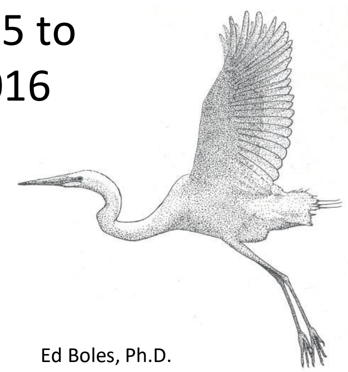
Rapid Ecological Assessment of Crooked Tree Wildlife Sanctuary Lagoon/Wetland Ecosystem

Wet Season 2015 to
Wet Season 2016



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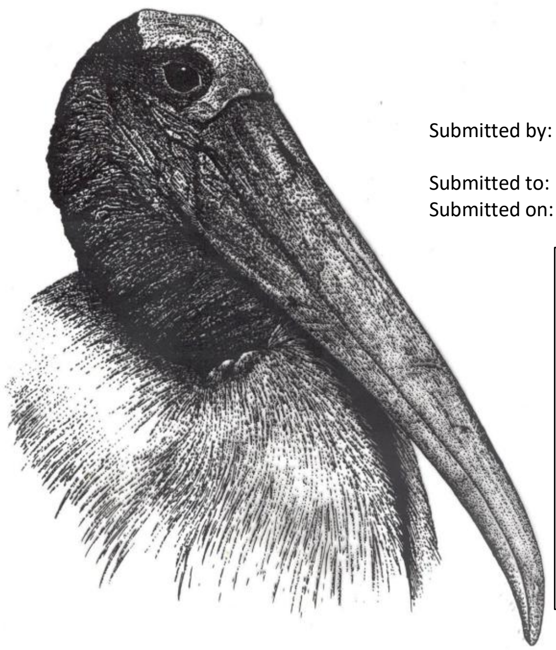

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Acknowledgements

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Acronyms Used in this Document

AMSL	Above mean sea level
ANDA	Association of National Development Agencies
BACONGO	Belize Association of Conservation Non-government Organizations
BAS	Belize Audubon Society
BAHA	Belize Agriculture Health Authority
BBIS	Belize Biodiversity Information System
BRCS	Belize Red Cross Society
BTFS	Belize Tropical Forest Study
BTIA	Belize Tourism Industry Association
BTB	Belize ~~Tourist~~ Tourism Board
CBC	Christmas Bird Count
CBS	Community Baboon Sanctuary
CCAD	Central American Commission on Environment and Development
CI	Conservation International
CITES	Convention on International Trade of Endangered Species
CPOM	Coarse Particulate Organic Matter
CTC	Crooked Tree Corridor
CTWS	Crooked Tree Wildlife Sanctuary
DEFRA	Department for Environment, Food, and Rural Affairs, U. K. Government
DoE	Department of the Environment
DOM	Dissolved Organic Matter
EIA	Environmental Impact Assessment
FPOM	Fine Particulate Organic Matter
GEF	Global Environmental Facility
GIS	Geographical Information System
GoB	Government of Belize
IUCN	International Union for the Conservation of Nature
MBC	Mesoamerican Biological Corridor
MNRE	Ministry of Natural Resources and the Environment
NBBCP	North Belize Biological Corridor Project
NEMO	National Emergency Management Organization
NEP	Net Primary Production
NICH	National Institute of Culture and History
NGO	Non-government Organization
NPAPSP	National Protected Areas Policy and System Plan
PA	Protected Area
PACT	Protected Areas Conservation Trust
POM	Particulate Organic Matter
PfB	Programme for Belize
RAMSAR	International Convention on Wetlands and Waterfowl
REA	Rapid Ecological Assessment
SEA	Southern Environmental Alliance
TNC	The Nature Conservancy
UB	University of Belize
UNCBD	United Nations Convention on Biological Diversity
UNFCCC	United Nations Framework Convention on Climate Change
WCS	Wildlife Conservation Society
WWF	World Wildlife Fund

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Rapid Ecological Assessment of Crooked Tree Wildlife Sanctuary Wetland Ecosystem, Wet Season 2015 to Wet Season 2016

Executive Summary

This rapid ecological assessment (REA) of the Crooked Tree Wildlife Sanctuary (CTWS) was undertaken to describe the general characteristics of this extensive wetland and lagoon system, discuss actual and probable pathways through which energies flow and nutrients cycle, inventory major aquatic and semi-aquatic organisms in residence with a focus on indicator groups, and identify major current and future environmental challenges. In addition, recommendations for conservation strategies, sensible solutions to issues observed, research needs, and community opportunities, particularly for youth, are provided. This was achieved through an extensive review of available and relevant literature, site visits, and field-based assessment activities. Building on information compiled in the 2002-2003 REA (Boles and Saqui, 2003) and subsequent research, supplemented with results of field work, this REA document offers a more thorough compilation of information available about this protected area and its importance within the protected areas system, both as a key component of the proposed Northern Belize Biological Corridor network and currently functioning "Northern Hydrological Corridor."

Sitting within a flat coastal landscape, this wetland is surrounded by savannas, broadleaf forests and several buffer communities, including Crooked Tree Village, one of the oldest settlements in Belize, being founded on the extraction of logwood. Core families of this small, independent, and relatively isolated community have lived with and depended upon the natural resources of what is now CTWS for many generations. Their lives and their future changed rapidly, triggered by events of 1984. That year was the opening of a causeway across Northern Lagoon, physically connecting this village to the rest of Belize by way of the Northern Highway. It was also the year that the lagoons and wetlands surrounding Crooked Tree Village was declared a protected area, and the use of its natural resources for the first time fell under rules of management. The most contentious issues involve fishing, the invasive tilapia now being one of the more common commercial species extracted, and cattle rearing, which includes the challenge of jaguar predation on herds (an issue being addressed by the Forest Department wildlife officers).

Established as a protected area in 1984, being co-managed by the Belize Audubon Society and the Forest Department since 1986, and becoming a world-recognized Ramsar site in 1998, this 14,763 hectare (*this figure is debated*) sanctuary includes the primary wetlands system of the Mopan-Macal-Belize Rivers watershed that stretches across central Belize. Famous for over 60 species of aquatic birds, many of them winter residents and seasonal migrants, and other wildlife of conservation importance, CTWS attracts visitors from around the world. Notable threatened species inhabiting this sanctuary and adjacent areas include Jabiru Storks (*Jabiru mycteria*), Yellow-headed Parrots (*Amazona oratrix*), Jaguars (*Panthera onca*), Pumas *(Puma concolor)*, Baird's Tapirs (*Tapirus bairdii*) and Neotropical River Otters (*Lontra longicaudis*). Sometimes during high water stages in the wet season West Indian Manatee (*Trichechus manatus*) enter the lagoons. Species of concern found in CTWS are Morelet's Crocodiles (*Crocodylus moreletii),* Central American River Turtles *(Dermatemys mawii)*, and Common Sliders *(Trachemys scripta).*

Comment [C1]: As per the IUCN Red List the Morelet's crocodiles are now listed as Least Concerened

This wetland and lagoon system is also vital to many communities downstream, particularly in Belize City, because of its function in absorbing much of the floodwaters carried by the Belize River. This function has been greatly inhibited first by the construction of a causeway across Northern Lagoon in 1984, later partially corrected by splicing in two bridges to re-establish water flow, and a second, improperly build causeway across Western Lagoon in 2009. Agricultural encroachment is occurring along the western edge of the Western Lagoon and the Northern end of CTWS that connects with the New River Watershed, a very important hydrological corridor. As a result, both hydrological and ecological functions of this lagoon system have been affected. CTWS is further threatened by global and regional climate change, having consequences for communities downstream, particularly in lower lying areas of Belize City.

Ecologically, this intricate wetland and lagoon system is a very dynamic biomass production and detritus processing system composed of a rich network of trophic pathways through which energies flow and nutrients cycle. Biomass is produced by the photosynthetic work of abundant cyanobacteria and algae living as phytoplankton, periphyton, and benthic organisms in the top millimeters of sediment, and by pastures of emerged, floating, and submerged aquatic macrophytes that extend throughout the wetlands and over most of the shallow lagoons. During normal dry seasons all of the wetlands and much of the water in the lagoons dry up, exposing sediments to full sun and concentrating fish and other strictly aquatic life into the remaining shrinking bodies of water. This typically occurs as thousands of migrating aquatic birds arrive to take advantage of the abundant and easily accessed food resources. During extreme dry periods, lagoons dry up to a few ponds and the braided stream channels that meander through their beds.

The surge of nutrients that fuels the build-up of the volume of fish and aquatic invertebrate biomass that, in turn, feeds this world-renowned assemblage of aquatic migrants is largely produced during the wet season. During the high water periods, not only are cyanobacteria and algae growing in great concentrations, but submerged, floating, and emerged aquatic plants are rapidly growing, many of these plants pushing oxygen into sediments. Single celled producers create copious amounts of dissolved organic matter (DOM), while macrophytes create not only DOM, but massive amounts of particulate organic matter (POM) in the form of detritus, often swept into large mats by wind and waves. While many aquatic and terrestrial herbivores feed on green macrophytes, many other organisms are ingesting the detritus, starting with fungi that break down cellulose, making this nutrient resource and the accumulation biofilm growth (algae, fungi, bacteria, protozoa, microinvertebrates) rich food for detritivores. Meanwhile DOM is absorbed by bacteria, as well as algae and other organisms that are part of the "microbial loop," which feeds this material back into the main part of the trophic system. In addition, the rhizosphere surrounding the roots of aquatic plants, and the hyporheic zone within the sediment layers, as well as the periphyton growing on any submerged living or non-living surface, work together to process massive amounts of organic material through this system. Besides enriching wetland and lagoon ecosystems, receding flood waters flush many of these nutrients into the Belize River and from the Belize River into the coastal waters of Belize, feeding our coastal zone ecosystems.

There are many species of organisms involved in this complex and highly interconnected trophic system, with ecology tables for each major group being compiled and placed in the appendices of this document. The taxonomic list of plants found at CTWS and immediately surrounding areas compiled by Goodwin, *et al*. (2013) contains 57 families represented by 155 plant species. Of these, 20 were recorded from adjacent forests, 93 species were listed from the savannas, 31 from the wetlands, and twelve from disturbed areas. Growth habits represented included 87 herbaceous plants, 5 epiphytes, 11 trees, 1 palm, 22 shrubs, 16 shrublets, and 13 climbers. A list of wetland and aquatic plants contains 76 species within 46 families. There are at least 13 families and 30 species of fishes, 34 species of semi-aquatic and aquatic amphibians and reptiles from 14 families, 68 species of semi-aquatic and aquatic birds out of 17 families, and at least 20 species of mammals that are strongly associated with CTWS wetlands and lagoons. There are also several key aquatic invaders that have moved into CTWS or threaten to do so, some of these species imposing significant impacts on local aquatic species populations where they occur.

Having been inhabited and modified in many ways by Ancient Maya to modern times, this wetland/lagoon/stream ecosystem complex bares a heavy foot print from drainage canals thousands of years old to recently constructed causeways that have dammed up water movement and disrupted hydrologic connectivity. As a principal member of the co-management team charged with overseeing the protection of this area, the Belize Audubon Society has inherited a large responsibility. They have made great strides in outreach to buffer communities, training and hiring rangers, promoting educational programs that engage local youths, promoting ecotourism, working with farmers to develop best management practices, and helping develop site capacities. There are many recommendations made that should be considered in future plans, strategies that further involve local residents in conservation initiatives. This includes development of a long term, self-funding wetlands research and education project that involves local youth, informative community members, international and Belizean students and researchers, and key government agencies. CTWS is a very special place in the world, offering many lessons in community-based conservation and wetland ecology.

Rapid Ecological Assessment of Crooked Tree Wildlife Sanctuary Wetland Ecosystem, Wet Season 2015 to Wet Season 2016

Objectives

This rapid ecological assessment (REA) of Crooked Tree Wildlife Sanctuary (CTWS) was conducted at the request of the Belize Audubon Society (BAS) during a period from December, 2015 to December 2016. It follows up and builds on a previous REA document (Boles and Saqui, 2003). The overarching objectives of this present effort are to:

- Review all available literature relevant to CTWS
- Describe the general ecological and morphological characteristics of this extensive system using available reports, Google Earth© imagery, and field sampling efforts (water quality, ecological mapping);
- Identify aquatic macroinvertebrate biological indicators (and compile information on other indicator groups) useful in assessing ecological health of the system and updating taxonomic lists and ecology tables for plants and animals of the Crooked Tree wetland complex;
- Conduct a human impact assessment using Google Earth© 2015 imagery, field mapping with GPS units, previous reports, and interviews with local people knowledgeable of impact sources;
- Recommend conservation strategies, identify research needs, and propose solutions to issues observed.

The result of this effort has been the accumulation and organization of information on the geology, hydrology, soils, vegetation, wildlife and social components of CTWS. General descriptions of the ecosystems, ecology tables of plants, invertebrates, and vertebrates associated with the aquatic environments, and a history of people within this area have been compiled. Field efforts have been conducted to collect information on water quality, macroinvertebrate communities, wildlife, and social issues within the area. This final draft combines information from over 90 peer-reviewed research publications, thesis and dissertation documents, unpublished working documents, and other gray literature directly addressing CTWS, buffer communities, and surrounding landscape; management plans; interviews of local experts; the Wet Season 2002/Dry Season 2003 REA (Boles and Saqui, 2003); and a series of on-site field efforts. It is not a complete document, still requiring additional work in many areas. However, this current updated REA provides a framework on which additional information can be compiled, and is the latest edition in an ongoing effort to better inform managers, community members, present and future researchers, and anyone else interested in CTWS ecology and conservation.

Introduction

CTWS, established in 1984, is located in northern Belize and is made up of two separate parcels, the general latitudes and longitudes bracketing these parcels given in Table 1. CTWS property falls mostly within the Belize District~~s~~ but also extends into the Orange Walk District, and is roughly about 45 km (32 mi.) north of Belize City (53 km by the Northern Highway). It lies about 28 km inland from the Caribbean Sea. Elevation of this relatively flat landscape ranges from 3 to 15 m (10 to 45 ft.) AMSL (Ramsar, 2000). Crooked Tree Village sits on the higher land surrounded by the Northern and Western Lagoons, being completely encircled by the protected area, but lying outside of the actual sanctuary boundaries. Two other buffer communities are adjacent to CTWS, Rancho Dolores on the upper end of Spanish Creek, and Lemonal located along the same creek about 10 km further downstream. Biscayne is located on the Northern Highway between the Northern/Southern/Western Lagoon system and the Mexico/Jones Lagoon system.

Table 1. Latitude and Longitude Descriptions of CTWS Parcels.

DESCRIPTION OF POINTS	LATITUDE	LONGITUDE
Larger Western Parcel surrounding Crooked Tree Village		
Most northern point- of larger western parcel	17°95′ N	88°55′ W
Most southern point- Southern Lagoon	17°62′ N	88°53′ W
Most western point- Spanish Creek	17°63′ N	88°60′ W
Most eastern point- Lower Black Creek	17°68′ N	88°44′ W
Mexico Lagoon/Jones Lagoon Parcel		
Most northern point	17°77′ N	88°44′ W
Most southern point	17°67′ N	88°40′ W

The CTWS lagoon and wetland system has become a globally recognized Ramsar wetland conservation site famous for its water birds and other wildlife, many of which are CITES listed species (Figure 1). It is the primary wetland system within the Belize River Watershed and the largest wetland system in Belize. CTWS attracts tourists, student groups, and researchers from around the world. This 14,762.7 hectare (36,479.3 acre) wildlife sanctuary (Meerman, *et al*. 2000) is co-managed by the Belize Forest Department and BAS, with efforts to involve buffer communities.

The sanctuary has faced many challenges, striving to maintain a balance between conservation and traditional sustainable use of fisheries and other resources, while building a local nature-based tourism sector that brings money into the community. Despite the many issues and hurdles that must be addressed when co-managing such a globally important natural resource, CTWS ranked 15th out of 65 protected areas within Belize that were evaluated for management effectiveness by Walker and Walker (2009).

~~CRWS~~ CTWS is made up of subtropical freshwater lagoons and wetlands sitting within a savanna- dominated gradient belt between deciduous forest and coastal lowlands (see Ramsar, 2000). The sanctuary boundaries enclose a dynamic patchwork of permanent and seasonally shallow freshwater lagoons, swamps, marshes, and stream and river reaches. These wetlands and lagoons can become very shallow, with some water bodies drying up completely in the dry season (March to May). Deeper portions of the lagoons may have wet season depths up to 3 m. In the wet season water level rises significantly, particularly when the Belize River is in flood stage, with wetlands around the margins of the lagoons extending far into the savanna landscape.

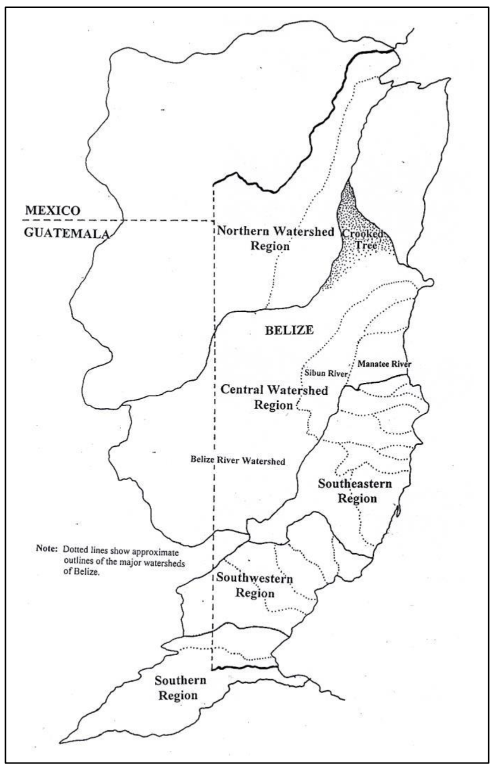


Figure 1. Watershed Regions of Belize Showing Crooked Tree Wildlife Sanctuary Area (stippled).

This very productive wetland ecosystem harbors abundant producers, including pastures of submerged aquatic plants and algae within the lagoons, swamp forests of logwood (*Haematoxylon campechianum*), the largest remaining stands in Belize, Calabash (*Crescentia cujete*), and mimosa (*Mimosa pigra*), large areas of sedge (*Eleocharis interstincta*) and grass marshes, thick patches of lilies, inundated savannas, and riparian forest (especially along Black Creek). The plant and algae biomass, both as living tissue and detritus, supports an abundance of aquatic invertebrates, that in turn provide for a rich fish fauna, that ultimately feed a large diversity of wildlife, with birds representing the greatest numbers of non-fish vertebrate wildlife species and numbers of individuals. Not only does this wetland system provide habitat for many avian permanent residents, but it is also vital to many winter resident and transient migratory bird species, particularly during the dry season when fishes become concentrated in shrinking ponds and lagoons. This wetland provides habitat and food resources for over 60 species of water birds and another 24 species of birds strongly associated with lagoons and wetlands, acquiring their food resources directly from these systems.

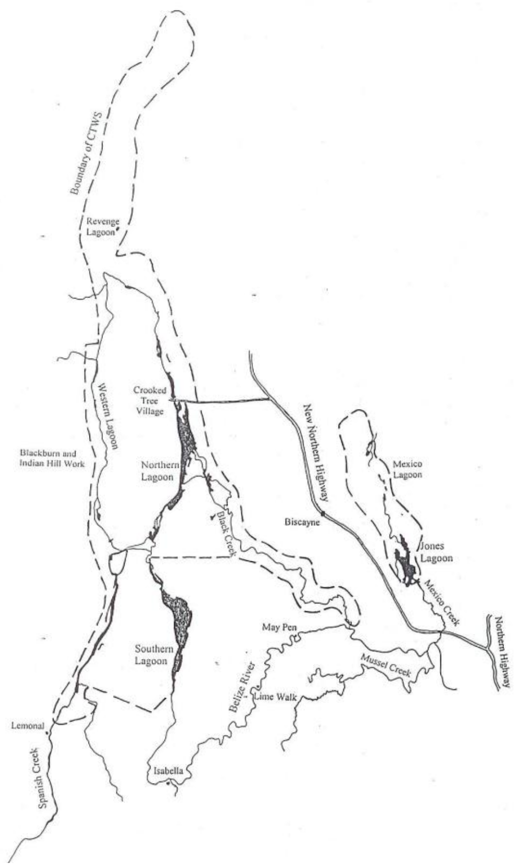


Figure 2. General Geography of the CTWS Area.

CTWS is the Government of Belize property, which includes all water bodies and wetlands below the high water mark, except for a few private holdings where ownership is being challenged. Most of the wetlands and all of the lagoons fall within CTWS boundaries and are therefore protected. Once being the center of logwood production in the 19th century, there is now very little forest activity going on in the lands surrounding the sanctuary, but there is cattle ranching just outside of Crooked Tree Village, an important dry season fishery, some hunting and sport fishing, and a steady tourist industry created mainly around the birding community, but including nature enthusiasts of all kinds.

Northern, Western and Southern Lagoons are connected together into one aquatic system on the western side of the Northern Highway. Calabash Pond, Revenge lagoon, Western lagoon, Spanish Creek, Poorhaul Creek, and Southern Lagoon drains into the Belize River at Isabella through a small creek. Northern Lagoon (also call Crooked Tree Lagoon), and all of the small creeks and wetlands draining into it connects to the Belize River just upstream from Compass Point through Black Creek. Most of Black Creek is also part of the sanctuary. The smaller Mexico and Jones Lagoons are located east of the Northern Highway and discharge into the Belize River downstream of Grace Bank through Mexico Creek (Figure 2).

Northern and Western Lagoons run roughly parallel to one another for about 16 km, being separated by an island that averages about 3 km in width. These two lagoons are connected together in the northern part of the CTWS. Southern Lagoon, forming the southern park boundary, is connected to the southern end of

Northern Lagoon by about 3.5 km of small creeks. Through the northern end of CTWS, where Northern and Western Lagoons connect, there is sometimes flow into the New River Watershed when the Belize River is in high flood (Ramon Frutos, personal communication). This is a very important "hydrological corridor" that should be recognized and preserved.

Ecosystem services provided by Crooked Tree Wildlife Sanctuary go beyond producing great quantities of plant and algal biomass that make up the base of the wetland trophic web, and providing vital habitat for many resident and visiting wildlife species. CTWS plays a critical role in flood control, absorbing, retaining and slowly releasing a great volume of water, thereby reducing the floodwater threat to Belize City. (Walker and Walker, 2014). CTWS, in conjunction with Burdon Canal Nature Reserve, both originally designated as protected areas for associated bird populations, are vital flood water regulation systems during heavy rainfall events, protecting Belize City from flood damage, especially those areas lying at or below sea level that are particularly vulnerable to flooding (see Walker and Walker, 2011), and approximately 18% of Belize's population that live in the city (SIB, 2014). Essentially these are examples of hydrological corridors. Despite this essential flood-mediation service, lack of understanding of this function and poorly planned construction of causeways have impacted water flow within CTWS lagoon and wetlands system, placing thousands of Belize City residents at risk. This issue becomes even more important when climate change impacts, such as more punctuated rainfall events, are taken into consideration.

Village leaders are struggling to identify the best use of those resources that are a strong part of their history and heritage. Likewise, conservation organizations such as the Belize Forest Department, Ramsar International Wetlands, and the Belize Audubon Society are concerned with the effective management of this critical wetland system. A well-developed management plan represents the interests of all stakeholders while promoting long-term conservation, and is based on a deeper level of understanding of the ecology of the protected area. This REA strives to help provide at least some of the information required to move forward with conservation and management strategies that are realistic, practical, holistic, inclusive, and effective.

This Rapid Ecological Assessment (REA) is a process whereby information on CTWS is collected and organized as maps, tables, graphs and descriptions. It was conducted over a relatively short period of time using existing information resources (reports, maps, satellite imagery, survey data, and interviews with GoB and NGO agency personnel) and field-gathered information (GPS data, water quality, biological assessments, and consultation with select community membersnd local experts). Specific methods used in this effort are described in detail within the report sections where appropriate.

The resulting REA document is intended for use by diverse stakeholders interested in the conservation, management and appropriate use of the CTWS ecosystem complex by:

- describing many of the ecological components and functions of the CTWS wetland ecosystem and its interconnectedness with adjacent wetlands;
- compiling taxonomic and ecological tables of major groups of organisms with the wetland system;
- identifying and describing high impact/stress sites;
- proposing management strategies, activities, and needs;
- listing potential research efforts that can contribute to conservation and wise use management;
- suggesting strategies for further engaging youth and elders;
- increasing environmental awareness among ecosystem residents and resource managers;
- promoting continued and focused research projects that contribute to a greater understanding of the ecology, history, and social interrelationships.

Establishment and Management of Crooked Tree Wildlife Sanctuary

Background and Development

In 1968 a National Parks Survey Group was established to recommend areas of Belize to be considered for protection, and it was proposed that a bird sanctuary be established which included the southern tip of Northern Lagoon and upper Black Creek. A proposal was prepared for BAS to establish a reserve at Crooked Tree (Sprunt, 1972). The Belize Audubon Society (BAS) suggested in 1981 that that a greater area of Crooked Tree be established as a protected area. With the passage of the Wildlife Sanctuary Declaration (Crooked Tree) Order 1984 (Statutory Instrument No. 95 of 1984, December 8) CTWS was declared a protected area. Initial support for the newly formed wildlife refuge was provided by funding from the Wildwings Foundation, New York City (Scott and Carbonell, 1986).

The legal description of the park recorded in SI No. 95 is very confusing, with some components being in conflict. This has led to a range of area estimates of the protected areas from 14,762.7 hectare (36,479.3 acres) (Meerman, et al. 2000) to 16,713 hectares (41,297 acres). The protected area includes all of the lagoons, streams, and wetlands/land for a distance of 300 feet (91.4 m) inland from the high water mark around the perimeter of these water bodies. Of course much of this area has not been accurately mapped, the water level varies significantly throughout the year and from year to year, and within Crooked Tree Village this designated strip of land includes private property.

Under the National Parks System Act of 2000 (replaced by the National Protected Areas System Act, 2015) and the Wildlife ~~p~~Protection Act of 1981 (revised in 2000) the defined area of CTWS and its wildlife was placed under the administrative and enforcement responsibilities of the Forest~~ry~~ Department. Laws allow for approved research, education, and recreation activities, with no extraction of any material unless permitted by the Forest Department. Because of its long history as a local natural resource, artisanal and traditional extraction of specific CTWS fisheries resources has been continually allowed but controlled through issuance of fishing licenses by the Belize Fisheries Department, particularly for those fishers who use nets. Many fishers who use rod and reel or that collect tilapia are not licensed. Also during 1981, the Government of Belize passed a revised set of game laws that made it illegal to hunt any water birds except for migratory ducks.

Belize Audubon Society was approached concerning the management of the sanctuary, formally assuming that responsibility in 1986. This was later sanctioned by co-management agreements (1995, 1999, ~~and~~ 2004 and 2015) between BAS and the Belize Forest Department. Management of CTWS was given to BAS because the GoB had very limited staff, funding, and trained technicians (Enriquez, 1993). BAS was charged with raising funds to maintain and develop infrastructure and to enforce rules and regulations. Much of the funding to operate CTWS has largely been contributed by international conservation organizations (Dada
2000). The day to day management of the sanctuary, development and implementation of a management plan (approved by the Forest Department), and monitoring to determine the success of management efforts are the responsibility of BAS. Funding has always been a challenge, with entrance fees charged to visitors being split among the Government of Belize (30%) Crooked Tree Village (10%) and BAS (60%). This arrangement was changed in 2004, where BAS was given permission to retain the 30% of the entrance fees which would have otherwise gone to the Government, and this is used for ~~The portion of the fee received by BAS goes for~~ staff salaries, equipment and administrative costs, with additional funding being sought from other sources. The Forest Department is responsible for enforcement of the laws pertaining to the protected area. BAS and the Forest Department share responsibility for maintenance of access roads, marking park boundaries, and keeping communication equipment working.

Comment [A2]: BAS and FD not responsibility for access roads

The Crooked Tree Village community and other buffer communities also have a valuable role to play in the management of CTWS. Ideally residents of buffer communities, often people who depend directly on resources of the protected area, should be involved in developing management strategies and plans, with the understanding that full conservation can only be achieved through the support of an informed and knowledgeable community. However, from the establishment of the CTWS, there has been conflict among many community members, BAS, and the Forest Department in the development and application of the management plan. However, BAS representatives considered the first meetings with community members concerning establishment of the sanctuary as having been very positive.

Villagers supported setting up the wildlife sanctuary for protection of water birds, and were assured that hunting of waterfowl would be regulated, but no restrictions would be placed on commercial fishing activities (Johnson, 1998). Some villagers attending these first meetings remember events differently, recalling more confrontational meetings. The management plan limited access to those traditionally used fisheries resources by villagers, leading to the development of resentment and distrust toward BAS. This ultimately lead to intervention by the Dispute Resolution Foundation, through Ramsar funding, promoting renewed dialog to address the issues, re-establish trust, and encourage mutual acceptance of wise use practices (Parchment and Smith, 19__).

In addition to its park management responsibilities, BAS has strived to encourage tourism in Crooked Tree in order to create more economic benefits to the community. It has also implemented programs to promote environmental education and awareness among community members of the value of the Crooked Tree wetlands. In ~~The~~the past the Belize Tourism Industry Association (BTIA) has helped BAS to create a business association and an advisory council made up of key members of the Crooked Tree community.

Ramsar

An inter-government conference was held in 1971 in the town of Ramsar, Iran during which 18 nations committed to the sustainable use and protection of wetlands within their respective territories, signified by the Convention on Wetlands. Today more than 114 nations and almost 1,000 wetlands are on the Ramsar List of Wetlands of International Importance, collectively representing over 70 million hectares. Two sites are listed for Belize, including CTWS and Sarstoon Temash National Park, recognizing the international importance of these wetlands. The Ramsar "Wise Use" concept promotes the sustainable use of wetlands for the benefit of present and future generations such that the natural properties and functions of the ecosystem are preserved, while providing the greatest benefit to present generations (Ramsar Convention, Regina, Canada, 1987). Aguacaliente Wildlife Sanctuary, a 2,223 hectares (5,492 acres) protected area declared a sanctuary in 1998, was at one time being considered for Ramsar status.

To qualify as a Ramsar site, the wetland must have international importance and support species that are vulnerable, endangered, or critically endangered, or contain ecological assemblages of organisms that are threatened (Ramsar, 2000). Because of its compliance with these conditions as a wetland, Crooked Tree Wildlife Sanctuary was recognized as a Ramsar site in 1998. It was considered to be a wetland having international importance because it is a critical habitat for many migratory bird species, some of them being internationally protected, as well as many local species. In the dry season these shallow water lagoons are vital to wetland birds, providing many readily caught fishes. Threatened species inhabiting this sanctuary are Jabiru Storks (*Jabiru mycteria*), Yellow-headed Parrots (*Amazona oratrix*), Jaguars (*Panthera onca*), Pumas (*Puma concolor*), Baird's Tapirs (*Tapirus bairdii*) and Neotropical River Otters (*Lontra longicaudis*). Sometimes during high water stages in the wet season West Indian Manatee (*Trichechus manatus*) enter the lagoons. Species of concern found in CTWS are Morelet's Crocodiles (*Crocodylus moreletii*), Central American River Turtles (*Dermatemys mawii*), and the Common Sliders (*Trachemys scripta*). CTWS protection actually helps to fulfill Belize's obligations under the Convention on International Trade in Endangered Wild Flora and Fauna (CITES). Also because there is a strong traditional culture of wetland resources use, particularly fishes, by buffer communities, it was recognized that these extraction activities could negatively impact the wetland system if not appropriately managed for the benefit of wildlife and people.

Comment [A3]: Check IUCN population of Morelet's Crocodile as it is listed as Least Concerned.

Buffer Communities of Crooked Tree Wildlife Sanctuary

There are four primary buffer communities associated directly with CTWS, with members of other near-by villages and towns entering the reserve occasionally to poach resources. Table 2 gives population and residence data for these buffer communities based on the Belize census count for 2010. Population of all buffer communities together is under 2000 people.

Crooked Tree Village is completely surrounded by CTWS, covering about 6.4 km^2 (2.5 mi^2) of a 50.0 km^2 (19.3 mi^2) island. It is the largest of the buffer villages, having a population of about 806 people, its residents relying on fishing, cattle, cashews, tourism, and jobs in Belize City. Lemonal, lying to the southwest of CTWS along Spanish Creek, is made up of about 117 people. Biscayne lies to the west of CTWS and has a population of 319, and Bermudian Landing sits on the bank of the Belize River about 8.0 km (5.0 mi.) south of CTWS.

Table 2. Population and Number of Households for most CTWS Buffer Communities.

COMMUNITUY	POPULATION	NUMBER OF HOUSEHOLDS	DATE ESTABLISHED
Crooked Tree	806	224	1750
Biscayne	518	129	1976
Gardenia	303	78	~~Recent~~1985
Lemonal	169	41	1926
TOTAL	1,796	472	

Crooked Tree, Biscayne, and Gardenia show very gradual population growth and village expansion, due to both increasing size of families and migration of people from May Pen, Maskall, Sandhill, and Belize City. However, there is also a counter movement of people out of these villages and to Belize City in pursuit of jobs. The younger generation is generally less interested in traditional livelihoods and is likely to seek employment outside of the villages. Some residents of Crooked Tree are actually people returning home from the United States, often building homes, but not necessarily living in the village year round. The population of Lemonal has been reduced by a third, largely attributed to the incorporation of students into a neighboring primary school. The May Pen population has greatly been reduced due to loss from extensive flooding.

Currently only Crooked Tree and Biscayne Villages have primary schools (Crooked Tree Government School, Biscayne Government School). Lemonal students are bussed each day to Flowers Bank Infant School, Rancho Dolores Middle School, and Double Head Cabbage Upper School. High school students from Crooked Tree, Biscayne, and Gardenia travel each day to Ladyville Technical High School or to high schools in Belize City. Lemonal students attend Belize Rural High School in Double Head Cabbage. Those students seeking tertiary degrees attend St. John's College Junior College in Belize City and the University of Belize in Belmopan.

Very recently a socio-economic assessment of CTWS buffer communities was conducted to determine the livelihoods, skills, capacity building needs, level of dependency on CTWS resources, and interest of community members in participating in livelihoods related to natural resources (Castillo, 2014). Based on interviews of a representative number of residents, these communities are largely Creole, with educational levels averaging higher than reported for the country as a whole. Most people draw their livelihoods from cattle ranching, farming, fishing, and holding jobs in Belize City and other local areas.

Neighboring Protected Areas and the Northern Belize Biological Corridor System

Programme for Belize promoted the Global Environment Facility (GEF) funded Northern Belize Biological Corridors Project (NBBCP), a World Bank project. This is an effort to not only conserve biodiversity and genetic flow among protected areas, but also facilitate sustainable development in the Corozal, Orange Walk, and Belize Districts. The main objective of the NBBCP is to preserve linkage of protected areas of Northern Belize largely through community participation. CTWS is a critical link in this corridor network (Figure 3).

A study has identified the optimum network of corridors and optional routes that link together protected areas, allowing wildlife migration among these areas, ensuring genetic exchange among otherwise potentially isolated populations (Meerman, *et al*., 2000). In addition to biological corridors, the study also identified nodes, or large areas of relatively intact habitats that are not under protected status, but remaining more or less intact and naturally vegetated. Although Belize still has some large forested areas remaining, these ecosystems are being rapidly fragmented, making corridor establishment an urgent requirement.

CTWS is part of a corridor network d~~pr~~escribed by Meerman, *et al*. (2000) for Northern Belize, interconnecting all of the northern protected areas, with many pieces of these corridors passing through private property (Figure 3). Besides being a very important focal area that supports many threatened/endangered species and species of concern through an abundance of photosynthetic and consumer production, it is also a very important piece of the corridor connecting key components of the Northern Belize Corridor network.

Viewed from the perspective of a wildlife corridor, the Crooked Tree Corridor (CTC) offers a long, narrow swath of broadleaf forest (suitable as a wildlife corridor) lying between short-grass/sedge savanna and tall herbaceous sedge-dominated marshland, both of which are more open and much less functional as actual corridors. CTC is one of the most extensive and complex corridor within the Northern Belize Corridor network. Specifically it connects the Esteves Node with the Belize River Node through Spanish Creek and forested land running along the western edge of Northern Lagoon. The CTC is connected to the New River Corridor. The Western Lagoon corridor is connected to Esteves Node through savanna habitat and some high riparian forests lining the creeks within Revenge Lagoon Area. However, excessive savanna fires and land subdivision in the Revenge Lagoon area threaten this corridor.

Some of the CTC is protected by CTWS (lagoons and wetlands up to maximum high water level) and will also be protected by the proposed New River Lagoon Reserve. However, there are large patches of private lands, consisting of poorly defined boundaries, lying next to or within the described corridor, with the British American Cattle Company holding large portions (supposedly this Texas-based corporation donated, or proposed to donate 72.8 hectares/180 acres, including 1,311m/4,300 ft. frontage along the Northern Lagoon, to BAS, www.bacc.com/audubon.htm). Besides Crooked Tree Village, the villages of Lemonal and Rancho Dolores are associated with the CTC. In addition Programme for Belize and BAS have vested interest in the CTC. Land use along this corridor includes fishing, grazing of livestock and small-scale agriculture on the higher, less flood-prone areas.

The Esteves Node is considered to be a key component in the network. It offers a mix of what Meerman, *et al*., (2000) describe as "Tropical evergreen seasonal broadleaf lowland forest over calcareous soils…tropical evergreen seasonal swamp forest…short-grass savanna with needle-leaf lowland open forest." It is connected to Freshwater Creek through five smaller corridors, two of those connecting through Freshwater Creek Forest Reserve, and to the Belize River through the CTC (Figure 3).

The Biscayne Corridor, also made up of evergreen seasonal broadleaf lowland forest over calcareous soils and evergreen seasonal swamp forest, connects the Belize River Node to the Esteves Node. This corridor is also of particular interest to CTWS because it incorporates Jones Lagoon. Being too narrow to serve as a main corridor, this strip would serve as a support corridor for the CTC. Containing a good bit of agriculture and private lands, establishment of this corridor would require developing a close relationship with Biscayne community, particularly in maintaining the Northern Highway Crossing. This crossing

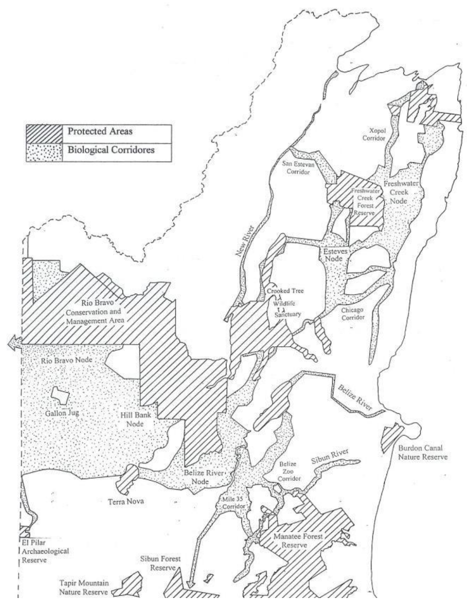


Figure 3. Proposed Corridor Linkages Among Protected Areas of Northern Belize Based on Maps in Meerman, *et al*. (2000).

links Mexico and Jones Lagoons to protected areas west of the highway, and will be a serious threat to wildlife using this corridor, which must be taken into consideration when establishing this system (Meerman, *et al*., 2000).

The New River Corridor consists of a long, thin strip of "tropical evergreen seasonal broadleaf lowland forest over calcareous soils" bordered mostly by agriculture, but also sections of "tropical (or subtropical) evergreen seasonal alluvial forest…tropical evergreen seasonal swamp forest…evergreen broad-leaved scrub with much *Miconia* spp…**and*+…tall herbaceous reedland" (Meerman, *et al*., 2000). It connects the CTC with New River Lagoon and all of New River, including Lamanai. New River Corridor connects 18 communities, including Orange Walk and Corozal. Besides residential areas, land use includes tourism, fishing, conservation, and small-scale and intensive agriculture.

CTWS is therefore a very important component within the Northern Belize Corridor network as proposed. This critical role adds significant conservation value to this protected area and should be a component of the overall protected area management plan and awareness and outreach campaigns. It also affords opportunities to be engaged in any network-wide corridor monitoring projects and programs. Of course the very necessity for the corridor system is due to the extensive human activities ongoing in and around CTWS and its neighboring corridors and protected areas. Human activity in this area is diverse and, in some spots, extensive, and dates back at least to the Ancient Maya, as evidenced by the archaeological sites such as Chau Hiix.

Ecology of the Crooked Tree Wetlands

Lagoons are wide bodies of water that are often associated with and essentially have streams or rivers running through them, becoming more evident during the dry season when water levels are very low. Movement of water within wider lagoons is much slower than that of narrower rivers, allowing for fine particles of materials to settle out of the water and build up sediment in thick layers. Lowland lagoons are often affiliated with a large fringe of productive wetland areas that are flooded during the wet season.

Wetlands are areas that are inundated by water during most or a significant part of the year while being dry land during the rest of the year. These ecosystems are populated with plant communities composed of species that can tolerate cycles of flooding and exposure. Wetlands are very important components of watersheds, providing many vital ecological services. These nutrient rich systems often serve as nurseries for larval and juvenile aquatic organisms during high water seasons. Large amounts of detritus are usually produced by wetland plants during the high water period, much of which is processed and exported to connected ecosystem types. During low water season, as wetlands dry up and water bodies recede, wetland sediments become wetland soils, often supporting fast growth of terrestrial and semi-aquatic sedges and grasses, which may be heavily browsed by terrestrial fauna. Wetlands are often important storage sites for organic carbon that build up as deposited detritus in anaerobic environments over time.

During high flow conditions, wetlands absorb and temporarily store large amounts of floodwater, releasing this water back into river systems as river stages fall. This helps to reduce the magnitude of flood events within a watershed system. They hold water for long periods of time, allowing some of it to slowly infiltrate geologic layers and help recharge aquifers. Wetlands also provide diverse habitat for wildlife of many kinds, contributing to biodiversity of the landscape. Wetland areas often occur in mid to low reaches of watershed systems, differing in size, structure and plant community composition from upstream to downstream. Evidence of all these ecological services can be observed in the CTWS lagoons and wetlands.

CTWS is located in a vital part of the Central Watershed Region of Belize (Figure 1). It is a large, relatively flat lower reach wetland of the Belize River that catches much of the floodwater during high flow events. The sanctuary covers about 14,762.7 hectares (36,479.3 acres) (Meerman, et al. 2000), most of this area consisting primarily of swamps, marshes, waterways, and lagoons. The sanctuary and surrounding higher land, supporting associated forests and dry savanna, range from about 3.05 to 13.7 m (10 to 45 ft.) above sea level. Sitting within the wetland-rich landscape of Northeastern Belize, the Crooked Tree wetlands are interconnected with wetlands within New River Watershed through groundwater and sometimes flooded swamp and marsh areas during extreme high water events particularly along the northern end (Figure 4).

Scattered wetland patches throughout this area often become filled with water as wet season rains raise the water table. The actual extent of groundwater reservoirs and seasonal rainfall effects is very poorly known, but sub-surface connections among wetland areas are suspected in this flat landscape. Maintaining hydrological interconnectivity is vital to maintaining the health of the Crooked Tree Wetland Ecosystem and the critical services it provides. The most obvious example of the consequences from cutting connectivity is seen in the history of the old causeway across the Northern Lagoon and more recently the improperly built causeway across the Western Lagoon. Less obvious is the connectivity between Crooked Tree wetlands and New River watershed and its wetlands, recognizing the importance for maintaining hydrological interconnectivity.

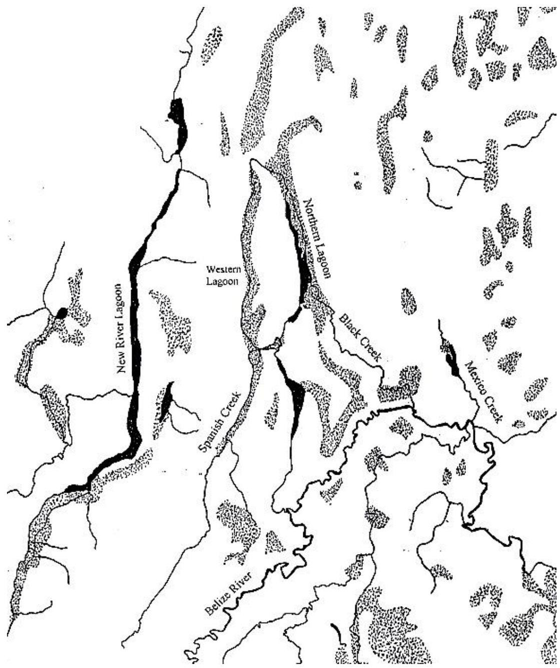


Figure 4. Surface Waters and Wetlands of the CTWS and Surrounding Area (stippled area shows wetlands).

Climate, Topography, and Hydrology

The Crooked Tree area lies within the subtropical moist climatic belt, being part of the Tropical Humid Forest Biome within the Campechean Province, with a wet season (June to December), a dry season (between January and May), and often a second short dry season in August (Mackler and Salas, 1994), at least before the effects of global climate change during the past few years. The mean monthly minimum temperature of 16.2°C (61.2°F) and a maximum temperature of 28.0°C (82.4°F) occurs during the height of the wet season, while mean monthly minimum temperature of 24.4°C (75.9°F) and a mean monthly high of 33.0°C (91.4°F) characterizes the dry season.

Maximum/minimum average monthly temperatures for the heavy flood years 2008 and 2013, recorded at the Tower Hill Station (National Meteorological Service) are graphed in Figure 5, showing general seasonal agreement, with some variation between the years. Low average minimum temperatures for 2008 occurred in March and November (about 16°C and 16.5°C), and for 2013 in January and March (about 17.5°C in both months). Maximum temperatures occurred in May and August (both months reaching averages of 28.5) for 2008 and in April and May (averages of 28.0 to 28.5°C) for 2013.

During an average year, without the occurrence of El Niño or La Niña events, the seasonal rains begin in early May and end during mid to late November. Typically there is a reduction in rainfall between June and July, with maximum rainfall occurring in the months of September and October. Records for the Philip Goldson International Airport reveal mean monthly rainfall reaching an average of 275 mm in September and

October, and lowest rainfall rates in March averaged 52.50 mm. Annual rainfall at CTWS is about 1200 -2000 mm (47-79 inches), the majority falling during the wet season. However, yearly patterns vary greatly. There are no established stage and rainfall gauges near enough to CTWS that could provide meaningful data for the site (Frutos, personal communication), but data was used from the closest weather station at Tower Hill. The drier years were 1962-1963, reaching from about 1,050 mm to about 980 mm, 1975 with just over 900mm, and 1995 that reached just over 1000mm (Figure 6). The wetter years of 1979 and 1984 reached about 1,700mm, while the flood years of 2008 and 2019 each had over 1800mm, roughly twice the amount of annual rainfall during the drier year of 1975, but below the 2000mm highest rainfall given.

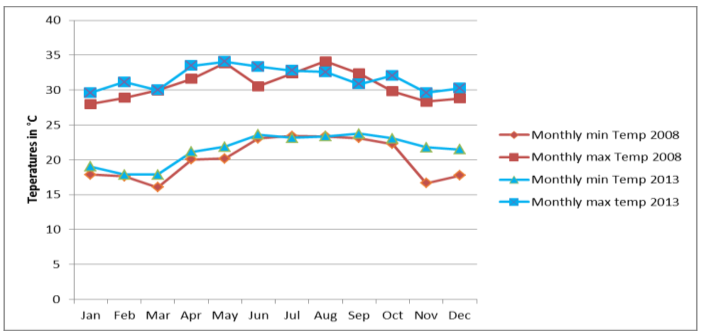


Figure 5. Maximum/Minimum Average Monthly Temperatures for 2008 and 2013 Recorded from the Tower Hill Station (National Meteorological Service).

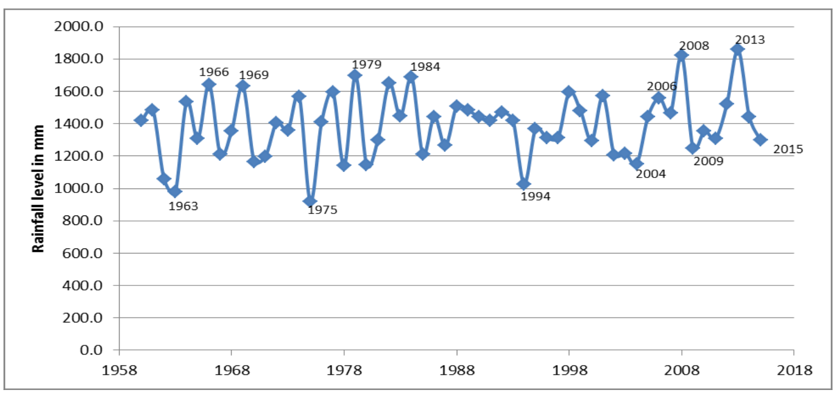


Figure 6. Average Annual Rainfall Data for 1960 to 2015 Recorded at the Tower Hill Station (National Meteorological Service).

Average monthly rainfall for the drier years of 1963, 1975 and 1994 are shown in Figure 7. The years of 1963 and 1975 were the driest, with all of the surface water having dried up within CTWS lagoons in June, 1975. There was a very short wet season in 1975 that was centered on September and October, with average monthly rainfall reaching 340mm to almost 360mm. By comparison, Figure 8 shows average monthly rainfall for 2008 and 2013. January and October of 2008 had monthly rainfall averages over or near 400mm, while rainfall was more evenly spread across the wet season during 2013.

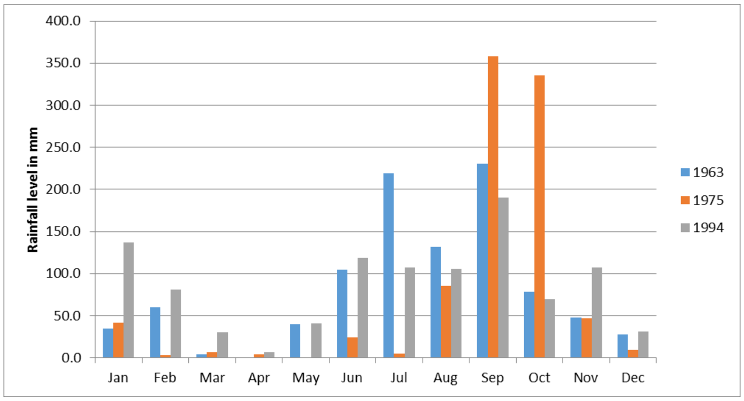


Figure 7. Average Monthly Rainfall for the Drier Years of 1963, 1975, and 1994 Recorded at the Tower Hill Station (National Meteorological Service).

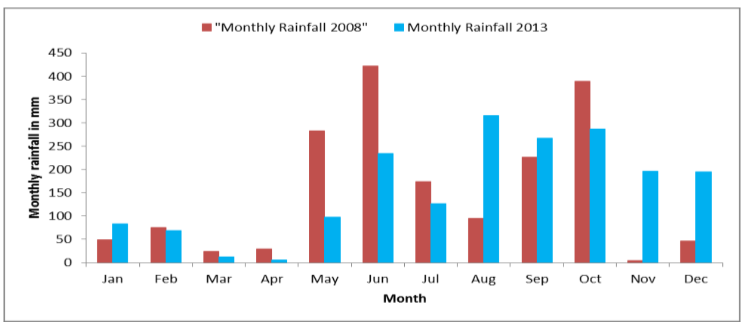


Figure 8. Average Monthly Rainfall for the Flood Years of 2008 and 2013 Recorded at the Tower Hill Station (National Meteorological Service).

River discharge data is available through the Belize Hydrology Unit that maintains river gauge stations around the country. The closest gauge on the Belize River that provides the most relevant information for CTWS wetlands and lagoons is the Double Run Gauge located near where Black Creek intersects the Belize River. The monthly average daily discharge per month for the Belize River at the Double Run Gauge recorded for the drier years of 2003, 2004, and 2009 (see Figure 6) is graphed in Figure 9. There are very low discharge rates shown for the months of March, April, May, and June for all three years, with discharge peaks during October and November. Figure 10 depicts average daily river discharge per month for the wetter years of 2006, 2008, and 2013. Low flow period for 2006 included March, April, and May, while the peak flow occurred in July, the monthly daily average reaching over 300 m^3/seconds. Both 2008 and 2013 low flow period lasted from February to May, with peak daily average flows of about 375 to 400 m^3/second being reached in October and November. These data demonstrate a relatively wide variation in the flow characteristics among different years, with up to three months difference between peak flows in one year compared to another. Discharge is of course governed by the volume of rainfall received, with annual temporal climatic patterns becoming harder to define during this era of climate change.

Comment [A4]: There is a Hydrology Gauge located at CTWS.

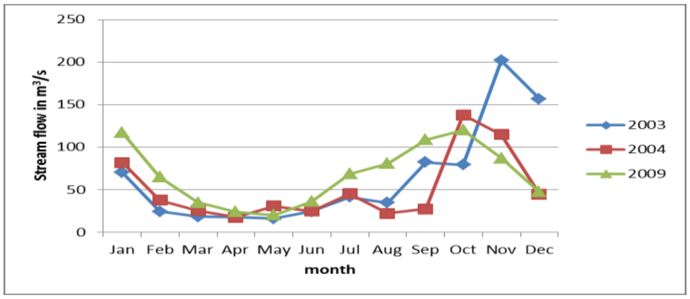


Figure 9. Average Daily River Discharge per Month for the Drier Years of 2003, 2004, and 2009 Based on Data from the Double Run Gauge, Belize River (Hydrology Unit).

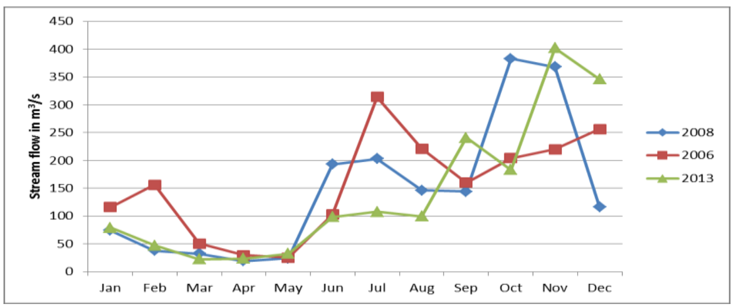


Figure 10. Average Daily Discharge per Month for the Wetter Years of 2006, 2008, and 2013 Based on Data from the Double Run Gauge, Belize River (Hydrology Unit).

The entire CTWS watershed is about 960.8 km^2 (370.96 mi^2) in size, but the flat landscape prevents an accurate size assessment to be made (Ramsar, 2000), preventing exact delineation of the watershed. This movement is complicated by a patchwork of wetlands and highlands, the level of the groundwater reservoir, and the physical structure of the lagoon basins—including depth and expanse of lagoons, size of outlets, size and scatter of swamps and marshes, and engineered constrictions such as causeways and canals, that affect filling, retention, and discharge of the lagoons. Complexity of surface hydrological basins, channels, and wetlands affect water retention time. Flow patterns can be seen on close inspection of GoogleEarth© images. During low water months Spanish Creek flows northeastward, and is joined by Governor Creek about 3 km downstream of Lemonal, near where wetland areas begin to make up the stream banks. Spanish Creek is joined by flow from the Western Lagoon, then turns eastward, is joined by the Southern Lagoon, and then flows into the Northern Lagoon through a heavily braided channel. Northern Lagoon empties into Black Creek, which in turn meanders southeastward to join the Belize River. Flow is reversed during high water times, and during very high water Northern and Western Lagoons, joining at Backlanding Waterside, may flood Revenge Lagoon and Calabash Pond, marsh/wetland areas north of Backlanding that probably overflow into New River during high water. There may be considerable movement of subsurface waters between CTWS lagoons and wetlands, and neighboring New River drainage. Further hydrological investigation is needed.

Where Western and Northern Lagoon meet at Backlanding Waterside, they are connected by small streams, direction of flow dependent on water conditions. Northern Lagoon is the largest and most accessible lagoon, having the largest water storage capacity. Crooked Tree Village sits along its western shore about 7 or 8 km downstream of its juncture with Western Lagoon. About 2.5 km downstream of Crooked Tree Village where Northern Lagoon discharges into Black Creek, which flows about 15 km, passing by Wa~~i~~shing Tree and intersecting Belize River near Compass Point.

It is important to better understand the hydrology of the CTWS ecosystems in order to better understand the impact and dynamics of cyclic flow patterns. Movement of water into and out of the Crooked Tree wetland ecosystem is controlled in part by the drainage of surface flow within the wetland catchment and the rise and fall of the water table within this wetland region. These components are determined in part by the stage of the Belize River and the amount of rainfall, both on site within CTWS and in the headwaters of the Belize River Watershed. Water pushed into lagoons and wetlands when Belize River is in flood stage, and drained from wetlands and lagoons when the river stage is low drives the ecology of this system.

This seasonal/annual rise and fall of water level within CTWS is the key ecological control that affects life cycle patterns of microbes, plants, and animals within this ecosystem. Generally the lagoons are at their highest stage in December, with some parts of Northern Lagoon reaching 2.5 m (8.2 ft.), but by May much of the lagoon can be almost entirely dry except for a few pools and a thin stream in Northern Lagoon and Southern Lagoon, and Blackwater Creek and Spanish Creek still containing water. Overall the area of the lagoon is reduced by about two-thirds and some years more. Figure 11 compares high water and low water seasons for the Northern Lagoon as depicted on two different sets of topography maps. Topography maps made from 1978 to 1980 over flights show low water conditions and those from 1988 to 1991 over flights show high water conditions. Both dry and wet season water levels can be more extreme than shown in this figure. Two views of Northern Lagoon are offered in Figure 12, one image showing high water conditions and the other showing low water, with the river that meanders through the lagoon being visible.

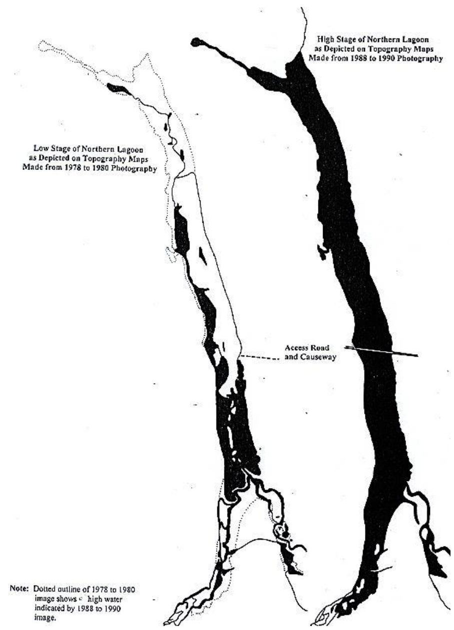


Figure 11. Comparison of Surface Water Area of Northern Lagoon During Low Flow/High Flow Seasons on 1978-1980 and on 1988-1990 Topography Maps of Belize.

a b

Figure 12. a. Northern Lagoon During the Wet Season. b. Northern Lagoon During the Dry Season.

A second smaller savanna/wetland system, roughly 567 hectares (1,400 acres) in size (Ramsar, 2000), located east of the New Northern Highway, is included in the CTWS. This system is made up of Mexico Lagoon (a marsh/wetland area), Jones Lagoon (a larger, more open and shallow lagoon surrounded by wetlands) and Mexico Creek that flows into the Belize River at Grace Bank. During the dry season, all of Mexico Lagoon and much of Jones Lagoon will often dry up, but merge together during high water periods.

In summary, as one large CTWS system, dry season flow is predominately from north to south, discharging into the Belize River from the lagoons through Black Creek for Northern, Western and Southern Lagoons, and through Spanish Creek for Mexico and Jones Lagoons. In the beginning of the dry season a substantial volume of water is stored in the lagoon system, particularly in the northern end that constitutes Backlanding and Revenge Lagoon. Slowly, as the river stage drops to low flow levels, this mass of water drains back into the Belize River through the connecting streams, and seeps into groundwater storage. Dry season flow is probably largely maintained by groundwater discharge as this subterrarian water resource is slowly drained down, only to be recharged when wetlands are inundated again during the following wet season.

During the latter part of the wet season, land surrounding the lagoons is inundated and sometimes covered by almost two meters of water. During flood years the causeway may be under water and parts of Crooked Tree Village and other surrounding communities impacted by rising waters as the Belize River backs up into the wetlands and lagoons. Normal high floods can reach up to 5.5 m (18 feet) in the middle of the lagoons and about 1 to 2 m (about 4 to 7 feet) above normally dry ground. Major floods resulting from tropical storms and hurricanes, such as created by Hurricanes Mitch and Keith, and by more common tropical depressions, as occurred during 2008 and 2013, can result in higher water levels that may inundate homes.

Heavy brown floodwaters entering the lagoons from the Belize River carry large loads of suspended silt and clay. These waters also transport a lot of detritus (leaves, limbs, whole trees) that sometimes clog waterways, occasionally causing local flooding conditions. Typically flood waters rise relatively fast, while receding waters tend to fall much slower. In the case of Northern Lagoon and Western Lagoon, the damming effect of the causeways that restrict flow may act to cause waters to recede much slower, extending settling time for suspended solids to settle out of the water column, causing heavy deposits of mud to build up in the lagoons and streams.

The lagoons are essentially settling basins where suspended silt and clay can build up as mud (see Figure 12b). This is process causes issues due to inappropriate construction of the causeways where debris can block the notches that allow some flow through the older causeway structure. Spanish Creek and Black Creek to a lesser degree show patterns of braided streams (See Figure 11). This is an indication that the volume of sediment being contributed to these flowing water systems is greater than the volume and velocity of flowing water can transport, with excess sediment loads being deposited in the stream bed, building up sediment layers, and eventually causing the stream main channel to divide into many smaller channels. During low flow conditions, Black Creek typically discharges waters rich in tannins, giving it a dark tea color from which its name was probably derived, visible GoogleEarth© imagery where it empties into the Belize River.

Today there are several widely used watershed models available that can help develop a more complete understanding of the many factors and the interaction of those factors that control or influence the hydrologic behavior of the CTWS wetland and lagoon system. Such models take into consideration such factors as climate (minimum/maximum temperature, rainfall, evapotranspiration), geology and soils (porosity, infiltration rates, surface runoff), groundwater recharge and flow, reservoir storage capacity, land use (agriculture, forest cover, non-porous surface areas) and water use (water extraction/irrigation, water diversion), and other components. Some of these models are relatively easy to use and economical to run. Information required for such physics-based models is readily available within Belize through Government offices. Once loaded with the appropriate data on the system of focus, the model can be used to examine different scenarios that may occur, including climate change patterns and land use changes. Select models are useful predictive tools for studying and understanding hydrologic processes and the potential impacts that particular human activities may impose, contributing to analysis, diagnosis, and ultimately decision making when considering implementing specific actions that may affect system hydrology.

Geology and Soils

Belize can be divided topographically and geologically into two distinct areas—the flat limestone Yucatan platform to the north and eastern coastal area, and the steep Maya Mountains dominating the southern region. The Yucatan Platform is the large, relatively flat piece of continental shelf underlying Northern Belize, as well as southern Mexico and Northeastern Guatemala. It has been covered by sedimentary rocks made up of the calcium carbonate shells of mostly microscopic marine organisms, during a time when this present landscape was part of a shallow sea floor (late Mesozoic and early Cenozoic Eras, about 160 to 56 million years ago). These limestone layers are up to two kilometers thick in some places, and besides calcium carbonate, include deposits of gypsum, other evaporite minerals, dolomite, and intrusions, nodules, and sediment deposits of silica dioxide.

Northern Belize savannas are associated with coarse palaeo-alluvial deposits derived from material eroded from the Maya Mountain Massif and littoral deposits of an ancient sea (Wright, *et al*., 1959). Limestone outcroppings scattered through these deposits usually support forests. Most of the streams and rivers, and the lagoons and wetlands of CTWS lie over more recently deposited Quaternary (1,800,000- 10,000 years ago) sediments (Figure 12). These alluvial deposits consist of siliceous sand and bedding plains of water-impermeable clay (Ramsar, 2000). Alluvium was deposited by floods during periods of low global sea level, and by modern reef communities and calcium carbonate sequestering algae and microbial organisms during the last interglacial age when the sea level was much higher than today. These wetlands continue to serve as settling basins for river-borne sediments. Early Tertiary (66 MYA) deposits of limestone, marl, gypsum, and chert nodules (listed in order of abundance) compose the geology of higher lands around the wetlands on the eastern side of this landscape, which includes Mexico and Jones Lagoons. The higher grounds around the wetlands on the western side, which includes Northern, Western, and Southern Lagoons and their interconnecting streams, is the result of Late Tertiary deposits and are made up of clay, gypsum, sand, chert, marl, and limestone. Silicate sand is an abundant component of these sediments. These descriptions and the map in Figure 13 were derived from the composite map compiled by Cornec (2002).

Central American savanna soils are complex, having been described by several different researchers using different classification schemes. Beard (1953) discussed four types of soils lying beneath Belizean savannas he considered to be four different stages in the later part of a development series, all originating from alluvial sediment weathering over a bedrock of limestone. The youngest of the four types, called Pelly soil, is a somewhat deep sandy loam overlying water impermeable mottled sandy clay that supports a "broken ridge" made up of Caribbean Pine (*Pinus caribaea*) and Cohune Palm (*Orbignya cohune*), and consists of a moderately deep sandy loam on top of an impermeable red and white mottled sandy clay. Where Cohune Palm begins to fall out of the vegetation, leaving Caribbean Pine and oaks, the clay layer lies so close to the surface that much of the otherwise standing water becomes runoff that erodes sandy loam and clay, leaving behind a layer of sand lying over clay, creating the Belize savanna soils, or Baker soil. The main vegetation found on Baker soil is basically sedges and grasses, sometimes with palmetto and trees including Calabash (*Crescentia cujete*) and White Poisonwood (*Cameraria latifolia*).

The British Honduras Land Survey team lead by Charles Wright conducted scientific description of the soils of the entire country and created a 1:250,000 scale soils map for Belize (Wright, *et al*., 1958a). That portion of the soils map including the CTWS area is traced in Figure 14. The western side of CTWS and surrounding area is largely covered by mature soils built up from coastal deposits, these same soils also found in large areas and scattered patches throughout the CTWS area. Adjacent areas just west of Western Lagoon are covered in flinty soils deposited as early sub-mature alluvial soils with limestone added during intermittent periods of inundation from sea level rise. The western side of Crooked Tree Island is covered largely in non-saline organic soils, the central and eastern areas are characterized by flinty limestone enriched soils, and the north-central area contains a large patch of mature coastal deposit soils.

