CHAPTER 2

THE AQUATIC HABITATS OF LAGUNA DEL TIGRE NATIONAL PARK, PETEN, GUATEMALA: WATER QUALITY, PHYTOPLANKTON POPULATIONS, AND INSECTS ASSOCIATED WITH THE PLANT *SALVINIA AURICULATA*

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ABSTRACT

- Water bodies in Laguna del Tigre National Park (LTNP) were classified according to eight macrohabitat types (refer to Table 1.1). The physico-chemical properties, water quality, phytoplanktonic flora, and insects associated with the aquatic plant *Salvinia auriculata* are reported for each water body examined.

- The pH of the park's waters ranged from acid (6.78) to alkaline (8.30), from turbid and dark to aquamarine, and from eutrophic to oligotrophic. The water quality of the park was generally good. Coliform bacteria were detected in 37% of the samples, but fecal coliform bacteria were detected in only 13% of the samples.

- A freshwater, mollusk-based reef was discovered in the Río San Pedro near the town of El Naranjo.

- Fifty-nine genera and 71 species and morphospecies of phytoplankton were recorded. Diatoms (Bacillariophycea), followed by chlorophytes (Chlorophyceae) and cyanophytes (Cyanophyceae), dominated the samples. Multivariate analyses revealed that the single most important source of variation determining phytoplanktonic composition was pH, and the second was conductivity.

- Forty-four morphospecies and 26 families of insects were found on *Salvinia auriculata*. This result highlights the great diversity of insects in the littoral aquatic systems of the park.

- The molluscan reef should be conserved, and a water-quality monitoring program should be initiated.

INTRODUCTION

The results of a limnological assessment of Laguna del Tigre National Park (LTNP) are presented, including the following: 1) descriptions of aquatic macrohabitats encountered during the study (refer to Table 1.1 and Appendix 1); 2) an evaluation of water quality using biotic measures such as the presence of coliform bacteria and *Escherichia coli* as well as abiotic measures; and 3) an evaluation of patterns in the diversity of phytoplankton within the park. In addition to this limnological component, we examined the composition of insects associated with floating plants, specifically *Salvinia auriculata*.

This limnological study is intended to serve as the basis for more intensive monitoring studies of aquatic systems in the park. The monitoring of aquatic organisms such as plankton and insects has certain advantages over chemical analysis in determinations of the health of aquatic ecosystems (UNESCO, 1971). Benthic insects, for example, maintain a relatively stable composition that is determined by responses to average conditions in their aquatic environment over time, whereas chemical analyses only reflect water quality at the time samples were taken, which may be quite variable depending upon the time of day or year (McCafferty, 1998). Monitoring using plankton and aquatic insects may represent a good option for recording environmental changes in LTNP, as they have in other freshwater systems in Guatemala (Basterrechea, 1986, 1988, 1991; Herrera, 1999). Furthermore, these organisms are important in their own right. Plankton are fundamental components of the aquatic food chain, and aquatic insects are among the principal groups of organisms that convert vegetable material into animal tissue in freshwater ecosystems. Thus, these organisms form the support for the existence of many organisms including fish, amphibians, and birds (Merritt and Cummins, 1984).

Although several studies have considered aquatic invertebrates in Guatemala, including studies of the Río Polochic by the biology department of the Universidad del Valle and by Basterrechea and Torres (1992) in LTNP, this is the first study in Guatemala to consider the relationships between insects and the floating plants *Salvinia auriculata*. *S. auriculata* is a relatively common and easily sampled aquatic plant in lotic aquatic systems in LTNP (see León and Morales Can, this volume) and thus serves as an ideal substrate from which to gather aquatic insects and to consider their relationships to the environment. The objective of this component of the limnological study is to examine the feasibility of more intensive studies of insects on aquatic plants as a monitoring tool for LTNP.

METHODS

Water Quality

Samples of water and sediment at 33 sample points in five focal areas were usually taken near the margins of water bodies (see sample depths in Table 2.1). Temperature, pH, electrical conductivity, and dissolved oxygen values were obtained using portable instruments. Depth at each point was measured using a handmade depth gauge. Transparency of water column was measured using a Secchi disk. Alkalinity was determined using the Gran method, modified by Carmouze.

Table 2.1. Limnological results at each sampling point.

