WATER QUALITY ASSESSMENT OF A TROPICAL FRESHWATER MARSH USING AQUATIC INSECTS

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ABSTRACT

Laguna Cartagena, located in the municipality of Lajas, is the only natural freshwater lagoon of Puerto Rico. The lagoon gives refuge to many animal and plant species, some of them endemic and endangered. Agriculture in contiguous lands has caused sedimentation and eutrophication, affecting not only its hydrology but its capacity to sustain a high diversity of aquatic life. To restore the Lagoon, its actual condition was assessed based on the physical-chemical (pH, temperature, dissolved oxygen (DO), nutrients and heavy metals) and biological characteristics (aquatic insects) of two sites on the southwestern section of the lagoon.

A total of 67 insect species in 33 families were collected; 48 of them were new records for the lagoon. Insects belonged to five different orders Hemiptera, Diptera, Coleoptera, Odonata, and Ephemeroptera. Hemiptera and Diptera were the most abundant orders, exceeding 75% of the overall sample. Meanwhile, Coleoptera (21 species), Odonata (17 species), and Hemiptera (16 species) were the orders with higher species diversity, although represented mainly by a few dominant families. Ephemeroptera was the least abundant and diverse order, represented by one species of the family Baetidae. Abundance and diversity was related mainly to DO concentration. According to Simpson and Shannon-Wiener biotic indexes, both sites (1 and 2) showed a higher diversity during February and March. The Hutchinson t-test for Shannon – Wiener shows a significant difference of aquatic insect diversity between the two study sites.

Among physical-chemical parameters measured at the lagoon, only DO and depth had significant fluctuations, meanwhile temperature and pH remained within acceptable ranges for the Puerto Rico Environmental Quality Board (PREQB). Ammonia and phosphate were 60 and 7 times, respectively, above those permitted by the PREQB. According to PREQB and EPA, reported values of heavy metal are not toxic to aquatic life. Chemical data indicate Laguna Cartagena has moderate water quality while biological data indicate the lagoon has a fair water quality.

Laguna Cartagena is a constantly changing environment. During the year of sampling the lagoon had variable physical-chemical parameters, vegetation and insect community; however, the variability was similar to those wetlands of eastern USA.

Further long-term studies should be done to understand better and predict the hydrological changes and population dynamics of the lagoon.

Resumen

La Laguna Cartagena, localizada en el municipio de Lajas, es la única laguna natural de agua dulce en Puerto Rico. Ésta le provee refugio a muchas plantas y animales endémicos y/o en peligro de extinción. Sin embargo, el uso de las tierras aledañas para la agricultura ha traído como consecuencia la sedimentación y eutroficación de la misma, afectando no solo su hidrología sino su capacidad para sostener una alta diversidad de organismos acuáticos. Con el propósito de restaurarla, se examinó la condición actual de dos localidades en la región suroeste de la laguna, basándose en sus características físico-químicas (pH, temperatura, oxígeno disuelto, nutrientes y metales pesados) y biológicas (insectos acuáticos).

Se colectó un total de 67 especies de insectos pertenecientes a 33 familias; de las cuales 48 especies no se habían reportado en la laguna. Se colectaron insectos de cinco órdenes diferentes: Hemiptera, Diptera, Coleoptera, Odonata y Ephemeroptera. De éstos, Hemiptera y Diptera fueron los órdenes más abundantes, sobrepasando el 75% del total de organismos colectados. Mientras, Coleoptera (21 especies), Odonata (17 especies) y Hemiptera (16 especies) fueron los órdenes de mayor diversidad, aunque representados mayormente por unas pocas familias dominantes. El orden Ephemeroptera fue el orden menos abundante y diverso, representado por una sola especie de la familia Baetidae. La abundancia y diversidad de las especies se relacionó mayormente a la concentración de oxígeno disuelto (DO). Según los índices bióticos Simpson y Shannon-Wiener, ambas áreas de muestreo (1 y 2) mostraron una mayor diversidad durante los meses de febrero y marzo. El "Hutchinson t-test" para Shannon–Wiener mostró diferencias significativas en la diversidad de insectos acuáticos de las áreas de muestreo.