Lowland savanna soils are exposed to salt spray, saltwater intrusion into aquifers, and other coastal influences, and by wet season/dry season cycles. These soils overlay a relatively flat landscape that has~~with~~ poor drainage. These relatively young soil deposits largely consist of siliceous palaeo-alluvium that has been derived from the Maya Mountains and deposits of palaeo-coastal materials (King, *et al*., 1992). Usually these soils are course and contain fine size fractions that are deposited into lower lying areas having reduced drainage. Deposits in most flat areas have heavy clay components that impede drainage and affect plant root depth. Savanna soils are acidic, poor in nutrients, and subjected to impacts from storms and fires during wet to dry seasons. Savannas found more inland, such as those around CTWS, typically are higher in relief, better drained, older, sandier, Pliocene deposits and are typically covered in dense pine forests. Organic matter in the savanna soil profile is typically found within the upper 10 cm. Within the sublevel there is often a layer of very fine inorganic material, mostly clays that impede horizontal movement of water within the soil (Bridgewater, *et al*., 2012).

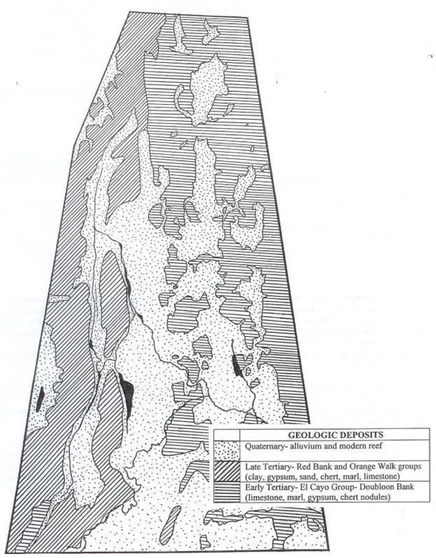


Figure 13. Geology of the CTWS Area (see Cornec, 2002).

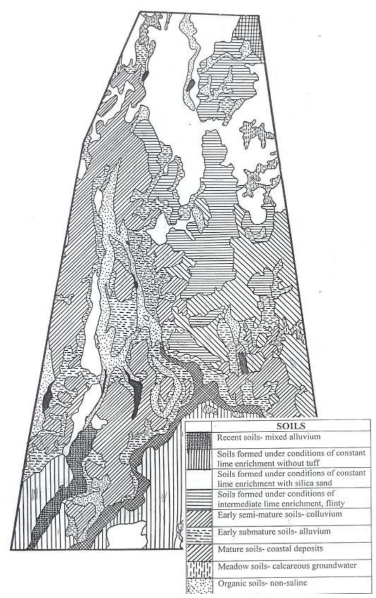


Figure 14. Soils of the CTWS Area (Wright, *et al*. 1958a).

Long-term buildup of organic-rich alluvium within Crooked Tree wetlands from Belize River floods has also developed very fertile soils, as is typical of many wetlands. Savanna wetland soils often contain higher levels of organic material. This organic buildup not only reduces sediment/soil porosity, resulting in poor drainage, but also contributes to the buildup of anaerobic environments that break down detritus much slower, contributing to the buildup of sequestered organic carbon. It must be remembered that general soil maps are informative at the landscape scale. At the local scale, savanna environments are very patchy and heterogeneous, resulting in a wide variation of soil characteristics within a small area (Bridgewater, *et al*., 2012).

Upland savanna soils (Mountain Pine Ridge soils) in contrast are very old, deeply weathered, leached of nutrients, acidic, with kaolinite clay and iron oxide end products, and with drainage over sharp terrain. Lowland savanna soils are much younger and are affected by freshwater and marine water. Sometimes impermeable clay layers underlie sandy layers, creating conditions for poor drainage and waterlogging that few plants can tolerate, while well drained savannas support pine and oak trees (Furley and Ratter, 1989;

Furley, et al. 2001). Savanna soils of Northern Belize are typically palaeo-alluvial, coarse sediments from the erosion of mountains and from littoral sediments from ancient shorelines (Wright, *et al*., 1959). This terrain also includes areas of elevated calcareous formations that support forest biomes (Goodwin, *et al*., 2013).

Many of the lowland savanna soils sampled during the Darwin BTFS project had pH values from about 5.3 to 5.7, with higher levels due to ground water or perched water table influences. Cation exchange capacity was low overall, adding to the characterization of savanna soils being nutrient poor. Clay deposits tend to dominate savannas of low relief (see Bridgewater, *et al*., 2012).

Fires

Fire is a defining characteristic of savannas, to the point where many savanna plants are fire adapted. Fires not only affect savanna ecology, but also indirectly influence the surrounding wetlands and ultimately lagoon systems. Nutrients within savanna biomass are liberated by fires and those not taken up in new vegetation growth can be moved toward water bodies during rain events. The effect of fire on savanna has been heavily investigated in Belize (Kellman, 1984; Kellman, et al., 1985, Miyanish and Kellman, 1986), but the effects on the surrounding wetlands have received very little attention.

Fire suppression within savannas was a primary component of management practices, promoting recruitment and growth of *Pinus caribaea*. Pines increase nutrient content in the soil, which supports other fire sensitive plants, changing the structure of the savanna vegetation. Based on studies in Belize, Kellman (1984) noticed that in typical savannas where fires are allowed to burn naturally, woody plants occur in small numbers and more flammable but fire tolerant species of grasses and sedges dominate, maintaining savannas.

Fires tend to significantly reduce those fire-susceptible species, such as many broadleaf forest trees, possibly creating patterns of savanna woodlands to largely open grassland (Furley, 1974, 1976; Hicks *et al*., 2011) as seen in lands around CTWS. Fire occurrence affects the concentration of organic matter in the soil, the concentration of carbon and nitrogen, and the availability of these nutrients to plant and algal communities. Each of the savanna sub-types recognized are defined by the frequency and intensity of fire, with present day vegetation assemblages reflecting fire tolerance more than soil characteristics (Bridgewater, *et al*., 2012). The common occurrence of fires creates fragmented forest patches (Kellman and Meave, 1997).

Fires frequently occur within the savanna areas around CTWS. A map of fire prone areas around CTWS compiled by Meerman (2001) shows that fires are induced in areas surrounding the sanctuary (Figure 15). Although lightning strikes are attributed some fires, many savanna fires are set by humans, often as a way to stimulate new growth of grasses that attract deer and other game animals (Edgar Carrera, Wildlife Officer, Belize Forest Department, personal communication). Fires may also be set to prepare land for agriculture and for pasture development.

Given that fires occur during the dry season when water level is low, many hectares of wetland savanna are exposed. This potentially increasing the likelihood that nutrients released will reach aquatic ecosystems through both surface runoff and eventual inundation by rising water levels. Strategies to investigate contribution of fire released nutrients to aquatic systems will help in understanding the critical linkage of CTWS lagoons and wetlands to surrounding lands and the possible impacts of land use activities on production.

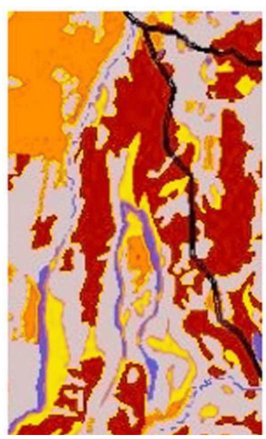


Figure 15. Fire Prone Areas within CTWS Landscape (Meerman, 2001) (*yellow-low, orange-intermediate, red-high fire potential*).

Biomes and Vegetation

Lowland savannas of Belize, including savanna wetlands, are characterized by very shallow, poorly drained soils and are very close to the sea and coastal influences (Bridgewater *et al*., 2012). These highly leached soils are also very nutrient poor, but very patchy, therefore having variable but often poor agricultural application (Hicks *et al*., 2011). Lowland savannas are utilized by a wide range of species, including savanna specialists such as White-tailed Deer (*Odocoileus virginianus*), Yellow-headed Parrots (*Amazona oratrix*), and Lesser Yellow-headed Vultures (*Cathartes borrovianus*) (Tilson and Miller, 1983), as well as a high number of endemic species, giving these ecosystems high value as conservation areas (Bridgewater, *et al*., 2012). However, savannas throughout Central America are threatened by agricultural expansion.

A range of key ecological services have been attributed to savannas of northern Belize (Wells, 2013). These include the following areas:

- Carbon sequestration through vegetation, contributing to climate stabilization;
- Regulation of surface runoff velocity in flood conditions, dampening downstream flood peaks;
- Regulation of soil water acidity and filtration of nutrients and pollutants;
- Control of soil erosion by vegetation, reducing surface runoff and increasing the soil shear strength during floods;
- Provide habitat for a large diversity of wildlife, many endemic species, helping maintain regional biodiversity.

CTWS is essentially a lagoon/river/wetland/riparian ecosystem complex with small bits of savanna included within the boundaries of the sanctuary. However, CTWS is surrounded by savanna and its associated biomes (*terrestrial ecosystem defined by dominant plants*). The landscape is a patchwork of broadleaf forest to wet savanna or wetlands to open lagoon gradients. These biomes may grade one into the other across sharp ecotones (*transition zones between biomes*), such as often seen between broadleaf forest patches and surrounding savanna; broad and more gradual ecotones as between pine savanna and open savanna; and fluctuating ecotones, as found at the edge of the wetland and dryland and the shore of the lagoon that move laterally upslope and down slope from wet season to dry season. The ecology of surrounding savannas, part of the CTWS watershed system, strongly influences the ecology and health of the Crooked Tree wetlands. Also significant research has occurred in these savannas over the years.

Several studies have focused on CTWS and savanna landscapes of Northern Belize or included these areas over the past 130+ years. The history of botanical and vegetation mapping for this wetland area involves several research groups attempting to define and delineate broadleaf forest, savanna, and wetland types. Following up on Morris's publication of the Land of British Honduras in 1883, Stevenson (1928) added mangrove and savanna to the three vegetation types Morris described (pine ridge, broken ridge, cohune ridge), drawing focus on wetlands and savannas. Stanley and Record (1936) expanded this classification system to include brackish savanna, freshwater savanna, pine forest, and swamp forest, along with other forest types, describing woody plant species associated with each vegetation category. Lundell (1937) also described regional vegetation types using similar descriptions, some of these categories represented in CTWS.

In the mid to late 1950s Charles Wright and his British Honduras Land Survey team adopted the strategy of describing distinct tree species associated with each vegetation category used by Stanley and Record (1936) for the vegetation categories they identified, described, and depicted in their 1:250,000 scale vegetation map for the entire country of Belize (Wright, *et al*., 1958b). Besides the use of aerial photographs, this work was based on extensive field assessment. Figure 16 shows the vegetation types in the CTWS area identified by Wright *et al*. (1958b) and the classification system used distinguishing between lime-loving forest species and non-lime-loving species. This classification mirrors soil types of the Crooked Tree wetlands as shown on the Wright, *et al*. (1958a) soil map of Belize (Figure 14). The vegetation map shows pine savanna and broadleaf forests, with strips of transitional forests. However, the classification system does not distinguish between marsh and swamp wetlands.

Early ecological research in savannas of Belize was focused on upland savannas and targeted species of economic importance, such as pine (Kellman, 1979, 1984, 1985a, 1985b; Kellman and Miyanishi, 1982; Kellman and Sanmugadas, 1985; Kellman, *et al*., 1985). Researchers have considered that savannas are created in response to climate, soil conditions, and fire (Beard 1953, Sarmiento 1984).

Kellman (1984), working within the upland savanna of the Mountain Pine Ridge, considered that multiple factors may be involved, with vegetation structure within Belizean savannas responding to soil nutrient availability and fire occurrence. Savanna soils were found to be nutrient poor, with decaying plants sometimes creating nutrient patches (Kellman, 1979). These relatively high-nutrient sites often support a diversity of hardwood species such as mahogany (*Swietenia macrophylla*) (Kellman and Miyanishi, 1982; Kellman 1985b). Most of the woody plants growing in nutrient patches are not fire resistant as are pine trees and select grasses and sedges (Kellman 1984). These general observations largely hold true for lowland savannas examined in later years.

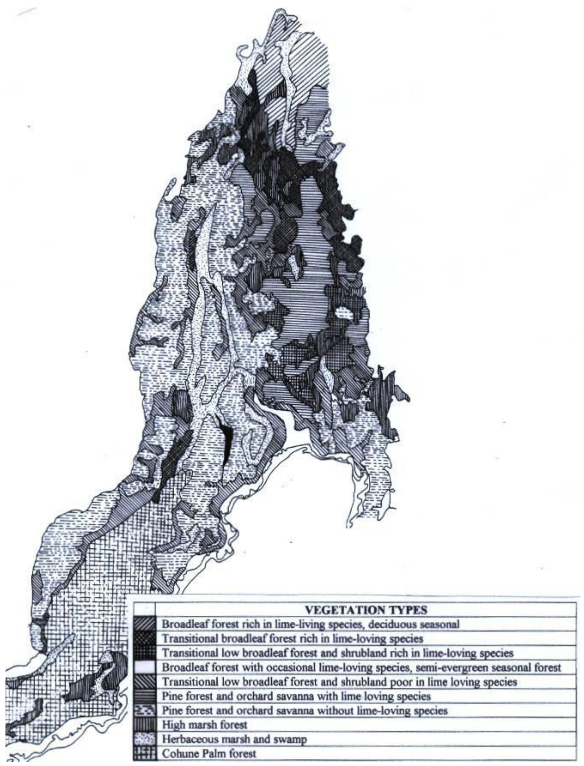


Figure 16. Vegetation of the CTWS Area by Wright, *et al*. (1958b).

In the 1990s a group of researchers worked on improvement of the Wright, *et al*. (1958) system using satellite images (King, *et al*., 1992). This effort was conducted as part of a land resource assessment for Northern Belize, categorizing land cover. Five principal vegetation types are found in the CTWS area as described by King *et al*. (1992) and Mackler and Salas (1994) (Table 3).

Other vegetation classification systems have been applied to Belize. The map produced by Brokaw and Iremonger (1995), using Landsat imagery, is based on the UNESCO vegetation classification system that is intended for global use, allowing broad-scale comparisons to be made among different countries. Vegetation categories were described by physical structure, topography, altitude, seasonality, leaf form, and typical species assemblages.

An assessment of the Maya Forest within Southern Mexico, Northern Guatemala and Belize was funded by the U.S. Man and the Biosphere Program/ Tropical Ecosystems Directorate. Conservation International (2000) produced a map from 1995 to 1998 TM satellite imagery showing the central island to be about two fifths agriculture/urbanization (Crooked Tree Village), two fifths secondary forest, and one fifth medium to high forests. Swamp and marsh areas line the water bodies. Much of the northern end of the island is savanna and a lot of the southern end is classified as secondary forests. Between the western boundary of the reserve and a belt of savanna along the eastern side of New River Lagoon lies a strip of medium to high forest.

Table 3. Principal Forest Types of the CTWS Area Described by King *et al*. (1992) and Mackler and Salas (1994).

FOREST TYPE	CHARACTERISTICS AND DOMINANT SPECIES
Broadleaf Forests or **High Ridge Forests**	These forests occur on limestone soils of higher elevation. Typical species are those that do not tolerate extensive root inundation and include Santa Maria (*Calophyllum brasiliense*), sapodilla (*Manilkara zapota*), cedar (*Cedrela mexicana*), allspice (*Pimenta dioica*) and mahogany (*Swietenia macrophylla*).
Pine Savanna or **Pine Ridge**	These forests are found on well-drained, acidic, sandy soils, and dominate the island of Crooked Tree. This forest type is characterized by relatively low tree diversity and more open canopies. Typical species include Caribbean pine (*Pinus caribaea*), oak (*Quercus* sp.), palmetto palms (*Acoelorraphe wrightii*), Cocoplum (*Chrysobalanus icaco*), and craboo (*Byrsonima crassifolia*). Understory species are dominated by grasses and sedges. This is a fire prone vegetation cover. It has been heavily exploited for many years for lumber (pine), charcoal (oak), fence posts and crab pots (palmetto). These forests also support large stands of cashew (*Anacardium occidentale*) that are being increased in size by local residents.
Rush/Sedge Lands or **Savanna**	This cover is primarily herbaceous, lacking most of the woody species typical of Pine Savanna, and is typically inundated by water for about six months out of the year.
Cohune Palm Forest or **Cohune Ridge**	These forests grow along creek and lagoon banks where soils are rich and well drained. These have proven to be the more agriculturally productive soils and often support cattle pastures. These forests are typically composed of cohune palm (*Orbignya cohune*), Guanacaste or Tubroos (*Enterolobium cyclocarpum*), Hogplum (*Spondias mombin*) and Gumbo-limbo (*Bursera simaruba*). Cohune palm forests often grades into Broadleaf forests.
Freshwater Swamp Forests	This forest type is found along the littoral zones of lagoons and ponds and along the edges of creeks. These forests are flooded during the wet season and are dominated by those trees that can tolerate cycles of exposure and inundation. Typical trees include thick patches of logwood (*Haematoxylon campechianum*) within the more inundated areas, as well as Bribri (*Inga affinis*), Provision Tree (*Pachira aquatica*), Cohune Palm, Guanacaste, dogwoods (*Lonchcocarpus* spp.), figs (*Ficus* spp.), pokenoboy (*Bactris* sp.) and Cotton Tree (*Ceiba pentandra*).

Meerman, *et al*. (2000) described the area as consisting of narrow strips of broadleaf forest bordered on each side by short-grass savanna and tall herbaceous reed land. Meerman and Sabido (2001) produced a Central American Ecosystem Map that shows two different savanna types with the argument that more refined classification is artificial because additional categories actually are successional stages. Vegetation categories used in the Belize Ecosystem Map relevant to CTWS are listed below (Table 4). CTWS as it appears on that map is shown in Figure 17.

Bridgewater, *et al*. (2002), working in the Rio Bravo Conservation and Management Area, conducted a detailed botanical study of a savanna, and identified the following 6 savanna sub-categories, including savanna consisting of dense trees, a type that was left out of the Meerman and Sabido (2001) system. Also 5 categories of wetland ecosystem types were recognized by Bridgewater, et al. (2002). The problem is that many of the categories used by Bridgewater, et al. (2002) were not easy to identify on available remote imagery or were too small to appear on the imagery. Categories include:

- Grassland/scrub grassland
- Pine/palmetto savanna
- Palmetto thicket
- Savanna orchard
- Woodland and pine ridge
- Oak thicket

- Fringing riverine red mangrove
- Cutting grass marsh
- Marl flat
- Sedge marshland
- *Eleocharis* Calabash marsh

Table 4. Definitions of Savanna Ecosystem Types of the CTWS Area Described by Meerman and Sabido (2001).

Tropical evergreen seasonal broadleaf lowland forest over calcareous soils: Central Eastern Variant

- Generally well-drained soils overlying limestone;
- Annual rainfall less than 2000 mm, the dry season being very prominent and lasting from February until May;
- Fires restricted to areas where milpa farming is practiced;
- Locally deciduous forests with trees 15 to 20 m high;
- Species include *Acacia* spp., *Bursera simaruba, Coccoloba* spp., *Lonchocarpus castilloi, Simarouba glauca, Manilkara zapota, Cupania* sp., *Sabal mauritiiformis, Pouteria* sp., *Guettarda combsii, Vitex gaumeri, Swietenia macrophylla*.

Tropical evergreen seasonal broadleaf lowland swamp forest of Northern Belize: High variant

- Poorly drained soils overlying calcareous rock;
- Annual rainfall less than 2000 mm, the dry season being very prominent and lasting from February until May;
- Fires restricted to areas where milpa farming is practiced;
- Low, broken canopy having characteristic deciduous characteristics, with open canopy areas with developed herbaceous layer predominately made up of sedges such as *Scleria bracteata*;
- Trees include *Croton niveus, C. billbergianus, Coccoloba cozumelensis, C. acapulcensis, Zygia* sp., *Sabal mauritiiformis, Calophyllum brasiliense, Simarouba glauca, Amyris elemifera, Bucida buceras, Bactris* spp., *Dracaena Americana, Swietenia macrophylla, Gliricidia sepium, Manilkara zapota, Metopium brownei, Ouratea nitida*, with *Haematoxylon campechianum* found in wetter sections, woody vines may also be found.

Evergreen broad-leaved scrub with much *Miconia* spp.

- Not included in description

Short-grass savanna with needle-leaf lowland open forest

- Pale, course topsoil over compacted finer grained soils that are mottled bright red and white; soils are acidic and nutrient poor (King, *et al*., 1992);
- Soils saturated during the wet season but drought-stressed during the dry season;
- Annual rainfall less than 2500 mm, the dry season being very prominent and lasting from February until May;
- Frequent fires converts this vegetation type to open short-grass savanna;
- This is a transitional vegetation type from short grass savanna to tropical evergreen seasonal needle-leaf lowland dense forest;
- Sparse *Pinus caribaea* is dominant tree, with *Acoelorraphe wrightii, Xylopia frutescens, Quercus oleoides, Byrsonima crassifolia, Hirtella racemosa*, and *Chrysobalanus icaco*, with herbaceous layer dominated by sedges and including *Cassytha filiformis, Passiflora urbaniana, Gynerium sagittatum*, and *Turnera aromatica*; low shrubs of *Clidemia* sp. and *Curatella americana;*
- Apparently important as a breeding habitat for *Amazona oratrix*.

Short-grass savanna with shrubs

- Pale, course topsoil over compacted finer grained soils that are mottled bright red and white; soils are acidic and nutrient poor (King, *et al*., 1992);
- Dense subsoil prevents water infiltration, creating inundation during wet season, excess dry conditions during dry season;
- Annual rainfall less than 2500 mm, the dry season being very prominent and lasting from February until May;
- Vulnerable to fires
- Scrublands may occur as small islands of dense packed trees and shrubs within the sedge/grassland
- Sedges include *Rhynchospora* spp, *Bulbostylis paradoxa* and *Fimbristylis vahlii*, with *Eleocharis* spp and *Cyperus ligularis* in wet areas; grasses include *Aristida appressa, Eragrostis maypurensis, E. elliotii, E. acutiflora, Mesosetum filifolium Leptocoryphium lanatum, Panicum rudgei, Trachypogon spicatus, Sporobolus cubensis, Paspalum pulchellum, P. peckii, Axonopus poiophyllus, Sporobolus cubensis*
- Woody species include *Acoelorraphe wrightii, Quercus oleoides, Pinus caribaea, Mimosa albida, Miconia* sp*., Cameraria latifolia, Calyptranthes* sp*., Chrysobalanus icaco, Roupala montana, Clidemia* sp*., Crescentia cujete, Metopium brownei, Hippocratea excelsa, Curatella americana, Erthroxylum guatemalense, Gliricidia sepium*;
- Herbaceous layer well developed, containing *Xyris* sp., *Eriocaulon* sp., *Bletia purpurea, Cassytha filiformis, Borreria* sp., *Chamaecrista* spp., *Drosera capillaris, Coutoubea spicata, Cipura campanulata, Passiflora urbaniana, Zamia polymorpha*

Predominantly tall herbaceous reed land

- Not included in description

The Central American Ecosystem Map was updated in 2004 with the creation of the Belize Ecosystem Map. Biomes of Belize are classified by the UNESCO physiognomic classification scheme, based on plant structure categories useful globally. Besides dominant vegetation type, components such as seasonality, climate, and elevation are included. CTWS as seen on the Belize Ecosystem Map is seen in Figure 18 (Meerman, 2005; see Cameron, *et al*., 2011). However, finer resolution of general biomes delineated by UNESCO classification systems show, for example, that savannas are composed of wetlands, woodlands, and forests within large expanses of sedge/grasslands, thus being far more complex than just sedge/grasslands. This level of ecosystem/habitat complexity is very important to local biodiversity levels.

Beginning in 2009, a three-year project, Savanna Ecosystem Assessment: Belize (SEA), funded by the UK DEFRA Darwin Initiative, was undertaken for the purpose of compiling data on taxonomic research and mapping of savannas to support conservation initiatives. Based on SPOT imagery, the 2010 Savanna Ecosystem Map was conducted, showing the amount of savanna contained within protected areas. Figure 19 shows the savanna that occurs within the CTWS boundaries. Ultimately information on distribution and associations of savanna plant species and descriptions of lowland savanna soils were included in the 2012 Belize Ecosystems Map that resulted from this project (Bridgewater, *et al*., 2012).

Land surrounding Crooked Tree wetlands is dominated by lowland savanna. Goodwin, *et al*. (2013) describes lowland savanna as natural or semi-natural area below 500 m (1,640 ft.) altitude dominated by native sedges and grasses, often containing a few select trees and shrubs, and subjected to the effects of fire. Included are those hyperseasonal savannas exposed to alternating seasonal patterns of drought and flooding. There are several other definitions used for savanna investigations conducted in Belize (Bridgewater *et al*., 2002). Moving in an upslope direction, open wetlands and marshes grade into waterlogged savanna, and then into dry open to wooded savanna lands that are often interrupted by broadleaf forest growing on drier soils, essentially forest islands. Savannas are very special habitats, productive and biologically diverse, even though soils are often acidic and nutrient poor.

Savannas of northern Belize are the most northern extent of lowland savannas in the neotropics (Bridgewater, *et al*., 2012). About 130 km^2 (50.2 mi^2) of savanna occur within the CTWS, out of which only about 4.43 km^2 (1.7 mi^2), or about 3.4% are seasonally waterlogged savanna (Bridgewater, *et al*., 2012). Waterlogged savannas are relatively rare, representing only about 2% of the lowland savanna land found in Belize. Because it is rare and important, this class of savanna, this special kind of wetland, may require special consideration in conservation planning (Cameron, *et al*., 2011).

Waterlogged savannas are actually wetlands, with soils becoming saturated in the wet season and often supporting thick rubbery layers of cyanobacteria and algae mats that dry into thin, brittle crusts during the dry season. It is often difficult to determine where dry savannas end and wet savannas begin, with these different areas actually representing successional stages where one type replaces another over time. Savanna wetlands are usually characterized by a few species of small trees and herbs adapted to poorly drained, inundated soils. Typically small wetland patches occur scattered within dryer savanna. Other, more open wetlands within CTWS are extensive, making up most of the littoral edges of lagoons that reach high into the surrounding savanna during the wet season and recede during the dry season into a few small ponds and streams.

Cameron, *et al*. (2011) define lowland savannas as “any natural or semi-natural, fire-influenced ecosystem within the confines of Belize under 500 m (1,640 ft.) in altitude with a continuous herbaceous layer dominated by native grasses,” similar to that used by Goodwin, *et al*. (2013). This includes trees and shrubs, such as Caribbean Pine, Palmetto, oak, Craboo, and other woody plants that add ecologically significant structural components to the savanna. It also takes in hyperseasonal savannas inundated by water during several months to half a year—wetlands. It includes both wetlands and broadleaf forests that are strongly associated with the savanna and forms a functional part of its ecosystem, representing three savanna groups—open savanna, tree-dense savanna, and seasonally waterlogged savanna. This definition is similar to that used by Meerman and Sabido (2004). Savannas are categorized into three patch-level classes by Cameron, et al. (2011) that transition into one another, these categories being described in Table 5.

Note: Comparison of these maps created from remote imagery over the past 15 years reflects changes in technology, image resolution, image availability, and ecological perspectives. In the early days of geographical information system technology, remote data was not readily available, and when it was available, it was typically five years old or older.

Today GoogleEarth© offers very accessible and high quality imagery that is available to anyone able to connect to the internet. These images are typically 2015 to 2016 and appear to be updated periodically.

Even though technological advancement affords greater resolution and accuracy, historical maps are still valuable resources. Not only do they document the development of conservation and research in Belize, they contain information that continues to be useful, especially in this era of global change.

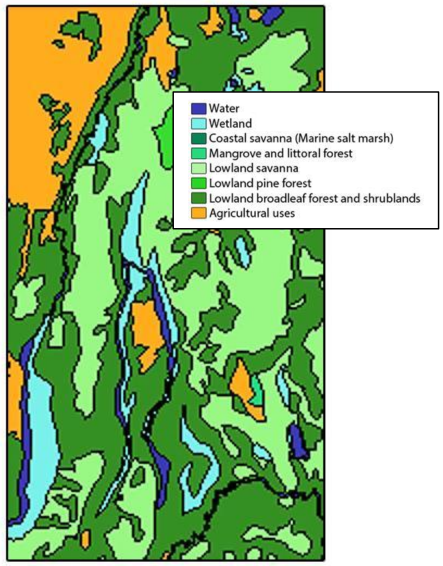


Figure 17. CTWS Ecosystems on the Central American American Ecosystem Map by Meerman and Sabido (2001).

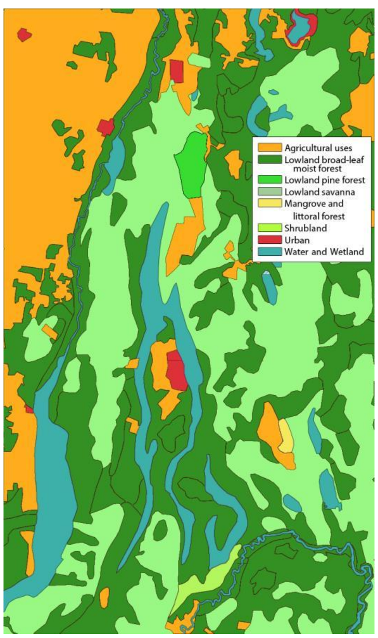


Figure 18. CTWS Ecosystems on the Belize Ecosystem Map by Meerman (2005).

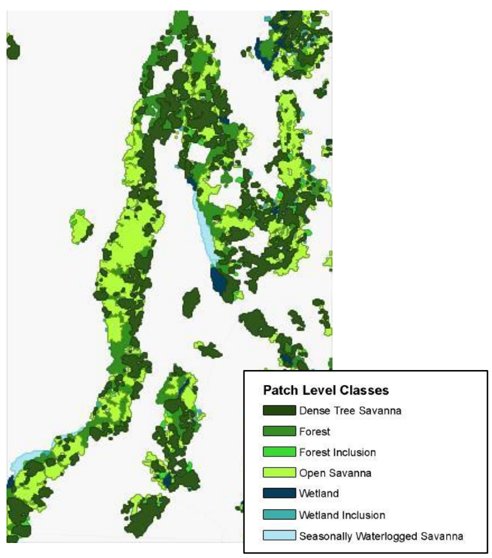


Figure 19. CTWS on the Savanna Ecosystem Map by Cameron, *et al*. (2011).

Table 5. Definitions of Patch-level Savanna Vegetation Types of the CTWS as Described by Cameron, *et al*. (2011).

Forest Type	Description
Open Savanna	Partially to fully open area with scattered pine, oak, craboo, with a canopy of less than 10%; shrub layer, some with underground stems, in small patches around Caribbean Pine, *Curatella Americana, Byrsonima crassifolia,* Myrtaceae spp., sometimes thick patches of oak; grass/sedge dominated herbaceous layer, and depending on moisture*, Buchnera pusilla, Polygala* spp., *Agalinis* spp., *Utricularia* spp., *Alophia silvestris, Drosera capillaris*.
Dense Tree Savanna	Partially open, 10% to 50% cover, thick pine, oak, craboo, and palmetto stands, with pine and sometimes oak dominating, palmetto clumps smaller than found in Open Savanna, many broadleaf associates in dryer areas; lower, 1-2 m, shrub layer with *Miconia albicans, Calliandra houstoniana, Melochia spicata, Clidemia sericea, Davilla kunthii, Calea* spp., Myrtaceae spp., *Erythroxylum guatemalense*, with taller species being *Acoelorraphe wrightii, Byrsonima crassifolia, Curatella americana*; herbaceous layer well drained and grass dominated, plus *Cassytha filiformis, Hypericum* spp., *Spermacoce* spp., *Diodia apiculata, Sauvagesia erecta, Alophia silvestris, Curculigo scorzonerifolia*; sometimes *Chamaecrista* spp., *Zornia reticulata, Clitoria guianensis*, and *Tephrosia nitens* found in oak-dominated forests
Seasonally Waterlogged Savanna (with shrubs and trees)	Trees often appear spaced as in an orchard, most being 5-8 m or shorter, *Bucida buceras* reaching 15 m, high density of small trees and shrubs, relatively open canopy, no pine or oak; described as a transition between other savanna and wetlands, but is itself a wetland; other woody species being *Haematoxylon campechianum, Heteropterys lindeniana, Dalbergia glabra, Cameraria latifolia, Coccoloba reflexiflora, Jacquinia macrocarpa, Semialarium? mexicanum?, Myrica cerifera?, Malpighia glabra, Chrysobalanus icaco*, and *Acoelorraphe wrightii*, with *Crescentia cujete* in wetter parts; epiphytes include *Phthirusa* sp., *Tillandsia* sp., other bromeliads, orchids; sedge-dominated herbaceous layer, less species diverse than drier savanna, tufts supporting herbs requiring drier areas, wetter areas dominated by *Eleocharis interstincta*, but including *Mimosa* sp., *Nymphoides indica*, and *Sagittaria lancifolia*.
Forest inclusions	All broadleaf forest with closed canopy and absence of a continuous herbaceous layer, savanna trees may be present but do not dominate.
Wetlands	Waterlogged areas most of the year dominated by sedges or cutting grass, but missing trees, larger than 50 hectares.

Bridgewater, *et al*. (2012) produced a map showing the general extent of Northern Belize sanvnnas and those savannas in protected areas (Figure 20). An estimated 22 to 27% of Belize lowland savannas are included in some protected area, roughly 433 to 436 km^2 (167 to 168 mi^2) (Meerman, 2005; Cameron, *et al*., 2011; Bridgewater *et al*., 2012). The level of actual protection afforded by each protected area is variable (Walker, *et al*., 2009). The largest protected savanna areas in northern Belize are within the Rio Bravo Conservation and Management Area and the northern end of CTWS harboring sections of "dense tree savanna" and "open savanna", and the eastern littoral zone of Northern Lagoon made up of "seasonally waterlogged savanna" (Bridgewater, *et al*., 2012). Figure 20 shows the savanna areas in and around CTWS. Out of a total of 129.9 km^2 (50.2 mi^2) savanna recorded for CTWS, about 12.9 km^2 (5.0 mi^2) are dense tree savanna, 7.4 km^2 (2.9 mi^2) are open savanna, and 4.43 km^2 (1.7mi^2) are seasonally waterlogged savanna (Bridgewater, *et al*., 2012).

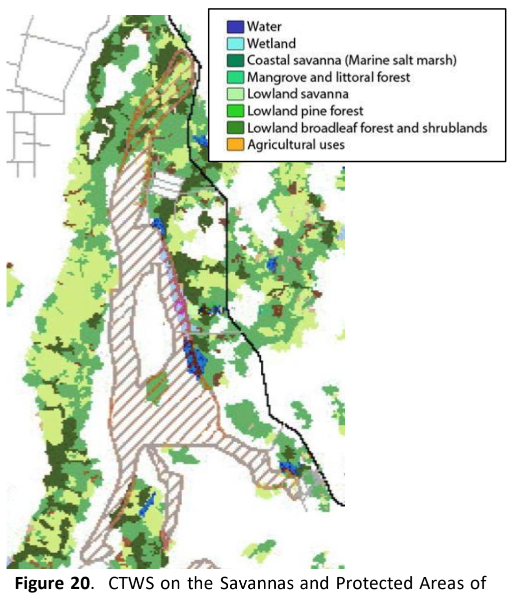


Figure 20. CTWS on the Savannas and Protected Areas of Northern Belize Map by Bridgewater, *et al*.

Goodwin, *et al*. (2013) provide five sub-categories of savanna, listing associated plant species (Table 6). This system allows for classification of wooded savannas, and includes two different wetland classifications, one being "seasonally waterlogged savanna with shrubs," and "wetlands" that are actually marsh areas and lagoons without shrubs. Wetland gradients reflect environmental gradients (Brinson, 1993).

Table 6. Definitions of Savanna Vegetation Types of the CTWS Area as Described by Goodwin, *et al*. (2013).

Forest Type	Description
Oak Woodland	Well-drained area with thick oak canopy (*Quercus oleoides*) generally having developed understory of shrubs (*Calliandra houstoniana, Russelia sarmentosa, Miconia albicans*), with some forest species (*Tabernaemontana alba, Hampea trilobata*); herbaceous layer sparse, few grasses, heavy litter layer, termites common.
Pine Woodland	Well-drained sandy soils, thick pine (*Pinus caribaea*), many times with dense understory of oak and shrubs, herbaceous layer of grasses and rich species list (*Hypericum terrae-firmae, Turnera spp, Oxalis frutescens, Clitoria guianensis, Sauvagesia erecta*)
Palmetto Thickets	Poorly drained soils containing flooded potholes and raised clumps, thick patches of palmetto (*Acoelorraphe wrightii*), associated shrubs (*Parathesis cubana, Acmella filipes, Hibiscus costatus, Mimosa* spp.)
Open Savanna	Poorly drained grassland (many sedges as well), herbaceous layer dominated by sedges and grasses, seasonal herbs (*Polygala* spp., *Xyris* spp., *Utricularia* spp., *Drosera capillaris*-last two are carnivorous plants), with *Pinus caribaea, Quercus oleoides, Acoelorraphe wrightii* and *Byrsonima crassifolia* growing in shrub islands.
Seasonally Waterlogged Savanna (with shrubs and trees)	Areas flooded many weeks during the wet season, includes shrubs (*Crescentia cujete, Cameraria latifolia, Dalbergia glabra, Bonellia? macrocarpa?, Haematoxylon campechianum*), this habitat typically lying between savanna and wetlands.
Wetlands	Fully flooded marshes and lagoons that include *Eleocharis* spp., *Cladium* sp., *Sagittaria lancifolia, Nymphaea ampla*).

As evident by several generations of botanical research (see Brokaw, 2001) and savanna research, there is a wide array of patch-level savanna classification systems that have been in use. Ultimately a more refined, single, standardized system would be necessary to help coordinate future research and conservation efforts. Many of these descriptions can be roughly correlated, but there are differences that should be resolved.

Caribbean pine (*Pinus caribaea*) is the dominant tree within drier Belizean savannas, with the transition areas between savanna and forest and drier, sandy soils supporting dense growth of oak (*Quercus oleoides*) (Bridgewater, 2012). Two small tree species, Craboo (*Byrsonima crassifolia*) and the Sandpaper Tree (*Curatella americana*), are able to tolerate waterlogging and do well in wet savannas. Thick patches of Palmetto Palm (*Acoelorraphe wrightii*) occur around water courses, growing in clumps, an adult plant producing suckers or clones, resulting in a clump of palmetto palm that originated from a single individual (Milne, 1997; Furley, 2008). Roots develop just above the water table, and can grow in wet or dry environments. The heavy fibrous stems are fire resistant. Seed dispersal is usually by peccaries, agoutis, and several different species of birds. White Poisonwood (*Cameraria latifolia*), Calabash (*Crescentia cujete*), and Bullet Tree (*Bucida buceras*) are also found in wetter savannas. Species of Melastomataceae are indicators of nutrient-poor soils characteristic of savannas. Some of these plants are depicted in Figure 21. Some plants, such as Craboo and the Sandpaper Tree are so well adapted to savanna conditions that they are considered indicator species for Neotropical lowland savannas. Buttonwood (*Conocarpus erectus*) and Red Mangrove (*Rhizophora mangle*) are also present within these areas.

Epiphytes, such as the cow horn orchid (*Myrmecophila tibicinis*), are also common in savannas. Out of the 41 endemic plant species recorded for Belize, 17 are specialists found in savannas (Bridgewater, et al., 2012). The Old Man's Beard (*Usnea* sp., family Parmeliaceae) is a lichen commonly found in the swamp trees around the lagoons, a symbiotic relationship between a fungus (Ascomycota) and an alga (Chlorophyta) (Figure 22e and 22f). This lichen has a wide range of medicinal uses (Ceker, *et al*., 2013) and is listed in Appendix C, a taxonomic list of medicinal plants found within the CTWS area.

a b c d e g

Figure 21. Common Woody Plants. a. Calabash (*Crescentia cujete*). b. Calabash limb with fruit. c. Logwood (*Haematoxylon campechianum*). d. Provision Wood (Pachira aquatica). e. *Mimosa* sp. f. *Mimosa* Flower. g. Red Mangrove (*Rhizophora mangle*).

Figure 22. a. "Orchard" Savanna. b. Palmetto Palm (*Acoelorraphe wrightii*) Growing as a Clump. c. Cow's Horn Orchards (*Myrmecophila tibicinis*). d. Devil's Gut Cactus (*Selenicereus testudo*). e. Bromeliad (*Aechmea magdalenae*). f. Old Man's Beard Lichen (*Usnea* sp.). g. Lichen up close.

On one end of the gradation, occupying the higher, drier, and often sandy soils, are more closed-canopied broadleaf and pine forests (woodlands) with a broken, patchy herbaceous layer. Intermediate are more open savannas with open canopies ranging from many to very few trees and shrubs, with well-developed herbaceous layers dominated by native grasses in drier, better drained areas, and by sedges in wetter areas, with other plants mixed in. These areas may experience short periods of flooding, but not as extensively as savanna wetlands that are inundated for sometimes months out of the year, such as *Eleocharis* marsh and cutting grass marsh (Cameron, *et al*., 2011).

Savanna woodlands contain semi-open to dense canopied area, ranging from 10 to 50% canopy coverage, made up of oak, Caribbean Pine, Craboo, and Palmetto Palm, an extensive list being compiled by Lenthall *et al*., (1999). Woodlands are pine or oak dominated, with similar associated woodland tree and shrub species. Often savanna woodlands have lower shrub layers, from one to several meters high, and the herbaceous layer is composed of more grass species than sedges if drainage is good (Cameron, *et al*., 2011) (Figure 23).

Figure 23. Short scrub species of woody swamp plants.

Waterlogged savannas or savanna wetlands are one end of the gradient that may give way to large, open lagoons in the wet season. The wet savanna orchard, essentially a swamp forest with a canopy that is relatively open, tree species spaced somewhat evenly apart and reflecting a planted "orchard," contains a larger density of small trees and woody shrubs while lacking both pine and oak (Cameron, *et al*., 2011). Sedges dominate, but the herbaceous layer is not as species rich as is that of the drier open savannas.

There are several riparian forest areas along some of the stream reaches within CTWS. There is not a list of these riparian tree species for the sanctuary. However, Horwich and Lyon (1990) describe species composition of lowland gallery or riparian forests of northern and central Belize as being made up largely of trees listed by botanical family in Table 7.

Table 7. Primary Tree Species of Lowland Gallery or Riparian Forests in Northern and Central Belize Listed by Horwich and Lyon (1990).

Anacardiaceae
Hog Plum, Jobo (*Spondias mombin*)
Arecaceae
Cohune Palm (*Attalea cohune, Orbignya cohune)*
Bombacaceae
Ceiba, Cotton Tree, Yaxche (*Ceiba pentandra*)
Burseraceae
Gumbo Limbo (*Bursera simaruba*)
Fabaceae: Caesalpiniaceae
Bookut, Stinking Toe (*Cassia grandis*)
Tiliaceae
Balamash, Caulote (*Luehea seemannii*)
Combretaceae
Bullet Tree (*Bucida buceras*)
Fabaceae:Mimosaceae
Guanacaste, Tubroos (*Enterolobium cyclocarpum*)
Bribri (*Inga affinis*)
Polygonaceae
Wild Grape (*Coccoloba belizensis*)
Sterculiaceae
Bastard Cedar, Bay Cedar (*Guazuma ulmifolia*)

Plant diversity within Central American upland savannas have been investigated by many researchers over the years, while lowland savannas have been relatively ignored (Cameron, *et al*., 2011). Lowland savanna/wetland systems within Belize have been recognized as habitat for a diversity of plants and animals, and are being threatened by a growing assortment of stressors from human development projects to climate change. As mentioned above, the three year BTFS project (2009 to 2012), funded by the Darwin Initiative and conducted through the University of Edinburgh, the Royal Botanic Garden of Edinburgh, and Belizean institutional partners, focused on a floristic description of the lowland savannas of Belize as an initiative for savanna conservation. Information about soils and plants of savannas contributed to updating the National Ecosystems Map produced in 2012 (Bridgewater, *et al*., 2012). Results of BTFS included an extensive taxonomic list of savanna plants and associated forest types (Hicks, *et al*., 2011; Goodwin, *et al*., 2013). BTFS documented over 950 plant species, which makes up 28% of the flora of Belize as recorded by Balick, *et al*. (2000), with savannas only representing about 10% of the land surface of Belize (Bridgewater, *et al*., 2012). Savannas are collectively more species rich than previously thought.

Appendix A contains a taxonomic list of all plants found at CTWS and immediately surrounding areas listed by Goodwin, *et al*. (2013). A total of 56 families represented by 155 plant species were identified. Of these, 20 were recorded from adjacent forests, 93 species were listed from the savannas, 31 from the wetlands, and twelve from disturbed areas. Growth habits represented included 87 herbaceous plants, 5 epiphytes, 11 trees, 1 palm, 22 shrubs, 16 shrublets, and 13 climbers. Out of those plants collected for the Crooked Tree and surrounding area, one was a new species for Belize and two species are endemic to Belizean savannas. Roughly half of the species are semi-aquatic to aquatic, with most of the plant families containing one or more of these water-adapted plant species.

Other outputs produced by the Darwin BTFS include a data-base of collections and documents on a website (http://www.eeo.ed.ac.uk/sea-belize/savanna). Another valuable web site allows access to the Savanna Ecosystem Map and database for savanna plants managed by the University of Oxford, Department of Plant Sciences (http://www.plants.ox.ac.uk/bol/seabelize/Search/Index). Plant collections can be reviewed with a map interface (http://xweb.geos.ed.ac.uk/~belize/). Sets of plant photographic guides have been developed to assist in training technicians and researchers involved in savanna-based projects (http://www.geos.ed.ac.uk/research/eeo/sea-belize/education.html). BTFS data contributed to the National Land Use Policy and to the Belize Ecosystems Map 2012 edition available (http://www.biodiversity.bz) (Bridgewater, *et al*. 2013).

Comment [A5]: Is there any new species of plant on Geoffrey Wells research in CTWS and the Savannas?

Wetlands and Lagoons

Wetlands are made up of a large number of different habitat types with patchy distribution. Wetlands are also typically characterized by a strong seasonal pattern that includes somewhat predictable and periodic changes in water levels, which can impose considerable influences on wetland biota. The hydroperiod, or length of time a wetland is inundated, is often the main factor that determines local density, distribution, and species composition of wetland plant assemblages (Gunderson, 1994). Hydroperiod, together with water depth and frequency of droughts can greatly affect the distribution patterns, population dynamics, species interactions (especially among predators and prey), and food web associations of aquatic and terrestrial organisms (Urban, *et al*. 1993; Newman, *et al*., 1996, Turner, *et al*., 1999; Liao, *et al*., 2001). This means that from high water season to low water season the foraging area, food availability, water availability, shelter, and available habitat space changes greatly for many vertebrate species, requiring wildlife to be able to change their behaviors and even diets in response to changes in water level and patch dynamics.

The actual CTWS property is a wetland/lagoon system containing very little dry savanna, but including savanna wetland. Regardless, the savanna lands outside the sanctuary dominate the wetland/lagoon watershed, having a very pronounced effect on the aquatic system, and must therefore be considered in understanding the ecology of CTWS. As mentioned above, there is a gradient including broadleaf forests in upper elevations, through savanna forests, open savanna grassland, and savanna wetlands (including swamps and marshes) to open lagoons. Within this larger system, there is continual movement of water, sediments, dissolved solids, nutrients, organic matter, heavy metals, and pesticides from upslope forests, grasslands, pastures, roads, and houses to the lower areas within the landscape—wetlands and lagoons.

Many researchers have focused on the savanna lands and associated wetlands for several generations, as reviewed above. However, little attention was paid to the wetland component of the landscape system. This is also reflected in the reduced focus on aquatic plants within the savannas. Of course limits have to be set for research projects, and an actual focus on wetlands, lagoons, streams, and rivers within the area would be a great undertaking in itself. Although marginal attention has been paid to many wetland/aquatic components, researchers compiled a list of patch-level categories and descriptions in recognition of these features. The range of names used by various research groups over the past 60 years to delineate wetlands and water bodies of the lowland savannas of Belize are listed in Table 8.

Table 8. Categories Describing Wetland and Aquatic Habitat Areas of Northern Belize Used by Five Groups of Researchers in the Past 60 Years.

RESEARCHERS	WETLAND/AQUATIC HABITAT CATEGORIES
Wright, *et al*. (1959)	Transition Low Broadleaf Swamp Forest High and Low Marsh Forest High Swamp Forest
King, *et al*. (1992) and Mackler and Salas (1992)	Rush/Sedge Lands or Savanna Freshwater Swamp Forest
Meerman and Sabido (2002)	Tropical Evergreen Seasonal Broadleaf Lowland Swamp Forest of Northern Belize- High Variant Predominately Tall Herbaceous Reed Land
Bridgewater, *et al*. (2002)	Fringing River Red Mangrove Cutting Grass Marsh Sedge Marshland *Eleocharis* Calabash Marsh
Cameron, *et al*. (2011) and Goodwin, *et al*. (2013)	Seasonal Waterlogged Savanna with Shrubs and Trees Wetland intrusion

A focused description of wetland components at both landscape and patch levels is needed. Cameron, et al. (2011) defines wetlands as areas that are "predominately waterlogged year-round and expected to be dominated by sedges, but lack a dominant tree layer," with *Eleocharis* and cutting grass marshes also included. This definition does not include swamps as wetlands, or at least does not distinguish between marshes and swamps, which differ in many respects. Several varieties of marshes and swamps occur, with many factors besides water inundation influencing species composition. This REA focuses on wetland areas and associated lagoons and streams/rivers of CTWS, but does not try to offer a definitive description of these components, a task that is beyond this project and an exercise that should involve consultation with a group of experts.

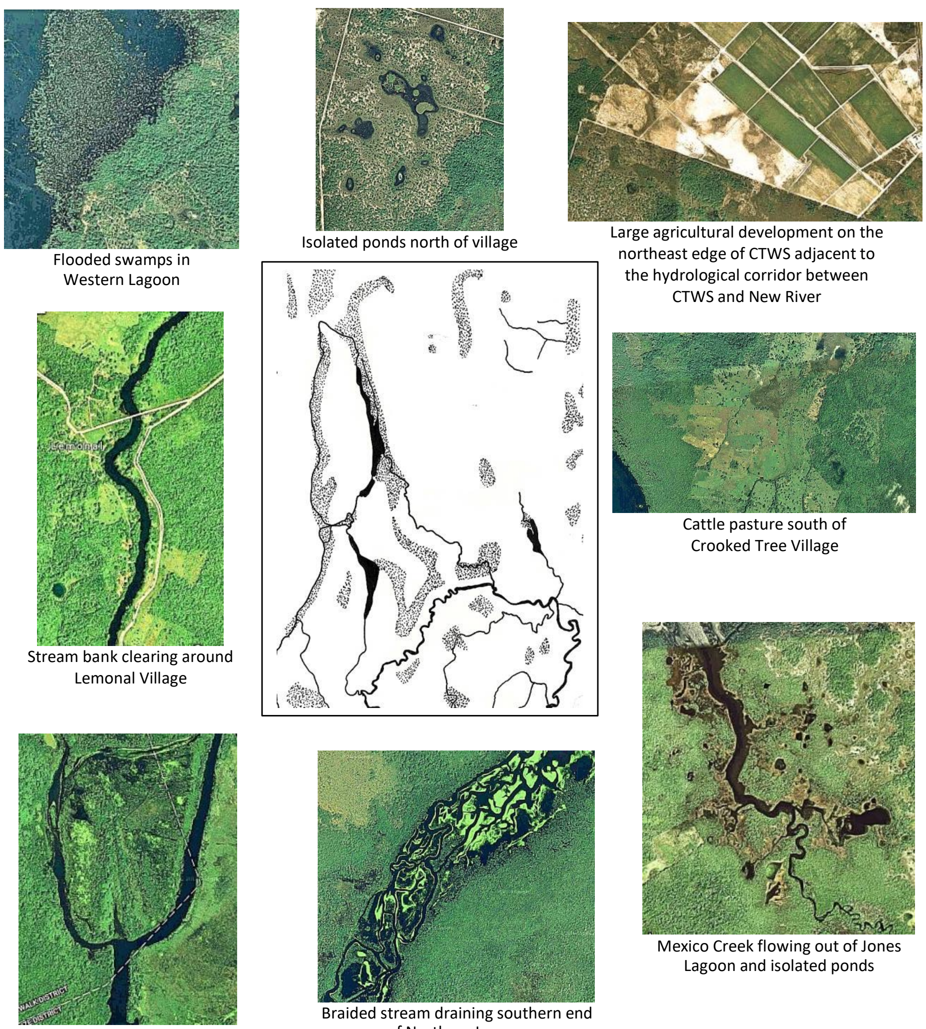
Wright, *et al*. (1959) listed tree species found within the categories used to build the first vegetation map of Belize, included in Table 9, along with a little general ecology of each species. A comparison of all categories listed in Table 8 should be made and a master species list for trees and herbaceous plants compiled. Then each species listed within those descriptions of swamps and patchy marshes with tree associates should be developed. However, this is a project for a botanist familiar with the species addressed.

All of these different classification systems emphasize different vegetation characteristics and when taken together, along with Google Earth© (IKONOS and QuickBird imagery), a more holistic perspective of the Crooked Tree wetlands and forests emerges. Using Google Earth© to explore the area illustrates the point made by Cameron, *et al*. (2011) that at a coarse scale savannas appear to be grassland, but at finer scales reveal wetlands and spare and dense forests, representing "savanna associates." Classification systems applied at more coarse scales can underestimate wetland area. Google Earth© allows the viewer to zoom out to a regional scale or zoom in to a patch scale of 1 cm/20 m. Comparison of the Conservation International map with Google Earth© 2015-2016 imagery can help to understand the rate of change in vegetation cover relative to agricultural development and urbanization. Cameron, *et al*. (2011) found that data for Belize on Google Earth© was consistent and positions were in agreement with SPOT imagery by 30 to 50 m.

Table 9. Primary Tree Species of Transitional Low Broadleaf Swamp Forests Listed by Wright *et al.* (1959).

TAXONOMY	NOTES
Transitional low broadleaf swamp forest trees	
Anacardiaceae	
Metopium brownie Black Poisonwood, Chechem	Important lumber tree in Central America, has urushiol in bark that causes contact dermatitus
Spondias mombin Hogplum	Often growing along streams, small trees to 20m; edible fruit with thick skin, pulp used as febrifuge, diuretic; introduced to Africa, India, Bangladesh, Sri Lanka, Indonesia
Apocynaceae	
Stemmadenia spp. Horse's Balls	Shrubs or trees with latex sap
Bignoniaceae	
Tabebuia guyacan Black Mango, Yellow Mayflower	Tree grows up to 50 m; flowers in 1 or 2 bursts during the dry season, but some individuals flower in the wet season
Clusiaceae	
Vismia baccifera	Synonym is *V. ferruginea*; shrub or small tree up to 5 m; flowers mostly in early dry season, with second flowering in early wet season
Fagaceae	
Quercus sp.	Possibly several species requiring taxonomic work
Fabaceae: Papilionoideae	
Dalbergia stevensonii Honduran Rosewood	A valuable timber species; grows up to 30 m; listed on CITES Appendix 11 in 2013
Rubiaceae	
Coccoloba spp.	Evergreen shrubs and trees; this genus includes Sea Grape
Guettarda combsii	
Verbenaceae	
Vitex spp.	Genus native throughout tropics and subtropics of the world
Vochysia hondurensis White Yemeri	Synonym of *V. guatemalensis*; light, strong wood for interior construction, canoes, veneer, light construction, charcoal, crushed seeds used for diarrhea, dysentery, colds
Guazuma ulmifolia Bay Ceder, West Indian Elm	Medium size tree, up to 30 m; usually found in pastures and disturbed forests, introduced to India and Indonesia
High and Low Marsh Forests	
Arecaceae	
Metopium brownie Black Poison Wood, Chechem	See above
Sabal mauritiiformis Bay Palmetto	Native from South America to Mexico, popular ornamental species growing 9 to 18 m (30 to 60 ft.)
Bombacaceae	
Pachira aquatic Provision Tree	Native to Central and South America, wetland tree, commercially sold as an ornamental
Caesalpiniaceae	
Bucida buceras Bullet Tree	Native to Mexico, Central America, Caribbean, and Northern South America, common in coastal and inland swamps, wood hard and durable, insect and fungus resistant, used for houses building
Haematoxylon campechianum Logwood, Bloodwood Tree	Native to Mexico and Central America, once used as a source of fabric dye, important source of haemotoxylin used as a histological stain and pH indicator, bark and leaves have medicinal uses
Inga affinis Bri Bri	Native to Central and South America, nitrogen-fixing tree, nectary glands on leaf rachis, seed pods with white pulpy seeds, pulp is eaten, grows along water, riparian forest
High Swamp Forest	
Bombacaceae	
Pachira aquatica, Provision Tree	See above
Chrysobalanacaeae	
Chrysobalanus icaco Cocoplum	Tropical Africa, Americas, and Caribbean, southern Florida, Bahamas; shrub 1 to 3 meters to tree 2 to 6 meters, salt tolerant grows on beaches, also grows inland, fruit is edible
Fabaceae: Papilionoideae	
Pterocarpus officinalis Swamp Kaway	Grows 20 to 30 m tall, curved and fluted wide buttresses, grows in moist to swamp forests, often near mangroves, sometimes in pure stands

A general landscape survey was conducted of the CTWS area from GoogleEarth©. Several key features (water bodies and agricultural activities) are shown and referenced on a locator map, demonstrating the potential application of this readily available technology in Figure 24. This information that can be measured and quantified, providing a powerful tool useful in rapid assessment projects and monitoring programs.



Flooded swamps in Western Lagoon

Isolated ponds north of village

Large agricultural development on the northeast edge of CTWS adjacent to the hydrological corridor between CTWS and New River

Stream bank clearing around Lemonal Village

Cattle pasture south of Crooked Tree Village

Mexico Creek flowing out of Jones Lagoon and isolated ponds

Junction of Spanish Creek, Western Lagoon and Southern Lgoon

Braided stream draining southern end of Northern Lagoon

Figure 24. CTWS Water Bodies and Agricultural Activities, Images Enhanced for Clarity, Based on Screen Shots from GoogleEarth© 2015/2016 Remote Imagery.

The high water survey of the Crooked Tree wetlands revealed a very productive system that creates great amounts of biomass in several major forms, living and non-living. Cyanobacteria and algae producers, benthic and planktonic, create biomass as cells and dissolved organic matter (DOM) they extrude, representing a major food energy source for many aquatic organisms. Macrophyte producers create large amounts of living tissue and detritus made up of dead leaves, stems, roots, fruits, and flowers, as well as DOM, of aquatic plants (Figure 25a), wetland swamps (Figure 25b), riparian forests and terrestrial plants. Combined, these two living biomass and detritus production systems (microphyte and macrophyte) probably overwhelm the ability of the Crooked Tree wetland ecosystem to process and consume it all. Some of this organic matter may become sequestered below the redox zone within the sediment, stored as peat and out of circulation at least for a while. Another large component is exported to other communities, mostly downstream communities, remembering that flow can be in either direction depending on season and behavior of the Belize River. Then there is the measure of consumer productivity, largely in the form of fishes and birds, transported in and out of the watershed system with the movement of migrating organisms. Research to map out the details of wetland/aquatic production within CTWS is required to validate, roughly quantify, and describe details of detritus production and respiration, nutrient cycling and spiraling, and energy flow.


a


b

Figure 25. a. Mat of Aquatic Grass and Snowflake Lilies within Northern Lagoon. b. Littoral Swamp Around Northern Lagoon Inundated During Wet Season.

Plankton Ecology

Qualitative plankton samples were collected with the use of plankton net (120 micron) towed behind a canoe or kayak in deeper water, or cast from a pier, docked boat, or log and hauled shoreward. This was done to develop the most basic description of this community, recognizing the contribution of planktonic organisms to the ecological cycles and flows within and through lake and lagoon ecosystems. Samples were preserved in 90% isopropanol, labeled, and later examined under a stereo microscope at 40X magnification. Results of this very crude survey are given in Table 10.

There is a pronounced diel cycle within plankton of the Northern Lagoon, as indicated by samples collected after sunset and after sunrise. Of course day samples were rich in phytoplankton. Day samples contained an abundance of diatoms, other algae, and *Volvox* colonies. Samples include the cases of several Testacidae (Amoeboid protozoans). Small Cladocera represented the more abundant larger zooplankton seen at that magnification. Some small Copepoda were also present in the sample, along with a few Ostracoda.

Night samples contained no detectable photosynthesizers, but were rich in zooplankton. Copepods dominated night samples, representing an estimated 90% of total numbers of fauna seen. Cladocera and Ostracods were found in larger numbers compared to day samples, and larger individuals were collected. Night samples also contained several aquatic insects, including a few mayfly naiads (Ephemeroptera), biting midge (Ceratopogonidae), and non-biting midge (Chironomidae) larvae.

Table 10. General Categories of Organisms Found in Plankton Samples from Northern Lagoon.

DAY TIME PLANKTON SAMPLES		**NIGHT TIME PLANKTON SAMPLES**	
Diatomaceae	Some tests present		
Volvocida-*Volvox*	Seen when samples were first collected		
Testacidae	Tests present but identification uncertain		
Annelida	One small annelid found		
Cladocera	Many small individuals seen	Cladocera	Large and small individuals seen
Acariformes	A few	Acariformes	A few present
Ostracoda	Some small individuals observed	Ostracoda	Several large and small individuals
Copepoda	A few small individuals present	Copepoda	Great many (90%), several species
		Ephemeroptera	Very few young instars not identified
		Ceratopogonidae	Very few individuals
		Chironomidae	Several individuals found in samples

It is presumed that many of these zooplankters settle to the benthic area during the daytime, also presumably a as predator-avoidance behavior, and maybe avoidance of intensive solar radiation. However, it will require more extensive and quantitative sampling of plankton within the CTWS lagoons and wetlands over a longer period of time in order to more fully describe and understand patterns and processes of this very critical freshwater component of the production system.

Effectively study plankton within this system requires, a good quality compound microscope with 400X and 1000X ocular lenses and applicable taxonomic keys are required. Live samples should be viewed and images recorded soon after collection. This will allow for soft bodied organisms such as protozoa and non-arthropod invertebrates to be identified. Special sub-samples should be preserved with Lugal's solution to allow for identification of phytoplankton. Mounted slides should also be made of specimens for examination and confirmation of identifications by visiting experts when such opportunities arise. Likewise, a reference collection of larger specimens stored in 4 dram glass vials with appropriate labels should be maintained. Where possible, photographs should be taken of good quality specimens. Developing a pictorial archive will go a long way toward developing a more complete and accurate taxonomy list and provide a valuable tool for future sample identifications. Unused portions of all samples should have alcohol or other preservatives replaced and properly archived should these samples be required in future investigations as comparisons.

Consideration should be given to acquiring a high quality research applicable digital microscope. Often these units are designed to plug directly into a computer and are relatively inexpensive as compared to conventional microscopes. This device can make the job of archiving specimens much easier and more routine. Programs can be downloaded for the computer that allows the digital microscope to photograph thicker specimens from top to bottom, progressively re-adjusting focus from the top to the bottom of the specimen, and then merging all of the in-focus components of a photograph set into a single image showing the specimen in focus throughout its depth of field.

These same techniques should also be applied to other taxonomic groups focused on during an REA or in subsequent research endeavors. This includes periphyton and macroinvertebrate sample specimens. Photographs are more readily shared with taxonomists around the world and response from these experts is more immediate when photographs rather than specimens can be shared. This also avoids having to acquire government import or shipping permits for sending specimens to experts in other countries.

Periphyton, Benthic Producer, and Benthic Micro-fauna Ecology

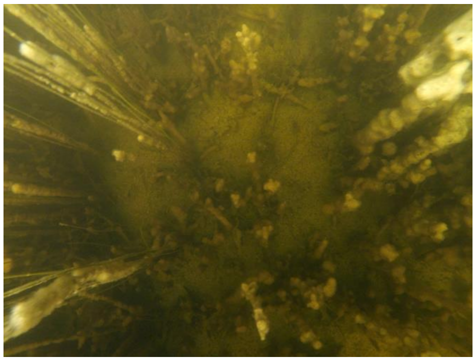
The list of producers begins with cyanobacteria and algae, faster growing and often under-estimated wetland ecosystem producers. Given the inconspicuous volume of these single celled producers and their very rapid turnover, they are major nutrient processers and recyclers. These micro-producers occur as plankton (*micro-organisms, including algae suspended in the water column*), periphyton (*bacteria*, *algae, diatoms, and associated micro-organisms attached to and growing over any submerged surface area*), and benthic (*on and within the sediment*) assemblages. Cyanobacteria can fix dissolved nitrogen gas into nitrogen forms that can be incorporated into trophic cycles. Algae and Cyanobacteria can pull dissolved nutrients from the water and rapidly produce copious amounts of biomass. This complex assemblage of micro-producers responds to sudden nutrient inputs into the water faster than macrophytes. Though their individual sizes are often microscopic, their total annual biomass production and contribution to the ecosystem can be comparable to, if not greater than contributions of the larger and far more visible macrophytes.

Different types of periphyton, representing many different growth forms, occur on different kinds of submerged surfaces, including dead leaves and wood from wetland trees and shrubs, stems and leaves of aquatic plants, the surface of sediments, and the surface of suspended and settled organic and mineral particles. Taxonomic compositions of organisms making up periphyton assemblages are yet to be determined for the CTWS lagoon/wetland system. Different substrates typically support different groups of organisms, depending on the nature of the substrate and the water within which it occurs.

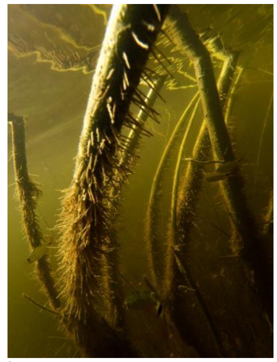
Several growth forms were noticed within CTWS wetlands. Figure 26a shows the grass and sedge dominated shoreline of Jones Lagoon during the high water stage with a loose layer of organic particles, including algae and associated organisms, that covers the sediment below the water level. Figure 26b shows this same area in the low water stage, with exposed and dried sediments covered by a dry crust of algae/cyanobacteria material that will revive once submerged again. Sediment in the more open water of the lagoon, well over a meter deep but supporting stands of sedge (Figure 27a), is also covered by this flocculent material. Besides the flocculent, sedge and lily stems, as well as submerged sedges and broadleaved aquatic plants, support heavy periphyton growth (Figure 27b). Much of this collective, pale-colored periphyton "blanket" that covers aquatic macrophytes, submerged wood, and substrata in the water is very "spongy" with spaces holding bubbles within the mass, presumably oxygen generated by photosynthesis (Figure 28a and b). These bubbles cause long "tubes" of periphyton to be carried upward, slide off of sedge stems, and float freely at the surface of the water. Other sites produce floating cyanobacteria/algal mats that form on the bottom and rip away as they grow thick and capture oxygen bubbles that make them buoyant.

a b

Figure 26. a. Sedge and Grass Vegetated shoreline with Algae-covered Sediment in Wet Season. b. Dried Algae Mat Formed During Dry Season at Littoral Edge of Jones Lagoon.

