TECHNICAL REPORT ON FRESHWATER WETLANDS

REPUBLIC OF MAURITIUS

Prepared for:

MINISTRY OF THE ENVIRONMENT AND NDU
GOVERNMENT OF MAURITIUS

Prepared by:

NWFS Consultancy
4050 NW Carlton Ct
Portland, OR 97229

STEM Consulting Ltd. and

THE WATERSHED COMPANY

750 Sixth Street South
Kirkland WA 98033

(Final- 15 June, 2009)

TABLE OF CONTENTS

Page No.

TABLE OF CONTENTS (cont.)

List of Figures **Page No.**

List of Tables

EXECUTIVE SUMMARY

This report presents a review of the wetlands of the Republic of Mauritius prepared for the Ministry of the Environment & NDU. This report forms part of a larger study of Environmentally Sensitive Areas of Mauritius and Rodrigues. A survey of the Grand Baie wetlands was also undertaken initially and that report was submitted separately (April 2008), although biophysical and geospatial data from that survey have been incorporated into this report. Information contained with this report cover freshwater wetlands falling within four separate ESA type classifications: Coastal Marshlands, Upland Marsh, Lakes & Reservoirs and Rivers & Streams. However, greater focus was directed at the coastal and upland marsh types since these proved the most poorly characterised and formed the main intent of the project objectives.

The specific objectives of this study were to locate, delineate, map and characterise the physical, biological and ecological characteristics of Mauritian wetlands. In addition, a field survey of the following habitat disturbances was undertaken at each wetland: (1) patterns of habitat fragmentation; (2) percentage of edge-habitat disturbed; (3) types of adjacent land-uses; and (4) backfilling and flooding risks to infrastructure and houses. Finally, land tenure and ownership were determined for each wetland.

We identified 203 coastal marshlands in Mauritius of which approximately half were habitat fragments of once-contiguous wetlands. Coastal marshland generally reside in areas less than 20 metres above sea level (asl), with around 13% of the total documented area falling below sea level, based on an interpolation of the base 10 metre topographic contour data made available to the project. The bulk of these sub-zero marshlands are located in the Grand Baie, Post Lafayette/Roches Noire, Wolmar and Belle Mare/Palmar areas.

Coastal Marshland appears to aggregate along margins where normal riparian drainage has failed to form or been removed through historic land use change.

Consequently, it appears to be acting as the main hydrological system in the Riviere du Rempart and Flacq districts.

Based on standardised vegetation surveys and mapping of each site, we characterised these wetlands into four structural and community types: (1) Open-water and grass-dominated wetlands; (2) Open-water and *Acrostichum*-dominated wetlands (with *Rhizophora*); (3) Vegetated wetlands dominated by *Typha* and grass; and (4) Vegetated wetlands dominated by *Typha* and *Acrostichum*. We examined biological diversity across these wetland types and found that wetlands dominated by *Acrostichum* of either open-water or vegetated structure supported the following: 1) more total biodiversity, 2) more plant diversity and 3) more terrestrial plant diversity, than the wetland types (1 & 3) dominated by grass and *Typha*. Aquatic plant diversity, alternatively, was found to be significantly higher in vegetated wetlands (3 & 4) compared to open-water wetlands. There was no effect of wetland type on fauna diversity. In summary, it appears that wetlands have acted as important refuges for plant species in the coastal lowlands of Mauritius. The low-lying and frequently rocky features of these wetland habitats has made them unsuitable for agriculture and ensured the protection of many native plant species, particularly immediately adjacent to and within the buffering ecotone.

Continued urbanisation and expansion of residential housing was identified as the key contemporary threat to Mauritian wetlands, exacerbating earlier losses of wetlands from centuries of farming in the lowlands. The process of backfilling and fragmenting wetlands has markedly reduced the area of wetlands within most major Defined Settlement Boundaries and disturbed most wetland edges. The construction of homes in these low-lying areas has also increased the risk of flooding to houses and infrastructure.

More than 600 individual upland marsh features were identified through classification of remotely-sensed imagery (SPOT panchromatic, 10m resolution) combined with a basic net of field-collected, data control points. A filter was applied to remove areas less than 100 m^2. Upland marsh is principally found in the Plaines Wilhelms district, particularly with the Black River Gorges National Park and adjoining State Forest

Lands between 500 and 720m above sea level (asl). They are characterised by localised, flat topography and slow drainage. Highly clustered, upland marsh features are relatively small (900 m^2 on average) as small-scale, topographic relief shapes presence of marsh-like conditions. Vegetation consists primarily of sedges, grasses and a variety of endemic *Pandanus* spp. (Vacoas). They are intermixed with endemic heath and exotic plantation forest (mainly *Pinus* spp.) in the main areas.

Upland marsh, lakes and reservoirs are almost exclusively found on State Land in some of the more remote areas of the island. Consequently, while they represent important ESAs and rank highly in terms of conservation value, they are presently subject to few of the pressures currently being exerted on coastal marshland. All upland marsh features have been assigned to High or Moderate Conservation Value categories due to their limited distribution, hydrological role attached to reservoir function and repository of endemic Mauritian biota. Few of the most significant upland marsh areas appear under threat with virtually all of the remaining area located within areas of State Land. Most lakes and reservoirs have been assigned a Moderate Conservation Value. Bassin Blanc has been assigned High Conservation Value due to its relatively undisturbed condition and repository of endemic Mauritian biota.

1. INTRODUCTION

1.1 Background

It is only in the last decade that wetlands in Mauritius have received any formal recognition of their environmental values, or were afforded even partial legal protection. In 1997, Mauritius signed the Ramsar Convention, an inter-governmental accord established to protect and foster the wise management of wetlands for the conservation of migratory birds. This resulted in the designation of a key wetland reserve, the Rivulet Terre Rouge Estuary Bird Sanctuary, in 2001. Although the Fisheries and Marine Resources Act of 1998 provided a legal mechanism for the protection of some wetlands, it was limited in scope as it considered only wetlands that were contiguous with the marine environment. This lack of protection for freshwater wetlands and their general proximity to lowland coastal areas, which are under heavy development pressure, has resulted in the loss and fragmentation of many such wetlands in Mauritius.

The importance of coastal wetlands as habitats with valuable environmental and economic functions was highlighted more recently in the National Development Strategy (2003), which identified them as one type of Environmentally Sensitive Areas (ESAs) needing urgent consideration in any further development of Mauritius. The National Development Strategy recommended two planning policies: first, that wetlands needed priority protection (Policy Env2), and second, that many wetlands may require ecological restoration (Policy Env3). These recommendations are embodied in the text of the draft Wetland Bill (2007). The Wetland Bill provides for "The sustainable development, management, protection and conservation of wetlands and wetlands resources in the Republic of Mauritius." Under this new draft legislation, wetlands are to be identified based on ecosystem criteria listed in Schedule One of the Bill, and a management plan is required for each site.

1.2 Current Status of Wetlands in Mauritius

As part of this review of wetlands and other Environmentally Sensitive Areas (ESAs) of Mauritius, a recent field survey of wetlands of the Grand Baie area was completed, and a separate report prepared for the Ministry of Environment and NDU, Government of Mauritius (Ministry of Environment and NDU 2008a). The Grand Baie survey identified 12 remaining wetlands, encompassing a total area of 15.4 hectares, which is about 43% of their original extent in 1980. The Grand Baie wetlands were singled out as a management priority because flooding of residential properties has recently increased in frequency, as ever more residential properties are being constructed in backfilled wetlands (Environmental Risk Report for Grand Baie, 2004). The unrelenting pressure on the wetlands adjoining the Grand Baie and its ultimate consequences for the sustainable development of this important international tourist destination highlights a process that is spreading to other areas as further development proceeds. Yet, the distribution, extent and biology of these important habitats in Mauritius remain poorly resolved. Despite some recognition of the important environmental services being delivered by wetlands, the absence of an integrated knowledge base has retarded efforts to develop effective policy. Without well-crafted policy in place, it remains difficult to understand the implications of wetlands use and protection on private-sector growth and public good, and to formulate cost-effective management of these areas in a manner consistent with national and international best practice.

1.3 Project Aims

The Terms of Reference of this project aim to address these critical information needs. The main component of the TOR call for the study to locate and classify all wetlands in Mauritius and Rodrigues, and to provide land-use recommendations for each site using three main categories:

a) Wetlands of high biodiversity value that should be fully protected;

b) Wetlands where certain specified types of development activity could be permitted;

c) Wetlands where development could be allowed.

1.4 Project Outputs

The Terms of Reference for this project require four main actions:

1) Identify and locate all wetlands in the Republic of Mauritius;

2) Prepare survey maps of each wetland at 1:5000 scale;

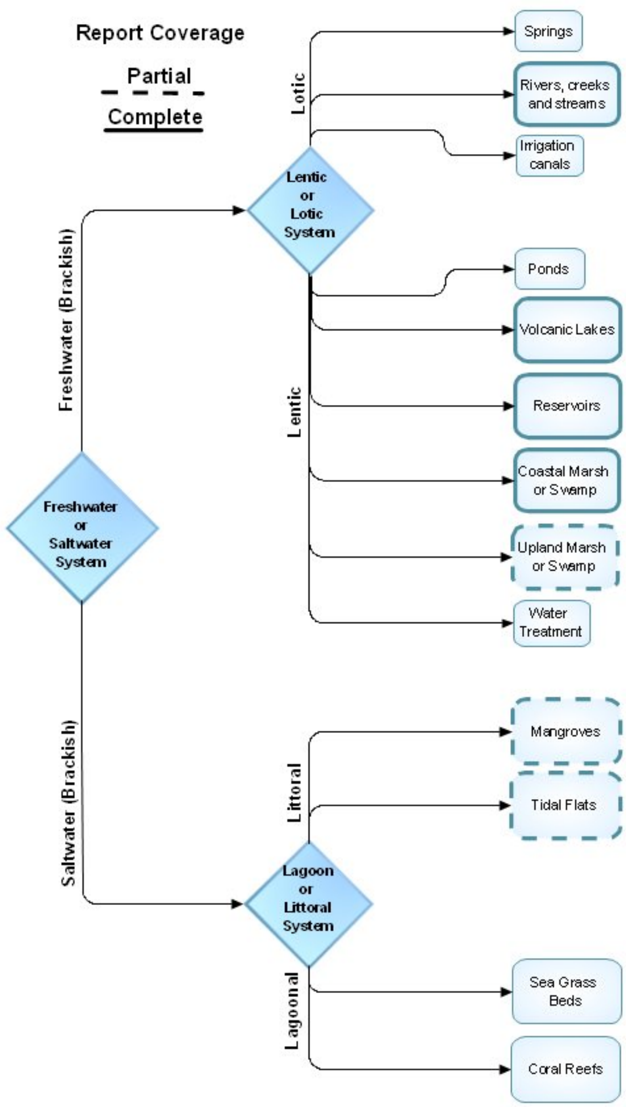
3) List the ecological and physical characteristics of each wetland;

4) Categorise wetlands into three groups based on their conservation values and appropriate land-use guidelines.

1.5 Wetland Types in Mauritius

The Ramsar Convention adopts the widest possible definition of a wetland in order to ensure that areas of international importance for migratory birds are not precluded from listing. Considering this widest definition and applying it to Mauritius and Rodrigues yields a suite of thirteen wetland types (Figure 1). These types can be classified based on salinity, tidal and flow rate attributes.

For the purposes of this study, it was agreed to define wetlands as "Areas of fresh or brackish water to varying depth, not actively attached to the marine environment via natural or man-made surface channels or flows, and characterized by soils, plants and animals whose distributions are affected by, or adapted to, permanent or frequent inundation and/or complete saturation" (Ministry of Environment and NDU 2008b). This is consistent with the marsh component of wetlands as defined in the Fisheries and Marine Resources Act 1998 and the Wetland Bill 2008 (Draft), but does not include areas continuously submerged by seawater. Adopting the full suite of prospective wetland types sensu Ramsar Convention, would yield an unworkable framework in forging a balance between protection and sustainable development since the full range of wetland area under this approach would cover the entire lagoon and invariably require areas actively contributing to sustainable livelihoods attached to fishing, tourism and recreation to be removed from use entirely due to the structure of the analysis. The estimated cost of carrying out such an approach would ultimately preclude its implementation and limit the value of critical findings attached to Freshwater Marshland conservation.