De los parámetros físico-químicos estudiados en la laguna, el DO y la profundidad del agua fueron aquellos que presentaron la mayor fluctuación, mientras que la temperatura y el pH no variaron mucho y permanecieron dentro del rango aceptado por la Junta de Calidad Ambiental de Puerto Rico (JCA). Los valores para amoníaco y fosfato fueron de 60 y de 7 veces, respectivamente, por encima de los valores permitidos por la JCA. Según la JCA y la EPA, los valores de metales pesados medidos no representan un riesgo a la vida acuática. Los resultaos de parámetros físico-químicos muestran que la Laguna Cartagena es un ecosistema acuático con una calidad de agua moderada, mientras que la data biológica muestra que es un ecosistema con una calidad más baja.

La laguna Cartagena es un ecosistema muy cambiante. Durante el año de muestreo, la laguna presentó una variación drástica en sus parámetros físico-químicos, vegetación y comunidad de insectos; aunque mostrando un “comportamiento” comparable a humedales del este de los Estados Unidos. Recomiendo que se realicen estudios adicionales, a largo plazo, para entender y poder predecir los cambios hidrológicos y la dinámica poblacional de la laguna.

Dedication

To all my family especially my parents Héctor and Aida, my sister Jetzabeth, my brother Héctor Javier and my grandmother Haydeé. Thanks for all your love and for being a model to follow.

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PREFACE

Study site background

Laguna Cartagena, which has been part of the Caribbean Wildlife Refuge since 1989, is the only natural freshwater lagoon in Puerto Rico. The Refuge, located in the municipality of Lajas, occupies 4.29 km^2 from which 1.06 km^2 are part of Sierra Bermeja, a mountain range that is believed to be geologically the oldest in the Caribbean, and which is covered with a protected native forest and grass lands, including the endemics *Eugenia woodburyana* and *Aristida chaseae*.

Hydrology: according to Díaz-Soltero (1990)

At the beginning of the 1800's, contiguous lands to Laguna Cartagena were not used for agricultural purposes. The lagoon received water from rainfall, runoff, and various intermittent streams. Water levels varied seasonally, but reduction of water volume was affected mainly by solar and wind evaporation.

During the early 1900's, the hydrology of the lagoon was already modified by man. The lagoon was used during the dry season (March to September) to irrigate nearby sugarcane fields, and two canals perpendicular to the north shore were employed to send the water to pumps; by 1924, the northeastern pump was forsaken. Danforth (1926) reported that inflows to Laguna Cartagena in the 1920's came from several temporary streams from heavy rainfall, and occasionally the lagoon overflowed into the tributaries of the Boquerón River which drains to the sea. Average depth at that time was 0.6 to 0.9 m and maximum depth was 1.5 m. Danforth (1926) also reported the lagoon dried periodically.

Throughout 1950, water hyacinth (*Eichhornia crassipes*) was introduced to control water level in some areas. In 1955, the principal canal of the Lajas Valley Irrigation System initiated operations which changed the hydrology of most of the southwest portion of Puerto Rico, including Laguna Cartagena. Laguna Guánica and El Anegado were drained in 1953; Laguna Cartagena was not drained because of its high ecological value and because it would have been difficult to dry the area completely (Colón, 1982; cited in Díaz-Soltero, 1990). However, it was used for irrigation purposes. In 1956, a floodgate was built at the western end of the lagoon to maintain a constant water level; nevertheless, this structure actually decreased the water level of the lagoon. When the floodgate was vandalized in 1960, water levels were lowered even further (Colon, 1982; cited in Díaz-Soltero, 1990).

Díaz-Soltero (1990) reported four sources of water inflows into Laguna Cartagena: rainfall, two streams (Quebrada Platina and Quebrada Margara), the irrigation canal (1.2 m) and an unknown quantity of subterranean water. Thus, in the latter 1980s, the lagoon maintained a maximum water depth of approximately 2-3 m. Water exited the lagoon from a discharge from the west canal, evaporation, and evapotranspiration. Currently, a hydrologic basin of 28 km^2 drains into Laguna Cartagena. During my survey (approximately one year), the water level fluctuated from 0.2 m in the dry season to almost 2 m in the rainy season.

