a littoral forest. The wetland is maintained by a combination of runoff from its catchment area and water exchange with the sea via a small tidal channel, thus pond depth varies based on rainfall pattern and tidal movement. Consequently, the salinity varies from brackish during the wet season to hypersaline during the dry season, resulting in the wetland being known locally as Great Salt Pond. The structure of the wetland changes periodically in response to major stressors, but comprises a central area of water and trees surrounded by tidal flats, except on the southern side where the mangrove forest is fairly dense (see Figure 1).

Figure 1. Location of Great Pond on St. Croix, U.S. Virgin Islands.

(A) U.S. Virgin Islands located east of the Dominican Republic and Puerto Rico. (B) Location of Great Pond on St. Croix. (C) Aerial photograph of Great Pond, 2007.

Sources: ESRI, HERE, USGS, FAO, NPS, Google Maps and the GIS User Community.

A dominant feature of the wetland is the mangrove stand, comprised primarily of red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), and white mangrove (*Laguncularia racemosa*). Buttonwood (*Conocarpus erectus*) is present, but sparse. The management plan for the St. Croix East End Marine Park (The Nature Conservancy, 2002) states that most of the park's mangrove species are in Great Pond. Other tree species found in the littoral forest are manchineel (*Hippomane mancinella*), sea grape (*Coccoloba uvifera*), and seaside mahoe (*Thespesia populnea*). The main herbs and grasses at the edges of the wetland are crab grass (*Sporobulus spp.*) and sea purslane (*Sesuvium spp.*), with salt marsh spike-grass (*Distichilus spicata*) and salt marsh cordgrass (*Spartina alterniflora*) occurring to a lesser extent. On the land adjacent to the wetland, the vegetation is dominated by thorn scrub, which merges into overgrown pasture.

The wetland provides a home or foraging area for a range of faunal species. Crabs include the fiddler crab (*Uca spp.*), blue land crab (*Cardisoma Guanhumi*), and the marine blue crab (*Callinectes spp.*). Great Pond is one of the largest breeding sites for birds on St. Croix, and is listed by BirdLife International as an important bird and biodiversity area (IBA). The IBA Fact Sheet (BirdLife International, 2016) states that 72 species of birds, including 39 migrant species, were identified at Great Pond during 2002–2007. Birds found at Great Pond include five species that are endangered locally, and one species – the white-crowned pigeon (*Columba leucocephala*) – that is listed as Near Threatened globally.

Depending on the salinity and whether the tidal channel is open, species of fish historically found in the wetland include southern sennet (*Sphyraena picudilla*), barracuda (*Sphyraena barracuda*), mullet (*Mugil spp.*), tarpon (*Megalops atlanticus*), and common snook (*Centropumis undecimalis*). Finfish species identified during a 2016–2018 study included yellowfin mojarra (*Gerres cinereus*), slender mojarra (*Eucinostomus jonesii*), schoolmaster snapper (*Lutjanus apodus*), shortfin molly (*Poecilia Mexicana*), french grunt (*Haemulon flavolineatum*), common snook (*Centropomus undecimalis*), lyre goby (*Gobionellus boleosoma*), frillfin goby (*Bathygobius soporator*), redband parrotfish (*Sparisoma atomarium*), doctorfish (*Acanthurus chirurgus*), and the invasive tilapia hybrid (*Oreochromis spp.*) (Durdall, 2018). The study noted reduced species diversity compared with historical data. The species of tarpon found at Great Pond is classified Globally Vulnerable (IUCN, 2018).

A near-shore barrier reef creates a shallow back-reef lagoon, dominated by seagrass, that supports fishing, swimming, water sports, and snorkeling by the local community.

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Conservation status of the wetland

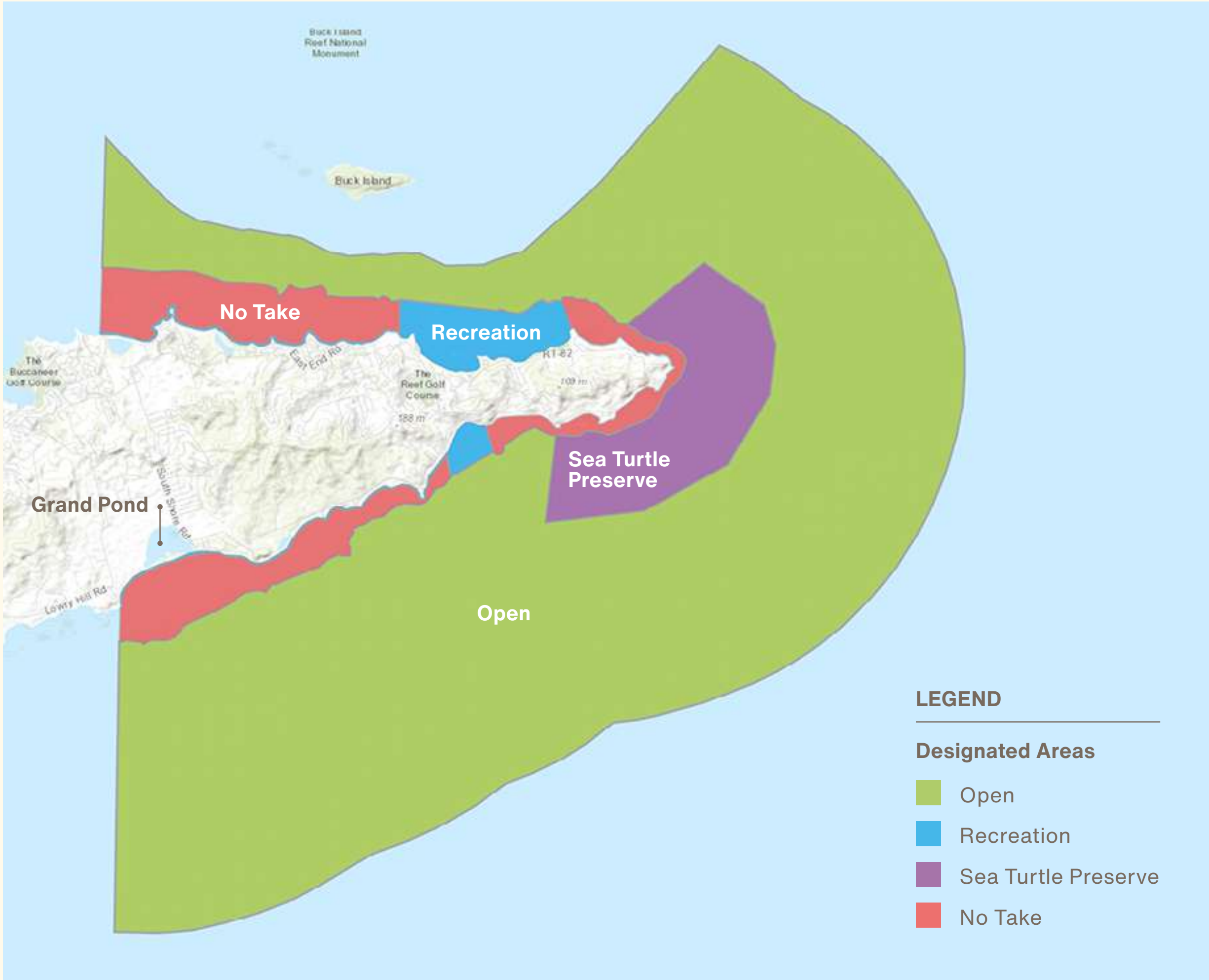
A 2010 publication on wetlands in the U.S. Virgin Islands (Conservation Data Center, 2010) highlighted local and national laws that provide the legal framework for wetlands management in the U.S. Virgin Islands. Additionally, program associated directly or indirectly with wetlands are being implemented by public agencies and nonprofit organizations. Great Pond, as well as juxtaposing ecosystems, have been recommended and designated for protection under several local and national program. Though the wetland is public land, most of the surrounding land is privately owned.