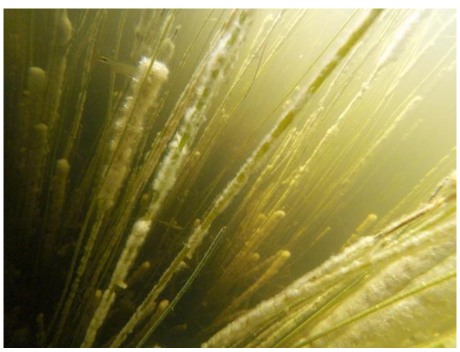


a



b

Figure 27. a. Loose Flocculent of Algae "Crumbs" Covering Meter-deep Sediment of Northern Lagoon Among Periphyton-covered Sedge. b. Close-up of Periphyton on Roots of Semi-aquatic *Mimosa* sp.



a

b

Figure 28. a. Periphyton Covering *Eleocharis interstincta* Stems in Marsh/Swamp Patch Wetlands. b. Up-close View of Periphyton Showing Bubbles in the Organic Matrix.

Periphyton is a prominent component of the CTWS lagoon/wetland system and probably a major contributor to production of DOM and POM biomass. There are many consumers that likely take advantage of this constantly available resource, including Central Tetras (*Astyanax aeneus*) (Figure 28a) and tilapia (*Tilapia mossambicus, T. niloticus*), as well as other organisms. This particular component of the ecosystem needs to be more thoroughly investigated in order to understand its importance, taxonomic richness, nitrogen processing contributions, and energetics.

It is also important to understand something of the predator-prey relationship and the effect of this on both periphyton community structure and the grazers that depend on this resource, or at least are supplemented by this encrusting algal/microorganism community. Besides coarse organic matter, periphyton organisms liberate a significant amount of DOM, the fate of which represents another area of research interest. This may involve a microbial loop that include microbial populations found in both sediment and the water column, these microorganisms being able to rapidly absorb DOM and produce new biomass that becomes food resources for other components of the aquatic trophic structure. Perhaps there may be some similarities within wetlands as described in marine ecosystems.

Algal mud assemblages growing in among and on the surface of sediment grains and within interstitial waters (*water filling spaces between sediment grains*) are also associated with a complex assemblage of bacteria, protozoans and micro-invertebrates that play a key role in nutrient processing, oxygen availability and overall system productivity that deserve further investigation. Positive and negative impacts are imposed on sediment assemblages by benthic feeders and burrowers, such as catfish, Obscure Swamp Eels, and tilapia, disrupting sediment structure and increasing exchange of oxygenated surface water with low oxygen or oxygen-depleted sediment waters, and re-suspending silts and sequestered materials of the sediment—essentially the process of bioturbation. With the potential introduction of aggressive, invasive benthic feeders, such as armored catfish, the effects of continual bioturbation may have a greater impact on the ecology of the periphyton and interstitial assemblages of lagoons and wetlands than ever before.

Benthic algae and algal muds associated with wetland and lagoon sediments during the wet season are both far more extensive and very different from the structure of these communities found during the dry season. During wet season, there is a filamentous layer of algae, along with smaller algae and diatoms associated directly with and occurring deeper within the upper millimeters of sediment. These interstitial algae are very active producers and a food resource for several important sediment foragers, both large and small. Much of this wet season biomass may also be flushed from the lagoon when high waters flow back into the Belize River as the river stage recedes during the oncoming of the dry season.

During the dry season when water level falls, exposing sediments, mats of filamentous algae and associated diatoms, cyanobacteria, and other organisms dry out to thin dark, brittle crusts (Figure 26b), remaining this way until this material becomes re-wetted as water level rises again and flood wetlands. All wetland sediments dry out, essentially becoming soils, sprouting grasses and sedges that are less tolerant of water inundation. Those exposed, moist sediments near the remaining water bodies during dry, low water periods, occur as wet blocks of “cake-like” material that easily breaks apart in layers that differ in color, texture, organic content, and interstitial algae. Typically there is a thin but heavily populated layer of earthworms burrowing through the organically rich layer, potentially a layer of earthworms that spread over much of the benthic area. Coring studies during wet and dry seasons would contribute to understanding the structure of wetland and lagoon sediments and the vertical distribution of benthic organisms.

Burrowing activity of earthworms promotes exchange of oxygen-poor interstitial waters within the sediment with water above the sediment that potentially contains more dissolved oxygen. Thus earthworms, and other burrowers, probably help increase the depth of the redox zone within the sediment. Bioturbation can drastically affect benthic assemblages of micro-organism, meiofauna, and macroinvertebrates. However, as suspended sediments re-settle, microbial activity continues, probably now with a little more oxygen availability and dispersal of waste chemical buildup (*being flushed presumably by suspending the sediment layers*).

Shallow sediment layers are constantly being disturbed by wading birds, and deeper sediments by diving birds, but to much less extent. Tilapia feed on algae, including those algae within the sediment, and can disturb sediments within deeper water that is beyond the reach of many wading birds. Other sediment disturbers include Morelet’s Crocodiles, Neotropical River Otters, and the occasional West Indian Manatee, but even more important are the impacts of people and livestock.

In the wet season, due to the rich microbial growth and activity in the sediments and in the buildup of incompletely digested POM, there may be an accumulation and buildup of organic materials. During the dry season, when waters recede, these biomass-rich, wetland sediments are exposed to the air, with much higher oxygen availability and metabolic potential. Dissolved oxygen concentrations in waters of CTWS can range from about 3.0 to 8.0 parts per thousand, representing about 0.3 to 0.8% concentration in water compared to 21% oxygen available in air. Exposed biomass buildup is broken down into more recyclable components by the time the next wet season begins. As waters rise, aquatic plant populations recover and the growth, detrital production, and breakdown cycle continues. Of course a lot of this production is exported to river communities and coastal zone communities through the continual interconnection of water flow and animal migrations.

A study of 63 water bodies was conducted in southern Mexico, Belize, and Guatemala, representing many different trophic states, sizes, altitudes, and precipitation characteristics to survey the diatoms, micro-crustaceans, and chironomids as useful bioindicators (Perez, *et al*., 2012). These groups are in plankton, periphyton, and benthic habitats throughout freshwater systems. Concentration of bicarbonate and trophic conditions of the water bodies sampled were the strongest factors influencing distribution of copepods and chironomids (non-biting midges), while diatoms, cladocerans, and ostracods responded strongly to conductivity, which is strongly influenced by precipitation and dilution. Northern Lagoon and Almond Hill Lagoon showed the highest taxonomic richness, with Northern Lagoon having the highest diversity of cladocerans (33 species) than any other site, as well as one of the highest densities of diatoms. Northern Lagoon and Almond Hill Lagoon ranked 4th and 5th in taxa richness among all sites. Table 11 lists most of the diatoms, cladocerans, copepods, and ostracods reported from the Northern Lagoon by this project (Perez, *et al*., 2012). This table also contains several species of large cladocerans and chironomids that were frequently collected in macroinvertebrate collections and are discussed in more detail later in this document.

Table 11. Diatoms, Cladocerans, Copepods, Ostracods and Chironomids Found in CTWS by Perez, *et al*. (2012).

Kingdom	**CHROMISTA**
Phylum	**BACILLARIOPHYTA**
Class	**BACILLARIOPHYCEAE**
Order	**Pennales**
Suborder	Raphidineae
Family	Araphidineae
	Fragilaria famelica
Suborder	Raphidineae
Family	Naviculaceae
	Brachysira neoexilis
	Brachysira procera
	Encyonema silesiacum
	Halamphora coffeaeformis
	Mastogloia smithii
	Navicula cryptotenella
Kingdom	**ANIMALIA**
Phylum	**ARTHROPODA**
Class	**CLADOCERA**
Order	**Anomopoda**
Family	Bosminidae
	Bosmina huaronensis
	Bosmina tubicin?
Family	Chydoridae
	Alonga dentifera
	Alonga ossiana
	Anthalona brandorffi
	Chydorus eurynothus
	Dunhevedia odontoplax
	Ephemeroporus barroisi
	Graptoleberis testudinaria
	Karualona muelleri
Family	Daphniidae
	Scapholeberis armata freyi
	Simocephalus serrulatus
Family	Ilyocryptidae
	Ilyocryptus spinifer
Family	Macrothricidae
	Streblocerus pygmaeus
Order	**Ctenopoda**
Family	Sididae
	Diaphanosoma brevireme
Class	**MAXILLOPODA**
Subclass	**COPEPODA**
Order	**Calanoida**
Family	Pseudodiaptomidae
	Pseudodiaptomus maeshi
Class	**OSTRACODA**
Order	**Podocopida**
Family	Candonidae
	Physocypria denticulata
	Thalassocypria sp.
Family	Cyprididae
	Cypridopsis okeechobei
Family	Cytheridae
	Perissocytheridea cribosa
Family	Limnocytheridae
	Limnocythere opesta
Class	**INSECTA**
Order	**Diptera**
Family	Chironomidae
Subfamily	Chironominae
Tribe	Chironomini
	Chironomus anthracinus
	Cladopelma sp.
	Corynocera ambigua
	Goeldochironomus sp.
	Lauternborniella sp.
	Parachironomus sp.
	Polypedilum sp.
Tribe	Tanytarsini
	Cladotanytarsus sp.
	Micropsectra sp.
	Tanytarsina sp.
Subfamily	Orthocladiinae
	Cricotopus sp.
Subfamily	Tanypodinae
	Labrundina sp.
	Procladius sp.

Aquatic Macrophyte Ecology

Aquatic macrophytes are relatively large producers than can be seen without magnification, with roots to whole plants continually, or periodically growing in water. Traditionally this includes the larger patchy and filamentous to "leafy" Chlorophyta (green algae), Rhodophyta (red algae), Xanthophyta (yellow-green algae), and Cyanobacteria (blue-green algae), as well as mosses, ferns, and flowering plants. This discussion focuses on the latter three categories. Generally ecological research focus has been on Chlorophyta and vascular plants (Thomaz, *et al*., 2003) that often dominate in producer biomass. Several studies have shown aquatic macrophytes to be key elements in the conservation of freshwater biodiversity and maintaining some of the critical services provided by freshwater ecosystems (Carpenter, *et al*., 1985; Carpenter and Lodge, 1986; Engelhardt and Richtie, 2001). Macrophytes provide an observable example of a detritus-based food web that can also be at least generally applied to the micro-producer scale. Aquatic and semi-aquatic macrophytes are performing the following critical services that help drive the detritus-processing system:

- Pulling nutrients (including micro-nutrients) from the sediments and the water column back into the open-water portion of the aquatic food web;
- Penetrating the redox layer with roots (emergent and submerged rooted macrophytes), exposing deeper sediments to water exchange, increasing oxygen availability to benthic assemblages;
- Providing oxygen to the roots, tissue that is entirely respiration-based, some of this oxygen entering the rhizosphere immediately surrounding every root and rootlet, maintaining microbial respiration, nutrient availability, and sediment biodiversity;
- Remove suspended particles by disrupting water movement and dissipating energy;
- Releasing nutrients extracted from sediment and dissolved in the water back toward the land in the form of detritus;
- Absorbing wave energy and stabilizing sediments;
- Providing substrate/habitat for periphyton, epibionts, macroinvertebrates, larval and juvenile fishes
- Developing living tissue as food for herbivores;
- Creating great amounts of detritus as food resources for many organisms;
- Sequestering carbon in the form of buried plant detritus.

There are examples of most life forms assumed by aquatic plants represented among the CTWS species. These include:

- Rooted submerged— completely submerged plants that are anchored by roots into sediment
- Free-floating—Plants that float on the water surface or just under the surface
- Emergent—plants growing rooted in the sediment and having foliage that reaches into the air
- Rooted Floating-leaved—rooted plants with leaves that float on the surface of the water
- Epiphytes—aquatic plants growing on other aquatic plants (Thomaz, *et al*., 2003)
- Amphibionts—plants that live mostly on saturated soil (Thomaz, *et al*., 2003)

Although phytoplankton and epiphytic algae may be abundant in freshwater systems, usually aquatic vascular plants produce much of the biomass, or at least the most visible volumes of material, that forms the base of freshwater trophic webs, with the largest portion of that biomass being consumed by aquatic earthworms, mollusks, insects, and crustaceans after plant material has died and partially decomposed through action of aquatic microbes (Madsen, 2009). Typically aquatic macrophytes that have emerged or floating leaves constitute some of Earth's most productive communities because they rarely suffer water limitations, and because leaves above the water have access to ample sunlight and carbon dioxide (Wersal and Madsen, 2012). Figures 29a and 29b show dominant floating-leaved and emerged aquatic plants in CTWS.

The vascular aquatic plants of CTWS represent a wide range of plant families (Appendix B), demonstrating many adaptation strategies for living in water (Scremin-Dias, 2003; Bornette and Puijalon, 2011). Despite their importance in wetland and open water ecology, freshwater aquatic plants have received very minimal research focus in Belize and represent a research challenge for aquatic ecologists and botanists.

a

b

Figure 29. a. Snowflake Lily (*Nymphoides indica*), a Floating-leaved Rooted Aquatic Plant. b. Sedge (*Eleocharis interstincta*), an Emergent Aquatic Plant, Both Important Marsh Plants at CTWS.

Submerged plants are less productive given that light rays are rapidly scattered by water and suspended particles. Slow diffusion rates and low availability of carbon dioxide and oxygen gases in water relevant to air limits growth of submerged plants that are often rooted in anoxic sediments. Photosynthesis may be inhibited by high concentrations of oxygen (Keeley, 1991). Free-floating aquatic plants have access to sunlight and carbon dioxide but, not being rooted, must extract nutrients from the water column by absorption through leaves rather than the rich sediment (Raven, 1981). Light availability creates strong gradients for aquatic macrophytes, resulting in zonation within lakes and lagoons, with some plants replacing others with depth, a pattern seen globally (Sculthorpe, 1967). Fast growing mats of aquatic vegetation can shade plants beneath, suppressing growth (Van, *et al*., 1976) (Figure 30).

Figure 30. A Patch of Snowflake Lilies Covering the Surface of the Water.

Juvenile and adult fishes, representing many different species, are dependent on aquatic macrophytes at some stage of their lives as habitat, nesting sites, food resources (both plant material and associated epiphytes), and protection from predators, with vegetated areas generally supporting more fishes than non-vegetated areas (Dibble, 2009). Many diving birds depend on emergent aquatic plants as nest sites (Wersal and Getsinger, 2009) and many of the submerged aquatic plants, leaves, and seeds as food resources. Within CTWS, free-ranging livestock often graze aquatic plants growing near the shore of the lagoon, churning up sediments as they feed.

Aquatic and wetland plants are also subjected to several insect herbivore species that can impact plant growth and development (Harms and Grodowitz, 2009). Within CTWS the more notable insect herbivores are moth larva in the family Pyralidae and possibly the non-biting midge, *Chironomus* sp., along with other species (Figure 31a and 31b). Notable vertebrate herbivores besides diving birds include tilapia, the Central American River Turtle, and the occasional manatee.

Many pathogenic fungi and bacteria are associated with aquatic macrophytes (Barreto et al., 2000; Shearer, 2010). Pathogens can potentially spread through aquatic plant introductions.


a


b

Figure 31. a. *Nymphaea ampla* Leaves Damaged by Pyralidae Moth Larva (possibly other invertebrate herbivores).
b. *Eleocharis interstincta* Damaged by an Unidentified Herbivore.

Oxygen presence or absence is arguably the most important chemical change imposed on an aquatic system, or any system. Aquatic plants play a key role in the availability or non-availability of dissolved oxygen within wetlands and collectively are ecosystem engineers that drive structural change (Jones *et al*., 1997) and affect the oxygen balance within the system. Aquatic vascular plants form habitat diversity and metabolic "hot spots" that accommodate microbes, algae, and animals (Kemp et al., 1984; Wetzel, 2001). All vascular plants must be able to transfer organic carbon and oxygen throughout all living tissue. Besides producing oxygen as a by-product of photosynthesis, many aquatic plants have a lacunar system, interconnected canals and spaces filled with air within the submerged tissue (Sculthorpe, 1967), that provides oxygen to the plant respiring tissue, such as submerged roots and stems (Grosse *et al*., 1996). Emerged plants can transfer organic matter through water and many have aerenchyma tissue that can determine oxygen and redox state in sediments (Wignad, *et al*., 1997). Given the continual oxygen availability at the roots, the organic matter and root detrital material support a very diverse and abundant microbial community associated with the rhizosphere of aquatic plant roots (Gunnison and Barko, 1989). Figure 32 shows the air spaces in the stem of *Eleocharis interstincta*, stems that grow up to two meters in length.

Figure 32. Air Spaces and Septa within the Stem of *Eleocharis interstincta*.

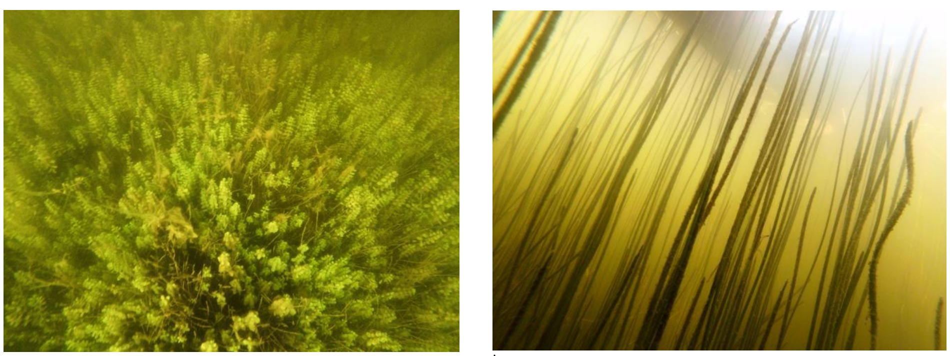
Plants with floating or emergent leaves transfer organic matter from above water to submerged tissue. These plants can actually withdraw oxygen from sediments and water by inputting organic carbon without providing oxygen to replace that consumed during respiration (Pokorny and Rejmankova, 1984; Scheffer *et al*., 2003). As already mentioned, plants with large amounts of floating leaf surface area can form thick mats, blocking sunlight from entering the water and reducing submerged photosynthesis (Caraco and Cole, 2002). Some floating-leaved plants also have well developed lacunar systems and can transport adequate amounts of oxygen to the roots (Dacey, 1980). Among those floating leaved plants that do not have oxygen transfer ability are serious invasive species that can impose serious changes in oxygen levels (i.e., Water Hyacinths).

Net ecosystem production (NEP), gross primary production minus total respiration, is a primary factor determining oxygen levels. A positive NEP indicates a net release of oxygen from metabolism within the system (Caraco and Cole, 2004). Wetlands that bury or export great amounts of organic carbon have a large NEP, and can represent a carbon dioxide sink and oxygen source. CTWS lagoons and wetlands are probably built up important carbon sinks, but continued investigation is required to confirm this expected process.

Exchange between open waters, typically with high oxygen concentrations, and vegetated waters low in oxygen due to increased respiration rates, helps reduce oxygen depletion. In addition, flowing water carries DOM and particulate organic matter (POM), with particulates settling out of the water column when transport water is slowed down by wetland plants. This provides food resources for protozoans and animals, and increasing organic material in sediments, thus increasing oxygen consumption. Additionally turbulence at the air/water interface, affected by currents and winds, increases levels of oxygen dissolved in the water (Turney *et al*., 2005), while aquatic plants with floating leaves reduces water movement and thus mixing of atmospheric oxygen with water, as shown in Figure 33. Aquatic plants can provide oxygen to sediment and water, as well as creating anoxic conditions by loading the system with organic material that leads to oxygen absorption during breakdown, and absorb large amounts of dissolved oxygen during night time respiration. These activities affect a wide range of sediment and water biochemistry, including nutrient cycling, pH, and other parameters.

Figure 33. A Patch of *Nymphoides indica* Absorbing Wave Energy on the Northern Lagoon.

Sediments contain the oxidation/reduction zone, or redox zone, typically marked by sudden change in color of the sediment a centimeter or less below the surface, sometimes deeper if there are many invertebrate burrowers and fishes that disturb the substrate. Chemosynthetic organisms concentrate at the redox zone, where they oxidize biologically and geologically derived reduced inorganic compounds. Oxygen availability at this boundary determines what compounds decompose and thus affect nutrient cycling (nitrogen, phosphorus, iron) (Wetzel, 2001). All of these processes discussed above are occurring within the aquatic plant “meadows” that cover much of the wetlands and lagoon littoral zone sediments of CTWS. A few transects photographed using a GoPro© camera revealed rich beds of aquatic plants (Figure 34a and b). Representing a full complement of growth forms, aquatic plants, cyanobacteria, and algae determine the overall ecological processes, patterns, and productivity of the CTWS ecosystem complex, including the very important job of detritus production.



a b

Figure 34. a. Large Bed of Submerged Broad-leaved Aquatic Plants. b. Submerged Portion of *Eleocharis interstincta*, Stems Growing over 2m Long, Indicating Density of Beds.

There is a seasonal pattern to aquatic macrophyte detrital production and breakdown, based on field observations of CTWS wetlands and lagoons. During the wet season abundant growth and build-up of aquatic plant biomass occurs, particularly among extensive beds of *Eleocharis interstincta*, *Nymphaea ampla,* and *Nymphoides indica*. Later in the wet season, some plants are broken away from rooted anchorages and form large, floating mats of detritus along the littoral zone, such as the *E. interstincta* mat shown in Figure 35a. Detritus mats may be concentrated by wind and wave action, often pushed into the more protected backwaters and swamp tree-lines at the edges of the open lagoons, as often occurs with *N. ampla* (Figure 35b). The wave action that helps form detritus mats may be a factor in the uprooting or breakage of sedge and lily stems, perhaps weakened by herbivores and burrowers. Mat detritus is colonized by bacteria, fungi, protozoa, microinvertebrates, macroinvertebrates (discussed in detail later) that collectively break down the material into smaller pieces of POM and continually add to the DOM pool of the lagoons and wetlands

a b

Figure 35. a. *Eleocharis interstincta* Detritus Mat. b. *Nymphaea ampla* mat at the edge of a swamp forest.

Lagoons and wetland shorelines accumulate detritus pushed shoreward by wind and waves (Figure 36a). Turbulent water transforms DOM into foam, also pushed against shorelines (Figure 36b). Shorelines move laterally up and down the shore face as water level rises and falls, spreading drift over the soil/sediment. Detritus and DOM represent nutrients taken up from wetland and lagoon sediments and "pumped" back to the surface and even back toward the land in the form of leaves, stems, seed, flowers, and pollen.

a b

Figure 36. a. Drift Line along the Shore where Floating Detritus has been Pushed Landward by Wave Action.
b. Foam Created when Dissolved Organic Matter is Mixed with Air by Wave Action.

Wetlands of Northern Lagoon are often dominated by the emergent *Eleocharis interstincta*, growing in thin to thick broken patches and bands between the open water and the tree line of the swamps, extending into the broken canopied swamp area. Growing between *Eleocharis* stands and at times integrated with the emerged stalks include Water Snowflakes (*Nymphoides indica*) (synonym: *N. humboldtiana*, see Balick, *et al*., 2000), White Water Lily (*Nymphaea ampla*) with large serrated leaves (Figure 37), Lanceleaf Arrowhead (*Sagittaria lancifolia*), shrub to small tree size Bullet Tree or Bulletwood (Bucida buceras), and Bastard Logwood (*Mimosa bahamensis)* growing around the edges of the Northern Lagoon shoreline, this assemblage and other species are particularly developed along the eastern side and northern end of the lagoon. Large patches of *Nymphaea ampla* and *Nymphoides indica* are also found in the small open backwaters within the fringing swamps of Northern Lagoon, the swamp trees serving as wind breaks.

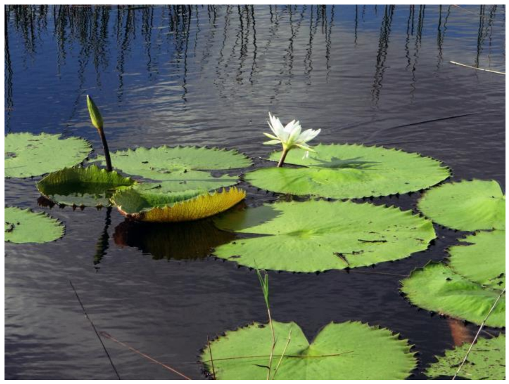


Figure 37. White Lily, *Nymphaea ampla*.

The Western Lagoon is largely covered from shore to shore by thick stands of *E. interstincta,* particularly the northern end (Figure 38a). Comparatively little emergent vegetation is found in the Sothern Lagoon. Jones Lagoon on the eastern side of the Northern Highway is very different from those lagoons on the western side of the highway. There is very little emergent and even submerged vegetation along the shoreline (Figure 38b). Instead, much of the sediment of this lagoon around is covered by a loose bed of crumbly to thin layer of algae, cyanobacteria, small submerged sedges and other associated organisms.

a

b

Figure 38. a. Northern End of Western Lagoon, Covered in Thick *Eleocharis interstincta* Marsh with No Open Water Areas, Except for the Causeway Canal. b. Jones Lagoon with Open Water and Littoral Zone Supporting Sparse Marsh Areas.

Bladderworts (*Utricularia*) form thick, dense, submerged mats among the emergent and submerged aquatic plants of the Northern Lagoon bottom (Figure 39a and 39b). Some of these patches are very extensive, and represent significant biomass. These plants do well in nitrogen and phosphorous poor waters, especially if there is abundant zooplankton available that the carnivorous *Utricularia* spp. use as alternative nitrogen sources.

Inland aquatic habitats were also examined for aquatic plants. Water mimosa, probably either *Neptunia oleracea* or *N. plena*—two trans-tropical possibilities listed by Balick, et al. (2000), were found in a few small ponds used for livestock during this survey. Water fern, *Salvinia auriculata*, is also found in isolated savanna forest ponds. In areas were *S. auriculata* were found, this floating aquatic macrophyte blanketed the surface of the water. During high water conditions, some of these isolated ponds become connected with the lagoon.

a b

Figure 39. a. *Utricularia* sp. Growing Below the Water Surface Among Submerged Macrophytes and Stems of Emerged and Floating-leaved Macrophytes. b. Close-up of *Utricularia* sp. Through Water Surface Showing Bladders.

Aquatic and semi-aquatic lagoon and wetland plant species reported from CTWS and surrounding areas are listed separately in Appendix B, with notes on ecology, distribution and biology. The BTFS project did not cover aquatic plants thoroughly and many of those aquatic plants found in CTWS not included in Goodwin, et al. (2013) are shown in red within Appendix A as listed in Balick, *et al*. (2000). However, this is not an exhaustive list and more work is required to properly inventory the aquatic plants of CTWS. The main need is to track down appropriate taxonomic keys necessary to identify neotropical aquatic macrophytes.

Wildlife

Wildlife of Concern

Crooked Tree wetlands and savannas provide important and even critical habitat for a rich diversity of wildlife, invertebrate as well as vertebrate. This highly productive wetland/grassland ecosystem complex creates tremendous amounts of green and detrital biomass during the high water season. Through there are many layers to this complex, seasonally dynamic trophic web, biomass produced feeds an abundance of macroinvertebrates, that feed many different fish species that in turn support many locally and internationally important wetland reptile, bird, and mammal species during the shallow water dry season.

Among the more notable and better known wildlife that inhabit CTWS and surrounding areas are species of concern such as Morelet's Crocodile (*Crocodylus moreletii*), Common Slider *(Trachemys scripta),* Central American River Turtle *(Dermatemys mawii),* Yellow-headed Parrot (*Amazona oratrix*), Jabiru Stork (*Jabiru mycteria)*, Baird's Tapir (*Tapirus bairdii*), Neotropical River Otter (*Lontra longicaudis*), Jaguar (*Panthera onca*), and Puma *(Puma concolor)*. During the high water season West Indian Manatee (*Trichechus manatus*) will sometimes enter the lagoons.

Comment [C6]: same comment as before

The following animal group discussions are focused on aquatic and semi-aquatic fauna that are known from CTWS or that are potentially found there based on reported ranges and habitats used. Although it is recognized that terrestrial fauna contribute to and draw from the resources of the adjacent wetland ecosystem, most terrestrial species (except for a few species that have relatively close associations with lagoons and wetlands) are omitted. Each group discussed is accompanied by ecology tables given in the attached appendices.

Aquatic Macroinvertebrates

Aquatic macroinvertebrates, as a general group, are ecologically important as food for invertebrate and vertebrate predators, and as shredders of large pieces of detritus (small surface area) into very small particles (large surface area), speeding up decomposition rates. Largely consisting of annelids, mollusks, crustaceans, and insects, macroinvertebrates are a major component of the diets of many fishes, amphibians, birds, and mammals, and therefore are a major link in the trophic cycle within CTWS wetlands and lagoons. Because of their collective ecological significance, diversity, and general abundance, analysis of aquatic macroinvertebrate assemblages are conducted to get a general understanding of the state of health of an aquatic system and to track changes that may occur particularly within streams and rivers, but also in lakes and lagoons.

For the purposes of this REA, benthic, detritus, and aquatic plant samples were collected from sites representing examples of open lagoon, flooded marshes, swamps, backwater ponds, and flooded marshes, and processed and examined for macroinvertebrates. Benthic samples were collected by scooping sediments up with a small bucket or a long-handled D-frame aquatic net with 500 micron mesh and washed either in the net or a sieve bucket having a 500 micron mesh. The remaining organic material was carefully picked through to remove any invertebrates found and those organisms were preserved in 90% isopropyl alcohol. Samples of floating leaves and detritus mats were picked through while sitting in the patch within a canoe, sorting material on trays, picking out macroinvertebrates and placing them in vials of 90% isopropyl and a label added. Specimens were later identified to the lowest level of taxonomic confidence, properly curated (labeled and preserved in fresh 90% alcohol) and included in a reference collection. Taxa collected are listed in the Macroinvertebrate Ecology Table found in Appendix D, with families represented and general responses to ecological conditions, based on descriptions in Voshell (2002) given in Table 12. Appendix E-1 and E-2 lists taxa and numbers of macroinvertebrates collected at composite sample sites listed in E-3. A total of 2,130 specimens were collected, representing 47 distinct taxonomic groups (order, family, occasionally genus).

The apple snail, *Pomacea* sp., is very visible within CTWS. It was found in abundance within most station samples and was observed, along with calcified egg cases on vegetation and other structures above the water line, throughout area in wet and dry seasons (Figure 40a). Large numbers of shells are everywhere around water and compose much of the shell hash within sediments (Figure 40b), possibly indicating a rapid turnover rate within the population and thus their importance in nutrient processing and as prey. Besides Snail Kites and Limpkins, these snails are also consumed by Great-Tailed Grackles, Morelet's Crocodiles, and catfish. A more intensive survey of this very important group of gastropods may reveal more than one species.


a


b

Figure 40. a. Apple Snail (*Pomacea* sp.) laying eggs on a tree bole just above the water line. b. *Pomacea* sp. empty shells on the shore of Northern Lagoon.

Table 12. Macroinvertebrate Families Found in Wetlands and Lagoons of CTWS, with Notes on Significance as General Environmental Indicators, mostly from Voshell (2002).

CLASS/ORDER/FAMILY	GENERAL TOLERANCE TO STRESS
PLATYHELMINTHES	
Turbellaria	
Tricladida	Relatively tolerant to relatively sensitive
ANNELIDA	
Hirudinea	High numbers indicate oxygen stress and possible organic pollution
Oligochaeta	
Lumbriculidae	High numbers- heavy organic matter breakdown, vertical mixing of sediments
Tubificidae	High numbers- low oxygen conditions, organic pollution, sewage
MOLLUSCA	
Gastropoda	Low numbers indicate soft water, water low in pH
Ampullariidae	Relatively tolerant (not covered by Voshell, 2002)
Ancylidae	Relatively tolerant
Physidae	Relatively tolerant, tolerates low levels of calcium carbonate and lower pH
Planorbidae	Range from fairly sensitive to pollution/low oxygen to facultative
Thiaridae	Invasive, highly tolerant, dominating in low oxygen and impacted habitats
Bivalvia	
Sphaeriidae	Facultative to somewhat tolerant
Unionidae	Relatively sensitive to facultative, high numbers- good quality streams
ARTHROPODA	
Arachnida	
Acariformes	Facultative as a group
Crustaceae	
Amphipoda	Facultative as a group, some sensitive, some tolerant of heavy metals, pesticides
Talitridae	
Decapoda	
Palaemonidae	Likely facultative, but little known
Insecta (Hexapoda)	
Ephemeroptera	
Baetidae	Generally facultative, ranging from sensitive to very tolerant of nutrients, siltation, low DO
Caenidae	Facultative, ranging from relatively sensitive to relatively tolerant
Odonata	
Gomphidae	Mostly relatively sensitive
Libellulidae	Mostly very tolerant, low oxygen, organic or nutrient contamination
Coenagrionidae	Relatively tolerant to vary tolerant
Hemiptera	
Belostomatidae	Very tolerant
Corixidae	Generally very tolerant
Gerridae	Relatively tolerant
Naucoridae	Possibly relatively tolerant but more study needed
Trichoptera	
Hydroptilidae	Generally facultative, with some taxa ranging from very sensistive to relatively tolerant
Lepidoptera	
Pyralidae	Primary macroinvertebrate herbivore
Coleoptera	
Dytiscidae	Most facultative, some relatively tolerant
Gyrinidae	Facultative
Hydrophilidae	Relatively tolerant to very tolerant
Scirtidae	(Probably facultative to relatively tolerant, but more study needed)
Diptera	
Ceratopogonidae	Mostly facultative, some tolerant
Tipulidae	Mostly facultative, but wide range of responses
Chironomidae	Mostly facultative, but wide range of responses, *Chironomus*- low oxygen conditions
Culicidae	Relatively tolerant

There are other snails found in samples from the area, including invasive species such as the Asian Thorn (*Melanoides tuberculata*), and possibly the Quilted Melania (*Tarebia granifera*) (shells only found), both in the family Thiaridae. These snails are discussed in more detail within the section of this document covering invasive species. Other snails include thin shelled species of Physidae that can often tolerate wide ranges of environmental conditions, species of Planorbidae (more empty shells than living snails found), and limpets in the family Ancylidae. There is a need for taxonomic keys to help sort out the mollusks of CTWS, with some keys, such as Thompson (1984) available for other subtropical areas within the region, in this case Florida.

The more obvious bivalve was occasionally collected in sediment samples, but larger shells can typically be found scattered along the shoreline. These bivalves, family Unionidae, have thin, oval-shaped shells that have a fin-shaped hinge (Figure 41). They appear to be abundant enough to be a significant contribution to food resources, based on the abundance of empty shells. These clams are probably some of the more important filter feeders found within the lagoons and wetlands. Many probably die when dry season occurs, but many may survive buried in sediments. Further study is required. Clams in the family Sphaeridae were also observed. A more extensive survey of Bivalves would require more intensive substrate sampling with a sediment dredge.

Figure 41. Unidentified Unionid Clam Common in CTWS Wetlands and Lagoons.

Detritus breakdown within sediments is also an important component of the trophic system. Heavy organic sediments are populated with aquatic earthworms that are as important to sediments as their terrestrial counterparts are to soil. In undisturbed detritus-rich sediments, submerged and exposed, there is an earthworm-rich layer that conceptually spreads through the sediment like a carpet just beneath the silty surface. These earthworms convert biofilm-covered pieces of CPOM into FPOM, much of it compacted into microbial enriched fecal pellets, as happens in the soil. Fecal pellets fall apart, exposing more surface area for colonization by microbes, increasing breakdown rates. Detrital-breakdown is largely based on availability of surface area, with earthworm activity increasing surface area as particle size is reduced. Earthworms and other shredders enrich sediment with biochemical compounds of many types in mucus, fecal pellets, and dead bodies. Burrowing activity of earthworms creates exchange between oxygen-poor sediment waters and the water above the sediment, which potentially contains more dissolved oxygen. Earthworms, and other macroinvertebrate burrowers, help increase the depth of the redox zone in lagoon and wetland sediments.

Leeches (Hirudinea) were occasionally found in samples. Most are predators of other invertebrates and some are parasites of aquatic and semi-aquatic animals. Species are known from a wide range of habitat types. Currently the taxonomy of CTWS Hirudinea has not been worked out, but specimens are archived.

Water mites (Acariformes) are commonly found in benthic and detritus samples. Usually they are not present in high numbers. Species within this group of arthropods are ecologically similar, but represent a diverse taxonomy. Most aquatic mites are piercer-predators, and the larvae and a few adult mites are external parasites, feeding on other aquatic and semi-aquatic arthropods. Given the lack of access to reliable keys, no effort was made to take mites collected from CTWS waters to lower taxonomic levels, although several different taxonomic groups could be distinguished. Many aquatic mites are micro-invertebrates.

Crustaceans are prominent in CTWS wetlands and lagoons. During a regional survey of the northern Neotropics, Northern Lagoon had the highest number of Cladoceran species than all other 62 sites investigated (Perez, *et al*., 2012). Several larger Cladoceran species were found in benthic, detrital, and plankton samples, but were not the prevalent group compared to other groups. Specimens are archived and available for further examination, and a taxonomic list is available from Perez, et al. (2012) (Table 11). Cladocerans are largely filter feeders, consuming algae, protozoa, microbial enriched FPOM.

Ostracods are found both in plankton and in benthic and detrital samples. A few were large enough to be considered macroinvertebrates. A few samples containing particles of organic material associated with high numbers of much smaller ostracods. As a group, ostracods are omnivores, feeding on detritus, bacteria, fungi, algae, and other materials. They often feed on loose detritus and biofilm by creating micro-currents that pull organic material up from the substrate, sweeping it through appendages adapted to filter out particles. Amphipods, family Talitridae (requiring confirmation beneath a microscope with better resolution), are very abundant within sediment and detritus samples collected, and are certainly very important. In general, freshwater amphipods are omnivorous scavengers and detritus feeders, rarely actually attacking living organisms, but readily feeding on recently killed organisms. They are probably important in helping to break down CPOM into FPOM, increasing breakdown rates. They are also abundant enough to be an important food resource. It is likely that the importance of micro-crustaceans within the wetlands and lagoons of CTWS is greatly understated by this rapid assessment. If sample techniques were selected that targeted micro-crustaceans, their importance in the system may become apparent.

Small palaeomonid shrimp were collected from one of the isolated ponds sampled. In low water periods, many large *Macrobrachium* sp. shrimp are abundant (Personal communication, Mr. Steve Tillett). Fishermen interviewed reported that during floods and within the wet season large numbers of “blue crabs”, “rati” crabs, and shrimp are harvested. Assessment of the importance of these larger crustaceans also requires selecting appropriate sampling strategies and designing a focused study effort.

Aquatic insects are a very important part of CTWS ecosystems. *Caenis* naiads were one of the most commonly encountered mayflies, often reported from lentic littoral zones typical of our sampling sites, including lakes, lagoons, and ponds. This genus has a set of large square gills, can tolerating low oxygen, heavy sediment, nutrient enriched conditions, and are found on silty bottoms among plant roots and patches of organic debris. They are primarily collector-gatherers and scrapers that largely feed on decaying plant material (Voshell, 2002). Given their tolerance of otherwise stressful conditions that other Ephemeroptera cannot tolerate, *Caenis* is not an indicator of good quality water. Massive swarms of *Caenis* adults gathered around lights at night during the wet season effort, but emergence in warmer climates is often year round. Mayflies in the family Baetidae were also encountered in some samples, and are also collector-gatherers and scrapers, with some species being very tolerant of heavy organic, low oxygen conditions. A few samples contained burrowing mayflies of the family Ephemeridae. Boles and Saqui (2003) reported finding the burrowing mayfly *Ephoron*, family Polymitarcyidae, but they were not collected during this recent effort.

Odonata were well represented in the collections, a very significant order of predators of other invertebrates, both as naiads and adults. Among dragonflies, the burrowing genus *Aphylla* (Gomphidae) was found in many sandy sediment samples, these naiads having a very elongated 10^{th} abdominal segment that probably gives access to oxygenated water. Also a few specimens in the family Libellulidae were collected. While Gomphids are considered to be relatively sensitive to stress caused by nutrient stimulated changes and low dissolved oxygen levels, Libellulids are typically more tolerant. However, those generalities may not necessarily apply to the *Aphylla* naiads found in CTWS wetlands. Overall, however, the most abundant odonates, as well as overall abundant predator within macroinvertebrates collected, were damselflies in the family Coenagrionidae. Two different genera within this family were distinguished based on the roundness or sharp angle of the back of the head, and very different gill structure. These damselfly naiads are climbers and sprawlers and tend to be rather stress tolerant and their abundance suggest their importance as predators.

True bugs, order Hemiptera, were represented by the families Naucoridae (creeping water bugs) and Belostomatidae (giant water bugs), both being piercer predators. This whole order is composed of air breathers that are not dependent on dissolved oxygen from the water, and can therefore tolerate low oxygen conditions that would eliminate many aquatic insects. They can also readily fly as adults and can abandon a location that becomes sub-optimal. At least one species of Gerridae are found at CTWS, skating across the surface of the water sometimes in great numbers, preying on insects and other small animals that become trapped on the surface film of inundated wetlands and open lagoons. Surface film dwellers of the family Veliidae were also present at CTWS, and like gerrids, are considered to be relatively tolerant of environmental stress conditions. Like other Hemiptera, they are also air breathers and are very mobile. Predator families of Notonectidae and Naucoridae were also represented in the samples. A few specimens of the collector-gatherer family, Corixidae, were found and it would be expected that this fast moving hemipteran is probably more abundant than indicated in samples.

Aquatic beetles are represented by the predator families of Dytiscidae (predaceous diving beetles), Gyrinidae (whirligig beetles), and Hydrophilidae (water scavenger beetles) at CTWS. Larvae of Scirtidae, a family of scrapers and collector-gathers that may also feed on algae appeared in many detritus-based samples. Then algal herbivore family of caddis flies, Hydroptilidae, was represented by a single speciman. At least two different Lepidoptera larvae, family Pyralidae, are very prevalent among attached and recently detached lily leaves, and probably constitute a very important herbivore group in these wetlands.

The non-biting midge family Chironomidae is well represented in CTWS wetlands. Many specimens collected belong to the genus *Chironomus*, also called “blood worms,” because of the presence of hemoglobin, a much more efficient oxygen carrier than found in the blood of other insects. In addition, this genus has clusters of gills attached to the ventral surface of the last abdominal segment before the anal legs, both adaptations allowing these larvae to tolerate low oxygen conditions. Given their abundance, importance in the breakdown of organic debris, and use as a food resource by many insectivorous invertebrate and vertebrate predators, these midge larvae are an integral part of the aquatic trophic webs (Voshell, 2002). Other midges found belonged to the sub-family Tanypodinae, largely predators of other aquatic invertebrates. The list of midge species reported from Northern Lagoon by Perez, *et al*. (2012) is a valuable aid in further identifying the more common chironomid species, a very important group that deserves greater attention.

Culicidae larvae are often collected around the littoral zone of the lagoons and from floating detritus material. These filter feeders are also air breathers, thriving in water heavy in dissolved organic matter and often low oxygen conditions. *Anopheles* larvae have no breathing tube and typically lie parallel to and just below the surface of the water, exposing an air vent lined with hydrophobic hairs to the atmosphere. These larvae are often found among detritus mats where they can filter out dense particles covered with biofilm with their mouth bristles, while being able to hide among the detritus, thus protected from many predators, especially fishes. Larvae of the genus *Culex* were also found in similar settings. This genus has a siphon and hangs from the water surface while they filter feed, and are often more exposed to potential predators.

Benthic macroinvertebrate communities are probably very important to this system, but fewer taxa of macroinvertebrates were collected from CTWS wetlands compared to streams and rivers. More extensive sampling is required during both seasons, including more focus on the littoral zone, backwater areas, isolated ponds, and stream reaches. Light traps and sheets should be employed in order to collect adult representatives of many aquatic larvae and naiads that otherwise may not be found. Surveys of dragonflies, damselflies and other adult aquatic insects should be conducted as well. There are also many phytothalmata or aquatic habitats associated with plants that should be sampled. Additionally, a specific effort should be made to sample mosquito populations and identify species and breeding habitats found within the area. In order to fully appreciate the diversity of invertebrates associated with the lagoon systems, an increased number of sampling protocols should be used, including bated traps, light traps, and dredge samples. Sample efforts immediately following falling flood stages may yield species that are not normally encountered.

During an early morning canoe run at 5:00 am before sun rise, December of 2015, there was a heavy fog lying low over the Northern Lagoon and condensing on the foliage of riparian and swamp trees along the edge of the open water. The condensation revealed heavy drapes of spider web on all of the branches within the trees overhanging or standing in the water (Figure 42). This indicates that there must be a significant amount of food resource for this dense population of spiders. Being over the water, it is suspected that the organisms that would become snared by this blanket of web are largely emerged adults of aquatic larvae (Chironomidae, *Caenis* sp., *Baetis* sp., etc.). This may be a significant amount of biomass moving from the water back to land-based predators, and a phenomenon that deserves further study.

Figure 42. Riparian/Swamp Canopy-dwelling Spiders Revealed by Condensation on Their Webs.

<u>Fishes</u>

CTWS lagoons and wetlands provide diverse habitat for many different fish species. Northern Lagoon was known for its freshwater fishery that has supplied a market in local communities for many decades. The lagoons are also known for the large Tarpon (*Megalops atlanticus*) that find their way into these systems during certain times of the year. However, not long after the CTWS was established, the fish assemblages of the lagoons and rivers began undergoing change in response to the introduction of tilapia (discussed in more detail under "Introduced Species" later in this document). There are a few documents available that give some insight into this system prior to the invasion, so there is no complete description of the composition of the assemblage before the influence of tilapia. Previous studies in Belize (Esselman, *et al*., 2006) and other locations in Mesoamerica (Lyons and Schneider, 1990) have revealed that the richness of native freshwater fish species is highest in coastal plain rivers, increasing as they near the sea. This is in part due to the fact that the majority of the fishes listed for the freshwaters of Belize are actually peripheral fishes derived from the marine environment, those species making up the largest group of continental fishes, being more common in waters closer to the sea (Greenfield and Thomerson, 1997).

A couple of rapid fisheries evaluations were compiled by Meekin (1985), a Peace Corp volunteer, and Miley (1994), a member of the Florida International Volunteer Corps. These short studies represent the only available baseline information on fisheries before the arrival of tilapia. Minimal formal studies are available on the fish populations of the area. Over 17 species were recognized from the area in these studies. Greenfield and Thomerson (1997) collected 25 species during the 1970s, some from Spanish Creek only. Meerman, *et. al*. (2000) reported 33 species of inland fishes from CTWS. Esselman, *et al*., (2006) conducted a fish survey of the area using a back-pack electro-fishing unit. However, his survey is not published.

A list of species observed by fishermen and researchers is given in Appendix F. A principal source of information for the 2003 REA of CTWS (Boles and Saqui, 2003) was the collective knowledge of some of the local fishers. The Wet Season 2002 Fisheries Team conducted interviews with five village fishermen. Most of the older fishermen interviewed average about 40 years in the trade. The most common fish caught by those fishermen interviewed include Yellowjacket Cichlid (*Cichlasoma friedrichsthali*), Redhead Cichlid or Tuba (*C. synspilum*), Maya Cichlid or Crana (*C. urophtalmus*), Bay Snook (*Petenia splendida*), and Tarpon (*Megalops atlanticus*) (Hecker, 1987). Stone Bass (a marine species?) was also reported, but identification is not certain. Fishermen also identified Central Tetra or Billum (*Astyanax aeneus*), locally called sardines, as important prey to larger predatorily fishes. Catfish (probably *Rhamdia guatemalensis*) and Blue Catfish or Baca (*Ictalurus furcatus*) are sometimes caught but the catfish are usually not kept. Tilapias (*Tilapia niloticus* and *T. mossambicus*) are common and important market fish, feeding mainly on algal mud and aquatic plants.

Tarpon usually enter the lagoon system with the inflow of floodwaters, remaining during high water and retreating as the water stage begins to fall. Other marine fishes reported from the area include Crevalle Jack (*Caranx hippos*) (may be Horse-eye Jack, *Caranx latus*), Black Snappers (may be Gray Snapper, *Lutjanus griseus*), Stone Bass (uncertain identification),and snook (*Centropomus* sp.). During high water, sharks, probably the Bull Shark (*Carcharhinus leucas*), are reported being sighted in the lagoons (Mr. Steve Tillett, personal communication). Freshwater Sawfish (*Pristis microdon*), CITES Appendix II, have also been reported caught in the lagoons in the distant past but have not been reported for years. Fishes that enter the lagoons with the rising water tend to stay longer periods than in the past because the receding waters tend to be retained longer due the causeway blocking and slowing the free flow of water.

Fish and their predator populations vary from wet season to dry season. During the dry season, much of the fishes become trapped in the deeper portions of the lagoon, the central portion of the river bed flowing through it. Attracted by the large amount of trapped fish prey, local density of birds, turtles, and crocodiles increase. This is especially true for migrant birds that are attracted to CTWS by this abundant and easily accessed food resource. Vultures and hawks also take advantage of dying and dead fishes as a food resource. Another resident fish predator is the Neotropical River Otter or Water Dog, often found around the rivers and deeper waters.

A great many fishes are confined to shrinking water bodies, and therefore suffer higher mortality rates due to degrading water quality and, as some fishermen indicate, reduced food availability. Fishermen described how thousands of fishes die, their bodies floating on the water surface, further deteriorating water quality conditions, increasing stress to the survivors. This seems to be particularly true for Jones Lagoon, where abundant fish occur but few wading birds and other predators gather to harvest these fishes, as compared to the larger lagoons on the western side of the highway (Mr. Steve Tillett, personal communication). During the dry season, fishes that do survive may be thin and many become infested with parasitic worms that grow beneath their scales.

A wide range of feeding guilds is represented by fishes of CTWS. Shad (*Dorosoma petenense* and *D. anale*) are plankton feeders but will also feed on benthic organisms. Catfishes in the families Ictaluridae and Pimelodidae feed on invertebrates and small fishes, often specializing in bottom feeding. Other benthic predators include the Obscure Swamp Eel (*Ophisternon aenigmaticum*)

Peocilid fishes are largely predators of invertebrates, many of the smaller species feeding from the surface of the water. However, the Pike Killfish (*Belonesox belizanus*) is a Poecilid that strictly eats other smaller fishes, mostly other Poecilids. Larger piscivores include the Bay Snook (*Petenia splendida*), a freshwater Cichlid, and snooks (*Centropomus* spp.) that enter the lagoons from~~form t~~he sea during high water, along with jacks and some of the other marine fishes that enter freshwater systems. The introduced tilapia largely feed on algae and plant material. Central Tetras (*Astyanax aeneus*) are found throughout much of Belize and are abundant in CTWS waters. They are very general in their feeding habits, tearing apart large prey, working in schools. They also pluck suspended particles out of the water column, graze on biofilm growing on sediment and rocks, and eat living plant material.

Amphibians and Reptiles

Crooked Tree Wetlands are abundant in amphibian and reptile residents. A list of reptiles and amphibians that have been reported for the CTWS wetlands and lagoons, or reptiles and amphibians that are expected to be there based on range and habitat descriptions (Lee, 2000) is given in Appendix G. Those listed are species that are associated with aquatic habitats. Many terrestrial species that are quite common in the CTWS terrestrial areas were not listed. A brief description of general ecology, trophic position, habitat types and reproductive patterns are given where such information was available.

Frogs and toads are important components of CTWS aquatic ecosystems, being both invertebrate predators and very important food resources for many wildlife species. Out of the Anurans found within this area, there are 16 species that are more strongly associated with these water bodies. Many of the non-listed frog species tend to breed in bromeliads and other arboreal aquatic sites. The 8 Hylidae, or tree frog species in the list, were sorted out of the rest because they use temporary pools, flooded pastures, and ditches during the wet season, as do Burrowing Toads (*Rhinophrynus dorsalis*), and Tungara Frogs (*Physalaemus pustulosus*). Both Bufonidae species, the Gulf Toad (*Bufo valliceps*) and the Cane Toad (*Rhinella marinus*) (synonym: *Bufo marinus*), use either temporary pools or permanent water bodies (see Meyer and Foster, 1996). The remaining 4 species, including the White-lipped Frog (*Leptodactylus labialis*), Sabinal Frog (*L. melanonotus*), Rio Grande Leopard Frog (*Rana berlandieri*), and Vaillant's Frog (*R. vaillanti*), all use a wide range of permanent water bodies and are the species readily consumed by many aquatic predators. Their tadpoles are important grazers of periphyton within permanent waters and juvenile and adult frogs are predators of insects and other small organisms.

Now listed on CITES Appendix I, Morelet's Crocodile (*Crocodylus moreletii*) were hunted commercially in Belize in the 1930s and 1940s, with no size limits, and many juveniles were harvested. By the 1950s people began to notice declines and in the late 1960s Morelet's Crocodiles were almost hunted to local extinction and conservation measures were required (Frost, 1974). *C. moreletii* living in the rivers, lagoons and wetlands of CTWS is only found in Guatemala and Belize, with populations within this country still under great pressure when Abercrombie *et al*. (1980) investigated their status in the late 1970s. Crocodiles were first protected in Belize under the Wildlife Protection Act of 1981, and a ban on the international shipping of skins put into place that same year (Marin, 1981). The population of *C. moreletii* has increased significantly since being placed under legislative protection.

Comment [A7]: same comment as before...just verify

A survey by Platt and Montanucci (1993) found no crocodiles at CTWS, however. The scarcity of crocodiles was also noted by community members. Fishers do report seeing *C. moreletii* fairly commonly in Northern Lagoon. A few crocodiles were found in Black Creek that connects the Northern Lagoon to the Belize River. Also some crocodiles were found in Mexico Lagoon and Jones Lagoon. Overall, based on the findings of this survey, indications are that the populations of northern Belize have recovered from extensive exploitation that occurred in the 1930s and 1940s. In a follow-up survey, Platt and Thorbjarnarson (2000) encountered larger numbers of *C. moreletii* in alluvial lagoons as opposed to rivers, creeks and coastal mangrove habitats. Although no immediate threats to *C. moreletii* populations were noted in Northern Belize, it was proposed that pesticide and other types of contamination of the habitats may produce long term effects imposed on those populations living in habitats surrounded by agriculture. Rainwater *et al*. (1998) and Wu, *et al*., (2000) have detected significant concentrations of organochlorine pesticides in eggs of *C. moreletii* of northern Belize.

The effect of the ban on export of hides in 1981 on *C. moreletii* populations in Belize is indicated by comparisons with previous surveys. Not only have numbers increased compared to Abercrombie *et al*. (1980, 1982), but the proportion of the population that are adults increased (Platt and Thorbjarnarson, 2000). Reduced numbers of adults documented by Abercrombie *et al*. (1980) may be a result of the tendency of older crocodiles to hide or move away at the approach of humans. The largest densities of crocodiles in Belize are found in lagoons that are not associated with rivers (such as karst sinks). However, the greatest numbers of juveniles were found in alluvial lagoons, even though nest failure is typically higher in these often flooded lagoons (Platt, 1996). When the first REA of CTWS was conducted (Boles and Saqui , 2003), it was recognized that the local population has dramatically improved over the past few decades, with fishermen claiming they can spot up to forty or more in some places. They reported many sightings along Black Creek and the Belize River. A few crocodiles were spotted during night walks along the Causeway in that earlier REA field effort.

Crocodile numbers increase during the start of the dry season because the fishes concentrated in smaller water bodies are easy to catch. Presumably *C. moreletii* move into the area from the Belize River and surrounding areas to take advantage of the available fish. The average crocodile measures about 1 to 1.2 m (3 to 4 ft.) in length with some of the larger individuals reaching up to 2.4 to 2.8 m (8 to 9+ ft.) in length.

Average size of clutch is about 25 eggs, with an average of 4 or 5 eggs per clutch being infertile. Nests are often built on small islands in the beginning of the wet season. Often nests are lost to flooding and predation (raccoons, gray fox, and ants). Juveniles feed on insects, apple snails, and crayfish. Larger crocodiles eat the same prey, but also consume fish, turtles, lizards, and small mammals. Alluvial lagoons (such as those of CTWS) may be important rearing areas, producing crops of juveniles that move into breeding sites upon becoming sexually mature, probably at the age of 7 or 8 years (Platt, 1996). Little is known about the adults, but they have been recorded eating apple snails, a cattle egret, and several seen eating the carcass of a cow.

Four families of freshwater turtles occur in Central American waterways and wetlands, including Kinosternidae or semiaquatic mud turtles, Emydidae or sliders, and Dermatemydidae containing the Central American River Turtle, all represented within CTWS, and Chelydridae or snapping turtles that are known from southern Belize. Belize boasts 8 freshwater turtle species (Appendix G) with all but *Chelydra serpentina*, the snapping turtle, residing in CTWS (Weyer, *et al*., 1986). The most abundant turtles include the Bocotora or Slider (*Trachemys scripta*) (Figure 40), the Mexican Giant Musk Turtle or Loggerhead (*Staurotypus triporcatus*) and the prized Central American River Turtle or Hicatee (*Dermatemys mawii*), which occurs in the rivers and lagoons of CTWS.

Turtles begin laying their eggs in the dry season in secluded banks, with hatchlings typically emerging during the dry season. Turtles are most abundant during the dry season when more fish are available. However they usually leave the ponds before these water bodies dry out. During low water periods, many turtles tend to bury themselves in the mud, coming back out again after the waters begin to rise. An increase in turtle populations was noticed after the causeway was built and water level rose, especially in Hicatee populations. The year after the construction of bridges in the causeway, a large number of dead turtles and fishes were reported (Hadley, 1995). One of the major problems for freshwater turtles is that they are commonly eaten throughout much of their ranges by people. *D. mawii*, the Hicatee, is particularly hunted and populations are suffering (Moll, 1986). Even in protected areas poaching can be heavy.

D. mawii is a relatively large, freshwater river turtle found in the watersheds of southern Mexico, Belize, and Guatemala that discharge into the Caribbean Sea, and is hunted for meat throughout its range (Alverez, *et al*., 1979). *D. mawii* nest in dispersed locations during the wet season when waters are high, avoiding intensive harvesting of nests by predators (Polisar, 1992). It seems to have been removed from most of its range, except for Belize, where it was common within the thinly populated and remote areas around Belize up until 1984. *D. mawii* began to decline in Belize as trails, roads, and development give people access to remote habitats (Moll, 1986, 1989). In response to declining numbers and excessive exploitation, *D. mawii* is listed in CITES Appendix II. Polisar and Horwitch (1996) discuss conservation of the Central American River Turtle.

Sliders (*Trachemys scripta*) are largely aquatic turtles, wondering away from water during the wet season sometimes (Figure 43). Adults feed mostly on aquatic vegetation, as well as macroinvertebrates and fishes, being active mostly during the daytime. They nest during the dry season, with females producing from 1 to 6 clutches, each containing from 9 to 25 eggs, and young turtles emerging 71 to 83 days later during the wet season (Lee, 2000). These turtles may also be harvested for food, with some larger turtles reaching 600mm (23.6 in.) in length. There are many sub-species of this turtle found throughout its range from Central and Eastern United States to Venezuela and Columbia

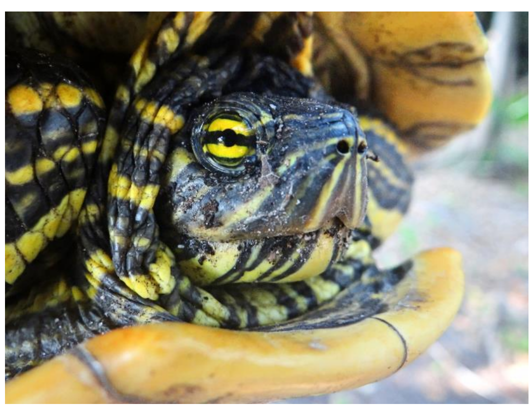


Figure 43. The Slider (*Trachemys scripta*).

Responding to a need for more information on this turtle in Belize, researchers were initially invited by Community Baboon Sanctuary members to survey a 32 km (19.9 mi.) reach of the Belize River. Research began in the later part of 1989, extending into other reaches of the Belize River, Rio Bravo Conservation and Management Area, and CTWS (Polisar and Horwitch, 1994). This study revealed that turtles were harvested throughout the year, but greatly increased during the end of the dry season, April and May, when shrinking water bodies make turtles easy to harvest, with a traditional Easter meal featuring Hic~~k~~atee (Polisar and Horwitch, 1994).

Typically turtles are hunted with nets, harpoons, or by free-diving, with selection going for the larger animals, the females (Polisar and Horwitch, 1994). The study showed that heavy hunting pressure caused both a population decline, but also loss of adult turtles, especially females. Legislative protection as per the Fisheries Act Chap 210, 210s: section 12:02 Laws of Belize rev. 2000s and educational outreach have helped sensitize people to the plight of *D. mawii*, but the Hic~~k~~atee is still vulnerable and in need of conservation management. Hicatee turtles have also been caught in fishing nets as bycatch in the Crooked Tree Lagoon.

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Four lizards are listed, but two have marginal association with water bodies, while the Brown Basilisk (*Basiliscus vittatus*) and the Green Iguana (*Iguana iguana*) are highly associated with lakes, lagoons, streams, and rivers, but do not feed on aquatic organisms. The Green Iguana is a good swimmer and can actually remain submerged for half an hour. Five species of snakes are on the list. The Boa constrictor (*Boa constrictor*), the Indigo Snake or Black-tail (*Drymarchon corais*) and the Checkered Garter Snake (*Thamnophis marcianus*) spend time associated with water bodies, will enter the water occasionally, and consume aquatic prey. The Western Ribbon Snake (*Thamnophis proximus*) is a semi-aquatic snake, and the Orangebelly Swamp Snake (*Tretanorhinus nigroluteus*) is an uncommon aquatic snake, both of which consume aquatic prey.

Birds

CTWS is internationally famous for its incredible birdlife. During the dry season, as the wetlands within the Peten, Guatemala and Yucatan, Mexico begin to dry up, aquatic birds begin to migrate to the lagoons and wetlands of CTWS. By April, the peak month, there are many thousands of cormorants, herons, egrets, and ducks, but many birds can be spotted throughout the dry season. Jabiru Storks arrive from Campeche, Mexico during November, begin building their large stick nests by December or January, and young fledge by June (see Barnhill, *et al*., 2005). The Peregrine Falcon catches coots and other water birds and Snail Kites, with their sharply curved beaks, ply the wetlands for Apple Snails. Colonies of Boat-billed Herons tuck away in the trees along the banks of Black Creek and Spanish Creek.

The CTWS Checklist put out by BAS records 294 species (minus 23 listed from only one or two historical records and 3 species that are only occasional visitors) seen in the area. This includes birds from all habitat types within the area, broadleaf forests to wetlands and lagoons, with occurrence of each species within the CTWS area being described. "Permanent residents" are of course also breeding populations within the area. "Seasonal residents" are birds that occur at CTWS and surrounding area during the breeding season and are assumed to be nesting. "Winter residents" are migratory birds that only spend the winter at CTWS and do not breed in the sanctuary. "Transients" are those species that are passing through CTWS during migratory flights. Out of the 294 bird species listed on the BAS CTWS Checklist (minus those already mentioned), 183 species are described as permanent residents, 62 as only winter residents, 12 species listed as both winter residents and seasonal residents, and 6 species that are only seasonal residents. Another 29 species are transients.

Comment [A8]: 331species have been recoreded at CTWS in eBird as of November 2017

The extensive network of waterways within CTWS creates optimum habitat for many aquatic birds, wading birds, and shore birds, as well as food resources used by more typically terrestrial birds. A sub-list of 81 aquatic/semiaquatic birds and those birds directly consuming live and carrion aquatic food resources, with ecology notes for each species, is in Appendix H. These birds are also listed in Table 13 according to their residence status, with permanent residents numbering 25 species, 15 of which are aquatic/semiaquatic and 10 are more terrestrial birds either specialized in eating aquatic organisms (Osprey, Snail Kite) or that feed on carrion during periods of large-scale fish die-off. Another 36 species of aquatic/semi-aquatic birds are winter residents in the CTWS area, 11 of these species being both winter residents and seasonal residents during breeding season, with 30 of those species being considered fairly common to very common. Four of those birds listed as winter residents in Table 13 are terrestrial species using aquatic food resources. Migratory transients are represented by 5 semi-aquatic species, and an additional four terrestrial birds typically harvest emerged aquatic insects or harvest invertebrates along the shoreline.

Table 13. Categories of Occurrence for Aquatic and Semi-aquatic Birds Residing in or Passing Through CTWS.

PERMANENT RESIDENT	WINTER RESIDENT (species that are also seasonal residents are shown in **blue**)		MIGRATORY TRANSIENT
Least Grebe	Pied-billed Grebe	American Avocet	Ruddy Turnstone
Anhinga	American White Pelican	Greater Yellow-legs	Semipalmated Sandpiper
Least Bittern	Neotropic Cormorant	Lesser Yellow-legs	White-rumped Sandpiper
Bare-throated Tiger Heron	Great Blue Heron	Solitary Sandpiper	Pectoral Sandpiper
Green Heron	Great Egret	Spotted Sandpiper	Laughing Gull
Boat-billed Heron	Snowy Egret	Western Sandpiper	Cliff Swallow
Roseate Spoonbill	Little Blue Heron	Least Sandpiper	Barn Swallow
Jabiru	Tricolored Heron	Short-billed Dowitcher	Prothonotary Warbler
Wood Stork	Cattle Egret	Long-billed Dowitcher	Louisiana Waterthrush
Muscovy Duck	Agami Heron	Wilson's Snipe	
Snail Kite	Black-crowned Night Heron	Gull-billed Tern	
Ruddy Crake	Glossy Ibis	Caspian Tern	
Gray-neck Wood Rail	White Ibis	Belted Kingfisher	
Purple Gallinule	American Wigeon	Merlin	
Limpkin	Fulvous Whistling Duck	Peregrine Falcon	
Northern Jacana	Black-bellied Whistling Duck	Tree Swallow	
Ringed Kingfisher	Blue-winged Teal	N. Rough-winged Swallow	
Amazon Kingfisher	Northern Shoveler		
Green Kingfisher	Ring-neck Duck		
American Pigmy Kingfisher	Lesser Scaup		
Black-collared Hawk	Osprey		
Common Black Hawk	Sora		
Black Vulture	Common Moorhen		
Turkey Vulture	American Coot		
Lesser Yellow Head Vulture	Black-necked Stilt		

Note: Those bird species shown in **green** are not considered semi/aquatic or aquatic birds, but are closely associated with wetlands and lagoons of CTWS.