It is important to understand how the hydrological regime of Laguna Cartagena has changed, since hydrology is the single most important factor determining the establishment and maintenance of specific wetland processes. Hydrology controls the abiotic and biotic characteristics of wetlands, although it in turn can be influenced by the biota. Hydrologic conditions can directly modify or change chemical and physical properties such as nutrient availability, degree of substrate anoxia, sediment properties, and pH. When hydrologic conditions change even slightly, major biotic changes can occur in species competition and richness and in productivity.

Wildlife and aquatic plants

Laguna Cartagena Refuge provides habitat to many endangered species. According to Danforth (1926), in the 1920's the lagoon was considered the most important breeding ground for resident waterfowl and migrant water birds in Puerto Rico. The Bird Checklist of the United States indicates approximately 120 species of birds have utilized Laguna Cartagena, some of them endemic species like *Vireo latimeri* (Bien-te-veo) and *Todus mexicanus* (San Pedrito). Laguna Cartagena has a very rich flora with approximately 26 species utilized as food for waterfowl (Díaz-Soltero, 1990). In the 1950's, additional cattail (*Typha dominguensis*) was planted to provide cover for waterfowl and other hydrophytes were introduced to increase available food for ducks (Díaz-Soltero, 1990).

Wetlands description and importance

Wetlands are described as areas where the water table is at, near, or above the land surface long enough each year to promote the formation of hydric soils and the growth of hydrophytes. Wetlands are important ecosystems and encompass 7-9 million km^2 (4-6%) of the Earth's land surface, although it was not until recent times that their unique properties and multiple values have become appreciated (Keiper *et al*., 2002). Some of the benefits to society and the environment include erosion and flood control; improvement of water quality; high biological productivity to support great diversity of plant and animal species like waterfowl, amphibians and other wildlife; and provide many recreational activities.

The National Research Council's 1995 list the seven major classes of wetland as freshwater marsh, tidal salt or brackish marsh, prairie potholes, fens, bogs, swamp bottomland, and mangrove forest. Laguna Cartagena is classified as a freshwater marsh. Freshwater wetlands are those in which salinity from ocean-derived salt is less than 0.5 ppt. These wetlands are one of the most productive and are characterized by emergent soft-stemmed plants, mainly herbaceous, inhabitating shallow water areas (Keiper, 2002).

Puerto Rico has an abundance and diversity of wetlands. However, the ecological values of these systems, their complexity, the services they provide, and their connection with the surrounding landscape are still not well understood. The wetlands that now occur on the Island may represent only a fraction of those existing before agricultural development, and those that could recover once agriculture diminishes are now threatened by urban development. There is no recently published information concerning freshwater wetlands in Puerto Rico, except for a field guide to the wetland plants (UPR, 2001). However, studies about mangrove wetlands indicate a rapid rate of loss compared to existing wetlands 50 or more years ago (personal communication, José Cruz, Department of Natural and Environmental Resources). There are some estimates regarding the extent of mangrove wetlands, although there are no such studies for freshwater wetlands.

Description of the problem

Altered wetlands often become dominated by non-native or invasive plant species, which can lower the biodiversity, decrease its functional value for humans and other species, and even result in complete wetland loss (Reed and Cahoon, 1992 cited in Owen, 1999). Currently, eutrophication caused by drainage of water from Laguna Cartagena, accumulation of organic matter, and intermittent inflow from runoff have resulted in increased growth of cattail and water hyacinth, forming a large marsh instead of an open freshwater body. There are not enough water supplies to sustain some key plant species necessary to maintain biodiversity of birds, and exotic plant species are competing with native ones, putting them in a major risk of extinction. Sedimentation, drought and vegetation changes have severely affected aquatic fauna like fish and some sensitive species of insects; both essential to waterfowl diet.

What can be done?

To restore the Lagoon, it is necessary to assess its actual condition. A study of water quality could measure the suitability of water for a particular use based on its physical, chemical and biological characteristics. A complete assessment of water quality is based on appropriate monitoring of these elements. Physical and chemical parameters that were measured in the present study included pH, temperature, dissolved oxygen, nutrients (nitrate, nitrite, orthophosphate, ammonia) and metals (cadmium, lead, zinc, and cobalt).