Sample Point	Sample Depth (m)	Max. Depth (m)	Visibility (m)	Temp. (°C)	pH	Oxygen (mg/L - % saturation)	Conductivity MS/cm
SP1	2.10	2.20	1.95	27.5	7.15	5.80 - 84.5	0.81
SP2	3.30	3.90	2.55	25.9	7.03	6.10 - 78.0	1.02
SP3	1.75	5.40	1.75	24.8	6.89	4.72 - 58.0	1.22
SP4	2.12	6.60	2.12	27.5	7.33	7.36 - 95.0	1.55
SP5	1.75	7.10	1.75	28.3	7.33	7.67 - 110	1.32
SP6	1.65	6.10	1.65	29.5	7.20	7.77 - 103	1.98
SP7	0.80	4.10	0.80	28.1	7.40	*	1.51
SP8	2.60	2.60	1.45	29.5	7.41	*	1.48
SP9	2.33	9.00	1.45	29.5	7.43	*	1.42
SP10	0.95	7.85	0.95	29.6	7.36	8.09 - 103.7	1.66
SP11	3.00	5.10	1.30	29.9	7.47	*	1.44
SP12	0.50	3.10	2.50	29.3	7.67	*	1.37
E1	1.45	1.45	1.45	29.3	7.76	*	0.63
E2	0.85	0.85	0.85	29.8	7.27	*	1.57
E3	1.50	1.50	1.30	29.7	7.20	*	1.54
E5	0.40	0.40	0.40	29.6	7.02	*	1.62
E6	0.70	0.70	0.70	29.1	6.99	*	1.70
E7	2.80	2.80	1.30	29.4	7.46	*	1.90
E8	3.75	3.75	2.00	29.2	7.50	*	1.81
E9	0.20	0.20	0.20	27.3	7.57	*	0.73
E10	0.40	0.40	0.40	29.5	7.73	5.88 - 70.0	1.49
E11	0.50	0.50	0.50	25.4	8.30	4.24 - 53.5	1.95
F1	0.80	0.80	0.70	29.0	8.23	7.42 - 96.9	0.33
F2	1.05	1.05	1.0	29.3	7.96	6.36 - 46.5	1.98
F5 A	1.05	1.05	1.05	26.5	7.84	0.02 - 0.5	0.92
F5 B	0.9	0.9	0.9	26.8	7.84	0.95 - 9.5	0.91
F5 C	0.45	0.45	0.45	26.5	7.84	1.45 - 19.3	0.90
F5 D	0.30	0.30	0.30	26.3	7.84	1.40 - 17.4	0.89
C1	0.40	0.40	0.40	26.3	7.06	0.85 - 8.30	1.27
C2	1.85	1.85	1.85	30.0	7.16	8.51 - 106.5	1.06
C3	1.50	1.50	1.50	28.7	7.20	6.78 - 91.0	0.63
Ca1	1.45	1.45	1.45	25.3	6.84	2.80 - 40.7	1.41
Ca2	0.35	0.35	0.35	25.9	6.78	2.66 - 33.5	0.67

(* data not available).

Additionally, the presence or absence of microorganisms that indicate water polluted by human waste, including total coliforms, fecal coliforms, and *Escherichia coli*, was determined. In the field only a qualitative test (Ready Cult Coliforms 100) was possible and is reported here. The addition of a chromogenic substrate that binds with coliform bacteria and an MUG fluorescent substrate that is highly specific to *E. coli* permits the simultaneous detection of total and fecal coliforms and *E. coli*. The presence of total coliforms was indicated if the solution turned blue-green. The presence of fecal coliforms was detected by a blue fluorescence and by a positive Indol reaction.

Phytoplankton

Plankton samples were taken at the water surface. Samples were obtained by filtering 100 L or 50 L of water through a 20-mm net; then samples were preserved in lugol. Sedgwick-Rafter chambers (100x and 450x magnification) were used to count and identify phytoplankton species and morphospecies. Patterns of species and generic richness were compared among sample points, and patterns of species composition and abundance among sample points were explored using multivariate techniques. Non-metric multidimensional scaling (NMMS; McCune and Mefford, 1999) was used to characterize patterns of change in phytoplankton composition and abundance across LTNP. Of the many multivariate techniques available, this technique is especially appropriate for characterizing differences in species composition among samples.

