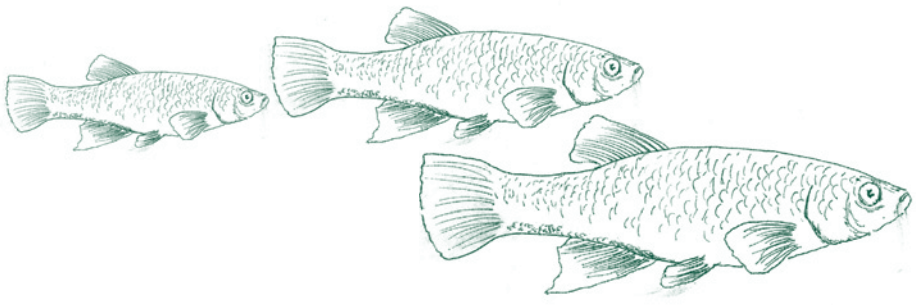
g e o m e t r i e s

land use strategies for preserving

coastal wetlands

Contents



introduction

1. Critical reasons to save our wetlands

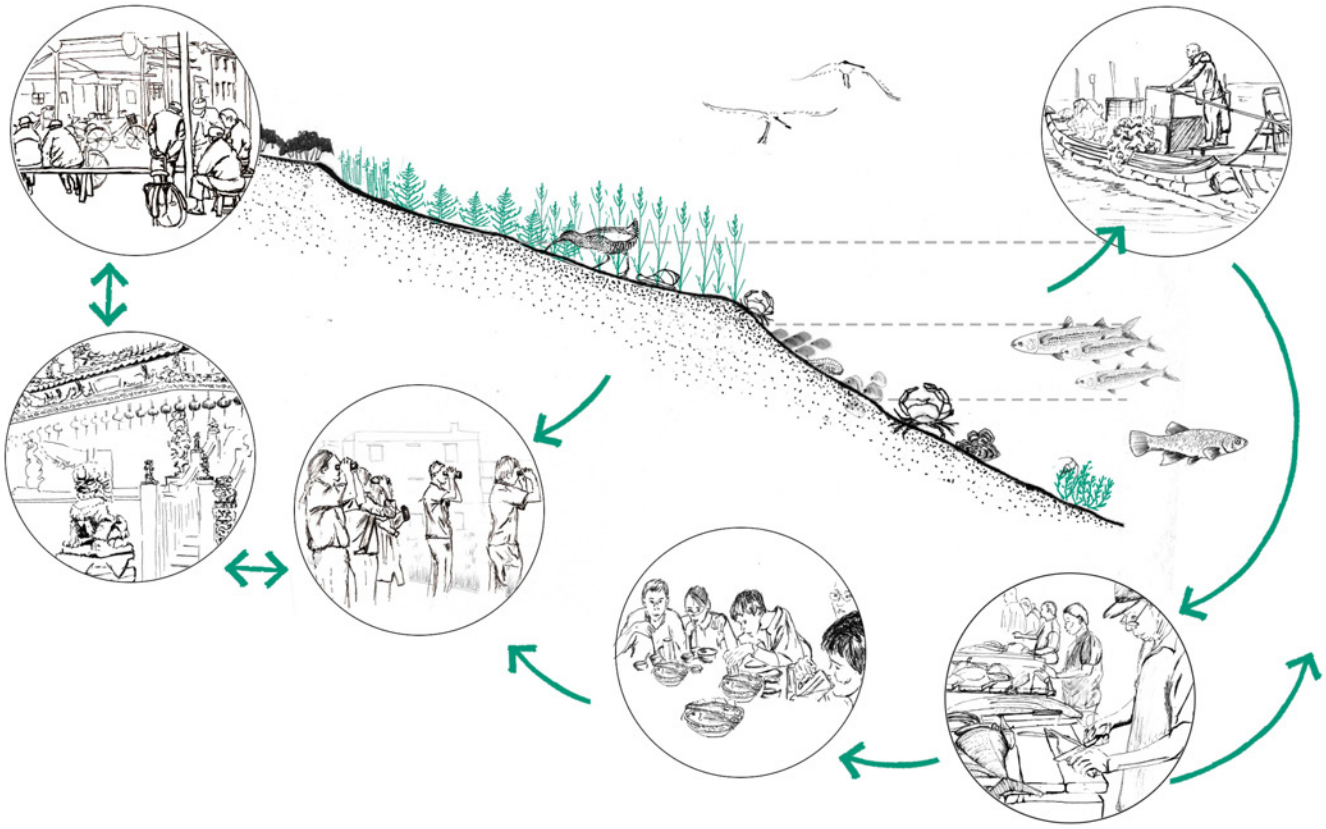
Coastal wetlands the world over are threatened from both land and sea. For example, during the 1970's the United States lost wetlands at an estimated rate of 121,406 hectares per year. Ninety-one percent of California's total wetlands have been filled; 88% of the wetlands in some developing countries were lost in the last 30 years alone. Global economies grow ever edgeward destroying the most productive marshes. Industry and agriculture are greedy for filled and dried land that previously was inundated. People build seaside residences and then bulkhead wetlands to protect private property; levees alter entire coastal hydrologies critical to wetland survival. Future structural protection of property could destroy 90% of the wetlands in some areas. In this century sea levels will rise an estimated .6 to 2.1 meters. This will push wetlands inland where both waves and urbanization prey on the vulnerable and changing ecosystem. The result of the two-sided squeeze is loss of the total area of wetlands at an unimaginable speed. Today a .6-meter rise in sea level alone would destroy as much as 43% of all wetlands in the U.S.

The loss of these lands diminishes not only wetland ecologies but also fisheries that support fisherpeople and healthy diets worldwide. In one example, an industrial complex was proposed that would fill Chi-ku Lagoon in coastal Tainan County, Taiwan. Some estimated 7,000 fishing jobs would be lost. That same industrial project, if built, would have sent one of the rarest birds in the world, the Black-faced Spoonbill (*Platalea minor*), into an extinction vortex from which the species would never recover.

This story is repeating in hundreds of other wetlands around the world at this very moment. And the story is disturbingly similar: local jobs, endangered species, and wetlands all lost to a single move of industrialization, urbanization, and/or government action. Only exceptional localities are able to resist the temptation of projects that promise great benefit which are typically short-term or illusory at best.

WETLAND ECOLOGY

MULTIPLE BENEFITS OF WETLANDS



REPORT SUMMARY

The goal of this report is to make it easier to preserve and reestablish wetlands as multi-purpose preserves that protect ecological function, accommodate fisheries, provide wildlife habitat, and allow for tourism and other local activity. The work presented here has grown out of ten years of research, planning, and advocacy focusing on wetland habitat for the Black-faced Spoonbill in Taiwan. This endangered bird is used often in the text to illustrate how wetland geometries affect wildlife. Examples from the San Francisco Bay Area also appear frequently in the text; the Bay Area is not only rich in wetland research, restoration, and activism, it is also the place we know best. Twenty years of open space planning and habitat preservation in the Los Angeles region, thirty-five years of community town planning across the U.S., and research in the Pacific Rim inform our efforts to encourage wetland and habitat preservation that considers the spatial needs of both people and wildlife.

Our experience suggests that wetland conservation only occurs when so many local goals are embedded in preservation that powerful forces for wetland ruination can be subdued. But political will alone is not enough. In order to achieve multiple functions development must be shaped with surgical precision. This is largely a matter of three-dimensional land use geometry. Each use – hydrological systems, fishery hatcheries, wildlife habitat, aquaculture and agriculture, tourism – has requirements that can be drawn in horizontal and vertical space and time. By mapping these temporal territories disastrous land use conflicts can be avoided and unexpected compatibilities can be revealed. This allows the multiple uses that are necessary for wetland conservation.

WETLAND LOSS IN SAN FRANCISCO BAY (1880'S-1988)

WETLAND LOSS IN NORTH CAROLINA OUTER BANKS (1780-2003)

Wetland loss in San Francisco Bay (1880's-1988)

Historically, the San Francisco Bay consisted of 76,862 hectares of tidal marsh and 4.9 hectares of undeveloped bay fill. Tidal marsh bordering the Bay now totals approximately 16,187.4 hectares–a loss of 80% overtime. The total current water area in the Bay is 2088 km^2. Only 19% of the wetlands are protected. The figure ground shows total wetland loss in orange (tidal flats and marshes are not included in the land area).

Wetland loss in North Carolina Outer Banks (1780-2003)

In the U.S. Fish and Wildlife Service National Wetland Inventory, North Carolina stood out among all southeastern states as having the most wetland loss, an estimated 485,623 hectares. Nearly all the losses were forested and scrub/shrub wetlands concentrated in the Coastal Flats region.

Today the State of North Carolina, through a variety of partnership programs, is focusing on the wetlands that remain particularly those in private land ownership. Ten national wildlife refuges, covering 158,232.2 hectares, protect and manage for the 8,175 plant and animal species which inhabit the Coastal Plain, Piedmont, and Mountain regions. Of those, 1,402 are presently considered rare, threatened, or endangered according to federal and state agencies and private conservation organizations. The figure ground shows the approximate wetland loss in orange (the land areas do not include marsh areas or estuarine scrub).

Wetland loss in Santa Monica Bay (1880's–2004)

By 1900, Los Angeles had a population of 102,479. The rising population and the development of an electric trolley car network, made the coastal areas desirable and accessible places to live. Development sprang up in Playa del Rey, Santa Monica, and Venice. In 1905 cigarette magnate Abott Kinney began the construction of Venice consumming 64.7 hectares of marsh to realize his dream of reproducing the idealistic Italian city on the Southern California coast. Today, only 5% of the wetlands of Santa Monica Bay that existed 300 years ago remain.

The effects of encroaching urbanization have significantly degraded even those wetlands that remain. Historically, Topanga Lagoon covered more than 12.1 hectares. In 1934, Caltrans realigned the Pacific Coast Highway, placing over 8,495 cubic meters of fill directly into the lagoon. Its surface area was reduced by 94% to its present-day size of just .8 hectares. The figure ground shows the approximate wetland loss in orange.

This report has five sections. The section that follows this introduction summarizes the basic spatial and temporal dimensions of wetlands and the creatures that depend on them, emphasizing the habitat needs of endangered and highly visible species. This is followed by a section on what visitors expect and need, focusing on ecotourism. Wetland case studies of various lengths follow. These describe the particular metrics that make wetland conservation practical and multiuse with a successful environmental and/or economic outcome. The report concludes with a discussion of planning principles for maximizing wetland function and an application of the principles using a currently-debated Taiwan site, Augo.

The wetlands highlighted in this report are primarily located around the Pacific Rim. These examples can be found in the eight case studies discussed in Section 4, in the sidebars, and in the text. They range in scale and type from national wildlife refuges to local parks and a city sewage treatment plant. The case studies were selected based upon our professional experiences; we drew lessons from wetlands we know well due to research, planning projects, or site visits. Each demonstrates exceptional benefits in one or more areas, but as a whole they reiterate the following lessons.

Wetlands can save species and support the regional economy. Suisun Marsh contains over 10% of the state of California's remaining wetlands and provides habitat for several endangered species, including the California Clapper Rail (*Rallus longirostris obsoletus*) and the salt marsh harvest mouse (*Reithrodontomys raviventris*). The marsh is also important to the economy as it supports 80% of the state's commercial salmon fishery by providing rearing areas for juvenile fish.

Wetlands are money makers. The economic, cultural, and recreational benefits from wetland tourism are just recently being systematically researched. They far exceed expectations, whether the benefits are direct or indirect. Pea Island National Wildlife Refuge (NWR) and the Outer Banks region illustrate that protected landscapes can simultaneously generate revenue and provide high quality habitat. In 2004 five million visitors to the area generated $619 million (U.S. dollars) in tourism revenues; nearly one half of the visitors go to the refuge.

Wetlands create unique partnerships and garner diverse funding sources. The creation of the Sonoma Baylands brought local advocates, environmental and open space acquisition groups, state and federal agencies, legislators, and the Port of Oakland together to achieve three goals in a single restoration project: to dispose of dredged materials, to restore tidal wetlands, and to provide habitat for endangered species. State and federal legislation was passed to make the restoration possible, with the federal government footing an unprecedented 75% of the bill.

Wetlands are worth paying for. To date federal and state agencies have spent over $200 million on land acquisition and management for Don Edwards NWR, with hundreds of millions of dollars likely to be spent on future acquisitions. Data indicates that the money was well spent: in 2002 FY the economic effect alone of every $1 spent on the refuge was estimated to generate a gain of $2.10.

Wetlands are natural treatment systems. Wetlands offer natural flood protection, erosion prevention, and water quality maintenance at a much lower cost and with greater benefits than any other system – natural or artificial. In the U.S. alone wetlands provide $4.9 trillion dollars of services annually. Suisun Marsh protects the quality of drinking water for 22 million people by preventing salt water intrusion. Arcata Marsh Wildlife Sanctuary treats the sewage of nearly 20,000 residents in the City of Arcata, keeping Arcata in compliance with state and federal water quality regulations while doubling as a world class birding destination.

Wetlands can inexpensively clean urban runoff. The DUST Marsh receives polluted stormwater from a 1,191.4-hectare urban watershed and cleans it before it is discharged into San Francisco Bay. Cleansing is achieved with low-tech interventions that are easy to install and maintain. The DUST Marsh project has been collecting data on levels of stormwater contamination since its inception in 1983. It is a well-established model for stormwater treatment and wetlands research in an urban area.

Wetlands can be managed to mimic natural cycles. Bosque del Apache, like many national wildlife refuges, manages water levels to maximize food and habitat for waterfowl, shorebirds, and other wildlife. The water management cycles mimic the historic hydrograph of the Rio Grande, which marks the western border of the refuge. This moist soil management strategy tightly binds wetland cycles to wildlife behaviors, resulting in high-quality and seasonally-appropriate wildlife habitat year-round. Complimenting this management strategy is a set of contracts with local farmers benefiting the refuge, the farmers, and the wildlife.

Effective wetland preservation almost always requires government involvement. Although wetland preservation has extraordinary economic benefits, these benefits have been and continue to be taken for granted by most private land owners and the general public. Exploitation of wetlands for single purposes is typically seen as a pre-existing right of private entrepreneurs without consideration for broader economic losses. Experience shows that successful wetland projects rely, at least in part, on government action for legislation, land acquisition, funding, and technical support.

Wetlands are beloved. At the Bosque del Apache volunteers contributed more than 35,000 hours of work in 2004, the equivalent of 4,375 eight-hour days. At Don Edwards, every hour of paid staff work is matched by one hour of volunteer work. Crissy Field was paid for almost entirely by private funds. The list of volunteer contributions to wetlands goes on and on – wildlife viewers, hunters, educators, and everyday citizens care enough about their local wetlands to donate time and money to protect them.

Wetland loss in Tainan County, Taiwan (1893-1995)

In the last century, the Chiku Lagoon area of Tainan County, Taiwan has lost an estimated 5,698 hectares of wetlands shown in orange in the above figure ground. (See Tseng-wen Estuary Refuge case study for more details).

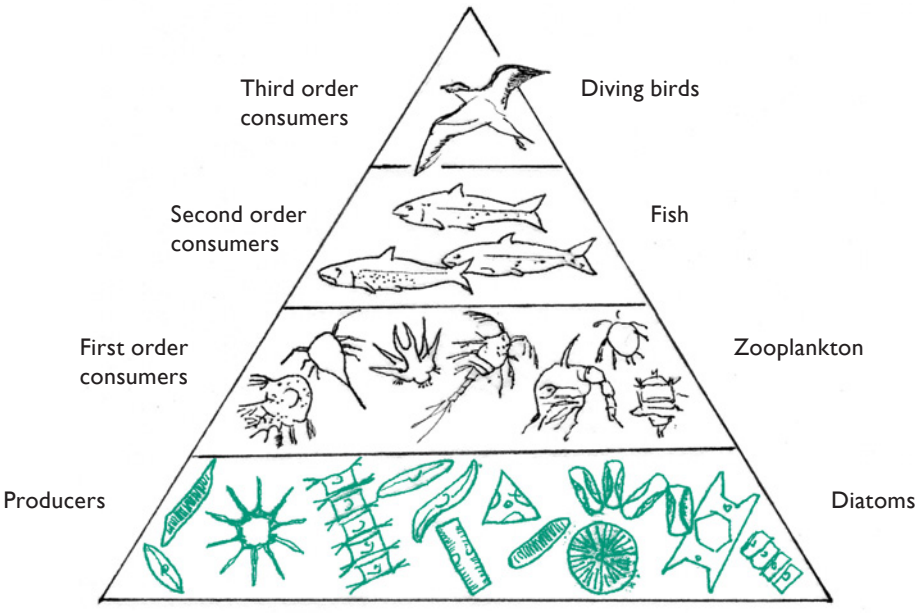
wetlands

2. What wetlands need to serve multiple uses

Coastal wetlands produce a vast array of services to humankind. They incubate local fisheries and provide nurseries for food webs that may extend thousands of miles beyond the wetland. They protect coastal uplands from storm surges, erosion, and flooding. They provide habitat for foraging, roosting, breeding, and migrating. They invite tourism and they can clean domestic wastewater, stormwater runoff, and other pollution. Few ecosystems, and no single constructed system, are so versatile. To receive maximum human benefits from wetlands, their ecological character must guide decision making. The question then is what habitat does or could an area provide? What species and processes are served?

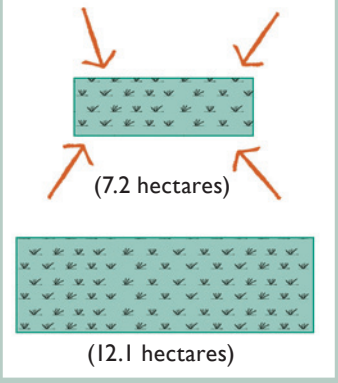
THE ECOLOGICAL BASIS OF CONSERVATION AND RESTORATION

Strategies for the conservation and wise use of wetlands have been defined at an international level by the Ramsar Convention on Wetlands, an intergovernmental treaty adopted in Ramsar, Iran in 1971. 1,629 wetland sites covering 145.6 million hectares have been designated for inclusion in the Ramsar list of Wetlands of International Importance since that time. Wetland evaluation criteria developed by the Ramsar Convention of 2002 provide an overview of the most critical landscape characteristics that should be considered when selecting wetlands to manage, preserve, or restore.



The food pyramid of a wetland is a complex system determined by the hydrological cycle. With the correct cycle of inundation, the rich wetland ecosystem can thrive, contributing to endangered species habitat, fisheries, tourism, water quality, and flood control.

Crissy Field Comparison



In the restoration of the tidal marsh at Crissy Field, an urban park in San Francisco, leading hydrologists concluded that a wetland needed to be at least 12 hectares to flush properly and to attract tidal shorebirds. But competing land uses (the park, the road, and historic airfield) shrank the Crissy Field wetland lagoon to just over 7 hectares. As predicted, proper tidal flushing did not occur and few shorebirds initially inhabited the space. The tidal inlet has closed on several occasions and studies are underway to determine the feasibility of expanding the marsh.

There are eight criteria. The first is adequate size, which is required for good ecological function. Large, uninterrupted expanses of wetlands generally provide more benefits. There must be adequate wetland area for each purpose, be it sewage treatment, a fish hatchery, or stormwater cleaning. As simple as this seems, wetland restoration projects often fail to provide desired results because they are too small for proper flushing or to provide adequate habitat for critical species. Every species requires specific habitat conditions that can be described as land uses with minimum extents. If the habitat provided is too small, the species will not thrive, leading to island effects and eventual local extinction. Some target species require large areas, favoring large wetlands over small. In some cases very small wetlands provide exactly what a key species requires. In other cases stopover sites that expand the territory of an endangered species may function well even if small.

The second Ramsar criteria is biological diversity. Usually a primary wetland restoration goal is to maintain diversity by preventing the extinction of endangered and/or valuable species. Thus, wetlands with high diversity are often favored over less rich sites. However, high diversity may be abnormally inflated by human intervention. Naturally high biological diversity makes sites especially important, but a site that supports only one species in danger of extinction is critical in terms of biological diversity. Therefore both sites of high natural diversity and those supporting an endangered species are high priorities.

Third on the Ramsar list is naturalness. Natural sites generally function better ecologically than disturbed sites. However, because so few habitats are truly undisturbed, naturalness must be considered in terms of healthy wetland processes rather than pristine appearance.

The fourth Ramsar consideration is rarity. Wetlands endemic to one region are especially critical. Typically, wetlands that occur in a limited area support rare and/or endangered species, making them essential for biological diversity.

Fragility is the fifth Ramsar measure of ecological priority. In land use planning the degree of fragility should determine the number and type of introduced uses. Generally, human use should be limited or prohibited in more fragile landscapes. Managing levels of use requires careful zoning of wetlands.

Although wetlands often are valued because they are rare, a wetland that provides a large extent of a typical feature or landscape type should not be undervalued. Typicalness is Ramsar's sixth criteria. Commonplace wetlands such as fisheries and nurseries are critical for maintaining large stocks of commercial fish products.

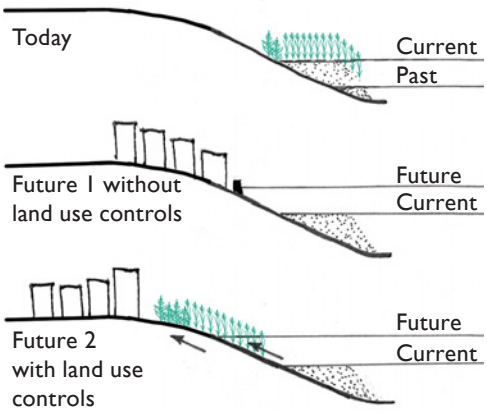
Seventh is the potential for restoration. Some wetlands have been so altered or polluted that it is almost impossible to improve or recapture ecological functions. Priority should be given to lands that have a greater chance of recovery. Frequently wetland-dependent species are near extinction because wetlands have been only slightly altered for salt farming or fish farming. Often these can be inexpensively returned to useful habitat. Allowing endangered animals to migrate to these replenished sites via stepping stones and corridors can save a species from extinction. In the case of the Black-faced Spoonbill, for example, this can readily be done in its Taiwan wintering grounds where thousands of hectares of abandoned salt ponds owned by the government are available to create both new core roosting areas and stepping stones leading to the cores.

Although the Ramsar Convention guidelines attend primarily to ecological purposes, the criteria list other features that should be considered. The eighth consideration includes religious, cultural, archeological, and socioeconomic characteristics. Fish and shellfish productivity, clean drinking water, protection against high wave action, indigenous settlements, tourism, local arts, faith-based practices, and wetland mythology are all considered important functions, often symbiotic with ecological function. Because there are so many disparate but interrelated purposes, wetlands must be carefully managed to satisfy multiple goals. This gives them extraordinary value, and makes land use planning for their long-term health essential.

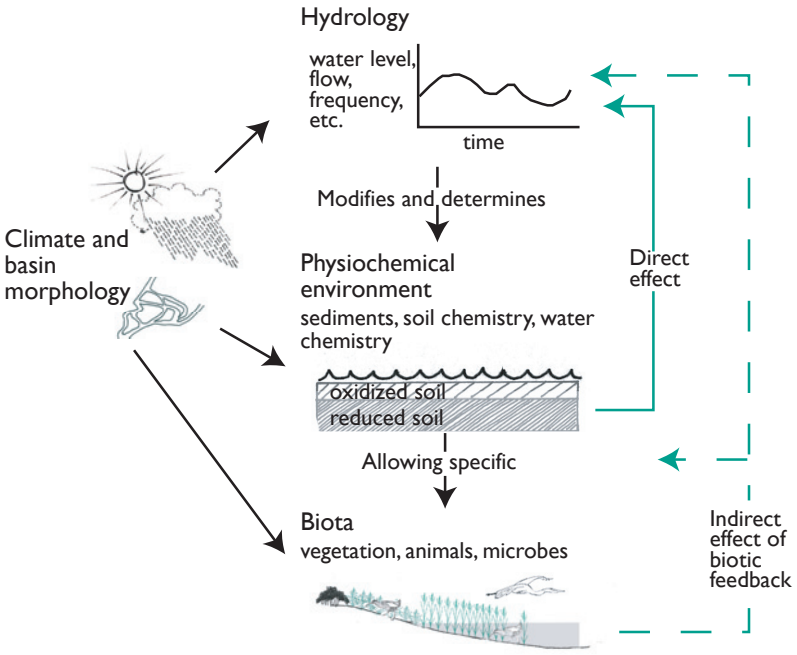
WATER GEOMETRIES

The Ramsar criteria provide insight into the general character of wetlands and the variables that should be considered when prioritizing wetland sites. But in order to function properly, wetlands have specific requirements at the site level. They do not perform without precise spatial and temporal geometry.

Hydrology is most important for proper wetland function – they must be inundated periodically. They require shallow water that moves slowly through the system. Water in coastal wetlands typically moves in and out daily or monthly with tides, changing depth in predictable patterns tempered by seasonal or episodic events. Wetlands inland from the coast or along rivers are influenced by surface inflows from upstream. Water flow and quality in coastal lands are impacted by ground water movement, freshwater flows from creeks and rivers, and urban runoff. The hydrology of the wetland affects species –plants and animals– composition, richness, and productivity as well as bioaccumulation and nutrient cycling. Therefore, coastal wetland function is dependent upon its entire hydrological system, which frequently extends several hundred miles upstream or is hidden from view in underground aquifers.



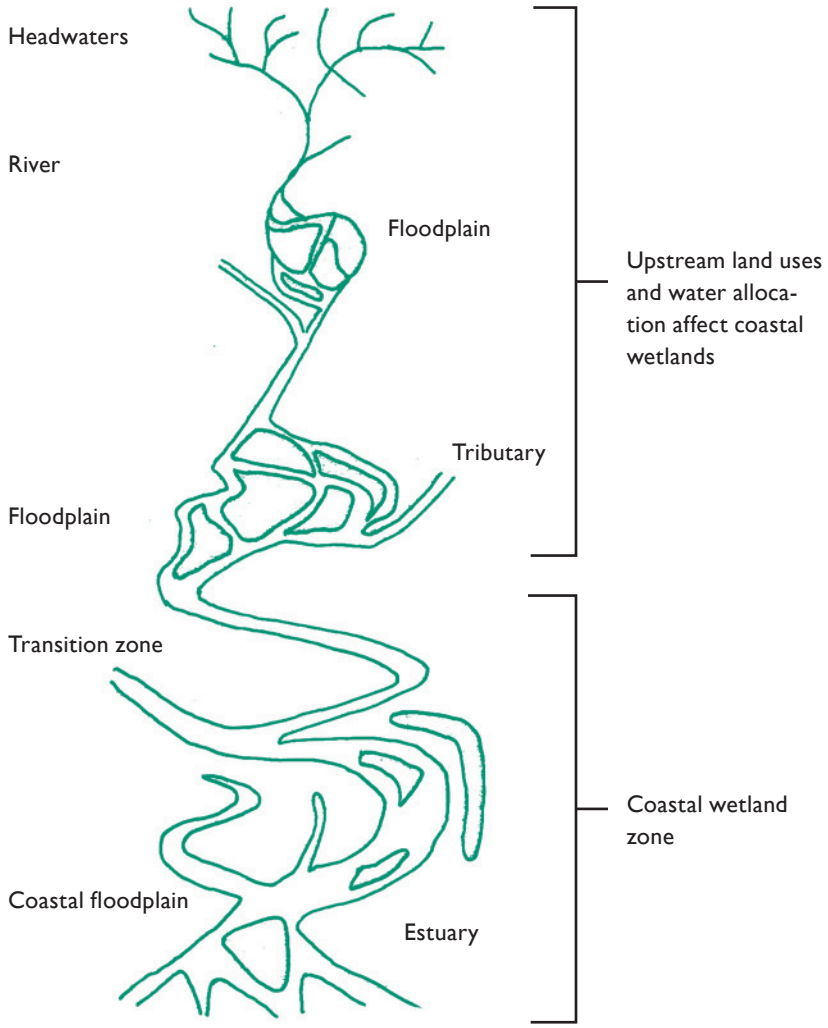
Wetlands are being squeezed out of existence by coastal development with levees and rising sea levels (Future 1). If urban development is well located, vegetation moves inland and re-establishes an intertidal zone (Future 2).



The wetland hydrology affects the physiochemical and biotic functions of a wetland system. In turn the wetland chemistry and the organisms feedback loops affect the hydrology of this complex system.

Interruptions in any part of this system can cause a wetland to malfunction. For example, levees constructed to protect urban land uses located too close to the coast sever tidal flows and destroy wetland function immediately. Similarly, ground water depletion causes salt water intrusion and/or land subsidence, both of which destroy wetlands, albeit more slowly and less visibly. The change in salinity and water level alter the plant communities and compromise marine habitat. Subsidence is ubiquitous along Asian coasts where diking began 6,000 years ago to create rice paddies and where, more recently, aquaculture is replacing natural wetlands. In these areas fresh water has been continuously pumped from the ground for human use. The land has sunk proportionally, eventually creating deep, salt-infested ponds suitable neither for fish farming nor wetland succession.

In every case where coastal wetlands continue to function well, water cycles are either left undisturbed or are managed to mimic natural flows. Wetland function is also dependent on precise acidity, temperature, soil structure, and chemical content. Generally, wetlands serve well to collect and hold chemicals, good and bad. This explains how they clean polluted waters. Wetlands hold suspended sediments and remove nitrogen and phosphorus from water. Hydric soils also modify basic chemicals, producing a great variety of inorganic and organic



The watershed-wide hydrology affects the function and health of the receiving wetlands ecosystem. This large complex system extends from stormdrains and culverted streams to headwaters miles away.

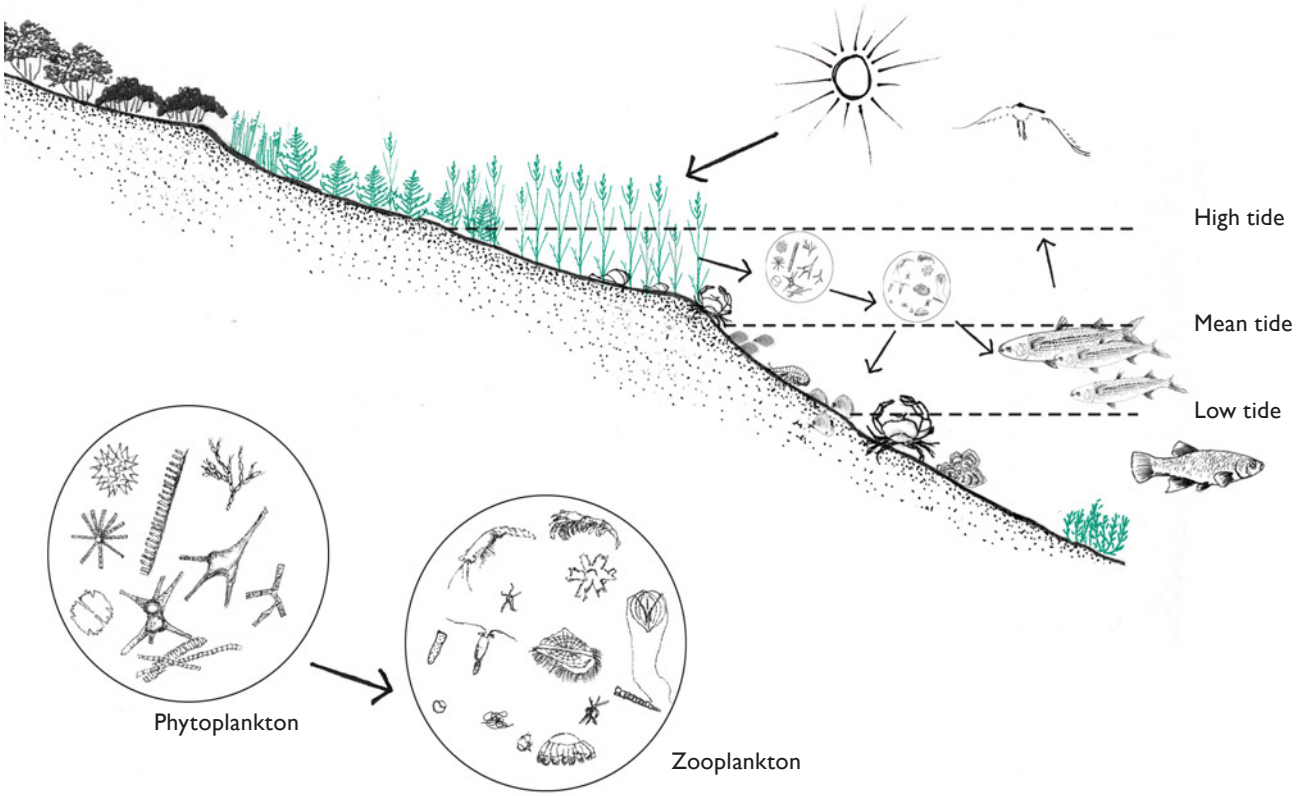
substances, thereby creating much more biomass than in comparable upland ecosystems. By some estimates, various wetlands produce between ten and a thousand times the biomass of terrestrial communities.