A 1960 report prepared for the U.S. Department of the Interior (National Parks Service, 1960) recommended acquisition of 200 hectares, including the wetland, for nature study, wildlife protection, and scientific research. Planning initiatives for a territorial parks system in 1981 and 1991 recommended the acquisition of the land surrounding the wetland for incorporation into the proposed territorial parks system, and for the site to be developed as a natural attraction and educational resource. The area is also included in the national Coastal Barrier Resources System, the purpose of which is to restrict development in low-lying areas that are prone to natural disasters, as well as protect valuable natural areas from being destroyed by incompatible economic development.

Although there is evidence of the ecological and economic importance of Great Pond, and clear local and national policy directions and support systems, the status and future of the site remain uncertain. The management plan for the St. Croix East End Marine Park states that the wetland is contained within the park (Figure 2), but the boundary description is ambiguous (the longitude for the western-most point of Great Pond Bay is incomplete, and the hydrology of Great Pond is determined by both tide and runoff from the watershed), and the management plan identifies no specific strategy targeting Great Pond.

The Act establishing the marine park, describes the boundary thus:

The park is comprised of the area that begins at the highest tide at the western-most point of Cheney Bay (17° 45’ 39” N, 64” 40’ 5” W); extends out to the three-nautical-mile territorial boundary; the border follows the three-nautical-mile territorial boundary around the eastern tip of St. Croix and ends at the highest tide line at the western-most point of Great Pond Bay (17° 71’ 35” N, 66’ 57” W) excluding any area under federal jurisdiction, and shall be administered pursuant to the St. Croix East End Marine Park Management Plan (Act No. 6572 of 2002).



St. Croix East End Marine Park. (2016). Story Map Journal.Retrieved June 13, 2020 from https://www.arcgis.com/apps/MapJournal/index.html?appid=9a963174e35c4c24aeec0b7b77410a7e

Figure 2. Boundary of the St. Croix East End Marine Park showing use zones, 2016.

Sources: Service Layer Credits: ESRI, HERE, USGS, FAO, NPS, OpenStreetMap and the GIS User Community. St. Croix East End Marine Park, (2016).

Great Pond is afforded an additional measure of protection by virtue of its location within the Great Pond and Great Pond Bay Area of Particular Concern (Figure 3). This designation, enabled by the national Coastal Zone Management Act 1972, uses a landscape planning framework that guides regulatory actions within any area designated as an area of ‘greater significance’ in the coastal zone. Designation of an area particular concern is based on the existence of: (1) significant natural areas; (2) culturally important areas; (3) substantial recreational opportunity or value; (4) existing or amenability to industrial or commercial development requiring a waterfront location; (5) urbanized and densely populated areas where shoreline uses are highly competitive or in conflict; (6) locations that would pose a significant hazard if developed; and (7) areas with existing or potentially important mineral resources (NOAA, 1979).

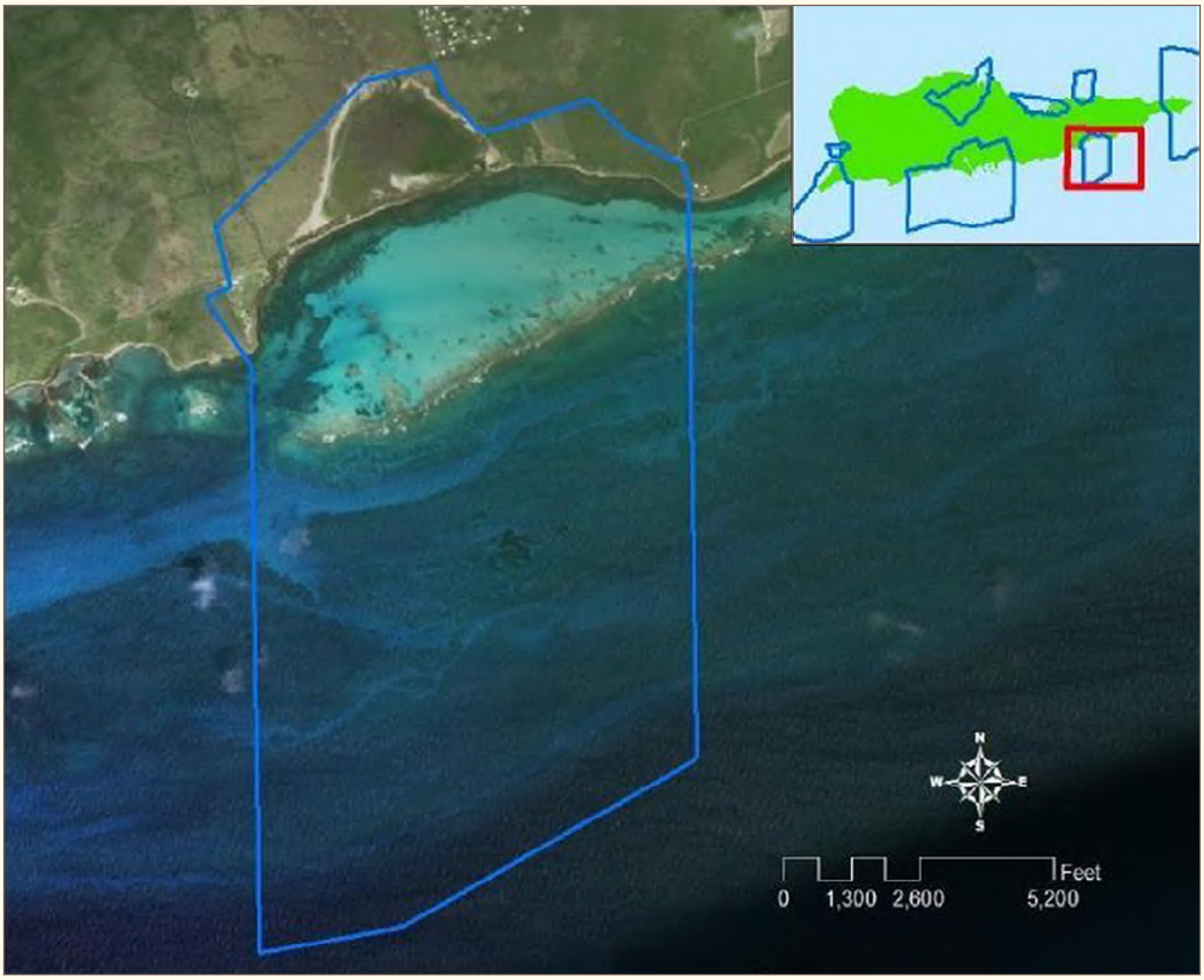


Figure 3. Great Pond and Great Pond Bay Area of Particular Concern.

Note: The insert shows the locations of other areas of particular concern on St. Croix.

Source: Service Layer Credits: ESRI, HERE, USGS, FAO, NPS, OpenStreetMap and the GIS User Community. (CDC 2000). Area of Particular Concern (APC). First edition. [ESRI Shapefile/20]. Eastern Caribbean Center, University of the Virgin Islands.

The Great Pond and Great Pond Bay Area of Particular Concern was identified as a unique natural area, and the program recommended that the area "should be preserved as a wildlife, educational, and natural area" (NOAA, 1979). However, no management plan was prepared for this area of particular concern, and Great Pond is subjected to threats from anthropogenic and natural sources.

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Threats

The wetland is used by the community for a variety of purposes. Recreational uses include bird watching, marine recreational activities, and occasional camping. Resource harvesting includes hunting birds, harvesting crabs, fishing (for food and bait), and harvesting mangroves and other trees. It should be noted that wetlands can be used sustainably, and degradation is usually the result of use intensity and types that overwhelm the ecological processes. Unfortunately, very little data exist on levels and patterns of resource use and extraction at Great Pond.

Agricultural activities on the surrounding land produce adverse impacts on the wetland. Land clearing for crop cultivation often involves fires, which affect the ecosystems in and around the wetland. Horse and cattle grazing on the surrounding land add nutrients to the wetland, though the impact has not been quantified. The greater concern for nutrient enrichment is the onsite sewage effluent disposal systems used in residential developments in the watershed.

Vehicular intrusion (associated with the fishing and recreational activities) produces damage to mudflats and beaches, and interferes with bird nesting activity. Disposal of solid waste on the mudflat on the eastern side of the wetland is a major threat: waste is produced onsite through recreational use of the wetland and adjacent beach and occasionally brought in from offsite.