Out of the 67 resident species of aquatic/semi-aquatic and aquatic resource using birds listed for CTWS, 46 species are common enough and present for long enough time to collectively have a significant effect upon the ecology of the wetland system. Of these 46 species of aquatic/semi-aquatic and fish/aquatic invertebrate/aquatic plant-feeding birds, there are 14 species of diving birds, 16 species of wading birds, 10 species of shore birds, and 6 fish predators that hunt on the wing. These shallow water lagoons and wetlands are critical for wading birds. During the dry season there are many thousands of birds that congregate in these waterways. During the dry season, thousands of birds have been counted in the lagoons, Table 14 giving relative numbers for key species. Water level is important in determining distribution of wading birds (Bancroft, *et al*., 2002). Habitat use by wading birds strongly reflects hydrographical conditions (Powell, 1987).

Appendix I lists information on occurrence, population estimates and status for Belize, and trophic position for 60 species of CTWS water birds covered by and Miller and Miller (2006). Their assessment was based on a decade of data in the Belize Biodiversity Information System (BBIS) maintained by the Wildlife Conservation Society (WCS) Belize office. The bird data base is the most extensive, compiled from many sources, and in particular from the birding community within Belize. The estimates for Belize populations throughout the country reported by Miller and Miller (2006) for those 60 species in Appendix I are based on Christmas Bird Count (CBC) data, Jones (2003), and the BBIS. Some of this information is quantitative, based on counts during aerial surveys conducted by Figueroa *et al*. (2004) and Martinez *et al*. (2004).

Table 14. Assemblages of Birds Often Occurring in the Following Relative Numbers at CTWS.

Neotropical Cormorants	*Phalacrocorax brasilianus*	many thousands
Great Egrets	*Ardea alba*	several thousand
White Ibises	*Eudocimus albus*	a couple of thousand
Limpkins	*Aramus guarauna*	a couple of thousand
Snowy Egrets	*Egretta thula*	a thousand or so
Wood Storks	*Mycteria americana*	a thousand or so
Blue-winged Teals	*Anas discors*	a thousand or so
American Coots	*Fulica americana*	a thousand or so
Boat-billed Herons	*Cochlearius cochlearius*	hundreds
Little Blue Herons	*Egretta caerulea*	hundreds
Green Herons	*Butorides virescens*	hundreds
Tri-colored Herons	*Egretta tricolor*	hundreds
Black-necked Stilts	*Himantopus mexicanus*	hundreds
Black-crowned Night Herons	*Nycticorax nycticorax*	a few
Bare-throated tiger herons	*Tigrisoma mexicanum*	a few
Rosette Spoonbills	*Platalea ajaja*	a few
Jabiru Storks	*Jabiru mycteria*	a few
Great Blue Herons	*Ardea herodias*	a few
Muscovy Ducks	*Cairina moschata*	a few

Table 14 list those species considered to be vulnerable or threatened/endangered and those species of concern for a total of 45 out of 63 aquatic and semi-aquatic birds (not counting the osprey, snail kite, and kingfishers) listed in Appendix I, with 5 of the 17 remaining species not being rated due to insufficient information (Miller and Miller, 2006). The Agami Heron and the American White Pelican are listed by the IUCN as "near threatened." Out of the 45 species of concern and vulnerable species, 14 are permanent residents, 11 are winter and summer residents, and 14 are only winter residents. Six species are only visitors or migrating transients within CTWS.

Belize CBC data collected by dedicated and seasoned birding groups from around the country, standardized to factor out differences in observation time, was graphed for all water birds recorded for at least five years were graphed by Miller and Miller (2006). The fourth column of the Appendix I table shows possible population trends indicated by this analysis, indicating the approximate percent of decrease or increase in populations that has occurred over the time for 40 species found at CTWS. Populations of four species, including Limpkins, remained the same, 13 species showed an increase in population size, and 23 species showed a decline. The Blue-winged Teal and the White Ibis showed increase of 5 and 6 times the population size when assessment began, and Black-necked Stilt, Lesser Yellow-leg, and Least Sandpiper populations appear to have doubled, based on these estimates.

The CBC data further suggests that Great Blue Heron, Great Heron, and Cattle Egret population numbers have declined by roughly 60%, and Common Moorhens have dropped by about 70%. Wood Storks and Gray-necked Wood-rails have been reduced by 80% and 85% respectively. Little Blue Herons, Green Herons, and Purple Gallinules have decreased by about 90% and Neotropic Cormorants and Northern Jacanas are down by 95%. Of course the CBC data is a relatively rough indicator of population health, but the indicator is of significant merit that the trends should be seriously considered.

Column 5 of the table in Appendix I indicate the status of 54 water birds found in CTWS for the entire country based on information from the CBC and other sources used by Miller and Miller (2006). Of these, 19 are considered vulnerable and endangered/threatened in Belize and another 26 species are considered to be species of concern. However, many of these same species are considered by ornithological experts in the country to apparently have secure populations within Belize (7 vulnerable and endangered/threatened species, and 17 species of concern). Status of CTWS bird species are listed in Table 15.

Table 15. Status of CTWS Bird Species Based on Miller and Miller (2006).

PERMINANT RESIDENTS	WINTER/SUMMER RESIDENTS	WINTER RESIDENTS	VISITORS/ MIGRATORY TRANSIENTS
Vulnerable and Endangered/Threatened Species			
Yellow-Crowned Night Heron Roseate Spoonbill Jabiru Stork Wood Stork Muscovy Duck Purple Gallinule	Great Blue Heron Snowy Egret Black-crowned Night Heron White Ibis Black-bellied Whistling Duck	Tricolored Heron Agami Heron Glossy Ibis Fulvous Whistling Duck American Wigeon Blue-winged Teal Northern Shoveler Lesser Scaup	
Species of Concern			
Least Grebe Anhinga Boat-billed Heron Green Heron Ruddy Crake Gray-necked Wood-rail Sungrebe Northern Jacana	Pied-billed Grebe Great Egret Little Blue Heron Cattle Egret Common Moorhen Black-necked Stilt	American White Pelican Neotropic Cormorant Western Sandpiper Least Sandpiper Wilson's Snipe Caspian Tern	Brown Pelican Ruddy Turnstone Semipalminated Sandpiper White-rumped Sandpiper Pectoral Sandpiper Black Tern
Species with Apparently Secure Populations in Belize			
Least Grebe Anhinga Least Bittern Bare-throated Tiger-heron Green Heron Yellow-crowned Night-heron Boat-billed Heron Roseate Spoonbill Ruddy Crake Gray-necked Wood-rail Sungrebe Limpkin Northern Jacana	Pied-billed Grebe Great Blue Heron Great Egret Snowy Egret Little Blue Heron Cattle Egret Black-crowned Night Heron Common Moorhen American Coot	American White Pelican Neotropic Cormorant Tricolored Heron Agami Heron Killdeer Greater Yellow-legs Solitary Sandpiper Spotted Sandpiper Wilson's Snipe	Brown Pelican Laughing Gull
Species with Insufficient Information to Assign a Category			
		Sora American Avocet Lesser Yellow-legs Short-billed Dowitcher Long-billed Dowitcher Caspian Tern	Black-necked Stilt

Note: Yellow highlight = species of concern
Red highlight = vulnerable and endangered/threatened species

Annual change in water level within lagoons and wetlands is a primary factor affecting reproduction and growth of prey organisms, and their availability to wading birds in particular, birds that specialize in hunting fish and other prey in the shallow littoral zones. Wet season to dry season fluctuations in water level therefore significantly affect bird populations in the Crooked Tree lagoons and wetlands. During high water levels of the wet season, the water line is very dynamic, moving up and down the slope of the lagoon basin and wetland fringe, often inundating swamplands. When the water is high, the shallow water areas are more extensive and prey is spread thinly. During the dry season, as water level falls, shallow water areas shrink around drying lagoons and ponds, concentrating abundant populations of fish, frogs, snails, clams, crustaceans and aquatic insects within these small areas, making them easy to catch. Great numbers of fish-feeding birds flock into the lagoons, ponds and streams during the dry season when food is hard to find in other places. Many birds from areas around Belize and the region take refuge in these lagoons during the dry season when smaller wetlands begin to dry up (Miller and Miller, 2006).

CTWS is also an important resting and refueling stop for five species of shorebirds engaged in autumn and spring migration to and from northern ranges. All of these species are listed as uncommon at CTWS except for the White-rumped Sandpiper. The extensive number winter residents, most of these being wading and diving birds, begin arriving in the beginning of autumn and many stay until around January to early February, the beginning of the dry season when prey becomes more readily available. Winter residents are able to store body fat in preparation for migratory flights. Of course the permanent residents and seasonal residents have ample food resources for raising fledglings. The density of fish predators that accumulate within the Crooked Tree wetlands, combined with the harvests of local fishers, is an indication of the abundance of fishes inhabiting this ecosystem, which reflects the volume of invertebrates and aquatic plants and algae required to maintain such biomass.

Water level change can have a very significant effect on the reproductive success of wading birds (Ogden, *et al*., 1980; Frederick and Collopy, 1989), affecting such factors as food availability within wetlands and lagoons. Number of nesting individuals within an area can be determined by the food resources available (Bildstein, *et al*., 1990, Frederick and Collopy, 1988). Also, overall nesting productivity can be related to the availability of food organisms (Frederick, 2002). Reproductive activities of wading birds are timed to external cues, such as the amount of rainfall and the effect of increased rainfall on wetlands. Wading birds' reproductive activity can be synchronized with external phenomena (namely, the amount of rainfall and its effects on local wetlands). Nesting by some species occurs during the dry season when surface waters are shrinking and fish and other aquatic prey are concentrated in small water bodies and are easy prey (Bancroft, *et al*., 1990).

Jones, *et al*. (2000) noted that at least 300 American White Pelicans were seen at CTWS in 1998; and that Glossy Ibis has been documented January 30-31, 1993, again in January 27 of 1995, and 12 individuals December 20, 1998; 40 to 50 American Wigeons were noted on February 1, 1997; Bonaparte's Gull was spotted in Northern Lagoon on March 4, 1996; and Forester's Tern was noted in Northern Lagoon on April 13,
1997. Ring-necked Ducks are recorded at CTWS from October 28, 1994 and other sightings through April 1, with 80 individuals counted January 29, 1994, flocks of 25 or greater seen often (Jones, *et al*., 2000). A small group of Masked Ducks were observed February 1, 1997 on Northern Lagoon (Jones, *et al*., 2000). Jones (2003) documented several unusual bird sightings at Crooked Tree, April 1 and 2, 2003. He indicated that the number of water birds was continuing to increase each year, with 300 American White Pelicans, 300 Glossy Ibises, 40+ Jabiru Storks, 60 Laughing Gulls (a large number for CTWS), and 40+ Common Terns being observed by seasoned birders. This was not only the largest concentration of these terns documented in Belize, but also the first time it was seen this far inland. One Crested Caracara was also observed, maybe extending its range due to deforestation in the Yucatan.

There have been several studies and detailed observations of notable bird species of the Crooked Tree wetlands and surrounding dry savanna and lowland broadleaf forests. Among this short list is the Jabiru Stork (*Jabiru mycteria)*, one of the most recognizable bird species of the wetlands, the largest bird in Belize, and the poster bird of CTWS (Figure 44). The Jabiru is not an ISBN species of concern, and populations have actually increased after it received legal protection within Belize in 1973. It is also protected by the United States Migratory Bird Act. Protection and conservation of Jabiru habitat is essentially protecting the wetland system.

Figure 44. Jabiru Stork (*Jabiru mycteria*).

These large storks inhabit freshwater marshes, savanna lagoons, and agricultural land having ponds (Hilty and Brown, 1986), including pastures, shrimp farms, and fish farms. Borjs (2004) documented that for Jabiru in Northern Belize, small fishes (15 cm or smaller) made up about three fourths of their diet, followed by Obscure Swamp Eels (*Ophisternon aenigmaticum*), Apple Snails (*Pomaceae* spp.), and large fish over 30 cm, such as cichlids, including tilapia, and catfish. They tend to be solitary nesters, using large trees in pine savannas and broadleaf forest patches surrounded by wetland savannas throughout their range. In the Crooked Tree wetlands, most of the nest sites are actually established outside of the protected area. It has been proposed that Jabiru Storks from Belize may migrate to the Usumacinta drainage in southern Mexico in July, returning to Belize in November or early December (Miller, 1995; Howell and Webb, 1995). Jabiru Storks are known to be able to soar up to a 1000 m high and travel large distances. However, a study of Jabiru in Belize by Figueroa (2005) did not observe movement, and considered Belizean populations to be non-migratory, moving out of the area only in extreme weather events, such as hurricanes.

Jabiru Storks primarily used the open areas around the New River Lagoon and CTWS area, those wetland areas that are seasonally flooded, with a few birds using habitats that included lowland dry savanna, lowland broadleaf forest and surrounding agricultural fields (Borjas, 2004). When the Belize River rises, flooding the lagoons, the foraging behavior, species of available prey, and distribution of Jabiru Storks across their range is affected by wetland water levels. This in turn influenced foraging behavior, distribution of storks in the landscape, and common prey items consumed.

Few efforts have been made to determine the extent of the population in Belize, which may actually be the largest population of breeding Jabiru Storks within Central America. Because of the restricted size and the patchiness of Central American wetlands, compared to the more extensive wetland areas of South America, the Central American Jabiru population is thought to be limited to around 150 individuals (Luthin 1984). The small population size potentially makes the Belize population more vulnerable to environmental impacts. This assumption has been supported with observations made by Borjas (2004).

Seasonal differences in foraging behavior have been observed at CTWS, where storks tend to occur alone or in small flocks, usually numbering less than 15 birds dispersed around the extensive area of the flooded wetlands during high water periods. Under low water conditions, when small pools and ponds form, concentrating fishes, storks feed in sizable flocks that may number up to 60 birds (Borjas, 2004). South American populations of Jabiru Storks often use coastal habitats (Spaans 1975), but in Belize only inland freshwater wetlands are used. They seem to favor shallow, non-vegetated wetlands within Northern and Southern Lagoons and New River Lagoon having good water quality, abundant and diverse prey species, and significant changes in water level from wet to dry seasons. The Nova Shrimp farm in the coastal wetlands of along the Northern Highway did accommodate a number of Jabiru and Wood Storks during its operation.

As wetland areas begin to dry up and aquatic habitats recede, high mortality rates occur among fishes and other aquatic fauna, and reduction and drying out of aquatic vegetation creates very open areas within wetlands. During this period of falling water levels, Jabiru Storks in Northern Lagoon hunt for food more often within open waters and mudflats, spending much less time along shorelines and remaining patches of vegetation (Borjas, 2004). During lowest water levels in the dry season, they tend to feed primarily in open water, as shorelines are greatly reduced and many exposed mudfats dried out by the sun.

Jabiru Storks are one of the few wading bird species in Crooked Tree and New River wetlands that forage in mudflats of the lagoons, almost exclusively harvesting Obscure Swamp Eels (Borjas, 2004). Nesting eels dig burrows in sediments beneath about 0.5 to 2.5 m of water, where male eels protect the eggs (Greenfield and Thomerson 1997). It was proposed that the bill of the Jabiru Stork, having a slight curvature and functional length, is morphologically adapted for extracting large swamp eels from the sediment (Thomas, 1985), which Borjas (2004) estimated to make up about 20% of the total diet for Jabiru populations in northern Belize. The ability to capture swamp eels from the extensive mudflats formed as seasonal water level drops allows Jabiru Storks to take advantage of a food resource that other wading birds, such as the closely related Wood Storks, cannot effectively access. Borjas (2004) suggested that eels were easier to handle and ingest, requiring less time and energy than more conventional fishes such as tilapia.

Figueroa (2005) conducted a study of Jabiru nesting behavior, finding that the Ceiba or Cotton Tree (*Ceiba pentandra*) was the tree species most often used, followed by the Caribbean Pine (*Pinus caribaea*). In addition to these trees, Barnhill, *et al*. (2005) also reported nests in *Tabebuia ochraceae?* (not listed in Balick, et al., 2000), *Acoelorraphe wrightii,* and dead trees, nest platforms being located 15 to 30 m above the ground, and also reported that one nest had been used for ten years. Nesting season in Belize is typically from mid-November until early June. They usually chose trees of sizable girth, often an over-story tree located near other nests, and near lagoons, savanna wetlands, and pine savannas. Nests are constructed high in the trees above the surrounding canopy. Once chicks have hatched, parents remain continually present at the nest for the first few weeks until chicks are large enough to discourage many predators. As they are growing, chicks use adjacent vegetation to help them move in and out of the nest as they develop their muscles. Figueroa (2005) observed that adults may make from 9 to 13 daily foraging trips to feed nestlings, and besides fish and Obscure Swamp Eels reported by Borjas (2004), recorded that toads, turtles, and crustaceans were also added to the nestling diet.

Average age at which Jabiru chicks fledge and abandon the nest is 96 days, from mid-April to the first of June in the study by Figueroa (2005). Barnhart, *et al*. (2005) reported that checks fledged 100 to 115 days after they hatched, with nesting season lasting from mid-December until late May. On their first flight, fledglings have to fly over surrounding trees to reach wetlands. Adults accompanied juveniles for 10 to 12 weeks after they fledge, teaching them critical survival skills. From the time adults begin repairing or building the next until fledging is about 24 weeks, plus 10 or 12 weeks adults spend with post fledglings, teaching them critical survival skills, parents invest 34 to 36 weeks rearing chicks. At the time of his study, Figueroa (2005) observed that there were about 25 breeding pairs of Jabiru in Belize.

Once on their own, older juveniles are very susceptible to predation by Morelet's crocodiles (*Crocodylus moreletii*), the only natural predator recorded for post-fledgling Jabiru Storks (Figueroa, 2005). Reduced area of suitable habitat may be responsible for limiting movement of Jabiru populations, resulting in sedentary populations in Belize. Based on years of observation, Figueroa (2005) presents a case that the small population size, suppressed gene pool, inbreeding, low survival of juveniles, loss of critical habitat, and degradation of remaining habitat create many challenges for this critically endangered species.

Howell (1998) reviewed sighting history of the Agami Heron (*Agamia agami*)in Belize, which appears to be locally common within CTWS. As with many wading birds, it tends to be seen near the end of the dry season when water, fish resources, and consequently birds, are clustered within the remaining streams, ponds, and lagoons. The Agami Heron may not often be observed because it tends to be reclusive and prefers habitats that are relatively inaccessible, such as heavily forested streams with overhanging vegetation and swamps, where they remain motionless or quietly creep through thick vegetation. Solitary birds are often seen, with sightings of pairs being less common. Herons perch and patiently wait over the water, stabbing fishes with their long bills when an opportunity occurs.

Neotropical Cormorants (Figure 45) are common winter residents at CTWS, their numbers building up to many thousands, becoming the most abundant aquatic bird species within the wetland system, with Great Egrets, White Ibises, and Limpkins, the next most abundant groups, following far behind (Table 14). These expert diving birds are largely fish eaters, but also feed on amphibians and

Figure 45. Neotropical Cormorants (*Phalacrocorax brasilianus*).

crustaceans (Lee, 2003) and, given their numbers, probably have a significant impact on fish populations. Cormorants, like all colonial roosting birds, also create concentrated, enriched patches of nitrogen in water where they roost in large numbers, potentially affecting local nutrient conditions and algal growth.

Figure 46. Great Egrets and Wood Storks Foraging Together.

Many wading birds tend to forage in mixed flocks, such as the more common Great Egrets and Wood Storks in May and June (Figure 46). Comparison of bill size between these two species suggests a potential division of prey resources by size and capture methodology. Great Egrets hunt visually, stalking prey in shallow water, striking fishes and frogs, and sometimes also snakes and crayfish, with quick jabs. Wood Storks also feed on fishes, frogs, and snakes. However, they forage tactically rather than visually. Typically they use their feet to disturb sediment and flush out any potential prey, while moving their open bills back and forth though the water. When a prey item touches their open bill, the bill is instantaneously snapped shut. There may be other factors that help partition resources.

Cattle Egrets are an introduced species from tropical Africa and Asia, with the first reported siting in Belize being 1956. They have been able to settle into an open niche not already occupied by native avifauna. Cattle Egrets represent another ecologically interesting bird in that they typically forage on land, spending much of their time in pastures associated with livestock, feeding on insects flushed by grazing animals. They often return to riparian or swamp trees overhanging water to roost. Effectively they transport terrestrial nitrogen directly to aquatic systems, creating sites of concentrated nitrogen enrichment.

Martinez and Arevalo (2005) reported on aerial surveys of ducks that started in September 2004 and ended in May 2005. Belize suffered through a series of long dry seasons starting in 2003, and some wetland areas were dried up almost totally except for a few ponds and streams of water. During this effort, five species were documented from the Northern Lagoon, including Black-bellied Whistling Ducks (*Dendrocygna autumnalis*) that had the largest population estimate for April. Blue-winged teals (*Anas discors*) were observed from November to May, reaching a density peak in January, the greatest number of ducks recorded being just over 2,000. This count was very atypical for CTWS where numbers of *A. discors* have reached over 20,000 during previous years.

Several resident birds of CTWS rely on apple snails (*Pomacea* spp.) (given as *Ampullaria* by Dourson, 2009) as important food sources. Miller and Tilson (1985) reported on kleptoparasitism of Limpkins by Snail Kites (Figure 47a and 47b), both heavy predators of apple snails. This was observed during the late dry season when water bodies have shrank and snail populations have become greatly reduced. Typically Snail Kites collect snails while in flight, extending a foot to pick up the snail and fly to a nearby perch to extract the snail from the shell with an effectively hooked bill. A kite may scan the ground for snails from its perch, and swoop down to collect one that it spots. Alternately a kite may fly 3 to 5 meters above the water, facing the wind, scouting for Apple Snails, the hunting method used mostly by kites observed at CTWS.

During the later dry season when the lagoon dropped significantly, leaving almost half of the lagoon surface area dry, and Apple Snails are less common, some Snail Kites were seen to steel snails from Limpkins (Miller and Tilson, 1985). Once a kite has spotted a Limpkin with a snail in its bill, the Snail Kite will swoop down, approaching the Limpkin from behind, and strike the bird. This often forces the Limkin to drop the snail, which the kite would then retrieve. Kites approaching Limpkins from the front or side were unsuccessful at steeling the snail, as the Limpkin would be able to avoid the attack. Kleotoparasitism may occur when many individuals of different species gather at a feeding site containing limited common resources.

a b

Figure 47. a. Snail Kite (*Rostrhamus sociabilis*). b. Limpkin (*Aramus guarauna*).

Several terrestrial bird species feed on aquatic prey. Some species, such as the Osprey (*Pandion haliaetus*) and five species of kingfishers, family Aledinidae, catch fishes directly from the water. Black-collared Hawks (*Busarellus nigricollis*) can also catch fish from the water, and feed on other aquatic animals. Other birds, including Black Vultures (*Coragyps atratus*), as well as several hawk species, feed on dead and dying fishes that are readily available and easily collected (Figure 48a and 48b). Several swallows, the Prothonotary Warbler (*Protonotaria citrea*) and the Northern Waterthrush (*Seiurus noveboracensis*) collect adult aquatic insects emerging or in mating swarms over the water.

a b

Figure 48. a. Black Vultures (*Coragyps atratus*) Feed on Dead Fishes. b. Immature Hawk with a Dead Fish.

The Yellow-headed Parrot, or Yellow-headed Amazon (*Amazona oratrix*), although not a wetland bird, was chosen by many Crooked Tree Village community members as a potential mascot for CTWS (BAS, 2009). They are the signature savnanna birds of Belize that almost everyone recognizes because they have been kept as pets, probably throughout the history of the country. Yellow-headed parrots are the most exploited parrot in the pet trade, with only about 7,000 wild individuals left. Wild populations, representing two or three races of the species, are restricted to three sites in Mexico and in Belize. The subspecies within Belize, *A. o. belizensis* is found throughout the country, breeding predominately in lowland pine savannas. They are severely poached throughout their range, with all remaining wild Yellow-headed Parrots being threatened.

A survey was conducted within the pine savannas west of the western boundary of CTWS. During this effort between 85 and 95 Yellow-headed Parrots were noted, most of these occurring in flocks of 50 and 10 foraging individuals seen near Crooked Tree Village (Bri~~e~~tt and Tillett, 2013). The remaining birds were pairs and a few single individuals dispersed throughout the savanna. During the survey it was observed that trees containing about 15 old nests had been felled, another 25 nest trees were noted which had been damaged from earlier poaching activity, but judged to be still usable, and 6 were actively be used. The active nests were found in relatively dense pine savanna, but many of the trees showed signs of having been chopped in years past. In addition, both Red-lored Parrots and White-fronted Parrots were also seen actively nesting throughout the pine savanna.

In Belize, Yellow-headed Parrots typically roost in pine forests and forage in near-by humid forest. Foods are fruits from wild and cultivated trees, including figs, Guava (*Psidium guajava*), Manila Tamarind (*Pithecellobium dulce*), Cockspur Acacia (*Acacia* sp.), Drunken Bayman Wood or Water-wood (*Zuelania guidonia*), a tropical Sapotaceae (*Pouteria amyggalina?*), a Solanaceae (*Solanum* sp.), palms, and young buds of trees and shrubs (Vázquez and Maldonado-Rodríguez 1990). Sometimes Yellow-headed Parrots may cause loss to crops such as corn, citrus, and bananas (Lowery and Dalquest 1951).It has also been noted that they feed heavily on cashew and mango trees in the village.

A multi-year research project focused on the Ruby-throated Hummingbird (*Archilochus colubris*) in its wintering ground within the land around CTWS (Hilton, 2014; Hilton, 2015). This hummingbird is a long-distance migrant nesting in Canada and the United States and wintering in Mexico and Central America. Work was conducted annually during middle of March from 2010 to 2014, mist-netting or trapping and banding 143 Ruby-throated Hummingbirds (Hilton, 2014). These birds are observed feeding on cashew flowers and insects attracted to the flowers. Color-marked captured and released birds were seldom observed, indicating that birds are not residing in CTWS, but passing through on northern migration routes. In addition, any other Neotropical migrant birds captured in mist nets during the study were also banded and documented, representing an additional 32 species at Crooked Tree. Data gathered on previously banded birds contributes to information on longevity, and all previously banded birds collected were banned at CTWS.

Mammals

CITES-listed mammals found in and around CTWS include Appendix-I listed Jaguar (*Panthera onca*), Puma (*Puma concolor*), Ocelot (*Leopardus pardalis*), Baird's Tapir (*Tapirus bairdii*), and Neotropical Otter (*Lutra longicaudis*). Appendix-II listed mammals found in the CTWS area include the White-lipped Peccary (*Dicotyles pecari*) and the Collard Peccary (*Tayassu tajacu*). Occasionally a West Indian manatee (*Trichechus manatus*) is even spotted in the Northern Lagoon during the high water periods. Black Howler Monkeys (*Alouatta pigra*) occur in the area and there are reports of Central American Spider Monkeys (*Ateles geoffroyi*) on the western side of the island near the Ancient Maya site. This area provides habitat for some of the most endangered and threatened mammals found in Belize and the region. Mammals focused on in this section are semi-aquatic and aquatic species that are directly associated with the lagoons and wetlands of CTWS, with the ecology table in Appendix J listing 19 such mammal species recorded from the area. If mammals associated with adjacent dry savannas and deciduous forests of the CTWS area were added in, the list would be far more extensive, especially if a survey of small mammals such as bats and rodents were included. Domestic horses and particularly cattle are also prominent mammals within the area that impose a significant impact on the local ecology and are considered under the agriculture section later in the document.

No list of bat species for CTWS and surrounding area was discovered, but a detailed study was conducted by Fenton, *et al*. (2001) for Lamanai. It is reasonable to believe that CTWS would have a very similar list if such a study was conducted. Table 16 list those species identified, representing over half of the total species of bats reported for Belize. Lamanai bat fauna is made up of 13 aerial foragers, 9 gleaners, 11 fruit and leaf eaters, one trawler, one flower-feeder and one blood-feeder. Of these, two species are strongly associated with water, and two other species that often forage over water (water-associated species highlighted in light blue). The Mexican Bulldog Bat or the Greater Fishing Bat (*Notilio leporinus*) is found in

Comment [C9]: Have you come across nay information on the following?

2006-2007 ***"National Monitoring Pilot Project Using Bats as Indicators"***
(Partners: Wildlife Conservation Society Belize, Belize Audubon Society)

lowland and coastal areas, often roosting in hollow trees within riparian forests in colonies of several hundred, foraging at night by trawling its feet through the water to gaff small fishes at the surface (Reid, 1997). The Proboscis Bat (*Rhynchonycteris naso*) is strongly associated with streams, rivers, lakes, and mangroves, roosting on rocks, logs, and tree trunks over water, and feeding on diptera flying above water starting before sunset. The Argentine Brown Bat (*Eptesicus furinalis*) and the Southern Yellow Bat (*Lasiurus ega*) often feed on emerging, swarming, or ovipositing aquatic insects.

Table 16. List of Bat Species Recorded for Lamanai (Fenton, *et al*., 2001).

Emballonuridae	
Diclidurus albus	Northern Ghost Bat
Rhynchonycteris naso	Proboscis Bat
Saccopteryx bilineata	Greater White-lined Bat
Saccopteryx leptura	Lesser White-lined Bat
Noctilionidae	
Noctilio leporinus	Greater Fishing Bat
Mormoopidae	
Mormoops megalophylla	Ghost-faced Bat
Pteronotus davyi	Davy's Naked-backed Bat
Pteronotus parnellii	Common Mustached Bat
Vespertilionidae	
Eptesicus furinalis	Argentine Brown Bat
Lasiurus ega	Southern Yellow Bat
Myotis elegans	Elegant Myotis
Myotis keaysi	Hairy-legged Myotis
Rhogeessa anaeus?	
Antrozoidae (listed in Vespertilionidae by Reid, 1997)	
Bauerus dubiaquercus	Van Gelder's Bat
Molossidae	
Molossus ater	Black Mastiff Bat

Phyllostomidae	
Artibeus jamaicensis	Jamaican Fruit-eating Bat
Artibeus lituratus	Great Fruit-eating Bat
Artibeus phaeotis	Pigmy Fruit-eating Bat
Artibeus watsoni	Thomas' Fruit-eating Bat
Carollia brevicauda	Silky-Short-tailed Bat
Carollia perspicillata	Seba's Short-tailed Bat
Centurio senex	Wrinkle-faced Bat
Desmodus rotundus	Common Vampire Bat
Glossophaga soricina	Common Long-tounged Bat
Micronycteris brachyotis	Orange-throated Bat
Micronycteris microtis	Common Big-eared Bat
Micronycteris schmidtorum	Schmidt's Big-eared Bat
Mimon bennettii	Golden Bat
Mimon crenulatum	Striped Hairy-nosed Bat
Platyrrhinus helleri	Heller's Broad-nosed Bat
Sturnira lilium	Little- Yellow-shouldered Bat
Tonatia brasiliense	Pigmy Round-eared Bat
Tonatia evotis	Davis' Round-eared Bat
Trachops cirrhosus	Fringe-lipped Bat
Uroderma bilobatum	Common Tent-making Bat
Vampyressa pusilla	Little Yellow-eared Bat

The Water Opossum or Yapok (*Chironectes minimus*) is a nocturnal, semi aquatic, solitary marsupial with webbed hind feet, water-repellent fur, and females have a water-tight pouch. These carnivores feed on small fish, crabs, crayfish, frogs, and insects that are caught in the water with their front feet (Reid, 1997; Gardner, 2008). Water Opossums are restricted to permanent water areas, particularly streams or rivers that typically have well developed riparian forests, but are also sometimes found in cleared forest areas. However, they cannot survive where the habitat has become too degraded. The majority of sightings are from clear rivers, lakes, and streams in hilly areas; and it is suspected to be rare in silty lowland waterways. Its presence is suspected in the rivers of CTWS. It is IUCN Red Listed as "Least Concern" (Cauron, *et al*., 2008).

It is an excellent swimmer and diver, paddling exclusively with its hind feet, the tail being used as a rudder, similar to other semi-aquatic mammals (Fish, 1993). *C. minimus* swims with its eyes and the top of its head just out of the water. Underground excavations are used as dens, accessed by a tunnel in a stream bank, sometimes with the entrance being just below the water (Emmons and Feer, 1997; Marshall, 1978). Litter size ranges from 1 to 3, with 2 to 3 being usual. Young are carried in the pouch of the female while she is swimming. The other Marsupials listed in Appendix J are opossums that frequent the banks and shores of streams and lagoons, foraging for food, some of which are aquatic organisms.

The Nine-banded Armadillo (*Dasypus novemcinctus*) is often spotted around water. They are actually good swimmers, gulping air to make themselves more buoyant (Reid, 1997). Alternately they can also walk along the bottom of a water body. The Northern Tamandua (*Tamandua mexicana*) was also included in the list because it is occasionally seen along swamp forest areas, but does not directly interact with the water.

A survey of small semi-aquatic mammal species CTWS is lacking. Small mammals, especially when numerous, can play very significant roles in the ecology of the wetlands, but often avoid notice. One example that should be found within CTWS is Coues's Rice Rat (*Oryzomys couesi*) (see Linzey et al., 2008). It occurs in cattail and sedge marshes and wetlands, beds of floating reed, small water bodies, sometimes around thorn scrub and riparian forests, brush, forest, and forest edge, and sometimes in rice and sugar cane fields (Reid, 1997). *O. couesi* is nocturnal (Wilson and Ruff, 1999), a good climber, and can swim and dive. These rats feed on green plants, seeds, insects such as ants, beetles and caterpillars (Alvarez, *et al,.* 1984; Hall and Dalquest, 1963). They weave nests within reeds about a meter above the ground or water, with breeding occurring throughout the year, gestation lasting about 25 days (Wilson and Ruff, 1999), and litter size being between 2 and 7 young (Reid, 1997; Wilson and Ruff, 1999).

The Mexican porcupine (*Coendou mexicana*) is another rodent that is commonly seen hanging out in riparian forests within savanna lands. The Paca or Gibnut (*Agouti paca*) is one of the most commonly harvested bush meat animals in Belize. It is very nocturnal and if alarmed, will run toward the water. Pacas can remain completely submerged for a short time, often being able to escape predators using this strategy. It is commonly spotted along lakes and lagoons.

The Neotropical Otter (*Lontra longicaudis*) is occasionally seen within the CTWS, but they are also very shy animals. This is a semi-aquatic carnivore, averaging 13 to 16 kg (28.7 to 35.3 lbs.) and reaching a mean size of 130 to 160 cm (51.1 to 63.0 in.) (Gallo-Reynoso, et al., 2013), ranging from northwestern Mexico to Argentina (Lariviere, 1999). This species is classified under CITES Appendix I as "Data Deficient" by the IUCN (IUCN, 2014; CITES, 2014).

Neotropical Otters have been studied in Mexico (Gallo, 1986, 1991, 1996), but there is no information on their distribution or ecological status in Belize (Chehebar 1990). Therefore information must be drawn from research from other countries in the region. *L. longicaudis* can be found in diverse aquatic and wetland habitats, including streams, rivers, and their riparian forests within deciduous and evergreen forests, rainforests, and coastal savanna swamps and marshes (Emmons, 1990). These otters require well-developed riparian forests (Redford and Eisenberg, 1992) with many suitable den sites. Otters can also be found in saltwater environments, but mostly occur inland up to about 1,500 m altitude (Emmons, 1990, Redford and Eisenberg, 1992). Even though *L. longicaudis* avoids polluted waters, they are often seen in human-inhabited areas, around farms and pastures (MacDonald and Mason, 1992; Rheingantz, *et al*., 2011).

Otters primarily feed on insects, crustaceans, mollusks, fish, but will eat birds, frogs, snakes, lizards, small mammals and even fruits, some prey being seasonal (Gallo, 1986; Parera, 1993; Passamani and Camargo, 1995; Gallo-Reynoso, 1996; Helder and de Andrade, 1997; Pardini 1998; Quadros and Monteiro-Filho, 2000; Platt and Rainwater, 2011; Rheingantz *et al*., 2011). They are opportunistic hunters, catching the slower prey (Pardini 1998, Quadros and Monteiro-Filho 2001). Most of the fish consumed are Cichlids, Pimelodids, Characids, Loricariids, and Anostomids (Passamani and Camargo 1995, Rheingantz *et al*. 2011), with representatives of the first three families recorded for the CTWS system. Crustaceans consumed include crabs and crayfish (Rheingantz *et al*. 2012). Platt and Rainwater (2011) witnessed predation of turtles (*Dermatemys mawii* and *Trachemys scripta*) by *L. longicaudis* at Cox Lagoon, Belize. In turn, otters, particularly their cubs, may fall victim to jaguars, dogs, larger raptors (Parera 1996), and of course sometimes people.

L. longicaudis breeding is in the low water season typically, but can happen year round in some parts of its range (Parera 1996). Gestation is about 56 days, and litter size from 1 to 5 cubs. Once heavily hunted throughout much of its range for pelts, currently there is almost no hunting pressure against *L. longicaudis*. However, Neotropical Otters are sometimes victims of automobiles. Intensive habitat destruction from deforestation, mining, and water pollution are becoming more threatening to the species (Gallo, 1986; Rheingantz, et al., 2014).

Northern Raccoons (*Procyon lotor*) are nocturnal omnivores that search the edges of lakes, streams, and rivers in search of aquatic or semi-aquatic prey (Reid, 1997). They will consume frogs, fish, clams, crabs, crayfish, turtle eggs, and other aquatic based foods. Their tracks are often very evident in the morning around shorelines.

The geographical range of the Black Howler Monkey, *Alouatta purge,* is being fragmented, creating small, reproductively isolated populations, especially in Mexico, due to hunting and habitat destruction (Horwich and Johnson, 1986). This same thing is beginning to happen in Belize. *A. pigra* are usually living in tropical evergreen and semi-evergreen forests within Belize, Mexico and Guatemala below about 300 to 450m elevation, in ecosystems characterized by a minimum of 25°C mean annual temperature and over 1,000mm of annual rainfall. In particular, *A. pigra* favors riparian forests that experience floods during the wet season. Within the Community Baboon Sanctuary (CBS) *A. pigra* troop size typically ranges from about 4 to 7 animals (Coelho, et al., 1976a; Bolin, 1981; Horwich, 1983).

Alouatta species are generally considered to largely consume leaves, but they also invest significant time eating fruits (Naville, et al., 1988). Two studies of *A. pigra* feeding ecology in Tikal, Guatemala found that troops relied on a single species of tree, *Brosimum alicastrum*, for leaves and fruit (Coelho, et al., 1976a; Coelho, et al., 1976b). This has left the impression that these primates are specialists. A feeding study conducted in the Community Baboon Sanctuary revealed that Howler Monkeys spent a little less than 25% of their time foraging, a little under 10% traveling, and almost 62% of their time resting. Of the forage time, roughly 41% was invested in eating fruit (depending on abundance), 45% feeding on leaves (both young and old), and 11% consuming flowers (Silver, et al., 1998*).*

This Belize study identified 74 different plant species that *A. pigra* foraged, 53 being tree species and the rest representing epiphytes and lianas, the 24 most commonly used trees being listed in Table 17. *Ficus* spp. (leaves, fruits) occupied monkeys for about a third of their feeding time, indicating importance of these trees to their diets. About 85% of the forest habitat where troops resided consisted of food trees. Many of these same species are found in the riparian forests of CTWS. This study showed how diverse and adaptable *A. pigra* diet is, allowing the Black Howler Monkeys to colonize a wide range of new habitats.

Table 17. Food Trees Used by Black Howler Monkeys at the Community Baboon Sanctuary, Listed in Order of Heaviest to Lightest Use (Silver, et al., 1998).

SPECIES	FAMILY	COMMON NAME
Ficus americana	Moraceae	Fine fig
Inga affinis	Mimosaceae	Bribri
Pithecellobium lanceolatum	Mimosaceae	Redfowl
Ficus maxima	Moraceae	Hicatee
Guazuma ulmifolia	Sterculiaceae	Baycedar
Ficus aurea/cotinifolia	Moraceae	Ficus sp.
Eugenia sp. 1	Myrtaceae	Blackberry
Andira inermis	Fabaceae	Ball seed
Miconia argentea	Melastomataceae	White Maya
Samanea saman	Mimosoideae	Beeftree
Coccoloba hondurensis	Polygonaceae	Black Grape
Ficus insipida	Moraceae	Cowfig
Combretum fruticosum	Combretaceae	Bottlebrush
Sapindus saponaria	Sapindaceae	Soapseed
Cecropia spp.	Moraceae	Cecropia
Paullinia clavigera	Sapindaceae	Inga vine
Lonchocarpus sp. 1	Fabaceae	Dogwood
Ficus yoponensis?	Moraceae	Quam fig
*Syngonium spp.*a	Araceae	Jimmy Palm, taitai
Lonchocarpus spp. 2	Fabaceae	Swamp Dogwood
Ficus obtusfolia	Moraceae	Brown Bat Fig
Ficus pertusa	Moraceae	Quash fig YL
Coccoloba belizensis	Polygonaceae	White Grape
*Fabaceae sp. 1*b	Fabaceae	Kaway

White-tailed Deer (*Odocoileus virginianus*) are largely terrestrial mammals. However, these deer are good swimmers and will also feed on aquatic vegetation along the shoreline. White-tailed deer are also important wild game used by local residents, along with Collared Peccary, Paca (*Agouti paca*), and Nine-banded Armadillo (*Dasypus novemcinctus*). Baird's Tapir (*Tapirus bairdii*), a protected animal occasionally illegally harvested for meat, spends a lot of time around mud wallows, and in rivers and lagoons. They are good swimmers and seem to prefer to defecate in the water.

The Jaguar (*Panthera onca*) is one of the few cats that will take to water, being a good swimmer. It catches and eats many aquatic and semi-aquatic animals, including pacas, turtles, iguanas, sometimes small crocodiles, and fish. There are issues in buffer communities between jaguars and cattle ranchers.

Proposed Trophic Interconnections within the CTWS Lagoon/Wetland Ecosystem

The above sections listing and describing the many plants and animals of CTWS is extensive but incomplete. It presents the challenge involved in trying to envision the ecological interconnections within the many different ecological components that make up such a complex set of ecosystems as represented in this protected area. To simplify this task, the vast amount of biodiversity discussed has been grouped into 31 broad functional groups or ecological categories, with the understanding that other categories could be justifiably added (Table 18). For each of these categories, examples are given and ecological roles described. The interconnections among these various ecological categories are shown in a flow diagram, with arrows showing movement of nutrients and energy from sources toward consumers, with sunlight being the initial energy entering the system and captured by the photosynthesizers within the CTWS lagoon and wetland trophic system (Figure 49). For simplicity, arrows showing recycled nutrient flow are not shown.

To summarize, aquatic macrophyte communities form the base of wetland ecosystems (see Thomaz, et al., 2003). Aquatic and semi-aquatic plants dominate wetland and shallow lagoon ecosystems, as typical of CTWS. They strongly influence physical (temperature, light) and chemical (dissolved gas concentrations, pH, conductivity, nutrient concentrations, dissolved carbon levels) characteristics of these ecosystems. Tropical and sub-tropical lagoons, being warmer waters, have low to medium O_2 levels, show scant amounts of CO_2, and have high pH levels, particularly around noon within stands of submerged aquatic plants.

Aquatic plants are living substrates where sometimes thick periphyton communities grow. Within water bodies having minimal movement, such as CTWS lagoons during a calm day, the boundary layer around aquatic plants and their periphyton communities is chemically different than surrounding open waters. It is typically richer in organic material from periphyton and macrophyte cells. It is usually almost stripped of dissolved CO_2, the primary source of carbon for cyanobacteria/algae/macrophyte photosynthesis. Being slow to diffuse through water from the surface, particularly still water, the only CO_2 available for completely submerged aquatic plants is from the respiration of periphyton and benthic organisms. The amount of respiration is dependent on the availability of dissolved oxygen, also used by the bacteria and zooplankton in the water column. Wetland sediments become anoxic, evidenced by the hydrogen sulfide (rotten egg) smell released when disturbing the sediment layers.

Many aquatic plant species, perhaps half, can utilize bicarbonate ions (HCO_3), occurring in much higher concentrations than CO_2 in most freshwater systems, with the exception of waters low in calcium carbonate. However, HCO_3 is more energetically expensive to use than CO_2, requiring enzymes such as carbonic anhydrase, which are energetically expensive to make. Even with this energetics cost, this is an efficient strategy for acquiring carbon in more alkaline waters.

Floating and emergent plants are not as restricted by low levels of CO_2, having direct access to the atmosphere. Other aquatic macrophytes can absorb CO_2 from the sediment through specialized transport vessels that conveys absorbed CO_2 to the leaves. Some submerged macrophytes have very finely divided leaves, greatly increasing the absorption surface available. Many macrophytes have aerenchyma, tissue structure containing open spaces that allow for physical connection of roots and leaves, and allowing transport of O_2 to roots.

Table 18. Description of Ecological Components within the CTWS Lagoons and Wetlands as Shown in the Accompanying Flow Chart. (Consumers are Light Brown, Producers are Green, Non-living Organic Matter is Gray).

ECOLOGICAL CATEGORIES	EXAMPLES	ECOLOGICAL ROLES
Top Shoreline Predators	Jaguar	
Top Aquatic Predators	Crocodiles, otters	Adults have no predators other than humans
Diving Birds	cormorants, ducks, grebes	Can capture fishes in deeper waters, eat smaller fish
Wading Birds	herons, egrets, storks	Capture fishes along littoral zone, eat larger fish
Shore Birds	sandpipers	Capture invertebrates, etc. along land/water interface
Bird Scavengers	hawks, vultures	Feed on dead/dying fish and other organisms
Marine Seasonal Piscivo. Fishes	tarpon, jacks, snappers	Enter from sea during high water to feed on fishes
Freshwater Piscivorous Fishes	Bay Snook	Feed on smaller fishes
Insectivorous Fishes	cichlids	Feed on aquatic macroinvertebrates
Omnivorous Fishes	tetras, catfish	Feed on a wide range of food material
Herbivorous Fishes	tilapia, adult tetras	Feed on algae and aquatic macrophytes, riparian leaves
Planktivorous Fishes/Inverts.	shad, rivulids	Feed on plankton suspended in water column
Zooplankton	water fleas, copepods	Consume diatoms and other plankton, are FPOM, DOM
Heterotrophic Bacterioplankton	heterotrophic bacteria	Produce and absorb DOM, freshwater microbial loop
Aquatic fungi, some bacteria	aq. fungi, some bacteria	Breaks down cellulose
Macroinvertebrate Predators	dragonflies, diving beetles	Prey on other macroinvertebrates, occasionally small fish
Macroinvertebrate Shredders	amphipods,	Create FPOM from CPOM as they digest biofilm
Macroinvertebrate Scrapers	snails	Scrape biofilm/periphyton from submerged surfaces
Macroinvertebrate Gatherers	*Caenis* mayflies	Gather loose organic material
Macroinvertebrate Filterers	clams	Sieve FPOM from the water column
Macroinvertebrate Herbivores	Pyralid moth larvae	Feed on living plant material
Macroinvertebrate Burrowers	earthworms	Digest FPOM in sediments, increase sediment oxygen
Swamp Trees/Woody Shrubs	represent several families	Create habitat and provide detritus to system
Free-floating Aquatic Plants	water fern, hyacinths	Can blanket open water surfaces
Emerged Aquatic Plants	sedges, grasses, cattails	Produce CPOM/DOM, cycle sed. nutr., inc. sed. oxygen
Floating Rooted Aquatic Plants	lilies	Produce CPOM/DOM, cyc. sed. nutr., inc. sed. O_2, shade
Submerged Aquatic Plants	milfoil,	Produce CPOM/DOM, cyc. sed. nutr., reduce. sed. O_2
Carnivorous Aquatic Plants	bladderworts	Feed on microinvertebrates, produce CPOM/DOM
Phytoplankton	diatoms	Produce FPOM/DOM, cyc. dissolved nutrients
Periphyton Algae/Diatoms	filamentous algae, diatoms	Produce CPOM/DOM, cyc. dissolved nutrients
Algal muds/benthic algae flock	filamentous algae, diatoms	Produce CPOM/DOM, cyc. dissolved/sed. nutr.
Detritus-short term POM	leaves, fruits, flowers	Cellulose that breaks down in days to weeks or months
Detritus-long term POM	wood	Cellulose that breaks down in years to decades or longer
Dissolved Organic Matter	Cytoplasm, secretions	All water soluble organics or organic emulsions
Organic Foam	flocculated DOM	Foam created when DOM mixes with air (waves, current)

Light availability for completely submerged photosynthesizers can also be very limiting. Water molecules increasingly absorb and scatter light wave bands with increasing depth. Light is also absorption and scattering by suspended plankton, silt, clay, and dissolved organic matter (tannins). Phytoplankton selectively absorb light within 400 t0 700 nm wave bands that is optimum for photosynthesis, but this energy is progressively limited by increasing water depth. Many submerged aquatic plants compensate in part for this by having higher concentrations of pigment in leaves and by having epidermal cells that also contain chloroplasts. Floating and emergent plants are not limited light absorption of water, as they have access to light before it actually reaches the water. However, they further contribute to reduced light below the water by shading, particularly those plants with large floating leaves or that grow in thick, dense layers.

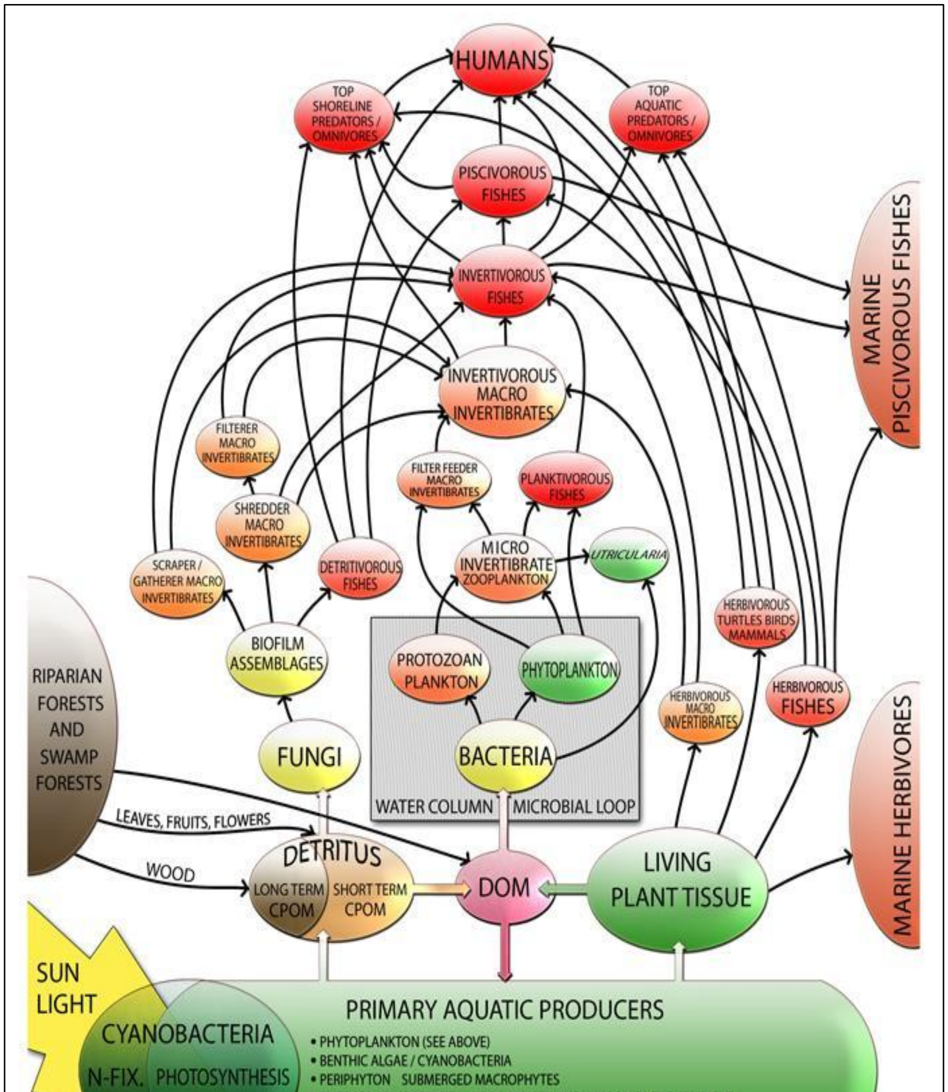


Figure 49. Flow Chart Showing Confirmed and Strongly Suspected Connections Among Different Ecological Components or Functional Groups of Organisms Found in CTWS, Indicating Movement of Nutrients and Energy Through the Trophic Web (*note that complete cycles, with back flow of waste/decomposition from each group, are not shown to avoid confusion within the diagram*).

Wetland macrophytes provide food as both living tissue and detritus. Because there is no risk of desiccation within an aquatic environment, except of course when wetlands completely dry out, aquatic plants typically have reduced cuticular layers. Also because of the density of water and therefore the reduced need for strong support structure, aquatic plants produce less xylem. Reduced production of these components means less drain on macrophytes energetically. Less cuticular material and xylem tissue also means that aquatic plants can be broken down more readily than terrestrial plants typically made up of large amounts of these decomposition-resistant materials.

Because most aquatic plants lack extensive structural tissue, and therefore break down faster, nutrients are rapidly released during decomposition of aquatic plant biomass. Much of the calcium, magnesium, phosphorus is available to other components of the ecosystem within the first week. Concentrations of nutrients within aquatic macrophyte biomass may be up to 3 to 12+ times that found in the water column. Macrophytes essentially extract nutrients from sediments, that would otherwise be removed from circulation within the ecosystem, and make these nutrients available to other organisms within the ecosystem.

To better visualize both the diversity and the different scales at which photosynthesis occurs, various categories of producers listed in Table 18 are depicted in Figure 50. This diagram shows the occurrence of the different producer groups that provide the base components of the trophic pyramid for the wetland/lagoon ecosystem. The illustration starts with the edge of a swamp forest and continues to scope down in scale to include interstitial algae in sediments, in an attempt to show interconnectedness.

Production and release of stored nutrients within macrophyte biomass is seasonal at CTWS. During normal high water conditions, the littoral zone, that zone of rooted aquatic plants, is extensive and covers much of the lagoon sediment. This represents a large area of primary production by aquatic and semi-aquatic macrophytes that rapidly decompose and are recycled. Much of this material is stranded in the drift lines around swamps and shorelines, breaking down much more rapidly where O_2 is more readily available. Great amounts of aquatic-based biomass are also exposed to the atmosphere and to terrestrial processes as waters recede during the arrival of the dry season. In addition, aquatic macrophytes add considerable amounts of organic material to the sediment of wetlands that becomes soil during the dry season.

Non-obligatory symbiotic relationships occur between some aquatic plants such as some bladderworts (*Utricularia* spp.), water hyacinths (*E. crassipes*), and water lilies (*N. indica*) and heterotrophic, nitrogen-fixing bacteria. Large amounts of dissolved organic matter (DOM) released by aquatic macrophytes supports growth of nitrogen-fixing bacteria, and the bacteria in tern supply nitrogen that supports plant tissue growth. Usually nitrogen fixation is more prevalent in the rhizosphere of aquatic macrophytes, with nitrogen not absorbed by plant roots being released into the water column where it is available to phytoplankton. The rhizosphere has been shown to be a very important component of soil systems in terrestrial settings. However, there is a need to investigate this phenomenon within aquatic systems. Additionally, many terrestrial plants, it is now recognized, have a very strong symbiotic association with mycorrhizae fungi that greatly increases the absorption capacity of terrestrial plant roots. Similar associations may occur with aquatic plants.

The actual role of aquatic macrophytes differs from system to system and is still debated in the literature. Production by microorganisms in tropical lagoons may be more important than that of macrophytes, but further study is required. However aquatic macrophytes greatly increase habitat complexity and availability, directly affecting diversity of aquatic organisms and availability of food resources at many scales. The littoral zone support aquatic organisms, juvenile fishes escaping predators, and offer nest sites for many wetland organisms. Currently there are few studies of aquatic macrophytes in the Neotropics, where on a global scale diversity is the highest (984 species compared to 664 species recorded for the Orient, 644 species in the Nearctic, and 614 species in the African tropics, with diversity dropping in the temperate areas of the world (see Thomaz, *et al*., 2011). Within the neo-tropics, 61% of the aquatic/semi-aquatic macrophyte species are endemic to the region.

Herbivores within wetland/lagoon ecosystems affect the abundance of freshwater macrophytes, thus affecting nutrient cycles and energy flow, with some investigators describing herbivores as regulators that affect ecosystem structure, functions, and services (Hairston, *et al*., 1960; Huntly, 1991; Polis, 1999; Estes, *et* *al.*, 2011). These observations and findings support a top-down control of ecosystems. Several obvious herbivores occur in CTWS ecosystems. The larger herbivores/omnivores including tilapia, Central American River Turtles, Coue's Rice Rats, ducks, and an occasional West Indian Manatee. Moth caterpillars of the family Pyralidae are active herbivores of water lilies, particularly White Lilies. In addition, some terrestrial mammals, including the White-tailed Deer and cattle, wade into the edge of the water and graze on aquatic plants.

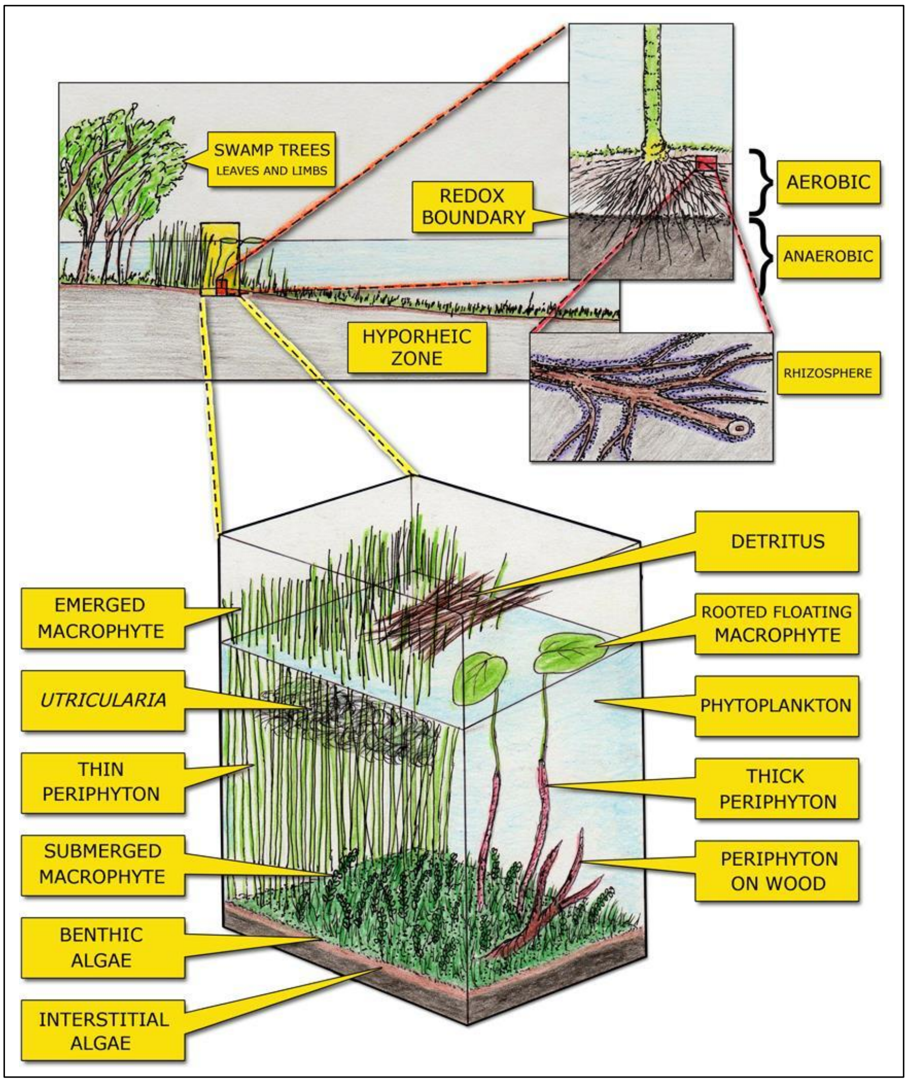


Figure 50. Graphic Representation of the General Producer Categories Found within CTWS Wetlands and Lagoons.

Meta-analysis of global aquatic macrophyte/herbivore studies show that herbivory is an important top-down structuring force in wetlands (Wood, *et al*., 2016). However top-down effects have not been studied as intently as have bottom-up effects of light, water temperature, and nutrients (Bornette and Puijalon, 2011). Wood, *et al*. (2016) found that herbivore biomass density, species richness, and taxonomic identify determine the degree of interaction effects between the primary producers and the primary consumers, or herbivores. In addition, the greater majority of the 165 studies reviewed by Wood, *et al*. (2016) indicated largely negative impacts on macrophyte abundance in response to changes in herbivore popuations. Any significant changes in the macrophyte/herbivore associations within aquatic systems can lead to trophic cascades, forcing ecosystem shifts (see Carpenter, *et al*., 1985; Estes, *et al*., 2011).

The impacts of herbivores to macrophyte populations are also related to macrophyte/herbivore "nativeness" (Wood, *et al*., 2016). Those assemblages characterized by herbivore invaders and native macrophytes tend to have greater reductions in macrophyte abundance as compared with invasive herbivore/invasive macrophyte assemblages, native herbivore/invasive macrophyte assemblages, and native herbivore/native macrophyte assemblages.

Human Ecology

Lowland savannas make up just over 10% of the Belizean landscape, roughly 168,000 hectares (415,130 acres) (Meerman and Sabido, 2001). This ecosystem complex is being severely threatened by agriculture and aquaculture that affect drainage patterns, nutrient cycling, nutrient loading, fire frequency, and habitat loss, ultimately degrading savannas. What happens on the adjacent land ultimately affects the CTWS wetlands and lagoons and the many organisms depending on these systems. The Ecosystem Map of 2010 compared against 1980 Landsat imagery and topography maps indicated that about 20,000 hectares (49,500 acres) have been cleared, about 12% of lowland savanna being lost (Cameron, *et al*., 2010). A portion of the savanna areas are wetlands that have no real agricultural value, but hold tremendous ecological and conservation value. Seasonally inundated savanna represents only about 3,100 hectares (7,660 acres) or about 2% of Belizean savanna area, but only about 900 hectares (2,224 acres) is under protective status (Cameron, *et al*, 2011).

These wetlands, including inundated savanna, littoral wetlands, and lagoons, produce or contain natural resources that have been used by residents for centuries. This includes game animals, fishes, palmetto, sand, and other resources. Each of these major areas of resource use is discussed below.

Land Use Classification

The team lead by Charles Wright conducted a scientific description of the Crooked Tree ecosystems (Wright, *et al*., 1959). The objective of this effort was not necessarily to describe ecosystems, but more for increasing the efficiency of land use in Belize by identifying the best utilization (primarily as forestry or agriculture) to which specific habitats could by assigned. Slope, soils and vegetation cover were used as the primary descriptive properties.

Using information presented in the 1958 soils and vegetation maps, a potential land use map of the country was developed by Wright, *et al*. (1958). Figure 51 shows those proposed land use patterns for the CTWS area. According to their report, the land immediately within Crooked Tree Village area was found to not be adequate for agriculture. The swamp areas are characterized by nutrient poor, waterlogged soils that provide marginal support for livestock. The pine savanna overlies sandy alluvial soils and is typically populated by pine trees (although most commercial pine has long since been stripped from the area) and patches of cashew tree stands. This area was determined to be useful primarily as cattle pasture and pine and cashew plantations, along with subsistence agriculture, hunting and harvesting of fire wood, activities that were already on-going. The third dominant soil type typifies the Blackburn Ridge west of Crooked Tree Village and along the western edge of the Western Lagoon. These are the best soils in the area that support the most developed vegetation cover and these are the soils that support much of the local agriculture.

The potential land use map developed by Wright, *et al*. (1958c) was developed prior to the widespread environmental awareness of the importance of wetlands and riparian forests. Some of the recommendations should be carefully examined. For example, recommendations concerning planting bananas and plantain along river banks, replacing riparian forests, can lead to severe erosion problems, loss of land due to bank failure and pollution of the water by pesticides, nutrients, and many land-based toxins (Archer, 1994). Replacing wetland areas with rice can reduce the wildlife productivity, nutrient storage and other valuable services provided by wetland systems. Ranging cattle in wetland area can also be a very unsustainable practice. An updated potential land use map of the CTWS area, taking into consideration the need for protected areas, buffers, small-scale corridors and other sustainable measures, would be valuable.

King *et al*. 1992 compiled a 1:100,000 scale map of land systems based on soils, vegetation characteristics, limiting factors and use potential. Figure 52 shows the CTWS area of that map of those land systems or land types. Table 19 lists the land types, main subunits, agricultural limitations, land usage and recommended usage (also see King, *et al*., 1993). As with Wright, *et al*. (1958c), application of these land use recommendations should also take into consideration the function of the local ecology and environmental concerns. The general land type encompassing the village area, much of the northern portion of the sanctuary and a large strip running between and parallel with the Western Lagoon system and New River is classified as Crooked Tree Plain. The Sibal Swamp land type surrounds much of the water courses within the sanctuary and their flood plains. The western side of the southern end of Western Lagoon, lands adjacent to the western side of Spanish Creek, and Spanish Creek itself lies within Lower Belize Floodplains land type. August Pine Plain is the next most abundant land type within the Sanctuary.

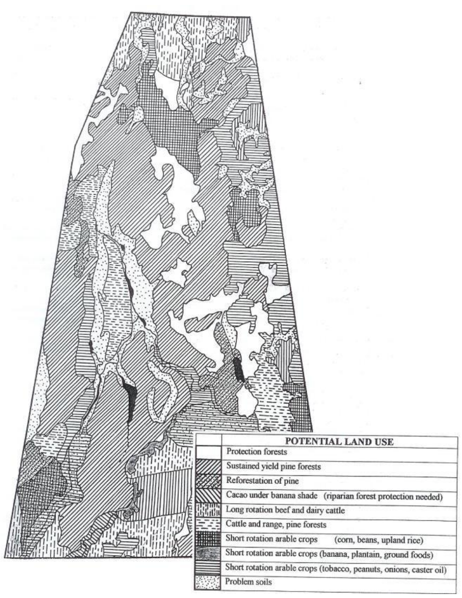


Figure 51. Potential Land Use for the CTWS Area Prescribed by Wright, et al. (1958).