The high primary productivity coupled with shallow water and a nutrient rich environment is ideal for micro-organisms which provide the base of the complex coastal food web that ultimately connects to people. The broken-down plant material, detritus, is consumed by filter feeders and other scavengers. These organisms then support many species of fish, shellfish, insects, amphibians, birds and mammals. The abundance of small habitats within a salt marsh allow numerous organisms to hide from predators, feed without expending much energy, grow faster, and raise young.

VEGETATION PATTERNS

Wetlands are characterized by hydric soils, high in hydrogen with oxygen deficiency. This slows the decomposition of detritus and initiates unique plant and animal communities. The plant communities able to thrive in wetlands have adapted and evolved morphologically and physiologically to high salinity levels, periodic inundation, dessication and the low oxygen levels of the soils. Given proper water movement, chemistry, and soil, nutrients held in wetlands can support communities of vegetation aligned in linear patterns like topography lines following water depths. In most coastal wetlands there is a predictable progression of plants, from deepest water to extreme high tide. These might include submergents, then cordgrasses (*Spartina* sp.) and pickleweed (*Salicornia* sp.) then saltgrass (*Distichlis spicata*) within mean and extreme high tide zones.

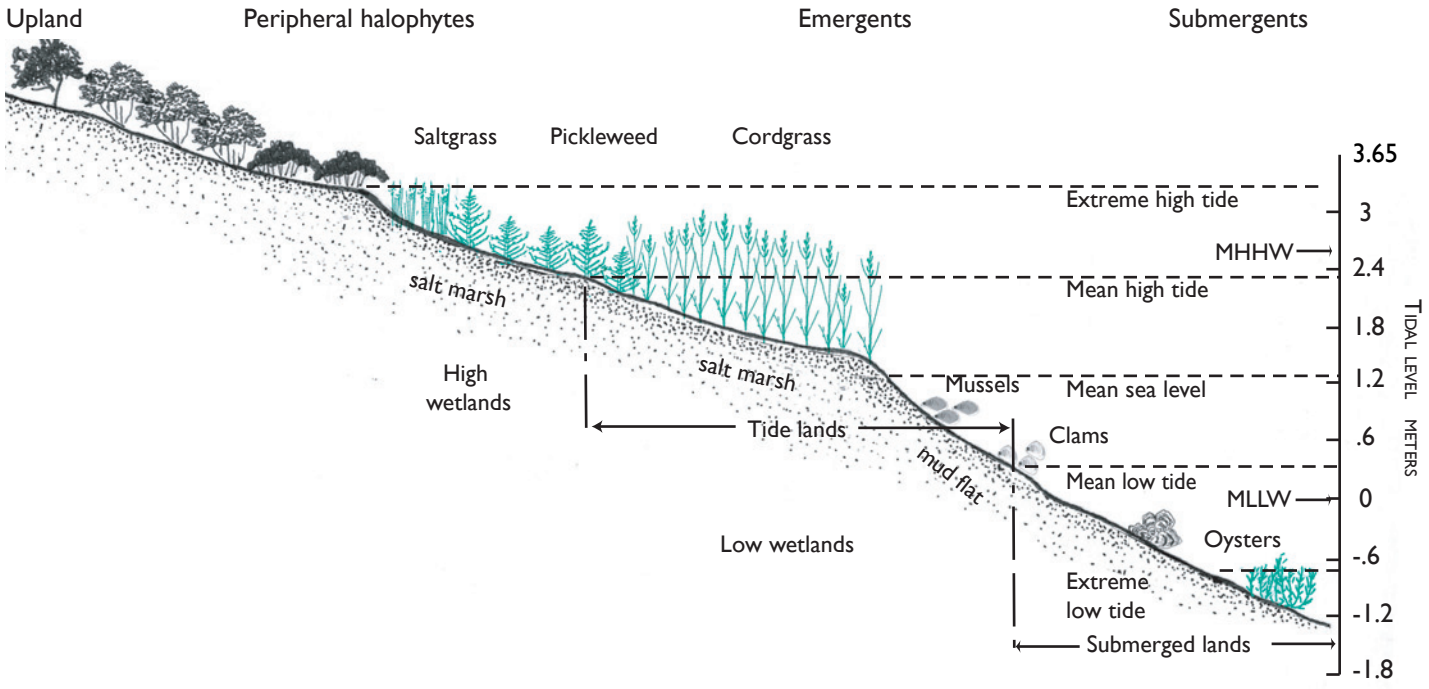
COASTAL WETLAND FOOD WEB



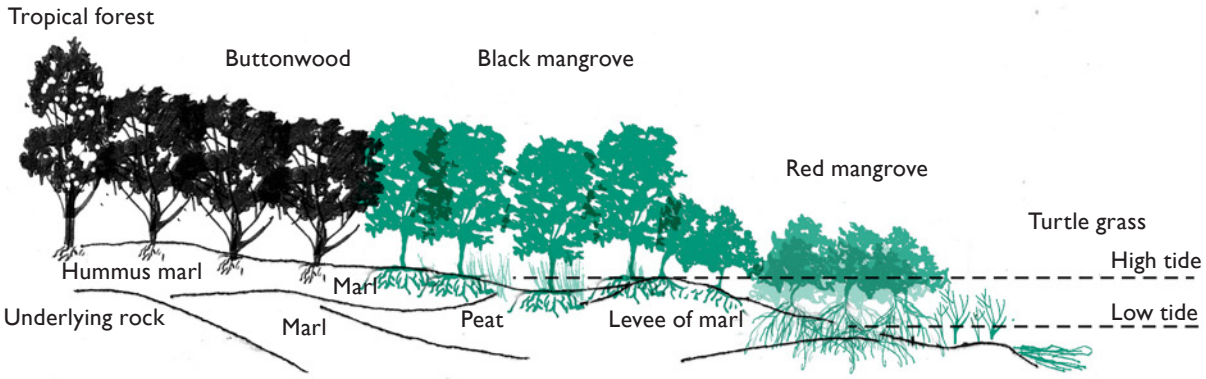
Mangroves usually follow a progression from red mangrove (*Rhizophora mangle*) to black mangrove (*Avicennia germinans*), with buttonwood (*Conocarpus erecta*) and tropical forest at higher elevations. Both coastal wetlands and mangrove swamps form an important interface between terrestrial and marine habitats.

Even when a wetland has been altered and natural vegetation has been removed, if proper water cycles are restored and there is diverse seed stock nearby, wetland plants will usually reestablish in two to six years. Litter base and sediment will stabilize within the same time period. Although undesirable plants may temporarily invade, most can be controlled. Vegetative fluctuations can be expected early on, but within four years restored vegetation is often indistinguishable from natural vegetation. As soon as the restored area has a stable sediment base and mature vegetation patterns, it begins to contribute almost all of the economic benefits of a natural marsh.

COASTAL WETLAND VEGETATION PATTERNS (NORTHERN CALIFORNIA)



MANGROVE WETLAND VEGETATION PATTERNS



If left undisturbed, this carefully balanced concert of vegetation, water, and soil gives us unmatched resources – food, fishing, jobs, tourism, recreation, and environmental education as well as flood protection, nutrient absorption and recycling, and oxygen production. But seldom have we left wetland geometries alone. In subtropical and tropical Asia, over 25% of all wetlands have been drained for agriculture. In some areas nothing remains of once-extensive wetlands. In the Red River Delta of Viet Nam nearly two million hectares have been destroyed; six million hectares have been lost in central Myanmar alone. In Singapore 97% of all mangrove wetlands have been destroyed, as have 78% in the Philippines.

COST-EFFECTIVE PRESERVATION VERSUS EXPENSIVE CREATION

However, there still remain significant coastal wetlands around the world. The simplest, clearest, and least expensive action is to preserve these wetlands via assertive, no-net-loss legislation. In the U.S., Section 404 of the Clean Water Act expressly requires no net loss and has been particularly effective at safeguarding the economies produced by wetlands.

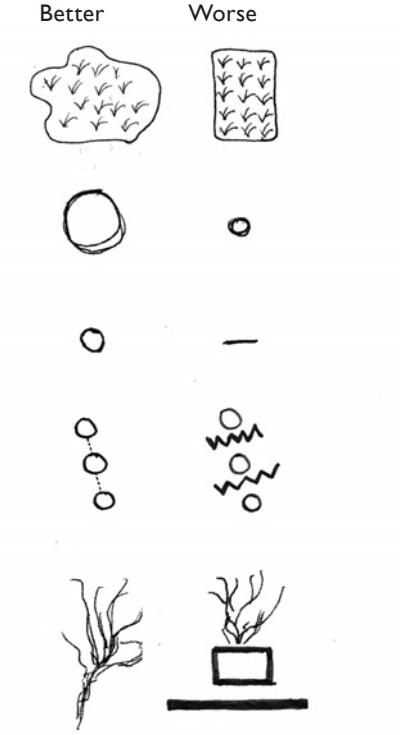
Preserving wetlands is always less expensive and easier than restoring or creating them anew. Following landscape ecology principles, the geometry of preservation is simple. Large, whole wetlands are better than small, fragmented ones. Even small ones are better than none. Small connecting wetlands are better than small disparate systems. No interruptions to natural hydrological geometries are better than minor ones; bulkheads, levees, and stream diversions should be avoided.

Where wetlands have been replaced with other uses, preservation is no longer an option. However, even in these cases inexpensive restoration is possible. Wetlands International scientists estimate that there are 130 million hectares of rice paddies worldwide. The majority of these are in Asia and many were created by converting wetlands. In other areas, wetlands have been converted to salt ponds and aquaculture. Thousands of hectares of ponds have subsided over time; many have been abandoned. If the slope and water depth are appropriate for a wetland ecosystem, these ponds are readily and inexpensively reclaimed as functioning wetlands, often by merely breaching levees at costs of only several hundred dollars per hectare.

Creating wetlands is more expensive. But even in pricey California, wetlands have been created in highly urbanized areas to serve multiple wildlife habitat and recreation purposes at a cost of only $70,000 per hectare. Creating or restoring larger areas is much less expensive per hectare than in small sites. Engineering of wetlands is least costly and most successful when designed to allow the ecosystem to adapt to natural constraints and not an imposed static structure, thereby requiring little human intervention. Over-engineering and complex technologies often invite failure; interventions based on knowledge of natural function and hydrologic regimes along with a few simple human interventions more often prevail. These simpler systems tend to be self-regulating and self-maintaining.

Conservation often requires only political will and zero expenditure per hectare. In contrast, constructing wetlands for wastewater treatment from scratch may cost as much as $75,000 per hectare. While this is relatively inexpensive given the typical cost of sewage treatment plants, from an economic perspective there is no question that wetland preservation is preferred over artificial wetland construction.

PREFERRED WETLAND GEOMETRIES



tourism

3. What tourists and ecotourists want

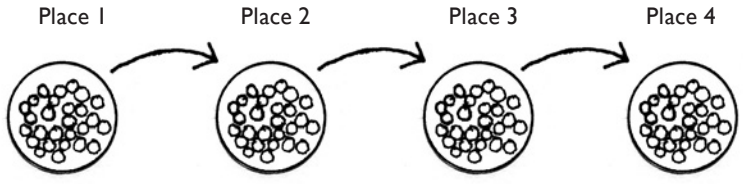
Tourism is one of the world's largest industries, making up more than 10% of the global economy. A growing market is tourism that emphasizes environmental, cultural, and natural experiences; what is often termed ecotourism. The International Ecotourism Society defines it as "…responsible travel to natural areas that conserves the environment and sustains the well-being of local people." It is estimated that ecotourism has an annual growth rate between 10 and 30%. However, ecotourism potential remains untapped in many countries.

WHAT IS AN ECOTOURIST

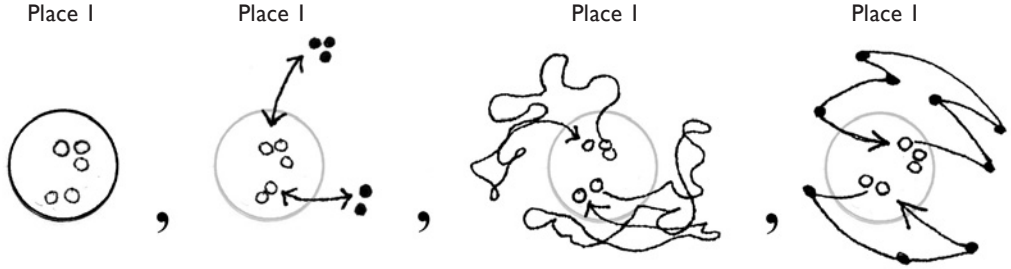
Ecotourists seek subtlety, uniqueness, and an experience that is markedly different from their everyday lives. They are typically well educated, well traveled, and have carefully studied the places they visit in advance of arrival. Ecotourists expect an interactive educational experience as well as a quality vacation. They seek site interpretation and opportunities to engage with knowledgeable hosts and guides to add to their understanding of a place, people, and landscape.

Ecotourists would prefer to travel in a small group and stay in one location for several days in order to learn about a place in depth. They often are demanding but willing to pay extra for a high quality experience and have been known to spend 10-20 times as much as a 'typical' tourist. Hand-crafted goods are desired. Insider, firsthand experiences are sought. Primitive, authentic accommodation is acceptable – the same ecotoursit will spend from $300 per night for a luxury safari tent in Zimbabwe or $8 per night for a thatched roof hut in Borneo. In sum, ecotourists seek nature, local culture, unspoiled landscape, and the unique character of a place.

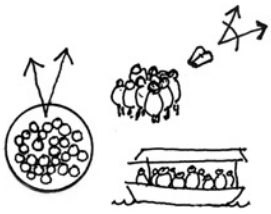
MASS TOURISM MOVES FROM PLACE TO PLACE



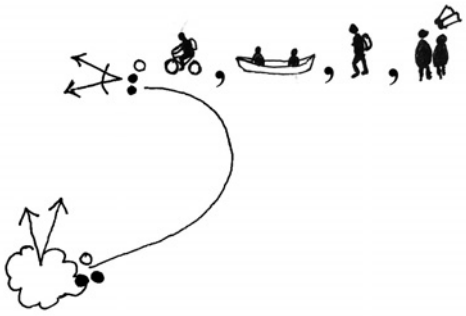
ECOTOURISM STAYS IN ONE PLACE



MASS TOURISM SIGHTSEEING



ECOTOURISM SIGHTSEEING



EXPECTATIONS OF ECOTOURISTS

There is a growing literature on how to cater to ecotourist preferences. The following is a discussion of their general expectations, many of which dovetail with the goals of wetland restoration and preservation.

Unspoiled landscape. Ecotourists come to experience a dramatically beautiful landscape. Coastlines, wetlands, creeks, and lagoons provide exactly the environment they seek. Ecotourists do not want their natural experience spoiled by development of any kind – they don't want urbanization, even tourist facilities, to blemish the natural landscape.

Preservation of species. Ecotourists will travel long distances to see exotic animal species, especially large, charismatic mega fauna such as endemic or endangered mammals or birds. Much of their time will be spent in nature as they are interested in all aspects of the ecosystem, large and small. Thus to attract ecotourists, natural areas need to be preserved for authentic wildlife habitat.

Birders are one type of ecotourist to attract. According to the U.S. Fish and Wildlife Service (USFWS), in the U.S. 18 million adults take trips annually to watch birds. Twice as many vacationers in 1990 preferred to watch birds than play golf. In 2004 there were 40 million visitors to U.S. national wildlife refuges, more than visitors to the Grand Canyon, Yosemite, Yellowstone, Acadia, Grand Teton, and the Statue of Liberty national parks combined. Bird and other wildlife watchers pumped $29 billion into the economy, averaging $100 million in each state, directly supporting 200,000 jobs, generating more than $1 billion in state and federal taxes. This would have placed bird-related recreation in the top 100 on the Fortune 500 list in 1996.

Unique character. Ecotourists also want to experience local culture and architecture and learn about local history. They want to see what is distinctive and are not interested in suburban buildings that look like they could be anywhere. Therefore nearby built areas may need protection in addition to natural areas. This is true in urban as well as rural places. More and more first tier cities recognize that daily access to nature for residents is important for quality of life. In fact, it is seen to positively affect property values.

One ecotourism destination that combines the natural environment and local culture is the Boondall Wetlands Reserve in Queensland Australia. The reserve was purchased by the City of Brisbane and declared a conservation area in 1990. Boondall is a 730-hectare reserve that contains mangrove, salt marsh, melaleuca woodlands, casuarinas, and eucalypt forest – wetlands of international importance. These wetlands are important feeding and resting habitat for migratory birds. The visitor's center for Boondall is a traditional Queenslander house that colonists built when they settled Australia. It was restored and moved to the wetlands. This type of architecture, referred to as the "Queenslander," has elevated buildings and porches that are well suited for the year-round heat and humidity. The raised platform and veranda porch allow for cooling and shading from the hot sun, they are light, open, and oriented toward views.

Knowledgeable hosts. Ecotourists expect knowledgeable hosts when they visit restaurants, inns, museums, or are on tours. They appreciate guides and hosts who can provide insider local information and details about the ecology, history, and

culture. They are willing to pay for the service. This implies that training is needed at the local level. Colleges and universities in many countries acknowledge this and some have developed full degree programs in hospitality business management. Local NGOs (non-governmental organizations) also play important roles in training, touring, and providing educational experiences for ecotourists.

The black howler monkey (*Alouatta pigra*) reserve in Belize, known as the Community Baboon Sanctuary, is an example of how local efforts to research and increase habitat can lead to an increase in species population. The rural villagers participating in the sanctuary have a strong tradition of respect and appreciation for these endangered monkeys that are found in abundance on their lands. Nearly all the landowners in the 5,200-hectare reserve, located on the Belize River, have signed voluntary conservation pledges signaling a commitment to make their farming practices work in unison with the needs of wildlife. Many of the local people have also donated portions of their farmland to provide contiguous habitat for the monkey. To supplement their farming income, many have opened their homes as guest houses for tourists visiting the sanctuary. Since 1985, the black howler monkey population in this area has grown from 800 to well over 1,000. In fact, the sanctuary has now begun transplanting monkeys from the reserve to repopulate historic habitat elsewhere in Belize.

Insider events. Sophisticated travelers and ecotourists want to have experiences that mass tourism does not provide access to, such as actually participating in local daily life. They want to be a part of these common occurrences and learn firsthand what local people do and what local practices are. They want to experience real work and will pay to participate in active duties of local vocations.

Olango Island in the Philippines is one example of where ecotourism is focused on the interrelationship of wetlands, birds, and local economic activity. The Olango Island Wildlife Sanctuary is a 920-hectare area managed by a local board that reports to the national Department of Environment and Natural Resources. The wetlands areas include 424 hectares of mangrove forest(made up of three species: *Lumnitzera racemosa*, *Avicennia marina*, and *Kandelia candel*), 33 hectares of mudflats, and areas of seagrass (*Halodule* sp. and *Thalassia* sp.) beds that are a critical stopover for thousands of birds that travel the East Asian Flyway.

Ecotourist activity is managed by a locally-organized and community-based group called the Olango Birds and Seascape Tour. Visitors are taken on boats to learn about the fishing industry, seaweed farming and processing, traditional shell craft, and local food preparation. Due to the potential impact on the fragile environment and the desire of local people to prevent the influences of alcohol, drugs, and prostitution, tourist use of the Sanctuary is limited.

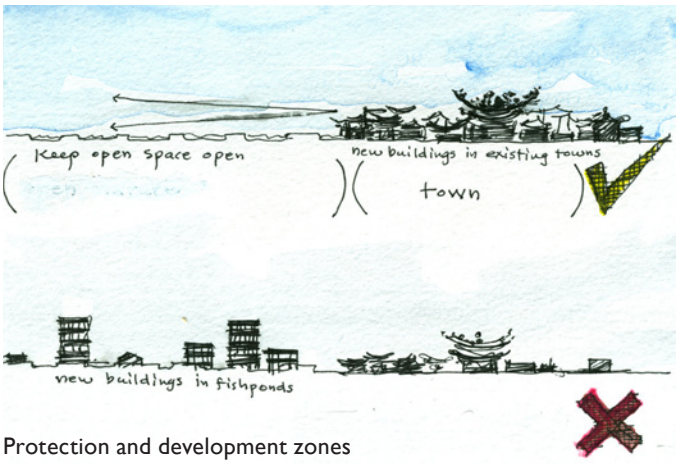
WHEN ECOTOURISM WORKS

Ecotourism works when the following strategies are employed:

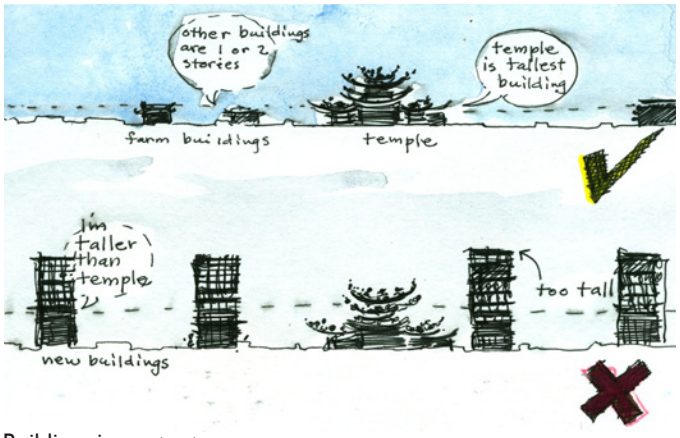
1. There is a management plan with protection zones (no tourists allowed), wilderness zones (tourists on foot only), moderate tourist use zones (education and visitor facilities), agricultural use zones, and development zones (lodging, services). Typically the management plan separates protection zones from development zones using a combination of public and private tools and resources for implementation.

2. There are design guidelines established that regulate the location and type of development. For example, development should be hidden by native vegetation so that the natural setting is not obscured. In the case of bird watching, the desire is to get as close as possible to wildlife without disturbing it or its habitat. At these sites provisions should be made for blinds and tours by local guides to secluded hidden spots. Any large scale tourist development should be clustered in and around existing cities, towns, and villages. Buildings should fit the city context. In open flat land buildings should be low to the ground and none should be allowed near the natural areas or in the open viewshed. There must be alternative transportation to protect local character and cater to ecotourists' preferences for experiencing nature: walking, biking, and boating.
3. Scientific research is conducted that establishes a baseline for existing conditions that can be used to monitor impacts of tourism and other nearby land uses. Local people, government, and scientists are involved.
4. There is a local entity managing the research, protection, and marketing of the site. There are inventories of resources, local and beyond, so that managers can link these resources, including a calendar of local festivals, maps of authentic places, traditional work, local arts and crafts, a list of national and international organizations focused on ecotourism, and funding sources.

GEOMETRIES OF ECOTOURISM

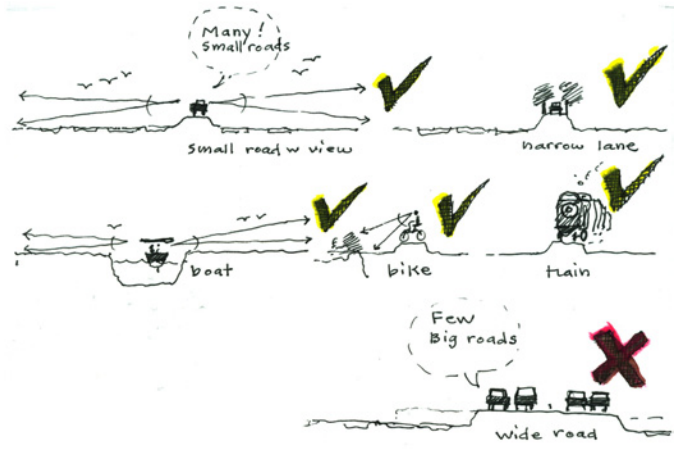


Protection and development zones



Buildings in context

Preservation and investment in existing cities and villages



Alternative transportation

Good Bad

5. The community receives direct financial benefits and empowerment from conservation: local people retain revenues, jobs, and other benefits. Ecotourism raises awareness of the country's political, environmental, and social climate, including the need to protect human rights and promote fair labor practices.

The New Jersey Pinelands Reserve in the U.S. employs the ecotourism strategies listed above. Today it exists as a 445,154.2-hectare biosphere reserve. This protected area, comprised of wetlands, farms, forests, and historic villages, is a weave of habitation and landscape protection varying in density from 4 people/100 hectares to 1,544 people/100 hectares. There are 850 species of plants found in the reserve. The agricultural production of cranberries (*Vaccinium corymbosum*) and blueberries (*Vaccinium macrocarpon*) which only grow in wetland areas form an economically-vibrant industry and major tourist attraction for the reserve.

Not all of the protected land is owned by the federal government – there are state and local government-owned lands as well as land owned and operated by local people (1/3 public, 2/3 private ownership). The Pinelands is controlled by a comprehensive management plan with a zoning system designed to protect its unique character and resources while allowing for some future growth. About 700,000 people were living in this area when it was established; and the plan allows for 137,000 new housing units. For each new house built at least 6 hectares of upland forest must be protected. There are also guidelines for commercial activity to concentrate it around existing towns.

MUTUAL BENEFITS FOR TOURISM AND WETLANDS

We emphasize ecotourism because it is a better fit with multiple wetland uses than traditional mass tourism. Although traditional tourism can stimulate the local economy, if it is not carefully managed it diminishes environmental health, sacrificing the very thing that tourists come for in the first place. Ecotourism, on the other hand, can positively affect wetlands by contributing, both socially and financially, to their protection and conservation. Yet unchecked ecotourism with access to rare and fragile places can be as harmful to wetlands as unmanaged traditional tourism. Properly practiced ecotourism ensures that the tourist attractions, as it were, are maintained in the long term.

Ecotourism is an industry that receives considerable support. In 2000 USAID established a $36 million fund for the creation and management of protected areas and to build local capacity to develop ecotourism industries. These activities are a way to promote environmental actions as well as create important ties between ecotourism and broader environmental protection policies, nationally and internationally. Ramsar, The Nature Conservancy, and a host of other international conservation organizations have ecotourism programs and funding.

case studies

4. Good wetland restoration models

Pea Island NWR

Hatteras Island, Dare County, North Carolina, USA

The Outer Banks of North Carolina, a chain of barrier islands midway on the Atlantic Seaboard, is surrounded by approximately 1,450 kilometers of water, making it the largest estuary system in the world. With 209 kilometers of coastline and villages that reflect over 400 years of American history, the Outer Banks is a major tourist destination. One stop in this network is Pea Island National Wildlife Refuge (NWR). Known as a "Birder's Paradise," it is estimated that 2.7 million visitors drive through Pea Island annually. This 21-kilometer long spit of land, in some places as narrow as .4 kilometers, attracts more than one million migratory birds a year.

HISTORY

Prior to wildlife refuge designation Pea Island was owned by several private waterfowl hunting clubs, and was used for commercial hunting and fishing, farming, and livestock grazing. In those years the island was a "wide, flat, sand fan" that was regularly washed over by the tide in spring time. In the late 1930's the federal government built the dunes to stabilize the islands and enable development. This landscape is habitat for over 365 bird species, including 25 duck species. Peregrine Falcons (*Falco peregrinus*), loggerhead sea turtles (*Caretta caretta*), Bald Eagles (*Haliaeetus leucocephalus*), Piping Plovers (*Charadrius melodus*) – all endangered species – can be found here over the course of a year.

PEA ISLAND NATIONAL WILDLIFE REFUGE

tourist destination

Project highlights
Tourist destination with high visitor numbers
Conscious effort to track visitor demographics and satisfaction
Impoundment management

Size
2,280ha (5,834ac) of land, 10,400.4ha (25,700ac) of Proclamation Boundary Waters

Established
May 17, 1937 (Act of Congress and Presidential Executive Order)

Land ownership
United States Government

Uses
Wildlife and habitat management, environmental education, recreation

Climate
Average yearly temperature is 21°C (70°F)

Rainfall
Average yearly rainfall is 109cm (43in)

Function
To protect habitat for migratory birds

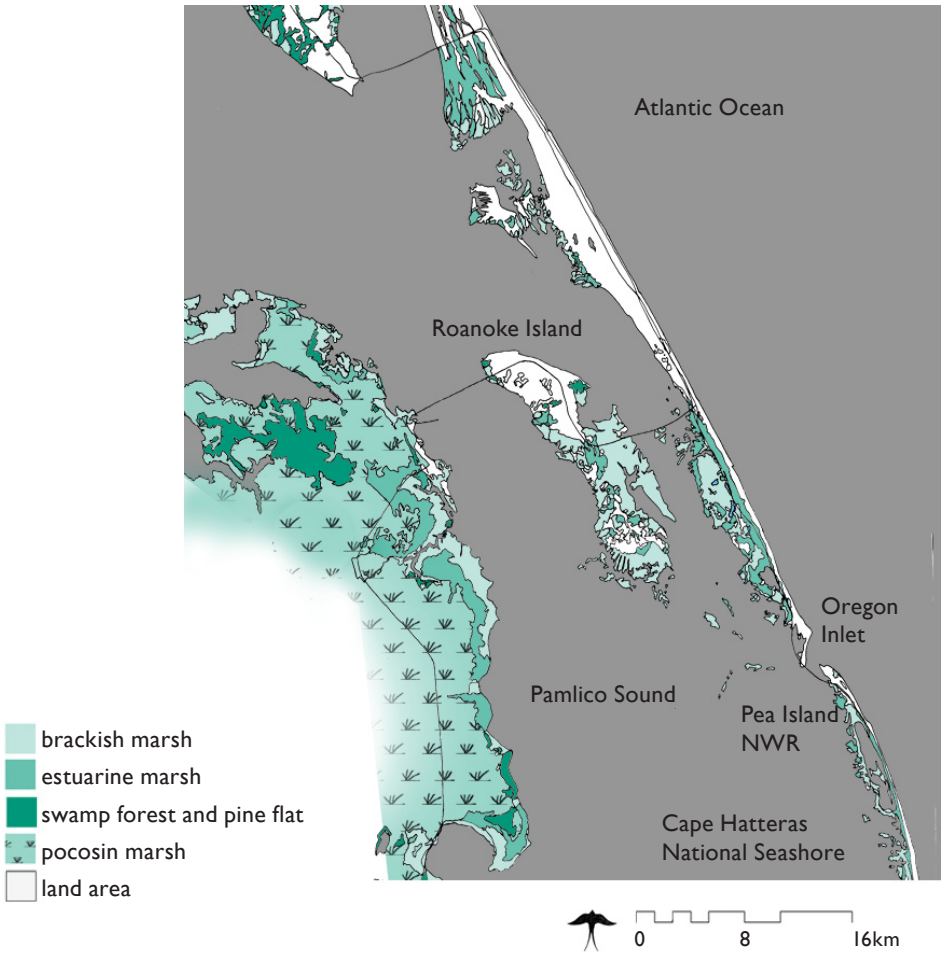
TOURISM

The juxtaposition of tourist-serving development and wild nature characterizes the Outer Banks, and is what visitors come to see. In 2004 there were over five million visitors that generated $619 million in tourism revenues, and $62 million in state and local tax revenues. Nearly 90% of the region's jobs are attributable to travel and tourism (10,910 jobs in 2004), generating $152 million in payroll.