Aquatic Insects Associated with *Salvinia auriculata*

In order to sample aquatic insects inhabiting *Salvinia auriculata*, we used a 25x25-cm quadrat. At each sampling point where we observed *S. auriculata*, we placed the quadrat over a randomly determined portion of the plant and collected all parts of the plant that fell within the quadrat. We placed the collected *S. auriculata* into a plastic bag with some water and, in the lab, washed the plant material carefully through a 250-mm net. We discarded all the large plant parts and kept the smaller material, including parts of the roots and the insects caught in the net. This sample was fixed in a solution of 80% formol. Insects in the samples were separated and identified to genus and, where possible, to morphospecies.

RESULTS AND DISCUSSION

Below, we present general results for coliform sampling, patterns of phytoplankton diversity, and a description of the aquatic insects gathered from *Salvinia auriculata*. A description of macrohabitat characteristics, water quality, phytoplankton diversity, and aquatic insects for each focal area follows.

Coliforms: General Considerations

The results of qualitative tests for the presence or absence of coliform bacteria at the sampling points are presented in Table 2.2. It will be necessary to continue this investigation in greater detail in order to reach conclusions regarding the management of water resources in LTNP. These results, however, provide a cursory view of the impact of human activities on water bodies in the park. About 37% of the sample points revealed the presence of total coliforms, and 13.3% of the points revealed fecal coliforms. Patterns of water quality within the park is discussed below.

Table 2.2. Results of a qualitative determination of coliform presence at the sampling points.

Sample Point	Total Coliforms	Fecal Coliforms
SP1	–	–
SP2	–	–
SP3	–	–
SP4	–	–
SP5	–	–
SP6	–	–
SP7	–	–
SP8	–	–
SP9	–	–
SP10	–	–
SP11	–	–
SP12	–	–
E1	+	–
E2	+	–
E3	–	–
E5	+	–
E6	–	–
E7	–	–
E8	+	–
E9	–	–
E10	+	+
E11	+	+
F1	+	+
F2	+	+
F5	–	–
C1	+	–
C2	–	–
C3	–	–
CA1	+	–
CA2	+	–

Phytoplankton: General Considerations

Considering the rapid nature of the sampling regime, we can provide only very general statements regarding the distribution of phytoplankton in LTNP. The sampling strategy determines in large part the subset of species recorded in a particular locale, such that in this study most phytoplankton species recorded were characteristic of superficial waters. In some cases, however, we observed phytoplankton that are intimately associated with the substrate (benthic), such as *Pinnularia*.

Six classes, 59 genera, and a total of 71 species and morphospecies of phytoplankton were identified in this study (Appendix 3). Two algas (a chlorophyte and a diatom) were not identified. Diatoms (Bacillariophyceae), followed by chlorophytes (Clorophyceae) and cyanophytes (Cyanophyceae), predominated in the samples. This pattern of abundance followed our expectations based upon the conditions reported previously in studies carried out in the Petén. Three additional classes of phytoplankton were observed: Euglenophyceae, Dynophyceae, and Chrysophyceae. The majority of phytoplankton registered here are cosmopolitan, whereas others are more frequently observed in particular environments.

The presence of certain species of phytoplankton indicated particular environmental conditions at some of the sampling points. For example, cyanophytes often indicate human contamination. In the majority of sampling points located along the Río San Pedro; Río Escondido (except points E8 and E9); and lagunas Santa Amelia, Buena Vista, Flor de Luna, and La Pista, *Microcystis aeruginosa* was present and indicates the presence of wastewater-associated contaminants. Nevertheless, it is important to note that the densities of this cyanophyte surpassed 1000 organisms/L only at points SP2, SP7, E10, and C3 (refer to Appendix 1). In the rest of the sampling points, densities were less than 400 organisms/L. *M. aeruginosa* has been recorded in other bodies of water within other departments (counties) of Guatemala, such as Izabal Lake (Basterrechea, 1986), and it is the most common phytoplankton species in Amatitlán Lake, which is eutrophic (AMSA, 1998). In these cases, the densities of *M. aeruginosa* are much greater than those within LTNP, and it is important to mention that these bodies of water exist under different conditions and were sampled differently from those in LTNP. There are generally few studies available for other comparisons. *Synedra ulna* is another species that indicates contamination and would provide a good indicator species in future studies in LTNP. It will also be useful to combine phytoplankton sampling with information on hydrocarbon concentrations to provide more concrete linkages between contamination and phytoplankton indicators.