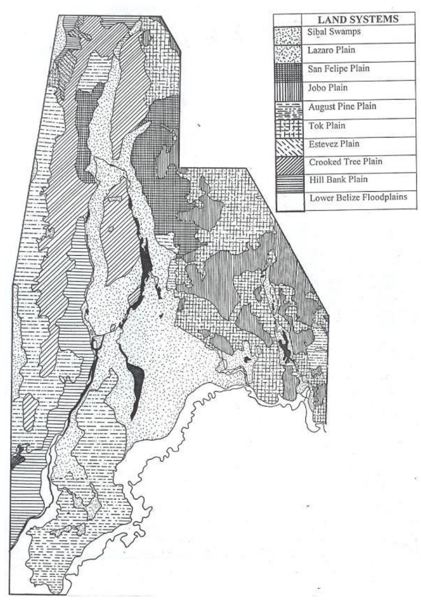


Figure 52. Land Systems of CTWS Area (King, *et al*., 1992).

Table 19. Land Types of the CTWS Identified by King, *et al*. (1992).

LAND TYPE	DESCRIPTION	USE
Sibal Swamp	Herbaceous swamps- Sibal soils, limited by wetness Savanna plain- Sibal soils, limited by wetness Marsh forest plain subunits- Sibal soils, limited by wetness	No land use; conservation proposed
Crooked Tree Plain	Undulating plain- Crooked Tree>Boom soil types, limited moisture and nutrients Re-deposited old alluvial wash- Haciapina > Sennis soils limited by nutrients, drainage and root room Low marine terrace- BV: Double Head Cabbage > (Hattieville + Duck Run) soils, nutrient limiting Pitted plain- BV: Double Head Cabbage > (Colonel English + Ycacos), nutrients, drainage and salinity are limiting factors	Agriculture limited to cashew; cashew, pine-apple, pasture, conservation recommended (3) [3>1] No current land use; pine, pasture and rice recommended (4) [3] Limited use as pasture; cashew, pasture and pineapple recommended (3) [3] No current usage and none recommended (3>4) [3]
August Pine Plain	Undulating plain- Boom > (Tok + Backlanding + Crooked Tree) soils, moisture, wetness and nutrients are limiting factors Re-deposited old alluvial wash- Haciapina > Sennis soils limited by nutrients, drainage and root room	Limited pasture use and no use recommended (4>3) [3>1] No current usage, pine, pasture and rice recommended (4) [3]
Lower Belize Floodplains	High floodplain bench- BV:Meditation + Morning Star >Bermudian Landing soils, limited by wetness and flooding Low floodplain bench backland- BV:Bermudian Landing soils, limited by wetness and flooding Low floodplain bench- BV:Lemonal > Freetown, limited by flooding Alluvial wash- Sennis soils, limited by wetness and root room	Used for limited cultivation and pasture; citrus and rice recommended (1) [3] Used for very limited cultivation and pasture; pasture, root crops and rice recommended (3) [3] Used for very limited cultivation and pasture; pasture, root crops and rice recommended (1) [3] Widespread cultivation; pasture and rice recommended (2-3) [4]
Hill Bank Plain	Flat plain- Ramgoat + Chacluum + Chucum > (Yalbec + Irish Creek) soils, limited by workability, root room, drainage and nutrients Undulating plain- Ramgoat + Chacluum + Chucum > (Yalbec + Irish Creek) soils, limited by workability, root room, drainage and nutrients Lower slope- Chucum + mottled Yalbec + Irish Creek > Pasmore soils, limited by workability, root room, drainage and nutrients	Very limited melpa use; timber, pasture and small holder agriculture recommended (3) [2] Very limited citrus and pasture use; timber, pasture and small holder agriculture recommended (3) [2] Not used; rice recommended (3) [2]
San Felipe Plain	Undulating plain- Felipe > (Boom + Tok), BV: Erindale soils, limited by wetness, nutrients and moisture Re-deposited old alluvial wash- Haciapina > Sennis soils, limited by nutrient drainage and root room	Limited use for sugarcane and pasture; no recommendation (4) [3>2] No usage; pine, pasture and rice recommended (4) [3]
Jobo Plain	Flat plain- Altun Ha > Puluacax soils, limited by workability, moisture, nutrients and wetness Lower slope- Mottled Jobo + Pucte	Used for coconuts, pasture and sugarcane; pasture, coconuts and pineapple recommended (4) [3>1] No usage; rice recommended (4) [3>1]
Tok Plain	Flat plain- Tok > (Boom + Buttonwood) soils, limited by wetness and nutrients Re-deposited old alluvial wash- Hiciapina soils, limited by nutrients and drainage	Used for shrimp farming and urban development; conservation and shrimp farming recommended (5) [3>1] Used for very limited cultivation; pine, pasture and rice recommended (4) [3]
Estevez Plain	Altun Ha + Tok > Boom soils	Not used; conservation recommended (4) [2<1]

( )- signifies agricultural value from 1 to 5 with 5 being the highest
[ ]- signifies conservation value from 1 to 5 with 5 being the highest

Conventional wisdom recognized savannas as unsuitable for agriculture, except where soils are built and well-managed. Recommendations of use included pine forest management, cashews, and even pasture (not a suitable use for several reasons), and aquaculture (also a use recommendation that should be carefully considered). Areas having better drainage are often used for houses and roads. Actually most of the national highway system has been built through savanna areas, including the Northern Highway that cuts through the CTWS. Savanna wetlands are unsuitable for most uses other than as prime conservation areas as wildlife habitat (see Bridgewater, 2012), birds being the most visible wildlife group. Cashews and cattle seem to be the more sustainable use of dryland savanna areas, with both of these ventures contributing significantly to the economy of CTWS buffer communities. These activities and others are discussed in more detail below.

Ancient Maya

In May 2013 the Archaeology Department was alerted about a threat to the Ancient Maya site of Chau Hiix, locally known as Indian Hill. Chau Hiix is located within CTWS on Crooked Tree Island along the eastern shore of the Western Lagoon north of the causeway (Ramos, 2013). A northern Belize business man contemplated using the site as a source of road fill material. A similar incident had happened at another site, Noh Mul, further north and residents were worried about a repeat of this tragedy. Archaeologists responded, finding evidence of land clearing by bulldozers for agricultural expansion, a common occurrence in Belize, but the actual site stones were not disturbed.

Chau Hiix stands as testament to the occupation of the CTWS landscape by Maya from at least 400 B.C. to 200 A. D. The central pyramid at this site is 22.9 m (75 ft.) tall, standing out within the flat savanna wetlands. It is one of the last un-looted Maya sites in Belize because Crooked Tree residents were careful to keep it secret for generations. Eventually it was discovered by the outside world and research began on the Chau Hiix site in the 1990s, the first publication appearing in 1991, with the latest publication found in this assessment appearing in 2007. A total of 12 publications, 2 unpublished Master's thesis papers, 5 unpublished Ph. D. dissertations, and 17 papers delivered at professional meetings resulted. These references have been included under a separate heading at the end of the reference section of this report.

Research and excavation at Chau Hiix focused on trying to understand the collapse of the Ancient Maya from the perspective that economic production of common people were suppressed by interference from high ranking administrators and bureaucrats. Dr. Anne Pyburn of Indiana University was the principle investigator. Comparisons of Chau Hiix with Altun Ha to the east and Lamanai to the west were made to recognize and explain patterns in their development and collapse. For example, Andres (2005) investigated the association between structural changes of the built environment and the social and political states at Chau Hiix, Lamanai, and Altun Ha. Architecture at Chau Hiix shares more similarity with nearby Lamanai (New River), still inhabited into the Spanish Conquest, than Altun Ha to the east that was abandoned after 800 A.D. Buildings housing the elite at Lamanai and Chau Hiix became less and less accessible before 800 A.D, then becoming more open and accessible after this date, reflecting changes in socio-political patterns at the time.

Wetlands in many parts of the world are drained to provide access to fertile soils for agriculture. Rich soils associated with rivers, lagoons, and wetlands around the country have spared the wetlands of northern Belize, allowing them~~n~~ to be relatively pristine during the past couple of centuries. However, current research is indicating that the extensive wetlands of northern Belize, including those of CTWS may have been modified by the Ancient Maya to enhance agriculture of the area during the dry season. Dunning, *et al*. (2006) propose that between 400 B.C and 250 A.D. many large depressions, or bajos, in the karstic landscape making up the region known as the Maya Lowlands (including part of southern Mexico, north eastern Guatemala, and northern Belize) were changed from shallow lakes and perennial wetlands to seasonal swamps. This perspective explains why the oldest Maya cities were established on the edges of bajos, why many of these cities were left abandoned from 100 B.C to 250 A.D., and why some centers where complex water management structures were built were able to survive into the Classic period. Much of the area around Crooked Tree appears to be in a relatively natural state. However, archaeological evidence indicates that the area has been extensively changed by ancient Maya (Pyburn, 1994). Much of the present day forested areas were probably cleared and the lagoon water levels affected by canals. Present day pastures and ancient shifting agriculture plots have converted the cohune ridge, especially on the western side of the Western Lagoon, into a patchy area of broken forest cover.

The area around the pyramid-shaped structures of Chau Hiix shows signs of agricultural activity. Evidence of dams and canals indicate that the Maya may have utilized irrigation systems for growing crops (Pyburn, 1994). One current hypothesis is that the Crooked Tree ecosystem may actually be a natural wetland that was extensively modified by the Ancient Maya to serve as an important agricultural site. Most of the sites lie around the Western Lagoon area. However, pottery shards are also commonly found within the Crooked Tree Village site. Findings indicate that the Crooked Tree Wetland area was greatly influenced by humans since at least 1200 BC and until the Spanish arrived. The conversion of bajos within Crooked Tree and much of the Maya Lowlands has been one of the most enduring and important human-induced changes recognized in the New World prior to the arrival of the Spanish (Dunning, *et al.*, 2002).

Recent History of Crooked Tree Village and Buffer Communities

This section is largely derived from the history section in the earlier CTWS REA (Boles and Saqui, 2003). Additional information has been added from more recent literature where appropriate. A more thorough literature review should include observations and details uncovered through interviews with elderly residents, a project effort that could be implemented by local students interested in project activities. While much of this section focuses on Crooked Tree Village, and does include such detailed description of the other buffer communities. However, these other communities have not been around as long as Crooked Tree Village. Much of this section draws heavily from the detailed dissertation work compiled by Johnson (1998).

The 50 km^2 (19.3 mi^2) island was home to about 650 residents making up 144 households at the end of the century, (Johnson 1998), and has changed little since then. The GOB census of 1990 placed the count at 780, but this number probably contained part-time residents. The center of Crooked Tree Village makes up about 6.5 km^2 (2.5 mi^2), with some households scattered on the outskirts (Boles and Saqui, 2003). Most villagers are of Creole ethnicity, sharing West African and Scottish descent. However there are several Garifuna, as well as some people who have migrated from other Central American countries, and a very few recent immigrants from the United States and the United Kingdom. A very strong kinship network exists within the village, and the majority of the residents are related by blood and/or marriage. The Christian religion is a very important component of this community, with seven churches established in the village. The most prominent denominations are Baptist, Nazarene, Wesleyan, and Seventh Day Adventist.

Residents share a long history of using natural resources of the lagoons and wetlands, with fishing being an on-going activity that feeds people in the village and generates income from outside of the village. Crooked Tree Village is over 270 years old, dating back to at least 1750 when it was originally settled as a logwood camp. This complex freshwater network provides ideal habitat for logwood, (*Haematoxylon campechianum*) and Crooked Tree Village still has the largest logwood population left in Belize, with many old stumps of this dense wood remaining as evidence to former extraction of this resource. This is one of the oldest continually inhabited places currently existing in Belize today. The newer villages of Rancho Delores and Lemonal are located on Spanish Creek and share these wetland resources with Crooked Tree Villagers.

Initially the main interest of British seamen in what is now Belize was using the labyrinth of cayes off shore as a place to hide out and raid Spanish ships carrying their loads of logwood and other goods bound for European markets. Logwood became a very valuable commodity due to the growing textile industry in England. These early buccaneers decided that they could make considerable profits by cutting their own logwood from the readily available stands that grew along the calm inland waters of the mainland, particularly in such places as the Crooked Tree area. Although Crooked Tree formally became a village in 1750, it was the most important logging camp in what is now Belize, being occupied by the British since the beginning of the logwood industry in 1650, being occupied for over 360 years.

Logwood is a small legume tree having a heavy, dense wood characterized by red heartwood used to make aniline dyes. Consequently, logwood was a very important commodity for the British market. The tree is a true wetland plant, being found in swampy areas where its roots can be inundated by water during part of the year and exposed during other times of the year. During the dry season, logwood cutters would penetrate the deepest areas of the now dry wetland swamp, set up camps and cut logwood. The cut logwood was placed in large piles and a trench was dug to each pile. During the wet season, these trenches would flood and the logs would be loaded into canoes that could then be floated down the trenches, into the lagoon and out to the Belize River to a place called Barcaderes. Here the logwood would be sold for export. This juncture is marked on a map from 1786 on the Belize River just downstream from where Black Creek joins the river (Dewer, 1928; Burdon, 1931). Logwood became a very rewarding enterprise and it is thought that early logwood cutters eventually began to buy slaves to help extract the resource. As more British moved into the area, attracted by potential profits, they brought more slaves with them to cut and harvest logwood.

Synthetic dyes were developed during the late part of the 1700s and logwood prices plummeted in the 1760s. During this time, the Spanish were entering the territory and destroying garden plots maintained by slaves. This acted to further aggravate depressed conditions caused by the drop in the logwood industry. The ten-year span between 1760 and 1770 was characterized by slave rebellions and many slaves ran away to start new lives (Bollard, 1977). Most of logwood and mahogany had been logged from the Crooked Tree area by 1786. There was a brief revival of the logwood industry during World War I but otherwise this resource has not been extracted for die manufacturing since its collapse. Villagers harvest logwood trees for use as fence posts, but on a limited basis. The wetland forests of Crooked Tree are the last remaining logwood stands of significant size left in Belize.

Crooked Tree lacked the large stands of mahogany that replaced logwood as the principal forestry export. Therefore it is proposed that a lot of the wealthier settlers moved away, leaving Crooked Tree to be settled by people described as free colored, free blacks, poor whites and runaway slaves. The abundant fish, game, cashews, and other fruits in the area, as well as its remoteness, may have been a principal factor promoting settlement of the area (Johnson, 1998). In 1841 there were only twenty houses established in Crooked Tree (Crowe, 1850).

Some Crooked Tree residents were still cutting limited amounts of logwood at the turn of the century, as evidenced by the applications for logwood licenses in government records. However, settlers at Crooked Tree were also planting, fishing, and hunting to provide for cash incomes (Johnson, 1998). Tributaries of the Belize River were being serviced by riverboats supplying merchandise to rural settlements (Leslie, 1987). By the early 1900s there was concern about the reduction of game and fishes in Belize. In 1917 the Lieutenant Governor and a committee of concerned people met to decide if regulations should be drafted to address deer hunting. One of the reasons for this concern was due to the large amount of deer killed in Crooked Tree during the high water season when herds concentrate on hills. Often the meat spoiled because it was actually the skins that were sought for making moccasins. A bill was passed in 1918 that established a closed hunting season for deer and outlawed deer hunting by lantern light. There was also some discussion about limiting the catch of turtles (Hicatee and Bocatora—Central American River Turtles and Sliders) in 1928, but no law resulted. The expanding market for crocodile and large cat skins in the United States enticed Crooked Tree hunters to supply this trade as well. These serve as examples of the growing influence of government in the affairs of rural peoples in the country. The people of Crooked Tree resented government intervention and filed petitions against some of the legislation (Johnson, 1998).

Crooked Tree Village was only accessible by boat up until 1984 when a three-mile access road and causeway was constructed across Northern Lagoon, connecting the village to the Northern Highway (discussed in more detail in a later section of this report). Consequently, villagers lived in relative isolation, developing a strong cultural identity with the wetland area around them that has been an important component of their lives. Throughout the history of the village, the surrounding ecosystem has provided game, fish, wood and other natural resources, supporting their independence.

Development slowly came to Crooked Tree. A major change occurred with the construction of the Northern Highway, an all-weather road, in the 1930s. This road encouraged development along the roadside rather than along rivers. Thus the highways, rather than rivers, became the main mode of transportation for commercial goods. Both due to the decline of timber exports and development of settlement along the new road system, older settlements along waterways near Crooked Tree, such as Revenge and Backlanding, vanished, but Crooked Tree endured. In the 1940s, the colonial government built a school and police station at Crooked Tree. Villagers petitioned in 1951 for the construction of road access Northern Lagoon to the village. Over the years, several such requests for both an all-weather road to the village and a bridge across the lagoon were filed with the government.

Government officials set up a commission in the 1950s to evaluate tourism potential for the country and proposals were made to set up wildlife sanctuaries and develop guided services for hunting and fishing. During this time European and U. S. sportsmen were coming to Belize. Keller's Lodge was established on the Belize River to capitalize on this growing interest and employed Crooked Tree villagers as guides. Also a U. S. investor built a trophy hunting camp in the Revenge area, specializing in jaguar hunting, hiring many men from Crooked Tree Village (Johnson, 1998).

The Crooked Tree Village Council formed in the 1950s. Today it meets up to ten times per year. The Council is made up of seven elected councilors and is headed up by the Village Chairman, representing the governing body within Crooked Tree. Primarily council members deal with community development and any other issues that affect the entire community.

In 1979 the new paved Northern Highway was built closer to Crooked Tree. This road made it possible for villagers to have relatively quick access to Belize City. Originally the lagoons and waterways served as transportation systems for travel and trade, a trip that took many hours and a lot of planning and preparation. However, an access road was built from the New Northern Highway to the shore of the lagoon opposite of Crooked Tree Village. The road provided a shorter route to the main highway, but also made the area much more accessible to hunters and fishers from outside of the community. Increasing pressure by commercial fishers depleted the resource, affecting the fishes available to villagers.

The causeway across the Northern Lagoon was constructed in 1984. This significantly changed the lives of the villagers. Many people acquired automobiles, buses began servicing the village, and house construction changed from bush materials and wood to concrete. This impact is discussed further in a following section.

The village has historically supported the United Democratic Party and when the UDP was voted into office, Crooked Tree Village received electricity, being connected to the national electrical grid in 1994 (Johnson, 1998), changing the lives of the people. It provided bright lights that typically change the diel cycles of people as they begin to stay up later at night. Fans added comfort on hot days and relief from biting flies at night. Refrigerators affected the diets, allowing for the storage of otherwise perishable foods. Televisions imported new cultural concepts into the community and promoted desire for more material goods. As families begin to consume these goods and services, they also acquired monthly bills. Currently there is still no village water system, with water resources being primarily supplied by private wells and rainwater vats.

Today economic activities include fishing, logging, cattle, charcoal production, and tourism. Charcoal is produced from local oak trees and is marketed in Belize City. The numbers of oak trees are declining. Areas that are less inundated by high water have been farmed for subsistence and are used for cattle and horse pasture. Livestock ranged over the area, including people's yards, and into surrounding savannas and wetland edges, but are now being restricted to pastures. Many villagers seek service and wage labor both within the village and in Belize City, an increasing source of income. Many families have relatives in the United States and the United Kingdom that send money. Crooked Tree Village is well known for cashew nuts, cashew wine, and a growing number of other cashew products, with an annual Cashew Festival being held each May. Hunting and fishing are still important practices that supplement food for some families. Tourism, encouraged by the formation of the CTWS, is the fastest growing industry in the area, becoming a more important contributor to the local economy.

Comment [A10]: as we understand it, the UDP supplied electricty to the village via generator (Sam Rhaburn) and then the People United Party who give the community electricity to the national grid (via Max Samuels).

Comment [A11]:

The first Tilapia Festival was in March, 2003, featuring locally caught tilapia, and drew a sizable crowd. Currently there are three resorts (providing hotel accommodations and dining rooms), three bed and breakfasts, and a restaurant in the village. Licensed guides provide boat trips and birding/wildlife walks. Some people provide crafts (embroidered fabric and dolls) and pack lunches for tourists. School for International Studies and other international student programs have used Crooked Village for home stays, with students residing in the homes of participating village families who receive income for providing room and board.

Many of the earlier settlements vanished when the local logging industry declined. In 1843 a Baptist missionary established a church and school on Spanish Creek at the present day site of Lemonal Village (Crowe, 1850). Other villages located along the lagoons and waterways include Biscayne Village and May Pen. Many of these settlements are of Hispanic ethnicity. Efforts are underway to involve these villages in the formation of the Spanish Creek Wildlife Sanctuary (SPWS). Program for Belize (PfB) manages a considerable portion of the Rio Bravo Conservation Area and has been acquiring additional land holdings in an effort to secure the protection of corridors linking protected areas in northern Belize with those in central and southern parts of the country. They currently hold lands adjacent to SPWS and CTWS.

Comment [A12]:

Comment [A13]: update..post 2004 REA, the Spanish Creek WS was established.

The Belize Red Cross Society (BRCS) conducted a Vulnerability and Capacity Assessment of Lemonal in September 2009, updated in 2011 (Belize Red Cross Society, 2011). This project was conducted with community members, the village council, and the Belize River Valley Branch of the BRCS. The project was funded by the European Union Humanitarian Office Community Based Disaster Preparedness Program. During this study, the population of Lemonal was 179 people living within 39 households (21 of those houses at risk of flooding), with 52.6% of the population being 18 years old or younger. The community population has fallen from a peak of 395 to its current level of 100 largely because of people leaving to find employment elsewhere. Of those families remaining, no one actually has clear title to the land they occupy.

There is a primary school in the village, St. Luke's Anglican School that also serves as a shelter in the event of a disaster. The school was originally opened at another site in 1918, and then moved to higher ground at its current location in 2003 in response to floods. In 2012, with the amalgamation of schools in the Belize River Valley area, students were relocated to other villages leaving lemonal without a primary school. Many villagers raise their own food, including crops (rice, corn, vegetables, root crops, fruits) and some livestock (chickens, ducks, turkeys, pigs, cattle, sheep), with food not grown in the Village having to be purchased from outside of the community. Flood waters often impact livestock and root crops, threatening food security. Fishing once provided a main income source but now fish are becoming scarce, requiring fishers to travel further and remain in the field longer to acquire marketable catches. Some fishers related that this reduced fish stock started to decline about 2004, with overfishing being proposed as the root cause. Hunting is no longer as important as it once was, attributed to new hunting laws and fines. Most homes (90%) have electricity but there is no running water (water being supplied by river water and rainwater vats), but all homes have sewer or pit latrines (at least at the time of this BRCS study) (Belize Red Cross Society, 2011). There is a good dry season road, but it floods and often impassable during the wet season. There is also public bus service on Fridays.

Comment [A14]: the road was paved in 2017 and bus service runs daily to and from the village.

The village is sitting on the banks of Spanish Creek, with many homes being located too close the water. The CTWS wetlands border the village on the northeast and New River Lagoon is on the northwestern side, with Spanish Creek forming the southern border. The village is very susceptible to flooding, a frequent occurrence. The community was demolished by the 1931 Hurricane, Hurricane Hattie in 1961, and flooding in 1979 and again in 2008, the worst recorded flood event to date (Belize Red Cross Society, 2011).

Initially the land where the village sits was used to grow rice and sugar cane beginning in the early 1800s. The property was sold in the late 1800s and was settled by the Banner, August, Anthony and S~~o~~utherland families, the Bull family from Back Landing, and the Crawford and Rhaburn families from Crooked Tree Village, with most of the current residents being relatives of Crooked Tree families. Before road access, people traveled to Belize City by river, requiring about 5 to 7 days. A telephone system was set up in the village in the 1920s. In the 1950s the men of the village cut roads into the village using machetes. During this same time period, the first Village Chairperson was elected. In 1986 a bridge was constructed across Spanish

Creek, a community center built in 1993, and electricity brought in in 1998. There is still no solid waste management system in place (Belize Red Cross Society, 2011).

Demographics, Land Division, and Cumulative Impacts of Crooked Tree Village

People living together in a community, whether that community is a village or a city, imposes collective and concentrated impacts on the ecosystem that supports them. If people were spread apart, each individual impact would possibly be minimal, but together we impose compounded impacts from which ecosystems sometimes have trouble rebounding. Crooked Tree Village provides an example of the interconnected impacts created by people, any group of people as we live our daily lives. As a collective of people, this village shares some of the same concerns, problems, and issues with any other collective.

A detailed map of our collective impacts and identified pathways through which our wastes spill into our surrounding ecosystem, provides a great tool through which we can address those impacts—together. Developing such a tool offers a collaborative process through which communities can collectively recognize their challenges and discover capacities to respond as a community. Given its size, small number of people, proximity to a globally recognized wildlife sanctuary, and tourism potential, Crooked Tree Village offers a good model for such an analytical process.

To begin recognize impact patterns in Crooked Tree and assess cumulative impact of the village, a basic plan showing land parcels and street right-of-ways provides a good geographical framework, such as shown in Figure 53. This plan was traced from Plan No. 1948, GOB Lands and Survey, 1990. It shows 120 properties, the largest being 22.47 acres in size. Problems exist where ill-defined private property boundaries occur adjacent to or even within protected areas (Meerman, *et al.*, 2000). The British American Cattle Company is a large landholder in the area. Topography maps (1:50,000 scale) developed from aerial photographs taken during 1978 to 1980 flights show 137 houses or other structures within Crooked Tree Village. Maps made from 1988 to 1990 over-flights show 125 houses, many of them spread out further from the village center than shown on the earlier maps. GoogleEarth© shows about 350 buildings (homes, hotels, churches, stores, barns). More field effort is required to better understand land ownership patterns within the CTWS area. This information is vital in promoting cooperative establishment of community-based corridors, nodes, buffers, and trails locally and within Northern Belize.

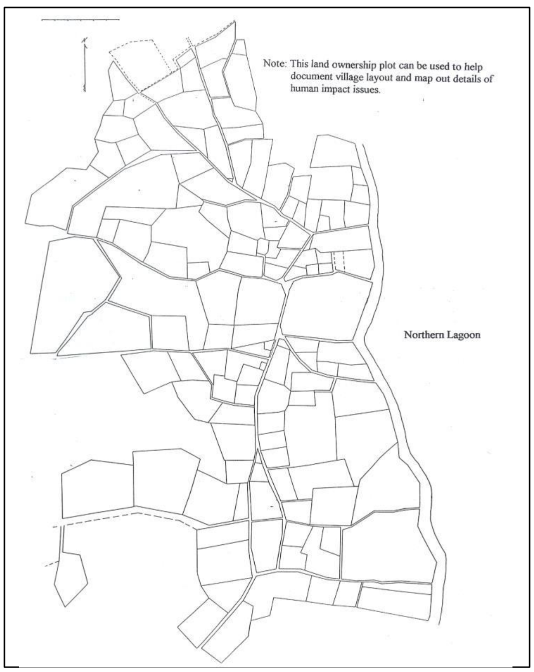


Figure 53. Plan of Lot Surveys in Crooked Tree Village**.**

Human Impact to the Crooked Tree Wetlands

This area has historically been occupied by people for at least the past three hundred years and by the ancient Maya for much longer. During this long-term occupation, the forest structure has been altered, the landscape has been modified for irrigation agriculture, and the littoral and riparian forests have been cleared or nearly cleared of logwood forests. Each CTWS buffer community has issues relating to resource use (hunting, fishing, forestry, agriculture), pollution (solid waste, sewage, animal fecal material, crank case oil, small scale hazardous wastes), cattle (nutrient loading, soil compaction, damage of riparian and littoral vegetation), and plant/yard crops (pesticides, maybe fertilizers). There are many impact issues confronting CTWS, some that can be resolved with simple intervention, while others will require creative solutions.

Part of the first REA of CTWS (Boles and Saqui, 2003) involved constructing a human impact map, identifying all visible sites representing a source of environmental stress, adapting a methodology based on The Nature Conservancy's "5S Framework for Site Conservation" (TNC, 2000) developed by Esselman (2000) for use in developing countries where scientific research capabilities are limited. Human impact mapping was used in the 2002-2003 effort to predict locations, identities and intensities of human impact activities within the main streams and lagoons of CTWS (Lee, 2002). During the first REA of CTWS, each navigable waterway was floated by canoe or motorized boat and all impacted sites recorded, the geographical position of each site taken with a Garmin 12 GPS unit. Stress sources identified within this study included loss of riparian buffer, livestock grazing in riparian and littoral zones, burning of habitat, road access points, and gill nets. Ecological stresses include sedimentation, nutrient loading, thermal alteration, habitat alteration, trophic alteration, habitat fragmentation.

Results showed that the areas around Crooked Tree Village and Lemonal were sources of "very high" ecological stress, a three-kilometer reach of northern Spanish Creek had "high" stress conditions due to the burning of riparian forest for livestock grazing. Rancho Dolores was also a "high" stress area, while Black Creek was determined to be under "medium" to "low" overall stress intensity. Sedimentation was the primary stress, followed by nutrient loading. Lemonal and the downstream portion of Spanish Creek were sedimentation "hot spots", due primarily to riparian deforestation and grazing. One kilometer of the lower Spanish Creek rated "very high" in terms of nutrient loading and Crooked Tree Village, Lemonal and Rancho Dolores rated "high". Nutrient loading was related to cattle grazing. However, no grazing impact was recorded for Black Creek and nutrient loading stress intensity was "low." Habitat alteration was "high" in the Lemonal area because of riparian deforestation while Crooked Tree Village and Black Creek rated only "medium" and "low" intensity values. Both Crooked Tree Village and Lemonal were "very high" intensities of riparian buffer loss. Most of these conditions persist today and in some situations have worsened.

Based on a GoogleEarth © examination of the area, a general map was made of the Crooked Tree Village and surrounding area (Figure 54). Also the following observations were made based on close examination of the imagery of the area and knowledge of the on-the-ground activities.

- Riparian deforestation for agriculture along Spanish Creek and west bank of Western Lagoon;
- Riparian clearing along western shore of Northern Lagoon in parts of Crooked Tree Village;
- Agricultural development that is encroaching on the hydrological connection between CTWS and New River Watershed to the north;
- Clearing of wetland swamps around many inland ponds;
- Construction of buildings along lagoon shoreline and next to inland ponds;
- Pastures developed in wetland areas
- Collections of discarded vehicles, with crank case oil, heavy metals, old batteries, etc.;
- Scattered piles of household garbage, discarded appliances, etc.
- Increasing number of sewage systems and outhouses as resident and tourist numbers increase;
- Increased road construction to reach more remote areas.

One of the most significant impacts to the Crooked Tree Village and Northern Lagoon system was the construction of the causeway. This engineering activity greatly modified the hydrology of Northern Lagoon, creating large permanent water bodies upstream of the impoundment and flooding logwood swamps. This issue was later partially corrected by splicing in two bridges that allowed water movement. However, 30 years later this same mistake has been repeated on the Western Lagoon by the GoB. Riparian deforestation and cattle grazing are two other primary impacts occurring within the area. Deforestation, generally combined with burning, removes buffer vegetation that acts to stabilize banks, filter out sediments and other pollutants from land sources, and provide organic matter to streams (leaves, limbs, fruits and flowers). These forests

Comment [A15]: add that to date, 2017, no bridge has been installed for that causeway to allow water to freely flow.

also shade streams and provide terrestrial and aquatic habitat (snags), enhancing local biodiversity. Protection of remaining forests and rehabilitation of stream and lagoon banks through reforestation efforts may provide viable solutions that can help solve several problems.

Figure 54. General Map of Crooked Tree Village Traced from Google Earth, showing Houses, Inland Lagoons and Ponds, Causeways, and Agricultural Sites.

Other potential impacts and solutions identified in the area through observation and interviews are given in Table 20. Most of the extractive activities such as fishing and logging are now more regulated, but the main challenge may be from those persons who access the area from other communities. Gill nets for fishing appear to have been replaced with seine nets. Logging is self-limiting as most harvestable trees are removed, but replanting should be encouraged to not only replace future stock, but to build back some of the forest area where appropriate. Waste generation and waste management may be one of the more critical issues, especially given the public health concerns associated with sewage (potential contamination of water wells) and solid waste (pollution of surface waters and providing breeding sites for container-breeding mosquitoes, such as *Aedes aegypti* and *Aedes albopictus*, vectors of Dengue, Zika, and other diseases. Sewage and solid waste issues are further complicated by tourism as more people visit the area during the tourist season and increasing waste volumes. A solid waste collection and management system is badly needed, an initiative that is being addressed for the country and may soon reach to these more remote buffer communities of CTWS. Sewage management offers special challenges, given the high water table that limits use of absorption fields. However, there are alternative small and medium size waste management systems and strategies now available that can function in this setting, including use of bioremediation units rather than absorption fields that can actually turn waste into plant nutrients that support green features, particularly on hotel grounds.

Table 20. Activities that Impact or Potentially Impact Environmental Quality of CTWS.

ACTIVITY	POTENTIAL IMPACTS AND SOLUTIONS
Gill Net Fishing	Catch includes many fishes that are not used, fishes left in the net too long are wasted. Hand line fishing and possibly cast netting can be more selective and less wasteful.
Fishing Native Fishes	Sustainable fishing pressure may have minimal impact, but increased fishing may reduce native species and affect pray and predator populations. Commercial fishing probably should be reserved for the local fishermen.
Fishing Tilapia	Extensive fishing of tilapia may help keep populations under control. Wild caught tilapia may be a viable fishery and a market already exists.
Fishing Turtles	Turtle populations are highly susceptible to over fishing. Limits on season, size and number (catch size and number of fishermen taking the resource) should be respected if populations are to be fished sustainability
Hunting	Hunting for local use as opposed to commercial hunting is more sustainable. Impact depends on game species, number of hunters and frequency of hunting activity. Also game population is dependent on rate of degradation of local habitats.
Logging Pine/Mahogany	Most mahogany has probably been removed, but replanting for the future is a good option. Pine may be harvestable on a sustainable yield basis and should be determined by evaluation of the stock. Excessive logging changes the structure of the upland forests.
Logging Logwood	At the current rate of logging for fence posts, this may be a sustainable practice. However, these logwood forests are the largest remaining patches and should be protected and wisely managed.
Cattle, Sheep, Horses	Livestock compact the ground, affecting infiltration, reduce ground cover through grazing, trample the littoral zone of the lagoon and add considerable amounts of manure to the water in the form of surface runoff. Tick populations are greatly increased in the local area that can have some impact on the tourist industry.
Small Scale Agriculture	Less impact as compared to large scale agriculture, particularly if the 66 ft. law is respected and integrated pest management practices used.
Large Scale Agriculture	Destruction of riparian forests (if 66 ft. law is ignored), increased sedimentation, discharge of pesticides and fertilizers are typical impacts. Many of these can be minimized by maintaining riparian and littoral forests and using integrated pest management practices.
Outhouses	Affluent may contaminate groundwater and wells.
Septic Systems	Affluent may contaminate groundwater and surface waters. This can be prevented or greatly minimized by construction of bioremediation filters where possible.
Well Water Use	Well water is probably sustainable for the local population, but excessive draw down for agriculture or other heavy demand use may lower the water table.
Household Waste	This includes solid waste, metal products (batteries, old appliances) and hazardous materials (cleaners, paints, solvents) and organic waste, all of which have specific impacts and ways of dealing with waste properly (Figure 55a and 55b).
Outboard Engines	Noise, fuel and oil spills, wakes and prop wash erode shorelines, props can damage turtles and manatee

a

b

Figure 55. Solid Waste is a Large Issue within Buffer Communities. a. Household Waste Dump on Land. b. Household Garbage Discarded in a Water Body.

Some of the more important categories of human impacts affecting CTWS are discussed under the following topic headings. Potential solutions are also discussed. Many of these solutions offer opportunities to engage local and international youth in project based activities that contribute to community needs while providing participating youth and community members with applied experiences.

Forestry

As discussed above, historically swamp forests have been heavily logged throughout the region. Characterized by low species diversity, swamp forests are relatively easy to manage, but are also subject to over-exploitation. Initially the British colonized what is now Belize during the 18th century in order to exploit Bastard Mahogany (*Carapa guianensis*), a common and marketable swamp forest timber tree (McHargue and Hartshorn, 1983), and Logwood (*Haematoxylon campechianum*) (Bolland, 1988). Logwood was almost completely stripped out of the landscape by middle of the 20th century, with the last extensive stands in Central America occurring at CTWS. Stumps of harvested logwood are seen today around much of the lagoon (Figure 56). Except for some harvesting of Logwood for fence posts, the wood being very decay resistant, there is no current market for this tree.

Other forest products are being/have been harvested from savannas in the area, working through the Belize Forest Department. Species include pine, palmetto, and oak. Pine is harvested, milled, planed, and pressure treated with copper acetoarsenite for use as a primary building lumber in Belize, the copper and arsenic-based wood preservative making the wood resistant to termites and fungus. Pine posts, essentially the heavy resinous heart wood of pine trees that remain after all of the outer, less resinous xylem has rotted away, were also harvested for house posts, as they last for years even when put in the ground. However, few people build conventional elevated wooden houses today, now preferring block and concrete structures.

Figure 56. Many Logwood Stumps Remain Around the Edges of the Lagoons.

Palmetto Palm has been used traditionally to build outside walls of bush houses because of its termite resistance. Replacement of traditions construction with concrete has reduced harvest of this palm. However, its seeds have an anti-cancer chemical that does have a small commercial market, and seeds are harvested on a limited basis.

Oak wood is harvested from the drier savannas and used to make charcoal. Cut into small lengths, the wood is smoldered for hours in low-oxygen ovens. These ovens are essentially one meter deep pits dug in the ground, filled with wood that is ignited and then the pit covered with sheet metal to reduce oxygen. Charcoal is then cooled, packaged in paper bags, and sold on the small, but relatively steady local market. Other forest produces may include “bush sticks,” representing a variety of species that grow straight pole wood, for use in cement construction, particularly to hold up plywood used to build forms for casting concrete roofs and balconies. Surrounding areas, including other buffer communities found on higher ground, may support some limited logging. However, outside of pine harvesting, other forest activities are very limited.

There are many savanna and wetland plants within CTWS wetlands and surrounding dry savanna and broadleaf forest areas that have medicinal and economic uses (Balick and Arvigo, 2015). Those plants on the botanical list for the area are given in Appendix C, along with their particular uses. A total of 45 species representing 32 different plant families are listed. Interviews with local people who hold to such knowledge would likely increase the size of this list.

Orchards, Livestock, and Aquaculture

Comparison of the 2010 Darwin Savanna Ecosystem Map with 1980 Landsat data indicate that out of the 168,000 hectares of lowland savanna of Belize, roughly 20,000 hectares (49,420 acres) (12%) have been converted to other uses (Cameron, *et al*., 2011; Bridgewater, *et al*., 2012). Most conversion is attributed to agriculture, with pasture development being the leading activity in northern Belize. Currently there is little crop agriculture on-going within the CTWS area, other than for cattle (discussed below) and cashews. Centers of agricultural production include the strip of higher ground along the western shore of Western Lagoon down to Rancho Deloris, the area for which the new causeway was built to serve. The other agricultural areas include the higher land around Crooked Tree Village on the island, largely pastures and cashew orchards. Cattle are free-ranged on land along the eastern side of the Northern Lagoon during the dry season. The third area of agricultural activity is found along the Northern Highway around Biscayne (Figure 57).

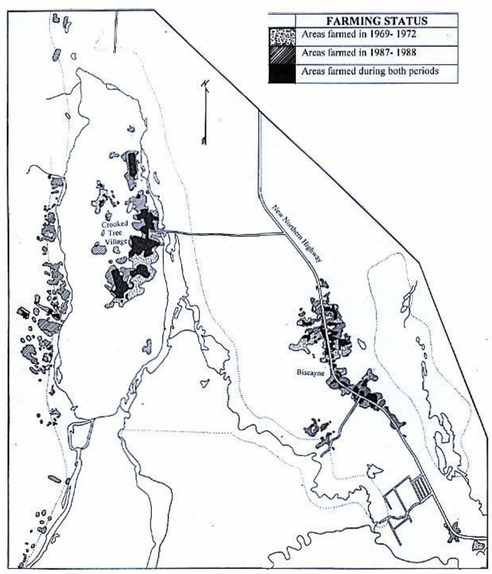


Figure 57. Land Under Agriculture During 1969-1972, 1987-1988, and Both Time Periods.

Figure 57 was compiled by King, *et al.* (1991), showing land use as depicted on aerial photographs taken in 1969 to 1972 and 1987 to 1988, and data form a Landsat TM image taken in 1987. The map shows land under agriculture during the 1969-1972 period, the 1987-1988 period, and land under agriculture during both periods. Agriculture has expanded over the time period mapped, particularly in the area along Spanish Creek where very little activity occurred during 1967-1972. About 5% of the land on the western shore of Western Lagoon was farmed during both periods, about 60% of the land around Crooked Tree Village was used during both times, and about 15% around Biscayne being under production during each time. Location of agricultural land actually shifted around on the landscape, with much of the agriculture along the Western Lagoon being created during that 15 to 16 year interim. Agriculture within Crooked Tree Village moved from the front of the village to areas in the back of the village, and from the northern end of the Biscayne area to the southern end during this period.

Comparison of this area with GoogleEarth© imagery (2015-2016 imagery) indicates that agriculture has expanded very little, if at all, on Crooked Tree Island. However, there has been expansion along the western shore of Western Lagoon, much of that increase occurring to the north and south of those cleared areas shown in Figure 57. There also appears to be some agricultural activity encroaching on the northern end of CTWS, that area that represents the critical connection with New River. There are also a few new access roads leading to a potential housing development (British American Cattle Company affiliated?) and an agricultural expansion area, particularly for a parcel in the northeastern edge of CTWS.

Cattle ranging has been an impact on most of the land types found in the area. Even lands classified as no use are heavily tracked by cattle going to water sources (Figure 58a). The principal problem with these land classification systems is that land use potential is assigned to select land areas without taking into consideration the functional importance of certain land types within ecosystems. For example, riparian forests are vital components of flowing waters. Littoral vegetation around lagoon edges, wetlands and corridors should also be considered when designing land use classification schemes for specific areas, given the many services they provide. These traditional classification components are useful, but should be applied with attention to the roles of land areas in the larger ecological landscape.

a b

Figure 58. a. Eastern Side of Northern Lagoon in Dry Showing Heavy Cattle Traffic. b. The Same General Area Flooded During the Wet Season.

Cattle and horses roaming free within the village have been a problem for many years. The cattle graze aquatic plants, especially lilies, during the dry season. This creates problems as cattle trample the littoral zone of the lagoon to access plants while dropping their dung directly into the water. Alternately as lagoon waters rise during the wet season, fecal material lying on the surrounding inundated areas nitrifies the water. Excess nutrients contribute to algal blooms that deplete oxygen availability in the water, which has a detrimental effect on local fish species, while enhancing food resources for the invasive tilapia. Since the 2003 REA, regulations have been adopted that require cattle to be enclosed in a fence and very few farmers allow free ranging livestock. This has reduced both the issues of cattle and fecal material in the lagoon and cattle wandering through people's yards.

BAS representatives hosted a meeting to consult with cattle farmers concerning issues of livestock related to water pollution and predation by jaguars (Carballo-Avilez, 2009). Five cattle farmers attended, and were at first somewhat skeptical about the meeting and failed to see any benefits to them or appreciate their relationship to CTWS, but then began to cooperate in the discussion. Farmers maintained that about 20 people were actually involved in raising cattle in Crooked Tree, but that most of these individuals abided by the regulations and kept their cattle behind fencing. However, they conceded that only five farmers did not comply with the regulations and allowed their cattle to free range. The cattle/jaguar issue will be covered in more detail later in the document under conservation initiatives.

Food production within buffer communities of CTWS has traditionally included orchards, gardens, pastures, cattle, horses, pigs and poultry. Tilapia ponds are now also a component of small farms. The impact of tilapia on the CTWS ecosystems is covered in more detail below. These fishes are now a part of the ecosystem and escaped tilapia from farm fish ponds is probably not much of an issue any longer. However, these ponds can serve as sources for new fish introductions if farmers are persuaded to experiment with other foreign fish species, and for the potential introduction of diseases and parasites into wild fish populations.

Hunting and Fishing

Crooked Tree villagers have traditionally exploited the aquatic and terrestrial fish and wildlife associated with Northern and Southern Lagoons from the beginning of its history. Hunting occurs by some of the locals, largely for table food and probably for local restaurants, with White-tailed Deer and Paca or Gibnut being the common game. Other game animals include for home use may include armadillo and occasionally ducks. Stricter game laws and other social factors have resulted in a general reduction of hunting, with hunting as a tourism activity being apparently non-existent.

What impacts are hunters having on the wildlife of CTWS? This is a challenging issue to investigate, given that hunters are less visible than fishers. Hunting includes a focus on select game animals, but also on wildlife perceived as serious threats to humans and livestock, such as jaguars. How big is the bush meat market? Do hunters harvesting game from the CTWS area supply the bush meat market in Belize City and Orange Walk, or the demand for wild meat among select restaurants and banquet events? These are all serious questions that will require additional research to address. Besides students and researchers in wildlife ecology and management disciplines, equipped with camera traps and other tools, they should also reach out and enlist the aid of local hunters, the one group of people who know this small industry intimately.

The main issue today is hunting of jaguar by cattle ranchers. As humans gradually encroach on jaguar territories and wildlife resources become scarce, the older and wounded jaguars will occasionally take a small calf. The response of farmers is to hunt down the jaguar, or at least a jaguar. Often the animal, guilty or innocent, is not killed but wounded. This then increases the likelihood that the wounded jaguar, potentially not able to hunt as effectively as before being injured, will resort to harvesting more easily captured cattle (Ms Shanelly Carillo, Jaguar Officer, Belize Forest Department, personal communication). The Belize Forest Department and Panthera have been working with farmers to help address the cattle/jaguar issue.

BAS implemented a campaign to work with farmers who were reporting problems with jaguars helped to develop 11 cattle farming "best practices," that not only helped reduce risk of livestock loss to jaguars, but also buffered the impact of farming to adjacent environments (Table 21) (Carballo-Avilez, 2009). Ultimately 10 out of 35 farmers signed a volunteer contract to implement 5 out of 11 practices identified. By the end of the campaign, 2 out of those 11 farmers successfully completed this goal. One of the recommendations from this effort was the enforcement of the National Parks System and Cattle Trespassing Acts. Ultimately this campaign did succeed in improving communication and the relationship between BAS and the buffer communities, and recognized the need to continue these outreach efforts (Carballo-Avilez, 2009).

Table 21. Eleven Cattle Farming Best Practices Devised with Farmer Input.

Keep cattle in fenced pastures
Practice effective pasture management by growing grass
Keep 300 feet or wider strips of forest around waterways
Leave large canopy trees in pastures to give shade for cattle and to help in water retention
Build living fences using Madre Cacao or Gumbo Limbo
Use legume ground cover (green manure) and other appropriate, non-environmentally harmful fertilizers
Provide some supplementary food to cattle (hay, sugar cane, molasses)
Use cattle dung for fertilizer and other profitable uses
Keep livestock penned during most of the dry season
Keep good business records
Treat cattle with necessary vaccines and medication

Fishing is still a very active enterprise within CTWS among buffer community fishers. A market for local fish has existed for generations, and fishing still provides income for several local fishers, including those from communities beyond the buffer communities, and a few fishers from Guatemala as well. Harvested fishes not consumed locally are sold to markets in Belize City and Orange Walk, with most commercial fishermen sell their catch to suppliers from Orange Walk. These outsiders are not allowed to fish in the lagoon and thus have to obtain fish from local fishers. The market is open to all types of fishes but Bay Snook, Red-headed Cichlid, and tilapia are preferred. Filleted fish is sold for a higher price. Tilapia can be sold for about $4 to $6 a pound when filleted. Primarily Maya Cichlid or Crana (*Cichlasoma urophthalmus*), Yellowjacket Cichlid? (*Cichlisoma friedrichsthali?*), Bay Snook (*Petenia splendida*), and Blue Catfish or Baca (*Ictalurus furcatus*) were the traditional catches. Around 1996 or 1997, two new tilapia species (*Tilapia mossambicus* and *Tilapia niloticus*), escaping from adjacent aquaculture ponds, became established within the CTWS lagoons. In a few years they dominated the catch, along with Bay Snook, while other cichlids became scarce.

The main fishing practices include hand lines, rod and reels, long seines, and some cast nets. A minimum mesh size is set to protect under sized fishes. Rod and reel fishing is a successful technique and the method used by most people. Gill net fishing is apparently not common and therefore has no effect on the current fish population. Seine nets can yield high numbers of fishes. During the early dry season, fishermen pay $20.00BZ per net haul to ~~BAS~~ to fish on select days of the week. A good net haul can be up to 500 lbs. of fish, made up mostly of tilapia, Bay Snook and Maya Cichlids. This harvest is conducted to reduce the numbers of fishes that are trapped in low waters and hopefully reduce the numbers of fishes dying during the late Dry Season. Some fishermen expressed the idea that more intensive fishing during the wet season would reduce the number of fishes that die during the dry season. This idea for managing tilapia populations merits further study. Figure 59a shows fishers going out early in the morning and 59b shows the seine net in a canoe that is often used to fish the lagoons.

Comment [A16]: Paied to Crooked Tree Village council NOT Belize Audubon Society and it is $30.00 to $75.00 per haul.

The prices have varied over the years to wehre it is now $75.It was in the in 2000's that people started paying the Crooked tree Village Council--it was a former BAS staff working at Crooked Tree who was also Vilage Chairman (Donald Tillett) at one point that's why people thought the money was being paid to BAS.

a

b

Figure 59. a. Fishers in Northern Lagoon. b. Canoe with Long Seine Net Often Used to Fish the Lagoons.

Many fishers see themselves in conflict with BAS, believing conservationists want to completely stop fishing, a custom that has been practiced for centuries. This was perpetuated in 1984 when the Crooked Tree ~~Act~~ was declared a protected area under the National Parks System Act and made it illegal to hunt, capture, or kill any wildlife within the sanctuary boundaries and therefore commercial fishing was suddenly prohibited, probably for the first time in over 300 years of occupancy by generations of people. However, limited fishing by people of the buffer communities for the table was allowed, realizing the minimal environmental impact of this traditional resource use. Also the Act prohibited plant collection and destruction of natural resources and cultural resources, with violations carrying fines ranging from $200 to $500 Belize dollars, and up to 6 months in prison (Enriquez, 1993).

Regulations were placed on independent-minded and self-sustaining people of Crooked Tree who were also very dependent on the natural resource markets for money to purchase those things they could not make themselves. Enforcement of hunting regulations for villagers was very minimal, while fishing was and is more regulated and therefore a point of contention for residents, particularly those who draw their primary livelihoods from the lagoons. This has been a very important wedge between the villagers and BAS from the time the CTWS was legally established (Johnson 1998).

This resentment tends to surface when local people are suspicious of activities conducted or condoned by BAS. For example, BAS permitted a regional fish assessment project, with a focus on Tilapia, conducted by Esselman (2006) to occur in CTWS lagoons. During this effort a fish kill occurred in the Northern Lagoon that raised concerns among community members over the electrofishing techniques being used in the study

(Williams-Thompson, 2007). The effort in CTWS was discontinued to avoid inciting community members who felt strongly about the potential connection. However, it was proposed that high dry season temperatures and low oxygen conditions during this time actually led to the fish kill.

Road construction has impacted fisheries in CTWS, particularly in Northern Lagoon (Hadley, 1995). When the access road to the Northern Lagoon eastern shore was built, it gave commercial fishers from outside of the village access to the fisheries resources traditionally used mostly by Crooked Tree fishers. Outside fishers used nets and soon fished out much of the fisheries resources. After the causeway was constructed in 1984, local villagers noticed increases in fish populations. The year-round deep water in the northern side of the causeway provided year-round habitat for fishes. However, the logwood forests were dying, indicating the impact the causeway was experiencing, which helped encourage splicing bridges into the structure.

Eventually the GoB was convinced to create openings in the causeway. A year after bridges were spliced into the causeway, a large fish kill was reported. During the second year reduced numbers of fishes were noticed. Fishermen have expressed concern that the notches are not deep enough to allow many fishes to cross easily and should be at least 3 to 4 feet deeper. Some believe that the fishes tend to retreat from the lagoons and seek refuge in source ponds within other parts of the wetlands, returning once the rains start up and water in the lagoon rises. However, some of the source ponds are beginning to dry out and logging roads are giving commercial fishermen access to these ponds, further threatening the fish populations.

When the notches were cut into the causeway, the swamp forest began to grow back, but not the same kind of plant growth as in the earlier swamps. Today large numbers of *Mimosa pigra* grew back instead of the original logwood. This thorny brush impedes passage into a lot of the backwater areas, perhaps giving fishes some measure of refuge from the fishermen. Fishermen have not noticed a reduction in the overall average size of their catch over the years, with the exception that the average size of tarpon seems to have increased. Some fishermen contend that fish populations are getting too dense, citing as evidence the extensive die-offs during the dry season, leading to the increased fishing strategies described earlier.

What impact is fishing having on the lagoons of CTWS? This question needs further investigation. However, some of the best investigators can be the local fishers themselves. The principal sources of information for this present effort included published literature and the collective knowledge of some of those local fishers. Often fishers in the area can provide considerable information on the kinds of fishes within the system, which species are the more abundant, what population shifts have occurred over time, observations of fish behavior, diets, breeding seasons, diurnal and annual cycles, and many other important bits of information. This knowledge can be gleaned through interviews of interested fishers, accompanying fishers during their fishing activities if permitted, and including fishers in research efforts. Those fishers who are interested can directly participate in research efforts, for example by keeping and preserving fish stomachs and scale samples with a data tag stating time and location of capture while cleaning their catch.

Tourism

Establishment of CTWS spurred growth of ecotourism as an alternative income for some Crooked Tree residents, an industry strongly supported by BAS. Recognized around the world for its birdlife, Crooked Tree Village has been a popular destination for serious birders for decades. Guided tours by highly trained and knowledgeable guides, boat tours and canoe rentals to spot birds from the water, and well maintained walking trails along the lagoon shores and through riparian and swampland areas (Figure 60) provide rewarding sightings. CTWS also attracts tourists looking for opportunities for quiet relaxation and new cultural experiences. Besides single visitors, couples, and occasional families, education tourism has increased in the area, involving groups of up to 20 individuals.

Figure 60. Elevated Walkway Over Areas that Flood in the Wet Season.

However, tourism, even ecotourism, imposes its own set of impacts on a local site. Three larger hotel facilities have been constructed within Crooked Tree Village, along with a few smaller bed and breakfast types of accommodations. Increased number of people on the island requires increased water usage, increasing traffic on the roads to bring guests in and out of the village and to take them on local expeditions, and to continually supply guests with food, water, and other commodities that have to be brought in from the outside, often on a daily basis. More tourism also means more waste water, both gray water from showers and laundries, and sewage. Increased wastewater in areas where groundwater is already high results in improperly treated waste that may contaminate wells and swimming water. Increased boat traffic on the lagoons and rivers of the area is another result of sight-seeing tours. These are motorized boats that suspend sediments and create wakes that erode into shorelines.

Many of these impacts associated with tourism can be managed. Careful planning and design is required from the start to help create facilities that provide for the needs of the tourists while minimally impacting the fragile ecosystems of CTWS. Tourist dollars can make valuable contribution to conservation. However, another important component of tourism management is tourist education. Enhancing tourist awareness of ecological issues and appropriate conservation attitudes and behavior is a valuable service of ecotourism.

Invasive Species

Invasive species are more often than not the result of human activity, with introductions being both accidental and on purpose. In comparison with marine and terrestrial ecosystems, freshwater ecosystems are more susceptible to successful invasive species (Sala, *et al*., 2000). CTWS has not been spared impact from invasive species. Invaders covered here include snails, fishes, and aquatic plants, but there are many other groups of organisms that should also be considered. Currently there are many ongoing activities that encourage new introductions into Belize. For example, there are aquarium shops or counters in large stores within Belize City and Spanish Lookout offering many varieties of freshwater fishes, most of which are hybrids and not an invasive threat, but some species are good invasion candidates. Besides fishes, a number of aquatic plants (likely not native to Belize, but not yet determined) are also offered for sale. In addition, the aquaculture industry of Belize has been a source of introductions and will likely continue to be a pathway for new species to enter the waterways of Belize. Then there are those occasional introductions on purpose, where some land owner for example, often someone from abroad, wants to see if a species of fish or frog from back home could survive in Belize (Author speaking from personal knowledge). Table 22 lists invasive organisms threatening the streams, rivers, lagoons, and wetlands of CTWS, or that have the potential to do so within the immediate future.

Dourson (2009) first found the Asian Thorn (*Melanoides tuberculata*) in the Bladen River. It was also collected in macroinvertebrate samples from CTWS wetlands and lagoons during this study. This species is found throughout the world tropics, is moving into temperate areas, and threatens to biodiversity (Van Damme, 2014). They are widely dispersed throughout Belize. It is not known how this snail arrived in Belize, or when. *M. tuberculata* is native to Middle East, eastern Africa, and Southeast Asia. It has successfully invaded habitats throughout the pantropical/subtropical belt, rapidly invading new habitats and becoming well established because of its high reproductive rate (Work and Mills, 2013). It is rapid spread by the aquarium trade, tolerates a wide range of environmental conditions, and has a wide range of food preferences (Coat, *et al*., 2009). Introductions have been repetitive and continuous, with snails sold over the internet by many companies targeting the aquarium market. It is known that birds can play a role in the spread of this species (Van Damme, 2014). Sometimes local predators, including crayfish, some snail-eating turtles, and raccoons can affect populations. It is also eaten by some cichlid species (Van Damme, 2014). Musk turtles in particular have been documented as important predators (Berry, 1975). High trematode-infection rates among raccoons suggest heavy predation on these snails that are known hosts (Hamir, *et al*., 1993).

Table 22. List of Actual and Potential Invasive Species that may Impact the Aquatic Ecosystems of CTWS.

SPECIES/TAXONOMIC RANKING	NOTES ON ORIGIN, ECOLOGY, AND INFLUENCE
MOLLUSCA	
Gastropoda	
Thiaridae	
Melanoides tuberculata Asian Thorn	Native to Middle East, eastern Africa, and Southeast Asia; spread through pantropical and subtropical belts; rapid spread through aquarium trade and by aquatic birds; high reproductive rate through parthenogenesis and sexual reproduction; tolerates a wide range of environmental conditions, including low salinity, low dissolved oxygen, high pollution levels, drought; wide food preferences; displaces some native snails; host for some flukes and introduced trematode
Tarebia granifera Quilted melania	Native to India, Southeast Asia, Philippines, Japan, Hawaii; appears to be pantropical and subtropical; introduced through aquarium trade; impacts many native snails; intermediate host to several trematodes; increased impact in areas where riparian forests have been removed
Bivalva	
Corbiculidae	
Corbicula fluminea Asian Clam	Native to China, Korea, southeastern Russia; introduced in North America probably by Chinese immigrants for food, now found in Mexico; rapid growth, early maturity, high fecundity, short lifespan, close association with humans; changes substrates and affects native bivalves
VERTEBRA	
Pisces	
Cichlidae	
Oreochromis niloticus Nile Tilapia *O. mosembique*	Native to Africa; broadly spread in Mesoamerica by aquaculture industry, spreads rapidly by floods; impact native fishes, eating eggs and fry, create eutrophication conditions, reduce native plants, introduce parasites to native fishes
Centrachidae	
Ctenopharyngodon idella Grass Carp	Native to Asia; herbivore introduced around the world for aquaculture and aquatic weed control, including Mexico and Venezuela; degrades aquatic plant communities; many other introduced carp species of concern
Loricariidae	
Pterygoplichthys Sailfin Catfish	Native to South America; spread through aquarium trade, established in North and Central America, Caribbean Islands, southern and eastern Asia, Indo-Pacific islands; can breathe air, tolerate low oxygen and low salinity, survive out of water short time; impacts sediments and aquatic plants, tunnels into river banks
Channidae	
Channa sp. 8 species	Introduced to North America by Asian immigrants; spreading rapidly, air breathers, survive out of water for extended periods
PLANTE	
Salviniaceae	
Salvinia auriculata Water fern	Native to South America, forms thick floating mats, blocks sunlight from water below, affects water quality in detritus breakdown, can absorb some heavy metals
Pontederiaceae	
Eichhornia crassipes Water Hyacinth	Native to Amazon basin; widespread in Central and North America; forms thick, dense floating mats, blocks sunlight from water below, affects water quality in detritus breakdown
Araceae	
Pistia stratiotes Water Lettuce, Water Cabbage	Origin is not known, but possibly South America or Africa; aggressive invader blanketing water ways and lagoons in coastal Belize
Poaceae	
Urochloa mutica (synonym: *Brachiaria mutica*) Angola Grass	Native of central Africa and Middle East; introduced into Central America but sometimes suppressed by other *Urochloa* sp.; introduced as pasture fodder; inhabits poorly drained wetlands and ponds, clogging ditches, taking over small water bodies

Habitats range from very low salinity to freshwater (Berry and Kadri, 1973), with *M. tuberculata* tolerating a wide range of hardness and pH, and often found on rock and mud substrata, as well as other sediment types (Vogler, *et al*., 2012). These snails inhabit streams, rivers, lakes, reservoirs, and other water bodies with no- to low flow, and can also survive in eutrophic environments, sewage polluted waters, and drought conditions (Vogler, *et al*., 2012). *M. tuberculata* feeds at night on algae, bacteria, deposits of organic materials, and putrefying flora. Although the snails have eyes, their vision is relatively poor, and therefore they rely on their strong sense of smell to find food. They can reproduce through parthenogenesis and sexual reproduction, giving birth to living young having developed in brood-pouches and emerging as juveniles at night (Heller and Farstey, 1990). *M. tuberculata* live about 2.5 to 3 years, with a high birth rate with relatively low mortality, allowing populations to build up rapidly and can be sustained for years (Vogler, *et al*., 2012).

M. tuberculata can directly displace some native snail species, introduce alien trematodes (Madsen and Frandsen, 1989), and have demonstrated predation on *Physella* spp. (Gastropoda: Physidae) eggs under laboratory conditions (Ladd and Rogowski, 2012). It is a host for the introduced trematode, *Centrocestus formosanus*, known to parasitize several fish species, and this snail will feed on the eggs of some benthic fish species (Mitchell, *et al*., 2007; Phillips, *et al*., 2010). Invasions by *M. tuberculata* lead to loss of biodiversity and structural changes in aquatic ecosystems (Pimentel, 2002), including community structure (Kerans, *et al*., 2005) and ecosystem functions (Arango, *et al*., 2009).

M. tuberculata may successfully out-compete native snails, especially from the family Hydrobiidae, that may carry *Schistosoma* (Pointier, 1993; Pointier, *et al*., 1993a), but *M. tuberculata* may be a host to other species of flukes that can infect humans, birds, and fishes (Dundee and Paine, 1977; Pointier, *et al*, 1993a; Pointier, *et al*., 1994; Scholz and Salgado-Maldonado, 2000; Guimaraes, *et al*. 2001; Ben-Ami and Heller, 2005; Bogea, *et al*., 2005; Derraik, 2008, Mitchell, *et al*., 2000). *M. tuberculata* is a first intermediate host to *Centrocestus formosanus*, a gill nematode (Ben-Ami and Heller, 2005; Tolley-Jordan and Owen, 2008) that can infect fish as well as some migratory birds, including the Green Heron, *Butorides virescens,* and the Great Egret, *Ardea alba,* (Mitchell *et al*. 2005).

Dourson (2009) also reported the occurrence of the Quilted Melania (*Tarebia granifera*), another small Asian snail that is also a detritus feeder, consuming diatoms and algae scraped from rocks and other submerged surfaces. While being well adapted to fast flowing waters, densities in still water tends to be higher, but their numbers do not seem to reach the densities in which *M. tuberculata* have been found (personal observation). *T. granifera* has been also been shown to be intermediate hosts of the trematodes *Paragonimus westermani, Metagonimus trematodes, Centrocestus formosanus* and *Stellantchasmus falcatus* (Madhyastha and Dutta, 2012). Shells of this species have also been collected from CTWS habitats in this study, but actual confirmation of living snails is needed.

T. granifera naturally occurs in India, Southeast Asia, the Philippines, Japan and Hawaii (Abbot 1952). This snail has contributed to the local extinction of several freshwater gastropods in Cuba, including *Pachychilus violaceus* (Pointier and Jourdane, 2000). Karatayev, *et al*. (2008) proposed that *T. granifera* impact on gastropod fauna is a beginning stage in the local extinction of native species. There are reports that introductions of *T. granifera* into habitats previously invaded by *M. tuberculata* result in *T. granifera* eventually outnumbering the earlier invader (Pointier, *et al*., 1998). Populations of *T. granifera* were investigated in relation to riparian deforestation in Trinidad (Moslemi, *et al*., 2012). It was determined that this invasive snail grew to greater size and density in those reaches where riparian forests had been removed as compared to stretches having well developed riparian forests. More exposure to sunlight increased algal production and food resources. Snails thus contributed more significantly to the local nitrogen cycle through fecal production. This indicated that these introduced snails can have a heavier impact on local nutrient cycles when riparian habitats are disturbed than when they are left intact.

There is also a bivalve of concern that seems to be moving from North America southward. This is the Asian Clam, *Corbicula fluminea,* native to China, Korea and southeastern Russia (McMahon, 1999; Mouthon, 2001), with the ability to invade fresh and brackish waters less than about 10 ppt salinity (Sousa, *et al*., 2009). *C. fluminea* was likely first introduced to North America by way of British Columbia, Canada before 1924

(Naranjo and Olivera-Carrasco, 2007) and again on the west coast of North America around 1938, probably by Chinese immigrants as a food resource (McMahon, 1999). It has moved across the United States and is now found in northern Mexico on both the Gulf and Pacific slopes. The clam was recorded in Veracruz in 1992 (Naranjo and Olivera-Carrasco, 2007). Along with *T. granifera* and *M. tuberculata*, the aggressively invasive *C. fluminea* has been reported from the Tuxpam and Tacolutla Rivers in Mexico (Lopez-Lopez, *et al*., 2009). It favors fine to coarse sandy sediment (Cordeiro and MacWilliams 1999; Sousa, *et al*., 2008), but has also been found in mud substratum (De la Hoz, 2008). Rapid growth, sexual maturity at an early age, high fecundity, short lifespan, and close association with human activities that help it spread and invade suitable habitats explain its success (Sousa, *et al*., 2008). However, *C. fluminea* is susceptible to organic contaminants (Souza, *et al*., 2008) and drops in water stage that leave sediments exposed (De la Hoz, 2008). This could possibly prevent it from becoming well established in CTWS wetlands should it reach Belize. The Asian Clam can change the substratum, affecting native bivalve species.