Although physical and chemical variables are commonly used to determine water quality, these parameters by themselves can only express the conditions of water at the moment of sampling. On the other hand, biological monitoring can give information about the water conditions for a longer period. For example, changes in vegetation and organisms could be the result of a past disturbance and not the present condition of the aquatic environment. Hydroperiod, vegetation, predator pressure, and trophic status could also affect distribution, abundance, and community composition of aquatic organisms, since biological communities reflect an overall ecological integrity.

Even though there are different biological variables for the assessment of wetlands, I decided to use aquatic macroinvertebrates because **(1)** they are one of the most common, diverse and abundant groups of organisms in inland and coastal freshwater wetlands; **(2)** their ubiquitous incidence favors comparative studies; **(3)** many of them complete their life cycles in wetlands; **(4)** their taxonomy is well studied (at least to family level) and identification keys are accessible; **(5)** the stationary nature of some forms help to determine the result of pollution of specific areas; **(6)** they react with a range of sensitivities to numerous kinds of stressors – so their presence, absence, abundance, morphology (asymmetry), physiology or behavior can indicate that the physical and/or chemical conditions are outside their favored limits; **(7)** they are crucially important to the overall functioning of wetland ecosystems because of their central position in wetland food webs - they feed upon wetland plant, detritus, as well as on algae, and in turn are consumed by wetland birds and fish; **(8)** and routine monitoring can be relatively inexpensive (Teels and Adamous, 2002; Rosenberg and Resh, 1993, Rosenberg *et al.* 1986). Also, there are different options for data analyses, like biotic indices, diversity indices and individual responses.

Many researchers interested in understanding the ecological functions of wetlands or conserving the biological diversity and ecosystems health of endangered wetland habitats are now focused on the invertebrate fauna. Batzer *et al.* (1999) have highlighted and synthesized many of these research efforts on invertebrates in freshwater wetlands of North America. Information on aquatic insects in the freshwater wetlands of Puerto Rico is scarce in the scientific literature. These studies are mostly of taxonomic nature (i.e. Leng and Mutchler, 1914, 1917; Barber, 1939; García-Díaz, 1938; Travers, 1938; Wolcott, 1948; Drake and Maldonado, 1954). Few ecological studies have used aquatic macroinvertebrates as water quality indicators or as a sign of environmental disturbances in the tropics, and less have been published. Neither they have been used to create biotic indices or to corroborate if pre-existing indices from other countries can be use to assess the condition of the different water resources in Puerto Rico. In the present study I monitored three types of variables: physical, chemical and biological, in Laguna Cartagena, Lajas, to have a better understanding of the interactions that occur within our freshwater wetlands resources, in order to facilitate their management. This survey also represents the first study on the diversity, abundance and ecology of aquatic macroinvertebrates at Laguna Cartagena.

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CHAPTER 1: Macroinvertebrate Community Ecology and Responses to Physical Disturbances and Management in Laguna Cartagena

Insects as bioindicators of environmental disturbances

Introduction

Endangered wetland ecosystems are getting much attention and the importance of insects in these environments is being acknowledged. Insects have proven to be a very useful tool for testing ecological paradigms (Batzer and Wissinger, 1996). Ecologists recommend the use of resident organisms, such as insects, as sensitive indicators of disturbances, in order to achieve and preserve the highest water quality on the diverse water resources.

Community structure of freshwater organisms has been used for biomonitoring since the revolutionary work of two German scientists, R. Kolkwitz and M. Marsson, early on 1900s; which lead to the development of indicator organisms. By 1920 Danforth revealed that insects were also important in the food web of waterfowl. Subsequent studies by wildlife workers during 1960's and 1970's revealed the same (Murkin and Batt, 1987 cited in Batzer and Wissinger, 1996). This is why much of the recent work on wetland insects have been subsidized by entities interested in wildlife.

According to Rosenberg and Resh (1993), biomonitoring is the systematic use of living organisms or their responses to determine the quality of the environment. Biomonitoring is one of the most valuable tools for environmentalists, because it is based on the straightforward premise that living organisms are the ultimate indicators of environmental quality (Mandaville, 2002). Rosenberg and Resh (1993) also said that "since water pollution is essentially a biological problem, making chemical measurements will be like taking snapshots of the ecosystem, whereas biological measurements will be like taking a videotape".