Several other phytoplankton genera were recorded in LTNP that have been reported in Amatitlán and Izabal lakes, including *Anabaena, Ankistradesmus, Ceratium, Cyclotella, Euglena, Fragilaria, Synedra, Lyngbya, Oscillatoria, Melosira, Merismopedia, Pediastrum, Staurastrum, Scenedesmus, Tabellaria,* and *Volvox*. *Coelastrum reticulatum* and *Golenkinia radiata* are species that were reported both in Izabal Lake and in this study. Most of the eight genera found in Petén Itzá Lake—*Cosmarium, Staurastrum, Cocconeis, Dinobryon, Navicula, Agmenellum, Microcystis aeruginosa*, and *Lyngbya*—were found in LTNP (Basterrechea, 1988).

We found a greater generic richness than that found by Basterrechea and Torres (1992) in the Río Escondido-Laguna del Tigre Biotope (22 genera), although the sampling season and methods were different. Basterrechea and Torres sampled areas only in lagoons within the biotope, as well as in Petén Itzá Lake; they reported 26 genera overall in this sampling: Petén Itzá (7 genera), La Carpa (3 genera), Pozo Xan (7 genera), El Toro (7 genera), and El Remate (12 genera). Sandoval (1997) reported 18 genera of phytoplankton in Petén Itzá Lake. The majority these genera were identified in LTNP. At some points, Sandoval reported dominance by Bacillariophytes, which were also common in this study.

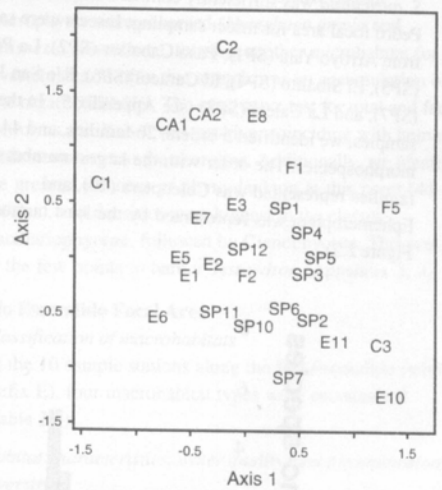

Figure 2.1. A non-metric multidimensional scaling ordination of sample points based upon phytoplankton densities.

The first two axes of the NMMS ordination (Figure 2.1) explained 58.8% of the variance in the original, unreduced distance matrix, and the axes were significantly different from those generated by randomized data (Monte Carlo permutation tests: P=0.035). The ordination indicates that the composition of phytoplankton from the ríos San Pedro and Escondido were broadly similar. All but one sample point (C3) in the Río Chocop/Río Candelaria focal area were distinct from the others. This difference in composition is related to the generally low richness in all of the Chocop/Candelaria samples except C3, which was relatively species rich (Appendix 3). Despite the ecological similarities between lagunas Guayacán (C2) and La Pista (C3) (see below), as well as their spatial proximity, these lagoons harbored distinct phytoplankton floras. NMMS axis scores were regressed upon environmental variables from Table 2.1 to explore which environmental variables are best correlated with patterns in plankton composition. Axis 1 scores positively correlated with only pH (R^2=0.14; F=4.13; df=1, 25; P=0.053), and axis 2 scores positively correlated with conductivity (R^2=0.15; F=4.46; df=1, 25; P=0.045). None of the environmental variables was able to explain a great deal of variation in species composition.

In most cases, the phytoplankton densities obtained were not particularly high (Appendix 4). It will be important to continue monitoring these and other sites within LTNP to evaluate changes in nutrient loads and other physico-chemical parameters and their effects on phytoplankton productivity.

Aquatic Insects Associated with *Salvinia auriculata*

S. auriculata was sufficiently common only at the Río San Pedro focal area for insect sampling. Insects were sampled from Arroyo Yalá (SP1), Paso Caballos (SP2), La Pista (SP3), El Sibalito (SP4), El Caracol (SP6), Río San Juan (SP7), and La Caleta (SP8) (see Appendix 5). In these samples, we identified 5 orders, 26 families, and 44 morphospecies. The order with the largest number of families represented was Coleoptera (10), and Ephemeroptera was represented by the least number (2; Figure 2.2).