The wetland serves as a sediment trap for surface runoff from its watershed of approximately 466 hectares. The sedimentation has caused some infilling of the wetland (Island Resources Foundation, 1993), raising concern regarding land management practices in the watershed. Sediment is also transported from the sea to the wetland by high-energy wave activity, particularly during storms (Bruce et al., 1989).

Major storms are also a source of threat. The mangrove forest was severely damaged by Hurricane Hugo in 1989, with significant mortality of mature trees, reaching 100% for black mangroves (Island Resources Foundation, 1993). A site assessment in 1990–1991 found that all species were recovering, a conclusion that was confirmed during a site survey in 2010 (Conservation Data Center, 2010). The probability of severe damage from intense storms that periodically make landfall on St. Croix is fairly high, as evidenced by the impact from Hurricane Maria in September 2017 (Figure 4), which resulted in a loss of foliage and damage to more than 80% of the mangrove trees (Durdall, 2018; Nemeth & Wilson-Grimes, 2018). A site assessment in 1990–1991 found that all species were recovering, a conclusion that was confirmed during a site survey in 2010 (Conservation Data Center, 2010). The probability of severe damage from intense storms that periodically make landfall on St. Croix is fairly high, as evidenced by the impact from Hurricane Maria in September 2017

Figure 4. Impact of Hurricane Maria, September 19, 2017.

(A) Pre-Maria (photo taken September 18, 2017) shows some loss of mangroves to the north and west of the pond, due primarily to an extended drought in 2015. (B) Post-Maria (photo taken September 23, 2017) shows complete loss of foliage after the passage of Hurricane Maria.

Source: NGS, 2018a; NGS, 2018b.

Climate change is likely to become a more significant threat to the ecological integrity of Great Pond. The pond's hydrology is determined by runoff from the watershed and water exchange with Great Pond Bay. However, increasingly severe droughts may increase the frequency, duration, and severity of hypersaline conditions in the wetland, as evidenced by significant die-off in the mangrove stand during a 2015 drought (Geographic Consulting, 2016). A 2018 study reported that the combination of the 2015 drought, hurricanes Irma and Maria in 2017, and another drought in 2018 resulted in greater than 80% mortality of the mangroves in Great Pond (Nemeth & Wilson-Grimes, 2018). Clearly, the cumulative impact of different stressors will require proactive measures to maintain the ecological integrity of the wetland.

One of the most significant threats to Great Pond is the possibility of a major development project in or adjacent to the wetland. Major projects proposed include a rocket assembly plant in the late 1990s and large mixed resort developments adjacent to the wetland in 1989 (Island Resources Foundation, 1993) and 2014 (Kossler, 2014). In May 2020, the U.S. District Court of the Virgin Islands ruled that the permit for a golf resort and casino development at Great Pond is valid (Carlson, 2020), underscoring the uncertain future of the wetland.

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A 2002–2003 socio-economic assessment of marine resource use in the U. S. Virgin Islands found that studies of marine resources focused primarily on resource description, with little information on resource use, area-specific activities, and use/user conflicts. As a result, there were significant gaps in the data needed to assess the social or economic importance of marine protected areas (Hinds Unlimited, 2003). Use of the shoreline bordering Great Pond Bay as a base of operations for water sports, fishing, and other forms of recreation was noted in the 2003 assessment and later during a 2010 use assessment of the St. Croix East End Marine Park (Geographic Consulting, 2011). Unfortunately, data gaps constrain the ability of policy makers and resource managers to make informed decisions regarding site management and development options for Great Pond.

Recommended actions

The flow of goods and services from the wetland to the community is disrupted by the intensity of resource use, resource-use conflicts, activities in the associated watershed, and natural disasters. Balancing the imperative to protect the ecological integrity of the wetland with the social and economic development needs of the community requires action on several fronts.

It is difficult to achieve significant threat reduction or resource enhancement in the absence of site-specific interventions. The wetland and portions of the surrounding lands should be designated a protected area and brought into an active management regime. A feasible solution is to amend the legislation for the St. Croix East End Marine Park to specifically include Great Pond. The revised boundary for the park should include the wetland and enough surrounding land to account for sea level rise and for effective buffering from adjacent land uses.

The pollution threats originating in the Great Pond Bay Watershed will be addressed through a watershed management program for the entire St. Croix East End Marine Park (Horsley Witten Group Inc, 2011). The Great Pond Bay Watershed was listed in the 1998 Unified Watershed Assessment Report as a Category 1 watershed, meaning the watershed did not meet clean water and other natural resources goals, and thus required restoration interventions (Department of Planning and Natural Resources and U.S. Department of Agriculture, 1998). Watershed management initiatives in the U.S. Virgin Islands are typically used to address non-point source pollution, resource preservation, and to support smart growth development (Watershed Planning Committee, 2001;

Center for Watershed Protection, 2008). Proposed pollution reduction interventions in the Great Pond Bay Watershed should be expanded from storm water and non-point source pollution management to include application of sustainable land management practices in agriculture and effluent disposal from residential development.

The most significant positive impacts are likely to result from changes in the attitudes and practices of individuals in the community. Increased attention to sustainable use of the wetland could increase the local population's perception of the value of the resource. It is important to remind stakeholders of the links between the ecological integrity of the wetland and the flow of goods and services to the community, particularly in relation to quality-of-life issues such as recreation, food security, and shoreline protection. The Department of Planning and Natural Resources should, in its public engagement program, articulate the value of the goods and services provided to the local community by Great Pond and associated ecosystems.

Designing appropriate management interventions requires current data on use patterns, use intensity, and levels of resource extraction. These data could also establish an ecological baseline, a baseline for site use, and improve data capture and management capacity. Determining the value of the ecosystem services provided by Great Pond would inform policy making and encourage increased engagement by the community.

Finally, actions at the site or landscape level need to be supported by an appropriate policy framework, which was initiated in 2010 with preparation of a wetlands management framework (Environmental Support Services LLC, 2010). The 2010 management framework is responsive to the intent of the Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention) and the associated guidance for national wetlands policies (Davis, 1993). As an interim step, the Virgin Islands Department of Planning and Natural Resources should designate wetlands as a high-priority focus area in the coastal zone enhancement program for the U.S. Virgin Islands (NOAA Office for Coastal Management, 2020). Such designation for the 2021–2025 period would result in the regulatory agencies and civil society organisations focusing their attention and efforts on the most important and threatened wetlands, particularly Great Pond.

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S4

CHAPTER

2

Laguna de Raya, Margarita Island, Venezuela

Management of a protected wetland

By

Andrea Rodríguez
Laboratorio de Ecología Marina, Escuela de Ciencias Aplicadas del Mar, Universidad de Oriente
Nueva Esparta, Isla de Margarita, Venezuela

Carolina Bracho
Laboratorio de Ecología Marina, Escuela de Ciencias Aplicadas del Mar, Universidad de Oriente
Nueva Esparta, Isla de Margarita, Venezuela

Laboratório de Invertebrados Marinhos do Ceará, Instituto de Ciências do Mar (Labomar), Universidade Federal do Ceará
Fortaleza, Ceará, Brasil

Abstract

Laguna de Raya, a hypersaline lagoon system on the southern coast of Margarita Island in Venezuela, is one of three lagoons forming the 1,670 ha Tetas de Maria Guevara Natural Monument, which includes a hills system, mangrove ecosystem, seagrass beds and local fauna. The principal risks are overfishing and extraction of the local sea urchin species (*Lytechinus variegatus*); aggressive fishing techniques, such as drag nets; pollution caused by wastes from boats and refrigeration trucks; and felling of mangroves trees. The Monument is governed under special administration. Recommendations include regulating sea urchin extraction and organising the community and local authorities to enforce these regulations.

Keywords:

Lagoon system | natural monument | mangrove | sea urchin | resources exploitation | Laguna de Raya | pollution

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Introduction

Coastal lagoons are water bodies separated from the sea by a wide sandbar with a mouth or relatively narrow channel through the current causes water to circulate (Cervigón & Gómez, 1986). Coastal lagoons and wetlands are breeding and recruitment areas for many species and provide a variety of ecosystem services such as fishing, biological resources, coastal stabilization, nutrient cycling, and cultural services such as recreation and tourism (MEA, 2005). For these reasons, they are considered some of the most productive and richest ecosystems of the world, with high biodiversity (Ramírez, 1996).