Resh and Kobzina made a database search from 1993 to 1998 at Berkeley, California, in which they confirmed that macroinvertebrates were the most popular group in biomonitoring practices (cited in Mandaville, 2002). Barbour *et al*. (1999), Kerans and Karr (1994), Merritt and Cummins (1996), among others, have described the advantages and disadvantages of using macroinvertebrates as bioindicators of environmental disturbances.

Many biotic indices have been created based on macroinvertebrates. In these, a numerical score is given to a specific organism at a particular taxonomic level. For example, in the Hilsenhoff biotic index and the family-level biotic index for arthropods, numbers from cero to ten are conferred to the collected specimens in which cero means very sensitive to contamination and ten is conferred to the most tolerant families or species (Hilsenhoff, 1988; Hilsenhoff, 1998). Undisturbed aquatic systems generally have a great diversity of species, dominated by the most sensitive ones. Meanwhile, presence of numerous families of highly tolerant organisms usually indicates poor water quality (Hynes, 1998). However, high diversity does not ensure that a site has a high ecological value (Dunn, 1994 cited in Giraldo and Garzón, 2002).

Even though the number of indices based on the benthic macroinvertebrate communities is probably about five times that of any of the other group, with about fifty indices currently in existence (Mandaville, 2002), tolerance values assigned to streams (i.e. like Hilsenhoff 1987) may not be applicable to wetland invertebrates because many wetland invertebrates are tolerant or adapted to the fluctuating oxygen conditions. These invertebrates are referred to as wetland specialists and include water boatmen, backswimmers, diving beetles, marsh beetles, mosquitoes, marsh flies, biting midges, horse flies, and families of snails, among others. When evaluating the impact of management practices, it is useful to weight the species abundances at a site to account for the prevalent organisms rather than the vagrant species (Dufrene and Legendre, 1997).

Laguna Cartagena is considered a managed habitat. According to Batzer and Wissinger (1996), managed habitats are locations where most research on marsh insects has been done; though research has been focused on temperate regions and specific wetland types (Finnamore and Marshal, 1994; Krieger, 1992; Murkin, 1989, Rosenberg and Danks, 1988 cited in Batzer and Wissinger, 1996). Some ecology studies have been done in Laguna Cartagena, however the only information sources related to invertebrates at the lagoon have resulted from the ornithological studies made by Dr. Stuart T. Danforth (1926) in which he mentioned those insects that were important in the diet of water birds (List 1-Appendix), and from subsequent studies of aquatic insects made by Dr. Julio Garcia-Díaz (List 2-Appendix).

Aside from their role in the feeding ecology of birds, invertebrates offer food chain support for many other organisms and play a major role in nutrient cycling and overall wetland productivity (Murkin and Batt, 1987, cited in Euliss *et al*., 1999). Unlike migratory wildlife, invertebrates that live in temporary wetlands must have adaptations to tolerate environmental extremes.

Tripp and Collazo (2002) studied the diversity and distribution of *Trichocorixia* sp. (Hemiptera) and *Artemia* sp. (Anostraca) in relation to water salinity at the Cabo Rojo salt flats, and discussed their importance as prey species for shorebirds. This may be the only Puerto Rico study on wetland aquatic insect ecology.

Through this chapter I am going to discuss how physical changes at Laguna Cartagena, from June 2003 to March 2004, affected abundance and diversity of aquatic insects.

Materials and methods

I. Study Site:

Laguna Cartagena Wildlife Refuge is located in the municipality of Lajas (18°01'N, 67°06'W) between two mountain ranges, the Central Cordillera which is north of the lagoon and the Sierra Bermeja, located south of it. The lagoon is about 20-30 m above sea level and covers an area of approximately 121 ha.

According to the Holdridge System (Holdridge, 1947) the lagoon is part of the subtropical dry forest. Mean annual temperature is 25°C (max = 39 ºC, min = 9 ºC), and mean annual precipitation is 97 cm (38 inches). According to Díaz-Soltero (1990) showers occur throughout the year, but heavy rainfalls occur from September to November, with a second peak usually in May; the same was observed during the present study, which shows little variation in the climate. Precipitation is the main hydrologic source for Laguna Cartagena, though a modicum amount could be from subterranean origin (Colon, 1982, cited in Díaz-Soltero 1990).