The Outer Banks Visitors Bureau has gone to great lengths to gather data on visitor demographics and satisfaction. For example, tourists to the Outer Banks and Pea Island have a particular visitor experience. The average visit is one week in length, "considerably longer than the national average." Many people rent homes, often two families together. The average expenditure is $60/person/day, or $2,294 total trip. Birders are considered by people in the Outer Banks tourist business to be among the "most affluent ecotourists."

According to studies visitors are typically found to be well educated, upper middle class families or couples. Perhaps the most interesting characteristic that defines a visitor to the area is "their loyalty" – close to 2/3 of first-time visitors return the Outer Banks again. Repeat visitors are more likely to be married, have a post graduate degree, and earn the highest household incomes. Given the proportionally high volume of visitors to Pea Island it is fair to say that they mimic the Outer Banks visitor profile.

PEA ISLAND AND THE BARRIER ISLANDS



The staff at Pea Island provides a rich calendar of activities for visitors – a wildlife program for kids, guided bird walks, a crabbing and fishing rodeo, and the Wings Over Water program. The fall is a favorite season for viewing migration, in fact the 2006 website of the local visitors bureau lists Pea Island as a top "highlight". It also appears on numerous websites specializing in outdoor recreation and tourism, such as National Geographic's Guide to Scenic Highways and Byways. In a 2004 survey tourists ranked wildlife viewing and bird watching 5th out of 13 vacation opportunities. Real estate agencies also provide information on the refuge.

MANAGEMENT

The Pea Island NWR is managed by the U.S. Fish and Wildlife Service (USFWS) and was established in 1937 to provide habitat for migratory birds (mostly waterfowl) and other wildlife. Interestingly, its waters were closed to hunting by presidential proclamation. It is administered by the nearby Alligator River NWR. The 36-member staff includes a biologist and wildlife interpretive specialist. Three paid employees work at Pea Island daily. The annual budget for both refuges is nearly $3 million.

Pea Island is the beneficiary of 35,000 volunteer hours annually, including student interns and Workampers from a program where a volunteer can live in his/her own RV on site in exchange for 32 hours of work per week. The Coastal Wildlife Refuge Society operates a gift shop in the visitor center to benefit refuge programs. While the administrative unit of the wildlife refuge is the USFWS, the refuge is also part of the Cape Hatteras National Seashore which is administered by the National Park Service.

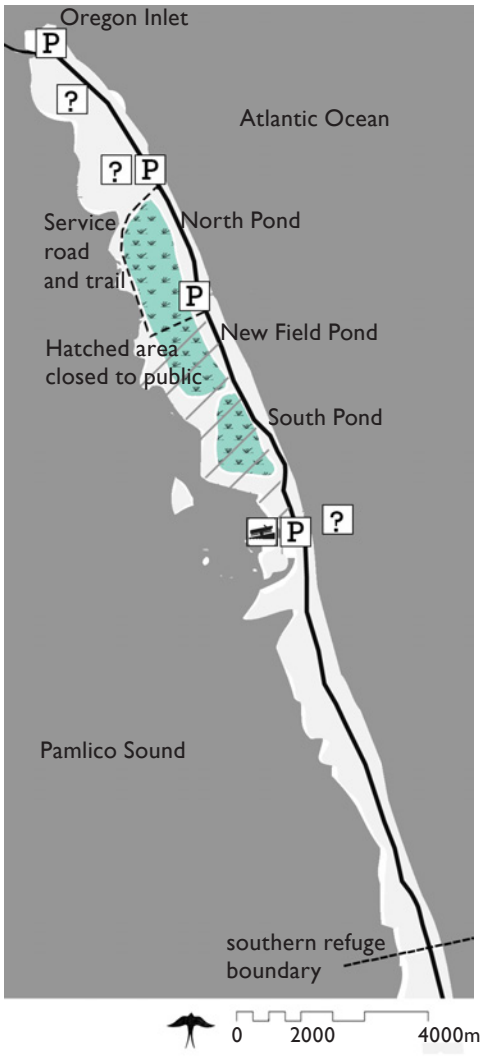
A plan for comprehensive conservation management is underway but intensive habitat management practices have been in place for years. Management tools include: water level manipulation in the impoundment ponds, prescribed fire, mechanical and chemical control of noxious and invasive plants, wildlife and habitat surveys, education and interpretation, outreach, partnerships, and law enforcement. Wet areas are managed for food production and to attract target species to capture for banding. Prescribed burns and mechanical brush control are conducted to restore historic plant communities.

CRITICAL GEOMETRIES

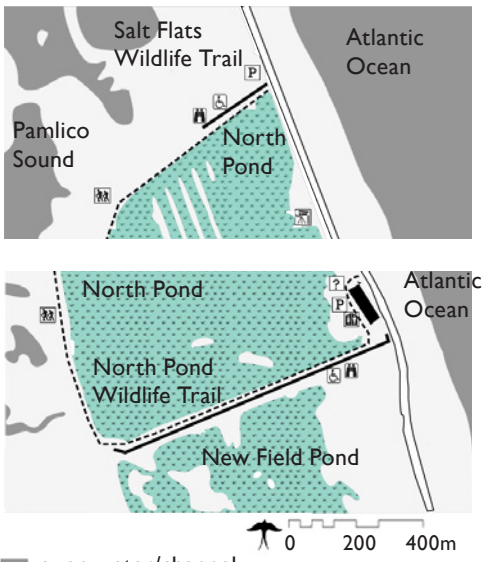
Pea Island's distinctive landscape characteristics include ocean beach, dunes, upland, fresh and brackish water ponds and impoundment ponds, salt flats, and salt marsh. The area is prone to tidal surges and is in the path of regular summer hurricanes.

There are 405 hectares of managed waterfowl impoundments, the water levels of which are managed in concert with tides to mimic dry and wet periods of natural wetlands and encourage maximum food production. To that end the ponds are flooded in the fall to maximize feed for winter migration and drawn down in the spring for migrating shorebirds. The site provides nesting, resting, and wintering habitat for migratory birds including Greater Snow Geese (*Chen caerulescens atlanticus*). They forage in the dunes and along the sound shore and eat mature dune plants that yield high energy dune peas (*Strophostyles helvula*), a reliable food source.

PEA ISLAND NATIONAL WILDLIFE REFUGE



ACCESS TO NORTH POND TRAILS

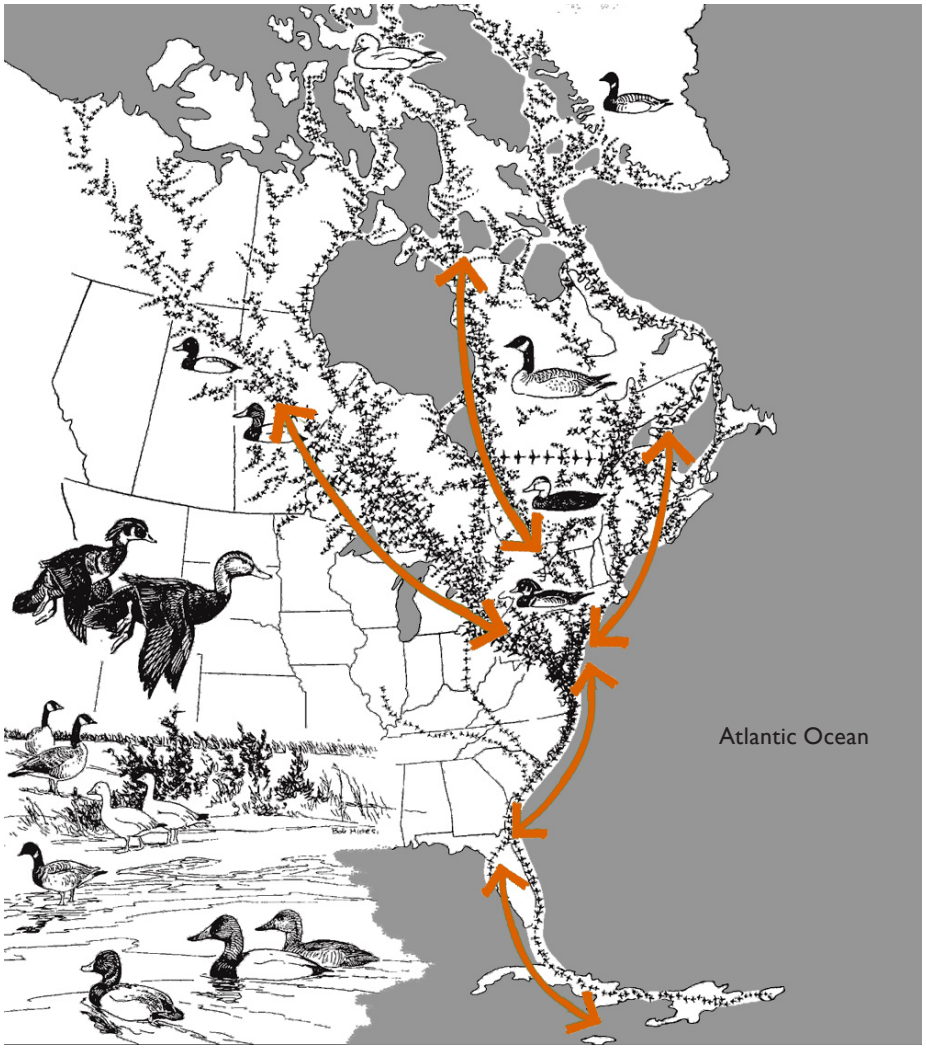


Tourism in National Wildlife Refuges

In 2004, 40 million visitors traveled to one of the National Wildlife Refuges for a unique wildlife experience. The J.N. "Ding" Darling NWR opened in 1954 preserving 890 hectares of mangrove wetlands. It is now 2,590 hectares of black and red mangroves, which are viewed by one million visitors annually. The 4.6 kilometer loop through the refuge provide views of twisting mangrove roots, alligators, and birds. It is said that a visitor can see 75 species of birds in one day.

Another refuge with high visitor numbers is the Chincoteague NWR, created in 1943. It is located in the barrier islands off the coast of Virginia and Maryland on the east coast of the U.S. The refuge is comprised of over 5,665 hectares of beach, dune, marsh and forest habitat. The staff has constructed 1,052 hectares of fresh and brackish marsh creating feeding and resting habitat for migratory and resident bird species. This refuge accommodates 1.5 million visitors a year.

ATLANTIC FLYWAY



There is a visitor center and limited parking on the island as well as observation platforms and towers with spotting scopes, one blind for the "serious wildlife enthusiast," and a .8-kilometer pond trail. The trail is fully accessible with wheelchairs available for loan. There are also guided canoe tours, sites for a boat to launch into the Sound, and a 6.4-kilometer service road trail. A number of uses are prohibited: dogs off leash, camping and hunting, and swimming in the ponds.

CHALLENGES

Tourist surveys indicate that the important attributes of the Outer Banks are the scenic areas and drives, historic sites, beautiful beaches, the clean environment, wildlife viewing, and fishing. Not shopping or golf. But these qualities are at risk. There is tremendous development pressure in the Outer Banks. In fact, the sources of visitor dissatisfaction are traffic (75%), overcrowding (60%), and overdevelopment (65%). This is not likely to change, and is expected to get worse. The estimated growth rate from 2000-2003 was 10.5% compared to 4.5% statewide. The population has increased 31.7% since 1990. New development is primarily low density – 30 persons/square kilometer on the Outer Banks compared to 64 persons/square kilometer statewide.

Arcata Marsh and Wildlife Sanctuary

Arcata, Humboldt County, California, USA

The City of Arcata is located 400 kilometers north of San Francisco on the northeastern shore of Humboldt Bay. It is home to the well-known Arcata Marsh and Wildlife Sanctuary (AMWS), a constructed wetland that treats the city's wastewater. Constructed in the 1980's AMWS is considered a model wetlands restoration project for its community involvement, innovative land use, and applications of appropriate technology in a small urban community. However, the most compelling aspect of AMWS is its success as a multiple use wetland. Not only does the marsh treat the sewage of nearly 20,000 people, it also serves as a wildlife sanctuary, an environmental education center, a recreation area, and a tourist destination.

HISTORY

Before European settlement the AMWS site was a salt marsh. The wet meadows and forests were used by the Wiyot Indians, who were tied to its seasonal and daily cycles for food, transportation, and building materials. In 1849 European explorers found their way to Humboldt Bay and by 1860 settlers had begun to farm the land. Much of the wetland area was diked and drained for agricultural and logging purposes. The marsh and bay were further altered with the building of a two-mile wharf and railroad track that connected to a shipping channel out

ARCATA MARSH WILDLIFE SANCTUARY

Project highlights
Cost-effective sewage treatment system
Multiple use wetland incorporating wildlife habitat, recreation, aquaculture, and education

Size
62.3ha (154ac)

Start and completion dates
1981 – 1986

Land ownership
City of Arcata

Uses
Wastewater treatment, wildlife habitat, recreation, ecotourism, environmental education

Climate
Average yearly temperature is 15°C (59°F)

Rainfall
Average yearly rainfall is 101cm (40in), with 80% of that falling from November to April

Function
To treat wastewater to meet state and federal water quality standards for discharge into Humboldt Bay, enhance wildlife habitat, and provide recreational and coastal access and environmental education to the public

multiple use

Environmental education across the Pacific Ocean

Guandu Nature Park in Taipei, Taiwan is located at the confluence of the Keelung and Danshui Rivers. The park contains 57 hectares of wetlands, lowland forest, mangrove swamp and freshwater marshes. Not only does it protect habitat and provide accessible open space for residents of the dense city of Taipei, it is also a venue for education and research on wetlands.

Similar to the Arcata Marsh, its grounds and visitor center are designed for both bird watching and educating visitors about the site. The park's 16 staff members and 200 trained volunteers give talks in the visitor's center and tours of the site explaining how wetlands work and the different roles of the animals that live there. Hundreds of school children visit each week for environmental education programs.

Additionally, the site provides opportunities for research-based work as students from undergraduate to post-graduate conduct experiments. The management of the site is itself an ongoing experiment seeking ways to improve water quality, creatively reuse gray water, and find inexpensive ways to ensure proper flushing of the wetlands

in the bay. The redwood forest east of the wetland was destroyed in the 1940's when it was harvested and milled by a local family that established two lumber mills. The ecosystem was further degraded in 1964, when 16 hectares of Arcata Bay were diked for an ocean-side landfill. After the fall of the lumber industry in the 1960's, the mills were donated to the city and became what is now Butcher's Slough. By the 1970's not only had the ocean-side landfill contaminated the neighboring land, but toxic leachate was reported in Humboldt Bay and the landfill was closed. In 1973 the Department of Health condemned the site. There were several proposals for the site's future use: a golf course, a marina, a motocross area, a baseball field. The City of Arcata determined that a nature center and marsh restoration area would be the most beneficial option.

PROJECT DEVELOPMENT

In the early 1970's Arcata's active wastewater treatment plant, constructed in 1949, still discharged unchlorinated primary effluent into Humboldt Bay. In 1974 the State of California enacted a policy under the Clean Water Act that prohibited discharge of wastewater into bays and estuaries unless "enhancement" of the receiving water was proven. In response to this policy the newly formed Humboldt Bay Wastewater Authority (HBWA) proposed the construction of a regional wastewater treatment plant that would serve communities in the vicinity. But as the cost of the regional treatment plant grew and the difficulties of incorporating other communities became apparent, opposition to the project grew. The Arcata City Council tried to convince both HBWA and the Regional Water Quality Control Board (RWQCB) that there had to be another way to treat sewage that would be less costly and more environmentally friendly.

In 1975 residents formed a group called "Citizens for a Sewer Referendum." They circulated petitions calling for a vote and eventually sued the HBWA, bringing the regional project to a halt. For Arcata to move forward alone, it had to find a treatment method that would demonstrate enhancement. Six years earlier Dr. George Allen, a retired fisheries professor at Humboldt State University (HSU), had started a wastewater aquaculture project near the old mill site to raise Pacific salmon (*Oncorhynchus* sp.) and cutthroat trout (*Oncorhynchus clarkii*) in mixtures of sea water and partially treated wastewater. In 1976 the idea of using Dr. Allen's fish project and a treatment marsh as enhancement emerged. The marsh idea was refined by another professor, Dr. Robert Gearheart.

The City of Arcata began to explore the idea of a decentralized treatment system incorporating constructed wetlands. A city Task Force on Wastewater Treatment determined that the constructed wetland system could provide a cost-effective and efficient wastewater treatment system that would simultaneously enhance the biological productivity of the wetland. In addition, it would facilitate the continuation of the aquaculture program. The system would also create a unique site for recreation and environmental education. In 1977 the City of Arcata took the AMWS idea to the RWQCB.

At the same time, proponents of the wetland sold the idea to the residents and business owners. Although most of the development community opposed the idea at first, opposition dwindled as arguments demonstrating the high cost of a traditional, centralized system were refined. In the mid-1970's the cost estimate for HBWA's regional treatment plant soared to $25 million (the final cost of Arcata's wetland was $7.1 million).

Finally, in a hearing before the State Water Resources Control Board in 1979 Arcata was granted permission to establish a pilot project with a $300,000 grant from the State. At that point the California Coastal Conservancy (the Conservancy) came forward to fund the wetlands restoration. The AMWS was dedicated on July 3, 1981. In 1983 the State gave Arcata the authority to develop the constructed wetland system and incorporate it into the original Arcata Wastewater Treatment Plant. In 1986 the Conservancy funded the Butcher's Slough Restoration, expanding the AMWS to its current size of 62.3 hectares. Since its completion in 1986, the integrated wetland wastewater treatment system has proven the ability of marsh plants, soils, and their associated microorganisms to successfully and cost-effectively treat wastewater to meet state and federal water quality standards.

Today the waterfront has been transformed into restored freshwater and saltwater marshes, brackish ponds, tidal sloughs, and estuaries. Trails through the AMWS are used for walking, jogging, bird-watching, picnicking, viewing the scenery, and fishing. Students and faculty at HSU in biology, environmental resources engineering, wildlife management, and botany use the marsh for teaching and research. Local environmental groups such as the Redwood Region Audubon Society use the site on a regular basis for nature walks.

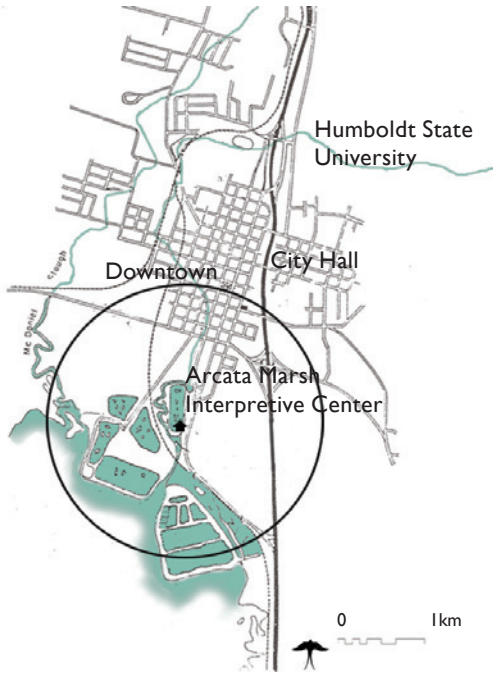
The wastewater treatment marsh is innovative and internationally known; it has become an integral part of Arcata's identity as an environmentally-conscious community. Recently the City of Arcata received funds from the Environmental Enhancement and Mitigation Program and the Wildlife Conservation Board to purchase 30.4 hectares of diked agricultural lands west of the Sanctuary. Plans are underway to cooperatively restore over 100 hectares of former tidelands.

TOURISM

Over 200,000 tourists arrive in Arcata each year and stay from one afternoon to an entire week. The Arcata Marsh Interpretive Center (AMIC) is staffed by the City of Arcata on weekdays and by community volunteers on weekends and holidays. AMWS does not allow commercial activities, but its location two blocks from the downtown brings patrons to local businesses. Events like the Oyster Festival, Waterfront Days, and Flush with Pride also attract tourists.

As a home or rest stop along the Pacific Flyway for over 425 species of birds, the AMWS has developed a reputation as one of the best birding sites along the Pacific North Coast. The marsh is a breeding area for ducks and other waterfowl and a feeding area for fish-eating birds. Four bird screens are available on the site to provide visual access to the many bird species without disturbing them. Tourists can also view the marsh vegetation; over 100 species can be found in the AMWS.

The popularity and awareness of the marsh is in part due to the Friends of Arcata Marsh (FOAM), formed in 1989 as a fundraising and environmental education organization. FOAM developed and expanded a docent program as tourism increased through the 1990's. In 1993 FOAM helped raise funds to build the AMIC, which now houses FOAM activities and is the starting point for visitors to the AMWS. Visitors come to the AMIC to learn about the political, biological, and engineering aspects of the marsh and participate in free weekly nature walks and monthly activities such as canoeing and clean ups.



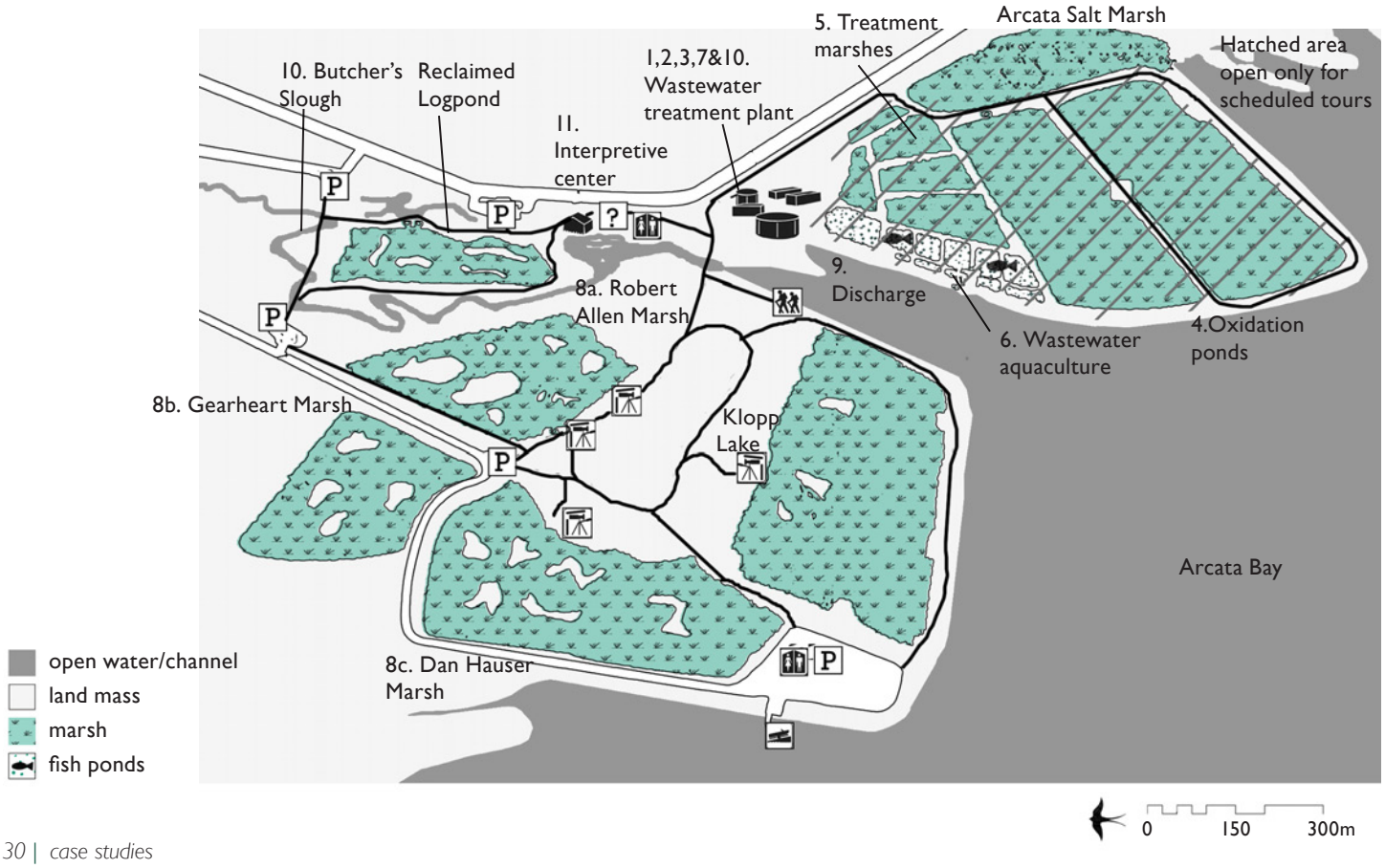
The proximity of Arcata Marsh to downtown means tourists walk less than 1.6km between shopping and the Arcata Marsh Interpretive Center, benefiting both land uses.

CRITICAL GEOMETRIES

The constructed wetland system is the cornerstone of Arcata's urban watershed renovation program. It includes major urban stream restoration, log pond conversion to swamp habitat, pocket wetlands, and a wastewater aquaculture program to restore commercially, recreationally, and ecologically important fish populations. The system is a hybrid of mechanical devices and natural treatment areas. Together these components create a functional wetland geometry for sewage treatment, wildlife habitat, and recreation. The spatial distribution of the wetland components is shown on the map below and their function is described in the text that follows.

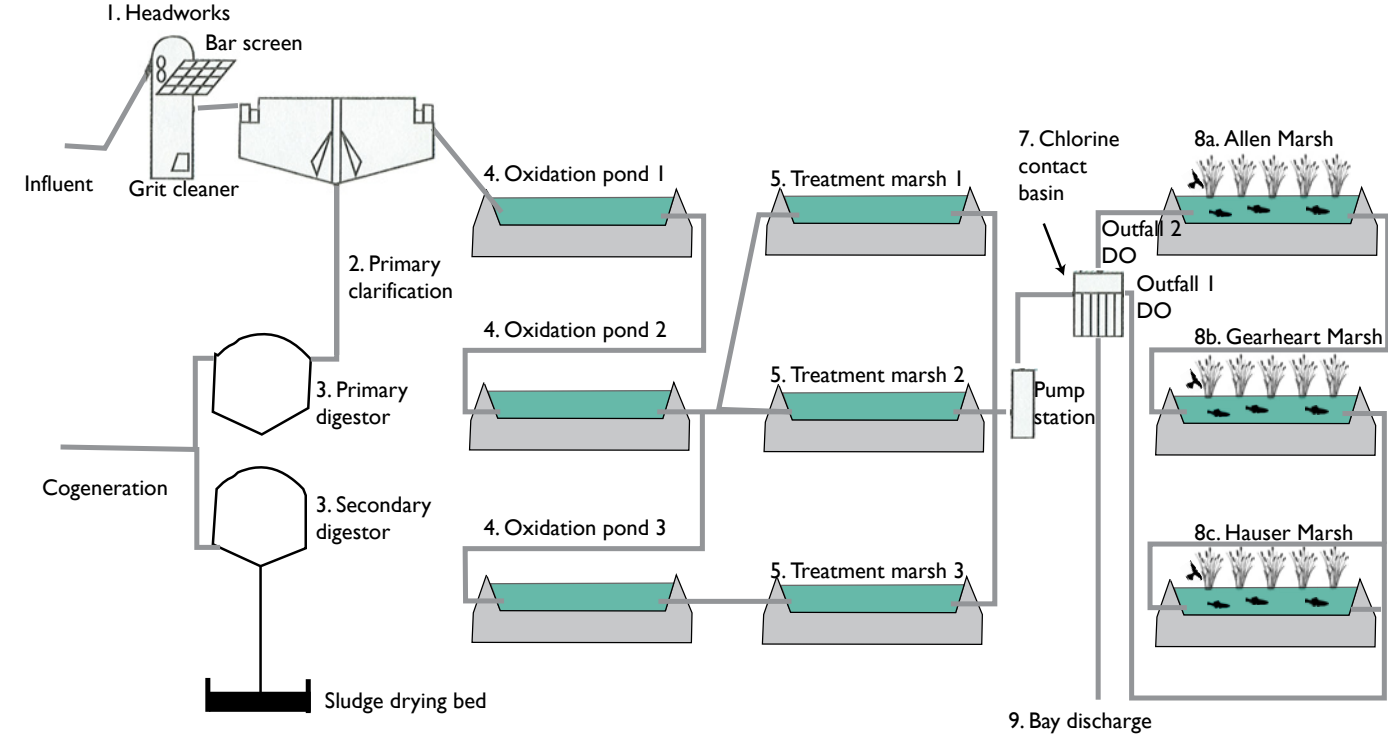
1. Headworks: The first phase in the treatment of raw sewage takes place in the headworks. The headworks remove inorganic materials from the raw sewage.
2. Primary clarification: Two clarifiers settle out any remaining suspended material that passed through the headworks, send the liquid waste to the oxidation ponds, and complete the primary treatment. The solids that settle out in the clarifiers are pumped to the digesters.
3. Sludge pumping and stabilization/cogeneration: These digesters, designed in conjunction with a methane recovery and cogeneration system, use compressors to recirculate methane gas through the sludge. The cogeneration component burns the methane gas and uses the heat to aid in the digestion.
4. Oxidation ponds: 18.2 hectares of ponds remove approximately 50% of the biological oxygen demand (BOD) and suspended solids that remain after primary treatment. Long detention times, plants, bacteria, and fungi treat the water to secondary standards.

ARCATA MARSH



5. Treatment marshes: Three .8-hectare treatment marshes reduce the levels of suspended solids and BOD that remain in the oxidation pond effluent. The marshes are planted with hardstem bulrush (*Scirpus acutus*), a freshwater marsh plant native to the area. This plant's effectiveness as a treatment species was proven by Arcata Marsh Pilot Project data. The treatment marsh's effluent is combined at a pump station where it is pumped to the disinfection facility.
6. Wastewater aquaculture project: Equal concentrations of Arcata's wastewater and seawater create an ideal environment for AMWS's fish rearing facility. Current fish projects include chinook (*Oncorhynchus tsawytscha*) and coho salmon (*Oncorhynchus kisutch*), steelhead (*Oncorhynchus mykiss*), and cutthroat trout. The project, run by HSU's Fisheries Department, includes egg collection and fertilization, rearing to smolt stage and release of the adults.
7. Disinfection: Chlorine gas is used to disinfect Arcata's wastewater before it is discharged to the enhancement marshes and again before it is discharged into Humboldt Bay. Any free chlorine remaining in the final effluent after the 60-minute contact time is removed with sulfur dioxide. Treatment areas 1-7 are open to the public only during organized tours given by the staff.
8. Enhancement marshes: After the first chlorination, wastewater is directed to the enhancement marshes, which are located northwest of the oxidation ponds. These three marshes (all restored from milling or agricultural uses) cover a total of 12.5 hectares. The marshes are managed to maintain the greatest diversity of aquatic plants and to maintain or improve water quality. Flow is directed through the enhancement marshes with sluice gates and wooden stop-log weirs. After disinfection, the wastewater flows first into George Allen Marsh (8a), then into Robert Gearheart Marsh (8b), and finally into Dan Hauser Marsh (8c). The effluent from Hauser Marsh is pumped back to the disinfection facility for final disinfection, then discharged into Humboldt Bay.