General description: Physicochemical, hydrological and biotic components

Laguna de Raya is located in the driest zone of the southern coast of Margarita Island at 10°55'37, 49" N and -64°6'58, 47" W (Figure 1; Varela & Massa, 1981). It is about 4 m above sea level, 1,300 m long and communicates with the ocean by a channel 100 m long, 40–60 m wide, and about 2.5 m deep (Vásquez-Suárez et al., 2010).

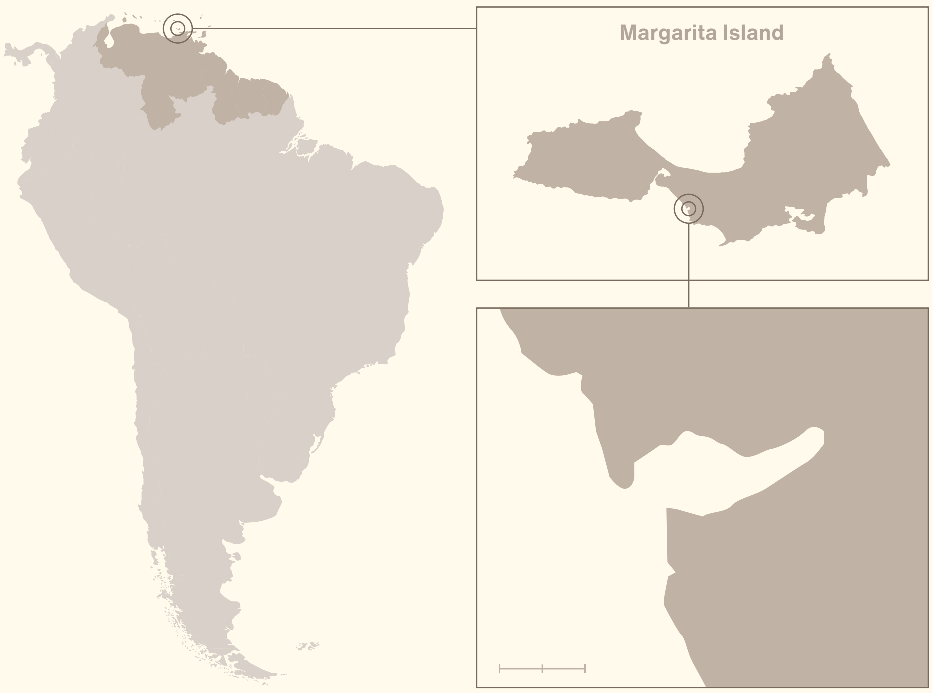

Figure 1. Laguna de Raya is on the south shore of Margarita Island off the coast of Venezuela.

Source: QGIS.org, 2021.

The average air temperature is about 28 °C and the lagoon's water temperature ranges between 26° and 32 °C. Its climate is semiarid, with evaporation 8–16 times greater than precipitation, which makes it a hypersaline coastal system with an average annual rainfall between 262 and 337 mm. Because of the influence of trade winds, the area has a dry season when the upwelling in the near ocean occurs, and a rainy season when the wind velocity is very slow. During both seasons the evaporation rate is higher than the precipitation rate. Laguna de Raya lacks direct tributaries and the natural drains are evident only during the rainy season (Herrera & Febres, 1975; Varela & Massa, 1981; Ramírez & Roa, 1994; Troccoli et al., 1999; Vásquez-Suárez et al., 2010).

The geomorphology is more like a small bay than a lagoon with a small volume and wide communication with the sea, thus it is likely to behave hydrographically more like a bay. The lagoon's sediment is mainly muddy with a dark grey colour and hydrogen sulfide smell (Varela & Massa, 1981; Zabala, 1982). The chlorophyll concentration varies during the year, with a significant phaeopigments concentration and a large amount of material in suspension. The inorganic portion of the sediments in the water is higher than the organic portion; and the amount of suspended material tends to increase gradually from the open mouth of the lagoon to the shallow inland end (Palazón & Penoth, 1989; Palazón & Penoth, 1994).

The surrounding vegetation is poor and mainly xerophytic. Species grow in groups or in isolation. They are Paja de playa (*Cyperus ligularis*), Cabezón (*Fimbristylis cymosa*), Horquetilla (*Chloris virgata*), Saladillo (*Sporobolus pyramidatus*), Comino rústico (*Mollugo verticillata*), Vidrio (*Sesuvium portulacastrum*), Bicho (*Alternathera canescens*), Barilla (*Batis maritima*), Grama (*Salicornia fruticosa*), Mariíta (*Egletes prostrata*), Campanilla (*Ipornoea carnea*), Alfombrita (*Euhorbia serpens*), Verdolaga (*Portulaca oleracea*) and Romero (*Suriana maritima*). Some areas are practically devoid of vegetation except where the wind has formed sandy banks on which grow intermixed Espinitos (*Lucium nodosum*), Bicho (*Croton punctatus*) and Tuna brava (*Opuntia caracasana*).

Lagoon vegetation is predominantly mangrove, represented by a community of three species: red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*) and white mangrove (*Laguncularia racemosa*), covering 23.6 ha of the lagoon's 57 ha. Another halophyte species, Godenia (*Scaevola plumeri*) is present and in the area closest to the city; between the dock and the jetty, there is a meadow of the seagrass *Thalassia testudinum and Syringodium filiforme* (Massa, 1981; Delascio & González, 1988).

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The catalogue of lagoon fauna comes from two publications. One reports the community structure of the 62 species of fishes, with more abundance of *Anchoa hepsetus, Eucinostomus gula, Diapterus rhombeus, Archosargus rhomboidalis, Atius herzbergii and Xenomelaniris brasiliensis*, as well as an important percentage of occasional and cyclic fish species (Ramírez, 1994). The second publication explains the meiofaunal variation in the lagoon's sediments with dominance of nematode and copepod species (like *Euterpina acutifrons*), as well as other taxa found in minor densities, including annelids, mollusks, foraminifera, tardigrades, helminthes, gastrotrich, radiolarians, flatworms, kinorhyncha, isopods, amphipods, echinoderms and other crustaceans, including species of foraminifera (Vásquez-Suárez et al., 2010).

Management status of the wetland

Laguna de Raya is located in the Tetas de Maria Guevara Natural Monument, which according to its management plan and regulations for use (República de Venezuela, 1995), aims to preserve and protect its ecological and scenic resources. The system is integrated by three coastal lagoons: Laguna de Raya, Boca de Palo, and Punta de Piedras. It is located in the Municipio Tubores at the south of Nueva Esparta state, which covers 1,670 hectares and is associated with two hills of singular cultural and historical connotation in the insular landscape.

Laguna de Raya is an area with special administration and is protected by law under the control of the Parks National Institute (INPARQUES) (República de Venezuela, 1995). The water system, mangrove ecosystem, and seagrass, as well as local and migratory sea birds, fishes and other local fauna are protected. The water system is part of the Managed Natural Environment where the artisanal extraction of sea urchins and crustaceans is allowed near the channels opening to the sea but not in the mangroves. Activities not allowed include mining, power transmission lines, publics works and roads, any earthwork and landscape alteration, motor vehicles traffic and especially felling of mangrove and commercial and sport fishing.

Threats: Overfishing, pollution, development

Coastal wetlands provide numerous benefits and use possibilities because their high productivity supports a large group of animals (fishes, mussels, birds) including a few vulnerable or endangered species (amphibians, reptiles). Although the lagoon has enormous species richness, there is not enough reported information on the state of its species. Among the most relevant roles of wetlands are that they decrease flood hazards, improve water quality, provide scenic and recreational value while providing fisheries and aquaculture opportunities. At a global scale, they help stabilize nitrogen, atmospheric sulphure carbon dioxide, and methane values. (Ramírez, 1996; Suárez, 2016).