Soils belong to the Fraternidad-Aguirre-Cartagena and Guayama-Aguilita-Amelia associations (USDA). Fraternidad Series soils are reasonably well drained, highly fertile and neutral to calcareous. Aguirre Series soils are rather poorly drained, have a clay surface layer, are of medium fertility and highly calcareous. Cartagena Series soils are poorly drained and more saline than Fraternidad and Aguirre. Aguilita Series soils are well drained and calcareous, with a clay surface layer of 12-20 cm over limestone. Amelia Series soils are gravelly clay loam of medium fertility. Guayama Series soils are localized on mountain sides of Sierra Bermeja; these soils are well drained with a cherty clay loam surface over volcanic rocs, acids and of medium fertility.

II. Methodology:

A. Sampling locations and schedule:

Aquatic macroinvertebrates were sampled in two sites on the southwestern section of the lagoon (Figure A-2). Sampling sites were previously chosen by the Fish and Wildlife Service because of accessibility or because the lagoon receives water inputs at those areas. Site 1 (18°00.704' N and 067°06.198'), when flooded, has an approximate depth ranging from 15 cm to 1.5 m, and dense emergent (*Typha dominguensis*) and floating (*Eichhornia crassipes*) vegetation. Site 2 (18°00.721' N and 067°06.045' W) is an open water area that, when flooded, has an approximate depth of 11 cm with a maximum depth of 40 cm, and sparse emergent vegetation. Even though site 1 and 2 are separated by approximately 200 m, the water at the two sites interconnects during heavy rains during November and May.

Five samplings were done in a period of ten months (June 25, 2003 – March 25, 2004). Only two samplings (February and March) were incorporated during the dry season (December-April), because inundation caused by November rains made the lagoon inaccessible for a couple of months. The other three samplings (June, July, and October) were during the rain season (May-November). Since the water level caused changes in the location of the shoreline, water coverage at the study sites varied during the year, a preliminary saturation curve (cumulative number of species/m^2) could not be made to determine the extension (m^2) of the sampling area at each site.

B. Macroinvertebrates sampling and identification:

Sampling with dip-net is a common method to collect macroinvertebrate in shallow vegetated wetlands. A D-shaped dip-net with Nytex® netting with 500 µm mesh was used to collect benthic macro-fauna. Dip-net hauls were taken in open water for one minute (1st sample) and between and within the aquatic vegetation for one minute (2nd sample). Defining the amount of time for sweeps assured repeatability protocols (Merritt and Cummins, 1996).

Collected organisms were removed from the D-shaped dip-net and the net was washed into a sieve to collect organisms attached to the netting. The sample was sieved though a sieve (0.5 mm mesh) to eliminate the excess sediments. Organisms were sorted from the detritus and stored in 70% ethyl alcohol. In the laboratory, organisms were identified using either a dissection microscope or compound microscope, and were stored in individual vials containing 70% ethyl alcohol.

Aquatic taxonomic keys (Heckman, 2002; Grant, 2001; Thorp and Covich, 2001; Needham *et al.*, 2000; Archangelsky, 1997; Merritt and Cummins, 1996; Peckarsky *et* *al*., 1990; Berner and Pescador, 1988; Fitzpatrik, 1983; Arnet, 1980**;** Smith and Fernando, 1980; Lehmkuhl, 1979; Pennak, 1978; Yung, 1954) were used to identify the collected specimens to species, or at least genus level, except chironomids that were identified to family level. Morphology of collected specimens was also studied to determine possible asymmetry of proto-wings and mouth parts.

Photos of the insects were taken and digitalized. This was complemented with drawings of diagnostic characteristics (Figs. 1.6-1.190).

C. Flora collection

Plants around both sampling sites were collected and preserved using a plant press. Species were identified later using a guide of common wetland plants in the Caribbean (UPR, 2001).

D. Characterization of insects

After identification, life cycles and trophic relations among specimens were established (Table 1.3) to understand better the community structure at the lagoon. By utilizing research literature which classifies insects as tolerant, somewhat tolerant, or sensitive in relating to environmental disturbance, insects from this study were categorized according to these same groups. Table 1.3 also includes insects collected in May 3, 2003, during a preliminary sampling.