TREATMENT SYSTEM SCHEMATIC



Design specifications for Arcata Marsh

Design population.....19,056 people
Average annual flow.....2.3 mg/day
Maximum monthly flow.....5.9 mg/d
Peak flow.....16.5 mg/d
BOD's load.....1,859.7kg/day
TSS load.....1,542.2kg/d

Primary treatment
2 primary clarifiers..7.9/18.3m diam.
Retention at design flow .....3.8 hrs
Retention at max. flow.....1.4 hrs

Treatment marshes
Total area.....3ha
Average depth.....61cm
Detention at design flow.....1.9 days

Chlorination/Dechlorination
Volume.....701,815.3L
Retention at design flow.....58 min.
Retention at max. flow.....30 min.

3 Enhancement marshes
Total area.....12.5ha
Average depth.....46cm
Retention at average flow.....9 days

9. Arcata Bay discharge pipe: After the final disinfection, the effluent is discharged to the Bay.
10. Fresh water sources: The water for AMWS comes primarily from Arcata's wastewater. Jolly Giant Creek, which becomes Butcher's Slough, also contributes to the marsh as it flows into Humboldt Bay.
11. The Arcata Marsh Interpretive Center: An environmental education center provides information about Arcata Marsh, community activities, and tours.

The enhancement marshes are the only part of the treatment system that are always open to the public for recreation and wildlife viewing. Klopp Lake, Butcher's Slough, the Reclaimed Logpond, and the Arcata Salt Marsh are not part of the wastewater treatment process, but they add valuable habitat and recreation areas to the wetland system on what was once landfill or mill land.

While design specifications must always be site and context specific, the specifications (listed in the sidebar) for Arcata Marsh are a useful starting point for understanding the relationship between a design population, the treatment methods, and land areas needed to treat sewage from that population.

CHALLENGES

While the AMWS has been a resounding success, it has had its share of management challenges for which AMWS managers have employed useful strategies. Restoration of native plants was complicated by the fact that birds often ate new growth of critical plants. To address this problem, managers drained marshes during the growing season to make them less attractive to birds, thereby giving the new plants time to mature.

AMWS also faced some challenges to maintaining water quality and treatment effectiveness in the marshes. When algae growth increased TSS load, the treatment system's performance went down. The AMWS responded by increasing planting at inflow and outflow, which reduced algae growth. The AMWS large bird population created high fecal coliform levels, so it became necessary to add a final chlorination stage to the water treatment process to mitigate the problem.

BUDGET

Arcata Marsh was completed over time and continues to be improved. The State of California awarded a $300,000 grant for a pilot study. The wetland wastewater treatment plant was completed at a cost of $7.1 million, which was 75% federal, 12.5% state, and 12.5% local funds. In 1987 the Ford Foundation awarded the City $100,000 from the "Innovations in Local Government" grant program for the AMIC, to which the Friends of Arcata Marsh provided an additional $56,000. The current annual operations and management budget is $1.4 million.

Sonoma Baylands

San Pablo Bay, Sonoma County, California, USA

The Sonoma Baylands Wetland Demonstration Project is located near the mouth of the Petaluma River along the northernmost shore of the San Francisco Bay in Sonoma County, California. A project of the Sonoma Land Trust and the California Coastal Conservancy (the Conservancy), the goal was to restore the site to its original ecological condition of a tidal salt marsh with particular attention to habitat for two endangered species: the salt marsh harvest mouse and the California Clapper Rail.

Tidal salt marshes occur at approximately 1.1 meters above sea level, or between mean sea level and mean high tide water. The Sonoma Baylands site, however, had subsided significantly and was below sea level. Fill was needed to bring the elevation of the site up to the level necessary for salt marsh restoration. At the same time that restoration planning was under way, the Port of Oakland was struggling to find a suitable disposal site for clean dredged materials. Environmental groups, fishermen, and swimmers opposed dredge disposal in the San Francisco Bay or in the Pacific Ocean, leaving the Port no apparent alternatives.

THE SONOMA BAYLANDS

cooperative funding

Project highlights
Creation of habitat for endangered species
Use of dredged materials in a tidal marsh
Significant government spending
Use of legislative authority to push for wetland restoration

Size
129.5ha (320ac)

Start and completion dates
1988 – 1997

Land ownership
Sonoma Land Trust

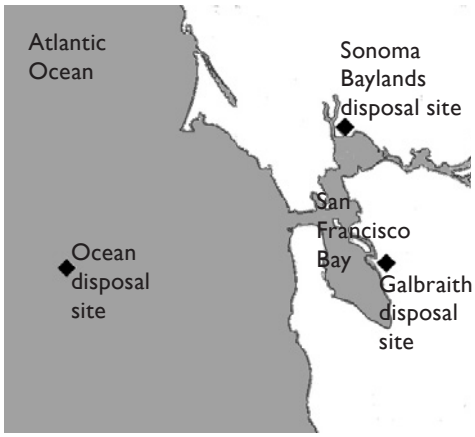
Uses
Protected tidal marsh lands for endangered species habitat

Climate
Mild winter and moderate summer, average yearly temperature 14.4°C (58°F)

Rainfall
Average yearly rainfall 75cm (29.5in)

Function
To increase tidal salt marsh habitat for the salt marsh harvest mouse and the California Clapper Rail (endangered species), restore tidal action in a diked bayland, and provide a dredge disposal site that is economically efficient and environmentally sound

POTENTIAL DREDGE DISPOSAL SITES



Between 1986 and 1991, each of the Port of Oakland's disposal site proposals was vehemently opposed and all of them were abandoned. The Port was unable to move ahead with a channel-deepening project that would allow the passage of larger ships into the port. This posed an economic threat, as the port is the largest shipping center in the San Francisco Bay Area and the nation's fourth largest port. Related industries employ over 100,000 people and generate more than $5 billion in regional economic activity. With larger ships unable to enter the port, Oakland stood to lose a significant amount of economic activity.

Early estimates of fill required for the Sonoma Baylands site exceeded 1.5 million cubic meters – the Port needed to dispose of approximately 5 million cubic meters of dredge. These needs yielded a unique partnership. When both parties identified the potential for mutual benefit, the planning process for using dredged materials for wetland restoration began.

HISTORY

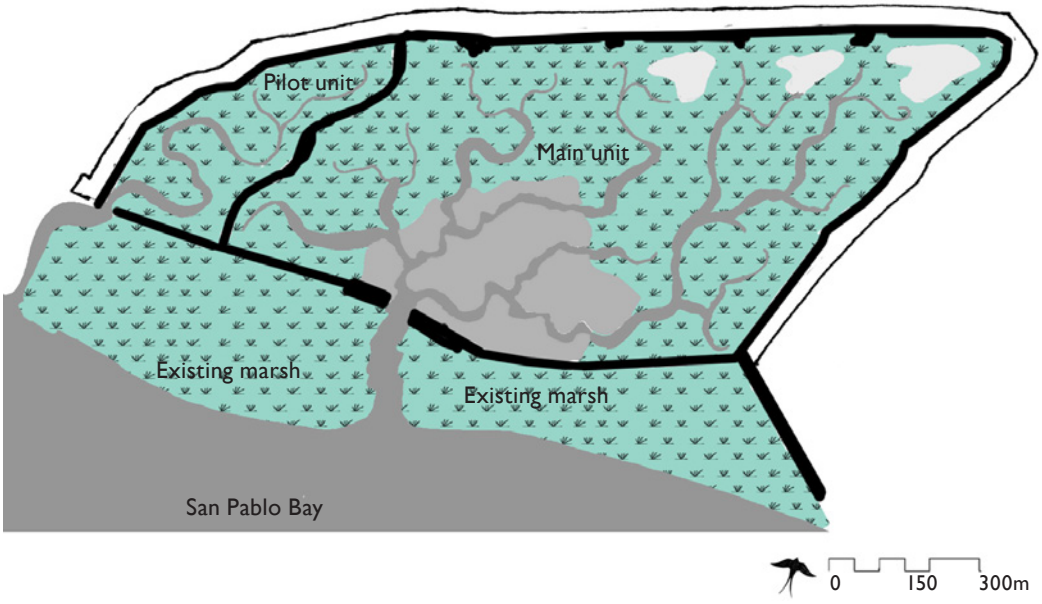
In 1850, approximately 77,295 hectares of tidal marsh bordered the San Francisco Bay. Since then nearly 80% of the Bay's tidal wetlands have been lost; converted to other land uses. Only about 15,460 hectares remain, and these are threatened by pollution, development pressures, erosion, and sea level rise.

The Sonoma Baylands site was once part of a tidal wetland system that extended along the northern edge of San Pablo Bay. The site is typical of lost tidal marsh almost a century ago - it was diked, drained, and removed from tidal influence for agricultural use. Since that time the land has subsided approximately 1.8 meters.

PROJECT DEVELOPMENT

In 1990 the Sonoma Land Trust purchased a 336-hectare tract of agricultural land using funding from the Conservancy. The goal was to preserve open space and restore wetlands in the northern San Francisco Bay. The land was purchased at a cost of $1.2 million; the Conservancy also provided $250,000 to hire a team to

20-YEAR PLAN FOR SONOMA BAYLANDS



design the 141-hectare parcel closest to the Bay and existing marshes. In 1991 the team recommended that before opening the Sonoma Baylands to tidal action, the surface elevation of the site should be raised with clean dredged material to speed the geologic and biologic evolution of the marsh.

With the promise of port dredge the team tested the toxicity of the material for one year to ensure that it would be safe to use on the site. They examined plant and animal samples for bioaccumulation of harmful chemicals and concluded that the dredged material was suitable for the site, and was, in fact, cleaner than much of the soil on-site. In calculating cost savings, it was estimated that barging the mud from the Port of Oakland to the site would cost only five percent more than an aquatic disposal 97 kilometers away. The extra cost lay in placing the sediment slurry onto the site, as opposed to dumping it into the ocean. Paying just five percent extra yielded the creation of over 120 hectares of tidal wetland, critical habitat for endangered species, and the satisfaction of fishermen, swimmers, and environmentalists who opposed aquatic disposal.

The Sonoma Baylands proposal also received strong support from the U.S. Environmental Protection Agency and from the U.S. Army Corps of Engineers (the Corps). However, a legal issue temporarily brought the process to a halt. The Corps stated that it could not support the project because it lacked Congressional authorization to do so. Further, the Corps tradition favored aquatic disposal, which it deemed to be more cost effective. At this juncture a coalition of organizations including environmental groups, the Conservancy, the land trust, and even the Port of Oakland began a campaign in support of the project. In 1992 Congress passed the Water Resources Development Act, in which they explicitly ordered the Corps to begin work on the Sonoma Baylands wetland restoration (Section 106). The Corps was instructed to create final engineering drawings, build the first phase of the project, and place the dredged material on the site so as to encourage the restoration of wetlands.

Congress also authorized the federal government to fund 75% of the $8 million project – the past policy only allowed a 25% contribution (Section 204). This authorization had national ramifications: restoration projects involving dredged material anywhere in the U.S. could now receive 75% federal funds. The Conservancy provided the remaining 25% for the Sonoma Baylands.

As directed by Congress, the Corps adopted the Conservancy's restoration plan. They began detailed design work in June 1993. In July 1994, Vice President Al Gore called the project a "win-win-win-win" deal when he spoke at a ground breaking ceremony at the Oakland Harbor.

CRITICAL GEOMETRIES

Fauna. The Sonoma Baylands was envisioned as a haven for the salt marsh harvest mouse and the California Clapper Rail and therefore their habitat needs were high priorities guiding site design. With existing data, the habitat needs for a sustainable population of both species was estimated at 80 to 100 hectares.

The salt marsh harvest mouse is listed as an endangered species that is found exclusively in tidal wetlands around San Francisco Bay in Northern California. It is considered to be a keystone species in both tidal and brackish marsh habitats. The

Persuading government to invest in Ballona Wetlands

The Ballona Wetlands are the only remaining large coastal wetlands in Los Angeles County, California and have been designated as wetlands of international importance by the United Nations' Ramsar Convention. This ecosystem once encompassed over 809 hectares of salt and fresh water wetlands, dunes, bluffs, and upland habitat. By the 1980's, the wetlands were severely degraded and reduced to fewer than 81 hectares. The area was further threatened by the luxury residential complex of Playa Vista, the largest development ever proposed in Los Angeles, which if implemented would have destroyed 64% of the wetlands.

Although Phase I of Playa Vista was approved in 1994, the project was delayed and scaled down through efforts of local environmental groups, statewide NGO's, and dedicated individuals in local and state government. Their strategies included environmental litigation against the developer and convincing the City and County of Los Angeles, the California Coastal Conservancy, and local and state politicians to purchase and protect the wetlands. This led the State of California to purchase 78 hectares for $140 million in 2003. Concurrently, legislation was passed forcing the developer to donate 195 hectares of contiguous open space and wetland to the public. To date, 70% of the land slated for development has been purchased or donated as open space. However, Phase II of Playa Vista threatens remaining wetlands, so the struggle to save Ballona Wetlands continues.

salt marsh harvest mouse is a "cover dependent" species that inhabits the middle to upper levels of dense pickleweed stands in tidal coastal salt marshes. It requires upland marshes for refuge during high tides.

Pickleweed, an upland marsh plant that tolerates full sun, alkaline soil, salt, no drainage, and seasonal flooding, is the salt marsh harvest mouse's primary food and shelter. In addition to pickleweed, the mouse eats stems and leaves of salt marsh plants and occasionally seeds or insects. Mouse behavior may include daily movement between marsh and high elevation grasslands in spring or summer, or when adjacent grasslands provide protection from predators during high tide or flood events. To create habitat for the mouse to thrive, ideal conditions for pickleweed are fostered to reduce potential growth of non-native invasive species.

The California Clapper Rail is a secretive bird which, if disturbed remains perfectly still, typically hiding in small sloughs or in dense vegetation. The rails run rapidly through vegetation using the sloughs as corridors, and when flushed may fly only a short distance before landing. They swim well, but generally only do so to cross sloughs, escape predators, or escape threats at high tide. Rails are most active at sunrise and sunset when they forage in marsh vegetation along channels and mudflat edges. They occur within a range of salt and brackish marshes but are currently restricted to the marshes of the San Francisco Estuary. In the North Bay, clapper rails live in tidal brackish marshes, forage in channel habitat and nest in native high marsh pickleweed and in gumplant (*Grindelia camporum*) lining channel edges. Like the salt marsh harvest mouse, the rail's habitat can be disturbed by the introduction of tule species.

The Conservancy reports that the first pair of nesting clapper rails was sighted at Sonoma Baylands in the summer of 2005, an event that has brought much excitement and made nine years of waiting and monitoring well worth the trouble.

Design. According to the site designers, the approach at Sonoma Baylands was to develop the conditions by restoring natural processes under which a marsh could evolve. This included utilizing the natural sedimentation in addition to the dredged material to raise the marsh to a functional level. The marsh vegetation should begin to establish as tidal flows create sloughs and sediment occurs within the restoration area.

Hydrologists estimated that by simply breaching the levee at one or two points, restoration of a tidal marsh habitat in the diked and subsided bayland would have taken from 35 to 50 years. They projected that raising the elevation of the site using dredged material would shorten the time frame to 10 to 25 years, a more efficient way to provide habitat to endangered species as quickly as possible. The project included the construction of peripheral and interior levees, earth-berm wave barriers, and the placement of dredged material.

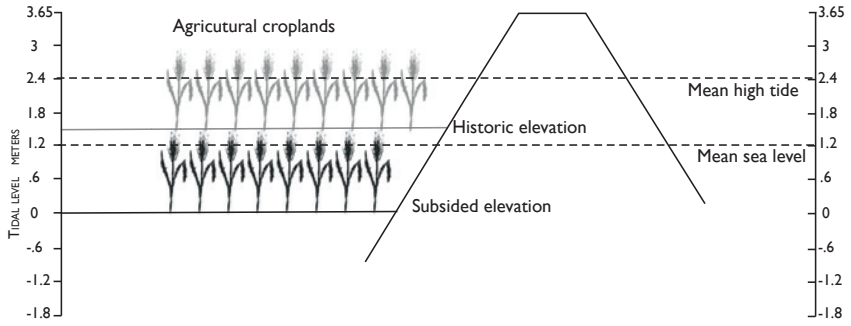
The Sonoma Baylands project was constructed in two major phases in two areas that are hydraulically distinct (see plan). First, a 15.8-hectare pilot unit was created using 158,569 cubic meters of dredged sediments from the nearby Petaluma River navigation channel. This phase was completed in November 1994 and partial tidal action was restored to the pilot site in January 1996 by breaching an old levee.

The second phase was the restoration of the 125-hectare main unit using approximately 1.9 million cubic meters of sediment dredged from the Oakland harbor. Placement of the material in the main unit was completed in November 1995 and partial tidal action was restored to the main unit in October 1996. Peninsulas built into the site were designed to control wind wave action and to guide tidal channel formation. Density and sinuosity of the peninsulas were based upon studies of existing and historic wetlands of a similar size.

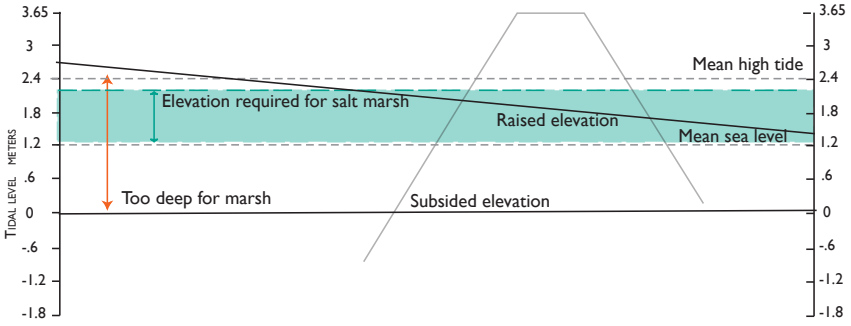
The tidal channel morphology was also determined by referring to tidal channels in existing and historic wetlands similar to Sonoma Baylands. To avoid damaging and disrupting endangered species habitat, the design team made the channels smaller than would otherwise be desired. The result is that they have taken much longer to scour out to their full size, so full tidal action still has not been entirely restored in the main unit. The pilot unit, though, now has full tidal action and the rate of sedimentation has increased.

Neither unit ever had sluice gates, weirs, or pumps to control water flow – the water level was controlled only by the size of the tidal channel. The design team anticipated that tidal action would gradually scour the channel to its ideal size for the system to reach equilibrium, a process which is happening. Tidal action in both units has brought in additional suspended sediments and plant propagules.

Diked agricultural lands



Marshland after breaching levee



The mudflats were diked and drained for agricultural purposes. Over time the expansive soil dried out and the land subsided. The elevation of the land relative to water level is critical to creating a successful marsh and should be assessed before breaching a levee. In this case the elevation was raised using dredged material from the Bay.

CHALLENGES

In hindsight, lower, wider peninsulas within the site would likely have been a better choice than the narrower, taller ones that were built. These taller berms are not subject to frequent enough inundation, and sometimes provide a path for predators such as foxes to enter the marsh. While these berms have worn down and will not be altered at this point, the experience has led the consulting team to favor lower, wider wave barriers.

Many people familiar with this project are of the opinion that the Corps didn't place enough dredged material on the Sonoma Baylands site. Placement of dredged material is an inexact science, and at a previous project the Corps used too much, leading to the formation of upland marsh instead of tidal marsh. On this project they overcorrected. The result is that sedimentation has taken longer. Some estimate that such a conservative fill volume set the project back five years. Others insist that giving the diked land a base and then allowing the rest of the sedimentation to occur naturally was the only way to ensure the formation of a naturally-functioning tidal marsh with sinuous channels.

Two years after the levees had been breached most of the Sonoma Baylands was still open water habitat. Sedimentation and plant colonization has happened more slowly than had been anticipated, despite the head start given to the site by the dredged materials. But natural processes are gradually altering the site. By late 2000 native cordgrass had begun to grow and by 2005 pickleweed was established.

MONITORING

It is critical to continue to monitor the process of wetland formation over time so that the next generation of projects can benefit from the data gathered and lessons learned. Unfortunately, in many projects that are struggling for funding, the monitoring stage is abandoned. This leads to uncertainty about whether or not project goals have been met and funds have been well spent. It can also lead to a higher number of repeated mistakes from project to project and missed opportunities for gathering data about how wetlands form and change over time. With this in mind the monitoring program for the Sonoma Baylands project is based upon success criteria, meaning that the site will be monitored until certain criteria are met. So far, the Corps has committed to 15 years of monitoring for this project. Tidal channel geometry, tide elevations, sedimentation and subsidence, bird populations (including density, species richness, species diversity, percent composition by group, and species of special concern), benthic macro invertebrates, fish, the establishment of marsh vegetation, and water quality are all monitored at the Sonoma Baylands.

DUST Marsh

Demonstration Urban Stormwater Treatment Marsh

Fremont, Alameda County, California, USA

The Demonstration Urban Stormwater Marsh (DUST Marsh) is a 22.3-hectare, seasonal and non-tidal freshwater marsh located in the Coyote Hills Regional Park on the eastern shores of San Francisco Bay. The hills, found at the fringe of the southeast shores of the bay, rise up above the surrounding flat lands, salt ponds, and wetlands reaching an elevation of 88.7 meters at Red Hill Summit. The marsh sytem was designed as a demonstration to treat urban runoff from a 11.9-square kilometer watershed before it reaches the Bay.

This prototype marsh was constructed in the early 1980's through a partnership between the Alameda County Flood Control and Water Conservation District (ACFCWCD) and the Association of Bay Area Governments (ABAG) to assess the use of natural resources for the treatment of runoff to meet stricter discharge standards for the Bay. The purpose was to test the effectiveness of artificial wetlands on urban water treatment, understand removal and uptake rates of pollutants, and assess the effect of the process on the health of the ecosystem. Since completion of the marsh system in 1983, monitoring has indicated success along a number of environmental variables. The increased number and

THE DUST MARSH

low cost and low tech

Project highlights

Low cost yet effective system for treating urban runoff

Low technology solutions for the management of vegetation and water

Effective demonstration with several years sampling research

Size

22.3ha (55ac)

Completion date

1983

Land ownership

Alameda County Flood Control District

Uses

Stormwater treatment and recreation

Climate

Mediterranean, average yearly temperature is 15°C (59°F)

Rainfall

Average yearly rainfall is 50.8cm (20in) with heaviest rainfall from November to March

Function

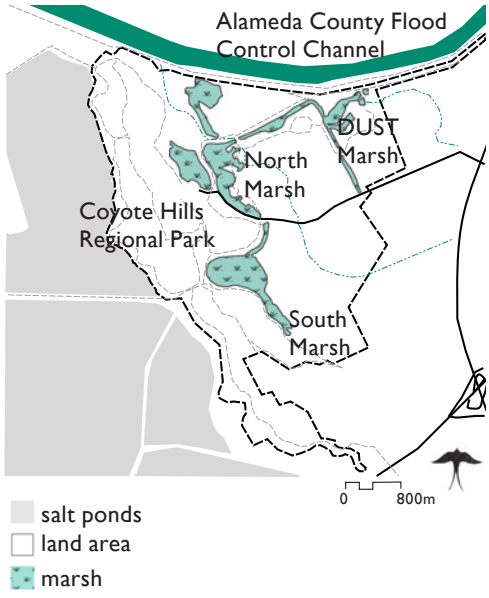
To complete a demonstration project that informs public works projects, capture and treat stormwater runoff from a 1,191.4ha (2,944ac) urban watershed, and reduce heavy metals in stormwater

abundance of aquatic species in the downstream part of the marsh indicate an overall improvement in water quality. In general, there is a continual reduction of pollutant concentration moving downstream from the debris basin at the beginning of the system to the Bay.

HISTORY

Ohlone Indians lived along this shore for more than 2,000 years prior to the initial mapping of the area in the 1850's. At that time the area was a salt marsh subject to the tidal flux of the Bay which wrapped around the back side of the hills (this is where the freshwater marsh is located today). It was bordered by a large freshwater willow (*Salix*, sp) marsh on the east and by a brackish pond on the south side. Several creeks from the East Bay hills fed the seasonal freshwater wetlands stretching to the east. Over time, much of the freshwater marshland was converted to farmland. With the increase of farming the salt marsh area was cut off from tidal influence by levees and gates, transforming it into brackish and freshwater marshes. The marshes found today are the product of 150 years of manipulation by private and public landowners.

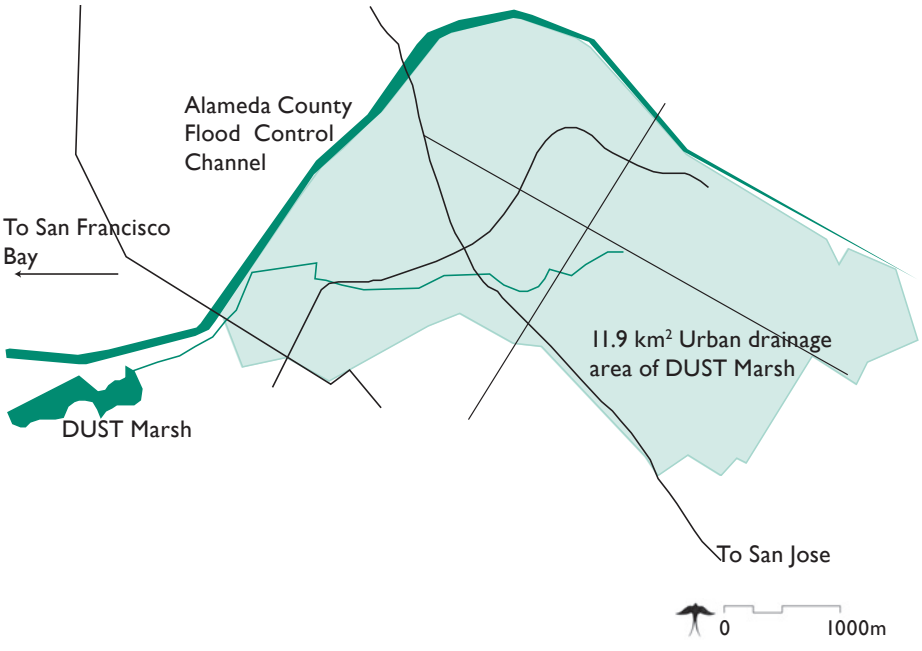
DUST MARSH IN CONTEXT



PROJECT DEVELOPMENT

In the early 1980's ABAG embarked on an investigation of how constructed or restored wetlands could be implemented around the San Francisco Bay to meet increasing water quality standards. Partnering with ACFCWCD and East Bay Regional Parks District (EBRPD), ABAG initiated the DUST Marsh project, a low-cost demonstration in the usually-expensive world of constructed wetlands. The land was acquired by ACFCWCD as a flood control basin in the 1950's and therefore land acquisition was not necessary. Funding for research, development, and construction came from a variety of sources – approximately $330,000 total– which translates to a cost of $14,798.00/hectare. The current management of the system by the two districts is minimal (mostly vegetation management).

WATERSHED SERVED BY DUST MARSH



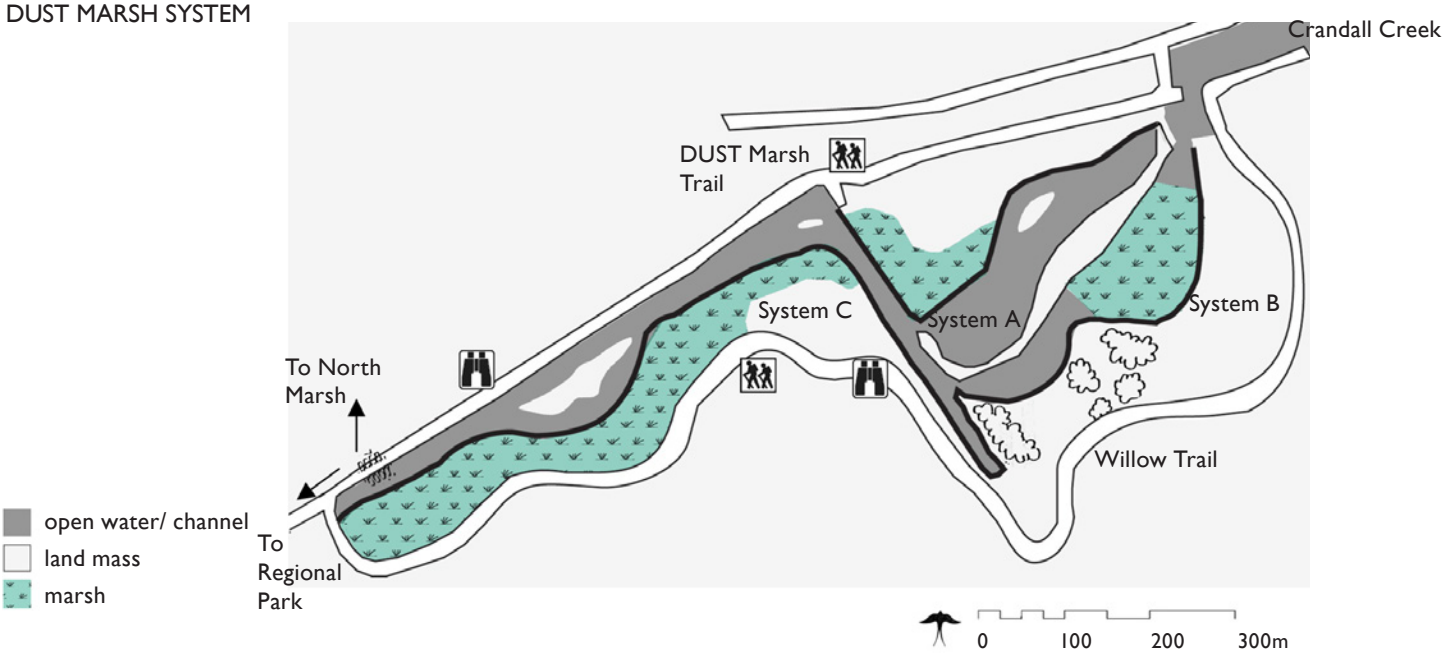
The early years of the demonstration were spent testing the effectiveness of the artificial wetlands. After seven years of scientific investigation, the County determined that wetland systems were removing pollutants, preventing uptake by plants, and producing a safe environment for wildlife. The system had been designed for incoming and resident water to have maximum contact with soil and plants for pollutant removal, while maintaining varying water depths and vegetative cover for habitat. Wind exposure was a design consideration used to mix the resident and incoming water, reducing overall toxicity levels and temperature and creating a more stable environment for aquatic biota and vegetation. Combined effects of soil, plants, wind, and several low-tech human interventions achieved pollutant removal and the emergence of a healthy marsh.

With the success of the DUST Marsh and the documentation of particular interventions, the model was then used to inform the design and development of other constructed wetlands. In 1998 ACFCWCD constructed the Tule Ponds at Tyson Lagoon based on the performance of the DUST Marsh system.