In a natural monument, possession and use of land is regulated by law. However, the boundaries of the protected area near Laguna de Raya are very close to the coastal lagoon system, allowing the nearby urban area to expand near the lagoon (Figure 2). Miloslavich and colleagues (2003) pointed out that of 21 Natural Monuments in Venezuela, only two show a level of risk from deterioration. In a rating of marine protected areas under pressure, on a scale of 0 to 100 (with 100 the most at-risk), the Tetas de Maria Guevara Natural Monument was rated at 60. Major threats to this area include the impact of human settlements, overfishing, poaching and pollution by maritime transport systems.

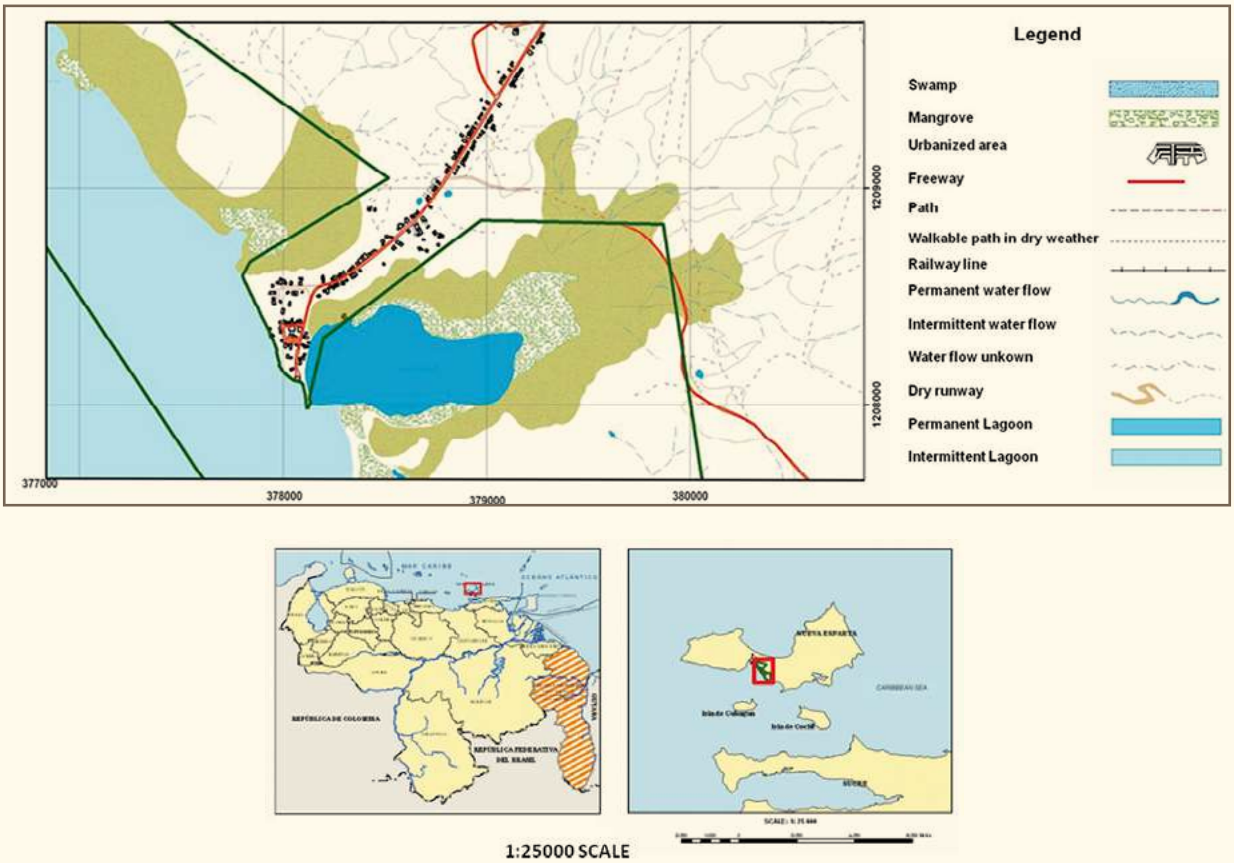

Figure 2. Map of Laguna de Raya within the Natural Monument Tetas de Maria Guevara (green line).

Source: adapted from INPARQUES, 2013.

Local sea urchin extraction

The community near the town, also called Laguna de Raya, is historically involved in fishing for the white sea urchin (*Lytechinus variegatus*). The gonads are used to make a variety of dishes that are part of the culinary tradition in the region's annual sea urchin fair.

The white sea urchin is one of the most abundant species of sea urchin in Venezuela's east coast, and is associated with beds of the sea grass *Thalassia testudinum* and muddy-sandy shallow bottoms. Sea urchins are sold at market in a presentation known as *Cazuela*, a seafood dish in which the urchin test is stuffed with processed gonads (Gómez, 2000). Sea urchins are harvested from May to August or September, while from October to April there is a self-imposed ban by the fishers. Although, exploitation data of the resource are unknown it is presumed that during the fishing season a large amount of sea urchins are extracted because every Cazuela is made from processed gonads of over 250 sea urchins (Gómez, 2001).

In the past few years, overfishing has reduced the abundance of urchins, as demonstrated in studies that compared the abundance in extraction and no-extraction areas. These studies revealed that the October to April ban imposed by the fishers does not allow adequate recovery of the resource; thus, management measures, as well use of cultures and re-population techniques, are necessary (Bracho et al., 2021).

Inappropriate fishing methods

One problem is aggressive fishing methods, especially the artisanal drag net. This net affects important ecological processes, influencing the species diversity in the coastal margin generally in the southwest of Margarita Island (Eslava et al., 2007). According to artisanal fishers, these nets are causing the destruction of marine bottoms, the catch of juvenile population and resource depletion (González et al., 2006).

Drag nets are not used inside the lagoon, but they are used in the near-coastal margin along the beach where the boats discharge their catches. This rectangular net is 600 to 1,000 m long and has a sack to collect fish. Previously, the nets were hauled by hand to the shore by fishers and families; however, lately the nets are pulled in by two boats that drag it from a distance from the coast to the shore, causing conflicts among fishermen over space and resources as well as damaging the bottom environment (González et al., 2013).

Wastes from loading refrigeration trucks

Recent economic hardships have led to the need for easy access to food sources, and sardine has lately become important for food security. Since early 2016, large amounts of sardines have entered Margarita´s coasts, thus increasing the levels of production and catch, which is why, artisanal fishers who usually catch sardines at the southwest of the island, had to find new places to offload their catches: Laguna de Raya was one of them. As fishers landed catches in Laguna de Raya, refrigeration trucks, which distribute the product across the country, came to the area to load the catch. The offloading and reloading of the fish cargo generate odour waste as the decaying matter is thrown by the trucks and boats to the shore. This waste caused complaints from the inhabitants, as well as pollution in local waters, affecting the sea urchins (M. G. Moreno, Fishing Inspector of INSOPESCA, personal communication, June 12, 2017).

Recommended tools for recovery, conservation and management

Because two important landing ports (Punta de Piedras and Boca del Río) are located nearby, it is not necessary to land fish at Laguna del Raya and discharge fishing waste into the lagoon. They are not allowed to do so in this protected area. Even with the boom in captures, fishers can download in landing ports if authorities establish fishing and landing shifts to carry out commercial operations in those ports.

Institutions charged with regulating fisheries (INSOPESCA) and national parks (INPARQUES) should actively intervene. They should implement precise management measures to protect the natural resources of the lagoon. They should:

- Sustainably manage the sea urchin fishery. Designate a legal ban, including minimum catch sizes during the fishing period. Involve the community in urchin production and restocking surveys. These measures are contemplated in the Fishing an Aquaculture Law (República Bolivariana de Venezuela, 2014), in Article 31, which gives the technical standards for the management of marine resources; and in the Article 36, which establishes that the exploitation of aquatic fauna in areas under special administration, is reserved for the artisanal fishers or the organization of their communities with the aim of ensuring the sustainability of marine resources.

- Implement fishing regulations regarding the drag net.
- Prevent the discharge of waste from fishing and loading activities in the lagoon.
- Establish monitoring and control programs to enforce laws and fine those who break the law.
- Extend the protected area of the Natural Monument to preserve the ecosystems in it. Carry out a public consultation in communities within the monument area, and study the entire zone.

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CHAPTER

3

Lau Lagoon at risk?

