Coastal Research Library 21

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Coastal Wetlands: Alteration and Remediation

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Preface

This volume of *Coastal Research Library* (*CRL*) deals with the general topic of coastal wetlands but specifically from within the purview of impacts that are deleterious to wetlands and kinds of restorative efforts that are deployed in attempts to correct wrongs resulting from human action. To this end, the volume is divided into three main parts: Part I, Impacts of Urbanization, Agricultural Occupation, Pollution, Climate Change, and Coastal Marine Influences; Part II, Impacts of Coastal Engineering and Environmental Degradation; and Part III, Restoration Techniques, Ecological Aesthetics, and Ecosystem Conservation (Sustainability and Biodiversity). These general subject area parts are in turn subdivided into chapters that are exemplars of degradation impacts or vignettes illustrating various approaches to restoration, either conceptually or in principle, and examples of new methodologies.

The geographical scope of this volume ranges from tropical to high-latitude coastal zones with various types of wetlands such as mangroves and salt marsh. A wide range of ecological considerations focuses on fisheries, intertidal benthic fauna, macrobenthic communities, and wildlife management. This selection of wide-ranging topics provides insight into the interconnectedness of various aspects of coastal wetlands. Provided here is a plethora of examples of successes and failures in attempts to correct the errors of human action when it comes to dealing with coastal wetlands. Sadly, many coastal wetlands around the world have been subjected to unwanted or unintended adverse impacts associated with urbanization, industrialization, and commercialization. With half of the world's coastal wetlands destroyed by such activities, it is imperative to absorb what is reported here in the following chapters that outline potential remediation efforts to save, conserve, or protect what is left of these valuable coastal ecosystems that are almost continually under threat from development.

Part I contains eight chapters that are examples of coastal wetlands adjacent to or overtaken by urbanization and agricultural occupation, which in turn result in degradation or destruction of coastal ecosystems. This dismal situation is further exacerbated by pollution, usually associated with urban development and/or agriculture, that compromises the integrity and in some cases the very survival of the remaining wetlands. Chapter 1 ("The Florida Everglades: An Overview of Alteration and Restoration"), by Charles W. Finkl and Christopher Makowski, discusses how urbanization, agriculture, and flood control destroyed about half of the Florida Everglades (a wetland of international importance [Ramsar Convention] and an international biosphere reserve [UNESCO]) and indicates failures of the world's most expensive reclamation effort that amounts to more than US$ 8 billion. Chapter 2 ("Recent Agricultural Occupation and Environmental Regeneration of Salt Marshes in Northern Spain"), by Ane García-Artola, Alejandro Cearreta, and María Jesús Irabien, deals with the reclamation of more than 50% of the original salt marshes that were degraded since the seventeenth century. This chapter illustrates how global temperate coastal wetlands with abundant sediment supply can be regarded as a soft adaptation measure that militates against consequences of climate change in the coastal zone. Chapter 3 ("Impact of Urbanization on the Evolution of Mangrove Ecosystem of the Wouri River Estuary [Douala, Cameroon]"), by Ndongo Din, Vanessa Maxemilie Ngo-Massou, Guillaume Léopold Essomè-Koum, Eugene Ndema-Nsombo, Ernest Kottè-Mapoko, and Laurant Nyamsi-Moussian, illustrates the deleterious effects of the urban environment on mangrove depletion around cities due to wood harvesting, sand extraction, and petroleum exploitation, in addition to coastal erosion and climate change. Unfortunately, the prognosis for a change in perception of mangrove degradation in this region is poor due to the absence of implementation of specific regulations to protect the mangrove forests. Chapter 4 ("Impacts of Coastal Land Use Changes on Mangrove Wetlands at Sungai Mangsalut Basin in Brunei Darussalam"), by Shafi Noor Islam and Umar Abdul Aziz Bin Yahya, continues in a similar vein by showing how increasing population pressure and economic development are detrimental to mangroves and salt marshes. Similar to the Everglades, there is the specter of conversion of water bodies and loss of open space where clearing of coastal mangroves and salt marshes result in a wide range of environmental issues and risks, not the least of which is severe pollution. This situation happens because the local authorities are unable to cope with the rapidly changing situations, internal resource constraints, and management limitations. Chapter 5 ("Land Use and Occupation of Coastal Tropical Wetlands: Whale Coast, Bahia, Brazil"), by Sirius O. Souza, Cláudia C. Vale, and Regina C. Oliveira, reports similar impacts in Brazil where coastal tropical wetlands are often compromised by the gradual expansion of population and economic cycles. Better planning proposals for land use and occupation are suggested for implementation. Chapter 6 ("Degraded Coastal Wetlands Ecosystems in the Ganges-Brahmaputra Rivers Delta Region of Bangladesh"), by Shafi Noor Islam, Sandra Reinstädtler, and Albrecht Gnauck, is perhaps the premier example in the world of population pressure on coastal wetland resources where 36.8 million people are living in the coastal region delta and who are dependent on coastal water resources. Unwanted impacts on the delta, tidal flats, mangrove forests, marches, lagoons, estuaries and other natural resources are elucidated in the light of ecosystem development and management strategies that are supposed to ensure communities with livelihood and sustainable development. Chapter 7 ("Handling High Soil Trace Elements Pollution: Case Study of the Odiel and Tinto Rivers and Accompanying Salt Marshes [Southwest