Invasive fish species can impose many ecological changes, particularly in nutrient limited systems (Capps and Flecker, 2013). African tilapias are the most broadly spread invasive fish in Mesoamerica (Canonico, *et al*., 2005). Tilapia, genus *Oreochromis*, is spread to most tropical countries of the world (Froese and Pauly, 2008, Welcomme, 1988). They can exploit a wide range of habitats, including rivers, lagoons, wetlands, and estuaries (Phillippart and Ruwet, 1982). Invasive tilapia can tolerate a wide range of habitats because of their very wide tolerance of different physiological conditions, including salinity (Courtenay, 1997). A few different species have been introduced to new habitats for the control of aquatic vegetation, as aquaculture stock, and as game fishes (Courtenay, 1997). They have been demonstrated to be involved in the reduction or local extinction of native fishes (possibly eating eggs and fry of other fishes), creating conditions that lead to eutrophication (Starling, *et al*., 2002), denuding lake bottoms of aquatic plants, introducing alien parasites to local fishes (McCrary, *et al*., 2001), and impacting local food webs (Taylor, *et al*., 1984). Actually the spread of exotic trematodes is a very serious problem involving many fish species (Mitchell, *et al*., 2005). Adult tilapia may compete with local fishes for space, particularly with cichlids looking for nesting sites. Juvenile tilapia may compete with other cichlid juveniles for food resources. Esselman, *et al*. (2013) discussed the spread of tilapia within rivers of northeastern Mesoamerica.

Tilapia were originally found in Crooked Tree in 1985 when a fisheries assessment of the lagoon/wetland system was being conducted, the pathway of its arrival being unknown (Miller and Miller, 2006). *Oreochromis niloticus, the* Nile Tilapia, and *O. mosembique* are the two species on concern. Crooked Tree fishermen interviewed by Esselman (2009) remember first seeing tilapia in 1990, and then it was reported in Rio Hondo in 1995, the Belize River near CTWS in 1996, and by 1998 spread within the Belize River and was found in the Sibun River and the Monkey River. By 1999 tilapia were reported in large numbers from Crooked Tree (Salas, 2001). It was 2002 before tilapia was detected in New River, and 2004 when they were first noticed in the North Stann Creek watershed (Esselman, 2006). Esselman (2009) estimated dispersal rates, based on distance from Crooked Tree, for first reported tilapia catches, with Mussel Creek and Belize River becoming populated in 6 years, the upper Belize River in 8 years, the Mopan River in 10 years, and the Macal River in 12 years.

The tilapia population probably built up rapidly within the lagoons before potentially dispersing outward to surrounding areas, the lagoon system offering ideal sources of food such as algal muds. This lag time between the first introduction of tilapia into Crooked Tree and the rapid spread into other areas, as discussed by Esselman (2009) certainly began before the first 1985 discovery mentioned by Miller and Miller (2006). Esselman (2009) identified two mechanisms contributing to the release and spread of tilapia throughout much of Belize, those being accidental releases from aquaculture facilities and large floods such as associated with Hurricane Mitch in 1999 and with subsequent hurricanes. This has led to changes in the availability of food resources for many wetland and lagoon organisms, possibly a change in trophic structure. However, there is little pre-tilapia information about the CTWS aquatic ecosystem complex to fully describe that change.

Using data collected from CTWS and other sites around the country, Esselman (2007) created and tested a predictive model that would indicate the potential spread of *O. niloticus* by comparing ecological conditions of waters in Belize where these invasive fish are found, and using the model to indicate future sites of invasion. More studies are required of the behavior of these tilapia species in CTWS lagoons and wetlands and the level of impact they have on native cichlids.

Several local fishers were interviewed by the field team conducting the earlier REA of CTWS (Boles and Saqui, 2003). A few long term trends were described. The most significant has been the increasing amount of tilapia found within the lagoon. The Mos Mos (*C. urophthalmus*) was once a popular fish that is seldom caught today. Fishermen have suggested that this is not from overfishing, but because they have been driven out of the area by the increasing tilapia populations. Tilapia does not seem to affect other fishes, except for *C. urophthalmus*. They usually breed about March. Some fishermen indicated that tilapia breed year round. Tilapia that are holding young in their mouths will spit them into the water when caught, giving the young a chance to survive. Fishermen have confirmed that tilapia usually feed on grass and reeds and some mud but seldom other fishes.

There is another invasive fish species approaching CTWS. One genus in the Suckermouth Armored Catfish family Loricariidae, *Pterygoplichthys* (the Sailfin Catfish genus) was found in Rio Bravo and Sylvester Village near Gallon Jug in November, 2012, specimens being captured by villagers during high water (CTV3 News Belize, November 29, 2012; 7 News Belize, 2013). Now that it is established in Belize, it can be expected to spread to other suitable habitats. *Pterygoplichthys* is represented by about 15 species of armored catfishes that are native to South America and are naturally distributed as far north as the Orinoco River basin. Several of these species have spread beyond their native ranges over the past 30 or so years, becoming established in many places around the world (see Page, 1994). As is the case with many introductions (Padilla and Williams, 2004), *Pterygoplichthys* has been spread through the aquarium and ornamental fish industry. Not only are they now well established in North and Central America, they have also reached Caribbean islands, southern and eastern Asia, and islands in the Indo-Pacific (Fuller, *et al*., 1999; Nico, *et al*., 2009). Once established in a new location, *Pterygoplichthys* populations build up rapidly and they disperse into surrounding areas (Nico*, et al*., 2009; Capps, *et al*., 2011).

These are mostly benthic fishes, living and feeding on lake and river bottoms. Their flatten bodies are covered by dermal bony plates and their sucker mouths help these fishes to anchor to the substrate in fast flowing water and specially adapted teeth are used to scrape up biofilm, algae, invertebrates, organic debris, and wood (Nico, *et al*., 2009). *Pterygoplichthys* can breathe air, and therefore can tolerate anaerobic waters and can survive out of water for a period of time. Loricariids are freshwater fishes, but some species can tolerate estuarine conditions, with some *Pterygoplichthys* spp. being able to tolerate salinity up to 10 ppt for a long period, thus being able to spread from one river system to another through estuaries (Capps, *et al*., 2011). Adults, possibly males, dig large burrows in the banks of rivers and lakes that are used for spawning and nesting, in some cases destabilizing river banks (Nico, *et al*., 2009).

Pterygoplichthys spp. inhabit many different kinds of habitats, from relatively cool, rapid-flowing, high oxygen streams; warm, slow moving lowland rivers; stagnant pools low in oxygen; and acidic (down to pH 5.5) to alkaline (pH up to 8.0) waters (Mendoza, *et al*. 2009). They may occur in soft waters to hard waters, and in water that is poor quality, even highly contaminated with pollutants. Often they are found in floodplain lakes, swamps, borrow pits, and other low-oxygen waters where they must breathe air for extended periods (see U. S. Fish and Wildlife Service, 2004). Usually *Pterygoplichthys* rest on the bottom of the water body, or move slowly, scraping the surfaces of underwater logs, rocks, and other substrata, and rising to the surface of the water, gulping air. Their enlarged stomachs seem to have a respiratory function (Armbruster, 1998). Observations of *Pterygoplichthys* at Volusia Blue Spring, an artisanal spring system in Florida (USA) revealed that adults are active day and night, while juveniles are active at night, hiding in the daytime probably to avoid predators, particularly birds (Nico, 2010).

Several animals have been observed feeding on *Pterygoplichthys*. In Florida, the North American River Otter (*Lutra canadensis*) was seen to occasionally catch and eat *Pterygoplichthys.* Initially ignoring these new, heavily armored fish, otters began preying on *Pterygoplichthys* after a few years, learning to flip the fish over and bite it through the thinner armor of the ventral surface (Nico, 2010). The American Alligator (*Alligator mississippiensis*) has also been recorded feeding on *Pterygoplichthys* in Florida (Rice, *et al*., 2007).

The presence of many different size classes, and females not having ovaries completely spent within populations surveyed, indicate several spawning periods in a year (Gibbs, *et al*., 2008). When *Pterygoplichthys* occurs in high densities, continual grazing and sediment disturbance removes detritus and algae on which other organisms depend, potentially impacting the trophic base of the aquatic system, and consequently affecting invertebrates and vertebrates within the food web (Nico, *et al*., 2014). One interesting observation of the Vermiculated Sailfin Catfish (*P. disjunctivus*) in Volusia Blue Spring, Florida is that many of these catfish tend to attach themselves to native Florida Manatee (*Trichechus manatus latirostris*) and feed on the epibiota growing on the manatees' skin (Nico, *et al*., 2009). The effect of this behavior on the manatees is not known, but could potentially stress the animals (see photographs, Nico, 2010).

Potential effects attributed to *Pterygoplichthys spp*. on the Global Invasive Species Database (GISD, 2014) include weakening river bank structure, increasing erosion, modifying aquatic food webs, disrupting aquatic plant patches, competing with local species, and possibly causing problems to wading birds trying to eat them. These invasive catfish also damage fishing nets. Where *Pterygoplichthys spp*. are present in large numbers, feeding and burrowing cause siltation problems and river bank erosion and even bank collapse (Hoover, *et al*., 2004, Nico, *et al*., 2009). *Pterygoplichthys spp*. graze over river and lake beds, sometimes pushing their heads under the sediment and thrashing their tails back and forth in vegetation patches. Aquatic plants are broken or uprooted, bed areas are de-vegetated, with plant detritus being added to floating detrital mats, further shading benthic habitats. Active grazing of algae and detritus eliminates food and habitat required by aquatic annelids, insects, and crustaceans that sustain local fish and bird populations (Mendoza, *et al*. 2009). In a river study in Chiapas, Mexico, Capps and Flecker (2013) observed that high concentrations of *Pterygoplichthys* increased concentrations of dissolved nitrogen through fecal production, creating essentially biochemical "hot spots" that represented altered nutrient dynamics, potentially affecting the local trophic web.

Should these catfish reach the CTWS lagoons and rivers, some impact can be expected. Crocodiles, river otters, herons, and cormorants may be potential predators, especially of the juvenile *Pterygoplichthys*. However, older individuals may have very few predators. They can be expected to have similar impacts as has been observed in other areas they have invaded. Sediments of the lagoons and wetlands and patches of aquatic plants will likely be heavily disturbed if population numbers build up. There is certainly ample food resource to sustain a sizable number of these invasive and aggressive armored catfishes.

Several other invasive aquatic species are being closely watched that have the potential to extend their new ranges into Belize and surrounding countries. Two groups of Asian fish introductions include several species of carps (Cyprinidae) and snakeheads (Channidae), with range extension predictions into Belizean ecosystems (Herborg, *et al*., 2007). The Grass Carp (*Ctenopharyngodon idella*) is an herbivore that was introduced into the United States for the control of aquatic weeds, and threatens macrophytes in areas where it occurs (Crossman and Cudmore, 1999), and can also affect phytoplankton, macroinvertebrates, and local fishes (Chilton and Muoneke, 1992). Bighead Carp (*Hypophthalmichthys nobilis*) and Silver Carp (*H. molitrix*) were introduced into Alberta, Canada and the southeastern United States for controlling lake eutrophication (Crossman and Cudmore, 1999; Mandrak and Cudmore, 2004) where they prey on smaller zooplankton and phytoplankton, probably competing for this resource with native juvenile fishes (Dong and Li, 1994; Fuller, *et al*., 1999). Black Carp (*Mylopharyngodon piceus*) eat mollusks and may compete heavily with other mollusk-feeding fishes (Ferber, 2001).

Snakeheads are another group of introduced fishes that are of concern. All snakeheads feed on other fishes and are air-breathers (Liem, 1987), thus they are able to live out of water for extended time periods. They were introduced into Canada and the United States by Asian immigrants for live fish markets (Courtenay and Williams, 2004; Courtenay, *et al*., 2004). Herborg, *et al*. (2007) lists eight different species of snakeheads that have the potential to invade Belize and surrounding areas. These include the Blotched Snakehead (*Channa maculate*), Bullseye Snakehead (*Channa marulius*), Giant Snakehead (*Channa micropeltes*), Chevron Snakehead (*Channa striata*), and Niger Snakehead (*Parachanna africana*). The Bullseye Snakehead is already well established in Florida and spreading (Courtenay, et al., 2004).

In a world of global climate change, economic globalization, and uncontrollable aquarium and aquaculture industries, more introductions can be expected in Belize and possibly into CTWS. Some introductions, such as the Cattle Egret (*Bubulcus ibis*), a migrant from Africa that was first recorded in Belize in 1956, find an available, open niche, settle in, and become integrated into the new ecosystem. However, that is a relatively rare outcome. Heavy predation on adults, larvae, and eggs of other species; competition for nest space and food resources with other related species; introduction of pathogens and parasites into their new ranges; serving as host for disease agents already present; and elimination of macrophytes or other important components of the aquatic ecosystems are typical examples of likely outcomes for introductions.

There are also several invasive plants that can become problematic within CTWS. Water Hyacinth (*Eichhornia crassipes*), in the family Pontederiaceae, is a wide-spread, environmentally threatening, and economically expensive invasive aquatic weed, with many millions of dollars being spent annually on its control, particularly within industrial waterways. Originally from the Amazon Basin, this plant has become established in roadside ditches of Belize City and surrounding areas. *E. crassipes* can create thick mats of deep, green, slick-leaved floating plants equipped the dense, feathery roots. These mats can block out sunlight and reduce other aquatic photosynthesizers. Water Lettuce or Water Cabbage (*Pistia stratiotes*), family Araceae, is also a floating aquatic plant thought to be from Africa, but maybe from South America. Its leaves are a lighter green color and covered with short, dense, water repellent hairs. It can also form dense mats and some of the small lagoons within southwestern Belize City are completely covered in this plant. Alien macrophytes can impose changes in dissolved oxygen available within aquatic ecosystems, having important consequences for many species within the system (Caraco and Cole, 2002; Caraco, *et al*., 2006).

If either of these plants were to become established in the CTWS lagoons, they could have some impact on the system. However, they have been growing in the proximity of the system for decades. If they have successfully invaded the area, they have not achieved the level of growth that has occurred in other areas of Belize, including many areas of the Belize River. It could be that the drastic change in water level within this wetland system is enough to keep these two aquatic plant species from reaching excessive densities in CTWS as seen in other locations. It could just be that for some reason neither plant has made it to the lagoons yet.

The small floating Water Fern, *Salvinia auriculata*, is a problematic invasive floating aquatic plant in Neotropical aquatic habitats (Barreto, *et al*., 2000; Lansdown and Gupta, 2013) that is found almost completely covering the surface of small ponds just up-slope from normal high water levels along the Northern Lagoon south of the causeway (Figure 61).

Figure 61. Water Fern (Salvinia auriculata).

Angola grass, *Urochola mutica* (syn. *Brachiaria mutica*), is an invasive aquatic grass from Africa that has been widely cultivated for pasture fodder (Barreto, *et al*., 2000). It tends to grow in wetlands, small ponds, and drainage ditches. Normally this plant is maintained by grazing livestock in pasture settings. However, when introduced into natural settings not grazed by cattle, it tends to grow aggressively.

This list of invasive species was compiled based on preliminary observations. There are others that are on the move, slowly working their way through the region, moving toward Belize. More careful and stringent investigations will potentially reveal other species. A complete assessment should include the smaller organisms, as well, those quite capable of traveling from one part of the world to another as a dried crust on the legs of long-distance migrants. In addition, many (maybe all) invaders are also hosts for parasites and pathogens, bringing many of these organisms with them as the move into their new ranges.

The Causeways

From the beginning of Crooked Tree Village, it has been isolated from the rest of Belize, especially during the wet season when the lagoons are full and filling the wetlands. Anyone needing to travel to Belize City did so by water, traveling down Spanish Creek and following Belize River to Haulover Creek and into Belize City, reversing this trip to return home. Initially an all-weather highway was constructed, but it only reached to within a few kilometers of Northern Lagoon. Then a farm-to-market road was built, connecting the eastern shore of Northern Lagoon directly across from Crooked Tree Village with the Northern Highway. Eventually a causeway, a road built atop an earthen and rock bed, was built across Northern Lagoon on 1984, physically connecting Crooked Tree to the rest of Belize and changing the lives and culture of the people forever.

Ministry of Works completed the 3,000 foot causeway across Northern Lagoon with the assistance of World Bank and the United States Agency for International Development (USAID) funding. This causeway has significantly affected Crooked Tree Village, changing the lifestyle of the people, and has severely impacted the ecology of not just Northern Lagoon, but the hydrological behavior of the whole CTWS wetlands system. Ultimately a huge mistake was partially corrected, improving the situation. But within three decades, the exact same mistake was repeated in the Western Lagoon with similar results.

The Northern Lagoon causeway project was carried out by engineers and heavy equipment operators without any kind of essential EIA or hydrological evaluation, or any other kind of study. Consequently, the original structure was put in without any provision for maintaining water flow, and therefore connectivity between the northern half and the southern half of the lagoon was cut. The northern end of the wetland was essentially dammed. Severe ecological impact resulted. Changes in water flow, and consequently, temperature, turbidity, pH, dissolved oxygen and sedimentation patterns, occurred. This resulted in changes in plant and wildlife community structure (Hecker, 1987).

The causeway has significantly impacted the forest on the north end of the Northern Lagoon when these forests were inundated for three years before the cuts were created in the structure to partially restore flow between both sections of Northern Lagoon. Hadley (1995) described the differences between these areas during the dry season (May). Forests on the north side of the causeway consisted of many dead trees, some uprooted and fallen on their sides. Other trees that appeared dead were beginning to sprout leaflets. Average tree height was about 3.7 m (12 ft.). Bromeliads were abundant on the dead trees. A greenish-yellow sharp grass, a *Mimosa* sp., young logwood (logwood brush), and other plants (hicatee berry, ball stomach) were noted as the understory. Soils were cracked and gravelly, with a significant amount of snail shells. The brown-gray top soil layer overlaid a whitish clay (probably marl) soil. Litter was about four or five centimeters deep, consisting of dead wood, mostly twigs. Logwood trees on the south side were well leafed and taller, up to approximately 9.1 m (30 ft.) in height. Understory vegetation lacked the grass noted in the north forest (at least in the plot surveyed), and was much more developed and had a higher diversity. There was a greater amount of young logwood in the south forest plot. Soil structure was similar to that noted in the north forest plot, but containing less organic matter.

Shifts in bird species composition was noticed after construction of the causeway. The northern side lost many of the birds that nested in the logwood trees once the trees began to die out. Fewer wading birds occurred on the north side because fishes were able to avoid capture by escaping into deeper water. However more ducks and swimming birds were found on the deeper waters.

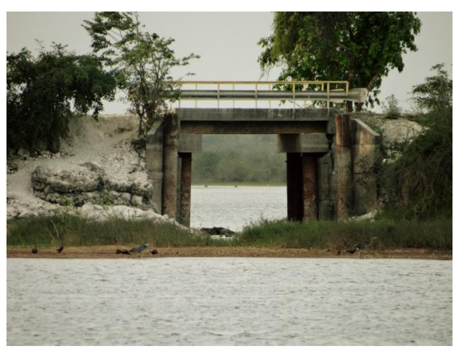
Economically and socially the causeway immediately had a strong impact on the village, and villagers appreciate its benefits. Because of the causeway, villagers have been able to travel more frequently to Belize City or Orange Walk over a much shorter time, and without having to do as much planning and preparation. Before the causeway, goods had to be ferried across the canal to the road head and loaded onto vehicles to be transported out, or off-loaded from supply trucks and ferried to the village. The causeway increased commerce, allowing more foods to be brought into the village from outside, reducing the people's dependency on hunting, fishing, and farming. This probably had a positive effect on local wildlife and fishes. The causeway also brought twenty-four hour electricity, allowing electrical lines from the national grid to be ran to the village over the causeway structure. Since construction of the causeway, people have been able to pursue work outside of the village and return by dark, bringing more money into the village. Development increased because the causeway allowed more building supplies to be brought into the village. Houses changed from mostly wood construction to block and concrete, in large part because trucks can deliver the steel, sand, gravel and cement to the building site.

As villagers become more prosperous, many are able to travel to the United States to work. Several villagers living abroad have returned to Crooked Tree. Some of those people returning home have brought personal savings from working jobs in the U.S. and England, investing in concrete houses with metal roofs businesses within Crooked Tree. The causeway has also opened the village to tourism, bringing with it the need for hotels, food, guides and boat trips. However, with increased access the village has lost much of its former “quaintness” and crime has increased, with more people from the city and surrounding towns moving in and out of the area more frequently (Hadley, 1995; Johnson, 1998). However, relative to many other villages around the country, Crooked Tree Village is still a peaceful, very friendly and inviting community.

The causeway has created a substantial amount of political controversy since its construction. The original concern was that the high water would damage the causeway and the suggestion was to cut water passages such as culverts through the structure. The stance of BAS was to leave the causeway as it was until the next year, upon which some decision could be reached (BAS, 1983). However, no action was taken for three years. Unusually high water occurred in the 1986 wet season. During this time the high water eroded the causeway. Ministry of Works responded by quickly but temporarily repairing the damage. Many people were not satisfied by the repair job and maintained that bridges should be built into the structure. Others however were appreciating the advantage of having a deep reservoir on the north side throughout the year.

Actually this became an interesting ecological question of debate—whether the causeway should be left as is and leave the artificially created high water ecosystem in place or modify the structure, draining the high water lake in hopes that a more natural system will develop in its place. In June of 1987 the CTWS Management Committee met to propose a solution to the problem. Ultimately they decided to leave the causeway intact. They reasoned that the dead logwood trees in the water would provide good habitat for fishes and that new stands of logwood would be established upslope. A plan was also made to allow the natural vegetation to grow along the shoulder of the causeway in order to protect it from further water damage (Figure 62a).

a photo by Jose Puc



b

Figure 62. a. View of Northern Lagoon Causeway Showing Sides Fortified by Vegetation. b. Bridge on the Northern Lagoon Causeway Connecting the Two Ends of the Lagoon.

A dory dock was to be built to help facilitate off and on-loading of produce when boats had to cross from one side to the other side of the causeway. They were not as concerned about the buildup of toxins as there was still a small creek connecting the Northern and Western Lagoons (Hadley, 1995). However, The First

World Congress on Tourism and the Environment met in Crooked Tree in 1992 and recommended that the causeway be cut. A 20 foot long bridge was built into the causeway that same year and a second bridge was installed soon afterwards (Figure 62b). It is still unclear if the "right" decision had been made (Headley, 1995). What kind of ecosystem would have ultimately developed if the more permanent high water lake had been allowed to remain?

The question is not one of just local conditions, however. In the long view, the functions provided by this incredible wetland system must be taken into account. CTWS wetlands and lagoons absorb tremendous amounts flood waters carried down the Belize River. The water backs up into these wetlands and is temporarily stored there, rather than arriving at Belize City all at once. It is then slowly released as floodwaters begin to recede, minimizing flood damage to downstream homes and infrastructure. Floodwaters also represent nutrient movement into and out of the lagoons and wetlands. Nutrient transport and distribution are some of the important ecological services provided by watersheds. Disruption of these natural processes always has long term consequences. A comparison of positive and negative effects of the un-notched and notched causeway is given in Table 23.

Table 23. Comparison of Positive and Negative Effects of Un-notched and Notched Causeways.

Uncut Causeway	Cut Causeway
A deep, year-round reservoir formed in the northern part of the lagoon and people could swim and bathe all of the time.	Water returned to normal levels in the reservoir, becoming low during the low season.
Loss of connectivity between the upper and lower sections of the wetland resulted in water quality changes.	Re-establishment of connectivity allows water to flow, reducing the water quality differences between the northern and southern parts of the wetland.
Logwood stands on the north side began to die out because their roots were waterlogged, but new logwood trees were possibly being established higher up slope.	Some re-growth may be occurring.
Reservoir was a hatchery for fish and turtles, allowing more dry season survivors than would happen during normal dry season water levels.	Low water during the dry season concentrates fishes and other animals that provide abundant food resources for the many wading birds that congregate in the area.
Wells that normally ran dry during the dry season were remaining productive year-round as the water table rose north of the causeway while wells south of the causeway dried up faster than normal.	Wells south of the causeway do not dry up as quickly during the dry season as occurred before notches were cut.
The stagnant water was beginning to accumulate organic detritus and farm waste that threatened to make the water unhealthy for household use.	There is some potential for organic materials to be flushed through the system.
The causeway created a barrier to dory movement and water transport of farm produce.	Boat movement is now possible through the cuts.

Hurricane Keith began hitting Ambergris Caye on October 1, 2000 and released one of the most intensive rainfalls recorded in the recent history of Belize as the storm moved across the northern and central regions of the country (BRCS, 2001). The highest recorded concentration of rainfall, occurring from September 29 until October 3 was at Ladyville, with 830 mm (326.8 in.) recorded. Many communities along lower Belize River flooded, particularly Crooked Tree Village, where water completely covered the Northern Lagoon Causeway, and inundated the access road leading out to the Northern Highway for about 0.4 km (0.25 mi.), cutting access off to the village. The causeway was topped again by floods in 2008 and 2013.

It would seem that Government would learn from this previous mistake and the consequences it caused. However, in May, 2009, the Deputy Minister of Works Edmund Castro officially opened the newly constructed 700 m (2,297 ft.) causeway across the Western Lagoon at a cost of $2.5 million Belize dollars (Figure 63a). The causeway was constructed with material dug from canals on either side of the structure (Figure 63b). The Deputy Minister acted without consultation with anyone, having completed no environmental impact assessment, not having acquired permits from the Forest Department to remove trees. He simply responded to the request of political supporters, constructing a second causeway across the Western Lagoon without any breaks or bridges, repeating the mistakes of the past. This act was perpetuated in the interest of a couple of farmers, but also connects Le~~a~~mo~~a~~nal and Rancho Delore~~i~~s to Crooked Tree. However, it places those people at risk who live in low-lying homes, and other structures and property lying downstream of CTWS, especially in the sea-level areas of Belize City.

a b

Figure 63. a. Western Lagoon Causeway Covered by High Water. b. One of the Canals that Run Along Each Side of the Western Lagoon Causeway, where Material was Excavated to Build the Causeway Structure.

This project also created unnecessary ecological damage to the Western Lagoon marsh. When standing in the middle of the causeway and looking northward, the marsh is brown. *Eleocharis* sp. stalks flowered, but the top 5 to 10 cm of each stalk was dry and dead (Figure 64a). There is inflow into this northern end of the Western Lagoon marsh from the northern end of CTWS, but no inflow from the Belize River. Turning around and looking south, *Eleocharis* stalks have flowered and remain green, plus there are many patches of woody shrubs and other plants throughout the expanse of this side of the marsh (Figure 64b). This side is still connected to the Belize River and probably does not suffer water stress. The actual cause of the brown marsh within the northern end of the Western Lagoon is not really known and needs further investigation, but it seems clear that the causeway created the situation, and that it is likely connected to the disruption of hydrologic connectivity.

a photo by Jose Puc b photo by Jose Puc

Figure 64. a. Western Lagoon Marsh North of the Causeway. b. Western Lagoon Marsh South of the Causeway.

This issue needs to be addressed, having been allowed to persist for over 7 years. It is imperative that this causeway be outfitted with bridges to open up exchange between both portions of Western Lagoon, and to allow the lagoon to more fully absorb high flow waters from the Belize River when it is in flood stage, helping once again to buffer flood impact to downstream communities.

Global Warming

Wetlands around the world, including CTWS wetlands, are already stressed by many human impacts. Miles of riparian forests stripped from the river banks, increasing fishing pressures, growing types and volumes of pollutants (sediments, pesticides, nutrients), invasive species, livestock in the lagoons and riparian forests, water extraction from the Belize River, dams and water diversion in the Macal River hydroelectric system, and the two causeways across Northern and Western Lagoons, all within the Belize River Watershed, are cumulative impacts, each affecting the other. All of these different impacts can be expected to worsen in the face of global warming, particularly given that aquatic ecosystems have restricted capacities to adapt to changing climatic conditions (Carpenter, *et al*., 1992). The consequences of these cumulative impacts are now and will be felt by people, wildlife, and ecosystems throughout this watershed.

Although Poff, *et al*. (2002) was focused on wetlands of the United States, many of the potential impacts listed that global warming may impose are relevant to CTWS wetlands. These impacts include increase in water temperatures and modification of wet and dry seasonal patterns, and thus wetland cycles and water levels critical to life cycles of organisms. Warmer waters are typically more productive, with the likelihood of more frequent algal blooms expected, with the consequential reduction on overall water quality. Also as water temperature increases, concentrations of dissolved gases such as carbon dioxide and oxygen are reduced, affecting both respiration and photosynthesis rates. As water temperatures climb, generally the metabolic rates of aquatic organisms increase. Overall increase in water temperatures will likely affect the distribution of many less adaptable species, but human disruption of corridors may restrict species movement and result in local extinction and overall biodiversity loss. Meanwhile other species may greatly expand their ranges, taking advantages of opening niches.

Changes in the hydrologic cycle, precipitation, evapotranspiration, and runoff volumes have a direct effect on aquatic habitat quality, thereby affecting productivity rates and biodiversity. Life cycles of many species are tied into water level changes, and as these patterns change, many organisms may not be able to adjust their life cycles to these new conditions, particularly migratory species. The flow regime (magnitude, frequency, duration, timing, flashiness) of streams and rivers (Poff, *et al*., 1997) and the hydroperiod (*the rise and fall cycle characterized by water depth, duration of high water conditions, frequency of changes, and flood seasonality*) of lakes and wetlands directly affects the habitat space available and access to nutrient resources (Poff, et al., 2002).

Significant changes in flow, considering water moving into and out of CTWS lagoons and wetlands, affect transport of sediments, nutrients, and pollutants that in turn affect water quality and consequently sensitive plant, animal and microbe species. Many studies show that increases in the frequency of floods cause a shift in composition of aquatic species, eliminating some organisms (Poff, *et al*., 1997). Long term changes in flow regimes of streams and rivers, and hydroperiods of lagoons will create changes in soil and vegetation characteristics, creating changes in affected populations of shoreline organisms (Burkett and Kusler, 2000) and level of water tables beneath soil. For example, prolonged high water conditions can kill some species of trees not adapted to these conditions, similar to what happened to logwood trees on the north end of Northern Lagoon when the causeway was first installed without openings. Even up slope trees can succumb to high water tables.

Likewise, long periods of dry, lower than normal conditions may lead to death of trees that require wet soils. CTWS wetland hydroperiods are primarily driven by the flow regime of the Belize River. Changes in the flow regime of this large river system will have significant ecological effects on the associated wetlands. Reduced magnitude or duration of high flow events can result in drying out and isolating wetlands and small water bodies. Wetlands surrounding Northern and Western Lagoons expand and contract based on the water stage of the lagoons, with water migrating up slope and lagoon ward depending on the rise and fall of water. Alternately more intense and punctuated flood events have been predicted, flushing soils into the drainage network and ultimately into the Inner Channel between the mainland and the Mesoamerican Barrier Reef. Aquatic plants and animals will have to adjust to theses constantly changing conditions or perish.

During the past 16 years, Crooked Tree Village and other buffer communities have been impacted by hurricanes and floods. Hurricane Keith (2000) and Hurricane Iris (2001) imposed structural damage to homes and facilities in the village. The hurricane season of 2008 had two tropical storms that impacted the CTWS buffer communities, Arthur and Tropical ~~Storm -~~ 16. The latter storm imposed the greatest impact, with community members having to be evacuated as flood waters rose to over 2 m (6.6 ft.) in height. Figure 65 shows a stand of trees where the lichens were killed off up to where the flood reached, marking the height of the water.

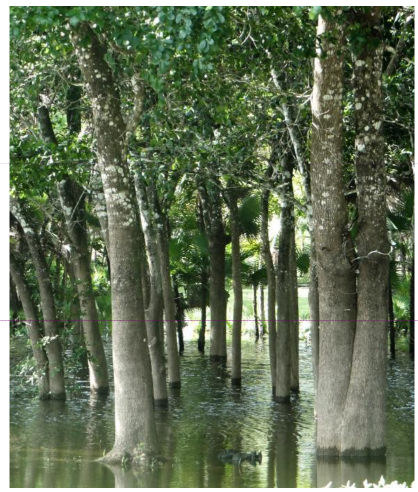


Figure 65. Trees Showing Height of 2008 Flood.

Tropical ~~Storm~~ 16 occurred over Belize in October of 2008, contributing to the flooding of Belize River, with water backing up into the CTWS lagoons and covering the causeway (NEMO, 2008). Then in November of 2013, following a month of heavy rains, flood waters again covered the causeways and much of the road leading into Crooked Tree Village and the sanctuary. Although not as high as the 2008 flood, these rising waters created economic hardship by interrupting tourism, threatening people's health from exposure to contaminated floodwater, disrupting movement into and out of the village for work, school, and food supply, and led to the loss of young boy's life as Belize Coast Guard had to assist in moving people in and out of the village. The village and surrounding area was also flooded (Moody, 2013). Belize Audubon Society was also intsrumental in assisiting villagers by ferrying people back and forth each day, with several trips a day. The Audubon office was also used as the base for the Coast Guard and Belize Audubon staff based out at Crooked Tree. These high waters remained for several weeks and foods can devastate the area economically, creating threats to public health, crops, livestock, and livelihoods. Volunteers working through the Japan International Cooperation Agency helped develop a flood response plan for Crooked Tree, identifying evacuation routes to high ground sites (Nishimura, 2015). However, adaptation to a new flow regime will require more than just an escape route or flood shelter.

Exceptionally dry periods can result with severe drying of the lagoons. This creates isolated pools with concentrated numbers of fishes and other aquatic organisms crowded together, further reducing oxygen levels already stressed by elevated temperatures. Excessive periods of drought may force susceptible biota into local extinction (Boulton, *et al*., 1992; Stanley, *et al*., 1997). Reduced water level during dry periods, as happens at CTWS, eliminates access to wetland food resources and nursery habitats, and reduces seasonal export of nutrients from wetlands to river ecosystems (Sparkes, *et al*., 1990; Bayley, 1995), potentially resulting in biodiversity decline and reduced productivity (Poff, *et al*., 2002). If nutrients are not flushed from lakes, the build-up can result in elevated production by algae, creating excessive algal growth, reduced dissolved oxygen availability at night, ultimately algal die-offs, and reduced water quality as toxins from dying algae are released (Poff, *et al*., 2002).

Impacts to groundwater resources can also greatly affect wetlands, especially those wetlands that are dependent on groundwater as a dominant water source. Reduced precipitation results in reduced recharge of aquifers. Also water extraction from groundwater resources can affect the availability of water for wetland

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habitats, leading to long-term change. Drier conditions force people to depend on aquifers more for water, leading to increased draw-down, with consequences for the ecological health of dependent wetland systems.

Many human activities, both directly related to global climate warming and indirectly related impacts, often favor non-native species capable of invading new habitats. These invaders may rapidly disperse and populate areas where less adaptable native species have been eliminated (Galatowitsch, *et al.* 1999). Ultimately, however, as new assemblages of native and non-native species form in response to migrations and range changes, predictions of ecological results is not possible with our limited understanding of species interactions (Poff, *et al*., 2002). Overall habitat fragmentation in Belize has resulted in the increased isolation of many aquatic ecosystems, making successful migration less likely for many plants and animals. Sorenson, *et al*. (1998) indicated that populations of breeding birds in some wetlands of the United States could be reduced by half with reduced precipitation and elevated temperatures. This reminds us that what happens to CTWS migrants in their summer or breeding ranges as a result of climate change will consequently impact the ecology of CTWS wetlands if those migrants are reduced.

Increasing global temperatures can be expected to favor increased frequency, intensity, and duration of large storms and hurricanes (Knutson, *et al*., 1998, McCarthy, *et al*., 2001). Frequent storms also bring more rainfall (Wigley, 1999). Long term changes in patterns of storms and hurricanes can affect species composition in wetlands and affect the rates of ecosystem processes, such as primary and secondary production and nutrient cycling (Mitchener, *et al*. 1997). Hurricanes can also greatly impact the structure of forested wetlands, affecting habitat complexity (see Stone and Finkl, 1995), and movement of soils and pollutants from upslope to wetlands, lagoons, and flowing waters.

Water Quality Assessments

Only sporadic water quality assessments have been conducted on CTWS waters, often related to specific research projects. The lack of water quality monitoring or at least occasional focused assessments is largely due to lack of equipment and expertise to maintain, properly calibrate, and routinely operate that equipment. Water quality data accumulated during the 2003 REA effort (Boles and Saqui, 2003) was acquired with equipment from the UB Natural Resource Management Program. Limited water quality assessment was conducted during this current REA, provided by two technicians from the DoE, a one day effort, the results of which is provided in Table 24.

This one day effort is somewhat revealing in that it provides a snapshot of water quality characteristics. The pH of water within the Northern Lagoon is slightly alkaline, which is in agreement with other studies (Mackler and Salas, 1994, Boles and Saqui, 2003). DoE data includes conductivity, a measure of the abundance of charged ions in the water that give electrical conductance capabilities as these ions occur in higher concentrations. Specific conductance is also reported, which is conductivity that has been adjusted for temperature. An interesting parameter is the oxidation/reduction potential (ORP) that is related to both the amount of dissolved oxygen (DO) and abundance of organic material in the water. DO and organic matter are both variables that are controlled by the producers within the system.

A more thorough water quality survey should be conducted in order to generate data from which more meaningful inferences can be drawn. Actually it is recommended that some kind of routine monitoring program be considered if water quality assessment is to become a useful tool in monitoring conditions within this wetland/lagoon system during both wet season and dry season periods and from both surface water and bottom water. If managers of BAS are considering developing a routine monitoring program, efforts should be made to standardize assessment protocols. This would involve targeting those basic parameters that are both meaningful to wetland conditions and that are comparable with other monitoring efforts occurring around the country. Parameters such as DO, temperature, pH, conductivity, turbidity, and ORP (Redox Potential) would be important to include. Given the importance of nutrient processing, measurements of nitrates, nitrites, ammonia, and total phosphorus may also be of interest. Efforts should also be made to standardize these procedures by using the same type of equipment and calibration techniques. Currently most organizations conducting water quality testing are using YSI multi-meters for measuring this addition to DO, pH, conductivity, and ORP. If nutrient analysis is to be added, investigations should be made into applicable equipment for that purpose that complies with what other groups are using.

Table 24. Physical and Chemical Water Quality Data, Wet Season, December 11, 2015.

	LATITUDE	LONGITUDE		TEMPERATURE (°C)	pH	CONDUCTIVITY (mS/cm)	SPECIFIC CONDUCTANCE (uS/cm)	DISSOLVED OXYGEN (mg/L)	TDS (g/L)	ORP (mV)	SALINITY (ppt)	BAROMETRIC PRESSURE
Station B	334471	1998569	surface	26.6	7.54	0.612	593	7.32	0.3835	-43.2	0.29	101.44
Station C1	337606	1966892	bottom	26.6	7.57	0.614	595	7.07	0.3900	-101.4	0.29	101.41
Station C1			surface	27.0	7.72	0.617	595	7.62	0.3835	-102.6	0.29	101.42
Station D1	337354	1967523	bottom	26.5	7.61	0.606	589	7.34	0.3835	-183.5	0.28	101.38
Station D1			surface	27.0	7.81	0.612	590	7.80	0.3835	-193.6	0.28	101.38
Station D2	337248	1967544	bottom	26.6	7.96	0.594	576	5.65	0.3770	-141.1	0.28	101.35
Station D2			surface	28.0	8.03	0.615	582	6.16	0.3770	-143.6	0.28	101.34
Station C2	337447	1967040	bottom	27.3	7.92	0.613	588	7.06	0.3835	-266.8	0.28	101.32
Station C2			surface	27.8	7.98	0.616	585	7.09	0.3770	-276.7	0.28	101.33
Station B2	337553	1966891	bottom	26.7	7.79	0.605	586	6.74	0.3835	-258.6	0.28	101.30
Station B2			surface	27.5	7.87	0.617	588	6.92	0.3835	-259.5	0.28	101.31
Station A2	337676	1966472	bottom	28.2	7.92	0.630	594	7.70	0.3835	-259.4	0.29	101.28
Station A2			surface	28.1	7.92	0.625	591	7.61	0.3835	-262.9	0.28	101.28
Station E1	337978	1965104	bottom	27.1	7.93	0.575	553	5.62	0.3575	65.3	0.27	101.14
Station E1			surface	27.1	7.89	0.580	557	5.61	0.3640	54.4	0.27	101.14
Station E2	337902	1965061	surface	27.6	7.65	0.589	561	5.96	0.3640	57.2	0.27	101.14
Station F1	338005	1964940	bottom	27.0	7.46	0.561	540	5.47	0.3510	12.7	0.26	101.13
Station F1			surface	27.0	7.47	0.561	540	5.57	0.3510	8.5	0.26	101.14
Station F2	337910	1964887	bottom	27.2	7.45	0.570	547	5.85	0.3575	5.9	0.26	101.12
Station F2			surface	27.3	7.45	0.567	543	5.87	0.3510	9.3	0.26	101.13
Station G1	338030	1964714	bottom	27.2	7.29	0.559	537	5.59	0.3510	15.7	0.26	101.13
Station G1			surface	27.3	7.30	0.550	527	5.61	0.3445	12.2	0.25	101.12
Station G2	337945	1964697	bottom	27.6	7.35	0.561	535	5.89	0.3445	5.6	0.26	101.12
Station G2			surface	27.4	7.35	0.563	538	5.82	0.3510	-2.9	0.26	101.13
Bas Office			surface	26.8	7.18	0.604	584	5.42	0.3770	-208.5	0.28	101.47
1st bridge, L			surface	26.8	7.38	0.613	593	6.40	0.3835	-178.7	0.29	101.46
1st bridge, R			surface	26.2	7.21	0.584	571	5.55	0.3705	-140.3	0.27	101.46
2nd bridge, L			surface	26.3	7.13	0.660	644	6.01	0.4160	57.5	0.31	101.46
2nd bridge, R			bottom	26.3	7.16		654	5.63	0.4225	-29.8	0.32	101.46
2nd bridge, R			surface	26.6	7.55	0.611	593	7.25	0.3835	-31.6	0.29	101.46
Station A1			bottom	26.6	7.55	0.611	593	7.25	0.3835	-33.4	0.29	101.46
Station A1			surface	27.0	7.71	0.615	592	7.85	0.3835	-43.3	0.28	101.46

Given the cyclic hydrological conditions and diversity of habitats within wetlands, and their interconnectivity within watersheds and coastal zones, these ecosystems greatly influence landscape-scale biochemical cycles. This continual transport and transformation of select and important chemicals is largely mediated by anaerobic microbes dwelling within water-logged soils and completely inundated sediments. Within wetlands, soils are exposed to air and sediments are those same areas once they are inundated with water over an extended period, enough for the transformation from terrestrial to aquatic life, and from aerobic to anaerobic environments. Those soils that are inundated long enough to create anaerobic conditions are considered to be hydric soils.

Wetland soils may be mineral soils, made up of less than 20 to 35% organic matter, or organic soils that contain higher percentages of organic matter. Organic wetland sediments are typically more acidic while mineral sediments are more neutral to alkaline. The re-flooding of exposed wetland soils tends to move pH towards neutral regardless if those soils are alkaline or acidic. Organic soils are less dense, contain more nutrients that are bound up in organic forms that are unavailable for plant growth, and have a higher cation-exchange capacity as compared to mineral soils. The particulate organic matter within CTWS lagoons and marsh wetland soils/sediments is predominately from lilies and sedges, along with a few submerged macrophytes, with wood and leaf fall from trees dominating in swamp wetland soils/sediments. As organic material breaks down within organic sediments, those sediments increase in density and become less permeable to water, slowly transforming from organic soils to mineral soils.

Because oxygen diffuses slowly through water, suspended and attached microbes use up this oxygen faster that it is replaced. This reduces oxygen available to roots, especially for submerged aquatic plants, and therefore affects availability of nutrients, with some toxic materials building up. Many emerged and rooted floating-leaved plants transport oxygen from the air to their roots, creating oxygenated zones around their roots, within the rhizosphere. Oxidized iron is reddish to orange or even yellow in color, while oxidized manganese is black. The rhizosphere, the thin soil/sediment layer surrounding all root surfaces, rich in oxygen, especially around the roots of aquatic that are connected to the air, is where metal oxides build up.

Within mineral sediments these metal oxides are reduced, becoming colorless, and often leached out of the sediment, leaving the grey to black parent material, a process called gleying. Anaerobic microbes are responsible for the reduction and/or oxidation of iron and manganese oxides within flooded wetland mineral soils (sediments), with organic matter providing substrate for those microbes. These biochemical processes are particularly active within warmer wetlands having more alkaline conditions, such as occurs at CTWS.

The ORP or redox potential is a measure of the availability of electrons within the water expressed in millivolts (mV). Reduction involves the release of oxygen from an oxidized metal, which is actually the gaining of a hydrogen atom, or rather an electron. As microbes metabolize organic material, the sediment is further reduced as mineral compounds accept electrons, allowing energy to be released from organic compounds until no more electron acceptors are available or the organic material is completely degraded. Terminal electron acceptors can include O_2, NO_3^-, Mn^{2+}, Fe^{3+}, and SO_4^{2-}, with O_2 creating the fastest reaction, and other electron acceptors supporting progressively slower reactions. Redox potential is reduced as electron acceptors are used up, with O_2 being the primary acceptor at 400-600 mV, nitrate being the acceptor at 250 mV, manganese at around 225 mV, iron operating between +100 and -100 mV, sulfides at -100 to -200 mV, and finally carbon, or CO_2, being the remaining terminal electron acceptor below -200 mV.

The insoluble ferric Fe^{3+} form of iron is reduce to soluble but toxic ferrous $Fe^{2+,}$ and similarly the insoluble form of manganese (Mn^{4+}) is reduced to the soluble and toxic Mn^{2+}. When the redox potential is low, sulfur is reduced to hydrogen sulfide (H_2S), a toxic gas. When sulfur reacts with trace metals (iron, zinc, copper) and precipitates out, sulfur availability is reduced. When ferrous iron is present, it reacts with sulfur to produce ferrous sulfide (FeS), which gives wetland sediments/soils a black color. When CO_2 is used as an electron acceptor (very low redox potential) by certain bacteria in the process of methanogenesis, methane (CH_4) gas is released.

Nitrogen transformations are important in wetland sediments, with organic nitrogen ultimately being mineralized to ammonium (NH_4^+). If sediments are aerobic, then nitrification is successively mediated first through *Nitrosomonas* bacteria (creating nitrite), then *Nitrobacter* bacteria (creating nitrate). Being very mobile in solution, nitrate may be leached from sediments, taken up by plants, or become denitrified into gaseous N_2 that escapes into the atmosphere. However, if soils are acidic, denitrification is inhibited.

Phosphorus is typically a primary limiting nutrient within freshwater marshes, but may be much more available in wetlands adjacent or downstream from agricultural sites. Wetlands actually act to retain phosphorus, which often occurs as a cation in aerobic sediments that can become bound up in organic matter or precipitate out as a phosphate with iron or aluminum within acidic conditions or with calcium and magnesium in more alkaline conditions. Phosphorus has a sedimentary cycle, in contrast to the gaseous nitrogen cycle. It is often present in wetlands as a cation. It may be tied up in organic litter in peat lands or in inorganic sediment in other wetlands. It can be made unavailable for uptake as the result of precipitation as phosphates with ferric iron and aluminum (acid soils), or calcium and magnesium (basic soils) in aerobic conditions, while becoming soluble under anaerobic conditions. CTWS wetlands are associated with karstic sediments, with high levels of dissolved materials created by the solution of limestone and dolomite.

CTWS is a sub-tropical, highly productive system that may serve as source and a sink for nutrients, while transforming nutrients from one form to another. With the inundation of wetlands with water in the wet season and the reduction of water during the dry, there are definite seasonal patterns of nutrient uptake and production of biomass, and nutrient release in biomass breakdown. Different chemical processes dominate in the dry season when wetlands soils are exposed and oxygenated, than occur in the inundated, anaerobic sediments during the wet season. Uptake is high during the wet season as aquatic plants grow and produce large amounts of detritus. Export is also high during the high flow season, especially as waters are receding and draining the wetlands at the end of the wet season.

Herbivory is relatively low in wetlands (maybe 5 to 10%) as compared to terrestrial ecosystems, which may be over 80%. In these wetlands, considerable exported organic bound nutrients are likely in the form of detritus and moving through detritus processing pathways. Because the CTWS wetlands are so strongly coupled to upstream and downstream ecosystems, continual seasonal cycles of nutrient exchange is occurring, part of the many ecological services provided by wetlands.

Concerns have been expressed about the potential impact of pesticides within the lagoon system originating from agriculture ventures such as those along the northeastern edge and the western edge of CTWS. However, pesticide analysis is a more involved and costly set of procedures and may be best considered as an occasional assessment based on situations that may demand such investigation, particularly following a survey of the kinds of pesticides used by farmers in the area.

In particular, a well-structured and thorough water quality study is called for in the Western Lagoon, comparing sites upstream and downstream of the improperly constructed causeway. This is a particularly serious water quality issue that also greatly affects the hydrologic functions of this wetland system. Such an undertaking can be conducted as part of a thesis or dissertation investigation, coordinated through BAS and the Forest Department, but also including involvement of or at least consultation with DoE, the Fisheries Department, and the Lands and Surveys Department.

Community Outreach, Education, and Ecotourism

Conservation and ecotourism are two very closely interrelated industries co-occurring and interwoven within CTWS and Crooked Tree Village, and slowly spreading to other buffer communities. Being a globally famous Ramsar site known for its seasonal congregation of aquatic birds by the thousands, many of the tourists that find their way to CTWS are birders, visiting between December and May. Some tourists are attracted to the rural village and its unique cultural heritage, and such annual events as the Cashew Festival. Currently there are three larger lodges available that offer dining, motorized boat tours, and a few rental canoes. There are smaller, more basic facilities that are less expensive, and some villagers offer a guest room in their homes, often with meals. There is also a campground for backpackers that can accommodate groups. A trail system with elevated walkways over areas inundated during the wet season encourages tourists to explore at their leisure. There are also very knowledgeable local guides who can provide group or individual tours, even horseback tours. Many people are repeat tourists, and even regulars. Both international and Belizean high school and university student groups now visit CTWS and often over-night at Crooked Tree Village or Bird's Eye View Campground, participating in field projects and environmental/social science courses.

The history of tourism development in Crooked Tree Village to reach this present day stage spans about 45 years. The early days of ecotourism at Crooked Tree were pioneered by Dora Wei~~ye~~r in the beginning of the

1970s. Mrs. Wei~~ye~~r was one of the founding members of the Belize Audubon Society and a renowned birder, and led birding expeditions around Belize, including Crooked Tree. In those days the journey required a long hike and then taking a dory across the lagoon to the village. Of course the reward was incredible and word of Crooked Tree spread among birders. Also during this time a faculty-led student group studying sociology was accommodated through a local church that arranged homestays, offering another model of tourism. A few over-night tourists stayed in private homes of a few villagers, a practice that continues today. However, ecotourism did not develop to the next, more sustainable level until construction of the approach road and causeway, with tourist numbers increasing each year from the late 1980s and into the 1990s, and began leveling off, fluctuating with world events such as September 11, 2001. These records are not accurate because many visitors did not sign the guest book (Enriquez, 1993), a situation that is still occurring.

Soon after the establishment of CTWS, BAS was asked by the Forest Department to serve as the primary, on-the-ground management organization for the new sanctuary. BAS has a long history of education and outreach at Crooked Tree and other buffer communities over the years. The main objectives were to bridge the gap between BAS and the community, and to develop more sensitive agricultural and development strategies. Also, while promoting conservation, BAS has also been a strong proponent for encouraging development of ecotourism in Crooked Tree Village and sensitizing people to the potential of the growing tourist industry. There is now a well-developed trail system throughout many areas of the village that lead tourist on walks through riparian forests and other habitats where wildlife may be sighted. Trained guides are available to lead birding walks or river tours. Many people of the village are quite knowledgeable of the wildlife, especially the birds, and are often very friendly and willing to assist tourists scouting out the areas around the village. BAS also has encouraged village youth who have interests in the ecology of their area and are considering careers related to conservation and tourism.

However, tourism development has its growing pains and it takes years to develop such an industry by developing a reputation. Tourists often arrive with a different interpretation and expectation of ecotourism than held by villagers (Johnson, 2006), and sometime there is conflict. Also tourism has a very strong impact on the entire community, whether community members are directly connected to the industry or not. Over the years there has been several in-depth research initiatives focused on the challenges of CTWS management in an effort to offer recommendations for a way forward. Hobday and Hobday (2002) conducted an assessment of visitor experience at CTWS and three other BAS-Managed Protected Areas. Leikam, *et al*. (2005) conducted an evaluation of co-management at both Cockscomb Basin Wildlife Sanctuary and CTWS.

Leiman, *et al*. (2004) recognized that at the beginning of the initial CTWS consultation process stakeholders were not aware of the issues and that communication was not effectively established between BAS and community members. Only a very limited community assessment was conducted and co-management initiatives were not followed, resulting in a decades-long division between many community members and BAS. However, they further pointed out that the mission of BAS was natural resource management, they had no expertise in community development, and strict deadlines were put in place. Additionally the funding provided BAS targeted natural resource management issues, and not community engagement efforts. Additionally, the Local Advisory Committee established to serve as a connection between BAS and the community was not very effective at bridging that gap. BAS was very effective at facilitating an education outreach effort at Crooked Tree, but did not have such presence in other buffer communities. This reach team offered many recommendations for improving interactions between BAS and buffer communities.

Haddle (2005) conducted a survey of the Crooked Tree Village to get community input as to the identification of economic, social, and environmental impacts of ecotourism. Ecotourism has promoted the development of infrastructure and economy within the village, even though these positive impacts are not spread equally. Job availability and overall money flow through the village has increased. The other part of the survey sought to understand community perceptions of the wildlife sanctuary, the people’s grasp of what a wildlife sanctuary is, attitudes of the people toward conservation, and the strength of the working relationship between BAS and the community. Haddle (2005) identified many factors, such as the regulation of fishing, hunting, and cattle rearing by the GoB and BAS, which has resulted in the build-up of resentment among many community members toward BAS. Other issues cited by survey participants included administrative changes with BAS, poor communications with villagers, and lack of transparency or accountability.

Local cultural traditions are not often perceived to be impacted directly by ecotourism, but conservation has forced changes on traditional use of natural resources, affecting livelihoods and independence. Haddle (2005) maintained that ecotourism is successful in Crooked Tree, but is not enough to support the importance of conservation, and cannot replace or compensate for the loss of the long-term subsistence lifestyles of many within the village, such as fishing, hunting, and cattle rearing. Direct benefits of ecotourism are not evenly spread through the community, but indirectly many villagers do recognize some benefits and do support this local industry. Community participation in conservation initiatives can only be expected if villagers see that they have influence in decisions relevant to management of CTWS.

Ecotourism has at least been able to offer an additional earning pathway for the community while traditional activities within the area continue. Many families of tour guides, restaurant owners, lodge owners, and lodge staff within the village have been able to afford better homes, drive better vehicles, and send their children to better schools. Although this is possible because of the causeway, electricity, and telephones, it was CTWS and development of ecotourism that encouraged development of the causeway that physically connected the village to the highway, providing access for tourist vans, buses to transport students to distant high schools, personal automobiles, and delivery trucks bringing cement, steel, blocks, and other construction materials. While these changes actually empowered many people within Crooked Tree Village, others such as fishers and hunters, were actually disempowered by the establishment of CTWS (Haddle, 2005).

CTWS and ecotourism has made Crooked Tree Village famous and has incited a measure of community pride. Many women and low income families have been empowered as their lives improved through jobs and professional development, being able to support their families. There is also a level of cooperation among villagers, with lodge owners hiring residents into job positions, and sharing guests when lodges are full. Although there is some resentment between those who profit more than others from the local industry, overall ecotourism seems to have brought the village closer together (Haddle, 2005).

BAS staff conducted a social marketing campaign at Crooked Tree with the intention of increasing pride in and awareness of the wetlands, encourage reduction of unsustainable and unplanned development that would impact the wetlands, and to promote workable guidelines for cattle farmers maintaining pastures near CTWS (Carballo-Avilez, 2009). Prior to the campaign a "knowledge—attitude—practice" pre-campaign survey was conducted within the rural buffer communities (Biscayne, Gardenia, Lemonal, Crooked Tree), and in Belize City. Information from these pre-survey results were used to design objectives and activities to increase knowledge about CTWS wetlands, change the view of wetlands from wastelands to that of critical natural resources, and to encourage the reduction of cattle impacts on the wetlands by changing the behavior and attitudes of farmers. The actual campaign, lasting 12 months, provided printed materials (farmer comic book, posters, coloring book), media productions (a song, video, radio outreach, a mascot), workshops, farmer demonstrations, school visits, advisory committee meetings, farmer meetings, women's meetings, and video shows. At the end of the campaign a post-survey was conducted to evaluate effectiveness of the effort, with analysis showing an overall knowledge increase of 21%, and a positive attitude change toward the wetlands rising by 17%.

The campaign also included biogas demonstrations and training was offered by the Inter-American Cooperation in Agriculture (IICA) and the Belize Agriculture Department at Central Farm for two of the farmers, the training offered by faculty from Earth University in Costa Rica (Carballo-Avilez, 2009). One biogas digester was actually installed at Crooked Tree Village, but the farmer eventually discontinued using this technology. A second biogas digester was installed and managed by a farmer from Lemonal, and five others scattered around the country. Other benefits of this campaign include media coverage of the October 20-24, 2008 flood, which highlighted the importance of CTWS wetlands in floodwater control, an event that was seen around the country (Carballo-Avilez, 2009). Also a junior birding and gardening club was developed for local youth. Birding equipment was acquired for youth to use.

Achieving fully engaged co-management of protected areas, where government agencies, management organizations, and buffer communities truly share in the stewardship of a protected area is the goal of many programs around the world, and certainly the goal for CTWS. Great strides have been made at CTWS, involving the Forest Department, BAS, and participating members of Crooked Tree Village, to promote co-management, while confronting many cultural, social, economic, and political challenges. Based on the ranking of management effectiveness by Walker and Walker (2009) for fourteen Belizean protected areas containing more than 5% savanna land, CTWS ranked 3rd behind Rio Bravo and Payne's Creek. This indicates that at least some management strategies are working and conservation for savanna (and wetland) areas considered successful, even though fully effective community-based conservation and co-management has yet to be achieved. Alternately other evaluations conclude that management is weak and need to include importance of ecosystem services to economically vulnerable stakeholders as well as large-scale agriculturalists (Wells, 2013).

Supported by the Multilateral Investment Fund affiliated with the Inter-American Development Bank, BAS was funded to implement the project "Strengthening Bird-based Tourism as a Conservation and Sustainable Development Tool" in CTWS buffer communities in order to generate income for residents through community engagement (Castillo, 2014). This effort entailed describing the demographics and economics of buffer communities, evaluate the level of skills and capacity among the residents, determine their level of interests and potential for engaging in bird-based tourism. Overall findings were that few residents had the appropriate management and organizational skills necessary for full engagement in tourism initiatives, but supported effort to create livelihoods focused on natural resources, and were willing to work with BAS on such initiatives. The only group that was not in support was the fishers. It was recognized that to move forward, this project would require collaborative efforts from the community, the Government of Belize, and the communities, and will involve capacity building, development of infrastructure, marketing strategies, and appropriate financing. CTWS is a globally famous, on-going experiment in developing community-based co-management, with many lessons to teach and strategies yet to develop and test.

Other activities that BAS partnered with the Village Council and Primary School during this project, so that the village and villagers of Crooked Tree benefit include trainings in Small Business Management, Conflict Resolution, Bird Guide Training; environmental education for the school kids-classroom presentations, bird club, school garden & rest benches in school compound; working with the CTVC to organize and made monetary donations for the Bird and Fish Festival for the community (2016/2017; organized and funded the Bird Fair at the primary school and invited other schools/conservation organization (2016); donated school supplies for CTGS's school year (2016). BAS continues to highlight and market Crooked Tree as a birding destination.

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Recommendations

The following list of recommendations is offered as a list of projects of need, possibilities for advancing conservation and research while providing opportunities to engage our youth in serious and professional learning experiences that can help build careers and responsible citizenship. Tasks identified can be ranked according to level of importance and urgency, perhaps by a committee that included strong community representation, with some items being removed completely and others added.

Many of these efforts mainly require some measure of skill (easily taught) and labor that can be provided by supervised internship teams. Such teams should ideally be made up of a Belizean student and an international student, each being very interested and maybe even passionate about the job focus of their mutual internship and the deliverable that will spin out of their collaborative efforts. Some of these tasks are ideal thesis and dissertation topics that would attract the interest of many graduate students from Belize studying abroad, or students from abroad looking for an international research experience in Belize. Whatever the case, institutional connections are made among CTWS communities, BAS, and universities abroad. Each of these items listed also represent opportunities to involve and work with community members from the conception, identifying and engaging the local experts within many areas, those people who can offer lifetimes of experience, observations, skills, knowledge, and history. Each of these projects can also attract the support and even involvement of many different GoB agencies focused on conservation, education, social issues, agriculture, forestry, fisheries, public health, water resource management, and effective community governance. Many of the proposed research initiatives target wetland and aquatic systems throughout the country (Esselman and Boles, 2001), with Crooked Tree offers opportunities to investigate many areas wetland ecology.

Given the importance and ecological complexity of CTWS lagoons and wetlands, Crooked Tree Village has the potential to develop a strongly ***community-based research and education industry.*** This kind of eco-tourism can engage a greater number of people that share directly or indirectly in benefits generated from visiting researchers, educators, and students to the area. Revenue would be generated through visiting participants from abroad that also allow for Belizean students to participate. There may also be funding available from international agencies, embassies, corporations and other sources for specific management and project goals that support conservation and wise use of the area's rich natural resources. In particular, this offers a pathway for youth of Crooked Tree Village and other buffer communities to can gain access to educational opportunities as well as job experiences by getting involvement in such an industry.

It is proposed that a long-term research program be set up through consultation with buffer communities, BAS staff, and local service providers. This program can consist of one-month research efforts, one conducted in the height of the wet season and the other in the height of the dry season. During each of these sessions many of the topics listed under research recommendations can be addressed by international and Belizean research teams overseen by a research coordination team. Month-long field efforts can be facilitated by renting an appropriate house within Crooked Tree Village for the duration of at least a month during the wet season and a month during the dry season. The house would provide a back yard where tarps can be stretched and tent camping accommodated, plus a bathroom, kitchen, field lab space, sample sorting and processing space, meeting space, and equipment storage. Supported by a vehicle for group transportation and perhaps half a half dozen canoes and kayaks, and as many bicycles, teams of participants (interns, graduate students, select community members, particularly youths and local experts) can invest energies into those research tasks listed below. Having a functional taxonomy lab on site can support many different research efforts, coordinated under a larger set of research objectives.

CONSERVATION AND MANAGEMENT

Many of the recommendations given below are beyond the reach of BAS working alone, but will require assistance from GoB and funding sources. Some of these tasks require involved work components, many of which can be achieved through internships and graduate student projects.

Re-establish hydrologic connectivity within the Western Lagoon- Get an engineer's recommendation as to appropriate strategies to reconnect the two ends of the lagoon, thereby re-connecting this hydrological corridor. This assessment, recommendations, and project implementation should be conducted during the upcoming dry in order to see the basins more clearly and have minimal impact during construction of bridges or large culverts.

Preserve the hydrological corridor connecting CTWS and New River wetlands- This exchange is particularly important when one or the other of these systems are in very high stage.

Conservation concern should include protection of Belize River and waters discharging into CTWS (Borias, 2004)- Environmental integrity of CTWS is strongly influenced by the amount and quality water flowing into the wetlands. Therefore it is important that CTWS management and buffer communities engage in and support efforts that promote watershed management within the Mopan-Macal-Belize Watershed, for which CTWS is the largest and most important wetland ecosystem.

Routine and occasionally intensive seasonal water quality sampling should be conducted- This would be a way of engaging staff and village volunteers (youth in particular) in assessment activities while generating useful information about the state of the lagoon(s) and other water bodies. At the most basic phase, this would involve acquiring, maintaining, calibrating, and routinely using a YSI multi-meter and support equipment capable of measuring temperature, pH, dissolved oxygen, conductivity, and ORP. YSI is recommended because that is the best field durable equipment for the investment and the brand that DoE, UB, and others use.

Reduce nutrient loading into feeder streams and rivers and in lagoons- Besides leaving adequate riparian forest buffers along every stream, cows, horses, and pigs need to be kept out of not just the streams and rivers, but out of the riparian zones. However, some ranchers may need help with finding alternative water access for their livestock.

Protect and restore riparian forests along streams and rivers and lagoon shores- This is a vital issue and should be addressed immediately. A buffer outreach effort is needed to address the importance of riparian and wetlands, as filter systems of the landscape, along with their many other ecological services. Sites should be identified for intervention/restoration initiatives near each buffer village school and restoration projects planned and implemented through community leaders, school administrators, and students.

Design solid waste management strategy- There is a need for setting up a solid waste management system to serve the needs of buffer communities and is connected to the national waste management plan currently being implemented.

Promote development of bioremediation for wastewater management- Identify suitable project sites where developers are willing to construct bioremediation systems to handle waste issues. Getting a good demonstration project set up in the village can help promote this initiative.

Monitor program for invasive species- There are several important new invasive species that can potentially find their way into the CTWS system. Residents should be aware of them and on the watch, with a process for reporting sightings or captures of invasive organisms if such occurs.

AWARENESS, EDUCATION, AND OUTREACH

Use portions of this REA to create a set of spin-off documents that promote and trigger action

- **A 30-50 page ecological atlas of Crooked Tree Wetlands**- This can be a fully illustrated , including photographs, cover (front and back) designed by one or more students from Crooked Tree Village or other buffer communities designed to supplement high school science and for sale to tourist (and soon to be tourist, including students going on study-abroad courses in Belize.
- **Updated brochure map of Crooked Tree Village**- This would help promote ecotourism and replace the current inaccurate map.
- **CTWS Biodiversity List**- The ecology tables in the appendices of this document can be made available, revised, and improved where appropriate to help promote wildlife and plant awareness.