Freshwater Marshlands can develop under various terrestrial landscape conditions depending on topography and dominant water sources. Generally, they can form from riverine flooding, a landscape depression, non-permeable edaphic structures, or estuarine and lake fringes. The delineation of wetlands is based on the presence of characteristic vegetation, soils and hydrology.

1.6 Wetland Ecosystem Services

Biological and Habitat Conservation Services

Wetlands are unique ecosystems where aquatic and terrestrial life forms assemble. Although they exhibit some biologically similarities, lentic and lotic wetland communities are shaped by very different hydrological conditions. Permanent inundation in the absence of strong currents, high dissolved organic carbon concentrations and thick organic matter accumulation in marsh/swamp wetlands requires specialized plant-forms (hydrophytic species) that can survive both inundation and low-oxygen soils. The gentle transitional zone (ecotone) along the edges of wetlands frequently supports a community composition that is distinctive and not represented elsewhere in the landscape. The transitional zone is where terrestrial and aquatic species overlap, and it is often both rich in species and biologically productive. In addition to the unique community composition, wetlands also provide crucial habitats for terrestrial species that have an aquatic life-stage or require water for survival, particularly amphibians, water-birds, snails and other invertebrates. Many migratory birds require some form of wetland habitat in order to successfully overwinter.

The biological diversity of wetlands results from their habitat diversity, their unique community composition, their species richness, and the presence of rare and endangered species. Biological diversity is one of the most important criteria to be considered when identifying areas for conservation within a protected-area network. A second key feature is the level of disturbance by adjacent land uses. Wetlands are vulnerable to disturbance for a number a reasons. For instance, water tables can be altered by adjacent activities, the aquatic nature of wetlands makes them highly permeable to pollution, and their edge habitats are vulnerable to disturbances such as backfilling. Many of the Grand Baie wetlands have already lost their transitional zone from backfilling. Additional threats include habitat fragmentation, altered water flows, and altered inundation periods caused by the concentration of water into smaller areas, which often increases water depth. All these factors affect the functioning of the ecosystem, which in turn will affect its biological diversity.

Hydrological Services

In addition to the significant biological values of wetland ecosystems, they also have a wider role in the natural hydrology of the landscape. Lotic wetlands, such as rivers, integrate the surface hydrology across the watershed. River networks drive landform evolution, acting as the fastest transfer route of dissolved and particulate matter from terrestrial to marine environments. Changes to this rate as a consequence of human land use alter the biogeochemical mass balance, with consequent ecological adjustments in both source and sink habitats. Lentic wetlands, such as coastal marshes and swamps, capture surface flows, slowing down water movement and buffering these rate changes. This allows large particulate matter to settle to the wetland bottom, reducing the export of terrigenous sediment and anthropogenic nutrient pollution to the surrounding coastal lagoons. Thus, wetlands function as natural "sediment and pollution traps" that help to buffer changes in lagoon water quality as a consequence of land use change.

Unfortunately, the backfilling of wetlands along the Mauritius coast has significantly decreased the area of wetlands and significantly increased surface water flow to the sea. This has resulted in elevated levels of suspended solids, nutrients from sewage and fertilizers, and contaminants entering coastal lagoons. Declining water quality and algal growth has already been detected in several portions of the lagoon (Baird et al 2003, Ministry of Environment and NDU). Coral-reef ecosystems are also highly sensitive to eutrophication (such as algal blooms that rob the water of oxygen) from nutrient runoff, sedimentation, and temperature changes, and must be protected from such sources if possible.

Mauritius occurs within the cyclone belt with each year typically bringing a cyclone within 100 kilometers of its coasts. The intense rainfall associated with such events can overwhelm the landscape, and has particularly heavy erosion and flooding impacts on mountain slopes, rivers, and floodplains. As a key element of the lowland floodplain, coastal wetlands are crucial in slowing water speed and thereby promoting aquifer replenishment and allowing sediments to settle out. In this way too, wetlands protect nearby marine environments.

In late March 2008, Mauritius was seriously affected by flooding due to heavy rainfall over three consecutive days. The recent flooding of homes in and around converted wetlands in Grand Baie and Flic en Flac during this period has demonstrated both weak municipal planning and limited public understanding about the risks of residential developments in wetlands. The low-lying topographical position of these properties means they have a high probability of experiencing future flooding. If such developments continue, expensive new infrastructure to reduce flooding will be needed. Even more importantly, such infrastructure will direct damaging, sediment- and pollution-laden flood waters directly into the surrounding lagoons, which could rapidly degrade an ecosystem that is vital to the tourism industry and long-term economic health of Mauritius. Despite these risks, as detailed in the 200

In general, future climate-change projections suggest that rainfall will become less predictable, with droughts and torrential rains becoming increasingly likely. The IPCC Climate Change Report (IPCC 2001) for Small Island States reviews a number of individual studies that predict an increase in cyclone intensity of 10-20% with increasing $C0_2$, and a decline in cyclone formation of 10%. Droughts will place pressures on Mauritian water supplies, whereas torrential rains will challenge the capacity of natural ecosystems and man-made structures to deal with floodwaters. Under such circumstances wetlands, with their many natural hydrological benefits for flood amelioration, water storage, and improving water quality, will contribute significant ecosystem services critical to the sustainability of future economic growth in Mauritius.

2. METHODS

2.1 Locating and Delineating Wetlands

Wetland Location

The adopted approach for locating wetlands is based on cross-referencing four data sources: (1) topographical maps of Mauritius at 1:25,000 scale (circa 1990); (2) higher-resolution outline-scheme maps at 1:5,000 scale (circa 2006); (3) expert local knowledge and (4) remotely-sensed imagery (SPOT-5, panchromatic, 10m resolution, 1:2,500 aerial photographs 1997-2000, QuickBird 2004-2008, 10-20m resolution).

Maps at 1:25k scale (Government of Mauritius 1990) were utilized as a base reference for identifying the location of many of the larger, more conspicuous wetlands: including 52 marsh/swamp and 17 major reservoir and lake features. This set was cross-referenced with 1:5k maps created as part of the District Council Outline Planning Scheme (Government of Mauritius 2006). The maps indicated an additional 27 wetland areas not spatially congruent with those positioned on the 1:25k Series. In addition, the distribution of the zero-height topographic contour across the country proved useful in locating areas most likely to exhibit planation features leading to water collecting, rather than shedding. A national-scale wetland location map provided by the National Parks and Conservation Service (NPCS) was also consulted and cross-referenced during this process.

Wetland locations were also triangulated utilizing Google Earth Pro and LandSat (1999) archival image data. The acquisition of new satellite data from SPOT-5 was completed in February 2009, after a significant delay, principally due to the coincident timing of the wetland project phase and high cloud cover conditions resulting from seasonal cyclonic activity and the prevalence of a La Nina-phase Southern Oscillation condition during the first half of 2008. Initial ground-truthing of Mauritius and Rodrigues was successfully conducted in May, 2008 by the Remote Sensing Specialist and further assessment of other wetland features, particularly those possibly existing under canopied forest or inaccessible upland locations were completed in March, 2009. Initial assessment based on slope and permeability conditions across Mauritius suggested that few locations in the main mountain range areas not already transformed by water impoundment or urban expansion provide topographic conditions necessary for long-term natural wetland development. In contrast, significant parts of the coastal lowlands exhibit topographic conditions consistent with water collection and marsh/swamp formation.

Candidate, mainly coastal, wetland locations were reconnaissanced continuously from February-May, 2008 ahead of the land survey and biological survey teams. The initial search proved to identify a large number of new wetland areas while confirming loss to land-use or positioning error of others featured in previous maps.

Wetland Elevation

The elevational distribution of wetland features considered in this report was undertaken. A 20 x 20 metre raster-based digital elevation model was created based on the 1:25,000 10-metre topographic (polyline) contour kindly provided by the Cartographic Division, Ministry of Housing and Lands. This resolution was a reasonable trade-off between the base data and size range of the wetland features targeted for analysis and the need to find a balance between emphasizing ridge and peak features vs. depressional/sink features. A ten-metre interval was insufficient to model the expected elevational distribution of wetland features and a kriging routine was undertaken within a GIS environment to interpolate a hydrologically-correct surface. Consequently, elevational ranges attached to wetland features in this report are subject to the error attached to the frequency of anomalous topographic features present at a sub-10 metre scale. Kriging merely interpolates elevational gains registered in the existing cover with some opportunity to emphasise positive and negative local anomalies. Nonetheless, in the absence of a more precise topographic coverage, this approach represents the best available route to model wetland elevational distributions within the specified project timeline. Topographic contours were not made available for offshore islets. Consequently, a combination of maps, GPS waypoints and Google Earth were used to triangulate approximate elevations for wetland located in these areas.

Wetland Delineation

Delineation of located marsh/swamp wetlands was generally based on the identification of hydrological features, hydric soils, and hydrophytic plants. The primary hydrological feature was the presence of permanent standing water or frequent inundation. Hydric soils are those are saturated with water during the plant-growing season and consequently develop anaerobic (low-oxygen) conditions that favor the growth and regeneration of hydrophytic vegetation (Sprecher 2001). Features that can be used to identify hydric soils include their sulfidic odor, gleying, redoximorphic features (such as a reduced matrix and zones of iron-manganese oxides), and oxidized root zones (*Survey Report of Grand Baie Wetlands*, Government of Mauritius 2008). Identified boundaries were delineated with a 5-10m location accuracy using a Trimble Global Positioning System (see *Survey Report of Grand Baie Wetlands* for further details).

Delineated wetland waypoints were converted into polygon feature shapefiles and incorporated into the ArcGIS-based ESA geospatial information system. Size, nearest neighbour, ownership and other salient features were subsequently incorporated into this system for rapid retrieval of wetland characteristics.

Upland Marsh areas were principally identified utilising SPOT-5 imagery. Areas defined by a spectral signature consistent with known marsh areas were classified and then filtered through the use of field GPS points attached to known features. Not all features were visited in the field, but the major formations constituting the bulk of the upland marsh ESA type were confirmed.

2.2 Ecological and Physical Characteristics of Coastal Marsh/Swamp Wetlands

As part of this study, all located coastal marshlands were physically surveyed in considerable detail and the corresponding land owners were identified. The following features were quantified:

Flora

Vegetation structure and composition were measured using line-intercept techniques. Each wetland was sampled using 1-7 transect lines, depending on wetland size, with each transect beginning at one margin of the wetland and continuing to the opposite margin. All of the 65 plant species that were encountered along the transects were identified by local botanical experts.

Fauna

The presence of terrestrial and aquatic vertebrates (mammals, birds, reptiles, amphibians and fish) and selected invertebrates (butterflies and mollusks) species was determined by visual sightings, acoustical cues, and other signs (burrows, herbivory patterns, footprints, droppings, and bones). No night-time surveys were undertaken.

Flora and fauna were grouped into the following four categories:

1) Mauritian endemics: native species known to occur only in Mauritius;
2) Natives: species known to occur naturally in Mauritius and elsewhere;
3) Cryptogenics: species that are possibly native to Mauritius;
4) Aliens: species introduced by human agency into Mauritius.

The conservation status of all native species was assessed using International Union for the Conservation of Nature (IUCN) Red List criteria (IUCN 2001).

Wetland Size and Shape

The total area, shape, and circumference of the each wetland were determined by delineating the wetland margin with a hand-held global positioning system (GPS) unit.

Soil and Hydrology

Soil and hydrological characteristics were assessed by digging numerous soil pits to a depth of 25-50 centimeters. Soil chroma (colored strata) and values were defined using Munsell Soil Colour Charts (Kollmorgen Instrument Corporation 1992). The salinity of standing water was measured using a salinity refractometer. Water clarity and source/periodicity were also noted.

Algae

We estimated the algal cover of the wetland surface area, as this can be an important indicator of eutrophication caused by excess nutrient pollution (reference).

2.3 Determining Human Disturbances (Pressures)

We also recorded a number of wetland attributes that indicated prior or ongoing human disturbance.

Edge Disturbance

We estimated the proportions of the total wetland edge that were disturbed and intact.

Wetland Fragmentation

Extensive backfilling has resulted in the fragmentation of many wetlands. We recorded three fragmentation conditions: (1) naturally fragmented, (2) fragmented by a road, and (3) fragmented by extensive development (such as housing or urban development).

Backfilling

The presence and composition of backfilling were recorded and where possible we recorded the extent of backfilling along the transitional zone of the wetland.

Surrounding Land Uses

We identified five different surrounding land uses: (1) no active land use, (2) rural-grazing, (3) rural farming (sugarcane or small-scale farmer), (4) urban with no houses or golf courses, and (5) urban with houses or golf courses.