It is important to mention that because the plants are mobile, there are occasionally connections between aquatic plants and the shoreline; therefore, many of the species inhabiting floating aquatic plants may also be semi-aquatic or terrestrial. Such processes may explain the presence of some Coleopterans such as the Scolitids. Despite the limited duration and extent of sampling, insect species richness on *S. auriculata* was considerable and indicates that more intensive descriptive studies and monitoring of this system are warranted.

Río San Pedro River Focal Area

Classification of macrohabitats

At the 12 sample stations along the Río San Pedro (with prefix S), five distinct macrohabitat types were encountered (Table 2.3; refer to Appendix 1).

Habitat characteristics, water quality, and phytoplankton diversity

The Río San Pedro is characterized by a relatively low current velocity. In the Río Sacluc (SP11), water levels were quite low. Sediment samples revealed considerable erosion of the river margin, probably due to the constant passing of boats.

Some general abiotic characteristics of samples from the ríos San Pedro and Sacluc are presented in Table 2.3 and include the following:

- The maximum depth of the central channel was found in front of the Scarlet Macaw Biological Station (7.10 m; Table 2.1), and the minimum was found in front of the Arroyo Yala (2.20 m).
- Samples were taken in the littoral zone of the rivers at depths ranging from 0.95 m to 3.30 m.
- Transparency values indicated that the euphotic zone reached the river bottom at 50% of the sample points.

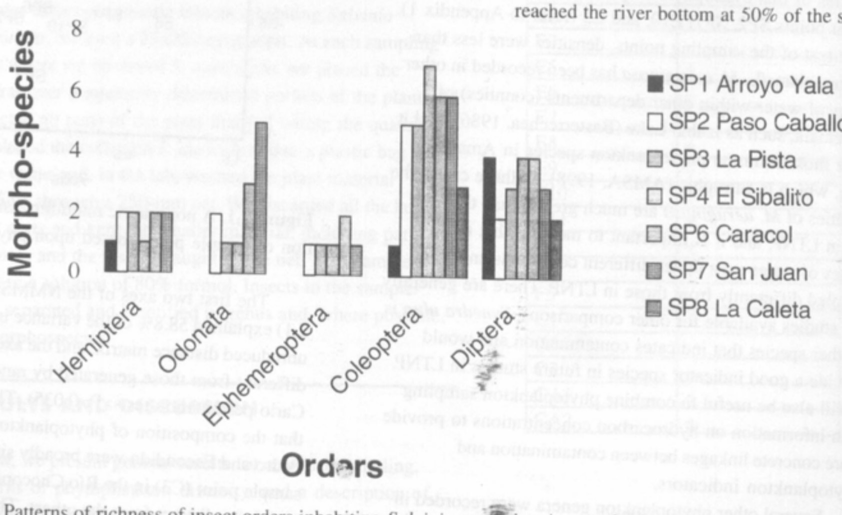

Figure 2.2. Patterns of richness of insect orders inhabiting *Salvinia auriculata* in samples in the Río San Pedro focal area of LTNP.

- Water temperature was high, varying between 24.8° C and 29.6° C.
- Dissolved oxygen concentrations were comparatively high at nearly all of the sample points.
- The waters of the Río San Pedro possess a comparatively high electrical conductivity. This characteristic is probably due to the karstic landscape through which the river flows. These waters may be classified as "hard" due to the high concentrations of calcium carbonate, which, in turn, may be related to the high conductivity values observed.
- Surprisingly, the pH of the water is neutral to slightly alkaline. Considering the geomorphological characteristics of this karstic region, we expected to observe a strongly alkaline pH (>8.5). The relatively large quantities of organic material in the water and high water temperatures may result in accelerated activity by decomposers (bacterias, fungi, and yeast). The production of organic acids in these alkaline waters may produce a nearly neutral pH (pH 8). The fast-running springs at arroyo La Pista (SP3) had colder water, a more acid pH, and greater electrical conductivity when compared to the San Pedro.
- The qualitative test for total coliforms, fecal coliforms, and *E. coli* was negative in all the samples that were tested. The number of phytoplankton species found at each sampling point was similar (Appendix 3), but the point with the lowest richness was SP 10. Genera such as *Tetraëdron* (SP2, SP3); *Kirchneriella* (SP2, SP3, and SP4); *Synura* (SP1, SP2, SP3, and SP6); and *Dinobryon* (SP3, SP4, and SP5) were recorded only within this focal area.