Promote professional Training for CTWS buffer community youth- Inform youth about opportunities in tour guide training, wilderness safety and first aid, water rescue, watershed ecology and conservation, wildlife ecology, etc. and involve them in programs such as ran through Monkey Bay Wildlife Sanctuary and other service providers.

RESEARCH OPPORTUNITIES AND TOPICS

Conduct a more detailed and complete GoogleEarth© based GIS analysis of CTWS and surrounding areas- Develop maps at landscape and patch scales, building a map set for use in the field during sampling activities and sightings.

Research and map out details of wetland/aquatic production within CTWS rivers, wetlands and lagoons- Validate, roughly quantify, and map detritus production and respiration; describe nutrient cycling and spiraling; show energy flow into, out of, and through the system.

Hydrological study of the wetland/lagoon system- Conduct current profiles, identify discharge/recharge characteristics, and apply appropriate models to better understand system hydrology.

Sediment mapping, sediment profile descriptions- This will involve coring and grab sample efforts. **Nutrient analysis**- Nutrient measurements, enrichment studies, and discharge site sampling is involved.

Phytoplankton/Micro-producer assessment- Development of a taxonomic list of algae and diatoms and identification of community structure of microproducers would be outcomes of this effort.

Zooplankton study- Diel sampling during wet and dry seasons with several mesh sizes would help compile a taxonomic list and understanding of zooplankton patterns and contributions to system ecology.

Periphyton survey- This may be a major area of wetland/lagoon energetics, requiring identification of principal algal species, description of communities and identification of community types.

Aquatic macrophyte survey- Video transects of wetlands and lagoon bottoms, specimen collections, compilation of photographs, taxonomic drawings, descriptions, and maybe even a taxonomic key would be compiled for aquatic plants of CTWS (later for Belize) as a field guide.

Macroinvertebrate survey- Multiple habitat sampling, focus on life cycles of certain key groups, herbivores and associated fauna within lilies and sedge, detritus processing detritus mat associates, shoreline macroinvertebrate assemblages and drift lines, shoreline subsurface detrital processing assemblages, algal mud assemblages are just some areas of focus, with all information contributing to the national survey funded by the Darwin Initiative through Dr. Rachael Carrie.

Fishes surveys through local fishers- Gut contents analysis of commercial species in cooperation with local licensed fishers, video assessment of fishes, information on species abundance, population shifts that have occurred over time, observations of fish behavior, diets, breeding seasons, diurnal and annual cycles and many other facets fish ecology can be gleaned through interviews and involvement of interested local fishers. Additional information may be acquired by accompanying fishers on fishing trips.

Wildlife surveys- Essentially any group including reptiles, frogs, turtles, select bird groups, mammals offer research opportunities, applying survey techniques such as camera traps to focusing on select species of concern.

Updated Land Use Map- Develop a current land use map of the area that involves consultation with all community community groups, taking into consideration easements for riparian forests, wetlands, corridors, wildlife breeding sites, drainages, and other important ecological components.

Oral History- Gather oral histories from elders and local experts. Interview key community members who can contribute to developing a more complete history of the area.

Glossary

Aerenchyma- soft plant tissue that typically contains air spaces, usually found in many aquatic plants, allowing those plants to transport air to their submerged root systems

Aerobic- describing organisms that are dependent on free oxygen availability or describing sediments and other habitats that contain free oxygen

Alluvium, Alluvial Sediments/Soils-

Anaerobic- describing organisms that are intolerant of the toxic effects of free oxygen availability or describing sediments and other habitats that do not contain free oxygen

Aquatic- organisms that live completely in water; see “semi-aquatic.”

Aquifer- a layer of permeable rock or sediment that can contain and transmit groundwater

Bedrock- solid rock that underlies loose soil or sediment deposits

Benthic, Benthos- the lowest zone or ecological region at the bottom of a water body that includes the surface of the sediment and sub-surface layers; organisms that live in the benthic zone

Biofilm- a living film of microorganisms and tiny associated organisms, and the polysaccharide material secreted by microbes covering any surface lying beneath the water

Biological Corridor- wildlife or habitat corridor that connects wildlife populations that are separated by development, agricultural areas, logging, roads and other barriers

Biomass- the total mass of living organisms and dead organic matter within a prescribed area

Biomes- naturally occurring plants and animals occupying a given habitat; a habitat or ecosystem unit defined by dominant plant types

Bioturbation- the disturbance of sediments by living organisms

Blackwater Stream- a stream originating from a wetland and containing a significant load of tannins that the water is amber in color

Broadleaf Forest- forest predominately made up of trees with wide leaves, as opposed to the needle leaves of pines and other conifers

Broken Ridge- a transitional forest within Belize, “ridge” being a local term for forest

Buffer Communities- towns, villages, and communities that occur just outside of protected areas boundaries

Carnivores- organisms that feed exclusively or almost exclusively on animal prey

Cation Exchange Capacity- total capacity of soil/sediment to contain exchangeable cations that influences the ability of soil/sediment to hold nutrients and creates a buffer against acidification

Causeway- an earthen embanked roadway crossing wetlands and/or water

Cellulose- insoluble polysaccharide material that makes up plant cell walls and fibers, giving structural support, and digested largely by fungi and microbes that can produce the enzyme cellulase

Chemosynthesis- the synthesis of organic compounds by bacteria using energy from reactions with inorganic chemicals, often in areas lacking sunlight

Clay- sticky, fine-grained material, particle sizes smaller than silt, that is plastic when wet, composed of hydrated silicates of aluminum

Coarse Particulate Organic Matter- large pieces of organic matter, leaves, limbs, to stems and recognizable leaf particles

Composite Sample- several samples taken at a site combined into a single representative sample

Conductivity- a measure of ability of water to conduct electricity, directly related to ion concentrations from dissolved salts, chlorides, sulfides, and carbonate compounds

Cyanobacteria- blue-green algae, photosynthetic bacteria, some of which can fix nitrogen

Detritivore- organisms that specialize in feeding on detritus and associated biofilm

Detritus- dead particulate organic matter

Detritus Mats- floating patches of dead particulate organic matter

Detritus Processing System- a system whereby detritus is colonized by cellulace producing fungi that begin the breakdown process, joined by bacteria, protozoa, and micro-invertebrates to create a biofilm that shredders then consume by tearing apart the decomposing detritus into finer pieces, some of which becomes food for filterers, and so forth

Dissolved Organic Matter- organic matter dissolved in water, consisting of sugars, cytoplasm of ruptured cells, and extruded materials

Dissolved Oxygen- oxygen dissolved in water and available to aquatic microbes and all gill breathers to support metabolism

Ecological Services- those benefits that we receive from our ecosystems that, in the case of wetlands, include creating and processing detritus, providing habitat for food organisms, sustaining local biodiversity, and absorbing and releasing floodwaters and thus helping regulate floods, as examples

Ecotones- boundaries between biomes or ecosystem types, often containing elements of each adjacent ecological unit

Evaporite- rock or mineral deposits remaining after water containing dissolved components have evaporated

Evapotranspiration- water that is returned to the atmosphere by direct evaporation from heated surfaces and through loss of water through leaves of plants

Fine Particulate Organic Matter- particulate organic matter that has been broken down into very small fractions that are often collected by filter feeders, with particles coated with biofilm

Flow Regime- describing river flood patterns based on frequency, magnitude, duration, timing (seasonal), and flashiness (how fast floods rise), all of which affects associated wetlands

Foam- organic, airy, solid material created when water rich in dissolved organic material is mixed with air

Herbivores- animals that feed on plants and algae

Hydric soils- soils that become cyclicly inundated by water long enough to develop anaerobic conditions

Hydrological corridor- connectivity between different water bodies/watersheds that allow for exchange, particularly in flat terrain

Hyperperiod- the cyclic rise and fall of water level within a lake or lagoon characterized by water depth, duration of high water conditions, frequency of change, and flood seasonality

Hyporheic Zone- the saturated sleeve of sediment/soil surrounding a water body where shallow groundwater and surface water mixes

Lacunar system- a network of open spaces in some aquatic plants that allows oxygen to be transported to the roots

Indictor Groups- select groups of organisms that are monitored to help indicate the general health of an ecosystem or habitat, those organisms being relatively easily collected, identified, and quantified, and their general ecology known

Interstitial Water- subsurface water found between sand grains of sediment

Invertivores- animals (and carnivorous plants) that feed on invertebrate animals

Lagoon- a small freshwater lake, often with a river or stream flowing through it

Littoral Zone- the areas near the shore of water bodies where light penetrates all the way to the sediment with enough intensity that aquatic plants can grow

Loam- a soil made up of approximately equal parts sand, silt, and clay

Macrophytes- large algae and plants

Marl- unconsolidated rock or soil containing clay and calcium carbonate

Marsh- a wetland dominated by herbaceous plants, typically grasses and sedges

Microbial Loop- a trophic pathway in aquatic ecosystems where dissolved organic carbon is absorbed by bacteria and returned to higher trophic levels in bacterial biomass

Model- systematic description of a phenomenon that includes important characteristics that phenomenon and helps to better understand the phenomenon; may be material, visual, mathematical, or computational in nature

Mud- mixture of silts and clays, often deposited as sediments

Nutrients- essential substances that provide the nourishment for the growth and development of living organisms

Omnivore- organisms that feed on a wide variety of both plant and animal tissue

Oxidation/reduction potential- also called redox potential, this is a measurement of the tendency of a chemical compound to attract electrons and thus become reduced, measured in in volts millivolts

Particulate Organic Matter- organic matter that occurs in solid form, from very large pieces to very small particles, as compared to dissolved organic matter

Periphyton- assemblages of organisms that are growing attached to or clinging to plants, wood, rocks, and other objects projecting above the sediment of water bodies

Photosynthesis- the process whereby green plants capture the energy of sunlight and package it into organic chemical bonds, using carbon dioxide as a carbon source, and generating free oxygen in the process

Phytoplankton- microscopic producers, such as algae, diatoms, and cyanobacteria, that live suspended in the water and are carried by currents

Piscivores-organisms that feed predominately on fishes

Planktivores- organisms that feed on plankton organisms

Plankton- large diversity of very small organisms that live suspended with in the water and are carried by the currents

Porosity- a measure of the amount or volume of open spaces within rock or sediment

Producers- organisms that are able to produce organic molecules through photosynthesis or chemosynthesis

Ramsar Wetland- a wetland, artificial or natural, temporary or permanent, designated as having world importance because of its ecological and cultural value as determined by the Ramsar Convention on Wetlands

Rhizosphere- the soil surrounding plant roots that is influenced by the chemistry and microbiology influenced by the growth, respiration, and nutrient exchange of plant roots

Ridge- a traditional term for "forest" in Belize

Sample- a small part of the environment collected and examined in order to better understand or describe the whole environment or environmental unit

Savanna- a grass and sedge dominated landscape with few trees that is drought and often fire resistant

Sediment- mineral and/or organic matter that is transported and deposited in a water body by water, wind, or ice, often harboring many kinds of living organisms

Semi-aquatic- animals that live partly on land and partly in water; plants that grow in water saturated soil

Sequestered Carbon- carbon that has been removed from circulation within the atmosphere and buried as organic material, often within anaerobic zones where it remains for long periods of time

Soil- the upper layer of the Earth in which plants grow, a mixture of organic material, clay, rock particles, moisture, and living organisms

Silica- or silica dioxide, the mineral making up quartz and quartz sand and clays

Swamp- a wetland dominated by trees and woody shrubs

Tannins- polyphenolic biological molecules produced by plants that bind to proteins and other organic compounds, making plant material somewhat resistant to decay

Trophic level-the position that an organism occupies within a food chain or the succession in which one organism eats prey organisms and is, in turn, consumed by other predator organisms

Turbidity- a measure of the cloudiness of water due to the amount of suspended particles (usually silts, clays, but can also be caused by plankton, affects the amount of light penetrating the water and light available for submerged plants and algae

Water Table- the level below which the soil is saturated with water; the top of an unconfined aquifer

Wetland- marshes, swamps, bogs, and other elements of the landscape that are covered part of the year by water and are dry during other parts of the year

Zooplankton- protozoa, micro-crustaceans, and other small invertebrates and tiny juvenile vertebrates that live within suspended in the water and carried by currents

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Maps and Plots

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Appendix A

Plants of Crooked Tree and Surrounding Area Reported by Goodwin, *et al*. (2013)

(Note that species in green font are new species found in this study,
species in blue font are endemic to savannas, taxa in red font were not reported in Goodwin, et al. (2013))

FAMILY	GENUS/SPECIES	HABIT	VEG. TYPE	*COLLECTION LOCATIONS					
				CT	40	41	BKB	BPR	19
POLYPODIOPHYTA									
POLYPODIOPSIDA									
Blechnaceae	*Blechnum serrulatum*	herb	wetland			X			
Salviniaceae	*Salvinia auricularia*	herb	aquatic						
	Salvinia minima??								
PINOPHYTA									
Pinaceae	*Pinus caribaea*	tree	savanna	X	X	X	X	X	X
MAGNOLIOPHYTA									
Magnoliidae									
Nymphaeaceae	*Nymphaea ampla* (serrated leaf	herb	aquatic	X					
	Nymphaea conardii?? or								
	Nymphaea glandulifera??								
Cabombaceae	*Cabomba palaeformis??*								
Ceratophyllaceae	*Ceratophyllum muricatum??*								
HAMAMELIDAE									
Myricaceae	*Myrica cerifera*	shrub	savanna	X					
CARYOPHYLLIDAE									
Nyctaginaceae	*Neea psychotrioides*	shrub	forest		X				
Polygonaceae	*Coccoloba barbadensis*	tree	forest	X					
	Coccoloba reflexiflora	tree	savanna	X					
Malvaceae	*Helicteres guazumifolia*	shrublet	savanna		X	X			
	Hibiscus costatus	shrub	savanna						X
	Luehea speciosa	tree	forest	X					
	Melochia spicata	shrublet	savanna			X			
	Sida cilaris	herb	savanna					X	
	Sida rhombifolia	shrub	disturbance					X	
Myrsinaceae	*Parathesis cubana*	shrub	savanna				X		
Sapotaceae	*Sideroxylon obtusifolium*	shrub	savanna	X					
DILLENIIDAE									
Dilleniaceae	*Curatella Americana*	tree	savanna			X			
Droseraceae	*Drosera capillaris*	herb	savanna					X	
Ochnaceae	*Ouratea nitida*	shrub	forest	X					
	Sauvagesia erecta	herb	savanna				X		
Passifloraceae	*Passiflora urbaniana (endemic)*	climber	savanna	X					
Theophrastaceae	*Bonellia macrocarpa*	shrub	savanna		X				X
Turneraceae	*Piriqueta cistoides*	herb	savanna	X			X		
	Turnera diffusa	shrublet	savanna	X	X			X	
	Turnera scabra	shrublet	savanna			X			
ROSIDAE									
Apiaceae	*Hydrocotyle umbellata*								
Celastraceae	*Crossopetalum gentlei (endemic)*	shrub	savanna	X					
	Hemiangium excelsum	shrub	savanna			X			

FAMILY	GENUS/SPECIES	HABIT	VEG. TYPE	*COLLECTION LOCATIONS					
				CT	40	41	BKB	BPR	19
Chrysobalanaceae	*Chrysobalanus icaco*	shrub	savanna	X	X				
Combretaceae	*Bucida buceras*	tree	wetland	X					
	Conocarpus erectus	shrub	coast		X				
Erythroxylaceae	*Erythroxylum guatemalensis*	shrub	sav/for			X			
Euphorbiaceae	*Caperonia castaneifolia*	herb	wetland			X			
	Euphorbia thymifolia	herb	disturbed					X	
	Euphorbia xbacensis	herb	savanna	X					
Fabaceae Caesalpinioideae	*Caesalpinia yucatanensis*	tree	forest						X
	Chamaecrista flexuosa	shrublet	savanna					X	
	Haematoxylum campechianum	shrub	wetland	X					X
Fabaceae - Faboideae	*Aeschynomene rudis*	shrub	Wetland	X					
	Andira inermis	tree	forest					X	
	Crotalaria pumila	shrublet	savanna	X					X
	Lonchocarpus rugosus	tree	forest						
	Pachyrhizus erosus	climber	forest						X
	Pachyrhizus ferrugineus	climber	forest						X
	Zornia reticulata	herb	savanna						X
Fabaceae-Mimosoideae	*Desmanthus pubescens*	shrublet	disturbance	X					
	Mimosa bahamensis	shrub	wetland						X
	Mimosa somnians	shrublet	savanna				X		
	Neptunin oleracea or *N. plena*	herb	aquatic						
	Pithecellobium lanceolatum	shrub	savan/for						X
Malpighiaceae	*Heteropterys lindeniana*	shrub	wetland	X					
	Malpighia lundellii	shrub	wetland	X					
Melastomataceae	*Acisanthera bivalvis*	herb	savanna						X
	Clidemia sericea	shrublet	savanna				X		
Myrtaceae	*Eugenia winzerlingii*	shrub	savanna	X					
Onagraceae	*Ludwigia octovalvis*	herb	wetland	X					
	Ludwigia peploides	herb	wetland						X
Oxalidaceae	*Oxalis frutescens*	herb	savanna		X				
Polygalaceae	*Polygala adenophora*	herb	savanna				X		
	Polygala hygrophila	herb	savanna				X		
	Polygala longicaulis	herb	savanna		X		X		
	Polygala paniculata	herb	disturbance	X					
	Polygala tenella	herb	savanna						X
	Polygala trichosperma	herb	savanna		X				
Phyllanthaceae	*Phyllanthus amarus*	herb	coast			X			
	Phyllanthus stipulatus	herb	wetland						X
Rhizophoraceae	*Cassipourea elliptica*	shrub	forest	X					
ASTERIDAE									
Apocynaceae	*Ascleplas curassavica*	herb	disturbance	X					
	Echites tuxtlensis	climber	forest						X
	Gonolobus cteniophorus	climber	savanna					X	
	Metastelma stenomeres	climber	savanna				X		

FAMILY	GENUS/SPECIES	HABIT	VEG. TYPE	*COLLECTION LOCATIONS					
				CT	40	41	BKB	BPR	19
Apocynaceae (cont.)	*Metastelma thalamosiphon*	climber	savanna	X					X
	Pentalinon andrieuxii	climber	disturbance	X				X	
Asteraceae	*Acmella lundellii*	herb	savanna						X
	Acmella pilosa	herb	disturbance	X					
	Ageratum ellipticum	herb	savanna					X	
	Ageratum peckii	shrublet	savanna	X					
	Calea ternifolia	shrublet	savanna						X
	Elephantopus mollis	shrublet	savanna			X			
	Mikania micrantha	climber	forest						X
	Wedelia acapulcensis	shrub	savanna	X				X	
Bignoniaceae	*Crescentia cujete*	tree	woodland	X					
Boraginaceae	*Heliotroplum filiforme*	herb	savanna	X					
Convolvulaceae	*Aniseia martinicensis*	climber	savanna			X			
	Ipomoea trifida	climber	disturbance					X	
	Jacquemontia pentantha	climber	forest	X					
Gentianaceae	*Coutoubea spicata*	herb	savanna	X					
	Eustoma exaltatum	herb	wetl/coast	X					
	Schultesia brachyptera	herb	savanna					X	
	Schultesia guianensis	herb	savanna		X		X		
Hydrophyllaceae	*Hydrolea spinosa*	herb	wetland	X				X	X
Lamiaceae	*Callicarpa acuminate*	shrub	forest			X			
	Hyptis conferta	herb	savanna						X
	Vitex gaumeri	tree	forest						X
Lentibulariaceae	*Utricularia adpressa*	herb	savanna						X
	Utricularia foliosa	herb	wetland						X
	Utricularia gibba	herb	wetland	X					
	Utricularia simulans	herb	savanna						X
	Utricularia subulata	herb	wetland						X
Loganiaceae	*Mitreola petiolata*	herb	wetland	X					
Menyanthaceae	*Nymphoides humboldtianum*	herb	wetland	X					
Orobanchaceae	*Agalinis hispidula*	herb	savanna				X		
	Buchnera pusilla	herb	savanna	X					
Plantaginaceae	*Angelonia ciliaris*	herb	savanna			X			X
	Bacopa bacopoides	herb	wetland						X
	Bacopa monnieri	herb	wetland	X					
Rubiaceae	*Diodella apiculata*	herb	savanna	X					
	Diodella teres	herb	savanna		X				
	Mitracarpus linearifolius	climber	savanna						X
	Morinda panamensis	shrub	forest	X					
	Richardia scabra	herb	disturbance			X			
	Spermacoce tenuior	herb	disturbance	X					
	Spermacoce verticillata	herb	savanna			X			
Santalaceae	*Phoradendron quadrangulare*	epiph/hemi	savan/wetl	X					
Solanaceae	*Schwenckia Americana*	herb	savanna	X					
Verbenaceae	*Lantana urticifolia*	shrub	disturbance			X			

FAMILY	GENUS/SPECIES	HABIT	VEG. TYPE	*COLLECTION LOCATIONS					
				CT	40	41	BPK	BPR	19
Verbenaceae (cont.)	*Phyla stoechadifolia*	herb	wetland	X					
	Phyla nodiflora	herb	wetland	X					
	Stachytarpheta miniaceae	herb	disturbance						X
LILIOPSIDA									
Iridaceae	*Alophia silvestris*	herb	savanna						X
	Cipura campanulata	herb	savanna	X					
	Cipura paludosa	herb	savanna						X
Orchidaceae M	*Bletia purpurea*	herb	savanna	X					X
	Encyclia alata	epiphyte	savanna						X
ARIFLOREA									
Araceae	*Pistia stratiotes (water lattice)*								
Lemnaceae	*Lemna*	herb	aquatic						
ALISMATIFLORAE									
Alismataceae	*Sagittaria lancifolia*	herb	wetland	X					
Hydrocharitaceae	*Najas wrightiana*	herb	wetland	X					
Potamogentonaceae	*Potamogeton illinoensis*	herb	wetland	X					
Najadaceae???	*Najas* (water-nymphs)???	herb	aquatic						
BORMELIIFLORAE									
Bromeliaceae M	*Aechmea bracteata*	epiphyte	savanna			X			
	Tillandsia balbisiana	epiphyte	savanna	X					X
	Tillandsia bulbosa	epiphyte	forest	X					
Pontederiaceae???	*Eichhornia crassipes (water hya)*	herb	aquatic						
Typhaceae	*Typha domingensis*	herb	wetland	X					
ZINGIBERIDAE									
Marantaceae	*Thalia geniculate*	shrublet	wetland			X			
COMMELINFLORAE									
Mayacaceae?	*Mayaca???*								
Cyperaceae	*Carex polystachya*	herb	wetland			X			
	Cladium jamaicense	herb	wetland						X
	Eleocharis geniculate	herb	wetland	X				X	
	Eliocharis interstincta	herb	wetland	X					
	Fimbristylis vahlii	herb	savanna	X					
	Pycreus polystachyos	herb	wetland					X	
	Rhynchospora barbata	herb	savanna	X			X	X	
	Rhynchospora colorata	herb	wetland	X					
	Rhynchospora divergens	herb	savanna	X					X
	Rhynchospora filiformis	herb	savanna					X	
	Rhynchospora globularis	herb	savanna			X		X	
	Rhynchospora holoschoenoides	herb	wetland			X		X	
	Rhynchospora microcarpa	herb	savanna	X					
	Schoenus nigricans	herb	savanna	X	X				
	Scleria bracteata	herb	forest	X					
	Scleria ciliata	herb	savanna			X			
	Scleria georgiana	herb	savanna	X				X	
	Scleria interrupta	herb	savanna					X	
	Scleria melaleuca	herb	savanna			X			

FAMILY	GENUS/SPECIES	HABIT	VEG. TYPE	COLLECTION LOCATIONS					
				CT	40	41	BKB	BPR	19
Poaceae	*Andropogon glomeratus*	herb	savanna	X					
	Aristida purpurascens	herb	savanna			X			
	Chloris barbata	herb	savanna	X					
	Dichanthelium acuminatum	herb	savanna					X	
	Eragrostis elliottii	herb	savanna	X					
	Ischaemum latifolium	herb	savanna	X					X
	Panicum laxum	herb	wetland			X			
	Panicum tenerum	herb	savanna					X	
Xyridaceae	*Xyris ambigua*	herb	sav/wetl						X
ARECIFLORAE									
Arecaceae	*Acoelorraphe wrightii*	palm	savanna			X			
TOTAL FAMILIES- 57	**TOTAL SPECIES- 155**		**TOTAL**	**68**	**13**	**27**	**13**	**25**	**40**

* The Collection Locations descriptions

CT—Crooked Tree Island
40—Mile 40 Northern Highway
41—Mile 41 Northern Highway
BKB--
BPR—Baker' Pine Ridge
19—Mile 19 Northern Highway

Note that Visaceae used by Balick et al. (2000) and Santalaceae used by Goodwin et al. (2013)
Euphorbiaceae used by Balick et al. (2000) and Phyllanthaceae used by Goodwin et al. (2013)
Scrophulariaceae used by Balick et al. (2000) and Orobanchaceae used by Goodwin et al. (2013)
Najadaceae used by Balick et al. (2000) and Hydrocharitaceae used by Goodwin et al. (2013)

APPENDIX B

Ecology Table for Wetland and Aquatic Plants of Crooked Tree Wetlands and Surrounding Area Reported by Goodwin, et al. (2003)

TAXONOMIC RANKING	ECOLOGY, BIOLOGY AND DISTRIBUTION NOTES
POLYPODIOPHYTA (Pteridophytes?)	
POLYPODIOPSIDA	
Salviniaceae	
Salvinia auricularia *Salvinia minima??* *Water fern*	Tropical, freshwater, free-floating, *S. minima* is an aquarium plant
MAGNOLIOPHYTA	
MAGNOLIIDAE (Paleoherbs?)	
Cabombaceae	
Cabomba palaeformis??	Aquatic herb, cosmopolitan, freshwater, Fl, entomophilous and anemophilus
Ceratophyllaceae	
Ceratophyllum muricatum Coontail	Cosmopolitan, freshwater, S, Fl, hydrophilous
Nymphaeaceae	
Nymphaea ampla White Lilly	Cosmopolitan, freshwater, Fl, E, S, Entomophilous
Nymphaea conardii?? Roundleaf Waterlilly	
Nymphaea glandulifera?? Sleepingbeauty Waterlilly	
CARYOPHYLLIDAE (Monocots)	
Amaranthaceae	
Alternanthera (7 species)	Cosmopolitan, freshwater, E, Fl, S, entomophilous
Polygonaceae	
Polygonum acuminatum	Mexico, widely dispersed in South America, E, Entomophilous, hidrophilous
Polygonum persicariodes	
Polygonum punctatum	
ROSIDAE	
Apiaceae	
Hydrocotyle umbrellata Pennywort	Tropical and sub-tropical America, Ff, entomophilous
Combretaceae	
Bucida buceros Bullet Tree, Black Olive Tree, Gregorywood, Oxhorn Bucida, Antigua Whitewood,	Wetland tree*; common resident of coastal and inland swamps; native to Mexico, Central America and Caribbean; very hard and durable wood resistant to fungus and wood boring insects; once used for house posts and bridge building; bark used for tanning leather.
Euphorbiaceae	
Caperonia castaneifolia Chestnutleaf False Croton	Tropical America, Ff, entomophilous Perennial wetland herb;
Fabaceae- Caesalpinoideae	
Haematoxylum campechianum Logwood, Campeachy Wood Campeche, Bloodwood Tree	Wetland shrub*; grows best in flat swamp areas often inundated by rivers; small bushy tree up to 15 m tall; often thorny and twisted, irregularly fluted trunk; large, long, somewhat straight branches bark peeling in flakes; wood produces grey, brown, violet, blue and black dyes; today used for fence posts

TAXONOMIC RANKING	ECOLOGY, BIOLOGY AND DISTRIBUTION NOTES
ROSIDAE (continued)	
Fabaceae- Faboideae	
Aeschynomene rudis Rough Jointvedge, Zigzag Jointvetch	Aquatic to semi-aquatic shrub*; native to South America' but occurs on other continents, including North America, as a weed in wet habitats such as rice fields; bristly and glandular stems growing near or in water: up to two meters tall; leaves with oval-shaped leaflets and large, flat, pointed stipules at base of each leaf; purple-tinted white flower; lobed legume pod narrowed between the seeds that breaks into segments containing one seed each when dry.
Fabaceae- Mimosoideae	
Mimosa bahamensis Bastard Logwood, Catsim, White Logwood Bush	Wetland shrub to small tree; spiny branches with alternate leaves that are twice pinnately compound; powderpuff-like groups of flowers at tips of stems; fruit pods with wing-like fringe that break into segments containing one seed each.
Fabaceae- Mimosoideae	
Neptunin oleracea	
Neptunin plena	
Malpighiaceae	
Heteropterys lindeniana	Wetland shrub
Malpighia lundellii	Wetland shrub
Onagraceae	
Ludwigia octovalvis	Neotropical, wide in S. America, AM, E, entomophilous, Wetland herb
Ludwigia pepliodes Floating Primrose-willow, Creeping Water Primrose	Perennial wetland herb; grows in moist to flooded wetlands; native to many areas of the Americas, naturalized on many continents; stem can reach over 2 meters in length, sometimes branching, forming mats on the mud or floats in the water; can be an aquatic noxious weed
Ludwigia peruviana Primrose willow Peruvian Primrose	Terrestrial to partly submerged erect shrub, native to South America, can form dense stands in waterways, grows in lentic to slow-flowing water and mud stream bank, seeds can be spread by birds, can spread by fragments that may form floating masses.
Phyllanthaceae	
Phyllanthus stipulates Stipulate Leaf Flower	Wetland herb;
ASTERIDAE	
Acanthaceae	
Hygrophila costata	Tropical America, AM, E, entomophilous Semi-aquatic to aquatic; Native from southern Mexico to Argentina; forms dense mats around littoral zones of water bodies
Justicia spp.- 11	
Bignoniaceae	
Ceratophytum tetragonolobum???	
Cuscutaceae	
Cuscuta indecora *Cuscuta pentagona*	
Gentianaceae	
Eustoma exaltatum	Tropical south America, AM, E, entomophilous, Wetland and coastal herb*

TAXONOMIC RANKING	ECOLOGY, BIOLOGY AND DISTRIBUTION NOTES
Hydrophyllaceae	
Hydrolea spinosa Spiny False Fiddleleaf	Wetland herb*
Lentibulariaceae	
Utricularia foliosa Leafy Bladderwort	Pantropical, Central and South Am, E, Sf, entomophilous Perennial aquatic herb; large suspended aquatic carnivorous plant; pantropic, found in Africa and in North, Central and South America.
Utricularia gibba Humped Bladderwort, Floating Bladderwort	Aquatic herb;; grows in ponds, lakes, shallow ditches, pools, bogs, swamps, and marshes in still to slowly flowing waters, occasionally growing but not flowering in deep water; water typically nitrogen/phosphorus poor; small, mat-forming carnivorous species.
Utricularia subulata Zigzag Bladderwort	Annual wetland herb; small, terrestrial, carnivorous plant living solitary or in large colonies if competition is low; pantropical, widest dispersal of any species in the genus; small yellow flowers that lack petals, self-fertilizing
Loganiaceae	
Mitreola petiolata Caribbean Miterwort, Lax Hornpod	Annual wetland herb; widespread- southeastern United States, Caribbean, Latin America, southeast Asia, southern Africa, and northern Australia; three distinct forms in New World based on inflorescence and fruit
Menyanthaceae	
Nymphoides humboldtianum Water snowflake Robust Marshwort	Some species cosmopolitan, Central and South America, E, Fl, entomophilous Water snowflake
Plantaginaceae	
Bacopa bacopoides	North temperate and cool South America, freshwater. E, S Wetland herb; ranges from Belize to Brazil
Bacopa monnieri Water Hyssop,Brahmi, Thyme-leafed Gratiola, Herb of Grace, Indian Pennywort	Perennial wetland herb; native India, Australia, Europe, Africa, Asia, and North and South America; medicinal herb used for cognitive enhancement and longevity
Rubiaceae	
Cephalanthus occidentalis	Africa and American continent, AM, E, entomophilous
Santalaceae	
Phoradendron quadrangulare Mistletoe	Savanna/wetland epiphyte/hemiparasite; capable of photosynthesis but uses host plant for some nutrients, minerals, and water through a haustorium that grows into the cambium of the host plant; most widespread mistletoe, Mexico to northern South America and parts of Caribbean
Verbenaceae	
Phyla nodiflora Turkey Tangle Fogfruit	Wetland herb; found from United States to South America, and tropical areas around the world, naturalized in many places; inflorescence has purple center surrounded by small flowers ranging from white to pink, ornamental, ground cover
Phyla stoechadifolia Southern Fogfruit	Wetland herb;

TAXONOMIC RANKING	ECOLOGY, BIOLOGY AND DISTRIBUTION NOTES
LILIIFLORAE	
Amaryllidaceae	
Hymenocallis littoralis	
ARIFLOREA	
Araceae	
Pistia stratiotes Water Lettice	Cosmopolitan (some species), tropical subtropical temperate, freshwater, Ff, E, entomophilous
Lemnaceae	
Lemna	Duckweed
ALISMATIFLORAE	
Alismataceae	
Echinodorus andrieuxil	Cosmopolitan, freshwater, E, Fl, S, entomophilous
Echinodorus anuphaeifolius	
Sagittaria lancifolia Lanceleaf Arrowhead, Bulltongue Arrowhead	Large emergent aquatic herb*; grows in fresh to brackish water, ditches, marshes, swamps, lake shores, and stream edges; grow from rhizomes beneath sediment; lance-shaped leaves, white flowers with three-petals on the end of long, thick stalks; asexual reproduction through rhizomes as well as sexually through production of achenes with single seed; germinate only under light in or out of water, but germination is shorter when submersed, reduced in anaerobic environments
Hydrocharitaceae	
Najas wrightiana Wright's Water Nymph	Cosmopolitan, fresh/saltwater, S, Fl, anemophilous, entomophilous, hydrophilous Submerged aquatic herb*; grows in ponds, lakes and slow flowing streams; native to Mexico, Guatemala, Belize, Honduras, Bahamas, Cuba, Venezuela; introduced into southern Florida; bushy with thin branched stems; linear leaves with coarse teeth, opposite or crowded and whorled, with sheath-like bases.
Najadaceae???	
Najas Water Nymph	
Potamogentonaceae	
Potamogeton illinoensis Illinois Pondweed, Shining Pondweed	Cosmopolitan, freshwater, marine, brackish, tropical, Fl, S anemiphilous, hydrophilous. Aquatic herb; rooted in sediment of shallow to deep water, from still water of lake margins to fast flowing rivers; submersed pant with submersed (lance-shaped and pointed) and floating (more oval shaped and rounded) leaves; flower spikes are thick stalks held above the water; becomes a noxious weed in many areas where it is introduced;
Potamogeton pectinatus	
Potamogeton pusillus	
Ruppia maritima	Family Ruppiaceae? Subtropical, temperate, salt and brackish water, S, Hydrophilous
BORMELIIFLORAE	
Pontederiaceae???	
Eichhornia crassipes Water Hyacinth	Pan-tropical and temperate American, freshwater, E, S, Ff, entomophilous
Pontederia cordata Pickerelweed	
Pontederia rotundifolia	

TAXONOMIC RANKING	ECOLOGY, BIOLOGY AND DISTRIBUTION NOTES
Typhaceae	
Typha domingensis Southern Cattail	Cosmopolitan, freshwater, anemophilous perennial wetland herb; brackish to freshwater wetlands; tropic and temperate regions worldwide; spreads by rhizomes once seedlings establish in disturbed areas; often in dense patches, may reduce local biodiversity, eliminate local plant communities; does well in eutrophic conditions, grows sparsely in undisturbed, low-nutrient wetlands, economically important in some regions for weaving; use in bioremediation, medicinal uses
ZINGIBERIDAE	
Cannaceae	
Canna indica	Tropical America, Subtropical, freshwater, AM, E, ornithophilous
Canna tuerckheimil	
Marantaceae	
Thalia geniculate Bent Alligator-flag, Arrowroot, Fireflag	Tropical America, Africa, AM, E Wetland shrublet; widespread across tropical Africa and much of the Americas, native to Africa, considered native to southeastern United States, Mexico, Central America, Caribbean, much of South America
COMMELINFLORAE	
Cyperaceae	
Carex polystachya Caribbean Sedge	AM, E, EP, anemophilous Wetland herb,
Cladium jamaicense Sawgrass	Large emergent aquatic/wetland herb; grows in fresh and brackish water wetlands, and along lake shores and can grow on dry land; stems sometimes over 2 meters tall, short and stout rhizomes, leaves grow from the base, and usually a meter long, stiff, flat to v-shaped, margins and the underside midrib with cutting saw teeth, large influorescence up to a meter or more tall
Eleocharis geniculate Bent Spikerush	Wetland herb*; sandy mudflats along seasonally receding lakeshores, shallow areas, fresh to brackish water
Eleocharis spp-17	
Oxycaryum cubense	
Pycreus polystachyos Bunchy Flat Sedge, Many Spike Flatsedge	Wetland herb; widespread in tropical and subtropical areas around the world, sometimes extending its range into temperate regions
Rhynchospora colorata Starrush Whitetop, White Star Sedge, White-topped Sedge	Perennial wetland herb*; native in southeastern to southwestern United States and Carribbean; spikes contain many tiny flowers toping 3–10 green and white bracts that grow to 10–15 cm long, real leaves sprout from plant base; insects attracted as pollinators (most species in this family wind-pollinated
Rhynchospora holoschoenoides Fly Beaksage	Wetland herb; originate in Africa?
Schoenoplectus americanus (syn. Scirpus americanus)	
Juncaceae	
Juncus marginatus	Cosmopolitan, Fl, E, Anemophilous
Ericaulaceae	
Erioclaulon spp.- 5	Tropical and sub-tropical, freshwater, E, S, anemophilous, entomophilousa
Mayacaceae	
Mayaca???	Tropical, freshwater, E, S, entomophilous

TAXONOMIC RANKING	ECOLOGY, BIOLOGY AND DISTRIBUTION NOTES
Poaceae	
Panicum laxum	Cosmopolitan, pantropical, AM, E, Fl, amemophilous Annual wetland herb; damp, seasonally flooded soils; produces culms 30–60 cm high; native of neotropics; invasive found on disturbed areas such as roadsides, becoming a weed in rice paddies
Panicum repens	
Phragmites australis	
Xyridaceae	
Xyris ambigua	Tropical south America, freshwater, E, anemophilous Savanna/wetland herb; perennial; up to 100 cm tall; leaves are grass-like, flowers are leaves, native to southern and eastern Mexico, Central America, Cuba, and the southeastern United States
ARECIFLORAE	
Blechnaceae	
Blechnum serrulatum Swamp Fern	Wetland herb; found in swamps and uplands in sun or shade, also grows in heavy organic soil; native to United States, Central and South America, Caribbean

Total families: 46
Total species: 77

NOTE: Scremin-Dias, E. ND Tropical Aquatic Plants: Morphoanatomical Adaptations. In Tropical Biology and Conservation Management, Volume I. Encyclopedia of Life Support Systems-source of family-level information

APPENDIX C

Savanna and Wetland Plants of Crooked Tree Wetlands and Surrounding Area
Recognized as having Medicinal and Economic uses (Balick and Arvigo, 2015)

FAMILY	GENUS/SPECIES	NOTES
Pinaceae	*Pinus caribeae* Caribbean Pine	Back pain, urinary ailments (tea, young branches and needles), cough (tea, young branches and needles plus lemon juice), parasites (pill, equal parts resin and garlic), excess uterine mucus, diabetes, gonorrhea (resin, used with other ingredients), construction (wood)
Alismataceae	*Sagittaria lancifolia* Lanceleaf Arrowhead, Bulltongue Arrowhead	Diarrhea, heavy menstruation, postpartum bleeding (tea, stem with other plants)
Apocynaceae	*Ascleplas curassavica* Poly Red Head, Butterfly Weed	Toothache (direct, latex of leaf or stem), earache (wash, whole plant), sinus congestion (drops, latex), colds (inhale, dried latex), itching, warts, wound (skin rub, latex), mastitis (skin rub, roasted fruit), rat poison (ingestion, dried leaves and corn)
	Pentalinon andrieuxii Snake Root	Headache, swelling, grief (tea or bath, chopped plant) diabetes (tea, root with Billy Web bark), snakebite, poison, hernia (tea, powdered root), snakebite (poultice, chewed root with other plants), snakebite pain and swelling (bath, whole plant)
Arecaceae	*Acoelorraphe wrightii* Palmetto, Honduras Pimenta, Hairy Tom Palmentto	Food (heart at tip of stem, seeds), sores, wounds (wash, heart and roots), bleeding (dusting, dried material around stem meristem), construction (walls, fences)
Asteraceae	*Acmella pilosa* Orosus	Headache (wash, whole plant, option for including other plants), cough (tea, leaves)
	Elephantopus mollis	Headache (poultice or wash, crushed leaves)
Bignoniaceae	*Crescentia cujete* Calabash	Food (soup and eggs, young shoots and leaves), earache (drops from heated flowers), cough (tea, pulp and seed of fruit plus other ingredients), colds (syrup from fruit), cough, asthma, bronchitis, lung congestion (tea, fruit pith and sugar), asthma and bronchitis (tea, fruit pith only), asthma (tea, leaves), blood builder (consume leaves boiled in salt water or fried with onions and garlic), dysentery (consume leaves soaked in water), retained placenta (tea, bark or leaves), bowls (dried fruit)
Celastraceae	*Hemiangium* excelsum	Promote sweat, fever (tea and wash, stems and young leaves)
Chrysobalanaceae	*Chrysobalanus icaco* Tie Tie	Food (fruit), vaginal discharge (tea, ground seeds), astringent (bark and leaves)
Combretaceae	*Bucida buceras* Bullet Tree	Charcoal, fuel, construction (wood), tanning (bark)
	Conocarpus erectus Button Wood, White Mangrove	Sores (bark, roasted and powdered), charcoal, fuel, construction (wood)
Dilleniaceae	*Curatella Americana* Sandpaper Tree, Yaha	Food (roasted seed), skin ailments (wash, leaves), diarrhea (tea, leaves), charcoal (wood), fine sand paper (leaves), tanning (bark)
Erythroxylaceae	*Erythroxylum guatemalensis* Swamp Redwood	Small construction (wood), hard, heavy and durable wood
Fabaceae-Caesalpinioideae	*Caesalpinia yucatanensis*	Measles, fever (bath, leaves and flowers)
	Haematoxylum campechianum Logwood	Haematoxylin dye (wood) was used for fabric dye and is also used as a histological stain and to stain protozoa; bark is used for diarrhea and the flower infusion for bronchial problems, and as an astringent and anti-inflammatory agent to treat gastric issues; local people in Crooked Tree use the wood as fence posts

FAMILY	GENUS/SPECIES	NOTES
Fabaceae- Faboideae	*Aeschynomene rudis* Waral k'ix	Toothache (mouthwash, root)
	Andira inermis Cabbage-bard	Induce vomiting, purge, narcotic, poison (bark), construction, house posts, frames (wood)
	Lonchocarpus rugosus Black Cabbage-bark	Firewood (wood)
	Pachyrhizus erosus Yam Bean	Food (tubers)
	Pachyrhizus ferrugineus Wild Jicama	Grief (tea, root), calmative (tea, leaves)
Fabaceae- Mimosoideae	*Mimosa bahamensis* Logwood brush	Indicator of good soil
	Pithecellobium lanceolatum	Bloody stool (tea, bark)
Gentianaceae	*Coutoubea spicata*	Believed to have magical powers
Lamiaceae	*Callicarpa acuminate*	Stomach or abdomen swelling (poultice, crushed leaves heated in oil), dysentery (tea, leaves), menstrual pain (steam bath, leaves and stems boiled), post birth (bath, leaves and vines boiled), lactation, continue milk flow (tea, leaves), psychoactive properties (seeds)
	Vitex gaumeri	Fodder (leaves and stems, cattle), asthma, malaria, chills (bath, boiled leaves), arthritis (poultice, mashed leaves with other plants), toothache (leaves chewed), skin fungus, rash, itching (wash, leaves), skin fungus, ringworm, infected sores (skin rub, bark toasted, powdered, mixed with oil), skin infections (poultice, fresh pounded bark), skin sores and wounds (poultice, crushed leaves), infected pustules (wash, bark, or poultice, graded bark), leishmaniasis (poultice, bark mashed, powdered and mixed with oil), biliousness, jaundice (tea, bark), firewood, construction (wood)
Malpighiaceae	*Heteropterys lindeniana*	Preserve fresh meat and fish (leaves)
Malvaceae	*Hibiscus costatus*	Improve blood circulation following snakebite (wash, root), snakebite (poultice, crushed seeds and garlic in animal fat)
	Luehea speciosa	Rope (inner bark), roof poles (wood), firewood (wood)
	Sida rhombifolia	Fever (enema, water from boiled roots), sprains (poultice, mashed root), burning urine, urine retention, gonorrhea, dry cough (tea, leaves), scorpion sting, snakebite (tea, whole plant minus roots-stimulates kidneys to eliminate toxins)
Marantaceae	*Thalia geniculate*	Wrap tamales (leaf)
Melastomataceae	*Clidemia sericea*	Cough (tea, leaves)
Myricaceae	*Myrica cerifera*	Kidney and bladder ailments, kidney stones, cleanse urinary tract, diuretic (tea, leaves),
Myrsinaceae	*Parathesis cubana*	Food (seeds), "discomfort" (bath, water from steeped leaves)
Nyctaginaceae	*Neea psychotrioides*	Food (fruit), fever (bath or rub, fresh fruit juice), edema, especially with pregnancy (bath, water of boiled leaves)
Onagraceae	*Ludwigia octovalvis*	Abscess (wash, whole plant and salt boiled in water), fever (bath, crushed stems and leaves)
Passifloraceae	*Passiflora urbaniana*	Fever, headache (wash, water of boiled vine), thrush (mouthwash, boiled leaves and stems)
Polygalaceae	*Polygala paniculata*	Stomach gas (tea, whole plant)
Polygonaceae	*Coccoloba barbadensis*	Food (fruit), stop bleeding of snakebite (poultice, root and graded seed toasted, mixed with fat), hemorrhaging (tea, root), wrap tortillas (leaf), construction, center beams (wood)

FAMILY	GENUS/SPECIES	NOTES
Rubiaceae	*Spermacoce verticillata*	Fodder (rabbits, goats, sheep)
Santalaceae	*Phoradendron quadrangulare*	Cancer (tea, vine and leaves), dog bite (poultice, crushed vine, leaves, garlic)
Turneraceae	*Turnera diffusa*	General pain (tea, whole plant), toothache (chewed, leaves)
	Turnera scabra	Expectorant, sedative (tea, whole plant), diabetes (tea, twigs and Bay Cedar bark)
Typhaceae	*Typha domingensis*	Food (root), fiber (seeds, leaves)
Verbenaceae	*Stachytarpheta miniaceae*	Measles, itching, sores (wash, roots, guava leaves)
TOT. FAMILIES-32	**TOTAL SPECIES- 45**	

APPENDIX D

Ecology Table for Aquatic Macroinvertebrates Collected from Crooked Tree Wetlands (2003 and 2016)

TAXON	TROPHIC ECOLOGY	HABITAT	NOTES
MOLLUSCA			
Gastropoda			
Ampullariidae *Pomacea*	Collectors- grazers, shredders	Lentic- littoral, muddy substrates, lotic-depositional	Very important in ecology of CTWS wetlands and lagoons as prey
Ancylidae	Generally scrapers	Lotic-erosional, typically on firm substrates	Relatively stress tolerant
Planorbidae	Generally collector-gatherers, some scrapers	More common on soft substrate, sometimes solid substrate sticking above the bottom, warm lakes and ponds	Hemoglobin in blood allows Planorbids to inhabit areas with low oxygen; facultative to somewhat tolerant of stress
Physidae	Generally collector-gatherers, some scrapers	More common on soft substrate, sometimes solid substrate sticking above the bottom	Somewhat tolerant of stress
Thiaridae *Melanoides tub* *M. gran*	Generally scrapers	Wide range of lotic to lentic habitats	Introduced from Asia by aquarium trade; somewhat tolerant to tolerant of stress
Bivalva			
Sphaeriidae	Collector-filterers	Lentic-littoral, lentic-profundal, lotic-depositional, lotic-erosional; occupy many habitats, largest diversity in fine silt and clay	Burrowers; not restricted to water with high amounts of calcium carbonate; can withstand drought by burrowing; facultative to somewhat tolerant of stress
Unionidae	Collector-filterers	Lotic-erosional, lotic-depositional, lentic-littoral; mostly in shallow rivers, also do well in shallow lakes	Burrowers, often restricted to water with calcium carbonate; relatively sensitive to facultative, preferring unpolluted waters
ANNELIDA			
Oligochaeta			
Lumbriculidae	Collectors-gatherers; ingesting substrate	Lentic- mud and detritus, lotic-depositional	Burrowers
Tubificidae	Collectors-gatherers; ingesting substrate	Lentic-littoral, mud and detritus	Burrowers, tube-builders; relatively tolerant of stress
Hirudinea			
	Predator-piercers kill small prey, insect larvae, snails, earthworms, leeches; exo-parasites consume body fluids but do not kill prey	Lentic-littoral and lotic-depositional, some lotic-erosional; most in ponds, lakes, marshes, streams with plants and detritus	Clingers, having two suckers, some species are swimmers; some can withstand moderate pollution
ARTHROPODA			
Arachnida			
Acariformes	Mostly predators-piercers, preying on aquatic insects, particularly diptera, and small crustaceans, larvae and some species are ecto-parasites of Diptera, Odonata, Dytiscidae, Corixidae, clams, snails	Mostly in lentic-littoral habitats with aquatic plants, but found in many kinds of freshwater habitats; common in lakes, marshes, swamps, bogs	Swimmers, but do not move far above sediment, some crawl or burrow in bottom, some climb on plants; active during daytime; inject digestive enzymes into prey; often parasitize high percentage of aquatic insects; facultative as a group, ranging from sensitive to tolerant

TAXON	TROPHIC ECOLOGY	HABITAT	NOTES
Crustacea			
Cladocera	Filterers, creating currents of water; feed on protozoa and algae, also FPOM	Found in most aquatic habitats except rapid streams and polluted water	Move by hopping and swimming, some important in plankton
Copepoda	Collectors-gatherers, scrapers, filterers; FPOM, periphyton, plankton	Lentic and lotic waters, littoral and benthic conditions, plankton	Mostly swimmers, some crawlers, some important in plankton
Ostracoda	Filterers, bacteria, fungi, algae, FPOM; larger species feed on living/ dead animals	Lentic waters, on algae, plant detritus, rooted aquatic plants, mud, gravel	Creeping, bouncing, and scurrying, some swim, some burrow
Amphipoda Talitridae	Collector-gatherers, shredder-detritivores, scrapers, predator-engulfers; omnivorous, feeding on wide variety of plant and animal material, mostly plant detritus	Lotic-erosional, lotic-depositional, lentic-littoral, subterrarian; mostly benthic among plant roots and debris	Crawl mostly, but swim just above surface of sediment, often swimming on their sides; often in large numbers and are important food organisms; generally facultative, but some sensitive to toxic metals and pesticides
Decapoda Palaemonidae	Primarily scrapers of algae and periphyton, predators-engulfers of aquatic insects, sometimes feed on strained sediments with microbes	Lotic-depositional and lentic-littoral; river backwaters, lake margins with dense aquatic plants	Strong swimmers; may be facultative but not well known
Insecta			
Collembola			
	Collectors-gathers, scavengers	Lotic-margins, surface film	Sprawlers, skaters
Ephemeroptera			
Baetidae	Collectors-gatherers, scrapers	Lotic-erosional, lotic-depositional, lentic-littoral; wide variety of habitats; around aquatic plants	Swimmers, clingers, and climbers; mainly swimmers in flowing water and climbers in still waters; generally facultative, sensitive to very tolerant of nutrients, siltation, low DO
Caenidae *Caenis*	Collectors- gatherers and scrapers; mainly plant detritus but sometimes dead animals	Lntic-littoral and lotic-depositional; favor quiet waters, silt bottoms among rooted aquatic plants	Sprawlers; generally facultative, ranging from sensitive to somewhat tolerant of nutrients, siltation, low DO
Ephemeridae	Collectors-gatherers, predators-engulfers, filterers	Lentic and lotic depositional	Burrowers
Polymitarcyidae *Ephoron*	Collectors- gatherers and filterers	Lotic erosional and depositional, lentic sediments	Burrowers
Odonata			
Coenagrionidae	Predators-engulfers	Generally lentic-littoral, a few lotic-depositional and lotic-erosional; ponds, lakes, marshes, swamps, ditches	Climbers, some sprawlers and clingers; somewhat to very tolerant of stress
Gomphidae *Aphylla*	Predators-engulfers	Generally lotic-depositional and lentic-littoral; streams and ponds to rivers and lakes; silt, sand, gravel, detritus	Mainly burrowers, a few sprawlers; burry in sediment with only eyes and tip of abdomen exposed; generally very sensitive, but range from very sensitive to somewhat tolerant
Libellulidae	Predators-engufers	Generally lentic-littoral and lotic-depositional; ponds, lakes, marshes, swamps, ditches	Mainly sprawlers, some climbers; often very active; usually most abundant dragonfly naiad; often covered in silt; usually very tolerant

TAXON	TROPHIC ECOLOGY	HABITAT	NOTES
Hemiptera			
Belastomatidae *Belastoma*	Predators-piercers; aquatic arthropods, tadpoles, fishes; injects enzyme that kills prey	Generally lentic-littoral or lotic-depositional; ponds, lake margins, marshes, ditches, river pools among plants and plant detritus	Air breathers and can store air in body bubble for deep dives; good fliers; attracted to lights; very stress tolerant
Corixidae	Collector-gatherers; re-suspend bottom material and ingest algae, diatoms, protozoa, rotifers, midges, mosquitoes, nematodes	Lentic-littoral or lotic-depositional; often associated with aquatic plants	Air breathers using bubbles when diving that act as a physical gill; many produce sound by stridulation; very stress tolerant
Gerridae	Predators-piercers; terrestrial and aquatic insects trapped on surface film; cannibalistic	Generally lentic-limnetic or lotic-depositional, maybe lotic-erosional on water surface film	Skaters on water surface; can dive and leave water during rain; air breathers, carry bubble under water; relatively tolerant
Naucoridae	Predators-piercers; mosquito larvae, midge larvae, Corixidae, small crustaceans	Lentic-littoral, lotic-erosional; wide range of still and moving water; many favor living plants and detritus	Crawlers, climbers, swimmers; naiads breathe through body surface from water and adults breathe air; preyed on by normal prey when molting; tolerance not well known
Notonectidae	Predators-piercers; insects, crustaceans, snails, small fishes, tadpoles	Lentic-littoral or lotic-depositional; typically in still waters with vegetation	Swimmers, often hang upside down from surface film; air breathers that carry bubble when diving
Veliidae	Predators-piercers; terrestrial and aquatic insects trapped on surface film; cannibalistic	Generally lentic-limnetic or lotic-depositional, maybe lotic-erosional on water surface film, favor more protected areas	Skaters on water surface; air breathers, can dive and carry bubble under water; relatively tolerant
Coleoptera			
Curculionidae	Shredders-herbivores, both chewing and mining living plant material	Usually lentic among aquatic plants	Mainly clingers, climbers, and sprawlers on plants; burrowers in plant stems
Dytiscidae	Larvae predators-piercers; adults predators-engulfers; prey on worms, leeches, cruataceans, true flies, dragonfly naiads, tadpoles, fishes	Larvae and adults lentic-littoral, lotic-depositional; shallow margins of ponds, lagoons, and slow streams, also many other habitats	Larvae swimmers and climbers; adults swimmers; adults rest with tip of abdomens touching water surface; larvae inject prey with digestive enzyme and siphon out digested materials; facultative to relatively tolerant to stress
Gyrinidae	Larvae and adults predators-engulfers; larvae feed on midge larvae, other inverts, cannibalistic; adults eat inverts trapped on surface film and organic material	Lentic-littoral, lotic-depositional; streams, rivers, ponds, lakes, lagoons in low energy shore-areas	Larvae swimmers and climbers; adults surface swimmers; adults may use a form of ecolocation for food resources; adults have divided eyes; rapid swimmers in circles and in groups; facultative response to stress
Hydrophilidae	Larvae generally predators-engulfers, wide range of inverts, can crush snail shells; adults generally collectors- gatherers, some predators-engulfers	Larvae and adults lentic-littoral, associated with vascular aquatic plants, lotic-depositional	Larvae generally climbers; adults generally divers and swimmers; larvae and adults are air breathers, adults recharging air bubble by breaking surface with an antennae, relatively to very stress tolerant
Noteridae	Predators-engulfers and collectors-gatherers	Mostly lentic, among aquatic plants	Mainly burrowers and climbers
Sciritidae	Mainly scrapers, collector-gatherers, scrapers-herbivores, piercers-herbivores.	Larvae generally lentic among aquatic plants; adults terrestrial	Mainly climbers and sprawlers

TAXON	TROPHIC ECOLOGY	HABITAT	NOTES
Staphylinidae	Predators-engulfers	Typically shorelines, lotic and lentic	Mainly clingers and climbers, also burrowers
Trichoptera			
Hydroptilidae	Herbivores-piercers of algal cells, scrapers of periphyton	Generally lentic-littoral, some lotic-depositional, few lotic-erosional; diverse permanent water habitats	Generally climbers and clingers; most live in portable cases, some attaching cases; most are facultative and some very sensitive to stress, a few proliferate in nutrient-stressed conditions with algal growth
Lepidoptera			
Pyralidae	Generally shredders-herbivores (leaf eaters)	Generally lotic, associated with vascular aquatic plants	Generally climbers and miners, stem borers
Diptera			
Ceratopogonidae	Generally predators (engulfers), collectors-gatherers	General lentic- littoral and lotic depositional	Generally sprawlers, burrowers or planktonic (swimmers); relatively stress tolerant
Chaoboridae	Predators (engulfers, piercers) of crustacean zooplankton, mosquito larvae, other macroinverts	Lentic-littoral, lentic-limnetic, lentic-profundal, sometimes lotic-depositional	Planktonic (thoracic/abdominal air sacs), may show daily vertical migration, sprawlers; relatively stress tolerant; some species air breathers
Chironomidae	Collectors- gatherers (a few filterers), scrapers, shredders-herbivores (miners), some predators-engulfers	Many types of habitats, lentic-lottoral and profundal, lotic-depositional	Burrowers (tube builders), some clingers; create delicate tubes of silk, silt, sand, FPOM; most diverse and abundant family of aquatic insects; process POM and important prey
Chironominae *Chironomus*	Typically collectors-gatherers, collectors-filterers	Lentic-littoral, profundal, lotic-depositional, erosional	Mostly burrowers and clingers, mainly tube builders
Tanypodinae	Mainly predators-engulfers and piercers	Many types of lentic and lotic habitats	Mainly sprawlers, swimmers, and burrowers
Culicidae *Aedes* *Anopheles* *Culex*	Generally collectors- filterers and gatherers; actively create currents; feed on algae, bacteria, protozoa, FPOM	Generally lentic-litoral, lotic-depositional (pools and back waters of lotic systems, pools, ponds, artificial containers, detritus mats, still waters in general)	Generally planktonic, swimmers; many disease vectors for humans and wildlife; relatively stress tolerant
Tipulidae	Generally shredders-detritivores, collectors-gatherers, some predators-engulfers	General lentic- littoral, lotic erosional and depositional (associated with detritus)	Generally burrowers and sprawlers; largest species number of any dipterian family; mainly facultative but wide range of species and responses to stresses

Note: Insect information taken from ecology tables in Merritt and Cummins (1996) and from Voshell (2002), information for non-insect fauna from Pennak (1989) and Voshell (2002).