Flooding Risk

We identified three categories of flooding risk: (1) none, (2) risk to infrastructure, and

(3) risk to houses.

Seasonal changes in wetland water-levels, are an important feature of wetland ecology and hydrological function, unfortunately this type of data require long-term monitoring, and hence was beyond the scope of this study. Our team visited each wetland on at least three occasions during the course of this study. However, all visits were during the same period (March-May) and thus we were unable to record any seasonal changes in water level or biotic composition.

2.4 Remote-Sensing Wetlands

The freshwater wetlands in the Mauritian uplands differ in structure, function and composition to those of the coastal lowlands. They also occur almost entirely within National Park and State Forest Lands and therefore are not as threatened by the pressing issues of backfilling and drainage facing the coastal wetlands. The upland wetlands are principally suffering from invasion by exotic species, and the continued removal of exotics is a crucial management requirement for their long-term conservation.

The upland wetlands span a range of different vegetation communities: heath-dominated sites, sedge wetlands, grass and occasional heath- and fern-dominated sites. Some exotic tree plantation areas have retained marsh hydrological features and appear to be returning to a marshland ecological state. The exotic-tree-dominated wetlands are a mosaic of several different vegetation assemblages composed of one or more of the following non-native species: pine trees (*Pinus*), gum trees (*Eucalyptus*), paperbarks (*Melaleuca*), bottlebrush (*Callistemon*) and travelers palm (*Ravenala*). The trees generally occur on hummocky terrain that offers relatively good drainage and lower soil moisture. Surrounding the hummocks, the water table is typically at or near the surface, giving rise to either standing water or nearly saturated soil that supports sedges, grasses, mosses and ferns.

We have not included these upland areas in our coastal-wetland analysis principally since these sites differ biologically from the lowlands and in any multivariate community analysis they would cluster by elevation, causing us to lose any detailed understanding of lowland sites.

Field surveys were undertaken to develop a general ecological characterisation of upland marsh habitat and its constituent plants and animals.

3. RESULTS

3.1 Geographic Features of Freshwater Wetlands

Geographic Distribution

At the beginning of this study a total of 44 wetlands were recognized in Mauritius (Tender Document, *Study of Environmentally Sensitive Areas in Mauritius & Rodrigues* [Project OMC/2/3]). This study has augmented this list with an additional 159 confirmed coastal marsh/swamp wetlands, bringing the overall total to 203 (**Table 1**). In addition, more than 600 upland marsh units have been identified through remote sensing. Sixteen major reservoirs/lakes and thirty-one major river systems have been grouped into individual wetland ESA types, respectively. These numbers cannot be considered conclusive since they will vary depending on the range of water features considered and how areas subject to seasonal and supra-annual variation in water tables are treated. There are hundreds of much smaller freshwater features, such as small retaining ponds and canals used for livestock or crop irrigation scattered throughout the country. However, these do not always present permanent, biological features distinct to wetland formations (**Figure 1**). The continued fragmentation of larger areas into a series of smaller units will also continue to increase the number of spatially discontinuous marshes and swamps, as well as changes to the physiography brought about through future infrastructural developments that can lead to water occlusion and spark an ecological succession resulting in marshland.

Table 1. Distribution of freshwater wetlands types across administrative districts in Mauritius, April 2009.

Administrative District	Coastal Marsh/Swamp				Upland Marsh/Swamp				Major Reservoirs/Lakes		Major Rivers
	No.	%	Area (ha)	%	No.	%	Area (ha)	%	No.	Area (ha)	No.
Black River	21	10.3	71.5	17.8	1	0.2	0.01	0.0	1	224	9
Flacq	95	46.8	114.1	28.4	3	0.5	0.03	0.1	0	0	4
Grand Port	15	7.4	40.3	10.0	27	4.5	1.2	2.2	2	34	5
Moka	0	0.0	0.0	0.0	88	14.6	7.0	12.4	6	479	3
Pamplemousses	7	3.4	28.2	7.0	0	0.0	0.0	0.0	2	125	2
Plaines Wilhelms	0	0.0	0.0	0.0	373	61.9	39.1	69.4	3	769	0
Port Louis	1	0.5	1.1	0.3	0	0.0	0.0	0.0	0	0	2
Riviere du Rampart	61	30.0	133.8	33.3	0	0.0	0.0	0.0	0	0	2
Savanne	3	1.5	13.1	3.2	111	18.4	9.0	16.0	2	13	4
	203		402		603		56		16	1643	31

* Mare aux Vacoas main and holding pond considered as single unit

Ground reconnaissance and inspection of archival QuickBird, IKONOS and MODIS imagery indicate that freshwater marshes and swamps are restricted to the island of Mauritius and its offshore islets. No freshwater wetlands were located on the smaller islands of Rodrigues, Agalega or Cargados Carajos using this approach. Two major sites on Rodrigues were inspected at Grand Baie and Mourouk and both areas were assessed to be principally under marine influence and have been delineated as inter-tidal mud flats within the broader ESA Network for this island.

On Mauritius, coastal marshes and swamps are disproportionately aggregated in the Northeast and East of the island (see cover map in **Appendix F**). Nearly three-quarters of all coastal wetlands are located in the Flacq and Riviere du Rampart districts (**Table 1**)(**Appendix F**). In contrast, coastal districts in the south and southwest exhibit few marsh or swamp wetland features. Large reservoirs and lakes are situated principally on the upper slopes framing the main cratonic belt running along a north-south spine of the central upland region.

Upland marsh areas are strongly aggregated in the south-central plateaux, often in association with large reservoirs (see maps in **Appendix F**). Virtually all of the recognized marsh area is restricted to three districts, with the bulk of this occurring on State Land (*sensu lato*) in the district of Plaines Wilhems (**Table 1**). Similarly, most large lakes and reservoirs are located on State Land (*s.l.*) in the districts (Moka, Plaines Wilhelms) that cover the main upland areas

Wetland Conversion. A small number of coastal marsh wetlands identified on the

1990 1:25k maps were confirmed to have been completely converted, primarily for housing, hotel, golf course or small-hold agricultural use (see **Appendix F Maps**). These include most notably a series of small features in the Point de Lescars, Providence, Flic en Flac and Point d'Esny areas. Other areas, such as Dagotiere (Moka District), may have been mis-classified in the 1:25k maps or have been, over time, impounded for freshwater storage and lost most of their wetland characteristics. The location of many upland marsh areas adjacent to the main reservoirs and within or near plantation forest areas indicate that a significant part of their original distribution has been converted for water storage and to a lesser extent large-scale forest and tea plantings.

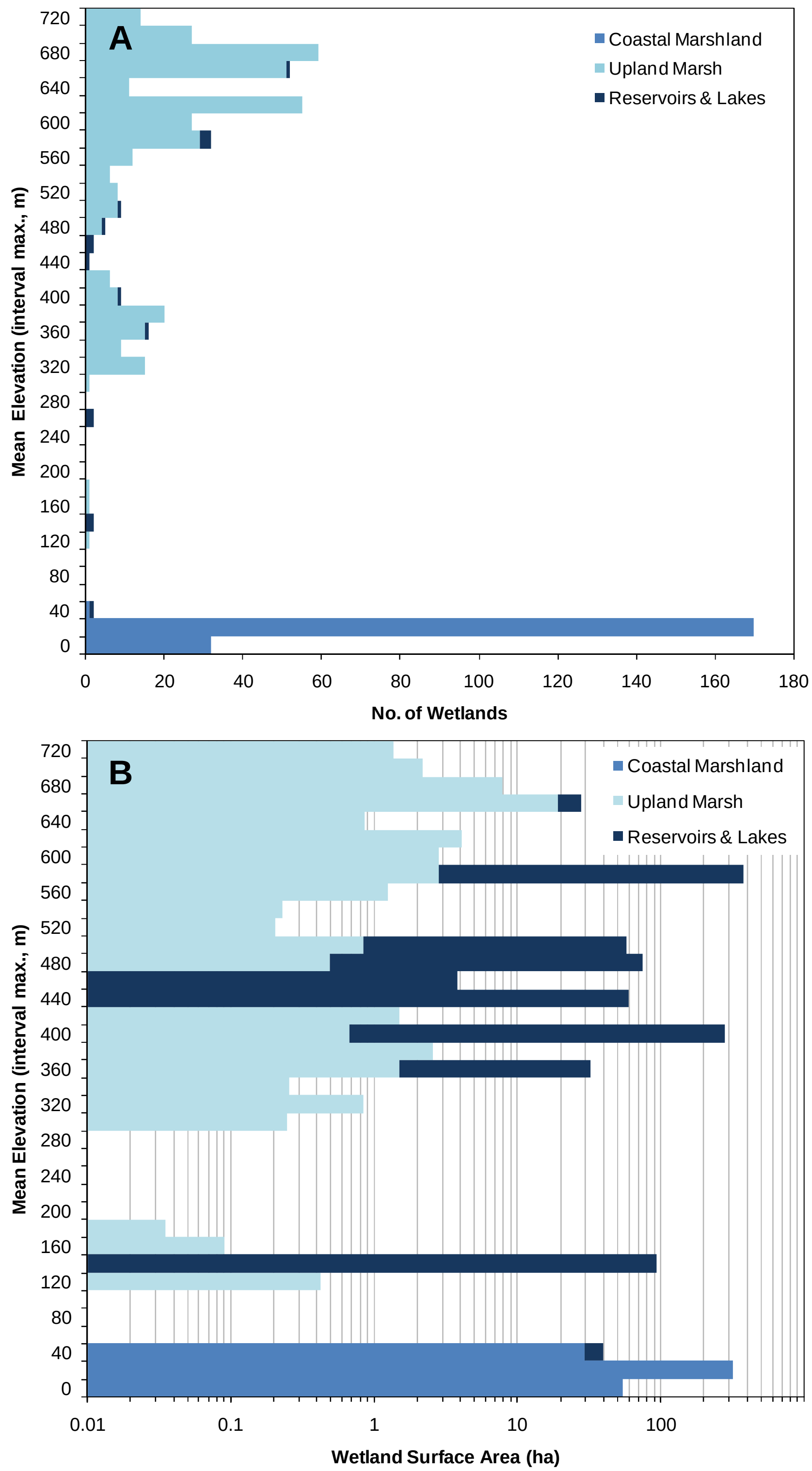
Wetland Fragmentation. About half of the coastal freshwater marshlands described in this study were once parts of contiguous, larger wetlands that have since been fragmented into smaller areas by roads, golf courses, agriculture and housing developments. This is the principal cause of the very large number of (primarily coastal) wetlands included in this report.

Elevational Distribution

Areas of coastal and upland marsh are strongly segregated by physiography with a 240m elevational gap separating the main distributional range of each type (**Figure 2A,B**). Coastal freshwater marshlands are strongly concentrated in areas less than 20 metres above sea level (asl). One large feature at Schoenfeld (Riviere du Rempart) is the only coastal marshland registering an elevation above 20 metres. The available topographic data and adopted geo-processing method used to refine this coverage (see Methods) indicate significant coastal marshland occupying areas at sub-zero elevations(Figure 2). Approximately 13% of the total coastal marshland area is expected to reside at or below sea level. Most prominent among these sites are marshlands located in the vicinity of Grand Baie, Poste Lafayette/Mare Sarcelle, Wolmar, St. Martin, Belle Mare/Palmar and Fort William (Port Louis).

The elevational position of upland marsh is characterised by a tri-modal distribution (**Figure 2A,B**) with the modal peak dampening with a decline in altitude. The most prominent part of this distribution, in both terms of area and number of features, can be found at the uppermost elevational range in Mauritius, between 500m and 720m asl. Upland marsh at this elevation accounts for more than 78% of the total area estimated to occur in Mauritius with the most significant formations located in the Le Petrin and Les Mares areas and within the vicinity of the larger lakes and reservoirs (see **Appendix F Maps**). All but four of the main lakes and reservoirs are located within 500 metres of the uppermost catchment limits, or divides, and the distribution of upland marsh is similarly placed. Nearly three-quarters of the identified upland marsh area falls within this same 500 metre belt. These areas are principally flat topographic areas positioned immediately above or adjacent to riparian headwaters feeding rivulets, rivers and reservoirs in Mauritius. Less than 5% of upland marsh area is expected to occur on areas of moderately steep slope (>10% grade).

Figure 2. Elevational distribution of three major freshwater wetland types according to **(A)** number of features and **(B)** areal extent. Note logarithmic-scaled abscissa in (B). Ordinate scale described by maximum value of each 20 metre interval.