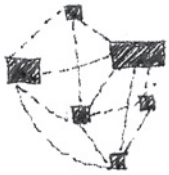
USERS

The proximity of DUST Marsh to Coyote Hills Regional Park has provided ready environmental education for students (from elementary through graduate school), community members, and park visitors. People also come to hike, bike ride, rollerblade, walk, bird watch, or take in the views across the San Francisco Bay. The visitor center at the parking lot has a museum with exhibits on the human and natural history of the area; programs are publicized in the Park District's monthly newsletter. Across from it is the Main Marsh where water-level boardwalk trails lead over and through the marsh. On the southeast side of the Main Marsh is a restored Ohlone village, built from reeds and constructed on an Indian shell mound. At the northeast edge of the Main Marsh, near Alameda Creek, is the DUST Marsh. There are observation platforms with benches where people can participate in bird viewing and water testing experiments and read the interpretive signs explaining the marsh ecosystem.

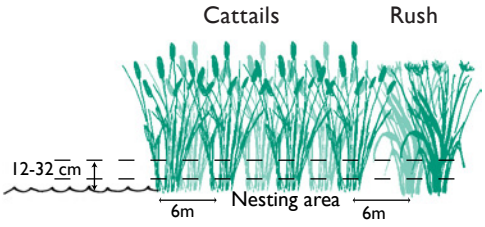
DUST MARSH SYSTEM



PROXIMITY OF SMALL MARSHES FOR HABITAT



NESTING AREA OF MARSH WREN



CRITICAL GEOMETRIES

Fauna. The native plant palette of cattails (*Typha* sp.), bulrush/tule (*Scirpus* sp.), oaks (*Quercus* sp.), and blackberry (*Rubus* sp.) enhance the habitat for wildlife. The Marsh Wren (*Cistothorus palustris* also called the Tule Wren) is the dominant species of the marsh – it can be found in wetlands from 0.1 to 20 hectares. They can live in small wetlands as long as they are adjacent to other wetlands to ensure genetic diversity. The dense stands of cattails that clean the stormwater are the preferred habitat of the wren. The polygamous male builds over 50 nests of cattails and tules stems 17 centimeters high and 7.6 centimeters wide in his territory and attracts females with over 210 songs.

A diverse population of birds species are found living in various areas of the marsh land, inhabiting the willows and tule, nesting in lower rushes (*Juncus* sp.), feeding in the open water, and circling the skies to prey on marshland residents. Tree Swallow (*Tachycineta bicolor*) houses were built and installed at the main marsh and System C as part of a children's activity. The muskrats will eat any vegetation that grows in the marsh, including tules and cattails which help keep the channels open. The population of these voracious eaters is kept in check by racoons and disease, otherwise the animals can destruct a marsh making houses of downed tules 1.5 meters high.

The habitat needs of aquatic biota also influenced design. The varying water depths provide diverse habitats. By shading the ponds and ensuring a mixture of resident and incoming water, a more stable water temperature is guaranteed for wildlife. Key aquatic biota are also indicators of a healthy marsh system.

Design. The success and efficiency of the system has been attributed to the vegetation and hydrology of the system. The marsh was constructed at the downstream end of Crandall Creek, a tributary of Alameda Creek, and on a partially-existing wetland (System C). Water from the creek, an earth-lined flood control channel, was diverted into a small debris basin and the DUST Marsh system. As part of the demonstration the spatial relationships between water (including depth and area), vegetation type, soil, wind, and sun were analyzed to assess how the system functioned for pollutant removal.

The system is composed of:

1. Debris basin: 1.2-meter-deep pool
2. System A (mixing marsh): a 1.8-meter-deep, 2-hectare lagoon with an island and a shallow cattail and tule marsh
3. System B (overland flow): a .9-meter-deep, 1.6-hectare pool
4. System C: a 1.5-meter-deep, 8.5-hectare channel

The debris basin and the series of weirs within it trap large debris and trash before the water reaches the marshes of Systems A and B. Two concrete sills then direct the water from the debris basin into the parallel systems A and B. System A mixes the incoming urban runoff with clean marsh water containing bacteria to treat the water. The prevailing winds disrupt water flow of the large surface area, mixing the resident water and incoming runoff. Large vegetation such as cattails or willows direct the winds and shade the pond to reduce water temperature. The islands act as additional mixing mechanisms by disrupting the flow of water while providing safe nesting sites for birds.

The varying sloped edges of the pond allow vegetation growth only in specific areas. The pond was designed to slow the velocity of the incoming runoff causing metals and other pollutants to rapidly drop out of the water. Pollutants are then sequestered in the deep water to prevent uptake or contact with plants or animals.

Urban runoff entering System B, the shallower system, flows into a shallow basin and then passes through plants and the upper soil layer. These filters accelerate the removal of pollutants. The water then passes through a row of tule and three underwater sills in a narrow channel before entering the common channel. The water recombines after several hundred feet and flows in to System C where the water travels very slowly.

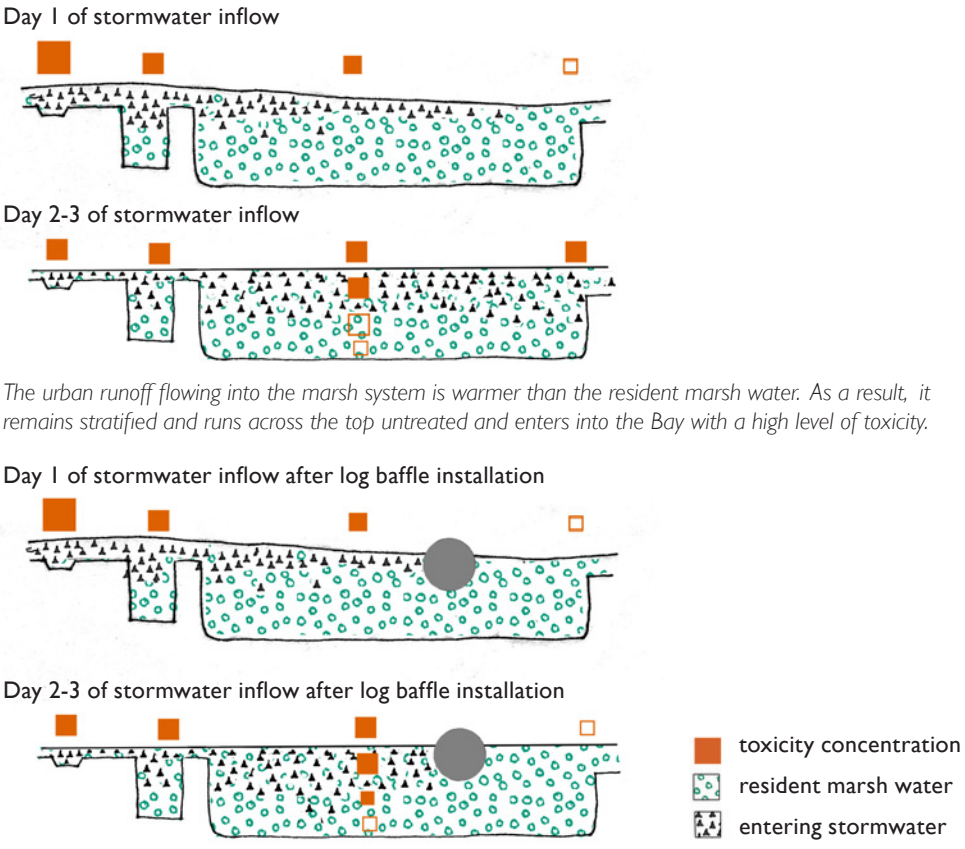
The linear pond, System C, was designed with a large surface area and minimal depth so the sun, soil, runoff, and plants would interact biologically, chemically, and physically to bring the runoff to a non-toxic state before it enters the North Marsh of Coyote Hills Regional Park. The pond was also designed for storage capacity with the ability to accommodate a .3-meter rise in water depth.

CHALLENGES

There were three majaor challenges in the DUST Marsh: the constructed wetland area available was smaller than desirable, stormwater bypassed the treatment system, and overgrown vegetation inhibited the system.

Critical factors for design of a constructed wetland

1. Watershed size
2. Land use and developed land in the watershed
3. Future development
4. Incoming water conveyance system
5. Type and quality of stormwater pollutants.



The urban runoff flowing into the marsh system is warmer than the resident marsh water. As a result, it remains stratified and runs across the top untreated and enters into the Bay with a high level of toxicity.

A log baffles was installed to break the surface flow of water, forcing the stormwater to mix with the resident water, increasing resident time in the marsh, allowing the stormwater pollutants to be removed. The log baffle created the conditions in which the stormwater could be treated and toxicity levels reduced.

There is a rule of thumb for sizing constructed wetlands that states that the wetland area should be 2 to 5% of the watershed area it is treating, while the specific size of the constructed wetland should be sized according to the hydraulic load and design storm of the watershed.The total area available for the DUST Marsh covers only 1.1% of the 11.9 square kilometer watershed. Because this area is less than the ideal, structural components needed to be integrated into the design before and after the initial construction to improve performance. ACFCWCD designed separate chambers for the processes of sedimentation, mixing, and biological treatment. In the agency's assessment it was determined that ponds should be designed in series to replicate a particular natural process. In this case, each system addressed a different method of pollutant removal, an approach that is useful for the demonstration.

Another challenge of the project was that the stratification of the entering stormwater and resident water in the channel resulted in inadequate detention time in the marsh, allowing toxic stormwater to enter the Bay. The system needs to have at least four days residence time to provide a safe environment for aquatic biota. To increase detention time and mixing, a floating log baffle was installed in the marsh system to disrupt the surface flow of water. Six large tree trunks were chained together and chained to the shore to prevent the warm runoff from flowing on top of the clear resident water and bypassing the marsh system.

The third challenge was overgrown vegetation. System B became overgrown with cattails several years after completion. In 1992, to address the situation, the water level was raised in System B by bolting a 10 by 20 centimeter timber onto the weir at the entrance to System A, the deeper pond. This directed the majority of the water through System B and was used to control vegetation growth. Additionally, System B was assessed to be more effective at pollutant removal.

In a system of this sort soil and vegetation slow the velocity of the runoff, effectively causing suspended solids to rapidly drop out. The vegetated creek bed of the Crandall Creek Flood Control Channel has proven effective at reducing concentrations of copper, lead, and zinc to background levels within 190.5 meters of the point where the stormwater enters the creek. This has demonstrated that flood control channels act as linear wetlands having a significant effect on pollutant removal. Narrow channels in the system were found to increase mixing potential and the contact between the incoming water and the soil and vegetation on the marsh. Both conditions increased the removal rate of oil, which is often abundant in urban runoff.

Don Edwards NWR

San Francisco Bay, California, USA

The Don Edwards San Francisco Bay National Wildlife Refuge (NWR), established in 1974, was the first urban wildlife refuge in the U.S. Its story is one of continued government commitment to meet habitat goals, restore lost environments, and create new environments for endangered species.

The refuge, currently 11,331.2 hectares, spans three counties (San Mateo, Santa Clara, and Alameda) in the southern portion of the San Francisco Bay. As a wildlife refuge set in an affluent urban context, with power lines and levees crisscrossing its protected lands, it faces particular challenges in acquiring high-priced land for habitat and species protection. Yet state and federal government agencies continue to meet the challenge and expand land holdings in order to fulfill the mission of the refuge. Currently 6,070 hectares of commercial salt ponds are being restored to tidal marsh and will be added to the refuge. This addition will bring its total area to 17,401 hectares.

HISTORY

As already mentioned, the San Francisco Bay Area has a human presence dating back thousands of years. The explosive growth in population in the nineteenth century, the discovery of gold, and the impacts of hydraulic mining upstream stressed the environment and silted in the marshlands at the edge of the Bay.

THE DON EDWARDS NATIONAL WILDLIFE REFUGE

government investment

Project highlights
Federal and state government commitment to funding wetland habitat
Excellent economic return for dollars invested

Size
11,331.2ha (28,000ac)

Established
1972

Land ownership
United States Government

Uses
Recreation and wildlife habitat

Climate
Mediterranean, average yearly temperature is 15°C (59°F)

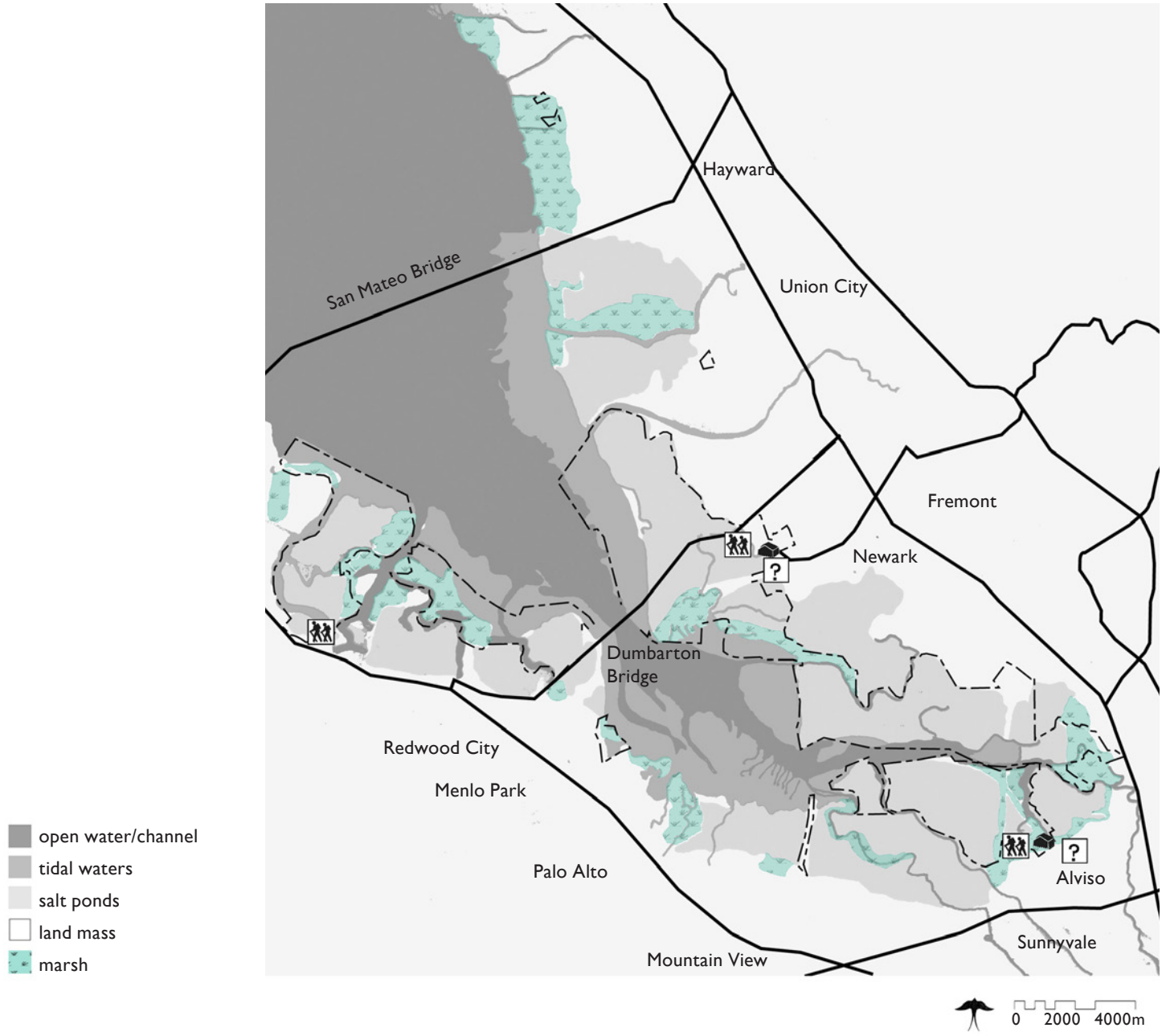
Rainfall
Average yearly rainfall is 50.8cm (20in) with heaviest rainfall from November to March

Function
To preserve and protect critical habitat for resident and migratory fowl, and provide the public with high-quality wildlife viewing and an educational experience

In 1854, the commercial salt industry began the conversion of marshlands to salt ponds. By 1936, the salt industry had grown and Leslie Salt Company had converted 16,187 hectares of marsh and salt ponds to commercial ponds.

In 1960, the U.S. Army Corps of Engineers determined that the Bay would be a river by 2010 if development practices were not curbed. At that time, it was estimated that 85% of the Bay's wetlands were altered. The South San Francisco Baylands Planning, Conservation, and National Wildlife Refuge Committee and Save the San Francisco Bay petitioned the federal government to establish a national wildlife refuge in the South Bay. With little response from the U.S. Fish and Wildlife Service (USFWS), the groups enlisted Congressman Don Edwards to put pressure on the federal government. President Richard Nixon passed

DON EDWARDS SAN FRANCISCO WILDLIFE REFUGE



legislation in 1972 and the wildlife refuge was established in 1974. It was renamed the Don Edwards San Francisco Bay NWR in 1995 in honor of the congressman's extraordinary efforts.

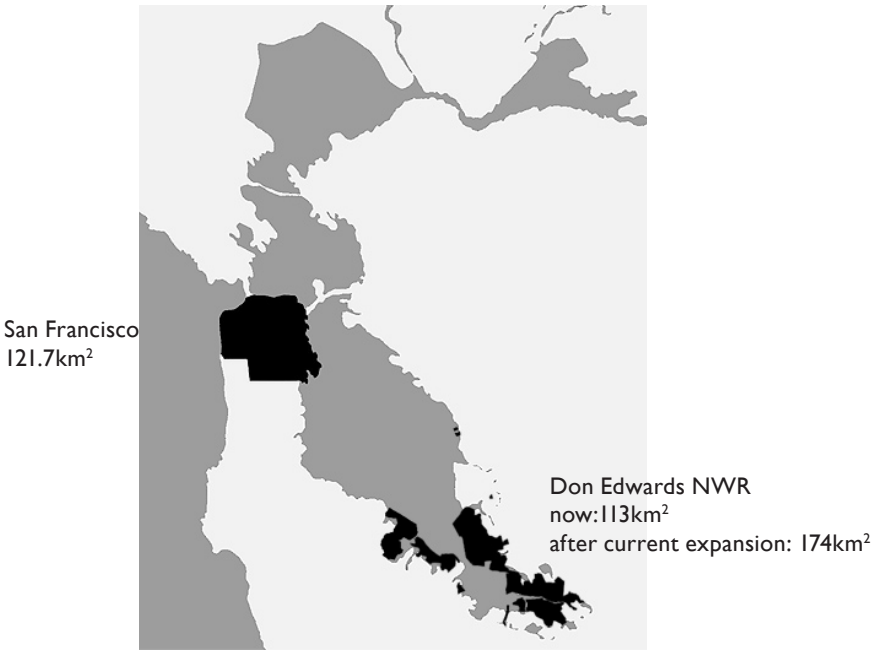
PROJECT DEVELOPMENT

The original legislation from the Nixon administration set aside 9,308 hectares for preservation. In the 1980's it became apparent that this was not a large enough area to protect wildlife and habitat. In 1988, again citizens mobilized and lobbied Congress to authorize a 8,094-hectare expansion of the refuge, which would total 17,401 hectares. Cargill Salt offered to sell 7,689 hectares including 32 kilometers of shoreline for $300 million. In July 2001, Senator Diane Feinstein of California authored a compromise: 4,856 hectares for $100 million. The State of California contributed $25 million and Congress authorized $8 million.

At the same time U.S. Secretary of the Interior Gale Norton noted the rundown condition of trails and bridges and the following year the refuge received funding for maintenance. A total of $1 million was put towards improving two of the most popular trails and the popular spot of the California Clapper Rail. Because it is an endangered species, strict construction practices were followed.

Today the refuge is in the process of adding over 6,070 hectares. The South Bay Salt Marsh restoration project along with a project on the Napa River is being funded by the State Wildlife Conservation Board at a cost of $72 million, $8 million was received from the USFWS, and $20 million from the Hewlett, Packard, and Moore Foundations. The California Coastal Conservancy has committed $25 million. Additional funding will eventually be sought for stewardship, restoration, flood management, and public access. Considering the costs of other projects in the Bay Area and depending on the construction work needed, this restoration cost could range from the low to high hundreds of millions over the next several decades.

DON EDWARDS NWR 1.4 TIMES LARGER THAN SAN FRANCISCO



CRITICAL GEOMETRIES

Flora. The refuge includes six zones (mudflats, salt marsh, salt ponds, open bay, upland, and vernal pool) designed to provide habitat for five endangered species. The marshes today are hardly the connective, extensive marshes of the 1850's nor do they have the three distinct, broad vegetation zones historically found between grasslands and the bay: cordgrass in the lowest (the most tidally influenced zone), pickleweed in the middle, and an upper zone of peripheral halophytes (salt-tolerant plants). The upper zones have either been filled in or converted to commercial salt ponds, resulting in very narrow bands on levees which no longer connect to grasslands. The pickleweed zone has decreased due to subsidence from groundwater pumping which increases tidal coverage, thereby reducing pickleweed habitat. The increase flow of freshwater runoff to the Bay favors brackish plants like cattails, not cordgrass. By recreating these large complex and complete marsh systems through restoration efforts, the habitat will be healthier and able to sustain a more diverse population of birds and wildlife.

Fauna. This refuge is one of the most important links in the Pacific Flyway. Millions of birds stop during spring and fall migration including Ruddy Ducks (*Oxyura jamaicensis*), Scaup (*Aythya* sp.), and Surf Scoters (*Melanitta perspicillata*), but the California Clapper Rail is the center of attention at this refuge. An endangered species at the upper end of the food chain, this bird is also a good indicator of the overall health of the marsh system. The LaRiverie Marsh, its favorite haunt, was originally a crystallization pond for salt production. In 1984, the USFWS drafted a California Clapper Rail Recovery Plan to ensure the enhancement of the salt marsh for the benefit of the rail. The dike was breached and the water was allowed into ponds that were graded for cordgrass.

The clapper rail population is restricted to fragmented salt marshes in the Bay. There are few transition zones and terrestrial predators have easy access to rail habitat via the levees. Currently, predators are reduced by a search-and-remove system or by trapping. Thus the physical characteristics of a marsh are important for the survival of the bird. The ideal habitat is a tidal marsh of 100 hectares with a network of first-order channels in proximity to other marshes. Buffers between marshes and upland areas reduce the threat of terrestrial predators like foxes and feral cats. Islands provide safe nesting habitats and refugia from predators.

The elevation of the marsh and its hydrology are important characteristics for marsh quality. With a high quality marsh, rails can survive in smaller areas. Smaller marshes are also more desirable in terms of allowing rails to hear mating calls. If they cannot hear each other's mating calls then the reproductive cycle is broken and the population is not sustaining. Other design and management practices for the rail may be developed in the new expansion.

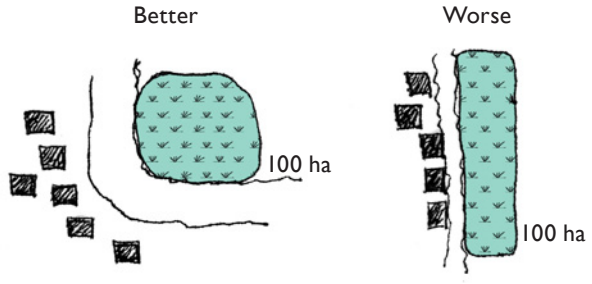
There are other management procedures in place to protect resident birds. During the nesting season (April to August) of the endangered Western Snowy Plover (*Charadrius alexandrinus nivosus)* Marshlands Road is closed to motorized vehicles because chicks can wander onto the pavement where they are hard to see on the gray asphalt. The road is open to bicyclists and pedestrians – there is a shuttle to the fishing pier for anglers. Plovers and other shorebirds like American Avocets (*Recurvirostra americana*) and Black-necked Stilts (*Himantopus mexicanus*) build their nest with materials from the levees and salt ponds in the flat open areas.

The elimination and shortening of vegetation zones has resulted in marsh areas less suitable for many species. For example, the increase in non-saline water entering the Bay decreases the overall salinity favoring bulrush and cattails over cordgrass. The salt marsh harvest mouse requires both a high marsh zone of pickleweed and an upper vegetated zone. The peripheral halophyte vegetation zones have been fragmented and reduced to 1 to 2 meters backed up against dikes, leaving the mouse no place to seek cover from predators during extreme high tides in late spring and summer. Although large areas of pickleweed have been restored and are habitable by the mouse, they remain unpopulated as the mice have no protection while moving between these fragments or seeking refugia during extreme high tides.

Design. The recently acquired salt ponds have a high salinity level of over 100 ppm (the legal limit in the Bay is 30 ppm). The refuge is in the process of conducting water quality tests for dissolved oxygen and pH levels to assess compatibility with aquatic biota. The ponds are also being gradually diluted to meet Regional Water Quality Control Board permitted levels of discharge. One method of reducing salinity is to release pond water at low tide. It seeps into the mudflat without disturbing the buried invertebrates and mollusks. When the tide

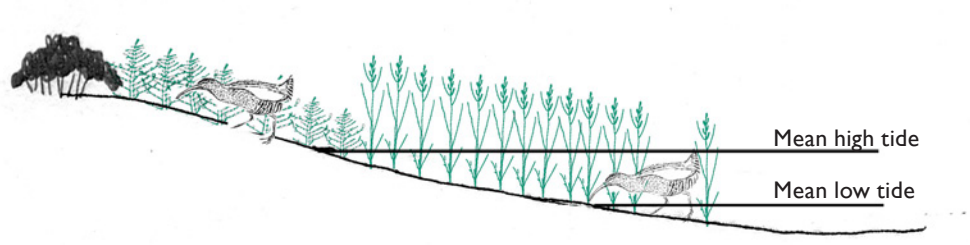
Design recommendations for California Clapper Rail

1. Create contiguous areas of tidal marsh with borders of cordgrass along bayfront
2. Restore complex sinuous tidal drainage system with deep channels to establish
3. Provide refugia (an area where climate remains habitable for a particular species when that of the surrounding area has changed i.e. high tides)
4. Isolate marsh from predator



It is essential to protect endangered species from the pressures of urbanization and terrestrial predators. A marsh with a large diameter is better than a narrow one and wider buffers are better than narrow ones. Both these conditions decrease the proximity of predators and disturbing land uses.

A complex tidal channel system not only creates a healthier marsh ecosystem but also gives the clapper rail pathways and hiding places to flee terrestrial predators. In contrast, a narrow marsh with few or no tidal channels allows predators easy access to prey.



The clapper rail not only needs safe lower mudflats with cordgrass for foraging, but also higher marsh for safety from tides and predators.

comes in, it may mix with the water in the mud, diluting the overall salinity. The chemical composition of the water has to be carefully monitored to maintain a healthy environment for the resident species. Once the pond salinity is stabilized the next step in restoration efforts will begin.

TOURISM

According to a study on the benefits of national wildlife refuges, the total number of visitors to Don Edwards in 2002 FY was 498,200. It is estimated that 85% of the visitors come to the refuge from farther than 30 miles away. The break down of visitor use of the site is as follows:

332,900 used the trails
41,400 used photo blinds and viewing platforms
27,600 used the visitor center
3,900 hunted waterfowl
500 fished

Don Edwards NWR boasts the most active education center in the refuge system. It is estimated that the recreation-related expenditures of visitors to the refuge totaled $3.4 million in FY2002. The majority of spending was correlated to consumptive activities, not hunting and fishing. There are a total of 65 jobs (part-time and full-time) generated as a result of refuge visitors, resulting in a total employment income of $1.8 million. In 2002, the economic effect for every $1 of refuge budget expenditure was estimated to be $2.10.

MANAGEMENT

Don Edwards is managed from its headquarters in Fremont along with five other refuges in the area which make up the San Francisco Bay NWR. These include the following national wildlife refuges: San Pablo Bay, Antioch Dunes, Salinas River, Elicott Slough, Marin Islands, and the Farallones. Close proximity to over six million people creates a large volunteer base for the refuge. In fact for every hour of paid staff work there is an equivalent hour of volunteer work.

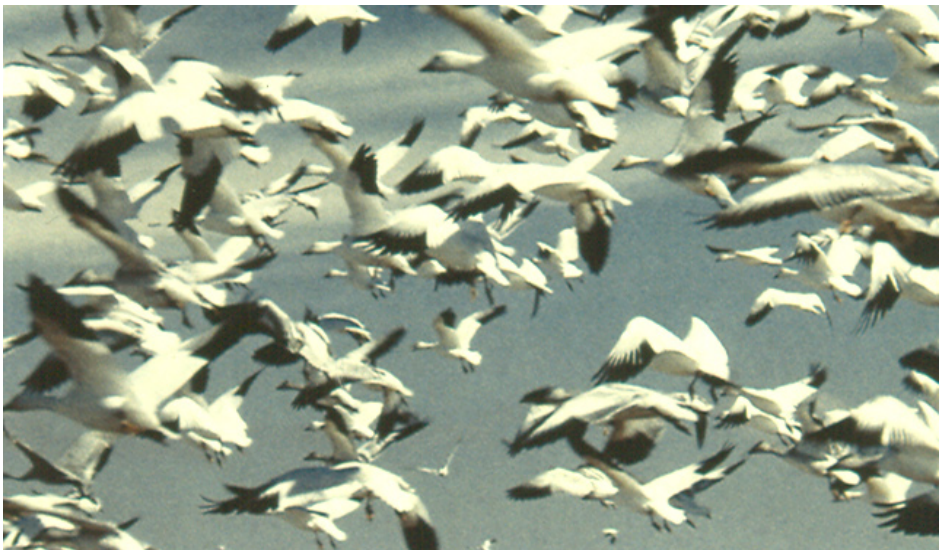
Bosque del Apache NWR

Socorro County, New Mexico, USA

The Bosque del Apache National Wildlife Refuge (NWR) is a model of innovative and cooperative wildlife management resulting from a unique partnership between the U.S. Fish and Wildlife Service (USFWS), local farmers, and volunteers. The collaboration has yielded a re-established wetland environment in an area previously devastated by agricultural practices, overgrazing, intense hunting, river diversion, and the invasion of non-native vegetation. The closely monitored management practices, which include a variety of techniques to create habitat for resident and migratory wildlife, feature exemplary reconstructed marshes, irrigation canals, cultivation for feed, moist soil management, and cottonwood (*Populus fremontii*) rehabilitation.

Over 14 kilometers of the Rio Grande run through the refuge located at the northern edge of the Chihuahuan Desert in south-central New Mexico. It is framed by mountains on three sides with elevations ranging from 1,372 meters at the river to 1,912 meters at Chupadera Peak. It encompasses over 230 square kilometers (23,067 hectares), including more than 50 square kilometers of wetlands. Located on the Central Flyway, the refuge is considered one of the top birding destinations in the U.S. Its success is measured in large part by the increase in bird populations –over 18,000 Sandhill Cranes (*Grus canadensis*) (up from 17 in 1940) and 30,000 Snow Geese (*Chen caerulescens*) (up from 30 in 1939) use the refuge annually.