Climate change as a convenient distraction in the Solomon Islands

By

Jan van der Ploeg
Australian National Centre for Ocean Resources and Security, University of Wollongong
Australia

Delvene Boso
WorldFish
Solomon Islands

Chrisanto Daokalia
WorldFish
Solomon Islands

Hugh Govan
School of Government, Development and International Affairs, University of the South Pacific
Fiji

Abstract

Lau Lagoon in the Solomon Islands is an area of great ecological and cultural value. It harbors extensive seagrass meadows, coral reefs, intertidal mudflats and mangrove forests. The Lau people live on artificial islands, built from coral rocks, in the lagoon. Climate change is thought to pose a severe threat to this way of life. In policy, science and development discourses, the erosion and abandonment of man-made islands is attributed to rapid sea level rise and extreme weather events. In this paper we demonstrate that this rhetoric risks distracting attention and resources from other, more pressing, environmental problems such as deforestation and overfishing.

Keywords:

Pacific | Malaita | policy narratives | resilience | community-based resource management | coral reefs

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Lau Lagoon

The Lau Lagoon extends for approximately 35 km on the northeast coast of Malaita in the Solomon Islands (Figure 1). The shallow bay contains the largest seagrass area in the country, interspersed with channels, deep pools and extensive coral reefs. The lagoon is fringed by mangrove forests and a barrier reef. The lagoon harbours a rich diversity of coral, fish and seagrass species, and has been identified as a priority area for marine conservation in Solomon Islands (Green et al., 2006).

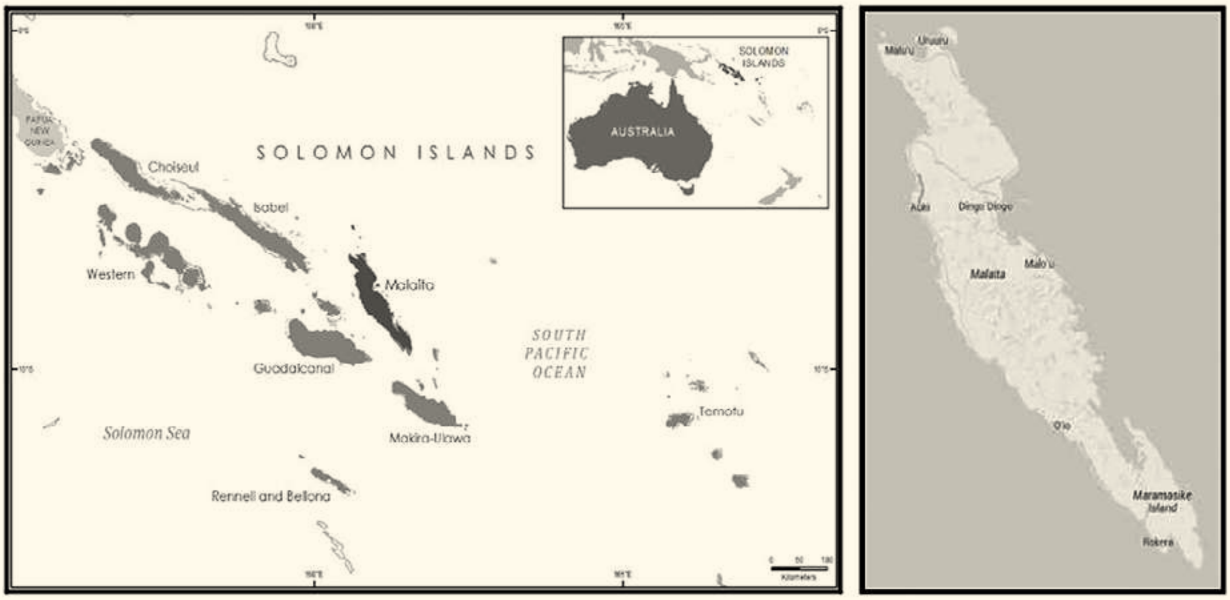

Figure 1. Map of the Solomon Islands. Inset: Province of Malaita with Lau Lagoon on the northeastern tip of the island.

Source: WorldFish.

What makes the lagoon truly remarkable is its large number of man-made islands (Ivens, 1930; Maranda, 2008). These islands, locally called called fera *'i asi* (village on the sea), are built by the Lau people by manually hauling and piling up coral rocks on shallow reefs to create stone walls often more than 3 m high. There are 94 artificial islands in the lagoon, of which 79 are inhabited (Satomi, 2012). Some of these islands, such as Sulufou, Funafou and Tauba, are relatively large (greater than 1 ha), and are densely populated (Figure 2). Others are very small (less than 100 m2). Some settlements were also built on natural islands in the lagoon. Other villages have been built in the mangroves by constructing coral rock walls and filling the enclosure with gravel and sand (Molea & Vuki, 2008). In most cases, these islands are just above the high-water mark (less than 30 cm). Most houses are constructed on stilts (Figure 3).

Figure 2. Satellite image of the northern part of Lau Lagoon.

Inset: the artificial islands of Niuleni and Funafou.

Source: MECDM.

Little is known about the origin of these man-made islands. Oral history recounts that the first artificial islands in Lau Lagoon were constructed around 600 years ago by people defeated in tribal wars on mainland Malaita. It has been postulated that the island settlements were an environmental adaptation to endemic malaria in the lowlands (Parsonson, 1966). In any case, a vibrant culture developed in the lagoon, and in the early 1900s the Lau had become the dominant ethnic group in North Malaita, largely due to their control of the lucrative labor trade (Randell, 2004; Moore, 2017).

Figure 3. Houses on stilts to avoid flooding at Funafou Island in Lau Lagoon.

The Lau are known as *solwata pipol* (saltwater people). Fishing forms the basis of their livelihoods, and the Lau have an in-depth knowledge of their marine environment (Figure 4; Akimichi, 1978). The Lau have names for at least 115 fish species and use a great variety of fishing methods in the lagoon. Fish, mangrove crabs, marine turtles and shells are bartered for root crops and vegetables with Baegu and Baelelea farmers from the uplands (Figure 5; Ross, 1978; Molea & Vuki, 2008). A complex tenure system regulates access to and use of marine resources in the lagoon. Reefs and deep pools are generally claimed by patrilineal descent groups, locally referred to as 'tribes' (Akimichi, 1991). In principle these collective rights are exclusionary, but in practice, others, particularly people on the matrilineal line, have historical usufruct rights. Traditionally, the Lau managed their fisheries by imposing temporal closures on certain reefs (Sulu et al., 2012). Such 'taboo areas' were ritually sanctioned by the priests; any violators would be eaten by sharks or saltwater crocodiles (van der Ploeg et al., 2019).

Figure 4. Alick Kunio catches a goatfish in the lagoon.

Photo © J. van der Ploeg, 2016.

Figure 5. Women barter fish for root crops and vegetables on Takwa market.

Photo © J. van der Ploeg, 2015.

Climate change as an existential threat

"As if we were enticed by a dream, the rising sea level is a reality unjustly struck at the very core of my people's sanity. It denies our dignity to live just as it destroyed our vulnerable homes and left us homeless. Once my people were warriors, now we're but a displaced uprooted people. Along our beautiful Lau Lagoon, human-made islands are washed, destroyed to their cores, uninhabited, deserted and ruined by Mother Nature. Unlike the frigate birds in the sky forced by the high tide and return when the tide is low, my people are uprooted and flogged unjustly by the effects of climate change and never to return to where they once lived." (Akao, 2016).

In a rather melodramatic opinion article in the *Solomon Star*, Reverend Philemon Akao highlighted the vulnerability of the Lau people to climate change. In the media, climate change is often described as "the greatest threat to the survival" of people living in the lagoon (Wilson, 2013). For example, a 2015 article in the *Island Sun* noted that "people's lives have been threatened as soil fertility and sea resources have been slowly exhausted due to climate change" and that "sea level rise is the biggest threat for the artificial islands now, as most of the man-made islands are now partially under-water even from normal high tides" (Figure 6; Bilua, 2015).

Figure 6. Climate change features prominently in the local media.

Source: Malaita Star, 2016; 2017.