Isolation (Nearest Neighbour Distances)

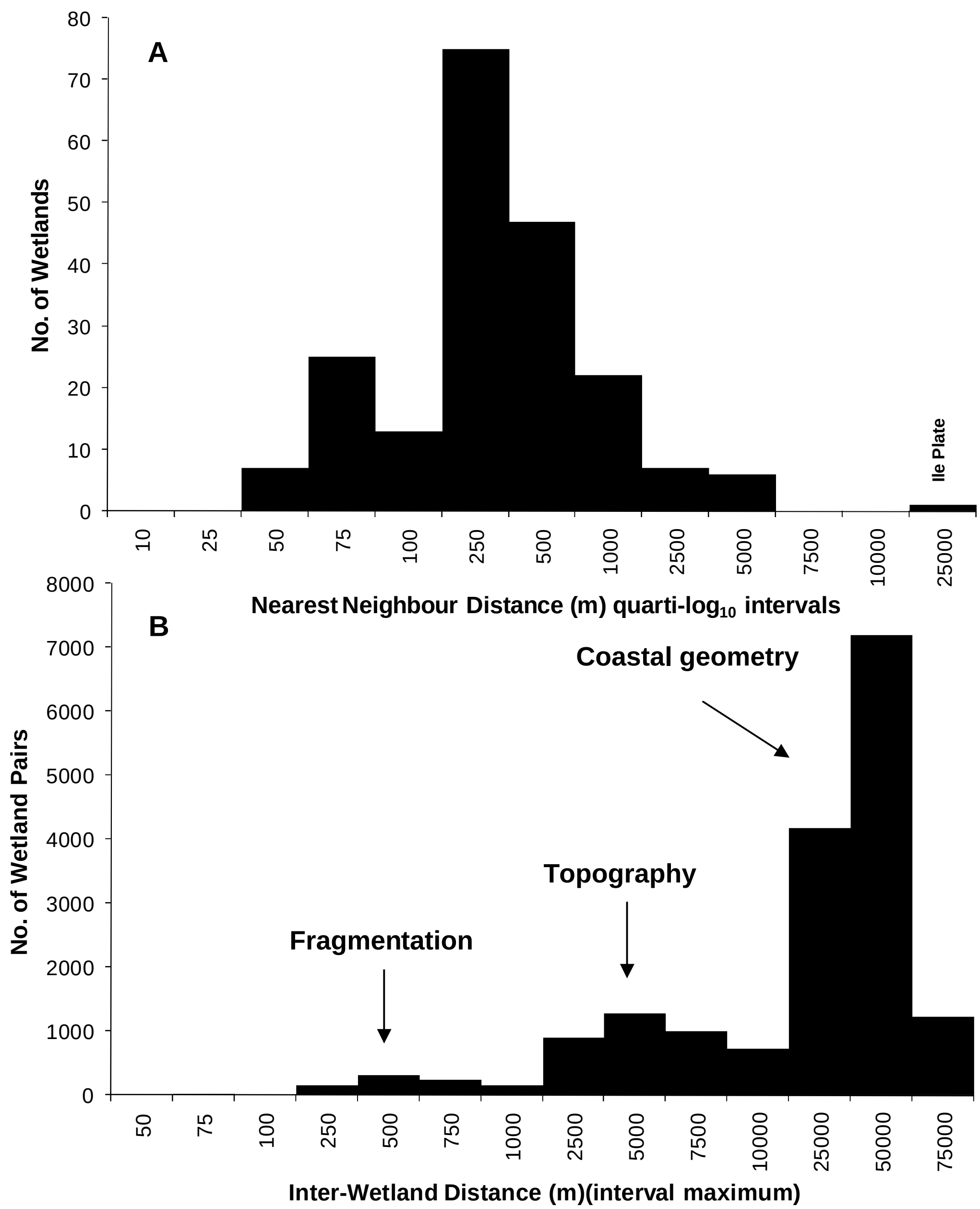
The average nearest neighbour distance between coastal marshlands (measured between projected centroids) is estimated at 453.7 metres (minimum 29.7 m, maximum 13,046 m) and indicates that features within this ESA type are significantly clustered (Nearest Neighbour Ratio: 0.2351, $Z = -20.85$, $p < 0.001$). The minimum distances between wetlands are log-normally distributed about the mean except for one statistical outlier represented by marsh wetlands situated on the offshore islet, Ile Plate (**Figure 3A**). This site is consequently the most geographically isolated from other areas showing similar marsh/swamp characteristics. The other relatively isolated coastal marshlands are generally located along the south and west coastlines (**Table 2**).

Table 2. Ten most isolated marsh/swamp wetlands based on nearest neighbour distances.

District	Wetland No.	Name	NN Distance (m)
Riviere du Rempart	210	Ile Plate	13046
Black River	112	Mare Samson (Petit Verger)	4227
Flacq	172	Anahita Resort GC (Mare aux Lubines)	3988
Pamplemousses	113	Point aux Piments	3947
Savanne	105	St.Martin	2974
Port Louis	87	Fort William	2521
Pamplemousses	178	Terre Rouge Bird Sanctuary	2521
Black River	76	Les Salines	1726
Black River	77	Les Salines 2	1726
Riviere du Rempart	233	South Riviere Citronier	1276

Creating a set of distances between all possible marsh/swamp wetland pairs provides a means to assess how these features cluster, if at all, in relation to spatial scale. Further analysis of this set shows that the distribution of wetlands is aggregated in a self-similar fashion across spatial scales (**Figure 3B**). Clustering at the smallest spatial scale (50m) largely reflects fragmentation processes. Fragmentation caused by backfilling for building and road installation and draining for agriculture is particularly evident where wetland area has been parceled into a larger number of property holdings. Staggered development of these parcels, principally through backfilling of a select subset of holdings, drives the fragmentation, rather than complete ablation, of wetlands. Where larger developments take place, complete ablation or modification of wetlands predominates.

Figure 3. A. Distance class distribution of nearest neighbouring coastal marshlands in Mauritius. **B.** Inter-marshland distance class distribution of marshtlands in Mauritius with clustering scales highlighted by putative cause.



Aggregation at the intermediate scale (500m) are interpreted as a topographic effect created by the patchy distribution of lowland plains along the north and east coastal areas. The effect of topography defines the true natural extent of conditions conducive to wetland formation, a situation echoed by early assessments of native vegetation types in Mauritius (Vaughan and Wiehe 1937). These regions are relatively flat with very low river drainage densities. Large-scale clustering (5000m) is interpreted as an interaction of larger-scale physiographic symmetry placing most lowland marshes and swamps in Mauritius along a perimeter. This adds a diametric component to the distance matrix as wetlands on opposites sides of the island's perimeter are paired.

Area and Size

Lentic wetlands in Mauritius are estimated to currently cover a total area of 21 km^2 (**Table 1**). This area, covering approximately 1.1% of total national land area, is principally comprised of several, large upland reservoirs and lakes (78% of lentic wetland area) and a much larger number of smaller coastal and upland marshes/swamps (19 and 3% of area, respectively)(**Table 1**).

The largest coastal marsh/swamp identified at Schoenfeld (No. 218), located near Poudre D'Or on the northeast coast, accounts for more than 7% of the total area of this wetland type. The largest ten coastal marshlands can be found in six of the nine administrative districts and are generally well distributed around the coast of Mauritius (**Table 3**). The eighth largest wetland, an area previously used as a small-hold agricultural reserve near Choisy (No 42), is of relatively recent derivation and previously undocumented. Coastal wetlands are approximately log-normally distributed with sizes ranging across four orders of magnitude with the largest units extending over areas that are 5 to 10 times the average of 1.98 ha.

Remotely-sensed upland marsh areas are considerably smaller than those found along the coastal margin. The largest is less than a ¼ of the size of its analogue on the coast (Schoenfeld). The largest upland marsh areas are strongly clustered, being found principally in the district of Plaines Wilhelm. Eight of the 10 largest units are concentrated in the area south of Mare Longue, at Le Petrin and a short distance south in the area of Les Mares. Upland marsh show a negative exponential decline with sizes ranging across three orders of magnitude, but with the largest marshes expected to cover areas that are 10 to 80 times the average of 0.09 ha.

Table 3. Ten largest coastal and upland marsh/swamp wetlands in Mauritius by estimated surface area.

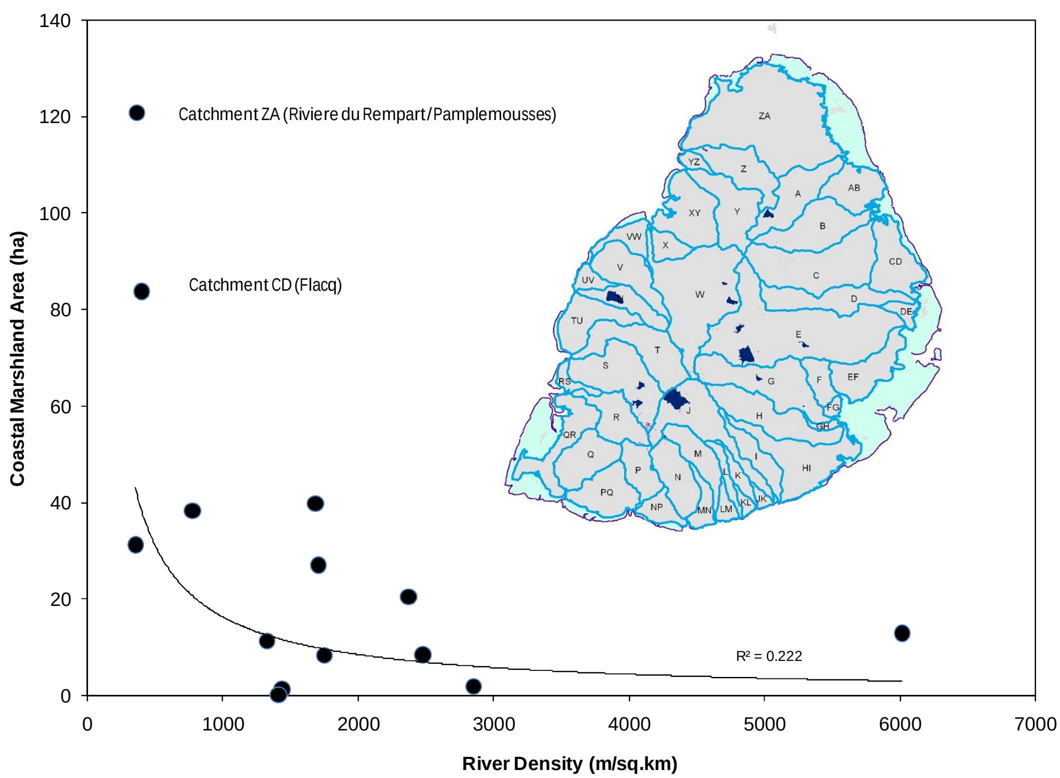
District	Wetland No.	Name or Nearest Town/Village	Area (ha)
COASTAL			
Riviere du Rempart	218	Schoenfeld	29.60
Pamplemousses	178	Terre Rouge BS	26.00
Black River	122	La Prairie	20.68
Riviere du Rempart	164	Baudot Estate	16.12
Grand Port	115	Pointe D'Esny	15.96
Riviere du Rempart	22	Mare Phedre	12.67
Flacq	159	Mare du Puit	11.38
Flacq	42	Choisy	11.34
Riviere du Rempart	24	Mare Campave	11.08
Savanne	105	St Martin	10.90
UPLAND			
Plaines Wilhelm	UM0408	Le Petrin Central	7.17
Plaines Wilhelm	UM0414	Le Petrin West	2.60
Plaines Wilhelm	UM0425	Le Petrin Eas	2.45
Plaines Wilhelm	UM0388	Mare Longue South	1.47
Plaines Wilhelm	UM0406	Le Petrin North	1.35
Plaines Wilhelm	UM0362	Mare aux Vacaos South	1.17
Moka	UM0734	La Chartreuse Midland	1.17
Plaines Wilhelm	UM0439	Le Petrin South	1.06
Plaines Wilhelm	UM0423	Le Petrin Central 2	1.01
Savanne	UM0589	Les Mares West	0.99

Hydrological Function

Coastal marshlands, rivers, streams, reservoirs and upland marsh define the main surface hydrological network in Mauritius. While rivers and streams largely perform a transport function, upland marsh, lakes, reservoirs and coastal marshlands carry out a storage function. This storage function is critical in provisioning freshwater, modulating discharge into the lagoon and buffering effects of large positive anomalies in precipitation, primarily due to strong, tropical cyclonic activity. Spatial analysis of coastal marshland distribution within hydrological catchments indicates that these wetlands tend to increase strongly in areas with particularly low river drainage densities (**Figure 4**). Two areas covering the north of the island (Catchment

ZA) and the Belle Mare/Palmar area of the Flacq district (Catchment CD) stand out in particular. In these areas, an extremely large area of coastal marshland is present in the virtual absence of normal riparian networks. These areas also have a larger number of marshlands occupying areas expected to sit below sea level (see section, *Wetland Elevational Distribution*). This relationship indicates that these areas are naturally susceptible to major flooding events, particularly during periods of unusually strong sea surge (see **Appendix C- Photographs**).