APPENDIX E-1

Aquatic Macroinvertebrate Collection Data for CTWS Lagoons and Wetlands

	20151212- NL CTL Aq Plants	20151213- NL CTL Detritus Mats	20151212-13 NL. CTL Drift Line	20151222- JL/ML Lily Patch	20160107- WL Sedge	20160108- NL CTL Lily Patch	20160518-19 NL CTL Aq Plants	20160520- NL North end Sedge	20160518- NL BAS Sub Aq Plants	20160519-WL Sedge	20160702-05 NL BEVI Aq Plants	20160705- NL Causeway Bridge	20161020-21 NL BAS Sub Aq Pl	20161020-NL Shoreline Limpkin	20161020-NL BEVI Drift Line	20161022- NL East Shore Cause-	20161021-WL Canal Sedge	**TOTAL FOR EACH TAXON**
ANNELIDA																		
Oligochaeta			2				62				92	1	18	2		3	5	**185**
Hirudinea			1						1									**2**
MOLLUSCA																		
Gastropoda																		
Ampullariidae																		
Pomaceae	2		1															**3**
Ancylidae		3								9								**12**
Planorbidae													19				2	**21**
Physidae		2	1		1				2				1					**7**
Thiaridae																		
Melanoides tub.							1					4						**5**
M. gran							3?	4?										
Unidentified							10		9	20		4	4	2				**49**
Bivalvia																		
Sphaeriidae		1																**1**
Unionidae							2											**2**
ARTHROPODA																		
Arachnida																		
Acariformes	4	2			14		3	6	3	1	60	7	4			1		**105**
Crustacea																		
Cladocera	2	7	4		4		8	9	1	17	3		29	2				**86**
Copepoda																1		**1**
Ostracoda								1			3							**4**
Amphipoda																		
Talitridae	17	71	48		23	2	4	12	8	1			1				1	**188**
Decapoda																		
Palaemonidae																		
Insecta																		
Columbola																		
Ephemeroptera																		
Baetidae					1			12	20									**33**
Caenidae	7	16					149	12	14	5	35	23	35	9			3	**258**
Ephemeridae									1				2					**3**

	20151212- NL CTL Aq Plants	20151213- NL CTL Detritus Mats	20151212-13 NL. CTL Drift Ln	20151222- JL/ML Lily Patch	20160107- WL Sedge	20160108- NL CTL Lily Patch	20160518-19 NL CTL Aq Pl	20160520- NL N end Sedge	20160518- NL BAS Sub Aq Pl	20160519-WL Sedge	20160702-05 NL BEVI Aq Pl	20160705- NL Causeway Bridge	20161020-21 NL BAS Sub Aq	20161020-NL Shoreln Limpkin	20161020-NL BEVI Drift Line	20161022- NL E Shore Cause-	20161021-WL Canal Sedge	**TOTAL FOR EACH TAXON**
Odonata																		
Coenagrionidae 1	24	41			5	1	2	6	10		2	1	4	3		5		**104**
Coenagrionidae 2	2	5			1			6	6	4								**24**
Libellulidae							2	6	2	2	2		1	1			3	**19**
Gomphidae																		
Aphylla							3					1						**4**
Hemiptera																		
Belastomatidae		1							3				2	1				**7**
Belastoma					1				2		1				1			**5**
Corixidae									1									**1**
Gerridae	1																	**1**
Naucoridae	1																	**1**
Notonectidae														4				**4**
Veliidae									4									**4**
Coleoptera																		
Curculionidae									3									**3**
Dytiscidae Adult	2				1			3	4			2		1	3		1	**17**
Dytiscidae Larva									3									**3**
Gyrinidae								2		1								**3**
Hydrophilidae Ad													2		3			**5**
Hydrophilidae La									7				1		1			**9**
Noteridae		1												2				**3**
Sciridae					1									11				**12**
Unidentified Adu.		1	3		1			3										**8**
Trichoptera																		
Hydroptilidae		1																**1**
Lepidoptera																		
Pyralidae Gills	7	24				5										5		**41**
Pyralidae No Gills	4	8		5	3								1					**21**
Diptera																		
Ceratopogonidae																		
Bezzia/Probezzia					5								2					**7**
Chironomidae																		
pupa		1	1		1		1		1	1	4						1	**11**
Chirinominae	14	71	8	33	66	6	6	2			20	6	23			6	17	**278**
Chironomus	8	3	14							4	1			1			1	**32**
Tanypodinae		13			6		14	1	4		17		2	1			2	**60**
Culicidae Pupa								12	13									**25**
Anopheles		4			1				5									**10**
Culex								10	33	3								**46**
Tipulidae										1								**1**
TOTALS	95	276	83	38	135	14	267	103	160	69	240	49	151	40	8	21	36	**1785**

	20151212-13 CTL Back Lagoon	20160108- Limpkin Trail Pond	20160705- Limpkin Trail Pond	20160702- BEVI Tilapia Pond	TOTAL FOR EACH TAXON
ANNELIDA					
Oligochaeta	13		1		**14**
MOLLUSCA					
Gastrapoda					
Planorbidae			7	4	**11**
Physidae			1	3	**6**
Thiaridae					
Melanoides tub.				8	**8**
Unidentifed				16	**16**
ARTHROPODA					
Arachnida					
Acariformes			23		**23**
Crustacea					
Cladocera	1	7			**8**
Copepoda		1			**1**
Ostracoda			2		**2**
Decapoda					
Palaemonidae			1		**1**
Insecta					
Ephemoroptera					
Baetidae					
Caenidae				1	**1**
Ephemeridae					
Odonata					
Coenagrionidae 1	1		6	1	**8**
Coenagrionidae 3			4		**4**
Aeshnidae			1		**1**
Libellulidae	1	1	3	2	**7**
Unidentified			12		**12**

	20151212-13 CTL Back Lagoon	20160108- Limpkin Trail Pond	20160705- Limpkin Trail Pond	20160702- BEVI Tilapia Pond	TOTAL FOR EACH TAXON
Hemiptera					
Belastomatidae					
Belastoma			1	2	**3**
Naucoridae				1	**1**
Coleoptera					
Dytiscidae Adult 1			2		**2**
Dytiscidae Adult 2			12		**12**
Dytiscidae Adult 3			2		**2**
Dytiscidae Adult 4			4		**4**
Dytiscidae Larva			1		**1**
Hydrophilidae La			2		**2**
Noteridae			1		**1**
Scritidae			11		**11**
Straphylinidae			1		**1**
Diptera					
Ceratopogonidae					
Atrichopogon		1			**1**
Bezzia/Probezzia				6	**6**
Chaoboridae			3		**3**
Chironomidae					
Pupa	3		1		**4**
Chironominae	28	1	2		**31**
Chironomus	99	18			**117**
Tanypodinae	1				**1**
Culicidae					
Pupa		1			**1**
Aedes			2		**2**
Anopheles		3			**3**
Culex		4	5		**9**
Unidentified larva			6		**6**
TOTAL	147	38	116	44	**345**

TOTAL MACROINVERTEBRATES SAMPLED DURING ALL FIELD EFFORTS- 2,130

APPENDIX E-3

Descriptions of Composite Sample Sites

COLLECTION SITES	GENERAL DESCRIPTION
Aquatic Macroinvertebrate Collection Data for CTWS Lagoons and Wetlands	
201512 NL CTL Aq Plants	Northern Lagoon front of Crooked Tree Lodge; sedges, lilies, submerged aquatic plants and mud
20151213 NL CTL Detritus Mats	Northern Lagoon front of Crooked Tree Lodge; sedge and lily detritus from floating mats
20151212-13 NL CTL Drift Line	Northern Lagoon front of Crooked Tree Lodge; detrital material, including sedge and lily debris; shoreline in a few centimeters or less of water; some wave energy
20151222-JL/ML Lily Patch	Jones Lagoon and Mexico Lagoon; within junction waters between the lagoons during high water
20160107-WL Sedge	Western Lagoon; sedge marsh with associated periphyton and bladderwort
20160108-NL CTL-Lily Patch	Northern Lagoon front of Crooked Tree Lodge; lilies, submerged aquatic plants, and mud
20160518-19-NL CTL Aq Plants	Northern Lagoon front of Crooked Tree Lodge; sedges, lilies, submerged aquatic plants and mud
20160520-NL North end Sedge	Northern Lagoon on the north end; largely sedge with submerged aquatic plants, flowing water where Northern Lagoon exchanges water with Western Lagoon
20160518-19-NL BAS Sub Aq Pl	Northern Lagoon front of Belize Audubon Society office; submerged aquatic plants in thin to thick mats, sedge, and lily patches/zones; sand and mud with roots
20160519-WL Sedge	Western Lagoon, sedge areas into the marsh from the canal reached by kayak
20160702-05-NL BEVI Aq Plants	Northern Lagoon front of Bird's Eye View Inn; sediments, detritus and material from patches of sedges and lilies
20160705-NL Causeway Bridge	Northern Lagoon Causeway eastern bridge, larger rock material with some sand and mud; flowing water
20161020-21-NL BEVI Aq Plants	Northern Lagoon front of Bird's Eye View Inn; sediments, detritus and material from patches of sedges and lilies
20161020-NL Shoreline Limpkin	Northern Lagoon inundated swamp forest, shoreline to 1m out, detritus primarily leaf material from trees
20161020-NL BEVI Drift Line	Northern Lagoon front of Bird's Eye View Inn, drift line within a few centimeters of water along shoreline, composed of sedge, lily, and other detritys
20161020-21-NL E Shore CW	Northern Lagoon in canal dug for causeway, eastern shore, inundated swamp forests adjacent to canal, thick growth of periphyton, some floating lily detritus mats
20161021-WL Canal Sedge	Western Lagoon canals dug to build the causeway, a canal lying on each side of the structure along its entire length, sedge-dominated with associated algae/periphyton and shoreline herbs and woody shrubs

Macroinvertebrate Collection Data for Isolated Water Bodies	
201512-13-CTL Back Lagoon	Isolated lagoon on north end of Crooked Tree Lodge property, surrounded by trees and including inundated trees; cleared of brush and cleaned during dry season; mud sediment the leaf detritus from trees
20160108-Limpkin Trail Pond	Pond along Limpkin Trail, covered in water fern; surrounded by trees, with some inundated trees; heavy leaf detritus from trees
20160705-Limpkin Trail Pond	Pond along Limpkin Trail, covered in water fern; surrounded by trees, with some inundated trees; heavy leaf detritus from trees
20160702-BEVI Tilapia Pond	Bird's Eye View Inn owner's home property, tilapia pond built by bulldozer; cleared bank area; mud sediment

APPENDIX F

Ecology Table for Fish Species Occurring or Known to Have Occurred in Crooked Tree Wetland Lagoons and Streams

TAXON	GENERAL ECOLOGY*	Source
CARCHARHINIFORMES		
Carcharhinidae		
Carcharhinus leucas Bull Shark	Enters deep, slow rivers and lagoons; females give birth to 1 to 13 pups, with estuaries and river mouths being common birthing areas; feed on fishes, other sharks, birds, mammals and invertebrates. It is considered to be one of the most dangerous sharks based on human attacks.	1
ELOPIFORMES		
Megalopidae		
Taropn atlanticus Tarpon	Adults are found in marine waters, but young will enter brackish waters and rivers and streams. They spawn offshore (late spring to early summer) and larva live in plankton. Juveniles feed on ostracods, copepods, insects and small fishes. Adults feed on fishes. These are popular game fish that can live up to 55 years.	1
CLUPEIFORMES		
Clupidae		
Dorosoma petenense Threadfin Shad	These fish are found in lakes, lagoons, rivers and estuaries. They are generally plankton feeders (phytoplankton, copepods, cladocerans, rotifers) that will feed on the bottom when plankton numbers are low. They spawn synchronously in early morning within shallow waters around logs, debris and aquatic plants. Larvae are planktonic	2
Dorosoma anale Longfin Gizzard Shad	Habits are probably similar to *Dorosoma pentenense*.	2
CHARCIFORMES		
Characidae		
Astyanax aeneus Central Tetra, Billum	This is Belize's most abundant and widely dispersed freshwater fish, found in large schools that dominate fish fauna both in numbers and total biomass. They are general feeders, tearing apart larger prey. Juveniles tend to school in shallower waters where they feed on insects while adults favor deeper waters, feeding on plant material (flowers, fruit, filamentous algae) and suspended particles. They will also graze on the bottom.	1 2
SILURIFORMES		
Ictaluridae		
Ictalurus furcataus Blue Catfish, Baca	This is the largest catfish found in Belize and is fished commercially. Usually eggs are laid under rock ledges, undercut banks, in hollow logs and other protected areas and eggs and young are guarded. They are generally carnivorous, feed on worms, larval and adult insects, mussels, frogs and fishes (which make up a larger part of the diet of adults).	1 2
Pimelodidae		
Rhamdia guatemalensis Guatemalan Chulin	These fish mostly eat aquatic insects, also feeding on crustaceans and small fishes. Greenfield and Thomerson (1997) only found it in Spanish Creek within this study area.	1 2
R. laticauda laticauda Filespine Chulin	Greenfield and Thomerson (1997) only found it in Spanish Creek within this study area.	2
ATHERINIFORMES		
Rivulidae		
Rivulus tenuis Dogtooth Rivulus	Greenfield and Thomerson (1997) only found it in Spanish Creek within this study area. It has been found in swamp areas, isolated savanna pools, backwaters isolated from rivers, and among dense aquatic plants near shore in lagoons and rivers. In captivity they feed plankton organisms.	2
Poeciliidae		
Belonesox belizanus Pike Killfish	This is the largest species in the family and feeds almost exclusively on fishes, particularly other poecilids and even their own young. New born feed on fish fry. They are found in shallow waters near shore, particularly near vegetation, in rivers and streams. They are also common in temporary pools formed in coastal savannas during floods. Reproduction is from May to June during the rainy season.	2

TAXON	GENERAL ECOLOGY*	Source
Poeciliidae (continued)		
Heterandria bimaculata Twospot Livebearer	This fish is found in a wide range of habitats from cold fast flowing streams of the MPR to large, slow, turbid rivers and lagoons.	2
Gambusia sexradiata Teardrop Mosquitofish	This fish is usually found near shore in pond and river habitats where vegetation occurs. It mainly feeds on invertebrates associated with aquatic plants and the shoreline. It is very salt-water intolerant.	2
Gambusia yucatana astralis Southern Yucatan Mosquitofish	It is not often found in rivers, preferring savanna pools with little or no vegetation. It generally feeds on the water surface away from shore. Three distinct forms are found in Belize, with one form being found along cayes inside of or along the barrier reef.	2
Phallichthys fairweatheri Picotee Livebearer	It has been collected in savanna pools and lagoons. Greenfield and Thomerson (1997) only found it in Spanish Creek within this study area.	2
Poecilia mexicana Shortfin Molly	It is reported to feed mostly on detritus in standing and slow moving waters, but has also been observed feeding on the bottom in relatively fast flowing waters.	2
Atherinidae		
Atherinella sp. 1 Belize Silverside		1 2
SYNBRANCHIFORMES		
Synbranchidae		
Ophisternon aenigmaticum Obscure Swamp Eel	This eel is found in muddy pools, lagoons and clear streams. Its biology is not fully known. It may be able to breath air and possibly burrows in mud.	2
PERCIFORMES		
Centropomidae		
Centropomus sp. Snook	Snooks are prized game and food fishes, common in inshore areas around mangroves but entering rivers. They mostly feed on other fishes and sometimes crabs and shrimp.	2
Cichlidae		
Cichlasoma friedrichsthali Yellowjacket Cichlid, Tuba		1 2
Cichlasoma meeki Firemouth Cichlid	This fish is popular in the aquarium trade. It breeds year round with increased breeding activity during April and May before the wet season. Males or mating pairs defend breeding territories until young are free swimming. Typically they nest in small rocky crevices. Young may be defended until they are three months of age. If one parent is missing, predation on young by other cichlids or central tetras greatly increases.	2
Cichlasoma octofaxciatum Jack Dempsey	This was one of the first cichlids used in the aquarium industry. Greenfield and Thomerson (1997) only found it in Spanish Creek within this study area.	2
Cichlasoma robertsoni False Firemouth Cichlid	These cichlids often feed by sifting through the sand and mud of the bottom.	2
Cichlasoma salvini Yellowbelly Cichlid	These fishes are popular aquarium fishes and are known for their aggressiveness when breeding and rearing young. Greenfield and Thomerson (1997) only found it in Black Creek.	2
Cichlasoma spilurum Blue-eyed Cichlid	This cichlid is found in habitats ranging from clear, cold mountain streams to lowland swamps. It is a popular aquarium fish with a relatively mild disposition.	2
Cichlasoma synspilum Redheaded Cichlid	This fish is omnivorous, consuming significant amounts of plant and detritus materials. It is a good candidate for aquaculture.	2
Ciclasoma uropthalmus Mayan Cichlid, Crana	This is a predatory cichlid that is saltwater tolerant. It breeds from mid-April until mid-November with spring and summer peaks, producing from 2,000 to over 6,500 eggs per female. In brackish water lagoons it is reported to feed mostly on shrimp and fishes.	1 2
Petenia splendida Bay Snook	It is a popular food and sport fish in Belize and is also sold in the aquarium trade. It is a predator on other fish species.	1 2
Tilapia mussambicus tilapia	This is an introduced species from aquaculture facilities. They feed primarily on aquatic plants, algae and mud rich in diatoms and algae. These fish are mouth brooders.	1
Tilapia niloticus tilapia	This is an introduced species from aquaculture facilities. They feed primarily on aquatic plants, algae and mud rich in diatoms and algae. These fish are mouth brooders.	1

* Ecology notes taken from Greenfield and Thomerson (1997).
1 Reported by local fishermen
2 Reported by Greenfield and Thomerson (1997) from collections made prior to 1977

APPENDIX G

Ecology Table for Amphibians and Reptiles Found in the Crooked Tree Wetlands

TAXON*	GENERAL ECOLOGY* Occur Inhabit Feed Nest Other
AMPHIBIANS	
ANURA	
Rhinophrynidae- burrowing toads	
Rhinophrynus dorsalis Burrowing Toad	These frogs are often found in seasonally dry forests and savannas. Adults are active at the beginning of the summer rainy season, breeding in temporary pools, flooded pastures, roadside ditches. Clutch sizes number to several thousand released into water in small groups or singly where they sink and hatch within days. Tadpoles swim in aggregations. Adults feed on insects, particularly ants and termites. They can survive drought in subterranean dens that they build.
Leptodactylidae- nest building frogs, rainfrogs, streamfrogs, robber frogs	
Leptodactylus fragilis??	
Leptodactylus labialis White-lipped Frog	They are common in many habitats, particularly permanent water marshes, breeding through the summer rainy season. Males call day and night. Eggs are deposited in foam nest that are established in terrestrial sites that flood.
Leptodactylus melanonotus Sabinal Frog	These common frogs are found in almost all freshwater habitats. Males may call day and night, breeding generally in the summer rainy season. Eggs are laid in foam nests at the water's edge
Physalaemus pustulosus *Tungara Frog*	Mostly found in savannas and deciduous forests, terrestrial, nocturnal, eats small invertebrates, forms large breeding groups in rainy season, found in temporary water bodies, roadside ditches, inundated pastures, puddles, livestock hoof prints, makes foam nests in shallow water with 200 to 300 eggs, amplectant males whip up foam with hind legs.
Bufonidae- toads	
Bufo marinus *Rhinella marinus* Cane Toad	Adults are usually found in open habitats, including secondary forests and savannas, often found around houses. Adults eat many kinds of invertebrates and vertebrates small enough to swallow, including members of their own species. They breed year round in temporary or permanent water bodies. Thousands of eggs are laid in long strings. Poison is toxic.
Bufo valliceps Gulf Coast Toad	These toads are common in open areas and around houses. They are primarily insect feeders. They are eaten by several snake species and birds of prey. Reproduction is year round but more so during heavy rains of the summer rainy season. Eggs are laid in long strings.
Hylidae- tree frogs, leaf frogs	
Agalychnis callidryas Red-eyed Tree Frog	Nocturnal, arboreal adults inhabit lowland forests and feed primarily on insects. Males call from vegetation around temporary pools. Females produce multiple clutches of 20-50 eggs laid on vegetation overhanging water. Tadpoles will feed on larvae of other frog species.
Hyla loquax Mohagony Treefrog	Nocturnal, arboreal adults inhabit lowland forests and savannas, feeding primarily on insects. Males call from vegetation around temporary or permanent water bodies. They breed in relatively deep water bodies, depositing eggs in water.
Hyla microcephala Yellow Treefrog	Frogs are arboreal and nocturnal, generally found in disturbed habitats, breeding in roadside ditches, flooded pastures where eggs are deposited directly in the water. Adults feed on insects.
Hyla picta Painted Treefrog	These nocturnal and arboreal frogs inhabit tall forests, savannas, secondary forests and human habitation. Breeding is during summer rains in forest pools, and other temporary waters where eggs are deposited in the water. Adults feed on invertebrates.
Scinax staufferi Stauffer's Treefrog	Frogs are typically found in open habitats, including savannas, breeding in temporary water bodies during the summer rains. Eggs are laid in water. Adults take refuge in bromeliads and other epiphytes during the dry season.
Smilisca baudinii? Common Mexican Treefrog	These frogs are found in almost all habitats. They are nocturnal, terrestrial and arboreal, breeding in temporary water bodies including roadside ditches, puddles and cisterns, with females depositing hundreds of eggs in a film over the surface of the water. Feed on insects and spiders.
Triprion petasatus? Yucatan Casquehead Treefrog	Nocturnal and arboreal, these frogs are found in seasonally dry forests and savannas, breeding in temporary water bodies and even artificial containers and depositing eggs in the water. They feed on invertebrates and small frogs.

TAXON*	GENERAL ECOLOGY* Occur Inhabit Feed Nest Other
Ranidae- true frogs	
Rana berlandieri Rio Grande Leopard Frog	Found in most freshwater habitats, including marshes, streams, cenotes and caves, occurring in high numbers in open and disturbed areas. Breed during the summer rains, depositing eggs in temporary or permanent waters. Feed mostly on invertebrates but will also eat small vertebrates
Rana vaillanti Vaillant's Frog	These frogs are common in lowland forests in association with lakes, slow moving rivers, temporary woodland pools, depositing eggs in small clumps in the water. They feed mostly on invertebrates, but will also eat vertebrates, including fishes.
REPTILES	
CROCODYLIA	
Crocodylidae- crocodiles	
Crodidylus moreleti Morelet's Crocodile	These crocodiles live in lakes, lagoons, rivers and ponds, sometimes entering brackish water. Juveniles and sub-adults feed mostly on invertebrates, switching to larger fishes, turtles, birds and mammals as they get older. Females build nests from decaying vegetation near the water in June and July, laying clutches of 20 to 40 eggs. Females attend the nests 75-80 days during incubation, then open the nests and carry hatchlings to the water.
TESTUDINES	
Dermatemydidae- Central American River Turtle	
Dermatemys mawii Central American River Turtle, Hicatee	These are completely aquatic turtles found in large streams, rivers, freshwater lagoons and sometimes brackish water. They are nocturnal herbivores, eating aquatic grasses, fallen leaves and fruit. Females lay 1-3 clutches (2-20 eggs) per year in nests excavated near the shore that are generally flooded by rising waters. Eggs can be submerged up to 27 days and still be viable. Sex of hatchlings is determined by temperature, with the lower temperatures producing males. These turtles are heavily hunted and endangered.
Kinosternidae- mud turtles, musk turtles	
Claudius angustatus Narrowbridge Musk Turtle	These turtles are found in slow moving streams (particularly with muddy bottoms), swamps, marshes and ponds. They may estivate during the dry season, buried a meter deep. They feed on earthworms, aquatic insects, snails, fishes and frogs. They nest during the dry season, producing clutches of 2-8 eggs that are incubated for 4-5 months.
Staurotypus triporcatus Mexican Giant Musk Turtle, Loggerhead	This aggressive turtle is found in slow-flowing rivers, lakes, lagoons and marshes. They feed on aquatic invertebrates, especially mollusks, and vertebrates, including mud turtles. They also eat leaves, fruits, seeds. They nest in the dry season, producing 3-6 egg clutches per female.
Kinosternon acutum Tabasco mud Turtle	These turtles are found in marshes. Lakes, streams and temporary water bodies in savannas and forested areas. Diet is not well known, but they likely feed on invertebrates. They nest in March and April, producing small clutches.
Kinosternon leucostomum White-lipped Mud Turtle	Commonly found in lowland swamps, streams and ponds, particularly in forested areas, they are nocturnal, feeding on aquatic invertebrates, fishes, snakes, aquatic plants, leaves and stems. Females lay small multiple clutches in shallow, leaf covered nests on the forest floor.
Kinosternon scorpioides *Scorpion Mud Turtle*	Common in ponds, streams, cenotes, lakes, slow flowing rivers; burry in mud during dry season, eats aquatic invertebrates, fishes, amphibians, and plants
Emydidae- pond turtles, box turtles, sliders	
Rhinoclemmys areolata *Furrowed Wood Turtle*	Common in savannas , forests, and marshes; eats plant material, invertebrates, and maybe turtle eggs
Trachemys scripta *(Pseudemys scripta)* slider, ornate tarrapin, bocatora	A predominately aquatic, diurnal turtle, this species is found in ponds, lakes, streams and rivers. Adults feed mostly on aquatic vegetation, leaves, stems, aquatic invertebrates and fishes. They are dry season nesters (January-May), digging nests in the ground and laying 9-25 eggs per clutch and producing up to 6 clutches per year. Incubation is 71-83 days, with hatchlings emerging during the rainy season, sometimes leaving the next 8 weeks after hatching. Temperature determines sex, with lower temperatures producing males.
SAURIA	
Corytophanidae-	
Basiliscus vittatus brown basilisk	These lizards are particularly found in habitats around water. At high running speeds, they become bipedal and are able to run across the surface of the water. They are diurnal and terrestrial, sometimes climbing small trees. They feed on insects and sometimes other invertebrates, especially as juveniles. Adults will eat seeds, stems and berries.

TAXON*	GENERAL ECOLOGY* Occur Inhabit Feed Nest Other
Iguanidae- spiny-tailed iguanas	
Ctenosaura similis Black Iguana	Common in sub-arid areas, thorn forests, human settlements, diurnal, mostly terrestrial, hides in burrows, under rocks and logs, eats plant material, juveniles eat more animal prey, mostly insects, adults may eat insects, lizards, iguana eggs, birds, rodents, bats; eggs buried in sand, communal nesting; hatching with beginning of rainy season, sometimes along steep river banks using burrows, prey on cavity nesting birds.
Iguana iguana Green Iguana	These large diurnal, arboreal lizards are often found in vegetation overhanging rivers and lakes and will readily enter the water when disturbed. They eat primarily plant material, particularly new leaves. Females build nest burrows in stream banks in March and April, sometimes making communal nests. Clutch size is 9-71 eggs with hatchlings emerging during the rainy season.
Scincidae- skinks	
Sphenomorhpus cherriei Brown Forest Skink	Found in leaf litter of lowland forests, occasionally near water but mostly terrestrial, nocturnal, feed on leaf litter invertebrates.
SERPENTES	
Boidae-boas and pythons	
Boa constrictor Boa, Wowla	These large constrictors are found on beaches, in savannas, mangroves and forests. They are good swimmers. Diet includes lizards, birds and mammals. They are live bearers, producing new born form July through September in broods of 12 to 50 young.
Colubridae- colubrid snakes	
Drymarchon corais Indigo Snake, Blacktail	These constrictors are found in savannas, mangroves, thorn forests and moist to wet tropical forests, often associated with water although they are primarily terrestrial. They especially feed on snakes (including venomous ones), but also fishes, frogs, toads, small turtles, birds and small mammals. They deposit clutches of 4-11 eggs during the summer rainy season.
Thamnophis marcianus Checkered Garter Snake	Uncommon, usually in marshes, swamps, edge of lakes and ponds, active night and day, eat frogs, toads, tadpoles, salamanders, fishes, earthworms; live bearers.
Thamnophis proximus Western Ribbon Snake	This is a semi-aquatic snake found in marshes, including brackish water and cenotes. They are mainly terrestrial but sometimes found in emergent vegetation. They feed on frogs, small fishes and tadpoles.
Tretanorhinus nigroluteus Orangebelly Swamp Snake	This is an uncommon, nocturnal aquatic snake found in shallow, slow flowing water (oxbow lakes, larger rivers, freshwater swamps, mangrove swamps) often in association with aquatic vegetation. They feed on fishes, frogs and tadpoles.

* List based on distribution notes and ecology notes taken from J. C. Lee (2000). A Field Guide to the Amphibians and Reptiles of the Maya World.

APPENDIX H

Ecology Table of Aquatic, Wading, and Shoreline Birds of Crooked Tree Wetlands

General Ecology notes are from Lee (2003) if source is not designated, with additional notes designated as superscript [1] are from Bull and Farrand (1977).

TAXON	GENERAL ECOLOGY Occur Inhabit Feed Nest Other
odicipedidae- Grebes; tailless, long-neck, stocky body, small head, short wing diving birds, can sink quickly and quietly	
Tachybaptus dominicus Least Grebe Diving Dopper	ommon permanent resident. Inhabit forested streams, rivers, lagoons, ponds, freshwater swamps and marshes (thick vegetation of ponds and slow flowing streams[1]). Eat aquatic insects and occasionally small crustaceans.[1] Floating nest of reeds and rushes and dead leaves anchored to rooted aquatic plants, 3-6 eggs.[1]
Podilymbus podiceps Pied-billed Grebe Diving Dopper	ommon winter and uncommon seasonal resident. Inhabit freshwater and saline marshes; lagoons, lakes and ponds; large rivers; occasionally coastal waters inshore. Prefers snags and thickets with dense vegetation hanging water. Rarely dives; mainly feeds on insects, spiders, small frogs and lizards from overhanging vegetation (also reported eating small fishes, aquatic insects, and crustaceans[1]). Perches on branch over water to eat. Some birds remain through the summer and breed regularly at Crooked Tree. Large floating nest using dead marsh plants anchored to rooted emergent plants, 5-7 eggs.[1]
Pelecanidae- Pelicans, long thin straight bill with nail at tip, lower mandible with extending pouch	
Pelecanus erythrorhynchos American White Pelican	ommon winter resident October to May. Inhabit fresh water lagoons, open water in marshes, shrimp farms, estuaries, sometimes in open sea. Fishes while swimming on surface, thrusting and scooping with bill; does not dive. Feeds mainly on fishes and crustaceans. Not recorded in Belize until 1981, with numbers steadily increasing.
Pelecanus occidentalis Brown Pelican	ccasional winter visitor October to May around Crooked Tree. Inhabits coastal zone and inshore waters, not as common in shrimp farms and inshore lagoons and ponds. Feeds mainly on fishes and crustaceans, catching prey by plunge-diving. Colonial nesting in mangroves. The only exclusive coastal species.
Phalacrocoracidae- Cormorants, dive from water surface and pursue prey by swimming under water; long thin bill with hooked tip	
Phalacrocorax olivaceus Neotropic Cormorant	Very common winter resident. Inhabits rivers, streams, lagoons, estuary waters, shrimp farms, rice fields, coastline and cayes. Feeds on fishes, crustaceans and amphibians. Colonial nesting in trees. Large numbers accumulate at Crooked Tree.
Phalacrocorax auritus Double-crested Cormorant	Occasional visitor. Inhabits mangroves, coastline and cayes, sometime shrimp farms. Colonial nesting in small groups in mangroves and inland swamps. Sometimes numbers build up at Crooked Tree.
Anhingidae- Darters, slimmer body, thinner neck, smaller head, longer tail than cormorants; long, thin, pointed bill	
Anhinga anhinga Anhinga	Fairly common permanent resident. Inhabit forested lagoons, sluggish rivers, lowland swamps in fresh and saline waters, mangroves, and innermost mangrove cayes. Feeds on fish and other aquatic organisms. Nest of sticks lined with fresh leaves built in trees, sometimes nesting in cormorant colonies.[1]
Ardeidae- Herons, egrets and bitterns; wading birds with long neck, long legs, and short tail; fold neck when in flight, spear-like bill	
Ixobrychus exilis Lease Bittern	Uncommon permanent resident. Inhabit tall grass marshes, stays hidden. Nest of reeds or cat tails often built over water, 4 or 5 eggs.[1]
Tigrisoma mexicanum re-throated Tiger Heron, Toby Full-pot	Uncommon permanent resident. Inhabit wooded streams, swamps, marshes, mudflats, lagoons, and sometimes mangroves, often perching in open on the ground or in a tree.
Ardea herodias Great Blue Heron	Very common winter resident and uncommon seasonal resident. Inhabit wet areas (freshwater and marine) that are less densely populated, shrimp farms, shallow margins of lagoons, wet fields, marshes, wet fields, and margins of lagoons, streams, seashores, river mouths, and mangroves. Often solitary. Feeds on fishes, frogs, rodents, crustaceans or large insects, stabbing with beak (also reported feeding on reptiles, small birds, and small mammals[1]). Usually solitary, and may establish feeding territories while wintering. May nest solitary, but usually in small colonies on cayes within mangrove and littoral forests. Nest of stick platform lined with lighter plant material, often in trees, occasionally on the ground, 3 to 5 eggs.[1]

TAXON	GENERAL ECOLOGY Occur Inhabit Feed Nest Other
Egretta alba eat Egret, White Gallin	Very common winter resident and uncommon seasonal resident. Inhabit non forested standing water areas, marshes, estuaries, lakes, river margins, tidal flats, and salt ponds. Usually forages singly, although loose groups gather in marshes. Stands quietly or walks slowly with kinked neck diagonal, seizing fishes and frogs with quick stabs (also reported eating snakes and crayfish[1]). Small nesting colonies on mangrove islands. Nests in temperate and tropical areas within six different continents, one of the world's most widely dispersed bird species. Nest is stick platform in a tree or shrub, 3 or 4 eggs.[1] Northern populations migrate south for the winter. Large congregations occur at Crooked Tree in May and June before and at the start of the wet season.
Egretta thula Snowy Egret, Gallin	Very common winter resident and uncommon seasonal resident. Inhabit non-forested standing water areas, marshes, lagoons, salt ponds, river mouths, or tidal flats; often forage in groups, which may drive fishes with coordinated movements. Feeds on small fishes and shrimp.[1] Usually roost communally. Small numbers breed in large cattle egret colonies and on small mangrove islands. A few may stay in Crooked Tree area until June, with possible nesting on Northern Lagoon's Bird Caye. Nest is stick platform in shrubs or reeds, 3 or 4 eggs.[1]
Egretta caerulea Little Blue Heron	Very common winter resident and uncommon seasonal resident. Inhabit non-forested and minimally forested standing water areas, fresh water marshes, lagoons, estuaries, salt ponds, mudflats, and mangroves; less often found along forested streams and rivers. Eats larger portion of insects than other herons, sometimes following plow in fields eating grubs.[1] Often occurs in congregations. Nest of sticks and rush stems in mangroves but does not nest in Belize. Northern populations migrate south in the winter.
Egretta tricolor icolored Heron, Blue Gallin, Blue Jacket	Common winter resident. Inhabit marshes, mudflats, estuaries, lagoons, coastal areas. Feeds on fishes, frogs, crustaceans and insects. Small nesting colonies in mangroves, frequently along with other heron species.
Bubulcus ibis Cattle Egret	Common winter resident and uncommon seasonal resident. Inhabit pastures, flooded agricultural areas and grasslands, rice fields, cleared areas, and mangroves. Nests in mangroves (stick nest in shrub or tree in marsh, usually in colonies, 3 to 5 eggs[1]). Associated with cattle and horses, feeding on terrestrial insects flushed by grazing. Recent invader from tropical Africa and Asia since the late 19th century. First recorded in 1956 in Belize but may have arrived before then. Large population has built up.[1]
Butorides virescens *(striatus?)* Green Heron, Po jo	Common permanent resident. Inhabit forested lagoons, ponds, streams, rivers, saltwater lagoons, swamps, mangroves, and sometimes mudflats. Feeds in open, stand quietly and walk stealthily, ambushes prey with quick stabs seizing small fishes, aquatic insects, and frogs. Searches for prey in muddy edges of water bodies.[1] Nest in mangroves and littoral forests of lagoons. Nest of stick and twig saucer in shrub or thicket around water, sometimes breeding in colonies, 3 to 6 eggs.[1] Northern populations migrate south.
mia agami ami Heron	Uncommon winter resident. Inhabit thick vegetation along swamps, rivers, lagoons, visible on open shorelines during the dry season. Nest in mangroves. Uncommon on mainland in dry season but fairly common in Crooked Tree wetlands.
Nycticorax nycticorax ack-crowned Night-heron	Fairly common winter resident and uncommon seasonal resident. Inhabit marshes, lagoons estuaries, and mangroves. Nest and roost in trees within colonies, sometimes nesting with other heron species. Stick or reed saucer nest in reed bed, thicket and sometimes trees, 3 to 6 eggs. Active at night but sometimes during the day (often roost in trees during daytime[1]). Very widespread, occurring in all continents except Australia and Antarctica. Northern populations migrate south for the winter. Small population stays at Crooked Tree during the summer and may nest.
ticorax violacea llow-crowned Night-heron	Fairly common permanent resident. Inhabit towns, lawns, river banks, ponds, swamps, marshes, mudflats, estuaries, mangroves. Sometimes feed beneath streetlights. Active at night but sometimes during the day. Often maintain communal roosts in mangroves and large trees. Nest of sticks in trees or on ground, single pair, small colonies, occasionally with other heron species, 4 or 5 eggs.[1] Northern populations migrate south for the winter.
ochlearius cochlearius Boat-billed Heron, Cupa	Fairly common permanent resident. Inhabit and feed along shorelines of wooded rivers, ponds and estuaries at night. Roosts during the day in trees along river banks. Colonial nesting in mangroves and dense riparian forests.

TAXON	GENERAL ECOLOGY Occur Inhabit Feed Nest Other
Threskiornithidae- Ibises and Spoonbills, medium to large wading birds, with downward curved (ibises) or spoon-shaped bills	
Eudocimus albus White Ibis	Very common winter resident and uncommon seasonal resident. Inhabit marshes, shrimp farms, rice fields, swamp forests, littoral forests, mangroves. Feed in soft mud that it probes for food (consisting of crayfish[1] and other crustaceans). Usually forages and flies in flocks. Builds stick nest in tree over water, 3 to 5 eggs.[1] Population size increased in the past two decades.
Plegadis falcinellus Glossy Ibis	Fairly common winter resident. Inhabit rice fields, marshes, flooded pastures. Builds stick nest in shrubs or trees, sometimes on ground, 2 to 4 eggs, nesting in colonies often with other heron species.[1] Eats crayfish (probably other crustaceans) and will eat insects and snakes.[1] Disperses widely outside of breeding season. May have migrated from Africa to New World in the 19th century.
Platalea ajaja Roseate Spoonbill	Fairly common permanent resident. Inhabit lagoons, rice fields, shrimp farms, frequents various fresh or salt-water habitats wherever shallow, open, still or slowly flowing water occurs. Feed on small fishes, crustaceans, insects, etc. collected by submerging bill or whole head. Usually feeding, roosting, in groups or flocks. Stick nest in low, dense shrubs and trees, 3 to 5 eggs.[1] Seasonal movements reflect changes in water levels. Population size has increased over past three decades.
Ciconiidae- Storks, large wading birds with heavy bills	
Jabiru mycteria Jabiru Stork, Turk	Fairly common permanent resident. Inhabit almost any fresh or salt water: marshes, wet pastures, rice fields, shrimp farms, margins of lagoons, estuaries. Feed on fishes, frogs, rodents, crustaceans or large insects, catching with quick stabs. Usually solitary but also in groups, may establish feeding territories while wintering. Nesting singly in large savanna trees, open pastures, along wide rivers, around estuaries. Once only in Belize during nesting season and wintered in Mexico, but now permanent resident with increasing protection, rice fields, and shrimp farms in Belize.
Mycteria americana Wood Stork	Very common permanent resident. Inhabit lagoons, marshes, rice fields, shrimp farms, fish farms, and estuaries. Nest freshwater swamps and mangroves in large colonies. Large stick platform nest in trees, 2 or 3 eggs.[1] Often seen circling high in the air on rising thermal air currents. Population size has increase over past three decades. Disperses widely after nesting season, accumulating in large numbers in Crooked Tree wetlands.
Cathartidae- New World vultures, carrion feeders	
Coragyps atratus Black Vulture	Very common permanent resident. Inhabit wide range of ecosystem types, typically occurring in flocks on the shoreline of Northern Lagoon. Feed on dead and dying fish, other carrion (and sometimes weak, sick, vulnerable birds and mammals[1]). Depends on sight to locate food. Nest in cavities of dead trees (also on ground and under shrubs and rocks, 2 eggs[1]). Most common vulture found in urban areas and shorelines.
Cathartes aura Turkey Vulture	Very common permanent resident. Inhabit wide range of ecosystem types except densely forested areas. Feed on carrion located with an acute sense of smell. Often roost in large numbers.[1] Two eggs without nest laid in rock crevice hollow tree or fallen hollow log.[1] Migratory, leaving its northern range during winter.
Cathartes borrovianus esser Yellow-headed Vulture	Common permanent resident. Inhabit open savannas, rice fields, shrimp farms, often associated with Turkey Vultures, avoids populated areas.
Anatidae- short, thick legs, webbed feet, oil gland to waterproof feathers; flattened bill with nail at tip	
Dendrocygna autumnalis lack-bellied Whistling-duck	Very common winter resident (late summer and autumn) and uncommon seasonal resident (smaller numbers winter to early summer). Inhabit littoral zones of ponds and lagoons with emergent vegetation, rice fields, coastal lagoons. Population increased during past three and a half decades, with rare sightings recorded before 1965.
Dendrocygna bicolor ulvous Whistling-duck, Fulvous Tree-duck	Fairly common winter resident (November to May). Inhabit large lagoons lined with marshes, estuaries, rice fields. Resident in Old World and New World. Currently non-breeding in Belize but expected to become established in future. Not recorded from Belize before 1986.
Cairina moschata Muscovy Duck	Common permanent resident. Inhabit forested banks and backwaters of large rivers, forested lagoons, swamps, marshes. Once common, but population reduced by hunting.
Anas americana American Wigeon	Rare winter resident. Inhabit lagoons, marshes, shallow farm ponds, rice fields, estuaries. Stay at surface of water and steel fish from diving birds, graze on young shoots in grain fields.[1]

TAXON	GENERAL ECOLOGY Occur Inhabit Feed Nest Other
Anatidae (continued)	
Anas discors Blue-winged Teal	Very common winter resident. Inhabit shallow standing or slow flowing water bodies, common in rice fields, flooded pastures, and freshwater marshes, river pools, salt ponds, estuaries. Feed mostly on plant matter and some invertebrates by dabbling, occasionally tipping up. Migrants usually occurring in flocks. Abundant at Crooked Tree.
Anas clypeata Northern Shoveler	Rare winter resident (late September to mid-April). Inhabit marshes, lagoons, rice fields, shallow farm ponds. Strains tiny aquatic animals out of the water through comb-like structures along sides of bill, also eating seeds and aquatic plants.[1]
Aythya collaris Ring-necked Duck	Fairly common winter resident (late October to early April). Inhabit open, deeper water of lagoons, ponds, estuaries, sometimes in rice fields. Small flocks often seen at Crooked Tree, but usually anywhere else. Feeds on seeds of aquatic plants and on insects and snails.[1]
Aythya affinis Lesser Scaup	Common winter resident (mid-October to early April). Inhabit open, deeper water of lagoons, estuaries, shrimp ponds. Mostly seen in Shipstern and Crooked Tree.
Accipitridae- Hawks, kites and eagles; strong talons and hooked bill for catching and killing prey	
Pandion haliaetus Osprey	Common winter resident. Inhabits areas with clear, still or slowly flowing water, salt or fresh, inhabited by surface swimming fishes, with perches (tall trees, poles) near water, sometimes seen far from water. Feed on fishes by foot first plunge/diving then carries preys in its talons to a regular perch, reversible outer toe and spiny foot pads help grip fish, occasionally eats lizards, small mammals, and birds (reported to exclusively feed on fish[1]). Nest in Belize on open platforms of broken tree trunks, poles, roof tops made from sticks (2 to 4 eggs). Widespread in New World, Old World, Australia.
Rostrhamus sociabilis Snail Kite, Wilk's Hawk	Very common permanent resident. Inhabit lagoons, freshwater marshes, sometimes rice fields. Feed on large snails, *Pomacea* spp., with sharply curved bill. Plucks snails from water or vegetation with feet, goes to regular perch to extract snails from shell. Stick nest in low shrubs or on ground, 2 to 5 eggs.[1] Especially common in New River and Crooked Tree. Occasionally soars at midday.
Busarellus nigricollis Black-collared Hawk	Fairly common permanent resident. Inhabit riparian forest of slow flowing rivers, and lagoons. Feed on mostly fishes, frogs, small birds, mammals, and large insects; catching prey in a swoop. Often soars on flat wings.
Buteogallus anthracinus Common Black Hawk	Fairly common permanent resident. Inhabit open forested areas near water, forest edges, towns, mangroves. Northern populations migrate south in winter.
Buteogallus urubitinga Great Black Hawk	Uncommon permanent resident. Inhabit forested areas typically, but not always, near water. Feed in rice fields and open areas. Found throughout mainland of Belize.
Falconidae- Caracaras and falcons	
Falco columbarius Merlin	Occasional winter resident. Inhabit open areas such as forest edges, lagoons, estuaries, beaches. Feeds on shorebirds, warblers, sparrows, other small birds, often when migrating.[1] Found in temperate zones worldwide.
Falco peregrinus Peregrine Falcon	Uncommon winter resident. Inhabit open areas with exposed perches, typically near water. Most temperate populations migrate south.
Rallidae- Rails, crakes (more terrestrial), gallinules, coots (more aquatic); highest extinction rate of any bird group (10% in 400 yrs.)	
Laterallus ruber Ruddy Crake	Common permanent resident. Inhabit abandoned fields, grassy ditches, flooded meadows, rice fields.
Aramides cajanea Grey-necked Wood-rail	Common permanent resident. Inhabit wet areas such as flooded meadows, marshes, rice fields, swampy and open woodland, forest streams, pools and marshes near wooded thickets, locally at mangrove edge.
Porzana carolina Sora	Common winter resident. Inhabit freshwater marshes, grassy flooded pastures, rice fields. Mostly eat seeds.
Porphyrio martinica Purple Gallinule	Uncommon permanent resident. Inhabit freshwater marshes, rice fields. Most populations in US migrate south. Nest of dead aquatic plant leaves and stems on floating platform or brush over water.[1]
Gullinula chloropus Common Moorhen	Common winter resident and uncommon seasonal resident. Inhabit freshwater marshes, shallow ponds with emergent vegetation, lagoons. Nest is shallow platform of dried stems of emergent aquatic plants sitting just above the water, 9 to 12 eggs[1]. Found in Old and New World, northern populations migrate south.

TAXON	GENERAL ECOLOGY Occur Inhabit Feed Nest Other
Rallidae (continued)	
Fulica americana American Coot	Very common winter resident and uncommon seasonal resident. Inhabit freshwater marshes, ponds, lagoons, rice fields, saltwater marshes, open water. Nests platform of aquatic plant stems and leaves, typically on the water and tied to emergent vegetation.[1] Temperate populations migrate south.
Heliornithidae- Sungrebes; elongated body, long neck, long broad tail, toes lobed, brightly colored legs and feet, pointed bill	
Heliornus fulica Sungrebe	Uncommon permanent resident. Inhabit swamps and forest lined streams.
Aramidae- Limkin; long neck and legs, wide, round wings, long bill	
Aramus guaraauna Limpkin, clukin' hen	Very common permanent resident. Inhabits open fresh water marshes, savanna wetlands, lagoons, ponds and river margins, occasionally flooded pastures and roadside ditches. Feed on snails, mainly apple snails, mostly *Pomacea*, (and frogs, tadpoles, and aquatic insects[1]), foraging singly, walking about with slow, jerky gait in search of prey. Shallow nest of aquatic vegetation built just above water level, sometimes stick nest in low trees and shrubs, 5 to 8 eggs.[1] Mainly nocturnal,[1] but common in day time at CTWS. Local movements according to water levels.
Recurvirostridae- Stilts and avocets; thin body, long neck, long thin legs, long thin bill	
Himantopus mexicanus Black-necked Stilt	Very common winter resident and uncommon seasonal resident. Inhabit lagoons, rice fields, shrimp ponds, estuaries, tidal flats; shallow salt or fresh water with soft, muddy bottoms. Feed on small aquatic insects, crustaceans, and mollusks. Usually in loose groups of up to 50. A few nest at Crooked Tree. Nest is shallow, grass-lined depression, nesting in loose colonies, 3 or 4 eggs.[1] Northern temperate populations migrate south for winter. Population increase in past three decades as shrimp and rice farming increased.
Recurvirostra americana American Avocet	Rare winter resident. Inhabit estuaries and shrimp farms. Feed by sweeping bill back and forth over water surface, collecting small crustaceans, insects, floating seeds.[1] North temperate populations migrate south.
Jacanidae- Jacanas; long legs and very long toes and claws for walking on floating vegetation	
Jacana spinosa Northern Jacana	Very common permanent resident. Inhabit shallow ponds, marshes, flooded pastures, rice fields, and riverbanks, essentially wherever aquatic vegetation, especially water lilies, or grasses extend over slow-flowing fresh or brackish water. Feed on aquatic insects, small fishes, snails, seeds. Long toes give ability to walk on floating plants, taking advantage of food resources not available to most other birds.[1] Nest of leaves and stems formed in a cup on mat of floating vegetation, nests made, eggs incubated, and chicks raised by males, often 4 eggs.[1]
Scolopacidae- Sandpipers and phalaropes; wide range of bill sizes and shapes, body sizes foraging methods and habitat use	
Tringa melanoleuca Greater Yellow-legs	Common winter resident (mid-July to mid-May), sometimes stay through summer. Inhabit marshes, shrimp farms, rice fields, mudflats, sand flats. Wades up to belly and can swim.[1]
Tringa flavipes Lesser Yellow-legs	Common winter resident (mid-July to mid-May). Inhabit marshes, shrimp farms, rice fields, mudflats, sand flats.
Tringa solitaria Solitary Sandpiper	Uncommon winter resident (late July to early May). Inhabit fresh water ponds, marshes, streamsides, flooded pastures, rice fields, and temporary pools. Feed on aquatic insects, small mollusks, and crustaceans, foraging alone or in small groups.
Actitis macularia Spotted Sandpiper	Common winter resident. Inhabit virtually every aquatic habitat from rain puddles to seashore; lagoons, streamside, farm ponds, shrimp ponds, rice fields, mudflats, sand flats, beaches. Feed on small insects, crustaceans, and small fishes. Gathers in small flocks to sleep.
Arenaria interpres Ruddy Turnstone	Uncommon transient. Inhabit sandy beaches having seaweed and coral rubble, shrimp ponds, sometimes lagoons. Roll small stones over along shore, catching animals that are revealed, dig holes in sand for crustaceans.[1] Nest in the Arctic and winters on coasts and islands around the world. Occasionally found at Crooked Tree during migration.
Calidris pusilla Semipalmated Sandpiper	Uncommon transient. Inhabit shrimp ponds, rice fields, mudflats, sand flats. Nest in Arctic Alaska and Canada, winters in southern Mexico, Caribbean, and South America
Calidris mauri Western Sandpiper	Very common winter resident (late July to mid-May). Inhabit rice fields, shrimp farms, mudflats, sand flats, sometimes beaches. Nests in Siberia and Alaska and winters Washington and New Jersey to South America.

TAXON	GENERAL ECOLOGY Occur Inhabit Feed Nest Other
Scolopacidae (continued)	
Calidris minutilla Least Sandpiper	Very common winter resident. Inhabit rice fields, shrimp ponds, sand flats, mudflats, lagoons, estuaries, beaches. Nests in Alaska and northern Canada and winters in southern US to South America.
Calidris fuscicollis White-rumped Sandpiper	Common transient. Inhabit rice fields, shrimp farms, lagoons. Nests in arctic Alaska and Canada, winters in southern South America. Numbers increase in mid-May when other shorebirds have left.
Calidris melanotos Pectoral Sandpiper	Uncommon transient (mid-August to early October, and from early March to late May). Inhabit shrimp farms, rice fields, marshes, lagoons. Nests in Arctic Siberia, Canada and Alaska. Migrates from Artic to Antarctic and back each year.[1]
Limnodromus griseus Short-billed Dowitcher	Very common winter resident (early July to late April). Inhabit coastal lowlands, estuaries, shrimp farms, mudflats, sand flats, and sometimes marshes. Occur in large flocks, feed in mud, probing with long bill rapidly up and down, catching worms, snails, crustaceans, aquatic insects.[1] Nest in subarctic from Aleutian Islands to Canada; wintering in coastal areas from California and Virginia to central Peru and Brazil.
Limnodromus scolopaceus Long-billed Dowitcher	Uncommon winter resident (late August to late April). Inhabit freshwater marshes and mudflats, shrimp farms, rice fields. Nest in high Arctic from Canada to Siberia, wintering from eastern and western US to northern Central America.
Gullinago delicata Wilson's Snipe	Uncommon winter resident (mid-September to mid-April). Inhabit Feed on benthic invertebrates in soft mud, probing with very long bill. Inhabit active drainage ditches, flooded pastures, rice fields, marshes, vegetated edge of mudflats.
Laridae- Skuas, gulls, terns and skimmers;	
Larus atricilla Laughing Gull	Uncommon transient. Inhabit coastal areas, cayes, offshore areas; sometimes inland lagoons during migration. Regularly seen at Crooked Tree and New River in spring.
Sterna niloticus Gull-billed Tern	Fairly common winter resident. Inhabit shrimp farms, lagoons, beaches. Feeds on fish and crustaceans, also catches insects in flight, catches insects in plowed fields.[1] Common in spring at Crooked Tree.
Sterna caspia Caspian Tern	Common winter residence. Inhabit shrimp farms, lagoons, estuaries, shallow tidal waters and salt ponds; often rest with flocks of other terns. Plunge-dive like a tern, but also settles on water to feed like a gull. Sometimes robs other tern of their catch; even eats eggs of other birds. Most common in spring at Crooked Tree
Chlidonias niger Black Tern	Common transient (early August to early November and form late April to late May. Inhabit offshore waters and large inland lagoons. Often will fly over land and hawk insects, also eats small fish and crustaceans.[1] Found in Old World and New World.
Aledinidae- Kingfishers; short legs, 3 backward facing toes, large and strong bill	
Megaceryle troquata Ringed Kingfisher	Common permanent resident. Inhabit open and forested banks of deep, smoothly flowing lowland streams, rivers, and swamps. Feed on fish captured by plunge-diving from overhanging branch, snag, or electric wire. Flies high with regular wing beats between bodies of water; solitary or in pairs. Nest in burrow dug in steep sandy stream bank, 5 to 7 eggs.[1] Found with Belted Kingfisher in cleared areas sometimes.
Megaceryle alcyon Belted Kingfisher	Common winter resident. Inhabit banks of roadside ditches, streams, rice fields, coastal lagoons, mangroves, and on electrical lines near water, staying away from streams and rivers with forested banks. Feed on fish captured by plunge-diving from overhanging branch or electric wire or when hovering above water. Also eats crayfish, crabs, insects, salamanders, lizards, and mice.[1] Winter from southern Alaska to northern South America. Individuals establish territories upon arriving in fall.
Chloroceryle amazona Amazon Kingfisher	Uncommon permanent resident. Inhabit mostly forested banks of streams, rivers, lagoons, but sometimes in open area such as rice fields and roadside ditches. Feeds mainly on fishes captured by plunge-diving.
Chloroceryl Americana Green Kingfisher	Common permanent resident. Inhabit forested banks of streams and rivers. Feeds mainly on small fishes captured by plunge-diving (also feed on small lizards and grasshoppers[1]). Nest in burrow dug into steep, sandy stream bank, 4 to 6 eggs.
Chloroceryle aenea American Pygmy Kingfisher	Common permanent resident. Inhabit pools, swamps, backwaters, vegetated shores of lagoons, not found along very fast flowing streams. Feeds on small fishes and insects

TAXON	GENERAL ECOLOGY Occur Inhabit Feed Nest Other
Hirundinidae- Swallows, long pointed wings, short week legs and feet, small bill with wide gape for catching insects in flight	
Tachycineta bicolor Tree Swallow	Very common winter resident (late October to early April). Inhabit mostly aerial, congregates over wetlands. Feed on flying insects.
Tachycineta albilinea Mangrove swallow	Common permanent resident. Inhabit rivers, lagoons, coastal areas. Feed on flies, winged ants, wasps, etc. by skimming close to water surface. Breeding pair defends nest site and foraging area, often a stretch of river or area of a lagoon.
Stilgidopteryx serripennis orthern Rough-winged Swallow	Common winter resident. Inhabit areas around lagoons, ponds, rivers, and streams in the Crooked Tree wetlands.
Petrochelidon pyrrhonota Cliff Swallow	Uncommon transient (mid-August to early November and early March to mid-May). Found over wetlands and lagoons when migrating.
Hirundo rustica Barn Swallow	Common transient (mid-July to late November and early March to early June). Seen over wetlands. Make long migrations, North American breeding birds wintering in places as far away as Argentina.[1]
Parulidae- Wood-warblers; small insectivores with thin pointed bill	
Protonotaria citrea Prothonotary Warbler	Fairly common transient (late July to early November and early March to late April). Inhabit low elevation in swamps, riparian forests of streams and rivers, mangroves.
Seiurus noveboracensis Northern Waterthrush	Common winter resident (late August to late May). Inhabit ground and low level of riparian forests of streams, swamps, forested estuaries, mangroves.
Seiurus motacilla Louisiana Waterthrush	Uncommon transient (mid-July to mid-April). Inhabit forested areas with flowing streams
Goethlypis trichas Common Yellowthroat	Very common winter resident (mid-September to late May). Inhabit marshes and savanna wetlands sometimes.

APPENDIX I

Summary of Occurrence Status, Belize Population Estimates, Species of Concern, the Status in Belize, and Tropic Position for the 60 Species Reviewed by Miller and Miller (2006)

SPECIES	OCCURANCE STATUS[1]	BELIZE POP. EST.[2]	CBC POP. TREND[3]	STATUS IN BELIZE[4]	TROPHIC POSITION[5]
Least Grebe	CPR	500-1000		AS,OC	aq inverts
Pied-billed Grebe	CWR/UCSR	250-500		AS,OC	aq inverts, sm fish
American White Pelican	CWR	0-50		AS,OC	fish, crust
Brown Pelican	OWV	500-1000	20% increase	AS,OC,AMP	fish, crust
Neotropic Cormorant	VCWR	1000-5000	95% decrease	AS,OC,H,AMP	fish, crust, amph
Anhinga	FCPR	250-500	50% decrease	AS, OC	fish, other aq org
Least Bittern	UCPR	250-500		AS	
Bare-throated Tiger Heron	UCPR	500-1000	10% decrease	AS	fish--
Great Blue Heron	VCWR/UCSR	1000-5000	60% decrease	V,AS,AMP	fish, frog, crust, etc.
Great Egret	VCWR/UCSR	1000-5000	60% decrease	AS, OC	fish, frog, snake, etc
Snowy Egret	VCWR/UCSR	500-1000	25% decrease	V,AS, H	sm fish, shrimp
Little Blue Heron	VCWR/UCSR	500-1000	90% decrease	AS, OC	fish, insect
Tricolored Heron	CWR	500-1000	same	V,AS,AMP	fish, frog, crust, insect
Cattle Egret	CWR/UCSR	5000-10000	60% decrease	AS, OC	ter insect
Green Heron	CPR	1000-5000	90% decrease	AS, OC	sm fish, aq insect,frog
Agami Heron	UCWR	100-250		AS,ET	fish--
Black-crowned Night-heron	FCWR/UCSR	500-1000	30% decrease	V,AS	fish--
Yellow-crowned Night-heron	FCPR	500-1000	90% decrease	V,AS	fish--
Boat-billed Heron	FCPR	500-1000	30% increase	AS,OC,	fish--
White Ibis	VCWR/UCSR	250-500	6X increase	V	crust
Glossy Ibis	FCWR	50-1000		V	crust, insect, snakes
Roseate Spoonbill	FCPR	250-500	20% increase	AS,V	sm fish, crust, insect
Jabiru Stork	FCPR	50-100	10% decrease	V,H, AMP	fish, frog, crust, insect
Wood Stork	FCPR	500-1000	80% decrease	V,H,AMP	fish, crust
Black Vulture	VCPR				carrion
Turkey Vulture	VCPR				carrion
Lesser Yellow-headed Vultur	CPR				carrion
Black-bellied Whistling-duck	VCWR/UCSR	25,000-100	20% decrease	V,AMP,H	
Fulvous Whistling-duck	FCWR	1000-5000		V,AMP,H	
Muscovy Duck	CPR	250-500	50% decrease	V,H,TE	
American Wigeon	RWR	50-100		V,H	fish, plant shoots
Blue-Winged Teal	VCWR		5X increase	V,OC,H	plants, some insect
Northern Shoveler	RWR	0-50		V,H	zoo plank, seed, plan
Ring-necked Duck	FCWR	500-1000		---	Seed, insect, snail
Lesser Scaup	CWR	1000-5000		V,H	
Osprey	CWR				fish
Snail Kite	VCPR				snail
Ruddy Crake	CPR	500-1000	5% increase	AS,OC	
Grey-necked Wood-rail	CPR	1000-5000	85% decrease	AS, OC	
Sora	CWR	250-500		II	seed
Purple Gallinule	UCPR	250-500	90% decrease	V	
Common Moorhen	CWR/UCSR	500-1000	70% decrease	AS, OC	
American Coot	VCWR/UCSR	1000-5000	50% increase	AS	
Sungrebe	UCPR	250-500	60% increase	AS, OC	
Limpkin	VCPR	1000-5000	same	AS	Snail, frog, aq insect

SPECIES	OCCURANCE STATUS[1]	BELIZE POP. EST.[2]	CBC POP. TREND[3]	STATUS IN BELIZE[4]	DIET[5]
Killdeer	UCWR	1000-5000	25% decrease	AS	
Black-necked Stilt	VCWR/UCSR	500-1000	2X increase	OC,II	Aq insect, crust, moll
American Avocet	RWR	250-500		II	Sm insect, crust,seed
Northern Jacana	VCPR	1000-5000	95% decrease	AS, OC	Aq insect,fish,snail,seed
Greater Yellow-legs	CWR	500-1000	same	AS	
Lesser Yellow-legs	CWR	500-1000	2X increase	II	
Solitary Sandpiper	UCWR	500-1000	60% increase	AS	aq insect, moll, crust
Spotted Sandpiper	CWR	100-250	same	AS	insect, crust, sm fish
Ruddy Turnstone	UCT	50-100	3X increase	OC	insect, crust
Semipalmated Sandpiper	UCT	1000-5000		OC	
Western Sandpiper	VCWR	1000-5000		OC	
Least Sandpiper	VCWR	500-1000	2.5X increase	OC	
White-rumped Sandpiper	CT	100-250		OC	
PectoralSandpiper	UCT	250-500		OC	
Short-billed Dowitcher	VCWR	50-100		II	worm,snail,crust,insect
Long-billed Dowitcher	UCWR	500-1000		II	
Wilson's Snipe	UCWR	500-1000	40% decrease	AS, OC	
Laughing Gull	UCT	500-1000	30% decrease	AS	
Gull-billed Tern	FCWR	250-500		---	fish,crust,aq/ter insect
Caspian Tern	CWR	100-250	40% decrease	II, OC	fish, bird eggs
Black Tern	CT	500-1000		OC	ter insect,sm fish,crust
Ringed Kingfisher	CPR				fish
Belted Kingfisher	CWR				fish,crust,insect,etc
Amazon Kingfisher	UCPR				fish
Green Kingfisher	CPR				fish, lizard, ter insect
American Pygmy Kingfisher	CPR				sm fish, insects

1- Based on the Crooked Tree Wildlife Sanctuary Checklist status ratings
2- Population estimates reported by Miller and Miller (2006) CBC, Jones (2003) and BBIS data
3- Population change estimates based on a decade of sighting records in CBC data
4- Status of water birds based on all data listed and judgment of seasoned birders in Belize
5- List of prey based on Bull and Farrand (1977)

Occurrence Status Codes		Status in Belize Codes	
VCPR	very common permanent resident	AS	apparently secure
CPR	common permanent resident	OC	of concern
FCPR	fairly common permanent resident	V	vulnerable
UCPR	uncommon permanent resident	H	hunted for meat
VCWR	very common winter resident	AMP	agriculture/aquaculture pest
CWR	common winter resident	ET	endangered/threatened in BZ
FCWR	fairly common winter resident	II	insufficient information
UCWR	uncommon winter resident		
UCSR	uncommon summer resident		
CT	common transient		
UCT	uncommon transient		

APPENDIX J
Ecology Table of Mammals Associated with Crooked Tree Wetlands
(Reid, 1997; Emmons, 1997)

TAXON	GENERAL ECOLOGY Occur Inhabit Feed Nest/Den Other
MARSUPIALIA	
Didelphidae- New World Opossums	
Didelphus marsupialis Common Opossum	Found in many kinds of habitat, mature evergreen forests, secondary forests, disturbed lowlands, stream banks, garbage dumps. Mostly nocturnal, rest in trees, dens in hollow trees, tangled vines, caves, crevices, hollow logs, burrows made by other animals. Food, includes prey on small vertebrates, invertebrates, carrion, fruit, nector.[1] Searches garbage dumps and raids chicken houses eating eggs and killing chickens. Females are mature at 7 months of age and can produce 2 litters each year of 20 or more per brood, but only 9 nipples and high mortality, averaging 6 young or so per brood, weaned when they are 3 months old. Live about 2 years (Gardner 1983a).
Didelphus virginiana Virginia Opossum	Found in many kinds of habitat from montane to lowland deciduous forests, but less abundant than Common Opossum in lowland evergreen forests, often associated with human settlements and garbage dumps. Dens in bush, rocks, hollow logs, burrows made by other animals. Females have 13 nipples and can raise more young than Common Opossum (Hunsaker, 1977).
Philander opossum Gray Four-eyed Opossum	Common in deciduous and evergreen forests, secondary forests, gardens, and near streams. Forages stream banks at night, feeds on shrimp, crabs, insects, frogs, small birds, mice, fruits of *Cecropia* and *Piper* spp. Leaf nests made in hollow trees or vine tangle, sometimes on ground. Litter of 2 to 7, with 2 or more litters per year (Fleming, 1973).
Marmosa mexicana Mexican Mouse Opossum	Common in dry deciduous forests, upland evergreen forests, secondary forests, grasslands, spending time in trees. Feeds on fruit and insects.
Chironectes minimus Water Opossum, Yupoc	May be rare or uncommon near forested streams and rivers, prefers rock and gravel bottomed fast flowing streams in hills. Mainly nocturnal, solitary, and terrestrial and semiaquatic. Hind feet webbed, both sexes with pouch, palms of forefeet rough textured with long fingers for capturing fish. Eat fish, frogs, crustaceans, insects. Den in leaf or grass lined burrows in stream banks, entrances above or below the water, and under roots and will nest on top of the ground. 2-5 young per litter, water tight pouch (Marshall (1978).
XENARTHA (Edentata)	
Myrmecophagidae- Anteaters	
Tamandua mexicana Northern Tamandua	Uncommon to fairly common in deciduous and evergreen forests, secondary forests, savannas, mangroves. Eats ants, termites, occasionally bees. Nocturnal and diurnal, terrestrial and arboreal. Dens in hollow trees, logs, holes in ground, or sleep on shaded branch. One young born and raised at a time. Lubin (1983)
Dasypodidae- Armadillos	
Dasypus novemcinctus Nine-banded Armadillo	Common in deciduous and evergreen forests, scrub forests, savannas. Eats ants, termites, beetles, snails, earthworms, a few small vertebrates, fruit, rotting carrion. Usually solitary, nocturnal, good swimmer. Dens in banks, several entrances, nest of leaves and grass. Gives birth to quadruplets. McBee and Baker (1982), Wetzel (1983)
CHIROPTERA- Bats	
Emballonuridae- Sac-winged Bats	
Rhynchonycteris naso Long-nosed Bat Proboscis Bat	Common in lowland forested areas associated with streams, rivers, lakes, and mangroves. Feed on very small insects, predominately Diptera and including mosquitoes, that fly over water just before or at dusk, typically being the first bats out for the sunset feeding. Roost very near or directly over water on steep banks, rocks, underside of branches in groups of a few to almost fifty, their fur blending with the background, individuals usually arranged in evenly spaced rows, taking flight together when disturbed. Single young born during the early part of the wet season.
Noctilionidae- Fishing or Bulldog Bats	
Noctilio leporinus Mexican bulldog bat, fishing bat	Common in wet lowlands and coastal areas, around lower rivers, lagoons, estuaries. Adapted to catch fishes just beneath water surface, using echolocation to detect prey and gaff-like clawed feet dragged through the water, also eating insects, frogs, crabs, with flying insects caught on wing making up much of diet during wet season. Can have two broods per year, April-June and September-October. Roost in hollow trees and caves. Hood and Jones (1984).

TAXON	GENERAL ECOLOGY Occur Inhabit Feed Nest/Den Other
Phyllostomidae- Leaf Nose Bats	
Phyllostominae- Gleaning and Carnivorous Bats	
Macrophyllum macrophyllum Long-legged Bat	Uncommon, often near streams with mature forests, evergreen, semi-deciduous, and dry forests. Skims prey on stream surface-beetles, water striders, midges, spiders, may trawl with hind legs to catch prey.
Trachops cirrhosis Fringe-lipped Bat	Fairly common, favoring lowland forests, common around ponds, swamps, and rivers. Forages over streams and wet areas, eating frogs, insects and lizards captured by mouth while in flight. Roosts in small groups in caves, culverts, hollow trees.
PRIMATA	
Cebidae	
Aloutta pigra black howler monkey, baboon	Locally common but declining outside of protected areas, found in evergreen and semi-deciduous forests, and remaining lowland riparian forests in group sizes from 2 to 10 individuals. They are diurnal and arboreal. Mainly forage on fruit and leaves of figs, cecropia and other trees.
RODENTIA	
Muridae- Rats and Mice	
Oryzomys couesi Coues' Rice Rat	Common, wetlands, floating detritus mats, small ponds, coastal marshes, sometimes scrub, forest edge, rice, sugarcane. Eats green plants, seeds, ants, beetles, caterpillars. Terrestrial/semi-aquatic, good swimmer, good climber. Weaves round nest among emerged aquatic plants about a meter above water or land, breeding around the year, 2 to 7 in litter.
Erethizontidae- New World Porcupines	
Coendou mexicanus Mexican Porcupine	Nocturnal, most often observed at night along riparian forests within areas that are seasonally dry, such as northern Belize
Agoutidae- Pacas	
Agouti paca Paca, Gibnut	Locally common but hunted for meat, found in evergreen, deciduous, and successional forests preferring to be near water-streams, rivers, swamps, low areas, riparian forests in agricultural landscapes. Eat fallen fruits, leaves, and some tubers. Nocturnal, terrestrial and solitary, rarely occurring in pairs. Den in burrows in stream banks. Take to the water when being pursued.
CARNIVORA	
Procyonidae- Raccoons and allies	
Procyon lotor Northern Raccoon, Coon	Common, found in rural areas near rivers, on beaches, in mangrove swamps, in towns. Omnivorous, eating fruits, vegetables, seeds, crayfish, crabs, mussels, fishes, frogs, turtle eggs, birds, bird eggs; raid garbage cans, dumps, corn patches, chicken coops. Nocturnal, terrestrial and arboreal, living solitary or a female with young, 2 to 5 young stay 9 months with female, 3 year average life span. Den in hollow trees, beneath rocks, in burrows. (Lotze and Anderson, 1979).
Lutra longicaudis *Neotropical River Otter*	Rare, always in or near water, clear, fast flowing streams, rivers, coastal lagoons, low level of disturbance. Eats fish, crustaceans, mollusks, other aquatic animals, and sometimes small mammals and birds. Diurnal, when not hunted, and nocturnal, semiaquatic and living solitarily (male and female pairs may stay together short time), or as a female with young, litter size of 1 to 5 with 2 being usual. Dens in burrow in river bank with entrance above or below water level.
Felidae- Cats	
Panthera onca Jaguar	Favors undisturbed lowland and foothill evergreen forests, but found in deciduous forests, savannas, and mangroves, often found around water. Prey on armadillos, pacas, agoutis, armadillos, peccaries, deer, tamanduas, coatis, turtles, iguanas, young crocodiles, birds and fishes. Usually nocturnal but also diurnal, good swimmers
SIRENIA- Manatees and Dugongs	
Trichechidae- Manatees	
Trichechus manatus West Indian manatee	Found in coastal estuarine and marine waters, but move up large rivers and into large lagoons during wet season, including Northern Lagoon. Feed on submerged and floating aquatic vegetation found in both fresh and marine waters.
PERISSODACTYLA- Odd-toed ungulates	
Tapiridae	
Tapirus bairdii Baird's tapir, mountain cow	Evergreen, deciduous, successional forests, streams, rivers, lagoons, swamps. Eats leaves of shrubs and low trees, grasses, fruits. Nocturnal and diurnal, good swimmers. Sometimes sleep and defecate in the water. Gestation period 13 months, one calf is born. Often hunted for meat.