The same arguments are regularly made in science, policy and development discourses. Rebecca Monson and Joseph Foukona, for example, wrote in a book about climate displacement that people in Lau Lagoon increasingly have to cope with changing wind patterns, extreme weather events, coastal erosion and saltwater intrusion:

> **"The people of Lau have experienced unusually high tides on several occasions. High tides have washed through the villages, destroying kitchens that are built directly on the ground of the islands; flooding houses; and carrying refuse from the toilets that surround the islands. Some islanders are now attempting to relocate to the mainland but most wish to remain on their islands."**
>
> ***(Monson & Foukona, 2014: 298).***

Along similar lines, James Asugeni and colleagues (2015: 23–24) report that the inhabitants of the artificial islands are deeply concerned about climate change: people are contemplating moving to higher ground and therefore call for government support: "the leaders in government must give us some help because the sea water has spoiled our place."

This call has certainly been heard. The Solomon Islands' National Adaptation Programs of Action (NAPA) identified the artificial islands on Malaita as "being the most vulnerable to climate change and sea-level rise [...] many of these communities and/or villages live on or at the edge of the sea and are often subject to impacts of storms, storm surge, sea-level rise, drought, saltwater intrusion, and flooding" (MECDM, 2008: 86). The Ministry of Environment, Climate Change, Disaster Management and Meteorology (MECDM) therefore considers resettlement as a potential adaptation measure for these communities.

Over the past years a number of projects have aimed to mitigate the projected effects of climate change in the lagoon. The Red Cross, for example, facilitated "participatory vulnerability and adaptation assessments" on several artificial islands in Lau Lagoon. It found that "access to usable water is a major problem due to increasing salinization of local water tables caused by rising sea levels" (Tuwere, 2010), and subsequently donated rain-water storage tanks to several communities. The United Nations Development Program implemented the *Strongem Waka lo Community fo Kaikai* (SWOCK) project to "promote and pilot community adaptation activities that enhance food security and livelihood resilience" in the lagoon. The project organized meetings to raise awareness on the impacts of climate change, physically mapped projected sea level rise by placing red pegs 1 m above the current watermark, and distributed vegetable seeds (Kauhiona, 2011). More recently, the Community Conservation Resilience Initiative (CCRI) conducted "participatory resilience assessments" on two man-made islands in the lagoon. The outcome was that:

> **"Sea level rise is a major external threat that impacts not only these two communities but also other islands and communities throughout the Solomon Islands. It is one of the biggest challenges in both the short- and long-term and is forcing the communities to consider measures as drastic as relocating to the mainland in Malaita"**
>
> ***(Akao, 2015: 11).***

In 2016, the Community Resilience to Climate and Disaster Risk Project (CRISP) conducted several scoping visits to the lagoon to "'increase the capacity of communities to manage natural hazards and climate change risks." And the Climate Displacement Land Initiative witnessed that "increasing numbers of these islands are now beginning to lay uninhabited as residents leave behind destroyed homes and flee the ever-worsening consequences of climate change" (Displacement Solutions, 2016).

If one succeeds in cutting through the bewildering number of acronyms and the development jargon, a clear narrative emerges. The environmental problems reported by Lau islanders seem to confirm global climate change models and scenarios: rising sea level is flooding and eroding the artificial islands in the lagoon forcing people to relocate to higher ground; salt water intrusion is contaminating freshwater supplies; changing rainfall is affecting agricultural productivity and exacerbating food insecurity; violent tropical cyclones are destroying houses and crops; and higher water temperature and ocean acidification are degrading coral reefs, seagrass meadows and mangroves in the lagoon. The island builders of Lau Lagoon are at the forefront of global climate change – the proverbial canaries in the coal mine.

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Hot air?

The question, however, is whether those impacts can be attributed solely to climate change. There is an inherent danger of confirmation bias when trying to validate models, particularly when these predictions are used as a basis for policy or development interventions. Walters and Vayda (2009) therefore advocate using a 'historical causal analysis' to understand environmental change. Such a pragmatic research methodology reveals that many of the assumptions of the climate change narrative above simply do not hold.

First, the assertion that climate change-induced sea level rise erodes the artificial islands thereby forcing people to relocate to the mainland confounds causes and effects. Over the past years some islands in the lagoon have indeed disintegrated, but this usually happens *after* its inhabitants relocate to the mainland. Thus, the abandonment of the islands leads to erosion – not the other way around. The artificial islands require constant maintenance to avoid the collapse of the sea walls; when people no longer live on an island it slowly falls apart. It is clear that people are abandoning the islands. In the 1970s approximately 5,500 people lived on the islands in the lagoon (Damon, 1974; Akimichi, 1978). The 2009 census recorded 2,750 people in Foueda ward (SINSO, 2009), a 5 percent population decline per year.

Over the past 50 years people have built new villages on the mainland. It would, however, be erroneous to attribute this to climate change. Malaria and tribal warfare, the main reasons to live on the islands, are no longer a constant threat. Many people opted to live permanently near their gardens and plantations. Others settled around the mission posts on the mainland, for example in Gwou'ulu and Takwa. And more recently there has been an exodus of people to the national capital Honiara in search of education, jobs and a different life.

Attributing the abandonment of the man-made islands solely to rising sea levels is reductionistic and flawed. Along similar lines, it is well-documented that sea levels in the western Pacific Ocean are rising faster than anywhere else in the world (IPCC, 2013). However, climate-induced sea-level rise operates in a dynamic, and little-understood, interplay with extreme weather events, plate tectonics, ocean currents and human interventions, which can have dramatic geographical consequences (Connell, 2015; Albert et al., 2016). In 2007, for example, an earthquake in Western Province caused a 3 m land uplift which destroyed mangroves and coral reefs (Sulu et al,. 2012).

Second, there is little empirical evidence for the claim that climate change is constraining agricultural productivity and threatening food security in Lau. The notorious 1997–1998 El Niño drought affected gardens in North Malaita, but the most serious problems were felt in the urban centers and on remote coral atolls (Barr, 1999). Historically, the Lau cultivated taro and yams on swiddens on the mainland. Traditional crop rotation schemes and fallows have been shortened because farming systems intensified over the past 50 years. Nowadays the Lau also grow sweet potatoes, cassava, peanuts and a variety of vegetables for subsistence. Copra, watermelon, cocoa, and betel nut have become important agricultural commodities. Consequently, soil degradation, erosion and pests have become serious problems.

Agricultural development is further hampered by a structural lack of technology, skills, credit facilities, farm-to-market roads, reliable energy supplies and agricultural extension services. Declining terms of trade for key agricultural commodities is another significant problem for farmers in Lau. Along similar lines, there are serious concerns about food security and nutrition in Lau Lagoon, particularly related to the replacement of traditional diets by cheap, nutritionally poor imports, such as noodles, and the resulting long -term impacts on health (Andersen et al., 2013).

A number of other interconnected social and political problems, such as youth unemployment, poor healthcare and education, gender-based violence, land tenure disputes, alcoholism and urbanization further exacerbate food insecurity and malnutrition. Climate change will likely aggravate these stressors (Bell et al., 2016). But whether climate change mitigation and adaptation action will help solve these complex problems is highly doubtful (O'Brien et al., 2004; Eriksson et al., 2020).

Third, few climate change predictions have captured public imagination so much as extreme weather events in the Pacific. Interestingly, climate models predict a substantial decrease in the total number of tropical cyclones in the South Pacific, although the intensity of the remaining storms might increase (Walsh et al., 2012). In Lau Lagoon, severe storms have destroyed entire islands. Tropical cyclone Angela, for example, caused a 9 m storm surge that flooded the islands in 1966 (SIHE, 2013). A year later, in 1967, cyclone Annie destroyed houses and coconut plantations in North Malaita. And cyclone Ida in 1972 caused massive devastation in the lagoon and encouraged landward migration (Connell, 1977). It illustrates that tropical storms have always been an integral part of life in Lau Lagoon (Schwarz et al., 2011). Likewise, king tides are flooding the man-made islands in the lagoon causing damage to houses. But to some extent this has always been the case.