Iberian Peninsula]"), by Sara Muñoz Vallés, Jesús Cambrollé, Jesús M. Castillo, Guillermo Curado, Juan Manuel Mancilla-Leytón, and M. Enrique Figueroa-Clemente, verifies that salt marshes are one of the most prolifically heavy-metal polluted systems in the world. The interesting aspect of this chapter is its explanation of how key native halophytes are able to phytoextract or phytostabilize trace elements leading to the recovery of native prairies of low tidal marshes. Chapter 8 ("El Yali National Reserve: A System of Coastal Wetlands in the Southern Hemisphere Affected by Contemporary Climate Change and Tsunamis"), by Manuel Contreras-López, Julio Salcedo-Castro, Fernanda Cortés-Molina, Pablo Figueroa-Nagel, Hernán Vergara-Cortés, Rodrigo Figueroa-Sterquel, and Cyntia E. Mizobe, like the preceding chapters discusses adverse impact of human activities on coastal wetlands, in this case in central Chile, but additionally brings in the effects of natural disasters such as earthquakes, tsunamis, ocean swells, and ENSO. Field monitoring is also discussed with the objective of eventually implementing ecological restorations.

Part II contains five chapters and deals with direct impacts of coastal engineering and environmental degradation. The chapters here focus on clearly established and obvious links between construction works and degradation of coastal wetlands that are induced by ancillary effects. Chapter 9 ("Physical and Morphological Changes to Wetlands Induced by Coastal Structures"), by Germán Daniel Rivillas-Ospina, Gabriel Ruiz-Martinez, Rodolfo Silva, Edgar Mendoza, Carlos Pacheco, Guillermo Acuña, Juan Rueda, Angélica Felix, Jesús Pérez, and Carlos Pinilla, focuses on procedures that are used to better understand the relationship between modifications of coastal processes and the response of a coastal environment, in the case of civil works in the development of a new port in Barranquilla, Colombia. The interest here is to ascertain what changes in physical conditions will produce negative effects on the stability of natural systems in coastal wetlands. Chapter 10 ("Long Term Impacts of Jetties and Training Walls on Estuarine Hydraulics and Ecologies"), by Alexander F. Nielsen and Angus D. Gordon, probes inlet instabilities caused by the construction of jetties that in turn adversely impact the distribution of seagrass, salt marsh, and mangrove forests on the east coast of Australia. Chapter 11 ("Mangrove Degradation in the Sundarbans"), by Ashis Kr. Paul, Ratnadip Ray, Amrit Kamila, and Subrata Jana, investigates aspects of mangrove degradation in the Sundarbans and identification of contributing factors via extensive fieldwork, geospatial techniques, and factor analysis. This chapter shows hypersalinity, storm effects, fishery development, land erosion, and sediment deposition parameters are mainly responsible for mangrove degradations. Chapter 12 ("Assessment of Anthropogenic Threats to the Biological Resources of Kaliveli Lake, India: A Coastal Wetland"), by Krishnan Silambarasan and Arumugam Sundaramanickam, focuses on various threats to Kaliveli Lake, which is one of the largest wetlands in peninsular India and considered a wetland of international importance by the International Union for Conservation of Nature and Natural Resources (IUCN). Anthropogenic activities such as infringement from agricultural lands, wildlife poaching, loss of surrounding forests, increased salt pan and aquaculture farming, and recreation constitute important threats to the well-being of this wetland. This chapter also explores measures for conservation and protective management. Chapter 13 ("Egyptian Nile Delta Coastal Lagoons: Alteration and Subsequent Restoration"), by Ayman A. El-Gamal, identifies causes of wetland degradation in the Egyptian Mediterranean coastal region to be pollution, deterioration of water quality, eutrophication, habitat loss, overfishing, siltation, and climate change. Field studies are being conducted in efforts to determine management practices that will improve the resilience of these coastal lagoons.