Figure 4. Relationship between coastal marshland area and river drainage density for each hydrological catchment (thick lines) in Mauritius. Catchment codes *sensu* Water Resources Unit.



3.2 Wetland Ownership

Approximately three-quarters of the estimated coastal marsh/swamp wetland area in Mauritius is under private ownership. The ratio of private to public ownership varies geographically with the largest private ownership of wetlands occurring in the northern villages of Grand Baie, Pereybere, Cap Malheureux and Choisy. These areas are characterized by multiple ownership of relatively small-parcel landholdings with boundaries dissecting marshlands (see **Appendix F Maps**). However, private holdings outside these areas are typically under single, mainly commercial, ownership.

The average size of wetland under private control is nearly 30% greater than those typically found on State Land (**Table 4**). The largest proportion of privately-owned marshland, however, is under control of a single owner. Again, this reflects the disproportionate number of the largest marshlands under single ownership. With complex ownership (>2 owners) scenarios attached to less than a quarter of all coastal marshland, opportunities for employing simple strategies towards the long-term maintenance of remaining areas should be viewed as excellent.

Table 4. Distribution of estimated marsh/swamp wetland area according to type of ownership.

Ownership	Total Area (ha)	%	Avg Size (ha)
	COASTAL		
Privately-Owned	***294.9***	***73.4***	***2.1***
1 owner	178.6	60.6	1.8
2 owners	21.4	7.3	1.9
2+ owners	94.8	32.2	3.4
State Land	***107.0***	***26.6***	***1.6***
	UPLAND		
State Land	***56.3***	***100.0***	***0.09***
BRG National Park	30.1	53.5	0.18
State Forest Land	17.5	31.1	0.06
Other State Land	8.7	15.5	0.07

The major lakes and reservoirs considered as ESAs and described in this report are situated principally on State Land (*s.l.*). Two reservoirs, Mare Piram, Valetta

(Mangrapoule) and Dagotiere are owned and operated by the private sector, primarily for irrigation purposes.

3.3 Ecological and Physical Characteristics of Coastal Marshlands

Vegetation Structure and Community Composition

We examined the vegetation structure and community composition of all coastal wetlands within a single ordination analysis (using a robust ecological ordination technique known as Nonmetric Multidimensional Scaling). Ordination is a multivariate statistical technique that can identify major gradients (patterns) in complex datasets, such as what we were dealing with in the present circumstances. For the analysis we used standardized data on the abundance of 61 plant species and one key habitat feature, open water, based on 1-7 transects per wetland (**Appendix D.1**). We excluded 10 singleton species from the analysis.

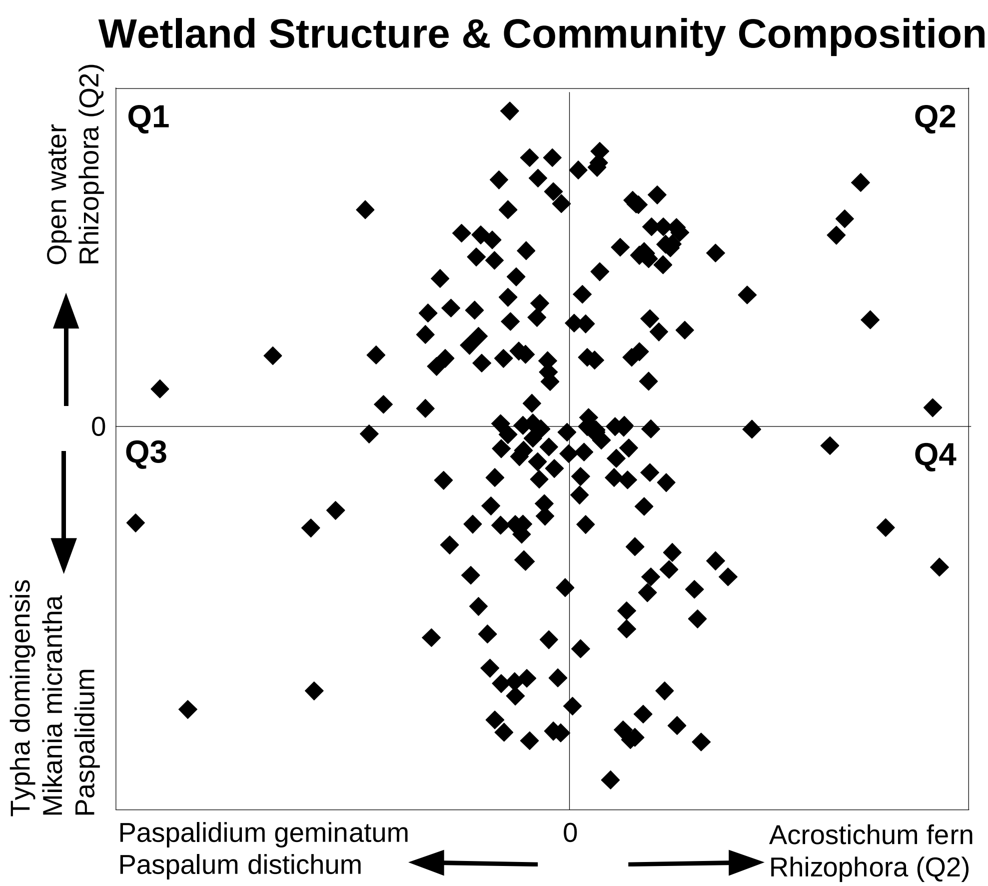
This analysis identified general features that can be used to distinguish the different vegetation of marshlands in Mauritius. The analysis identified two main gradients in the wetland data (**Appendix D.2**). The vertical (Y) axis describes a gradient of wetlands dominated by open water at the top of figure, and vegetated wetlands dominated by *Typha domingensis* at the bottom. The horizontal (X) axis delineates wetlands dominated by grassland species on the left side of the figure, and those dominated by the fern *Acrostichum aureum* on the right.

Using this analysis we have categorized all the wetlands into one of four basic types, based on their position within the four quadrats in **Figure 5**, as follows:

1) Type 1: Open-water and grass-dominated wetlands (quadrat 1)
2) Type 2: Open-water and *Acrostichum*-dominated wetlands (with *Rhizophora*) (quadrat 2)
3) Type 3: Vegetated wetlands dominated by *Typha* and grass (quadrat 3)
4) Type 4: Vegetated wetlands dominated by *Typha* and *Acrostichum* (quadrat 4)

The X and Y values in **Appendix D.2** show the position of each wetland in **Figure 5**. If the values are >0.5 they have been italicized and indicate those wetlands we believe are well described by this classification system, whereas those wetlands with low (<0.5) values near the center of the plot are not well discriminated by this classification system.

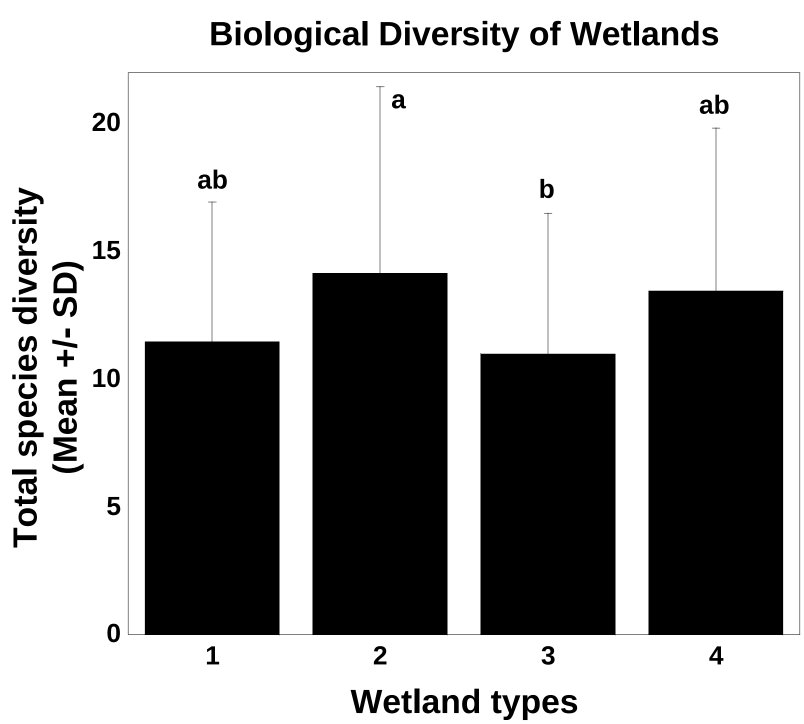
Figure 5. Ordination analysis highlighting the principal attributes that distinguish different coastal wetlands in Mauritius.



Biological Diversity of Coastal Marshlands

Total Biodiversity. We examined the biological diversity of Mauritian coastal marshlands through detailed surveys of the flora and fauna communities. The native flora and fauna species data were summed as a total biodiversity estimate (**Appendix D.4**) and examined with respect to the four wetland types classified from **Figure 5,** above. Wetland biodiversity was on average higher in the open water *Acrostichum*-dominated wetlands (Type 2) and vegetated wetlands dominated with *Typha* and *Acrostichum* (Type 4) than the open water and vegetated wetlands that supported grass communities (Types 1 & 3) (see **Figure 6**). The relationship between wetland types and biodiversity was significant (ANOVA $F_{3,168}$=2.45, P=0.06, Tukey test P<0.1 Type 2 > Type 3), with the greatest difference in biodiversity occurring between the *Acrostichum*-dominated wetlands (Type 2) and the vegetated wetlands dominated by grassland species (Type 4).

Figure 6. A comparison of the total biodiversity in the four major wetland types of Mauritius



Do larger wetlands support higher biological diversity? We examined total biodiversity of wetlands and their size using linear regression analysis; wetland size was a significant predictor of biological diversity ($F_{1,168}$=14.61, R^2=8.0%, P=0.0002). The majority of the wetlands were small and as a result, area only explained 8% of the variation we observed in total species diversity.

Native Plant Species Diversity. The flora surveys attributed plants to wet and dry habitat zones within each wetland. In a comparison of species diversity between the wet (inundated) and dry (non-inundated) zones of wetlands, we found most (63%) of the drier zones had more native plant species than the wet zones. Of the remaining wetlands, 24% had more species in the wet zones and 13% had similar values for both wet and dry zones (**Appendix D.4**)

We compared total plant species diversity between the four major types of wetland communities and found the same pattern as was determined for total biodiversity, where higher plant diversity occurred in the open water *Acrostichum*-dominated wetlands (Type 2) and vegetated wetlands dominated with *Typha* and *Acrostichum* (Type 4) than the open water- and vegetated wetlands that supported grass communities (Types 1 & 3). The relationship between wetland types and floral biodiversity was significant (ANOVA $F_{3,168}$=2.50, P=0.061, Tukey test P<0.06, Wetland Type 2 > Type 3), with the greatest difference in biodiversity occurring between the *Acrostichum*-dominated wetlands and the vegetated wetlands dominated by grassland species.

Do aquatic and terrestrial plant species follow the same biodiversity pattern? In two separate analyses, we examined 1) aquatic plant diversity and 2) terrestrial plant diversity among wetland types. We found that aquatic plant diversity was slightly higher in vegetated wetlands (Types 3 & 4) compared to open water communities (Types 1 & 2). The relationship between wetland types and aquatic plant diversity was significant (ANOVA $F_{3,168}$=2.60, P=0.054). However, terrestrial plant species followed the same pattern as total biodiversity and total plant diversity where higher terrestrial plant diversity occurred in the open water *Acrostichum*-dominated wetlands (Type 2) and vegetated wetlands dominated with *Typha* and *Acrostichum* (Type 4) than the open water and vegetated wetlands that supported grass communities (Types 1 & 3). The relationship between wetland types and terrestrial plant diversity was highly significant (ANOVA $F_{3,168}$=6.36, P=0.0004, Tukey test P<0.001, Wetland Type 2 > Type 3), with the greatest difference in diversity occurring between the *Acrostichum*-dominated wetland and the vegetated wetlands dominated by grassland species.