THE BOSQUE DEL APACHE NATIONAL WILDLIFE REFUGE



volunteerism

Project highlights
Strong partnership between staff and volunteers to steward the land
Management strategies informed by knowledge of seasonal flooding patterns, germination periods, and wildlife needs

Size
23,067.1ha (57,000ac)

Established
1939

Land ownership
United States Government

Uses
Recreation and wildlife habitat

Climate
Average yearly temperature is 13.7°C (56.7°F) the temperature can range from -17.8°C to 37.8°C (0°F to 100°F)

Rainfall
Average yearly rainfall is 20cm (7.9in), with the heaviest rainfall from July to September

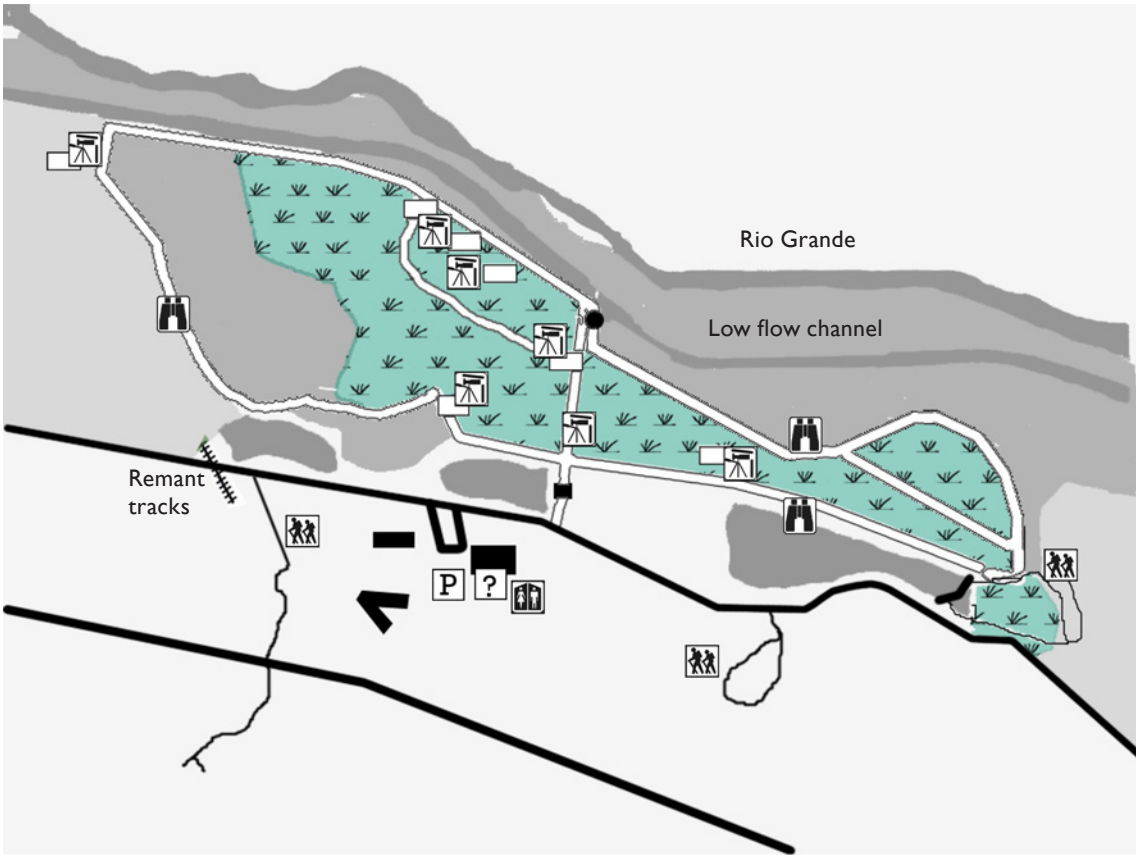
Function
To provide habitat and protection for endangered species, resident animals, and migratory birds with special emphasis on Sandhill Cranes, Snow Geese, Dabbler Ducks, and Canada Geese, restore riparian wetlands, and provide the public with high-quality wildlife viewing and educational experiences

HISTORY

The "woods of the Apache" were once inhabited by the Piro Indians who built two large pueblos, raised turkeys, and harvested the valley's natural bounty. In the sixteenth century El Camino Real, a 1,930-kilometer Spanish supply route between Sante Fe and Mexico City, passed through the area and was subject to Indian raids. Antonio Sandoval and his troops defended the route for which Sandoval was awarded the 24,281-hectare Bosque del Apache land grant. During the following 93 years, the land went through a series of sales, investment schemes, and foreclosures as well as landscape alterations from farming, oil drilling, dams, levees, and irrigation ditches. In 1906 water rights to the Rio Grande were granted to the Socorro Company and Charles Elmendorf. These rights later became the basis of the refuge's senior water rights to the Middle Rio Grande.

In 1936 the federal government surveyed the land to determine its suitability for a migratory bird refuge. Condemnation of the land was initiated through the 1931 Migratory Bird Conservation Act and the land was awarded to the Bureau of Biological Survey (predecessor to USFWS) on December 18, 1936. The landowner at the time, J. Fred Schoellkopf, was paid $5.36/hectare for 21,385 hectares. The refuge was formally established by executive order of President Franklin D. Roosevelt in 1939. Between the years 1939 and 1942 the federal Civilian Conservation Corps and Work Progress Administration worked to restore the refuge land.

THE BOSQUE DEL APACHE



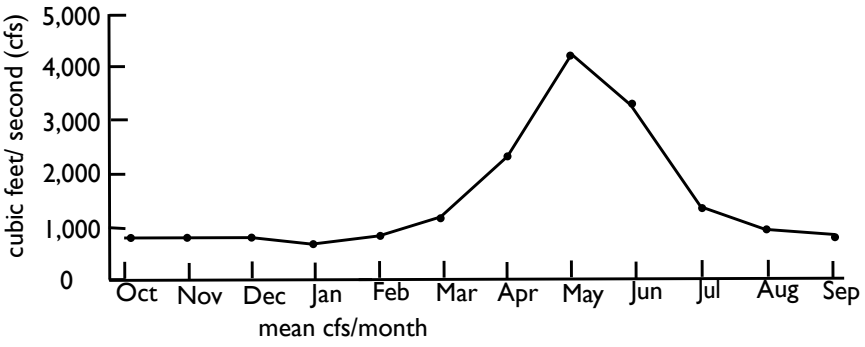
CRITICAL GEOMETRIES

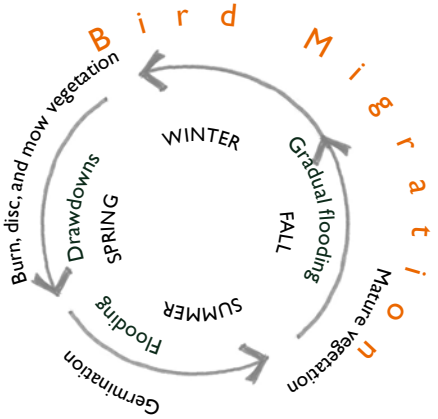
Design. There are different levels of management on the refuge: 12,484.6 hectares receive minimal management; the remaining 7,486.7 hectares are divided into five natural vegetation research areas. The heart of the refuge is 5,220.4 hectares of moist bottomlands. 1,537.8 hectares are the active floodplain of the river and the other 3,682.6 hectares are areas where water is diverted to create wetland, re-establish riparian forest, and irrigate farmland. A moist soil management system is used on 688 hectares of the refuge that manipulates water levels to mimic the historic hydrograph of the Rio Grande. This approach produces vegetation adapted to the Middle Rio Grande floodplain and therefore to wintering waterfowl.

The river is confined to its current channel through a dike and levee system, along with a low flow channel constructed in 1951 for flood control and irrigation. Canals carry water from the river to various areas in the refuge to water fields and flood areas, creating wetlands and shallow ponds for the birds. These canals are monitored daily, mowed, and cleared to keep them functioning. The water availability is dependent upon snow melt, spring rain, and wind. Therefore, the water use each year is judiciously planned to reflect the yearly conditions. For 2005, the consumptive water use based on production of waterfowl foods, riparian restoration, and row crop production for waterfowl was 8,502,144 cubic meters and the predicted water use for 2006 is 8,579,853 cubic meters.

The refuge has an annual management cycle that is strictly observed. In the springtime after the wintering birds have left, the seasonal wetlands are drawn down to renew plant production. Dry impoundments are disced or burned before flooding again to stimulate the growth of natural marsh plants simulating the scouring of spring flood events. Disturbance is created using tractors with discs, followed by a deep rake to penetrate the hardpan soil. The cycle is repeated when a marsh is mature, in the same way a flood event reopens a choked system. Wetlands are renewed approximately every 5 years, but the fall food monitoring is the true indicator for renewal. Up to 121.4 hectares are rotated out of production each year.

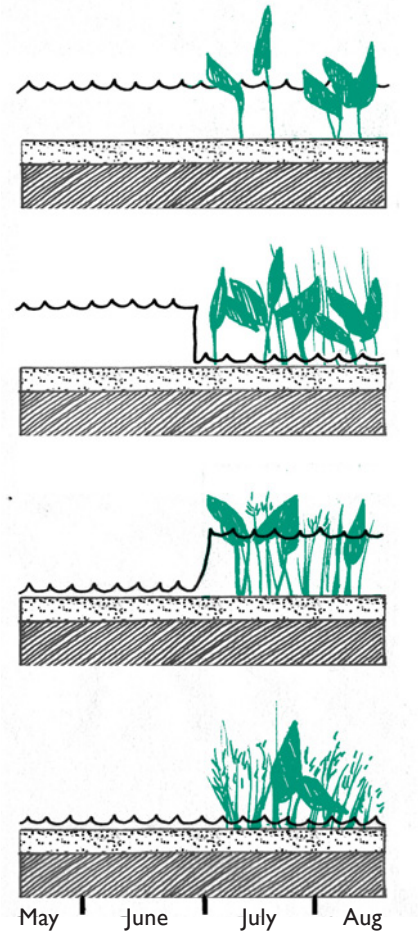
Wildlife foods grown include smartweed (*Polygonum* sp.), millets (*Echinochloa* sp.), sedges (*Carex* sp. and *Cypersu* sp) and bulrush. Drawdowns are scheduled throughout the spring season to respond to the germination periods, from forbs in the early spring to grasses in the late spring. Through the summer mowings and





The historical hydrograph (above) of the Rio Grande River was used to inform the current management cycle (illustrated on the right) for the Bosque del Apache.

WATER LEVELS MANAGED FOR HABITAT, VEGETATION GROWTH, AND FOOD SUPPLY



Lowest species diversity
Highest density obligate wetland
Perennials with no annuals

Mid-range species diversity
High density obligate wetland
Perennials dominate; almost no annuals

Mid-range species diversity
Low density obligate wetland
Mid-range diversity of annuals

Highest species diversity
Low density obligate wetland
Annuals with few perennials

irrigation schedules are managed carefully. Not only are areas of the drawdown staggered for vegetation production, they also provide mudflats for shorebirds and aquatic habitats for waterfowl.

As the fall season comes upon the refuge, the vegetation has matured, full of seeds for the wintering population. The wetland impoundments are gradually flooded to create aquatic habitats for midges, dragonfly nymphs, and other invertebrates and to soften the seeds for easier ingestion by the birds. The gradual flooding ensures there is food available throughout the winter and provides safe roosting and loafing areas for waterfowl. The ideal water depth is 15 to 21 centimeters.

The flooding schedule is based on the production of each impoundment, weekly water surveys and testing, and bird population predictions. Wildlife refuge staff also considers the bird population and tourist population when determining the flood schedule. The impoundments closest to the loop road and the impoundments with the least food production are flooded first when the bird and tourist populations are low to ensure secluded impoundments are available in peak season. Additionally, those impoundments with low food value are flooded first when the food demand is low. The goal is to flood just enough to provide adequate food for the current bird population, which doubles each week until the peak of the season. The highest production wetlands are set aside for the peak and just prior to freeze and migration when the birds need the most fuel.

The refuge staff strives to maintain a healthy bird population particularly in stressful times. These are typically when early fliers stop over briefly, when the bird population is at its peak, midyear when there are storms and most of the birds' energy is used to thermo-regulate (increasing the need for carbohydrates), and before migration when energy is needed for the long flight. At peak season, the birds are vulnerable to disease because of the artificially-dense numbers. By controlling flooding for habitat and food availability and utilizing adjacent farms, the staff is able to encourage birds to reside in different areas to reduce over-crowding and the possibility of disease outbreaks.

The USFWS has contracts with several local farmers who grow corn in their fields for the wintering birds. Both alfalfa and corn are grown on refuge farmlands. The alfalfa–a cash crop which is 2/3 to 3/4 of the refuge crop, is traded with the local farmers in exchange for their growing corn. The total food production on the refuge is about 1,800 kilograms of waterfowl-preferred seed/hectare. This number is monitored yearly and used to inform moist soil management practices.

Flora. The unique conditions of Bosque del Apache provide a balance of diverse habitats for 377 species of birds, grazing animals, other mammals, reptiles, fish, and amphibians. Their lands are comprised of 44% desert land, 44% grassland, 5% brushland, 3% wetland, 2% cropland, 2% forest land, and a riparian corridor.

As part of the management strategy cottonwoods, willows, and other water-loving vegetation that once lined the Rio Grande have been reestablished in the bottomlands. As elsewhere on the refuge, the primary management tool used is water level control. Seasonally-timed drawdowns allow native and invasive wetland plants to germinate. Flooding and mowing are used to combat particularly invasive species. For example, the fast-growing, invasive cocklebur (*Xanthium strumarium*) is mowed while sprouts of native species remain below the blade. Then the area is flooded to stimulate the growth of the desired wetland plants, which will shade out the cocklebur as it attempts to reestablish itself.

In other cases, invasives and non-natives are controlled using herbicides and fallowing fields. Salt cedar (*Tamarix ramosissima*), or tamarisk, was originally introduced as an ornamental plant and used for erosion control. Currently there are intensive efforts to remove this invasive species that has spread over large areas and offers little value as wildlife habitat. This is an expensive task, ranging from $750-1292/hectare, including the required two-year maintenance program.

The salt cedar is being replaced with cottonwoods, black willow (*Salix nigra*), and understory plants at a density of 120 plants/hectare and at a cost of $560-900/hectare. This vegetation has a much higher habitat value and reduces water consumption because irrigation needs are half that of salt cedar. With less water diverted, the benefits of the increased flow of the Rio Grande extend to fisheries and downstream waters users.

TOURISM

The refuge has hiking trails and viewing decks which provide fantastic views of birds and other wildlife. Human access to wildlife is limited to the loop road, giving the birds privacy and safe nesting areas. Some viewing areas have blinds and others are closed throughout the year to reduce the stress on the bird population.

National Wildlife Refuge System and volunteerism

The National Wildlife Refuge System (NWRS) manages over 37,600,000 hectares, fostering sound land use practice; protecting fish, wildlife, and biological diversity; preserving environmental and cultural values; and providing space for public use. In addition to their success in open space preservation, the NWRS has created an inspiring volunteer program that encourages stewardship through policies that promote volunteerism and citizen participation. This approach ensures that the public becomes invested in their lands and that the refuges respond to public input.

The NWRS Volunteer and Community Partnership Enhancement Act of 1998 established funds for NWRS volunteer programs, which today boasts over 218 "Friends of" groups. While funding for the refuges comes from Congress (largely through hunting related taxes), volunteers are invaluable to the success of these lands. There are over 36,000 volunteers a year; over 10 times the paid staff of the NWRS. Volunteers contribute 20% of the work necessary to maintain, operate, and enhance the refuges for the benefit of wildlife and the public. The value of volunteer hours is over $23 million dollars.

Volunteers getting it done at Crissy Field

Crissy Field is one of the most popular San Francisco parks with residents and tourists. The restored tidal marsh and native vegetation provide habitat for migrating birds along the Pacific Flyway. Crissy Field is a remarkably beautiful urban park, but even more remarkable are the volunteer hours and private donations that created it.

During the restoration from 1998 to 2001, over 3,000 volunteers from schools, corporations, civic organizations, and many individuals planted over 100,000 native plants representing 73 species to help the restoration effort of the tidal marsh. About 130,000 plugs of saltgrass grown for the project were installed by hand by volunteers.

In addition to benefiting from the work of thousands of volunteers, Crissy Field received financial support from a variety of people, from wealthy philanthropists to average citizens. The project was paid for almost entirely with private funds. A leading gift of $16 million from the Evelyn and Walter Haas, Jr., and Colleen and Robert Haas funds launched the project. In total, 2,400 donations were made to the project. Of these, 2,200 were $100 or less.

Each November the refuge hosts the Festival of the Cranes. There is a full program of workshops, hikes, tours, exhibits, lectures, and demonstrations for the full range of participants. Activities are centered on birding, wildlife management and research, wildlife rescue, raptor identification, native plants, conservation, geology, history, archaeology, astronomy, and photography. The Festival is organized by the Friends of the Bosque del Apache.

VOLUNTEERS AND PARTNERSHIPS

Bosque del Apache NWR has about 25 full-time employees, augmented by seasonal and temporary workers. Throughout the year, the work of paid staff is supplemented with roughly 100 different individuals from the National Wildlife Refuge Volunteer System (NWRVS). Volunteers contributed more than 35,000 hours during the FY2004. Volunteers at the Bosque:

1. Conduct fish and wildlife population surveys.
2. Lead tours providing information and interpretation to the visiting public.
3. Assist with laboratory research.
4. Take part in special projects such as bird banding and long-term monitoring.
5. Assist with habitat improvement projects such as re-establishing native plants.
6. Perform clerical, computer, and administrative duties, staff the visitor center.
7. Operate heavy equipment and assist in maintenance.
8. Photograph a variety of natural and cultural resources.

During the fall and winter – the most active time – there are approximately 30 Workampers (see Pea Island case for explanation). The volunteer program is primarily supported by the refuge's entrance fees.

Through observation and surveys staff and volunteers collect information on drawdowns, flooding, and the impact on vegetation growth and bird population. In 1995 the Long-term Biological Monitoring Plan was put in place to monitor and survey non-game species, including coyotes, mule deer, elk, reptiles, amphibians, and fish, as health indicators of the refuge. This Monitoring Plan relies on volunteers and interns who are trained in surveying and monitoring. The data informs management practices and the refuge's effectiveness at expanding and improving wildlife habitat.

Another organization that partners with and supports the refuge is the Friends of the Bosque del Apache, a non-profit organization. The group includes nearly 1,000 individual members, local businesses, and foundations from around the country. They operate the Bosque Nature Store at the refuge visitor center, where they sell books and nature-related souvenirs and rent binoculars and auto tour tapes. Proceeds from the store support refuge projects in wildlife management, visitor services, research, and special events. The Friends have also been successful in administering grants for refuge projects and raising funds for special projects.

The Friends develop and produce trail guide brochures, Bosque bird identification guides, and other interpretive materials. They also create exhibits in the Visitor Center, conduct interpretive tours, organize the Bosque Summer Workshop Series, and do volunteer training. *Habitat*, a monthly newsletter about the Refuge, is a Friends publication.

Tseng-wen Estuary Refuge

Chi-ku, Tainan County, Taiwan

Tainan County's Tseng-wen River Estuary North Bank Black-faced Spoonbill Refuge is one of Taiwan's 15 wildlife refuges. Although the site covers just 634 hectares (less than 3% of the country's refuge holdings), it is one of the world's most important winter habitats for the endangered Black-faced Spoonbill. Its designation as a refuge was an important step in the long struggle to protect spoonbill habitat.

The refuge is located in the Tseng-wen River estuary in southwestern Taiwan. It is part of a network of shoals, lagoons, sand dunes, fishponds, and mangrove forests bounded by Tseng-wen Creek to the south and Jiang-jiun Creek to the north. Another essential piece of the spoonbill habitat is Chi-ku Lagoon, just north of the refuge. The entire system of natural and man-made ponds covers an area of over 5,000 hectares.

THE TSENG-WEN ESTUARY REFUGE

saving a species

Project highlights
Protection of critical habitat for endangered species
Stimulation of the local economy

Size
Chi-ku Lagoon is a total of 1,700ha (4,200ac), of which 634ha (1,566.6ac) are a designated refuge; 280ha (692ac) of the refuge are core roosting habitat

Established
2002

Land ownership
Taiwan National Government

Uses
Recreation, tourism, commercial fisheries including oyster farming

Climate
Subtropical monsoon climate, average yearly temperature is 24.5°C (76.1°F), with winter mean monthly temperatures ranging from 15°C (59°F) to 20°C (68°F) and a summer mean monthly temperature of 28°C (82.4°F)

Rainfall
Average yearly rainfall is 150cm (59.1in), with a longer dry season (October to April) than wet season (May to September)

Function
To preserve habitat for the Black-faced Spoonbill, provide income for the local economy, and develop ecotourism

HABITAT LOSS IN INDUSTRY PLAN AND ALTERNATIVE PLAN

open water/channel
tidal waters
salt ponds
land mass
mangrove marsh
fish ponds

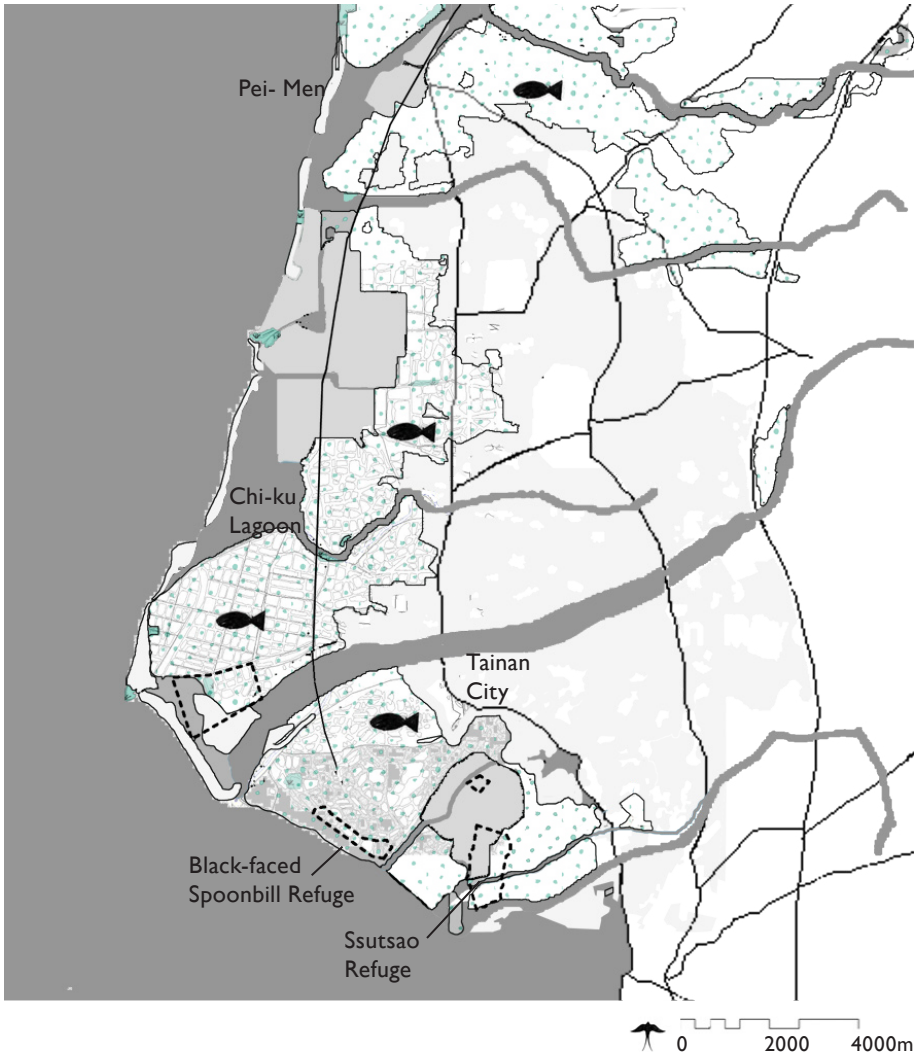
HISTORY

The vast landscape surrounding Chi-ku Lagoon was once part of a large bay called the Tai-chiang Sea. Early immigrants and trading ships entered Taiwan through this bay which acted as a natural defense, allowing Tainan City and Taiwan to flourish culturally, economically, and politically. Chi-ku Lagoon is the only remaining aspect of the sea, giving it historical and ecological significance.

Historically Chi-ku Lagoon and the wetlands of the estuary supported a thriving aquaculture and fishing industry, much of which is still present today. The 10-square kilometers lagoon is highly productive primarily due to inputs of nutrient-enriched freshwater. It is intensively used by oyster farmers and fished for finfish and shellfish. The local fishery currently employs 16,000 people and generates annual revenues of $3.2 billion NT ($122 million US). These jobs are the lifeblood of small towns and villages in Chi-ku, Chiang-Chun, and Pei-men townships.

The refuge is in the heart of an area that has been constantly threatened by development schemes beginning in 1992 with the Bin-nan Industrial Complex. The proposed 2,000-hectare project would have been located less than eight kilometers from the spoonbill's main roosting site. It would have filled 30%

THE TSENG-WEN ESTUARY REFUGE



of Chi-ku Lagoon, one of the last lagoons on the west coast of Taiwan. The project was approved but never built due to extensive opposition by local and international groups. The fight to stop Bin-nan raised awareness of the ecological significance of the lagoon and the plight of the spoonbill. Yet, wildlife and habitat remained at risk. After two birds were shot the national government responded by designating a spoonbill protection zone. In 2002 Tainan County Government announced the 634-hectare wildlife refuge (a 300-hectare core roosting area and a 334-hectare buffer) in accordance with the national Wildlife Conservation Act.

CRITICAL GEOMETRIES

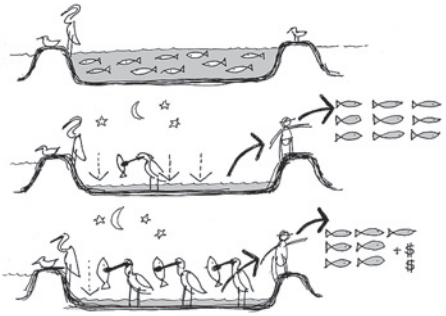
Hydrology. The shallow lagoon (less than 2 meters deep at low tide) connects to the Taiwan Strait through two narrow inlets. The lagoon receives most of its fresh water from the nutrient-rich Chi-ku River and Daliao Creek. Water from agricultural soils, mangrove swamps, and aquaculture ponds feed into these two water systems. The freshwater discharge varies from 265,000 to 563,000 cubic meters/day in the wet season to 85,000 to 240,000 cubic meters/day in the dry season. The salinity of the system is subject to seasonal variability. Water temperature ranges from 16°C in winter to 32°C in summer. Semi-diurnal tidal currents, primarily through the southern inlet and secondarily through the northern inlet, mix the 12,000,000 cubic meters of lagoon water and control the water level of the lagoon.

Flora and Fauna. The estuary and lagoon system surrounding the refuge is diverse: broad and interconnected natural wetlands lie adjacent to generations-old aquaculture ponds and mangrove forest. There are four primary habitat types in the refuge and surrounding estuarine area: sand dunes, mudflat, shallow water, and fishponds. It is a major wintering area for more than 100,000 migratory waterfowl of 150 species, hosting 19 bird species that are rare or endangered. The shallow water, fallow fishponds, and tidal flats provide ideal foraging habitat.

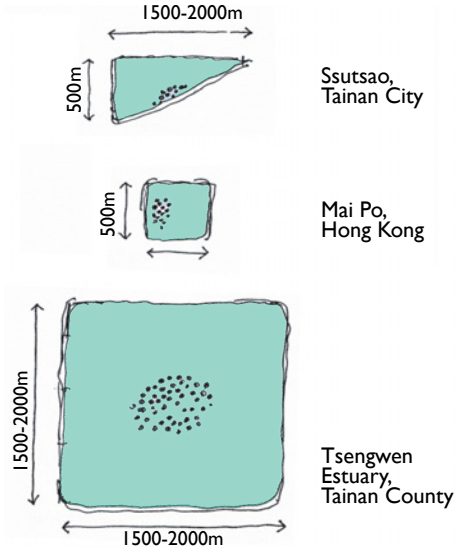
The most famous wintering bird is the endangered Black-faced Spoonbill. The 2006 international census recorded 1,480 spoonbills, found only along the East Asian Flyway. They breed and nest in the summer on small, rocky islands off the coast of Korea and winter in southwest Taiwan, Hong Kong, Macau, Vietnam, the Philippines, and southern Japan in coastal wetlands, river mouths, and lagoons. Only four of their 14 known wintering sites are protected – all are in China. The other 10 are used by more than ¾ of the world population.

Their main roosting area in Tainan County is over one square kilometer of open water. They require 500 to 1,500 meters of open water, 5 to 20 centimeters deep, although a depth of 8 to 16 centimeters is preferred for foraging. Advocacy to

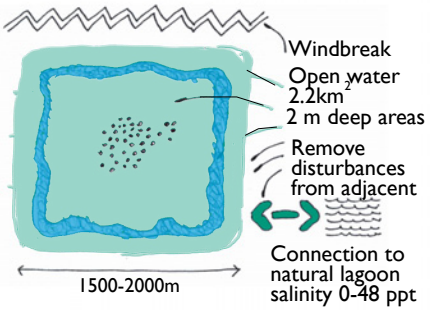
SYMBIOSIS WITH AQUACULTURE



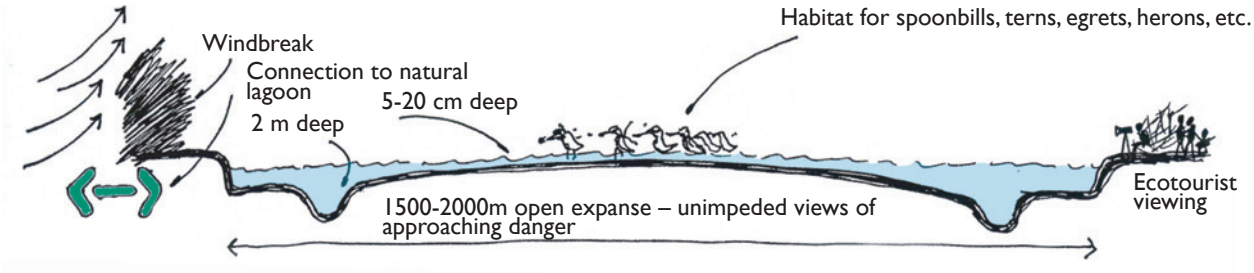
OPEN WATER ROOSTING NEEDS



GENERALIZED ROOSTING REQUIREMENTS



SPOONBILL HABITAT AND TOURISM BENEFITS



protect important foraging areas is lacking. However, researchers have proposed more aggressive management of fish production in the roosting area to artificially feed the spoonbill.

Knowledge of spoonbill geometries informed planning. It is believed that the foraging needs of eight spoonbills/square kilometer could be supported in the Tseng-wen area given the cost of fish-raising in the reserve and cost sharing with fish farmers. To achieve this, fishponds must be carefully managed. Controlling pollutants from nearby industry, urbanization, and transportation routes is essential for maintaining water quality. To successfully manage foraging habitat, researchers suggest a combination of mudflat and shallow water, or fishponds drawn down periodically. The birds will forage within 9 to 14 kilometers of their roosting area and the foraging area should be within 2 to 3 kilometers of tidal water. Other management guidelines are as follows:

- Allow access only to local fishermen, researchers, and bird watchers.
- Ask fishermen to draw down fishponds at scheduled times.
- Compensate fishermen for providing adequate and healthy "leftovers" to birds.
- Do not allow conversion of important habitat to urban land uses.
- Regularly monitor water quality and the surrounding area for possible toxins.
- Control domestic animals and other predators.

TOURISM

Designation of the refuge and the fight to protect the spoonbill have had positive effects on the local economy. It is estimated that as many as 1.5 million people have come in a year to see the spoonbill. Tourists have enabled nearby villages to develop an ecotourism industry, which includes boat tours in the lagoon run by fishermen and residents of nearby Lung-san Village.

Recently, local birding societies, residents, fishermen, artists, teachers, and groups like the Chi-ku Coastal Protection Association have become part-time travel agents, inn keepers, and local guides who share their knowledge and creativity through an education program and guided ecological tours. They also built bird-watching platforms and reused an old building for their tourist information center.

Villages along the coast hold events such as the clam-digging festival and celebrations to welcome the spoonbill when it returns in the fall. TEPU (Tainan Environmental Protection Union) organizes a race in which local communities, schoolchildren, and tourists can participate in events such as relay games, competition for best indigenous food, and an ecological tour to the mangrove.