E. Statistical analysis

The family and species abundance and diversity was calculated for each sampling date and for overall samplings (Tables A-1 to A-8). Simpson and Shannon-Wiener diversity indexes were applied to both sites on every sampling date. Values were graphed to illustrate the diversity and dominance observed during each sampling (Figures 1.3 and 1.4).

1) Simpson's Index $D = \Sigma pi^2 = \Sigma (ni (ni-1)) / N (N-1)$
2) Shannon-Wiener Index $H' = - \Sigma pi \ln pi$

where,

ni = number of individuals of species i

N = the total n umber of individuals in a sample

pi = ni /N

Hutchinson T-test (1970) was applied to Shannon-Wiener Index to determine if there was significant difference, in terms of diversity, between sites 1 and 2 (Figure 1.4).

3) $t = \frac{H'_1 - H'_2}{SH_1 - SH_2}$

4) H'= n log n – Σ fi log fi / n

5) Variance $SH = \frac{\Sigma \text{ fi} \log \text{fi} - (\Sigma \text{ fi} \log \text{fi})^2 / n}{N}$

6) Standard deviation $SH_1 - SH_2 = \sqrt{SH_1 + SH_2}$

7) Degrees of freedom $\frac{(SH_1 + SH_2)^2}{\frac{(SH_1)^2}{\Sigma n_1} + \frac{(SH_2)^2}{\Sigma n_2}}$

Jaccard index of similarity was also used. This was applied to sampling months in order to determine resemblance between them; resulting values were used to make a dendogram (Figure 1.5).

8) Jaccard Index J = C / (A+B) – C

where,

A = number of species in month a

B = number of species in month b

C = number of species in common

Results

A sum of 1207 insects, from 66 species, was collected from the two sites during the survey (Table A-7), 48 species new records for Laguna Cartagena. Insects were from five different orders: Hemiptera, Diptera, Coleoptera, Odonata and Ephemeroptera and were represented by 33 families. Hemiptera and Diptera were the most abundant orders at both sites, exceeding 75% of the overall sample. Meanwhile, Coleoptera (21 species), Odonata (17 species), and Hemiptera (16 species) were the orders with higher diversity; however, they were represented mainly by few dominant families. The occurrence of these orders and their respective families are illustrated in Tables A-1 to A-4. In addition, another 232 invertebrates, including gastropods, ostracods, copepods, and cnidarians (hydra) were recorded (Tables 1.2 and 1.4). Fewer vertebrates from the Classes Osteichthyes and Amphibia were also collected (Table 1.5).

Site 1 was represented by 58 species from 29 families and site 2 with 37 species from 21 families. Most conspicuous species in site 1 were Chironomidae sp. 1, *Centrocorisa nigripennis* and *Buenoa cf. macrophtalma*. Meanwhile site 2 was represented mainly by Chironomidae sp. 1, *Buenoa cf. macrophtalma* and *Buenoa cf. pallipes*. Ephemeroptera was the order with least representation at both sites, with only one family, Baetidae. Site 1 had a higher diversity and abundance of insects (Table 1.1).

Table 1.1 Number of specimens in each order of insects collected at sites 1 and 2 in samplings from June 25, 2003 to March 25, 2004.

Site	Total	Hemiptera	Diptera	Coleoptera	Odonata	Ephemeroptera
1	868	440	186	146	61	33
2	339	224	67	21	21	8
Total	1207	664	253	167	82	41
Percent		55	21	13.8	6.8	3.4

Table 1. 2 Non insect invertebrates collected at sites 1 and 2 in samplings from June 25, 2003 to March 25, 2004.

	Ostracoda		Gastropoda		Copepoda	Hydrozoa
Site	*Chlamydoteca*	Species 1	*Marissa*	*Tarebia*	*Macrocyclops*	*Chlorohydra*
1	43	-	4	2	4	-
2	62	14	18	2	92	3
Total	105	14	22	4	96	3