In summary, it appears that wetlands have acted as important refugia for terrestrial plant diversity in the coastal lowlands of Mauritius. It is probable that these low-lying and frequently rocky habitats have been unsuitable for agriculture and as a result have protected many terrestrial plant species. This is evident by the fact that wetlands that support grasslands had lower terrestrial plant diversity than those wetlands with the aquatic plant species *Acrostichum* and *Typha*. This is most likely because these grass-dominated wetlands are often only seasonally inundated and we have observed they

Table 5. The 15 most floristically-diverse coastal marshlands in Mauritius

Numeric ID	Total Spp	Dry Spp	Wet Spp	Wetland Type
146	29	23	6	Open water & *Acrostichum* dominated
114	26	13	13	Open water & *Acrostichum* dominated
39	24	18	6	Vegetated wetland with *Typha* and *Acrostichum*
147	21	15	6	Open water *Typha* & *Acrostichum* dominated
159	20	15	5	Open water & *Acrostichum* dominated
76	19	18	1	Open water & *Acrostichum* dominated
155	17	17	0	Open water & *Acrostichum* dominated
5	16	6	10	Open water & grass dominated
53	16	9	7	Vegetated wetland with *Typha* and *Acrostichum*
120	16	8	8	Open water & *Acrostichum* dominated
19	15	6	9	Vegetated wetland with grass and *Acrostichum*
22	15	9	6	Vegetated wetland with grass and *Acrostichum*
40	15	11	4	Vegetated wetland with grass and *Acrostichum*
95	15	10	5	Open water & *Acrostichum* dominated
231	15	12	3	Open water *Typha* & *Acrostichum* dominated

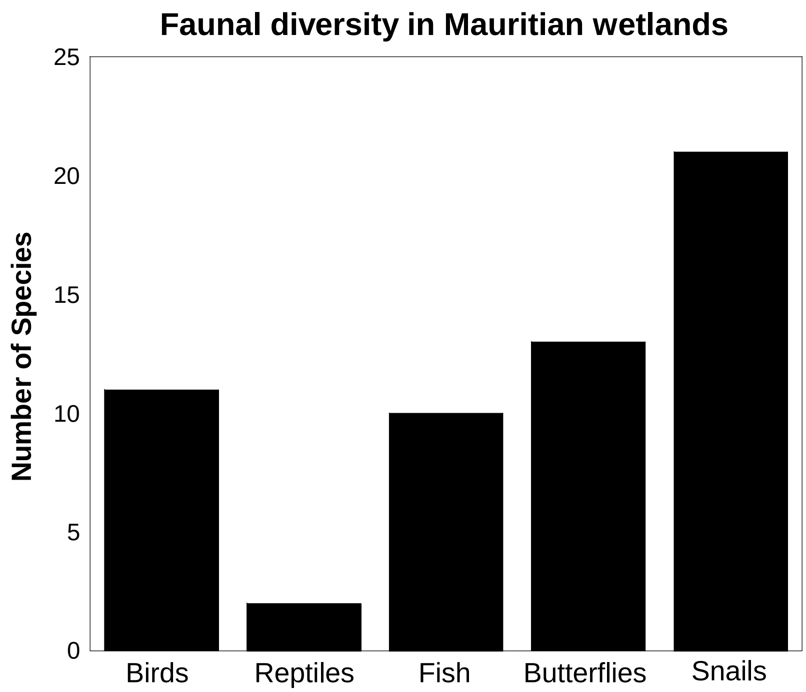
are subject to grazing in the large private estates. However, it is important to note that aquatic plant diversity, although lower in general than terrestrial plant diversity was higher in the vegetated wetlands that were dominated by grass, *Typha* and *Acrostichum* species. Finally, it is possible that these diversity patterns may also be influenced by other factors such as geology or geography are not directly associated with wetland structure and community composition. The 15 most floristically diverse wetlands are presented in **Table 5**.

Conservation Status of Wetland Plant Species. We detected no endangered species that were restricted to inundated habitats of wetlands, all the endangered species occurred in the terrestrial or transitional zone of wetlands (**Appendix D.5**). Within 24 wetlands, 12 endangered species were recorded. Most sites had only a single species but a few sites had more than 1 endangered species; (146 (3 species), 67, 126, 155 and 209 (2 species)). From a species conservation perspective it is critical if a species has many small populations or only a few, for example we found 1 endangered species present in 13 wetlands and another species 7 wetlands. Most importantly, 8 endangered species were found in only single locality signifying how critical these habitats are for their long-term survival.

We recorded 14 vulnerable species from 26 wetlands (**Appendix D.5**), with one species restricted to the aquatic habitat, the mangrove *Bruguiera gymnorhiza.* Most of these wetlands (16 sites) had only a single vulnerable species detected, but a few sites had more than 1 vulnerable species; (126 (7 species) 39 & 155 (3 species), 114, 146, 147, 181, 182 (2 species)). The IUCN designation of Vulnerable signifies that a species has more populations or larger populations than an endangered species. We found only 5 vulnerable species occurring in a single locality. Most (7) occurred in 2 or more sites with 1 species found in 7 sites.

Native Fauna Diversity. Wetland communities showed relatively high faunal diversity with 57 native species recorded from all of the wetlands. Snails were the most diverse taxa with 21 species detected (Figure 7). Although 14 species of migratory bird have been recorded previously for Mauritius wetlands, only 3 migratory birds were detected during this survey. The fauna surveys were undertaken from April-September 2008, so only those species staying for the winter would be detected. Our sampling would not have detected the palaearctic migrants that visit the Mauritius wetlands and coastal shores during the austral summer.

Figure 7. The diversity of faunal taxa from coastal marshlands



The five most frequently detected species across the Mauritian coastal wetlands are: 1) *Melanoides turculata* – snail (detected in 41% of sites; 2) *Leptotes pirithous* – butterfly (35% of sites), 3) *Zosterops bornicus* – bird (31% of sites); 4) *Butorides striatus* – wetland bird (30% of sites), 5) *Eurema foricola* – butterfly (28% of sites).
No relationship was found between total fauna diversity and the four types of wetland community. The 14 most faunally diverse wetlands in Mauritius are presented in **Table 6**, note that this table shares some wetlands with the most floristically diverse wetlands in **Table 5** (**Appendix D.4**).

Conservation Status of Wetland Faunal Species. No living individuals of endangered and vulnerable faunal species were detected in the wetland surveys. Snail shells were recorded for the solitary sightings of endangered and vulnerable faunal species. Shells were also located for three species of extinct snail. No living specimens of these species were detected.

Table 6. The 13 most faunally-diverse coastal marshlands in Mauritius

Numeric ID	Total spp	Endemic	Migrant
146	13	1	2
152	13	3	0
155	13	3	0
160	13	1	0
18	12	1	0
80	12	0	0
127	12	1	0
168	12	1	0
9	11	0	0
76	11	1	3
77	11	0	0
107	11	0	1
142	10	1	0

Migratory bird species were detected in 9 wetlands, and were normally only represented by 1 to 3 species. Terra Rouge Estuary Bird Sanctuary has previously recorded 14 migratory bird species, this high diversity of migrants may be partly due to the mud and tidal flat habitats that occur in this wetland and also due the temporal variability in migrant residency.

Physical Characteristics of Wetlands

Coastal Marshland Type Effects. What are the physical characteristics of these wetlands and how are these features associated with their structure and vegetation composition? To answer this question we searched for relationships (using Spearman rank correlations) between the ordination gradients described above and the following edaphic factors: water salinity, water clarity, algae, soil color and wetland area (**Appendix D.6**).

Almost half of the wetlands (49%) we sampled had very low water salinity (<3%); the few exceptions were sites close to the ocean or even contiguous with coastal estuaries. The wetlands with high salinity were dominated by open water with *Acrostichum aurean* and *Rhizophora* (salinity vs. X-axis, r_s=0.442, P<0.0001; salinity vs. Y-axis: r_s=0.281, P<0.01 [n=140 sites]).

We examined water clarity of the wetlands as a measure of how much suspended sediment occurred there. Vegetation structure and water clarity were strongly associated, such that vegetated sites dominated by *Typha* and grasses tended to have more sediment than did open-water sites (sediments vs. X-axis, r_s=0.288, P<0.001; sediments vs. Y-axis: r_s=0.379, P<0.0001 [n=171 sites]).

Algae levels in 65% of the wetlands were low to nonexistent. Algae appeared to be somewhat more abundant in the shallows of vegetated wetlands dominated by *Typha domingensis* than in other wetland types, although the relationship was not strong (algae vs. Y-axis: r_s= -0.156, P=0.06).

Of the soil substrates sampled, Gley-colored soils were the most abundant, occurring in 67 wetlands. Other soil colors were much less frequent, with Munsell Soil Code 10YR in 23 wetlands, Code 7 YR in 12 wetlands, Code 5Y in 15 wetlands, Code 2YR in 16 wetlands, Sand in 4 wetlands, and Rock in 4 wetlands. All of these substrates can occur in wetlands, but Gley-colored soils indicate a depleted or reduced matrix caused by almost constant soil saturation.

We found no significant relationship (P>0.05) between the total area of the wetlands and the structure and community composition of the vegetation (X and Y axes versus wetland area).

3.4 Human Disturbance of Wetllands

Most of the wetlands in Mauritius are found in coastal areas, which are being subjected to intense pressure from urban and residential developments. In addition, these coastal areas have historically been intensively modified for farming, given the high population density of Mauritius and its long history of human occupation. Most wetlands in urban areas (about 90%) have had some backfilling around their borders. This type of disturbance encroaches on the margins of each wetland and removes its transitional zone—an ecotonal area where wetland and dryland ecosystems interdigitate, providing a relatively complex region of high biological importance.

We examined human disturbance of Mauritian wetlands by measuring the following disturbance processes: 1) Habitat fragmentation; 2) Backfilling; 3) Edge disturbance; 4) Adjacent land uses; and 5) Flooding risk to infrastructure and housing (**Appendix E.1**).

Habitat Fragmentation

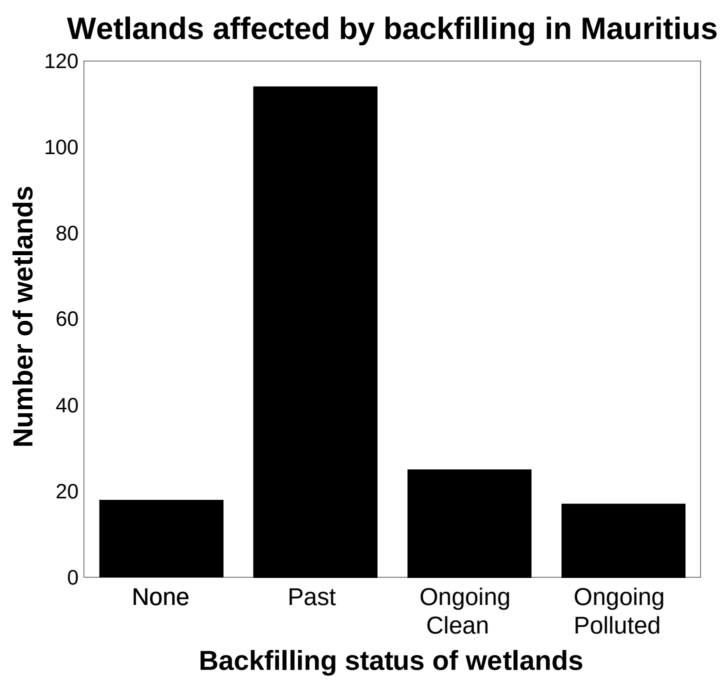
Fragmentation of wetlands occurs when a single large wetland is subdivided into several smaller wetlands by backfilling and land reclamation. We ranked the fragmentation of wetlands (1) not fragmented, (2) fragmented by a road, and (3) fragmented by more extensive development. More than half of the wetlands (60%) have been obviously fragmented, mostly as a result of extensive land development. This is probably an underestimate of the true figure, as long-term land use would have removed signs of the original wetland distributions.