Most tourists come in large groups by bus, which then dominate the local roads and require large parking lots. With the new Yunchianan National Scenic Area, which came about in part due to the notoriety of the spoonbill, more tourist facilities are proposed that could cause habitat fragmentation. To counter this trend villages are developing ecotourism plans that simultaneously facilitate tourism, protect habitat, and promote an alternative “blueway” transportation system.

VOLUNTEERS AND PARTNERSHIPS

Until the formation of the national scenic area, efforts to protect and manage the refuge and surrounding wetlands were ad hoc and grassroots. Although various NGOs cooperated during the anti-Bin-nan campaign, they have not coordinated

Mai Po Nature Reserve serving shrimp farmers and endangered species

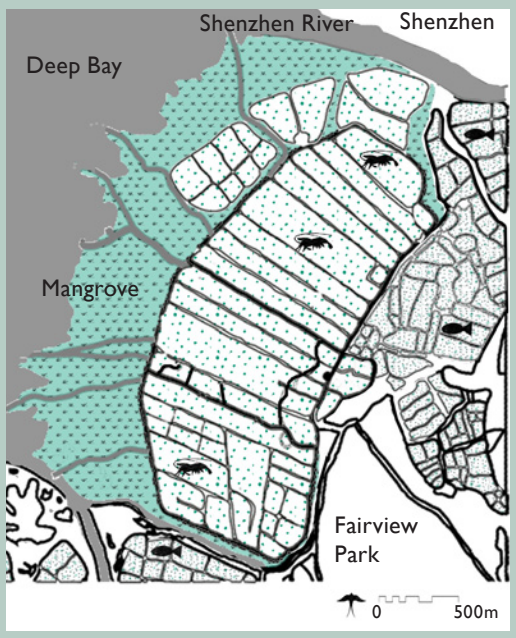
As early as the 1940's Mai Po Nature Reserve was identified as an important site for birds migrating along the East Asian Flyway. It has been on the conservation radar screen since 1976 when it was designated a Site of Special Scientific Interest, making it subject to special land use regulation. In 1995 1,500 hectares of wetlands at Mai Po and Hong Kong's Deep Inner Bay became the 7th of China's 30 Ramsar sites.

Mai Po has 400 hectares of mangrove forest, the 6th largest protected stand in China. There are 45 hectares of reed lands with six species of sedge grass, one of largest remaining reed lands in Guangdong Province. Recently Wigeon grass (*Ruppia maritima*) was found for the first time in Hong Kong since 1905. Thus it is no wonder that 72% of the bird species found in Hong Kong are found at Mai Po, including several endangered birds: Saunders' Gull *(Larus saundersi)*, Spotted Greenshank *(Tringa guttifer)*, Chinese Egret *(Egretta eulophotes)*, Oriental White Stork *(Ciconia boyciana)*, and the Black-faced Spoonbill.

The World Wildlife Federation Hong Kong has managed Mai Po since 1984. At the outset $423 million were appropriated for conservation and the development of the education center. In 1997 a management plan was adopted that established five management zones: core (the most protected), biodiversity, public access, wise use, and private lands. The shrimp ponds (*gen wai*) were of particular interest since they had historic, ecological, and commercial value. The 240 hectares of gen wai is one of largest traditionally farmed ponds in southern China. Because of the site's importance to birds and other wildlife, the ponds are managed to benefit farmers and wildlife. When farmers drain the ponds down to harvest fish, birds can feed in shallow water and exposed mud. During harvest months (November through March) one pond is drawn down every two weeks.

There is a significant education and scientific research program at Mai Po. Bird counts began in 1979, when 12,830 birds were documented. Counts reached their peak in 1997 (68,000) but the numbers have stabilized to 54,000, a decrease which is attributed to increased pollution of Deep Inner Bay. It is important to note that some of the most significant research on the spatial geometries of the spoonbill comes from Mai Po. Further, 140,000 members of the public visit the site each year, where staff has developed over 100 educational materials and teacher trainings.

MAI PO NATURE RESERVE



in planning efforts. Most of the local NGOs work with nearby communities and schools on the environmental educational and festivals. National organizations such as Wetland Taiwan are involved in wetland management research, and international groups like SAVE, International have provided advice on wildlife habitat issues.

CHALLENGES

Biologists and other scientists have contributed important knowledge over the years. However, because they are dependent on government funding for their research, some scientists have not been willing to voice their opinions to influence policy or express their visions for the best management of spoonbill habitat. This has resulted in faulty decision making on land use policy, habitat conservation, and restoration over the past decade.

The Tseng-wen Estuary Refuge is an essential step in protecting habitat for the spoonbill and other vulnerable species, but development pressure persists. An international airport has been proposed for the same site as Bin-nan and proposals for a municipal incinerator and a college campus also threaten spoonbill habitat. Further, new research has demonstrated the need to expand the spoonbill protection zone to capture necessary foraging areas. The original zone was defined by faulty science, the availability of government-owned land, and political expedience, rather than by conservation biology. As a result, the refuge is too small to support the wintering population of spoonbills. Some Taiwanese scientists have mistakenly argued that the spoonbills need only the small site. This was based on daytime observation when the birds roost in a small open water area (about 200 square kilometers). However, at night spoonbills forage far from the roosting site. This oversight was convenient– the government owned the land where the birds were observed during the day, obviating the need to acquire more land. Inaccurate information was used to justify filling ponds, further reducing available habitat. Since the refuge designation several outbreaks of botulism and a catastrophic spoonbill die-off in the area reduced the world population by 10%. Because of overcrowding the flock divided and now roosts in less protected, inferior areas, dramatizing the need to expand protected roosting and foraging habitat.

There are other important challenges to be overcome. Conservation of critical wetland habitat in Taiwan suffers from lack of international recognition. The Tseng-wen Estuary area is well qualified for designation as a Ramsar "Wetland of International Importance;" Ramsar sites have been established elsewhere based on much smaller populations of spoonbills. However, because Taiwan is not a member of the United Nations, it is not allowed to become a contracting party of the Ramsar Convention under the current rule. As a result, Taiwan cannot take part in efforts to protect migratory species and their habitats and the international community has no effective means to leverage action from the Taiwanese government to protect the wintering site.

As mentioned the National Scenic Area formed along the coastal area includes the main protected roosting site and extends two counties north. Although primarily interested in tourism, the National Scenic Area Director may designate four additional roosting sites as protected areas. The Director may also consider two additional sites in the future. Each could provide minimum roosting areas of one kilometer square of open water. These sites would provide an expanded set of habitat stepping stones, allowing the spoonbill population to thrive.

Activism in Korea

Within three decades South Korea's wetlands have largely been filled. By 1998, 35% of the country's coastal area was in the process of being diked and the government had plans to fill the remainder for agricultural or industrial uses, including the extensive, fragile Saemangeum tidal flats. A survey in 1998-1999 identified 63 wetlands that qualified for waterbird protection but only one site was listed under the rules of Ramsar. Scientists, a major force in Korean environmental activism, uncovered the government's intent to straighten the western coastline, removing most of the foraging grounds of nesting and migrating Black-faced Spoonbills.

In one reversal in 2000, the Korean government designated the southern tidal flat of Kanghwa Island as a natural monument to protect the breeding sites and an area of the wetlands spoonbills use to feed their young. As a result, all development within 500 meters of the coastline is now strictly regulated. Because the island has extraordinary cultural sites, economic benefits from tourism provide incentive to protect these landscapes with historic, visual, and ecological value. The legislation is an important precedent in coastal wetland protection that can be applied elsewhere.

Suisun Marsh

Solano County, California, USA

Suisun Marsh is located in southern Solano County 56 kilometers northeast of San Francisco. The marsh is bordered on the east by the Sacramento-San Joaquin Delta, on the south by Suisun Bay, on the west by highway 680, and on the north by highway 12 and the cities of Suisun and Fairfield.

Encompassing over 10% of California's remaining wetlands, Suisun Marsh is the largest contiguous brackish water marsh on the west coast of North America and a critical part of the San Francisco Bay-Delta ecosystem. The 46,943.5-hectare marsh contains 21,043.5 hectares of managed wetlands, 11,209.5 hectares of upland grasses, 12,140.5 hectares of bays and sloughs, and 2,550 hectares of tidal wetlands. The marsh provides habitat for more than 282 resident animal species and over 40 fish species and serves as a migratory stopping ground for thousands of waterfowl. It also has public hunting grounds and 158 private waterfowl clubs.

The marsh serves a number of important functions, just three of which are discussed here. First, it supports 80% of the state's commercial salmon fishery by providing important tidal rearing areas for juvenile fish, making it a significant contributor to the health of the regional economy. Salmon fry raised in Suisun Marsh grow twice has fast as those reared in the upper watershed, greatly

SUISUN MARSH

regional economy

Project highlights
Protection of critical habitat for endangered species
Preservation serves regional economy

Size
46,943.5ha (116,000ac) total; 21,043.7ha (52,000ac) managed wetlands, 2,549.5ha (6,300ac) tidal wetlands, 10,926.5ha (27,700ac) upland grasslands, 12,140.6ha (30,000ac) bays and sloughs

Established
2002

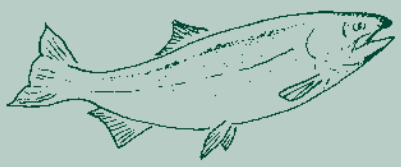
Land ownership
Public and private landowners

Uses
Recreation, commercial fisheries

Climate
Mediterranean, average yearly temperature is 15°C (59°F)

Rainfall
Average yearly rainfall is 54cm (21.4in)

Function
To preserve drinking water quality, receive mitigation bank projects, restore wetlands, and preserve 80% of the state's commercial fishing industry



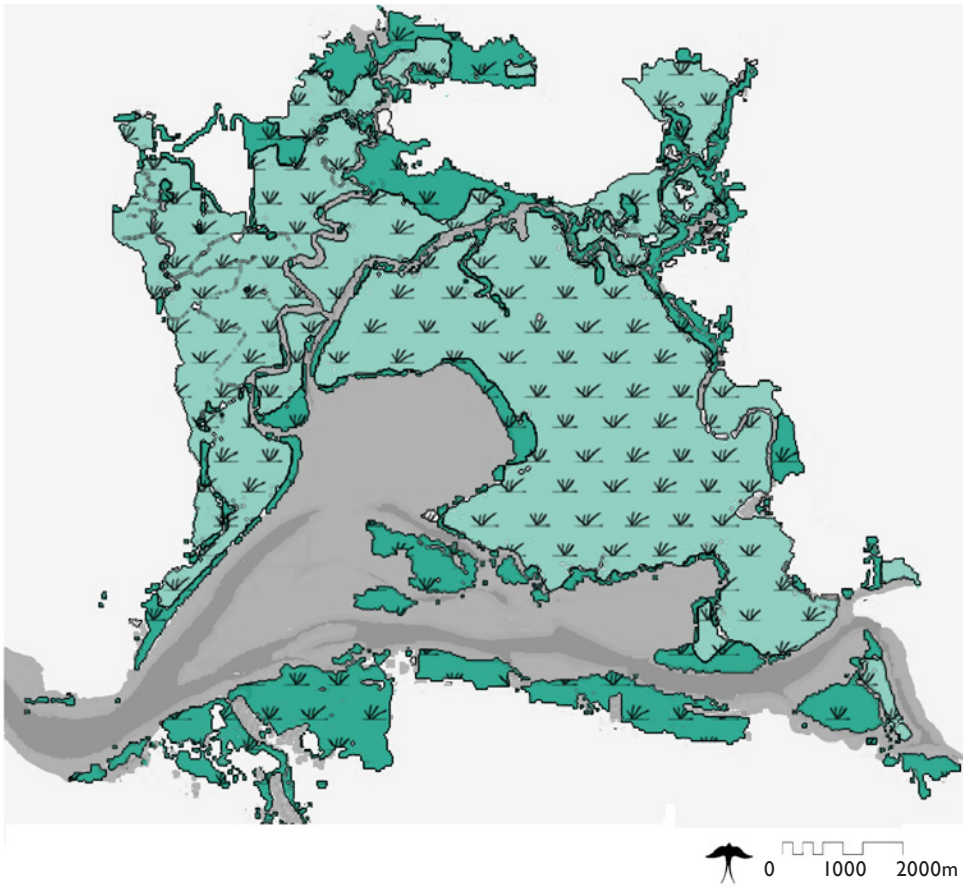
enhancing their chances of survival. Second, the Suisun Marsh system includes 370 kilometers of levees that prevent saltwater intrusion in the Delta, thereby protecting the drinking water supply for 22 million people. Finally, Suisun Marsh's close proximity to the urban areas around San Francisco Bay makes it an ideal location for recreational activities such as canoeing, hiking, environmental education programs, and wildlife viewing.

HISTORY

Historically, Suisun Marsh consisted of tidally-inundated islands separated by sloughs contained in nearly 27,520 hectares of tidal wetlands. The islands were created by sediment carried to the marsh by the Sacramento and San Joaquin Rivers and by sediment from the Bay deposited during daily tidal cycles. The predominant native vegetation was saltgrass, but there were also cattails, tules, rushes and pickleweed.

Suisun Bay was first diked around 1860 to graze livestock. The first duck clubs in the area formed soon thereafter. Other agricultural practices took the place of grazing until the soil salinity and poor drainage caused agriculture to fail altogether, despite various reclamation efforts. The area was quickly occupied by more duck clubs which utilized the agricultural levees by flooding the land seasonally to attract birds. By the 1930's, Suisun Marsh was primarily used by duck hunting clubs. Years of alterations from diking to hydraulic mining upstream, significantly changed the extent and type of wetlands present in the marsh. Today only about 2,550 hectares of historical tidal wetlands remain.

SUISUN MARSH



In 1927, the State purchased a portion of the marsh for protection as a state wildlife management area. In 1963 the Suisun Resource Conservation District (SRCD) was formed to manage the lands. Since the 1970's, the California State Legislature, State Water Resources Control Board, U.S. Bureau of Reclamation (USBR), California Department of Fish and Game (DFG), California Department of Water Resources (DWR), the SRCD, and other agencies have focused on preserving the marsh as a unique environmental resource.

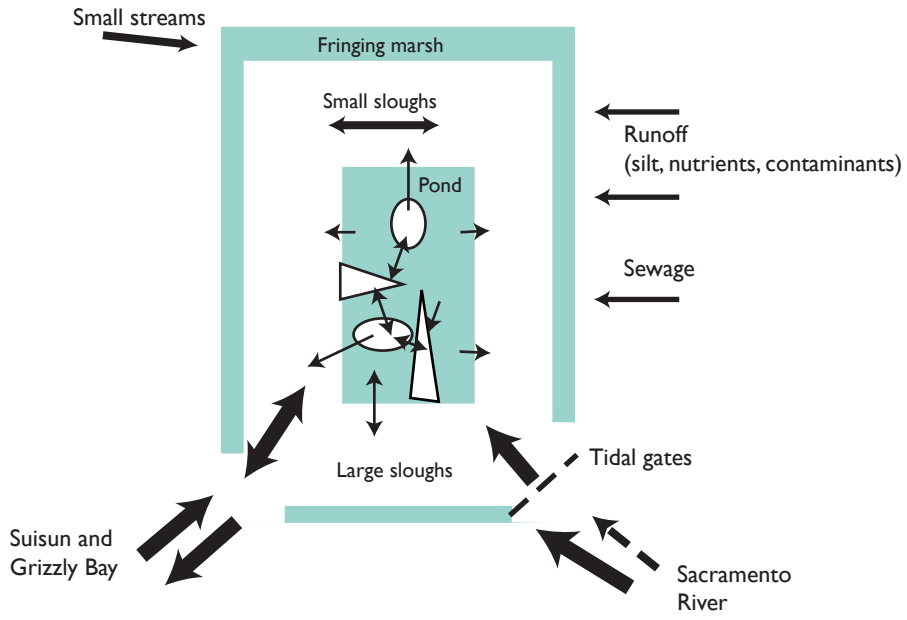
PROJECT DEVELOPMENT

In 1974, then-California Governor Ronald Reagan signed the Nejedly-Bagley-Z'berg Suisun Marsh Preservation Act requiring DFG and the San Francisco Bay Conservation and Development Commission (BCDC) to develop a protection plan for the marsh; it was dubbed the Suisun Marsh Protection Plan (SMPP). Many legislative acts, conservation plans, restoration projects, and workshops have been enacted since then to create and preserve water fowl habitat and aquatic habitat for species such as juvenile chinook salmon; and to protect water quality and restore historical tidal marshes. As regulations changed, the SMPP was amended to accommodate new federal and state requirements. In 1987, DWR, DFG, USBR, and SRCD signed the Suisun Marsh Preservation Agreement outlining the following provisions:

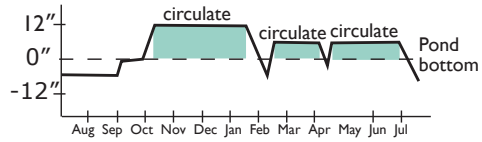
- Construct facilities to decrease salinity levels to meet water quality standards.
- Create a monitoring program for vegetation, wildlife and water quality.
- Facilitate mitigation for construction of facilities and upstream diversions.
- Improve wetlands to create and protect waterfowl habitat.

Although Suisun Marsh is subject to many state and federal regulations, the land ownership of the marsh is largely private and includes waterfowl clubs. Most of the clubs are part of a private land management program and are subject to the Suisun Marsh Preservation Agreement outlined above. The State of California and the DFG are also major landowners, while the DWR owns just 70 acres.

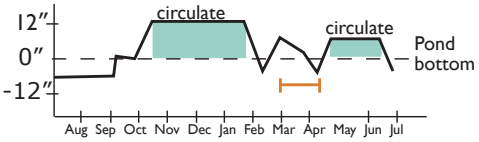
MODEL OF WATER FLOW THROUGH SUISUN MARSH



No intake restrictions/normal flood date/long hydroperiod



Juvenile winter-run salmon intake closure/long hydroperiod



Circulation schedules maintain salinity levels of the ponds critical to the health of the marsh. The top diagram shows the standard circulation and water levels for the year. The lower diagram shows how the management schedule is adapted for the juvenile chinook salmon, restricting circulation periods (in orange) in the ponds where they are found.

CRITICAL GEOMETRIES

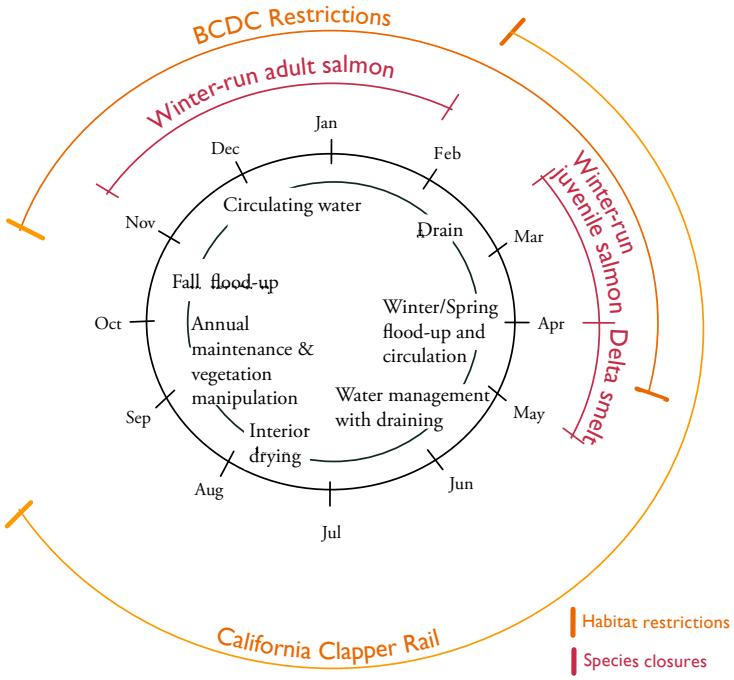
Design. Sophisticated government technology is at work in the Suisun Marsh. Models from the State's Bay-Delta management program are used to ask "what-if" questions related to impacts on Bay-Delta hydrodynamics and salinity. This information is then used to operate Suisun Marsh Salinity Control Gates (SMSCG) – a form of adaptive management. Wetland managers independently control water levels throughout the marsh system using a system of intakes, drains, and circulation ditches connected to ponds and sloughs.

Fluctuating the water levels in Suisun Marsh is important for several reasons. First, the exchange of high volumes of water helps to maintain natural soil salinity and water quality by flushing salts. Second, varying water levels provide more edge habitat for foraging and loafing, habitat that would not be available to wildlife if the water were too deep. Third, controlling water depth allows managers to encourage specific kinds of vegetation in their marshlands, providing food and cover for fish and wildlife.

There are different management schemes being carried out in different parts of the marsh at the same time. Management strategies are determined by soil type, water salinity, water depth, the duration of soil submergence, and goals for wildlife habitat and the growth of specific wetland plants in that particular area.

The standard water management schedule is as follows. Marshlands are fully flooded during high tide around October 1st, reducing the probability of mosquito production and providing ideal conditions for waterfowl, with water depths of 20 to 30 centimeters. After the waterfowl season ends in January, gradual drawdown begins during low tide, when water is released through drain gates out of the ponds and into the sloughs. Ponds are drained to about 30 centimeters below pond bottom level to encourage seed germination, but soils

MANAGEMENT CYCLE FOR SUISUN MARSH



must not be allowed to dry out. Following this drawdown, shallow flooding to about 15 centimeters is acceptable if necessary, as shallow water encourages plant diversity. Maintaining low water levels is most important from February to April, when germination rates are highest. The final drawdown takes place around the beginning of April but can vary from year to year. (The drain is timed to seed production). All landowners strictly enforce this management schedule or one similar to it.

When juvenile chinook salmon are present the water schedule changes slightly, calling for more fluctuations during the winter, precise salmon closure dates, and a focus on an environment suitable for the growth of food and cover plants for the fish. Other management schedules have been devised to encourage traditional watergrass (*Echinochloa crusgalli*), fat hen (*Atriplex triangularis*), and pickleweed; or to account for Delta smelt (*Hypomesus transpacificus*) restrictions.

Fauna and the regional economy. According to the Pacific Coast Federation of Fishermen's Association, 72,000 salmon-produced family jobs have been lost on the west coast of the U.S. over the past 20 years. Losses are attributed to inland habitat destruction among other things. Salmon, a species that is an integral part of California history and culture, is dependent on both coastal and riparian wetlands for its life-cycle stages. Several runs have been lost due to industrial development, mining, and logging.

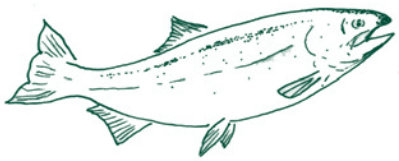
Because of the importance of salmon fisheries, federal and state resources are moving towards restoration and protection of their habitats. Under these circumstances Suisun Marsh is an incredible resource. To ensure that the habitat and food supply is suitable for salmon there are several monitoring programs in place. First, the movement of the salmon is monitored to verify whether there is a conflict between the operation of the SMSCG, the flooding induced for hunting season, and the provision of suitable salmon habitat. To determine the impact of the SMSCG on the stock of fish in Montezuma Slough, for example, scientists are documenting chlorophyll as an indicator of phytoplankton abundance. The main food sources for Suisun Marsh juvenile chinook salmon and striped bass (*Morone saxatilis*) are zooplankton and large phytoplankton.

While there are no other species in Suisun Marsh as economically important as the salmon, species diversity is ecologically important for the functioning of the marsh ecosystem. Among the better-known species in the marsh are the Suisun shrew (*Sorex ornatus sinuosus*), the California Clapper Rail and salt marsh harvest mouse, the river otter (*Lutra candensis*), and the tule elk (*Cervus elaphus nannodes*). Rare plants found in the marsh include the Suisun thistle (*Cirsium hydrophilum* var.), the Suisun marsh aster (*Aster lentus*), Delta tule pea (*Lathyrus jepsonii* var.), hispid bird's-beak (*Cordylanthus mollis* sp. *hispidus*), Contra Costa goldfields (*Lasthenia conjugens*), and Mason's lilaeopsis (*Lileaopsis masonii*).

Funding for the marsh

A full 90% of the costs of managing Suisun Marsh are funded by monies from hunting-related fees, licenses, and taxes levied at the local, state, and federal level. For example, salaries for biologists employed in Suisun Marsh are paid entirely by federal duck stamp money (since its inception in 1934, the federal duck stamp program alone has raised over $671 million for habitat conservation).

Also essential are monies from local hunting activities. Grizzly Island Wildlife Area (GIWA), a 4,244-hectare reserve in Suisun Marsh, is a popular public hunting and wildlife viewing area owned by the State of California and managed by the DFG. In 2004 GIWA auctioned off two bull trophy tags for $40,000 each. This income is augmented by the sale of waterfowl permits at $10 to $15 each. A biologist at GIWA estimates that at least 200,000 people visit the area yearly, and that at least 70% of those are hunters. Hunting revenues go to a general fund and are allocated as needed throughout the marsh.



application

5. Putting the lessons learned to work

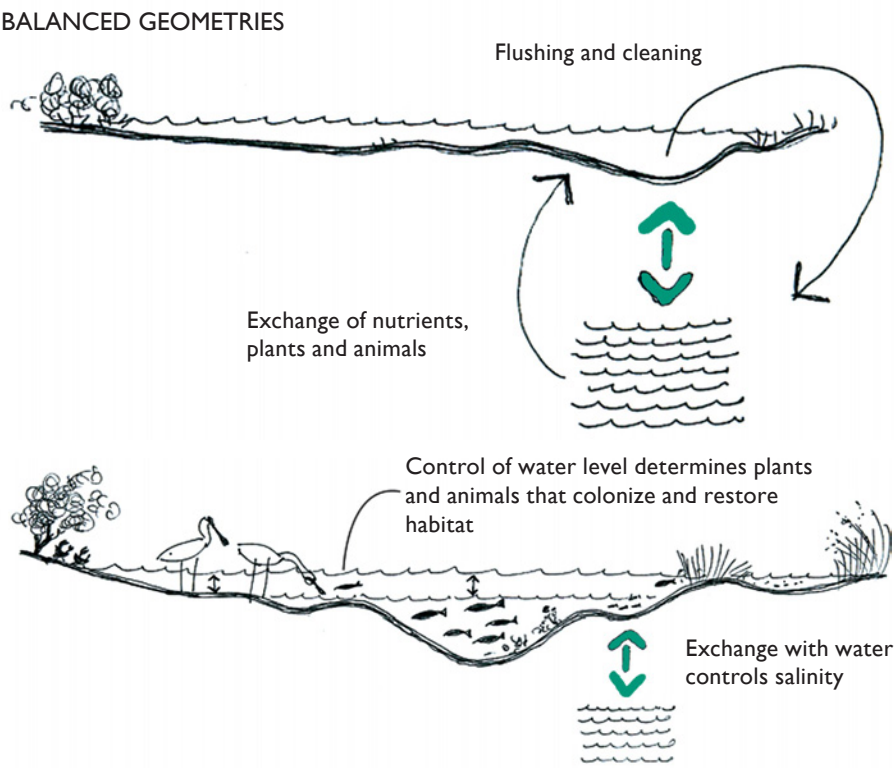
In conclusion we return to the question of how best to plan a wetland site to maximize multiple uses. If we are to preserve the natural benefits of wetlands, we can no longer ignore them, assuming they will survive without conservation practices. The press of human needs and urban development in coastal areas means that for wetlands to survive, they must be managed. Wetlands must be planned as a part of, not separate from, both the coastal landscape and urbanity.

The discussion begins with a set of principles that should be applied to wetland preservation, restoration, or creation to ensure ecological health and allow for multiple functions. The principles emerged from the Ramsar guidelines and the ecological needs of wetlands, the guidelines for ecotourism, and the lessons learned from the case studies. Clearly, knowing the geometries of both the environmental and social factors must be part of the approach to preservation and restoration and this is emphasized in the principles.

To show how the principles described below inform wetland preservation and management, they are brought to bear on a site that is currently being debated, the historic Augo wetlands in Chiayi County, on the western coast of Taiwan.

The first principle must be to protect existing wetlands. Areas where hydrological processes are still functioning in a wetland ecosystem should be identified and aggressively protected. Second to this, areas where wetland processes could be

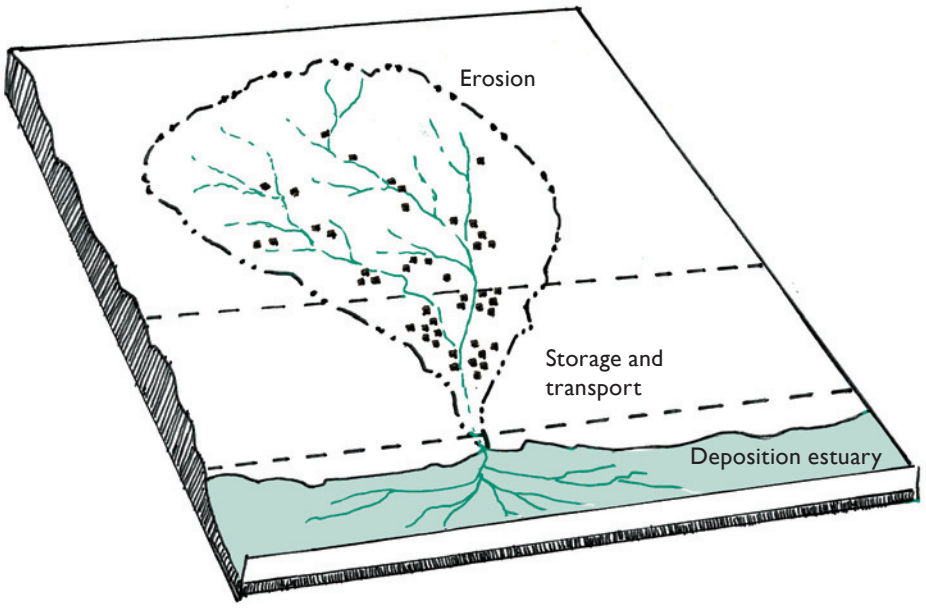
BALANCED GEOMETRIES



easily reestablished should be targeted. Unspectacular, commonplace mudflats, fish ponds, salt ponds, and subsided agricultural lands are prime candidates for restoration efforts.

The second principle is to protect the integrity of hydrological processes and exchanges. Because wetlands are dependent upon precise quantities and qualities of water flows from tides, rivers, and aquifers, watershed-wide management of hydrological resources is essential. Areas most critical to hydrological functions within the watershed should be identified and planned accordingly. Such broad and cooperative management across institutions and land uses requires the development of a watershed-scale plan. These plans can address everything from the preservation of forested mountain slopes to the form of urban expansion, the location of heavy industry, and the management of wastewater disposal. Ideally, watershed hydrology geometry shapes overall regional land use controls in ways that preserve wetland function. The Suisun Marsh case illustrates the delicate balance of water quality and quantity necessary to provide rearing habitat for salmon fry. To achieve this balance factors far beyond the site were considered and many institutions were involved.

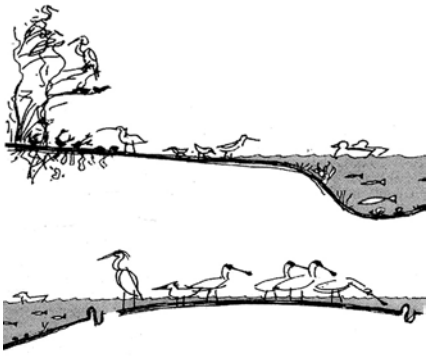
The third principle is to know which areas are rare, most fragile, undisturbed, have high restoration potential, or are critical for hydrological function and/or the survival of endangered species. In concert with the spatial needs of interior, indicator, or target species, these patterns serve to delineate the core wetland. The core is the area most essential for system function. It requires the most protection and largest extent. Precise mapping can yield a set of ecologically-determined zones of use, from the most fragile, where human entry may be limited or prohibited, to the least fragile, where recreation and compatible commercial activities can occur. When land use patterns are precisely drawn, spatial conflicts can be avoided, resolved, or accommodated, but only when the geometries are based on the best information available and not on political expediency.