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The missionary Walter Ivens, who made several visits to Lau Lagoon between 1895 and 1909, for example, wrote:

> **"The islands are all built up to a height sufficient to keep out high spring-tides, and the only danger of flooding is in December and January, when the very high tides which then occur may be banked up in the lagoons by a strong north-east wind. At such *times it is not uncommon for the water to come into the houses, but this is part of the life* and nobody minds"**
>
> ***(Ivens, 1930: 52, emphasis by the authors).***

What has changed is people's vulnerability to flooding: people nowadays have more goods, such as papers and electronics, that cannot become wet, and new buildings are often constructed with concrete and timber and are no longer on stilts.

Fourth, we know very little about how climate change is impacting the dynamics, vulnerability and resilience of coastal lagoon systems in the tropics (Carrasco et al., 2016). What we do know is that overexploitation and the use of unsustainable fishing practices, such as trammel nets, spearfishing at night and the use of dynamite, is threatening specific marine species, such as sea cucumbers, Maori wrasse and green bumphead parrotfish (Figure 7; Govan et al., 2011; Schwarz et al., 2013). We also know that many coastal communities are overexploiting mangroves for firewood (Warren-Rhodes et al., 2011), and that the extraction of corals for construction materials is degrading coral reefs (Albert et al., 2015; van der Ploeg et al., 2020a). We know that soil degradation, pests and diseases are impacting agricultural productivity (MDPAC, 2007; Wairiu, 2017). And we know that commercial logging companies are destroying mangrove habitats, causing oil pollution and triggering massive erosion (Bennett et al., 2014; Hamilton et al., 2017; Minter et al., 2018). Addressing these threats will effectively reduce the vulnerability of coastal communities to the long-term impacts of climate change. The converse is unfortunately often not the case. In fact, a narrow focus on climate change adaptation tends to distract from other, more pressing environment and development problems (Kelman, 2014).

Figure 7. Jimmy Oeta shows a green bumphead parrotfish (*Bolbometopon muricatum*) that he will transport to and sell at the market in Honiara.

Photo © J. van der Ploeg, 2016.

Addressing direct threats of overfishing, deforestation, and unsustainable agriculture

So why does the climate change narrative remain so persistent, despite the uncertainty, complexity and contradicting empirical evidence? Partly, it can be attributed to lazy journalism, bad science, disengaged policy and opportunism of development non-governmental organizations.

Partly, it offers a simplification for a range of wicked problems: such reductionism is useful – and perhaps even necessary – to mobilize resources in the political arena. This clarifies to a large extent why people in Lau Lagoon consistently report that climate change is a major threat for their survival. If staff from the Community Resilience to Climate and Disaster Risk Project, the Coping with Climate Change in the Pacific Island Region Program or the Community Conservation Resilience Initiative visit the lagoon, villagers will surely identify climate change as an important problem for their community in order to secure water tanks, seeds, building materials, training opportunities and other development aid (Figure 8). Likewise, when WorldFish facilitates community action plans, people will rank sustainable fisheries management as their number one priority (van der Ploeg et al., 2016). Indeed, the outcomes of many "vulnerability and adaptation assessments" primarily reflect poor social scientific research methods and manipulative participation processes. Despite the participatory rhetoric most climate change adaptation projects in Solomon Islands remain largely expert driven (PCESD, 2011: 182–202).

Figure 8. A climate change resilience and adaptation water tank in Ferafalu.

Photo © J. van der Ploeg, 2017.

And partly, climate change is a "convenient distraction" (Kelman, 2014: 123). A narrow focus on climate change risks *depoliticising* environmental and development problems in Lau Lagoon. An emphasis on a supposedly new, single, external, natural hazard – climate change – allows many stakeholders to escape from their responsibilities

(Gaillard et al., 2007). It is much easier to conduct another "participatory vulnerability and adaptation assessment" or draft "community climate change action plans" than to hold logging companies accountable or enforce fishing gear restrictions.

It is clearly not our aim to downplay the long-term impacts of climate change. The point is that the climate change threats projected on Lau Lagoon by scientists, journalists, policy makers and development experts are uncertain and distant, and in some cases flawed and misleading. The danger of these narratives is that they tend to dismiss facts that do not fit the hegemonic view as irrelevant, unscientific, or – worse – climate change skepticism. For example, the fact that new artificial islands are being constructed in Lau Lagoon is seldom mentioned in the literature. More importantly, by linking all conservation and development problems to climate change, these narratives risk disempowering rural communities, and negating community-driven efforts to conserve marine ecosystems and improve rural livelihoods (Figure 9). A major challenge is to avoid portraying the saltwater people of Lau Lagoon as helpless victims of climate change, but instead find practical ways to support these coastal communities in addressing the root causes of their vulnerability (Johannes, 2002; Govan et al., 2019).

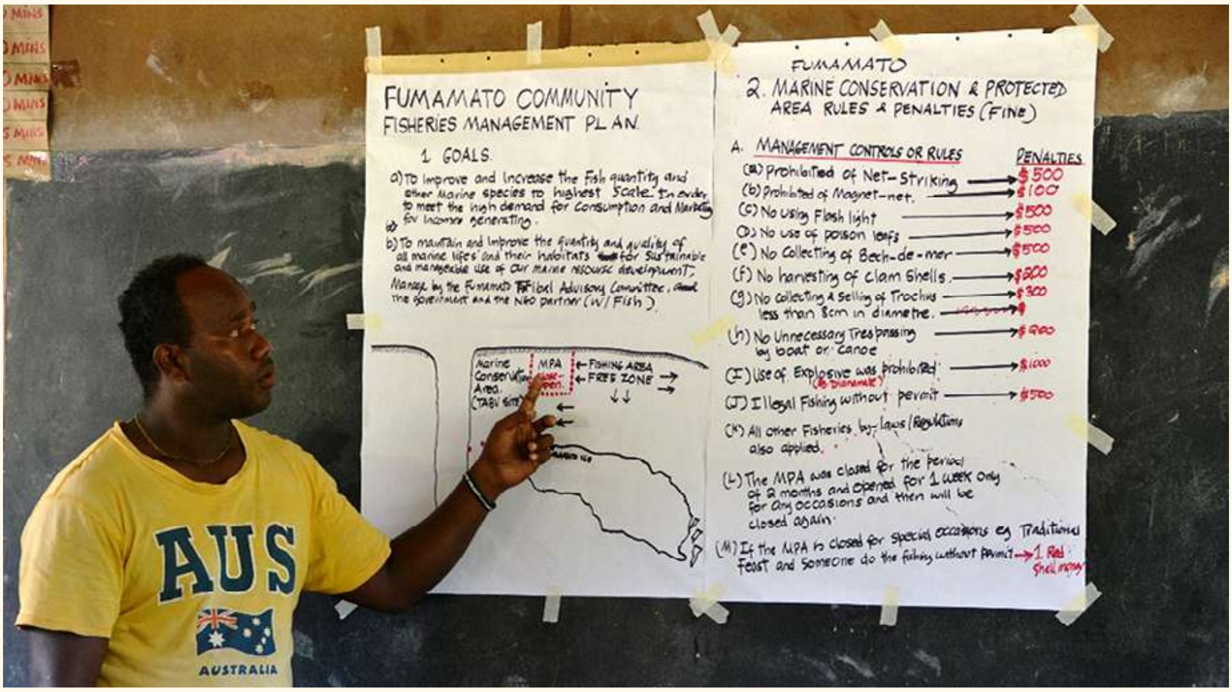

Figure 9. Joe Diau presents the rules of the Fumamato'o community fisheries management plan on Manaoba Island. Community-based resource management can protect marine ecosystems, improve rural livelihoods and empower communities.

Photo © J. van der Ploeg, 2015.

Conclusion

In this paper we have argued that climate change is perhaps not the most severe threat to people living on the artificial islands in Lau Lagoon. The considerable financial resources invested in climate change adaptation projects in the lagoon can better be used to address more direct threats to this unique wetland, such as overfishing and deforestation, and to address more urgent development problems such as the appalling condition of primary healthcare or the lack of farm-to-market roads (van der Ploeg et al., 2020b). In fact, it is increasingly clear that the protection and restoration of marine ecosystems is one of the most cost-effective measures to reduce the adverse impacts of climate change (IPCC, 2018; Gattuso et al., 2018).

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