Not surprisingly, we found that fragmented wetlands tended to be smaller than non-fragmented wetlands (r_s= -0.228, P<0.01 [n=155]). Interestingly, wetlands dominated by open water were more likely to be fragmented than were vegetated wetlands (fragmentation vs. Y-axis: r_s= -0.208, P<0.01, [n=174]), possibly because many of these wetlands are close to the coast where urban development has been most intense. Urban development also was significantly correlated with wetland fragmentation (r_s==0.472, P<0.0001 [n=168]). Finally, fragmented wetlands had a higher proportion of degraded edge habitats than did non-fragmented wetlands (r_s= -0.326, P<0.0001 [n=166])(all Spearman rank correlations).

Backfilling

Backfilling of wetlands is an enormous problem in Mauritius, affecting 90% of all wetlands (**Figure 8**). Most wetlands have had some backfilling in the past, mostly comprised of rocks removed from agricultural lands. What is of great environmental concern is the current backfilling that is affecting over 40 wetlands and is composed primarily of construction debris and rubbish. This is polluting the wetlands and potentially affecting nearby lagoons and aquifers.

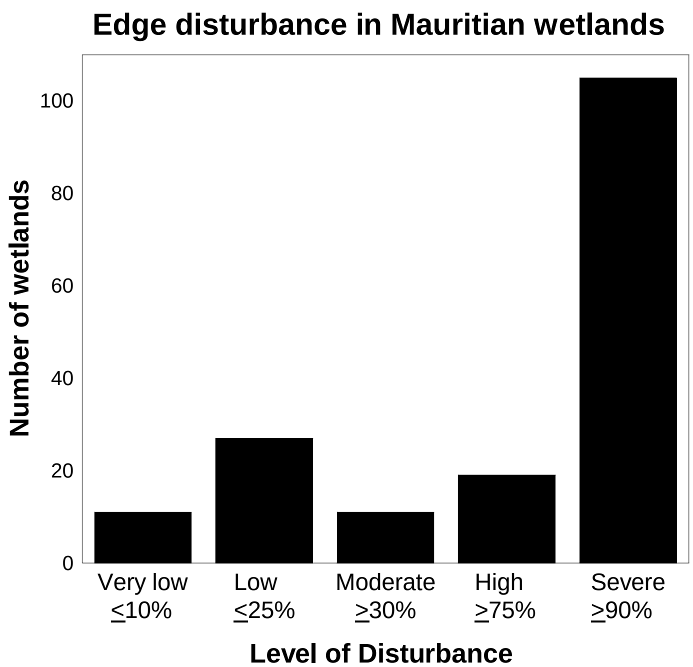
Figure 8. Backfilling of coastal marshlands in Mauritius.



Edge Disturbance

In general, the physical disturbance of a wetland initially occurs along its borders. We measured edge disturbance as a percentage of the wetland border that has been disturbed. We found that 105 wetlands have at least 90% of their border disturbed whereas only 11 can be considered intact with less than 10% edge disturbance (**Figure 9**). The remaining categories fall somewhere in between. This is a serious situation and, along with backfilling, represents a major threat to the ecological integrity of wetland habitats in Mauritius.

Figure 9. Proportion of coastal marshlands in Mauritius with varying levels of edge disturbance.



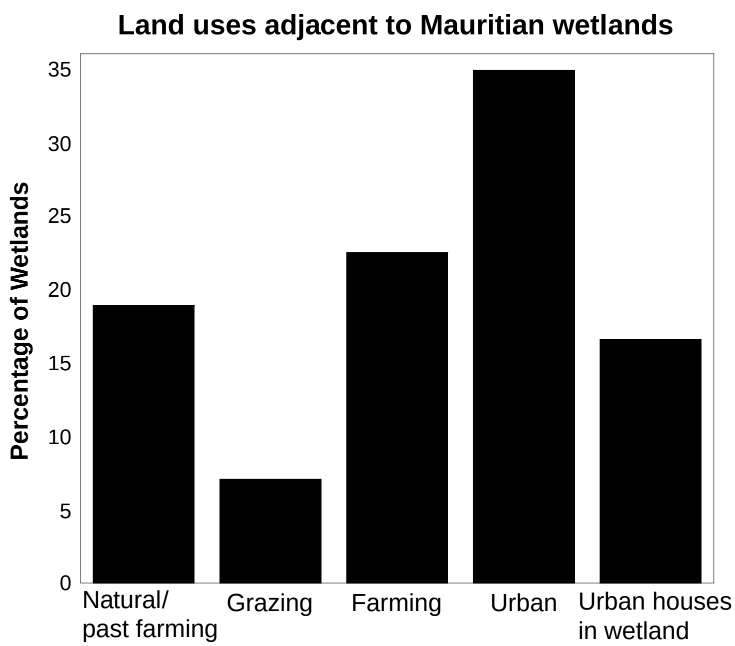
Wetlands with high levels of edge disturbance were most likely to have been backfilled (backfilling vs. edge disturbance: r_s= 0.416, P<0.0001 [n=181]). There was no significant relationship (P>0.05) between the vegetation structure and community composition (the X and Y axes) and edge disturbance, which means that edge disturbance is universal and not occurring more intensively in one type of wetland than another.

Adjacent Land-Use Intensity

Habitat disturbance in the form of either edge affects or habitat fragmentation are frequently driven by adjacent land uses. We identified five major land uses that are adjacent to or overlapping with wetlands. We rank these in order of increasing intensity using a quantitative ordinal scale: (1) natural land or abandoned farmland, (2) rural livestock grazing, (3) rural sugarcane or small-scale farming, (4) urban settings with no houses, and (5) urban settings with houses or a golf course. The last category involves a highly modified landscape with houses built within the wetland.

We found that half of the wetlands in Mauritius have now been overtaken by urban landscapes and that probably 20% of all wetlands have homes built within the original flood zone (**Figure 10**). Disturbance of wetland edges was significantly higher in urban than natural or rural areas (land-use-intensity scale vs. edge disturbance: r_s= 0.326, P<0.0001 [n=166]). In addition, backfilling was much more likely to occur in urban than non-urban areas (r_s=0.488, P<0.0001 [n=168]) (all Spearman rank correlations).

Figure 10. Land-use intensity adjoining coastal marshlands in Mauritius.

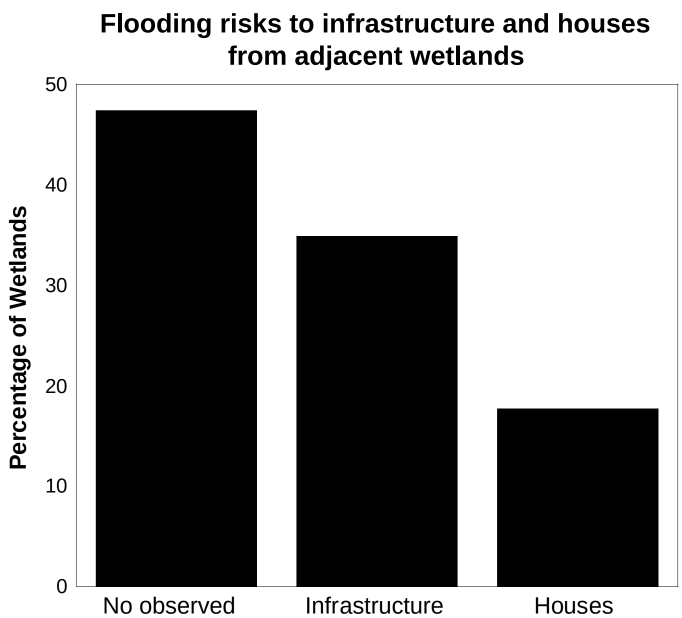


Flooding

We recorded information on wetland flooding of infrastructure (roads) and housing. Half of the wetlands showed signs of having flooded nearby homes or adjacent roads

(**Figure 11**). Building in wetlands was significantly responsible for most of the flooding (flooding vs. land-use intensity score: r_s=0.496, P<0.0001 [n=178]). Habitat fragmentation also significantly increased the risk of flooding to homes and roads (r_s=0.414, P<0.001 [n=184]), presumably because wetlands were closely juxtaposed with roads and houses when fragmented. We did not investigate flooding effects on grazing or farming lands.

Figure 11. Estimated frequency of flooding risk to infrastructure and houses adjoining coastal marshlands in Mauritius.



In summary, we find that urbanization is the major threat to lowland wetlands in Mauritius. Land-reclamation activities, such as backfilling and habitat fragmentation, are significantly reducing wetland area and various measures of ecological integrity. Rapid urbanization and ongoing housing construction in low-lying areas are seriously increasing flooding risk to nearby houses and infrastructure.

3.5 Assessing the Conservation Value of Wetlands

Assessing Conservation Value

We estimated the conservation value of wetlands based on four main criteria: 1) biological significance which includes species conservation status (presence of endangered and vulnerable species) and important fossil sites ; **Appendix D.5**); 2) biological diversity (fauna, flora and total species richness; **Appendix D.4**); 3) edge integrity and relative disturbance which we calculated using two separate measures: (1) the proportion of the wetland edge that is intact, and (2) a cumulative value from the separate scores for land-use-intensity, habitat fragmentation, flooding risk, and backfilling **Appendix E.1**); 4) wetland area (**Appendix E.2**). These four criteria were combined into a single table and a weighted ranking system applied to each attribute based on its relative contribution to conservation (**Appendix E.2**)

4. WETLAND CATEGORISATION AND LAND-USE RECOMMENDATIONS

4.1 Three-Point Value Categorisation

All wetlands were assigned to one of three Conservation Value categories based on their biological and physical features and the ecosystem service value they deliver. The three-point categorisation here is intended to be consistent with a broader categorisation of Environmentally Sensitive Areas described in the ESA Policy Guidance document (Ministry of Environment & NDU 2009).

4.2 Upland Marsh

Upland Marsh areas identified from the remotely-sensed imagery are limited in geographic range, size and, in many instances, permanence. Virtually all features are contained within State Land, National Park or State Forest Land areas, rendering any in-depth analysis of relative value somewhat redundant given the ultimate objective of identifying priorities for protection. Based on the biological assessment of the major features, however, some areas stand out and have been placed in a High Conservation category. These are primarily those containing high native content and plant taxa with highly restricted distributions, such as a number of *Pandanus* species, the large endemic amaryllis, *Crinum mauritianum*, and often inter-mixed with endemic-rich heath (Vaughn & Wiehe 1937; Atkinson & Sevathian 2005). Other areas have been placed in the Moderate Conservation category with no upland marsh allocated to the Low Conservation category, given their relatively restricted distribution and existing land designation status.

4.3 Lakes & Reservoirs

All lakes and reservoirs included in this report serve water storage functions of national importance. Nonetheless, reservoirs are man-made developments and may require additional works in order to maintain or improve their function. Consequently, all have been placed in a Moderate Conservation category which will allow these works to proceed, subject to existing restrictions enforced by the relevant authority. Grand Bassin uniquely serves a socio-cultural function and existing development would preclude assignment of the highest conservation status, given the restrictions placed on infrastructural development attached to this category. Despite its relatively modest volumetric holding capacity, Bassin Blanc is in a relatively natural state and retains some areas of high quality forest within its buffer that would clearly degrade further should any development proceed. It has been included in the High Conservation category.

4.4 Coastal Marshland

Coastal Marshlands are the most poorly documented and most threatened wetland type considered here. Consequently, significantly greater effort was allocated to the conservation value assessment of these features in order to provide the best possible scientific basis for classification.

We placed coastal marsh into the same three conservation categories considered for other wetlands: High, Moderate and Low based on the weighted rankings presented in **Appendix E.2**. These wetlands are presented as individual tables along with ownership information. Although the four major types of coastal marshland community were not included in this classification process. We examined their frequencies among categories to ensure that all wetland types were represented. The four marshland types were in almost equal abundance within the classification of Wetlands of Moderate and Low Conservation Values. However, half of the Wetlands of High Conservation Value were the wetland community Type 2 (Open water with *Typha* and *Acrostichum*), which reflects the general higher biodiversity of these communities. Other wetland types (1,3,&4) were in equivalent frequencies in the high conservation value category.

Marshland of High Conservation Value

The ranking analysis identified 54 coastal marshlands of high conservation value. Of these, 12 are worthy of special mention because they are associated with significantly higher values than the others. These include marshlands with the numerical identification numbers 39, 76, 99, 106, 107, 114, 117, 120, 126, 146, 155, 168 (**Table 7**). Wetlands within this classification have high biodiversity and are relatively intact with respect to habitat degradation, many marshlands in this classification also support endangered plant species. Of this total, only 26 marshlands are fully under private ownership, of which only two (18, 22) have more than a single owner and may require immediate management decisions regarding their future.