Part III covers restoration techniques, ecological aesthetics, and ecosystem conservation with particular emphasis on sustainability and biodiversity. Although some of the previous chapters include discussion of remediation, this section highlights restoration efforts that promote sustainability and biodiversity in the broadest sense. This section is thus a logical follow-up to the previous two sections that primarily identified threats or risks to coastal wetlands. Determination or identification of the problem is obviously the first step in remediation; otherwise, it is impossible to remedy causes of unwanted conditions or situations. These chapters are examples of efforts in a diverse range of ecological setups where management strategies are proffered as means of conservation and protection within the realm of restoration and remediation. Chapter 14 ("Coastal Wetland Restoration: Concepts, Methodology, and Application Areas Along the Indian Coast"), by Ramasamy Manivanan, features a new concept that uses natural restoration techniques for coastal wetland restoration using the Chilika wetland ecosystem as a prototype. The idea here is to create conditions under which coastal ecosystem processes can withstand and diminish the impact of stressors. Chapter 15 ("Ecological Aesthetics Perspective for Coastal Wetland Conservation"), by LeeHsueh Lee, posits a new approach to the conservation of coastal wetlands where it is suggested that aesthetic preference provides a critical connection between humans and ecology. Promoted here is the prospect-refuge theory and the preference matrix of the bioevolutionary hypothesis, based on aesthetic experience, that could drive landscape change and pull with it ecological quality. Chapter 16 ("Estuarine Ecoclines and the Associated Fauna: Ecological Information as the Basis for Ecosystem Conservation"), by Mário Barletta, André R.A. Lima, Monica F. Costa, and David V. Dantas, is based on the definition of ecocline as a "gradation from one ecosystem to another where there is no sharp boundary between the two" where there are relatively heterogeneous communities influenced by gradual changes between river-dominated and marshlike waters. This chapter explains how to generate descriptors of reference conditions taking into account how human impacts affect coastal systems while providing steps to guarantee the sustainable use of estuarine resources. Chapter 17 ("Alteration and Remediation of Coastal Wetland Ecosystems in the Danube Delta: A Remote-Sensing Approach"), by Simona Niculescu, Cédric Lardeux, and Jenica Hanganu, demonstrates advantages of using remote sensing techniques to classify coastal wetland vegetation in the Danube Delta (a Biosphere Reservation), which was altered by human intervention in over one quarter of the entire delta surface. The random forest supervised classification algorithm was used to advantage for the Sentinel-1 and Sentinel-2 data collection. Chapter 18 ("Implementation of a Wildlife Management Unit as a Sustainable Support Measure Within the Palo Verde Estuary, Mexico: An Example of the American Crocodile [*Crocodylus acutus*]"), by Omar Cervantes, Aramis Olivos-Ortiz, Refugio Anguiano-Cuevas, Concepción Contreras, and Juan Carlos Chávez-Comparan, is a species-specific study in the Palo Verde Estuary (a Ramsar site) that recognizes that pollution, fragmentation of ecosystems, and habitat destruction due to human action incite the need for strategic management practices to encourage harvest sustainability. This chapter represents an opportunity to reconcile human activities with the environment based on an analysis made from the perspective of the conceptual Driving Forces-Pressure-State-Impact-Response model. Chapter 19 ("Mangrove Inventory, Monitoring, and Health Assessment"), by Ajai and H.B. Chauhan, identifies threats to mangroves from human activities (reclamation of mangrove areas for human habitation, aquaculture, agriculture, and port and industrial development) and shows how the use of remote sensing data can be used to develop a model for mangrove health assessment. The model developed here is demonstrated through a case study in India. Chapter 20 ("How Can Accurate Landing Stats Help in Designing Better Fisheries and Environmental Management for Western Atlantic Estuaries?"), by Mário Barletta, André R.A. Lima, David V. Dantas, Igor M. Oliveira, Jurandyr Reis Neto, Cezar A.F. Fernandes, Eduardo G.G. Farias, Jorge L.R. Filho, and Monica F. Costa, discusses fishery management in Brazilian estuaries while pointing out the need for better statistics to help avoid the impacts of overfishing. The main thrust of this chapter is the explanation of the need to improve fishery management by compliance of ecological data and biological research, obtaining robust data for landing stats, and establishing a social profile of the fishery community to build better rules of comanagement. Chapter 21 ("Returning the Tide to Dikelands in a Macrotidal and Ice-Influenced Environment: Challenges and Lessons Learned"), by Laura K. Boone, Jeff Ollerhead, Myriam A. Barbeau, Allen D. Beck, Brian G. Sanderson, and Nic R. McLellan, deals with the lessons learned from the design, implementation, and monitoring of salt marsh restoration in the upper Bay of Fundy, Canada. They found that the bioengineering species saltwater cordgrass (*Spartina alterniflora*) performed well and could be used again in similar situations. Chapter 22 ("Macrobenthic Assemblage in the Rupsha-Pasur River System of the Sundarbans Ecosystem (Bangladesh) for the Sustainable Management of Coastal Wetlands"), by Salma Begum, investigates a non-forestry product (benthic invertebrates) of the Sundarbans (the world's largest mangrove forest) and found that the combined effects of environmental and biological parameters influence relative species abundance. Chapter 23 ("Ecological Services of Intertidal Benthic Fauna and the Sustenance of Coastal Wetlands along the Midnapore [East] Coast, West Bengal, India"), the last chapter in the book, by Susanta Kumar Chakraborty, shows the value and functional contribution of benthic biodiversity (macrobenthos and meiobenthos) for the continuation of the Sundarbans mangrove estuarine complex. These bioindicators are indicative of the health of this disturbed coastal environment.