Table 2.3. Description of sampling points along the Río San Pedro.

Macrohabitat Type	Sample Points
Permanent river	SP 1, 4, 5, 9, 11
Tributaries	SP 2, 3, 6, 7
Caños	SP 8
River embayments	SP 10
River rapids	SP 12
Bottom Types	
Sediments with large particles of organic material	SP1, 3
Sediments with small particles of organic material and elevated amounts of interstitial water (typical areas of deposition)	SP7, 8, 9, 10
Current Velocity	
Slow waters, almost stagnant	SP1, 7a, 11
Waters with current	SP2, 3, 7b (springs)
Areas with a High Diversity of Aquatic Macrophytes	SP1, 2, 3, 6, 7
Areas without Aquatic Macrophytes	SP4, 5, 8, 9, 10, 11

Notes on other invertebrates

There appeared to be a high diversity of macroinvertebrates associated with *Salvinia auriculata*. About 44 distinct taxa representing herbivore, detritivore, predator, and rasping trophic groups were recorded (Appendix 3). Miners that use sediment as well as living foliar tissue were also present. Approximately 10 morphospecies of adult Odonates were also collected.

A molluscan reef

In a section of the Río San Pedro referred to locally as the "rapids," we noted the presence of freshwater reefs composed of bivalve molluscs. This type of aquatic system is unique in the region and is generally uncommon in the Neotropics. The river bottom is composed of a 35-cm-deep layer of bivalve shells. Organic sediments were absent. Living bivalves were found on the surface of the reef. The fish *Cichlasoma sunsphilium* was associated with the reef and fed upon the periphyton growing on the shells. Inside the shells various nymphs of Ephemeroptera (Baetidae) and Trichoptera as well as other bivalves, gastropods, and platyhelminths were found. We conclude that these shells are important microhabitats for aquatic invertebrates inhabiting the river bottom in this area.

In a stretch of river with low current, aquatic macrophytes were observed (*Nymphaea ampla* and *Valisneria americana*), forming another microhabitat for invertebrates. Within that stretch was an accumulation of fine organic material. The qualitative test for total and fecal coliforms and *E. coli* was positive, coinciding with human settlements near to the shoreline. Additionally, we identified the greatest richness of phytoplankton at this point (44 species), and densities were highest in the classes Bacillariophyceae, followed by Cianophyceae. This was one of the few points to harbor *Tetraëdron* (Appendix 3, 4).

Río Escondido Focal Area

Classification of macrohabitats

At the 10 sample stations along the Río Escondido (with prefix E), four macrohabitat types were encountered (Table 2.4).

Habitat characteristics, water quality, and phytoplankton diversity

The Río Escondido has relatively steep banks and a narrow river margin. The shores are composed mostly of forest, disturbed forest, and sibal. A large section of the sibal was being burned during our survey. The forest at the northeasternmost station, Punto Icaco (E8), had a relatively closed canopy forest of different character than the remaining parts of the Río Escondido.

The Río Escondido ends as a shallow channel and marsh system, above which are relatively deep sections that widen and narrow regularly. The bottom is principally soft mud, but at Punto Icaco there was much detritus, logs, and leaf litter. Oxbow lagoons and dead arms comprise many habitats to the sides of the Río Escondido, often through sibal habitats rather than in forest. These habitats are now shallow and have very soft mud and mud/marl bottoms. Characteristics of the Río Escondido area are summarized in Table 2.4 and include the following:

- The lowest depths were recorded in the lagoons and embayments, and the greatest depth in the river was at E8.
- Transparency reached the bottom at all sampling points.
- In general, the waters here had high temperatures (from 26° C to 29.8° C), and the pH values were neutral to slightly alkaline (6.99 to 7.76).
- Sediments had high levels of organic material and interstitial water.
- Electrical conductivity in the principal channel of the Río Escondido was low at 1 MS/cm. On the other hand, embayments had very high conductivity values.
- The presence of total coliforms was recorded at E1, E2, E5, and E8, and the presence of total and fecal coliforms and *E. coli* was recorded at E10 and E11. No contamination of fecal origin was detected at the other points.
- The greatest richness of phytoplankton was recorded at points E1 (38 spp.) and E5 (35 spp.). It rained during the sampling of this river, increasing its flow, so it is possible that the phytoplankton sampling was affected by dilution. This may have resulted in a general slight reduction in species richness when compared to samples taken from the San Pedro. Some genera of phytoplankton recorded here, such as *Cosmarium* (E1, E2, and E6) and *Mallomonas* (E1, E2, E5, E7, and E8), were not found in the San Pedro.