A watershed-wide plan for water allocation and land use is essential and critical to ensure wetlands function properly .

The fourth principle is to map the spatial requirements of each of the potential uses and users of both core and adjacent lands. This information directs site-specific decisions about core, extent, and adjacencies. It can also inform the zones of use mentioned above. In order to preserve or recover wetlands of sufficient size, the geometries of every purpose must be drawn, from sacred sites, bird breeding grounds, and fish hatcheries to sewage disposal and tourism sites. For example, the research at DUST Marsh indicated that with specific structural components one hectare of wetland could effectively remove pollutants from a 53.4-hectare urban watershed. Thus, calculating the geometry for using wetlands as a stormwater filter informed the design of the minimum wetland size. Other uses yield other minimum extents, all of which must be considered. In the Tseng-wen Estuary Refuge a roosting area one kilometer square can support between 200 and 400 healthy Black-faced Spoonbills at the most. Only when each spatial requirement is known can the necessary size of the wetland be determined.

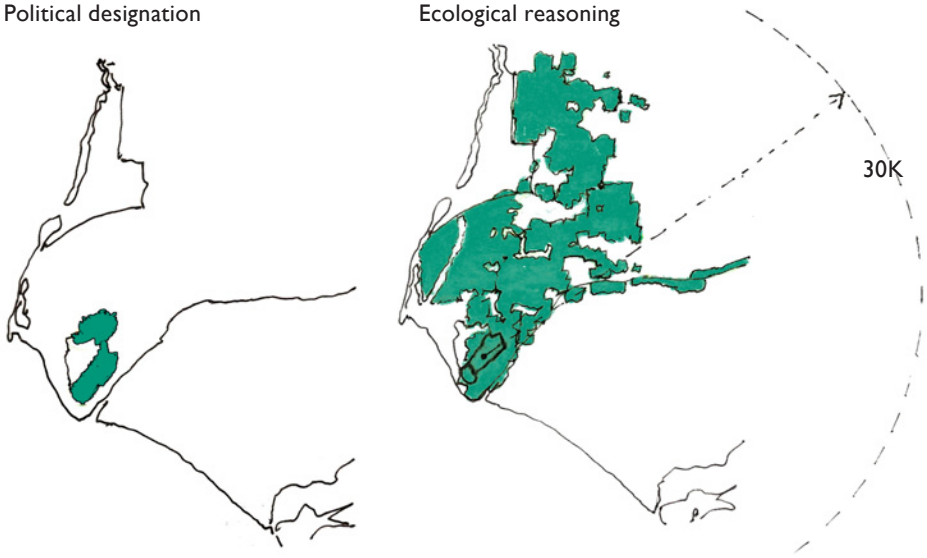
CORE ROOSTING REQUIREMENTS

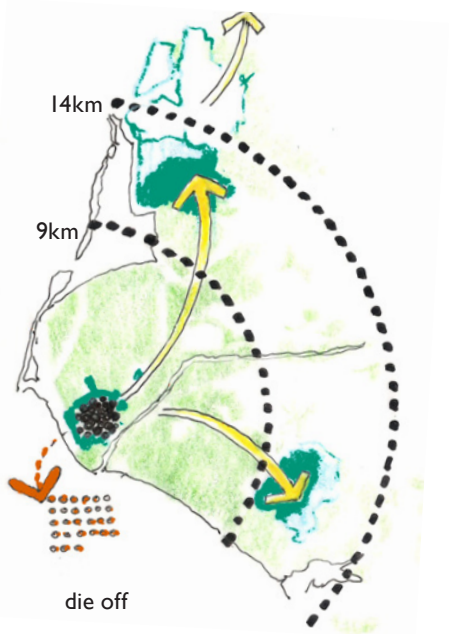


When conflict is great between human uses and wetland function, the core should be made as large as necessary and as small as is ecologically functional, allowing as many uses as possible without violating the ecological integrity of the wetland. But core wetlands often provide only part of what a species needs. Surrounding lands can be essential for survival, although they may be dominated by some other use such as agriculture or aquaculture. Uses and users of adjacent lands should therefore also be mapped. In the case of the Black-faced Spoonbill, the extent of the core preserve in the Tseng-wen Estuary Refuge was a matter of political debate rather than of ecological reasoning. The spoonbill roosts primarily during the day in shallow, open-water wetlands, areas that could be considered core habitat. But the birds forage at night in tidal wetlands and drawn-down fish ponds as far away as 30 kilometers (although the behavior of healthier birds indicates that foraging should be within nine to 14 kilometers of the roosting area). It takes approximately 20 square kilometers of fish ponds to support the foraging needs of about 100 birds under present aquaculture practices. The politically-determined

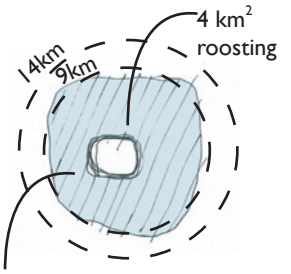
ROOSTING AND FORAGING PATTERNS

POLITICAL AND BIOLOGICAL DETERMINANTS OF REQUIRED LAND AREA

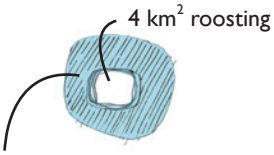




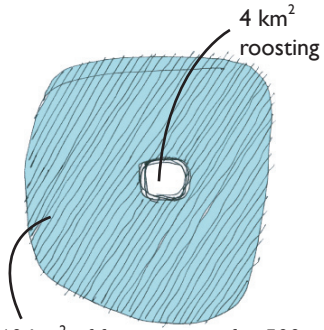
FORAGING MANAGEMENT ALTERNATIVES



20 km² foraging for 100 spoonbills under present condions- no net loss or increase of fishponds



12 km² foraging area of fishponds under increased productivity for 100 spoonbills



60 km² of foraging area for 500 spoonbills if all increase productivity

designation of the refuge ignored these geometries and protected only the core roosting area and a tiny fraction of necessary foraging area. This has contributed to botulism outbreaks that threaten the species. However, recent research indicates that with aggressive aquaculture management, the foraging area for 100 spoonbills could be reduced from 20 to 10 square kilometers. Because fishermen prefer fewer land use controls, agreeing on this smaller core area would reduce conflicts while still providing sufficient foraging areas.

The fifth principle is to apply the general tenets of conservation biology and landscape ecology when site specific research is unavailable. Lacking precise geometry, general principles must be employed, erring conservatively to protect unknown ecosystem functions. In such cases, the Ramsar guidelines become essential. Also essential are the rules of thumb of landscape ecology, which state that large habitat patches are better than small, connected patches are better than disconnected, patches that are wide and round are better than those that are long and narrow, and complex edges are preferred to smooth edges.

The sixth principle is to seek unexpected compatible land uses and partners. Wetlands and farmland are often seen as competing uses, just as non-profit open space advocacy organizations may be seen as generally at odds with big business. These stereotypes do not always hold true, and their breakdown often holds the most creative solutions to land use conflicts or lack of funding for wetlands. In the case of the Bosque del Apache, farming and wetlands management have a symbiotic relationship. Farmers who grow food for wildlife receive cash for crops in return. The relationship between the refuge and the farmers yields a net increase in system diversity. In the case of Sonoma Baylands, the Port of Oakland, an authority not known for environmental activism, turned out to be an ideal and willing partner; it reaped huge benefits in the form of a dredge disposal site, and proponents of the wetland benefited from the clean fill that made the restoration possible. At Arcata Marsh wetland habitat and sewage treatment productively coexist and interact. Single-purpose zoning typically segregates uses beyond ecological necessity and precludes cooperative arrangements between all parties affected by a wetland. Diversity and richness suffer from single-purpose land use. In many cases the productive interdependence of core and adjacent lands amongst diverse participants requires coordinated and integrated land use management and multi-purpose zoning.

The seventh principle is to consider the lowest cost alternative. Wetland preservation and restoration need not be prohibitively expensive. Ecological and other design goals can be achieved using simple interventions. The log baffle discussed in the DUST Marsh case, which improved water quality by encouraging mixing, is an example of a low cost solution with excellent results. Not only would this reduce overall costs, but it may enable undertaking more projects, increasing restoration and preservation efforts.

The eighth principle calls for a transparent process of grassroots planning. Wetland ecosystems only remain vital in urbanized areas when land use zones are based on accepted geometries of fact, are clearly mapped, integrate local needs with resource protection, and provide the means to adapt land use controls when new geometries are verified. Where geometries are uncertain, these uncertainties should be transparent to all stakeholders, who often will collectively set about

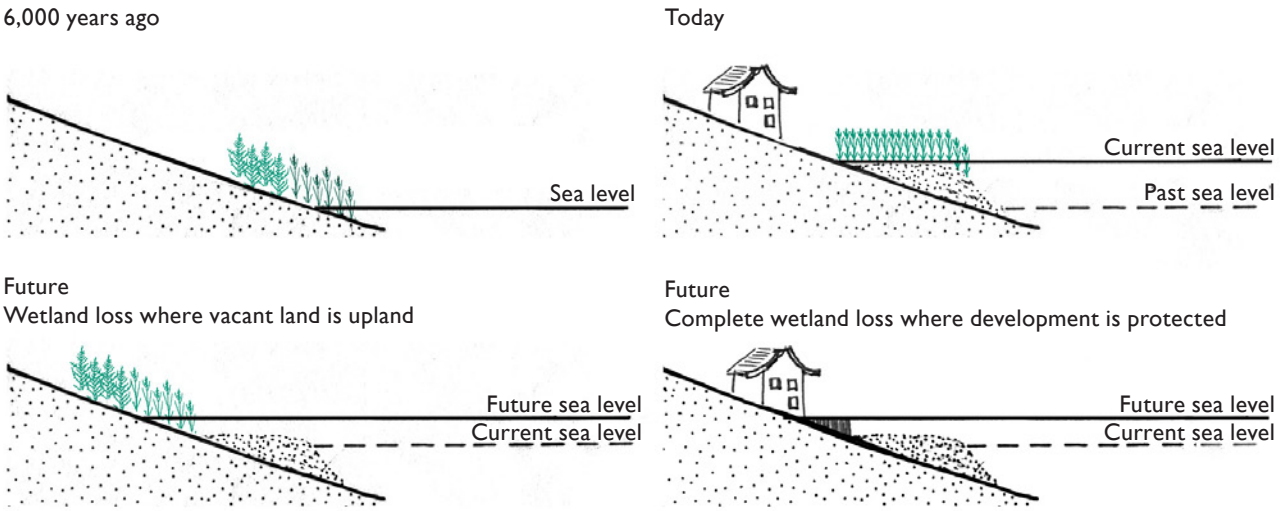
joint fact-finding to produce the missing data. Each geometry and zone should be locally named using traditional culture and native wisdom rather than scientific nomenclature. Rules and boundaries should be simple and straightforward. This approach suggests that local participation is essential in every aspect of resource management. And indeed it is. Experience shows that precise and well-integrated geometries underlie newfound coalitions between unlikely political partners, and grassroots engagement is as important to successful wetland function as water depth. However, very few local efforts are successful at wetland conservation without strong central government mandates for preservation, species protection, land use stability, and funding for acquisition and management. The partnership of powerful central government and grassroots actions are essential to healthy multifunctional wetlands.

The final principle is to consider ecotourism as part of any given project, but only when it can yield ecologically-beneficial outcomes. As discussed, tourism is a critical economic consideration in land use decision making, but it should be planned with careful consideration of fragile wetland ecosystems. Ecotourism works when there is a management plan, there are design guidelines to regulate development, scientific research is part of the plan, there is a local managing entity, and the community receives direct financial benefits and empowerment.

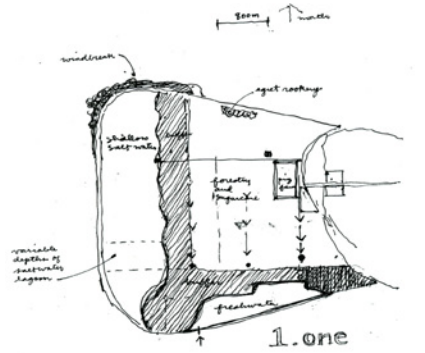
APPLYING THE PRINCIPLES IN AUGO, TAIWAN

How might these findings inform and direct a land use plan for Augo? Until it was diked and drained to grow sugar cane, Augo was a productive natural wetland. Within the levee, land was redistributed to create upland for cane production, leaving fish ponds and a deep water lake at the edges. Over time these lands subsided, agricultural lands were abandoned (similar to those in the Sonoma Baylands), and jobs in nearby villages were lost. The deserted areas in Augo became havens for raptors, waders, and dozens of other species of birds. An entire ecosystem evolved. The central government, which administered the lands, experimented with exotic tree farms. These provided a few jobs but destroyed raptor foraging habitat. A hog farm located on the uplands provided jobs but waste disposal posed an on-going problem.

SEA LEVEL, DEVELOPMENT, AND TIME



MAPPING THE PLACE

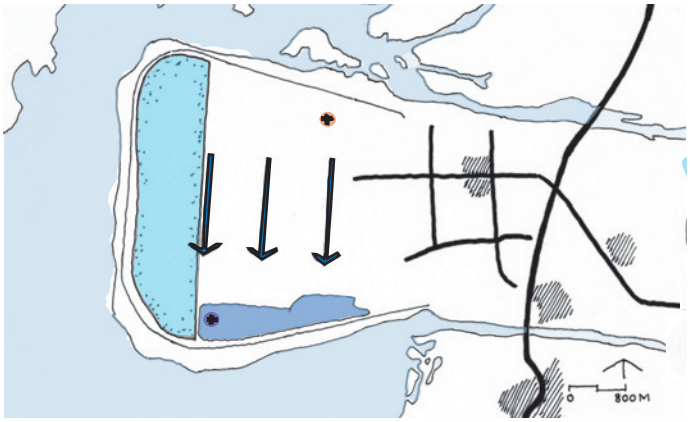


roads
lagoon
area for wildlife habitat and tourism
villages for tourism economy & pig farm
shallow saltwater habitat, fish ponds

Because Augo is a winter home for Black-faced Spoonbills, it has attracted the attention of scientists searching for areas suitable for habitat expansion to prevent the bird's extinction. Examining basic geometries reveals that Augo is a prime site for recovery. It is within the newly-formed Yunchianan National Scenic Area. It can inexpensively be returned to wetland. Yet its future is clouded by the many competing proposals that have been made for it; consensus will be a challenge. Proposals include everything from a military park, to forest land, to a destination resort complex (a development marketed as an eco-village, which in reality would only create zoo-sized habitats). None of these proposals has carefully assessed the requirements of critical species found on the site or the needs of the local economy. Neither have they considered the likely impacts of a rise in sea level. Fortunately, wise leaders in this National Scenic Area and the county planning agency are taking a cautious, scientific approach to future planning.

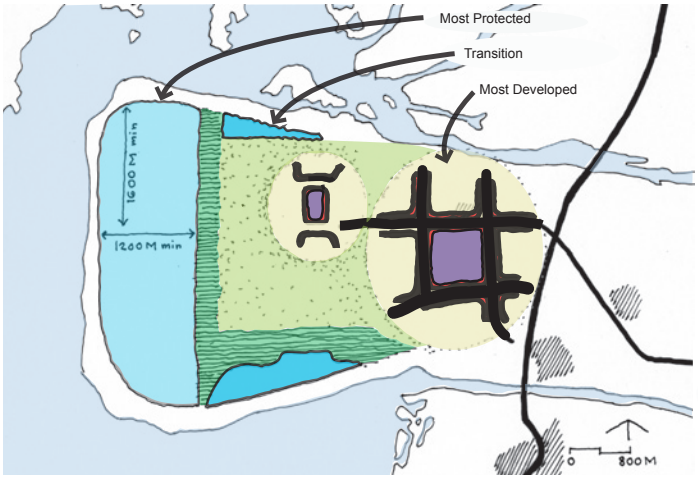
First, any plan for Augo must consider the hydrology of the site. The easiest and least costly wetland restoration could be accomplished with several new water intakes from the surrounding strait. Simply by controlling water levels, various wetland habitats could be established as was done in the Pea Island, Bosque del Apache, and Don Edwards wildlife refuges. If sediment fill is available, the levees could be breached, but only if the subsided elevations are raised appropriately. This is more costly but establishes a complex system similar to the Sonoma Baylands.

1. HYDROLOGY PLAN



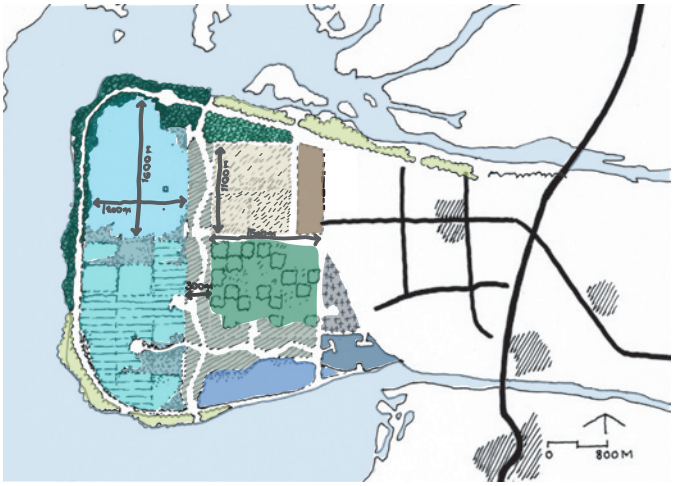
high point
low point
surface water flow
isolated saltwater
fresh water
lagoon
roads

2. DEVELOPMENT ZONES



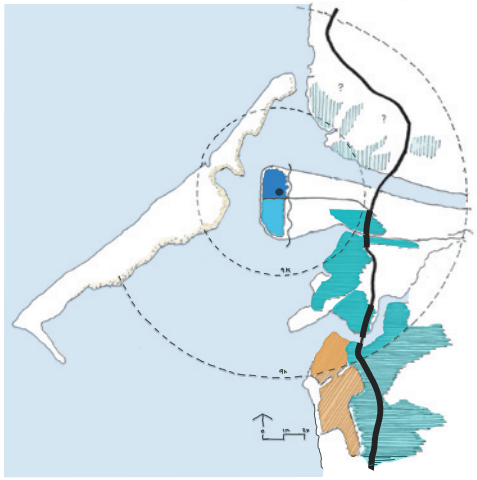
most protected
transition zone
raptor zone
buffer
development zones
new development
existing villages
lagoon
roads

3. ECOLOGICAL ZONES



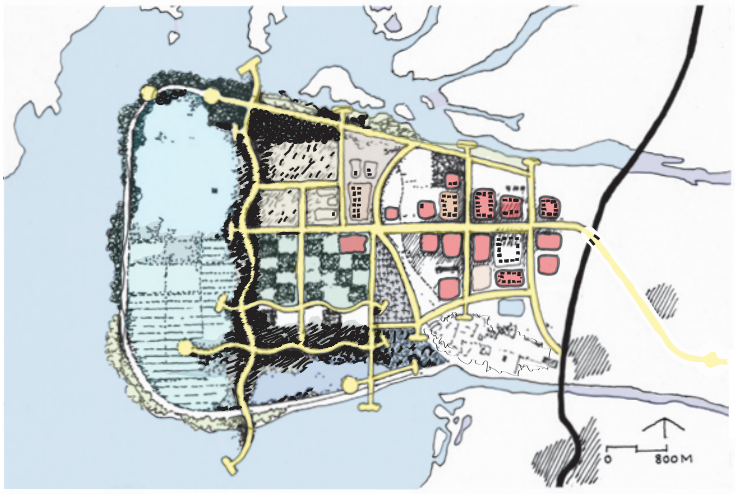
- windbreak
- egret rookery
- mangrove
- shallow pen
- managed fishponds
- marsh and mudflat
- freshwater habitat
- constructed wetland
- edge habitats/buffer
- grassland with trees
- woods, open fields
- insect habitat
- mammal habitat

4. FORAGING AREAS AND NEEDS



- roosting area
- potential managed area
- fishponds
- possible abandoned fishponds
- salt ponds
- shallow sand banks
- ocean
- highway One

5. ECOTOURIST ACCESS AND AMENITIES



- protected bird watching blinds on guided tour
- view spots
- ecotour routes
- new tourist destination
- cultural destinations and tourist accommodations
- overnight accommodations
- cultural attractions

The plan should also accommodate the spatial requirements of species of concern, from spoonbills to raptors, as well as the needs of local fisheries. Identifying potential wildlife habitat and expanded wetlands for fish nurseries at Augo is a matter of topography, hydrology, and vegetation. First, these create the potential for shallow (5-20cm) ponds with 1,200 meters of open water in every direction, which would meet requirements for spoonbill roosting as well as many other species. Wind screens would further improve such habitat. Second, varying water depths could create ponds, some of which could be seasonally drained, others which might be several meters deep year-round. The shallow ponds would create a key core roosting area and one of several stepping stone habitats. The deeper ponds would serve as foraging for birds and incubators for near-shore fisheries. To avoid disturbing wildlife, no access should be allowed on levees – access from the east via the existing road to a series of viewing blinds could be controlled by local guides. Along the southern edge a treatment marsh and deep fresh water lagoons would attract other species. At higher elevations in the interior of the site, a mixture of woods and open grassland would support raptors and other upland species.

For many bird species Augo will provide only a part of their required habitat. Egrets and herons roosting here may forage in wetlands and mudflats all along the coast. Likewise, spoonbills will forage in mudflats and drawn-down fish ponds as far away as twenty to thirty kilometers if necessary. More efficient and preferred foraging would be within several kilometers. Although drawn-down fishponds are essential for spoonbill survival, few are protected. In future land use planning, strategies for aquaculture conservation at a regional scale must be pursued to attract endangered species and the ecotourists who follow them.

The hog farm, which at first glance seems incompatible with habitat preservation, might be expanded to produce more jobs. This could only be accomplished by using existing and newly-created wetlands for hog waste treatment, similar to the Arcata Marsh process. Waste from the surrounding towns might also be treated here, thereby solving multiple problems with a single wetland expansion. The existing topography and drainage system within Augo already accommodates these various uses. A regional plan to manage water allocation and wastewater treatment would guarantee wise use as called for in the Ramsar guidelines.

The geometries of ecotourism, which would create local jobs, must also be sorted out, as well as the ecological highlights the Augo wetland could offer. Because it is a peninsula with limited access it is ideal for habitat preservation. Its isolation allows for zones from minimal human access to intensive human use. Logically, intense uses should be located near the existing village; the most protected areas should be located at the inaccessible extremities. By restricting entry to a single point near the village, habitat can be monitored and tourist entry to key wildlife viewing areas controlled by local guides. If, for example, tourists could only enter accompanied by a local guide, local people would receive significant economic benefits in direct and indirect employment.

It is essential to restrict even ecotourist entry from the most critical habitat areas, with the exception of a few carefully controlled viewing spots. In no case should access be allowed around the outer levees of Augo. Endangered species as well as many others require zones safe from human movement. The spoonbill, for example, requires at least 500-meters distance from human activity for roosting

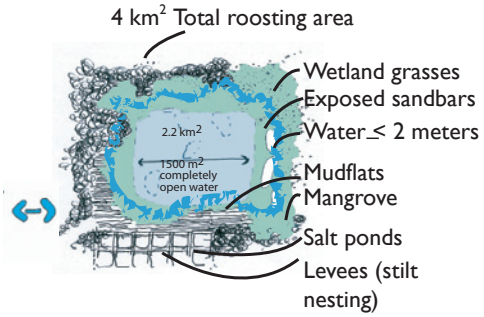
(in Hong Kong, spoonbills have been known to reject otherwise excellent roosting sites when people are present). Additional tourist activities could be located east of the village immediately adjacent to Augo, near primary roads. Hotels, bed-and-breakfast inns, shops, and restaurants could be established in available space in the existing villages and nearby towns. Economic benefits equal to those discussed in the Pea Island case should be expected, but only if new tourist facilities are integrated into existing villages. Stand-alone destination resorts provide fewer economic benefits for local communities.

To receive maximum economic returns, the future development of villages and towns near Augo and the tourist experience should be guided by the principles described in the tourism section. Guidelines to maintain authenticity, access to insider activities, unspoiled landscapes, and unique local character should be developed. The form of the villages should retain the traditional patterns of Chinese culture, architecture, and landscape. The scale, massing, and details of new buildings should reflect those traditions. Because wetlands are inherently open and flat expanses, buildings should be kept low, as they are in existing villages. New buildings should be no taller than existing temples; all buildings should be placed within or adjacent to existing towns in order to preserve the scenic landscape and receive the maximum local economic advantage.

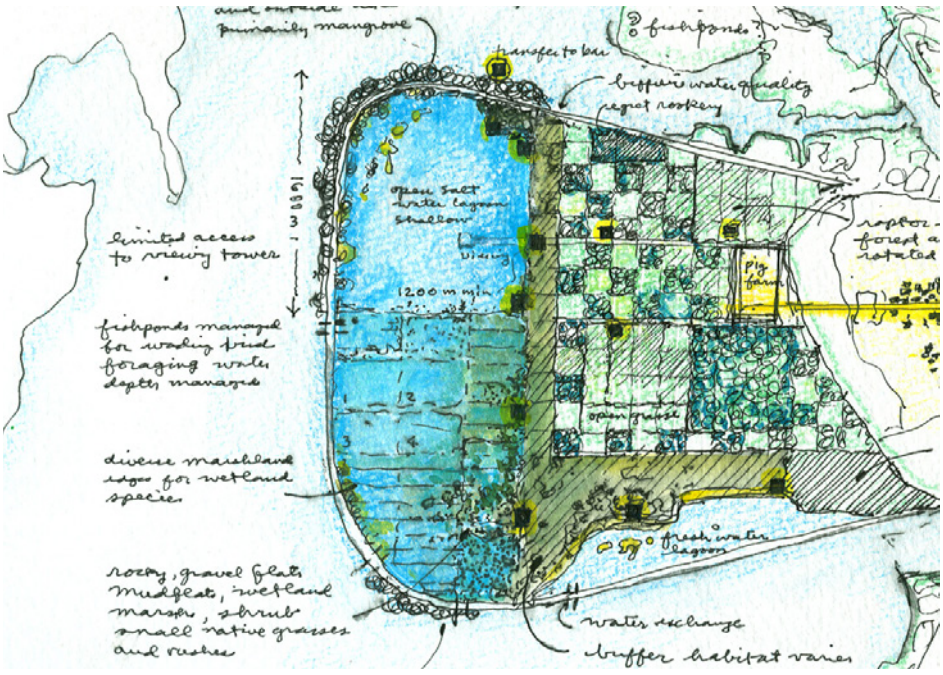
FINAL REMARKS

This report demonstrates that wetlands can effectively serve multiple purposes. In the case of Augo, pigs, forest, sewage treatment, tourism, and endangered wildlife can all be accommodated by integrating the precise geometries of each use. But development, hydrological interruption, and even unchecked ecotourists can destroy this carefully balanced system. Careful and on-going management that allows wetlands to function naturally is essential. This is the single, most fundamental lesson and message of this study.

CONNECTIVE HYDROLOGY



PROPOSED ECOTOURIST PLAN OF AUGO



references

6. Resources and contact information

COMMON AND LATIN NAMES OF SPECIES

ANIMALS

black howler monkey (*Alouatta pigra*)
loggerhead sea turtle (*Caretta caretta*)
river otter (*Lutra candensis*)
salt marsh harvest mouse (*Reithrodontomys raviventris*)
Suisun shrew (*Sorex ornatus sinuosus*)
tule elk (*Cervus elaphus nannodes*)

BIRDS

American Avocet (*Recurvirostra americana*)
Bald Eagle (*Haliaeetus leucocephalus*)
Black-faced Spoonbill (*Platalea minor*)
Black-necked Stilt (*Himantopus mexicanus*)
California Clapper Rail (*Rallus longirostris obsoletus*)
Chinese Egret (*Egretta eulophotes*)
Greater Snow Goose (*Chen caerulescens atlanticus*)
Marsh Wren (*Cistothorus palustris*)
Oriental White Stork (*Ciconia boyciana*)
Peregrine Falcon (*Falco peregrinus*)
Piping Plover (*Charadrius melodus)*
Ruddy Duck (*Oxyura jamaicensis*)
Sandhill Crane (*Grus canadensis*)
Saunders' Gull (*Larus saundersi*)
Scaup (*Aythya* sp.)
Snow Goose (*Chen caerulescens*)
Spotted Greenshank (*Tringa guttifer*)
Surf Scoters (*Melanitta perspicillata*)
Tree Swallow (*Tachycineta bicolor*)
Western Snowy Plover (*Charadrius alexandrinus nivosus*)

FISH

chinook salmon (*Oncorhynchus tsawytscha*)
coho salmon (*Oncorhynchus kisutch*)
cutthroat trout (*Oncorhynchus clarkii*)
Delta smelt (*Hypomesus transpacificus*)
Pacific salmon (*Oncorhynchus* sp.)
steelhead trout (*Oncorhynchus mykiss*)
striped bass (*Morone saxatilis*)

PLANTS

American cranberries (*Vaccinium corymbosum)*
black mangrove (*Avicennia germinans*)
black willow (*Salix nigra*)
blackberry (*Rubus* sp.)
blueberry (*Vaccinium macrocarpon*)
buttonwood (*Conocarpus erecta*)
cattail (*Typha* sp.)
cocklebur (*Xanthium strumarium*)
Contra Costa goldfields (*Lasthenia conjugens*)
cordgrass (*Spartina* sp.)
cranberry (*Vaccinium corymbosum*)
cottonwood (*Populus fremontii*)
Delta tule pea (*Lathyrus jepsonii* var.)
dune pea (*Strophostyles helvula*)
fat hen (*Atriplex triangularis*)
gumplant (*Grindelia camporum*)
hardstem bulrush (*Scirpus acutus*)
highbush blueberries (*Vaccinium macrocarpon)*
hispid's bird's-beak (*Cordylanthus molliss* sp. *hispidus*)
mangrove forest (*Lumnitzera racemosa*, *Avicennia marina*, and *Kandelia candel*)
Mason's lilaeopsis (*Lileaopsis masonii*)
millets (*Echinochloa* sp.)
oak (*Quercus* sp.)
pickleweed (*Salicornia* sp.)
red mangrove (*Rhizophora mangle*)
rushes (*Juncus* sp.)
salt cedar (*Tamarix ramosissima*)
saltgrass (*Distichlis spicata*)
seagrass (*Halodule* sp. and *Thalassia* sp.)
sedges (*Carex* and *Cypersu* sp.)
smartweed (*Polygonum* sp.)
Suisun marsh aster (*Aster lentus*)
Suisun thistle (C*irsium hydrophilum* var.)
tule (*Scirpus* sp.)
watergrass (*Echinochloa crusgalli*)
wigeon grass (*Ruppia maritima*)
willow (*Salix* sp.)

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NOTES

Wen-ling Tu and Shay Boutillier contributed to the research conducted for the case studies in this report.

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The photographs and graphics were produced by the authors but some are modified versions of illustrations or graphics originally produced by SAVE, the 205 students, or the agencies responsible for the sites profiled in the case studies. The spoonbill photograph on page 61 was taken by LinPen-chu, co-founder of the Tainan City Wild Bird Society.

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