What is presented in this volume is but a snippet of the global situation confronting coastal wetlands today, which entails a universal threat from human action. The chapters illustrate the status of coastal wetlands from the geographical spread ranging from the tropics to high-latitudes via studies in Florida, Spain, Cameroon, Brunei Darussalam, Brazil, Bangladesh, Chile, Colombia, Australia, India, Egypt, Romania, Mexico, and Canada. These vignettes carry the common theme of coastal wetlands under stresses of variable types ranging dominantly from human action and less so from natural causes related to climate change. With about half of the world's coastal wetlands already destroyed by either urban expansion or the development of industrial and commercial infrastructure, the remainder are seriously threatened by a range of human activities (e.g., wood harvesting and loss of surrounding forests, sand extraction, petroleum exploitation, infringement from agricultural lands, wildlife poaching, increased salt pan and aquaculture farming, fishery development, land erosion, sediment deposition, and recreation) that usually fall under the radar of governing bodies that either turn blind eyes to what is happening or do not have the available resources to control the deterioration of the wetland ecosystems.

The other main theme of the various chapters is that the remaining coastal wetlands worldwide that have or continue to receive protection usually cannot remediate the damage that has already incurred. Although large areas have come under the "protection" of various types of statuses (e.g., Ramsar Convention, International Biosphere Reserve [UNESCO], International Union for Conservation of Nature and Natural Resources [IUCN]), this does not guarantee proper management by local authorities. Although the intent is laudable, the practicalities of the present world situation is that population growth is out of control in many regions that contain coastal wetlands. Human pressure on wetland resources is immense, and constructive efforts to protect, preserve, and conserve coastal wetland ecosystems are currently too weak to achieve goals that will maintain this valuable resource base for posterity. Several chapters point to new research that is being conducted into innovative ways of understanding and comprehending how these ecosystems function so they can be better managed. But the research and implementation of its findings are generally too slow compared to population growth with the result that coastal wetlands remain under threat from a wide range of human activities that eventually harken the death knell. What is required are more stringent protective measures that will secure a sustainable and unfettered future for the world's mangrove forests, fresh- and saltwater marshes, lakes, estuaries, and lagoons. All of the chapters in this book indicate in one way or another the present status and probable conditions of coastal wetlands as we look to the future.

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Part I
Impacts of Urbanization, Agricultural Occupation, Pollution, Climate Change, and Coastal Marine Influences

Chapter 1
The Florida Everglades: An Overview of Alteration and Restoration

Charles W. Finkl and Christopher Makowski

Abstract The Florida Everglades, currently designated as a Wetland of International Importance (Ramsar Convention), an International Biosphere Reserve (UNESCO), and a World Heritage Site in Danger (UNESCO), was administered around the turn of twentieth century by federal and state ditch and drain policies to 'reclaim' the coastal wetlands for urban sprawl, agriculture, and flood control. Today, the so-called 'river of grass' is only about half of its original extent; the remaining oligotrophic wetlands have been compromised by an ingress of nutrient-rich polluted and contaminated waters from agriculture and urban development. Furthermore, the spread of invasive flora and fauna have further compromised these wetland environments. In attempts to repair some of the damage wreaked upon this unique subtropical coastal ecosystem, numerous programs have been implemented to produce the world's most expensive reclamation effort that amounts to more than US$8 billion. Positionalities of special interest groups and hegemonial overthrusts by various governmental agencies have produced a bewildering array of projects that fail to address the real causes of degradation while treating only symptoms instead. Due to the lack of common sense approaches of the restoration that deal with causes rather than symptoms, such as further wetland alteration to naturalize surface flow patterns of water and the inability to hinder the introduction/spread of exotic alien species, the Florida Everglades has evolved into something quite different from pre-settlement conditions, with major doubts that the ecosystem can be put back together again.

Keywords Wetlands • Urban sprawl • Agricultural runoff • Oligotrophic • Eutrophification • Invasive species • Flooding • Everglades Agricultural Area • Pollution • Environmental remediation

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1.1 Introduction

For an estimated 5000 years, water in southern Florida Peninsula once flowed freely from the Kissimmee River southward to Lake Okeechobee and over low-lying wetlands leading to the estuaries of Biscayne Bay, Card Sound, the Ten Thousand Islands, and Florida Bay (Davis and Ogden 1994; Gunderson and Loftus 1993; Lodge 1994). This slow-moving, shallow expanse of water covered almost 28,500 km^2, and for thousands of years this complex hydrologic system created a finely balanced ecosystem of ponds, sloughs, sawgrass marshes, hardwood hammock woods, and forested uplands in the southern half of the state (Gleason 1984; McVoy et al. 2001; White 1970). However in 1847, only two short years after Florida was granted statehood from the Union, the first known proposal to drain the overflowed lands of the Lower Peninsula was put forth (Light and Dineen 1994). This proposal was based on the reconnaissance operations of Generals William S. Harney and Thomas S. Jessup, who were responsible for exploring areas that included the Everglades, Kissimmee River Valley, and Peace Creek (Fig. 1.1). Using these findings as leverage, the Secretary of the Treasury, H.J. Walker, under the administration of President James K. Polk, moved forward with drainage plans by appointing local St. Augustine resident, Thomas Buckingham Smith, the task of making a general inspection of the Everglades area and to report his findings to Congress (Light et al. 1995). Although Smith was neither a trained engineer nor an educated scientist, he accepted the challenge in June 1847. The results of five weeks of investigation include vivid descriptions of wildlife, as well as, detailed measurements and careful analyses of the terrain. Smith described the pristine Everglades with poetic prose:

> Imagine a vast lake of fresh water, extending in every direction, from shore to shore, beyond the reach of human vision; ordinarily unruffled by a ripple on its surface, studded with thousands of islands of various sized, from one-fourth of an acre to hundreds of acres in area…

Smith wrote of lilies and "other aquatic flowers of every variety and hue." He described the sensation of drawing near an island by saying "the beauty of the scene is increased by the rich foliage and blooming flowers of the wild myrtle and the honeysuckle" (Davis 1943). Obviously touched by the beauty of the Everglades, he also commented on the solitude and solemn silence pervading the marsh. He commented it all "awakened and excited curiosity feelings bordering on awe." Although Smith was captivated by the magnificence of the Everglades, he remained stubborn in his recommendation to drain the swamp and use it to grow citrus, sugar, and other produce usually imported from the West Indies at that time. He envisioned that the drainage of the Everglades would lead to a coast-to-coast canal, much as St. Augustine's founder Pedro Menéndez had once described. When Smith reported to the United States Senate in June 1848, he lobbied that the Everglades could be reclaimed with a sensible system of canalling and by deepening the various streams that flowed both east and west to the coasts (Light and Dineen 1994). He believed that drainage would insure the growth of a new agricultural empire in south Florida.

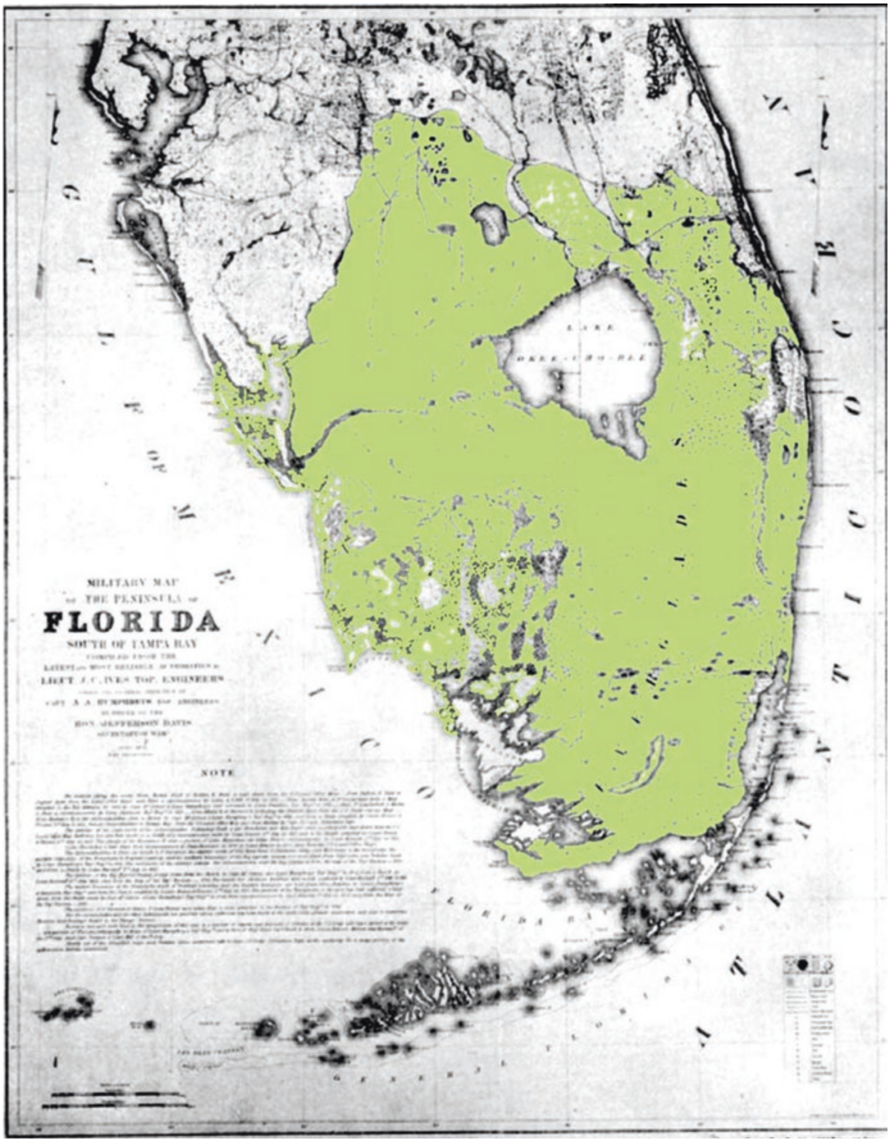

Fig. 1.1 United States military map of southern Florida drafted in the 1850s. Military campaign cartography, like this map created during the Seminole Wars, helped to understand the full geographic extents of the Everglades ecosystem. As shown above in a pristine state (*green* shading has been added to highlight this), this coastal wetland encompassed most of the southern tip within the Florida Peninsula and included not only all of the Everglades, but also the surrounding wetlands (e.g., Big Cypress Swamp and Kissimmee River Valley). Unfortunately, with this newly acquired knowledge of the Everglades, also came man's hubris to channelize and control this naturally dynamic environment (Credit: U.S. War Department)