Table 2.4. Description of sampling points along the Río Escondido.

Macrohabitat Type	Sample Points
Permanent river	E3, 8, 11
River embayments	E1, 2
Ephemeral (shallow) river	E10
Oxbow lagoons	E5, 6, 7, 9
Bottom Types	
Sediments with large particles of organic material	none
Sediments with small particles of organic material and elevated amounts of interstitial water (typical areas of deposition)	all except E11
Rocky bottom	E11
Current Velocity	
Slow waters, almost stagnant	E1, 2, 7, 8, 10
Waters with current	E3, 9, 11
Areas with a High Diversity of Aquatic Macrophytes	E3, 8, 10
Areas without Aquatic Macrophytes	the remainder

Flor de Luna Focal Area

Classification of macrohabitats

Water bodies at this site consisted exclusively of lagoons, three of which were sampled (F1, F2, and F5). Habitat characteristics, water quality, and planktonic communities are discussed below for each lagoon individually.

Laguna Flor de Luna (F5)

- This lagoon is shallow (1.05 m) with very high surface-to-volume ratio. This favors the mixing of the entire water column due to the action of wind (principally northeast winds).
- The lagoon was homothermic (26.3° C to 26.8° C), electrical conductivity was less than 1 MS/cm, and the pH was neutral to slightly alkaline. The qualitative analysis for total and fecal coliforms and *E. coli* was negative.
- During the collection of sediment samples, the presence of hydrogen sulfide gas was detected. This gas, together with methane gas (CH_4), results in the chemical reduction of inorganic nutrients in the water because reduction is favored in the hypoxic or anoxic environment at the sediment-water interface. For this reason, benthic macroinvertebrates were not observed in the sediments. However, water striders (Gerridae) were abundant on the surface of leaves and in the flowers of *Nymphea ampla* throughout the lagoon.
- Thirty-four species of phytoplankton were recorded here. This was one of the few points at which *Tetraëdron*, *Micrasterias*, *Staurastrum*, and *Spirogyra* were recorded.

Laguna Santa Amelia (F2)

- This lagoon was also shallow (1 m), favoring wind-generated mixing.
- As in Flor de Luna, the lagoon was homothermic (27.7° C to 29.3° C).
- Electrical conductivity ranged from 1.85 and 2 MS/cm.
- Oxygen saturation was from 8.6% to 46.5% at the surface.
- The water exhibited a naturally dark color; nevertheless, transparency persisted to the lagoon bottom.
- Collection of the sediment revealed the presence of hydrogen sulfide gas, and no benthic macroinvertebrates were observed. *Nymphea ampla* was abundant across the lagoon.
- Tests for the presence of total and fecal coliforms and *E. coli* were positive, which indicated fecal contamination by humans and livestock. The waters of the lagoon appear to be used for human consumption, and contamination levels in the lagoon should be monitored. Several uncommon phytoplankton genera were found here, including *Staurastrum*, *Spirogyra*, and *Mallomonas*.

Laguna Buena Vista (F1)

- This lagoon was shallow as well (0.75 m) and homothermic (29° C to 29.1° C).
- The pH here was alkaline (8.23).
- The lagoon measured 200x600 m and was extremely homogeneous.
- Nearby human populations use this lagoon for consumption and for washing and bathing. Not surprisingly, the test for total and fecal coliforms and *E. coli* was positive.
- Several uncommon phytoplankton genera were identified here—although in some cases these were also recorded in F1 and F5—such as *Micrasterias*, *Staurastrum*, *Sorastrum*, *Spirogyra*, and *Mallomonas*.

Río Chocop Focal Area

Classification of macrohabitats

Five sampling points (with prefix C) were located here, representing three macrohabitat types (Table 2.5). Water quality and planktonic/invertebrate communities are summarized in Table 2.5 and are individually discussed below for each sample point.