Table 7. Coastal Marshlands of High Conservation Value and their Ownership (SL =State Land)

Count	Numeric ID	Ownership	# Owners	Count	Numeric ID	Ownership	# Owners
1	**9**	Private	1	28	**28**	Private/SL	2
2	**18**	Private	10	29	**49**	Private/SL	2
3	**22**	Private	20	30	**76**	Private/SL	2
4	**35**	Private	1	31	**8**	SL	1
5	**67**	Private	1	32	**34**	SL	1
6	**70**	Private	1	33	**36**	SL	1
7	**89**	Private	1	34	**39**	SL	1
8	**95**	Private	1	35	**46**	SL	1
9	**97**	Private	1	36	**77**	SL	1
10	**99**	Private	1	37	**78**	SL	1
11	**101**	Private	1	38	**81**	SL	1
12	**103**	Private	1	39	**106**	SL	1
13	**117**	Private	1	40	**107**	SL	1
14	**120**	Private	1	41	**113**	SL	1
15	**122**	Private	1	42	**114**	SL	1
16	**123**	Private	1	43	**128**	SL	1
17	**126**	Private	1	44	**146**	SL	1
18	**147**	Private	1	45	**151**	SL	1
19	**152**	Private	1	46	**168**	SL	1
20	**155**	Private	1	47	**179**	SL	1
21	**159**	Private	1	48	**180**	SL	1
22	**183**	Private	1	49	**181**	SL	1
23	**213**	Private	1	50	**182**	SL	1
24	**228**	Private	1	51	**184**	SL	1
25	**231**	Private	1	52	**185**	SL	1
26	**100**	Private	1	53	**186**	SL	1
27	**7**	Private/SL	2	54	**214**	SL	1

Management Recommendations. Wetlands of high conservation value must be afforded protection at the earliest opportunity. These wetlands have high biodiversity values, endemic species, a relatively intact flora, and/or a low level of habitat disturbance. These sites should have a legal-protection framework that will shield them from inappropriate land uses, including the dumping of rubbish, discharge of effluents, backfilling, drainage, habitat fragmentation, and land reclamation. No major infrastructural developments should be permitted. Management plans for these sites will require regular monitoring to ensure that they are effectively protected *in perpetuity*. Classification as a marshland of High Conservation Value is consistent with a Category I ESA designation as delimited in the ESA Policy document (Government of Mauritius 2009).

Marshlands of Moderate Conservation Value

We classified 74 wetlands of moderate conservation value (**Table 8**). Wetlands within this category may include habitats that are intact but have naturally low species diversity, or alternatively, have moderate to high species diversity but have suffered from human-related degradation. One of the largest differences separating moderate from high conservation sites is the presence of endangered species. This is generally a valuable criterion, but because endangered species are also typically rare, detecting their presence is more heavily influenced by factors such as sampling effort, site accessibility, species mobility and growth form. Thus not recording endangered species in a locality does not signify they are absent, and if a site supports relatively intact habitat then it's important that it is recognised that endangered species could occur there. Approximately half of these wetlands are under private ownership. Fortunately, most have single owners but 12 sites have >1 owner and may require immediate review to ensure these areas are not fragmented.

Management Recommendations. Wetlands of moderate conservation value also need to be protected from land reclamation activities that involve backfilling, habitat fragmentation, and dumping of rubbish. Drainage activities and mining are also precluded. However, low-intensity activities, such as livestock grazing at sustainable stocking rates, could continue near these wetlands. Classification as a marshland of Moderate Conservation Value is consistent with a **Category II ESA** designation as delimited in the ESA Policy document (Government of Mauritius 2009).

Table 8. Coastal Marshland of Moderate Conservation Value and their Ownership (SL = State Land)

Count	Numeric ID	Ownership	# Owners	Count	Numeric ID	Ownership	# Owners
1	**5**	Private	4	39	**165**	Private	4
2	**6**	Private	7	40	**172**	Private	1
3	**10**	Private	14	41	**218**	Private	10
4	**11**	Private	5	42	**229**	Private	1
5	**12**	Private	7	43	**230**	Private	1
6	**13**	Private	6	44	**232**	Private	2
7	**14**	Private	1	45	**24**	Private/SL	20
8	**17**	Private	2	46	**41**	Private/SL	2
9	**20**	Private	3	47	**53**	Private/SL	2
10	**23**	Private	2	48	**56**	Private/SL	2
11	**30**	Private	1	49	**85**	Private/SL	2
12	**31**	Private	1	50	**112**	Private/SL	3
13	**33**	Private	1	51	**37**	SL	1
14	**40**	Private	5+	52	**38**	SL	1
15	**42**	Private	20+	53	**58**	SL	1
16	**43**	Private	1	54	**80**	SL	1
17	**60**	Private	1	55	**82**	SL	1
18	**72**	Private	1	56	**86**	SL	1
19	**92**	Private	1	57	**87**	SL	1
20	**102**	Private	1	58	**88**	SL	1
21	**105**	Private	1	59	**108**	SL	1
22	**116**	Private	1	60	**109**	SL	1
23	**118**	Private	1	61	**115**	SL	1
24	**119**	Private	1	62	**127**	SL	1
25	**121**	Private	1	63	**144**	SL	1
26	**125**	Private	1	64	**153**	SL	1
27	**130**	Private	1	65	**154**	SL	1
28	**134**	Private	1	66	**178**	SL	1
29	**137**	Private	1	67	**187**	SL	1
30	**138**	Private	1	68	**206**	SL	1
31	**140**	Private	1	69	**207**	SL	1
32	**141**	Private	1	70	**208**	SL	1
33	**142**	Private	1	71	**211**	SL	1
34	**148**	Private	1	72	**212**	SL	1
35	**156**	Private	0	73	**215**	SL	1
36	**158**	Private	1	74	**223**	SL	1
37	**160**	Private	3				
38	**164**	Private	1				

Marshlands of Low Conservation Value

We identified 76 wetlands with features consistent with a Low Conservation Value (**Table 9**). Many of these wetlands are remnants of once larger wetlands. Their low conservation value indicates they support very little, native biological diversity in addition to being highly disturbed by human activities. Most of the wetlands in this category are in private ownership with several occurring in golf courses.

Management Recommendations. Wetlands of low conservation value are those that have been highly modified by habitat fragmentation and backfilling. Although their habitat values may have been greatly diminished, their ecosystem service value particularly that attached to hydrological functioning still needs to be taken into account. Despite being disturbed, these wetlands may offer important protection to adjacent lagoons by slowing water movement and reducing sedimentation and pollution and nutrient flow into the marine environment. If the Government of Mauritius allows some of the small urban wetlands to be reclaimed, a thorough Environmental Impact Assessment should be undertaken to evaluate the impacts on adjoining ecosystems. In particular, the effects of wetland removal on water flows during major rainstorms and cyclones should be carefully considered. Classification as a marshland of Moderate Conservation Value is consistent with a **Category III ESA** designation as delimited in the ESA Policy document (Government of Mauritius 2009).

Table 9. Coastal Marshland of Low Conservation Value and their Ownership

Count	Numeric ID	Ownership	# Owners	Count	Numeric ID	Ownership	# Owners
1	**1**	Private	2	39	**111**	Private	13
2	**2**	Private	9	40	**124**	Private	1
3	**3**	Private	5	41	**129**	Private	1
4	**4**	Private	1	42	**131**	Private	1
5	**15**	Private	2	43	**132**	Private	1
6	**16**	Private	1	44	**135**	Private	1
7	**19**	Private	2	45	**136**	Private	1
8	**21**	Private	2	46	**139**	Private	1
9	**25**	Private	6	47	**143**	Private	1
10	**26**	Private	10	48	**145**	Private	1
11	**29**	Private	1	49	**157**	Private	1
12	**32**	Private	1	50	**161**	Private	3
13	**44**	Private	1	51	**162**	Private	6
14	**45**	Private	1	52	**174**	Private	1
15	**54**	Private	1	53	**177**	Private	2
16	**57**	Private	1	54	**219**	Private	1
17	**59**	Private	1	55	**220**	Private	1
18	**61**	Private	1	56	**221**	Private	1
19	**62**	Private	1	57	**234**	Private	4
20	**63**	Private	1	58	**237**	Private	2+
21	**64**	Private	1	59	**27**	Private/SL	5
22	**65**	Private	1	60	**55**	Private/SL	2
23	**66**	Private	1	61	**84**	Private/SL	2
24	**68**	Private	1	62	**47**	SL	1
25	**69**	Private	2	63	**48**	SL	1
26	**71**	Private	1	64	**50**	SL	1
27	**73**	Private	1	65	**51**	SL	1
28	**74**	Private	1	66	**52**	SL	1
29	**75**	Private	1	67	**133**	SL	1
30	**79**	Private	9	68	**210**	SL	1
31	**83**	Private	1	69	**222**	SL	1
32	**90**	Private	1	70	**224**	SL	1
33	**91**	Private	1	71	**225**	SL	1
34	**93**	Private	1	72	**226**	SL	1
35	**94**	Private	1	73	**227**	SL	1
36	**96**	Private	1	74	**233**	SL	1
37	**104**	Private	1	75	**235**	SL	1
38	**110**	Private	4	76	**236**	SL	1

5. LITERATURE CITED

Atkinson, R. & S-C Sevathian. 2005. *A guide to the plants of Mauritius*. Mauritian Wildlife Foundation. Port Louis, Mauritius. 192 pp.

Government of Mauritius. 1990. *Map Sheets 1-14. 1:25,000 Scale*. Series Y881 (DOS 329). Edition 6-OSD. Ordnance Survey (UK), Southampton, UK.

Government of Mauritius. 2002. *Strategic Environmental Impact Assessment of Marinas, Ski Lanes and Bathing Areas*. Ministry of Environment. Prepared by Mega Design Ltd, Entech Consultants, & WSP Walmsley. Port Louis, Mauritius.

Government of Mauritius. 2003a. *National Development Strategy*. Ministry of Housing and Lands. Prepared by Halcrow Group Ltd. Port Louis, Mauritius.

Government of Mauritius. 2003b. *Study on Coastal Erosion in Mauritius*. Ministry of Environment & NDU. Prepared by Baird Associates, Reef Watch Consultancy & Dr Michael Risk. Port Louis, Mauritius.

Government of Mauritius. 2004. *Study of Environmental Risks in Grand Baie*. Final Technical Report. Ministry of Environment and NDU. Port Louis, Mauritius.

Government of Mauritius. 2006. *District Council Area Outline Planning Scheme Maps. 1:5000 Scale*. Ministry of Housing and Lands. Prepared by Halcrow Ltd., Port Louis, Mauritius.

Government of Mauritius. 2008. *Survey Report of Grand Baie Wetlands*. Ministry of Environment & NDU. Prepared by The Watershed Co., NWFS Consultancy and STEM Consulting Ltd. April 2008. 49 pp + Appendices and 9 Maps. Port Louis, Mauritius.

Inter-governmental Panel on Climate Change (IPCC). 2001. *Working Group II: Impacts, Adaptations and Vulnerability*. Chapter 17. Small Island States. IPCC, UNEP & WMO.

Ministry of Environment & NDU. 2008. *ESA Study Inception Report*. Prepared by NWFS Consultancy and STEM Consulting Ltd. February, 2008. 52 pp.

Ministry of Environment & NDU. 2009. *Policy Guidance for Environmentally Sensitive Areas*. Prepared by NWFS Consultancy and STEM Consulting Ltd. June, 2009. 111 pp.

Ministry of Tourism. 2002. *Tourism Development Plan for Mauritius*. Prepared by Deloitte & Touche.

Sprecher, S. W. 2001. Basic concepts of soil science. Pages 3-19 in J. L. Richardson and M. J. Vepraskas (Eds.) *Wetland Soils- Genesis, Hydrology, Landscapes and Classification*. CRC Press LLC, Florida USA.

Vaughan, R. E. and P. O. Wiehe. 1937. Studies on the vegetation of Mauritius I: preliminary survey of the plant communities. *Journal of Ecology* 25: 289-343.

6. APPENDICES

APPENDIX A **Wetland Catalogue and Codes**

APPENDIX B **Wetland Photographs**

APPENDIX C **Wetland Size, Elevation and Isolation Data**

APPENDIX D **Wetland Biological and Physical Features Data**

APPENDIX E **Wetland Ranking and Value Categorisation**

APPENDIX F **Wetland Location and Property Tenure Maps**