His report to the 30th Congress was published as Senate Document No. 242 and proved to be the catalyst for the evitable drainage of the Everglades (Blake 1980; Snyder and Davidson 1994).

Even though the United States Congress immediately passed the "Swamp and Overflowed Lands Act of 1850," which conveyed the whole of Florida's swamp and overflowed lands to State ownership with the intent of draining them, it was not until the early twentieth century that large-scale alterations occurred (Finkl 1995; Light et al. 1995). The State Legislature wound up creating a Board of Drainage Commissioners and turned over to them the lands that were acquired in 1850 by the Swamp and Overflowed Lands Act (Light and Dineen 1994). This board was vested with government authority to:

> "...establish drainage districts and to fix the boundaries thereof in the State of Florida". Also, they were... "to establish a system of canals, levees, drains, dikes, and reservoirs…to drain and reclaim the swamp and overflowed lands within the State of Florida."

In 1906, the Trustees of the Internal Improvement Fund and the Drainage Commissioners purchased and operated dredges, and from 1906 to 1913, over 365 km of drainage canals were built, including the Miami, North New River, and South New River Canals by the Everglades Drainage District (EDD) (Light et al. 1995). Over the next 15 years, six large drainage canals and numerous smaller canals, totaling approximately 710 km, 75 km of levees, and 16 locks and dams were completed (Light et al. 1989; Sklar and van der Valk 2002). The newly constructed system of canals and locks was directly responsible for draining the northern and eastern parts of the Everglades region, with a majority of the canals originating at Lake Okeechobee and flowing easterly toward the Atlantic. This partial drainage of the Everglades subsequently opened the area to large farming settlements. By 1921, the population in the Okeechobee lake region was estimated to be around 2000 people, with newly cultivated lands in the glades yielding crops of sugar cane, tomatoes, beans, peas, peppers, and potatoes (Dovell 1947; Snyder and Davidson 1994).

Even with all the constructed canals, locks, and levees, which cost upwards of 20 million dollars, satisfactory drainage of Lake Okeechobee was not being met (Blake 1980). However, this was imperative since improper drainage did not afford sufficient protection to residents and farmlands from lake overflow during unusual weather. This impending hazard became all too apparent during the hurricane that struck Miami and the Lake Okeechobee region in 1926. Strong wind tides overflowed the banks of Lake Okeechobee causing over 200 deaths and millions in financial losses (Blake 1980; Chimney and Goforth 2001). Another hurricane in 1928 passed through the Palm Beach region on a path towards Lake Okeechobee with disastrous results. Wind-driven water off the lake, augmented by the torrential rains, overflowed the lakeshores and drowned approximately 2400 people, in addition to destroying a vast amount of property (Blake 1980). After these two catastrophes, the U.S. Federal government seized control under pressure from an outraged public. After a personal inspection of the area by President Herbert Hoover, the U.S. Army Corps of Engineers drafted a new plan that provided for the construction of floodway channels, control gates, and major levees along Lake Okeechobee's shores (Light et al. 1989). Construction of the Herbert Hoover Dike began in 1930 and in June of 1936, a national flood control policy was adopted by Congress (Light and Dineen 1994; Light et al. 1995). The Flood Control Act of 1936 established the policy that the Federal Government should:

> …improve or participate in the improvement of navigable waters or their tributaries for flood control purposes, if the benefits to whomsoever they may accrue, are in excess of the estimated cost, and if the lives and social security of the people are otherwise adversely affected.

Then, as if divine forces were at work to scorn the man-made decisions to excessively drain the Everglades, extreme dry spells of little to no precipitation occurred between 1931 and 1945. This successive lack of freshwater input resulted in a lowering of the groundwater, which then allowed seawater from the ocean to intrude on a multitude of wells that Miami and other coastal cities depended upon. In addition, the peaty, organic-rich soils of the Everglades that once depended upon the flooding ability of Lake Okeechobee to keep them moist were now subjected to desiccation (Snyder and Davidson 1994). Many areas caught fire in this dried-out state and were lost forever. The U.S. government was so focused on draining the Everglades, they never stopped to think that water conservation should be a necessary component of any drainage plan. In fact, structures designed to drain certain areas, thus protecting the people and farmland in time of floods, were also depriving the ecosystem of necessary moisture inputs during dryer periods.