Río Chocop (C1)

- The Río Chocop and the Río Candelaria are both classified as shallow rivers—that is, as semi-permanent streams—because during the dry season, the river levels drop dramatically and only a small amount of water flow is maintained. Both of these rivers had steep banks and overhanging forests with a closed canopy. The Chocop was almost dry with some areas of stagnant water and possibly a "biofilm" of bacteria on the surface of these pools.
- The test for the presence of total coliforms was positive, but for fecal coliforms and *E. coli*, the test was negative.
- There was little dissolved oxygen in the water column. The river bottom consisted of compacted sediments overlain by leaves from the adjacent terrestrial vegetation. Because of the lack of oxygen, there were few benthic invertebrates (the fragmenting trophic group was absent altogether). Large numbers of belostomatids (Hemiptera) were observed in shallower sections, however. This river is probably quite different during the wet season. For phytoplankton, this was one of the least species-rich points, with 28 species.

Table 2.5. Description of sampling points along the Río Chocop.

Macrohabitat Type	Sample Points
Ephemeral (shallow) rivers with muddy bottom	C1, Ca1
Permanent rivers with rocky bottom	Ca2
Lagoons	C2, 3

Lagunas la Pista (C3) and Guayacán (C2)

- These lagoons are ecologically similar and are thus treated together. Guayacán had some exposed limestone on its margin and aquamarine clear water (>2m visibility) over soft sediments. There was a margin with sawgrasses and margins of forest. There were many small pools in the forest associated with this lagoon that may represent springs.
- Wind probably mixes the entire water column in both lagoons. As a consequence, the lagoons were homothermic, dissolved oxygen was present to the bottom (>86% saturated), and conductivity was equal through the water column.
- The test for total coliforms, fecal coliforms, and *E. coli* was negative.
- In spite of the presence of dissolved oxygen in the water columns of both lagoons, we detected a strong odor of hydrogen sulfide gas in the sediment samples. These observations suggest a resistence from a microstratification of oxygen at the water-sediment interface. As a consequence, we expect an absence of macroinvertebrates in both lagoons.
- Guayacán harbored the fewest number of phytoplankton genera in the study (19), perhaps because of the oligotrophic status of this lagoon. Laguna la Pista exhibited a greater phytoplanktonic richness.

Río Candelaria (Ca1, 2)

- In this river the two sample points were quite distinct. At Ca1 the river was deep and had a slow current. Generally, the conditions were similar to those found in Río Chocop.
- Dissolved oxygen was present to the river bottom, although in low concentrations. Vegetable material was abundant on the bottom, and the presence of hydrogen sulfide gas was detected.
- The test for total coliforms was positive, and for fecal coliforms and *E. coli*, the test was negative. Twenty-seven species of phytoplankton were recorded here.
- The river at Ca2 was shallower (35 cm), had a more rapid current, and oxygen was present to the bottom.
- Electrical conductivity values were similar to those at Ca1.
- The test for total and fecal coliforms and *E. coli* was negative.
- Twenty-nine species of phytoplankton were recorded here, so both Candelaria sites were intermediate in richness when compared to the other sites. Several different trophic groups of benthic macroinvertebrates were observed at both points, including gastropod herbivores, filter-collecting Ephemeroptera, and odonate carnivores.

CONCLUSIONS AND RECOMMENDATIONS

With respect to the conservation and management of aquatic ecosystems in the park, two recommendations are offered:

- There is an urgent need to conserve the rapids of the Río San Pedro. These rapids possess a unique freshwater reef system that may also serve an important function by filtering suspended particles from the water.
- Many lagoons and streams within the park are little contaminated, and action should be taken to ensure their continued health.

With respect to future studies and monitoring the aquatic systems within the region, five recommendations are offered:

- Future studies should be executed at the basin scale and should be conducted over longer periods, encompassing the variation between the dry and wet seasons. Samples should be taken at different depths, and total and dissolved nutrients should be considered.
- The effects of human activities on the landscape, such as agriculture and the subsequent runoff of chemicals and waste, need to be evaluated at the basin scale.
- For phytoplankton monitoring, it would be useful to standardize sampling times among different sample points in order to avoid the effects of diel variation in the movement of plankton in the water column. This would reduce bias in comparisons among samples.
- Densities of coliform bacteria should be monitored and quantified in order to track accurately the degree of fecal contamination in the park and to identify those areas that are sources of contamination throughout the park.
- More intensive monitoring of aquatic insect populations needs to be initiated, and samples should be taken at different times of year in order to understand the effects of natural temporal variation and how this may interact with spatial variation caused by both natural and anthropogenic processes.

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