Just as water conservation was being debated and proposed as part of the ongoing Everglades drainage plan in the aftermath of one of the worst droughts in Florida's history, the unthinkable happened. In 1947, over 254 cm of rain fell on south Florida, more than tripling the region's total recorded rainfall for 1945. The Great Flood of 1947 started on March 1 when a squall line dumped a welcome 15 cm of water on the parched agricultural lands of the upper Everglades. Rain was subsequently plentiful in April and May, and then in June became so heavy that chairman Dewey Hilsabeck called an emergency meeting of the Everglades Drainage District (EDD), which still had jurisdiction over a vast network of drainage canals, dams, levees, locks, water-control structures, and hurricane gates (Light and Dineen 1994). By opening the hurricane gates at Lake Okeechobee, for example, the EDD could drain excess water from the upper glades into the lake, which was purposely kept low for such an emergency (Light et al. 1989). But when the torrential rains came in 1947, the EDD was starved for funds to pursue its flood control program, and to compound the problem, a hurricane had formed offshore in the Atlantic. Slowly the hurricane worked its way across the Caribbean, battering Puerto Rico and the Bahamas, and then took direct aim at Florida. On September 17, it smashed into the mainland, with winds clocked at over 250 km h^{-1} at the Hillsboro Lighthouse. In Fort Lauderdale, the New River overflowed its banks and whitecaps broke over downtown, flooding luxury homes on the finger isles. Saltwater destroyed Dania's tomato crop and rainwater drowned the orange groves of Davie and the bean fields of Pompano Beach. Migrant workers near Lake Okeechobee were evacuated to higher ground. In West Palm Beach, the National Guard was called out and President Harry Truman declared Florida in a state of emergency. Especially destructive was the surge of water pouring into Lake Okeechobee from the Kissimmee River Valley, since the lake was already full and the water had just one place to go: southward toward Fort Lauderdale and Miami through already swollen canals. In the space of just 25 days, two hurricanes and a tropical disturbance dumped more water on a saturated area. When the rains finally ceased, 90% of southeastern Florida, from Orlando to the Keys, was literally underwater. Over 20,200 km^2 of water stretched from Lake Okeechobee across the Everglades and the Big Cypress Swamp southward through Broward and Dade counties, resembling an inland sea (Light et al. 1995). The total damage of this event was estimated by the Corps to be over $60,000,000 (Blake 1980).

Following the disastrous Great Flood of 1947, the problems of this area came to a climax and the government finally realized the current drainage protocols were not working. This flood, coupled with the experiences of the drought in 1945 and the intrusion of contaminating saltwater into potable and irrigational well water, made it imperative that corrective action had to take place immediately in order to prevent further loss of life, end excessive property damage, and to responsibly conserve water for beneficial uses during periods of drought. Therefore, in the wake of these catastrophes, a comprehensive plan for flood control and water conservation, which would encompass the entire Everglades and south Florida region, was put forth, thus starting the Everglades restoration movement in the interest of flood protection, drainage, and water control (Davis et al. 1994; Light and Dineen 1994; Light et al. 1995, 1989).

The following comments and discussion explores different components of the Everglades and the various projects under the guise of ‘restoring’ this ecosystem back to a resemblance of its former self. Will human action today be able to correct what took such a short amount of time to destroy? That is the question. The discussion section thus offers an injection of common sense when trying to answer that question and, possibly for the first time in the quest for atonement, presents a realistic solution to the possibility of “restoring” the Everglades.

1.2 Florida Everglades: Before and After Anthropogenic Alteration

The Everglades once covered almost 28,500 km^2 of southern Florida. Just a century and a half ago, water flowed down the Kissimmee River into Lake Okeechobee, then south through the Everglades marsh to the tidal flats of Florida Bay (Fig. 1.2), which was the final destination of the pure sheet flow (McVoy et al. 2011). Dubbed the ‘River of Grass’ (Douglas 1947) for the sawgrass that flourished throughout the marsh, the Everglades was a mosaic of freshwater ponds, prairies, and forested uplands that supported a rich plant and wildlife community (Davis et al. 1994; Douglas 1997). Known throughout the world for its abundant bird life, the

Fig. 1.2 View from Florida Bay looking northwards toward the southernmost margin of the Florida Everglades. The northern edge of Florida Bay or the southernmost edge of the Everglades in the interface or ecotone between the bay and the freshwater Everglades wetland ecosystems. In the northeastern part of Florida Bay, the ecotone is characterized by shallow marl soils that are dominated by scrub forests of red mangrove (*Rhizophora mangle*, background) and by open flats of broadhead spikerush (*Eleocharis cellulosa*). These estuaries (foreground) are nursery grounds for many species of juvenile fishes and invertebrates. The flow of freshwater from the Everglades area is the major determinant of the conditions in Florida Bay. However, the ecology of Florida Bay is currently showing signs of stress in the form of large die-offs of seagrass, with *Thallassium testudinum* (i.e. turtle grass) being affected the most. These die-offs are usually followed by a decline in conditions, including toxic blooms of phytoplankton and algae (Credit: C.W. Finkl)

Everglades was a safe haven for several species of large wading birds, such as the roseate spoonbill (*Platalea ajaja*), wood stork (*Mycteria americana*), great blue heron (*Ardea herodias*), and a variety of egrets (Ogden 1994). Also unique, is the brackish mix of salt and freshwater, making it the only place on Earth where alligators and crocodiles coexist side by side (Mazzotti et al. 2008).

Once a concerted effort to drain the Everglades was made in the early twentieth century, large tracts of swamp were transformed into productive farmlands and cities such as Miami and Fort Lauderdale began expanding along the coast and inland to the newly drained marshlands. As the population grew, so did the need to develop more land and provide flood control to the new residents of southern Florida. In 1948, the U.S. Congress created the most expansive water management system in the world, and today, this network of man-made canals, levees, and water control structures channel and discharge approximately 6400 m^3 of water daily from the Everglades into the ocean (Light and Dineen 1994; Perry 2008) (Figs. 1.3 and 1.4).

Fig. 1.3 Current map showing the segmentation of the Everglades in southern Florida. The Kissimmee River flows from the north into Lake Okeechobee, which is bordered immediately to the south and southeast by the Everglades Agricultural Area (EAA, *dark orange*). As water, and discharged effluent, flow southward from the EAA, water conservation areas, Loxahatchee National Wildlife Refuge (*NWR*), Big Cypress National Preserve (*NP*), Everglades National Park (*NP*), Biscayne National Park (*NP*), and Florida Bay are all negatively impacted. Overall, the Everglades ecosystems that remain today are only a fraction of the original extent (see Fig. 1.1) (Credit: NOAA)

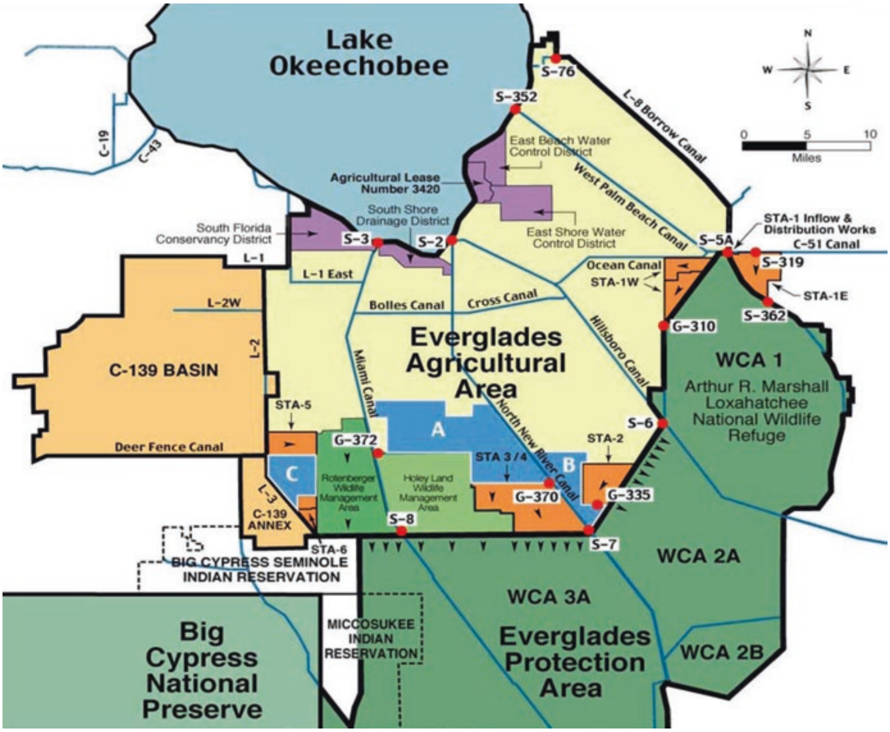

Fig. 1.4 Detailed managerial layout of the area surrounding the Everglades Agricultural Area (*EAA*), which includes a vast network of man-made canals, levees, and stormwater treatment structures to maintain water quality and control measures throughout the Everglades ecosystem. Notice how many different canals, basins, refuges, management areas, water conservation areas (*WCA*), stormwater treatment areas (*STA*), national preserves, and protection areas are needed to properly regulate one isolated agricultural area in the EAA (Credit: SFWMD)

However, this loss of water has forever changed the natural characteristics of the once pristine marsh. As the water receded, so did essential habitats of wading birds, fish, and dozens of animals. Saltwater intruded farther into the marsh from the coastal ocean and nonpoint-source pollution runoff flowed in from neighboring farms and cities. Changes in water quality also stifled the growth of native plants, allowing exotic species to take root and persist. As a result of these alterations continuing for the past 70 years, the Everglades is currently only half the size it was before the State of Florida was established (Browder and Ogden 1999; Ogden et al. 2005).

1.2.1 Geology

The Everglades sits on what geologists have named the "Floridian Plateau," an expanse of crust that includes the emerging portion of the tectonic platform (i.e. the Florida Peninsula) and the adjacent continental shelf region (Bryan et al. 2008;