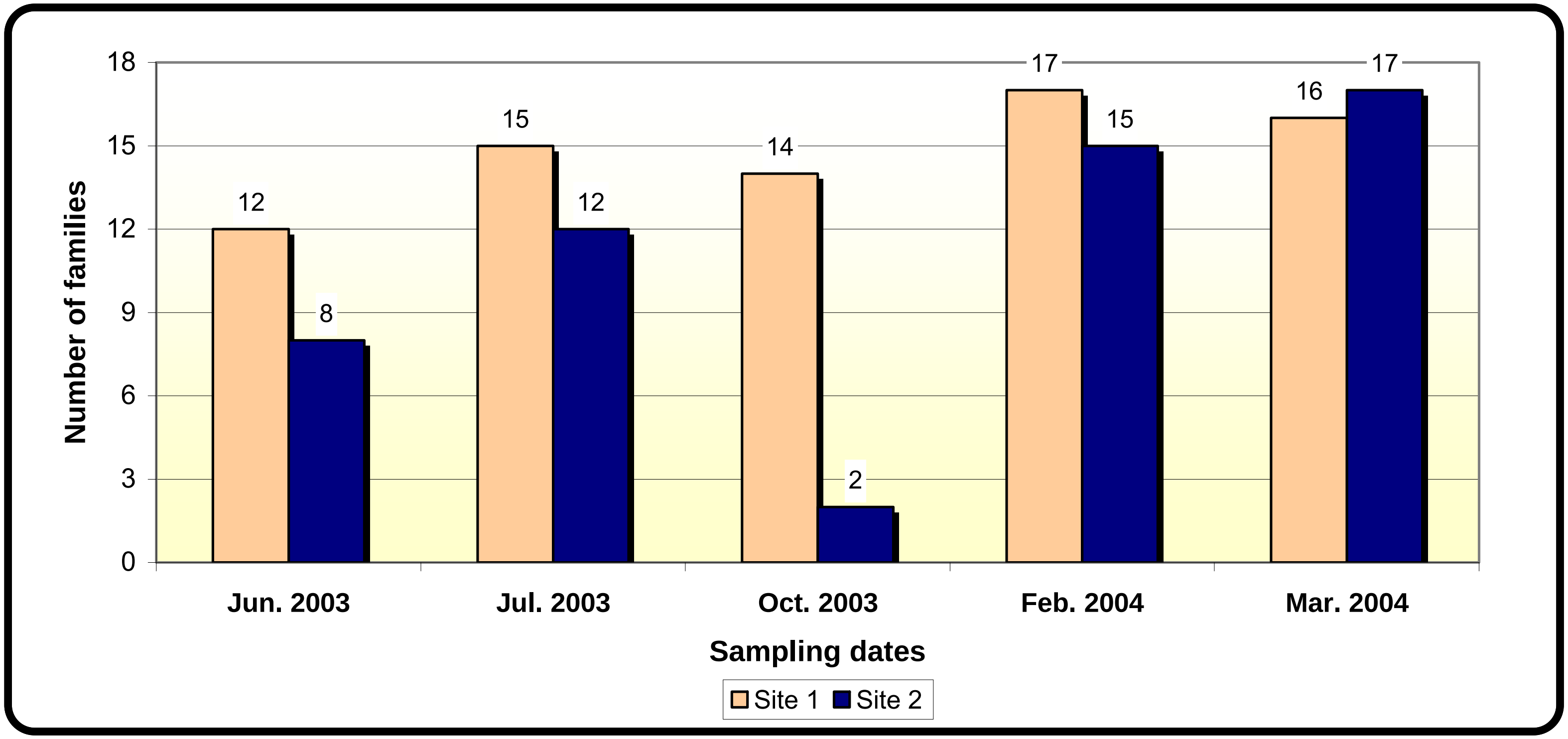

Figure 1.1 Diversity of insect families at two sites on the Southwestern part of Laguna Cartagena, from June 2003 to March 2004.

Table 1.3 Aquatic insects collected at Laguna Cartagena from May/3/03 to March/25/04: their feeding habits (C= cannibals, CG= collector-gatherers, D= detritivores, F= filters, G= generalists, H= herbivorous, O= omnivorous, P= predators, Pi= piercers, E= engulfers or S = stalk, Sc= scrappers, Sh= shredders, Sv= scavengers), life cycle (He= hemimetabolous, Ho= holometabolous) and indicator value (Low = not good, High= good because are sensible or tolerant).

Insects collected at Laguna Cartagena from May/3/03 to March/25/04			Recorded before from L. Cartagena	Recorded before from Puerto Rico	Feeding habits	Life cycle	Indicator value
Order	**Family**	**Genus/specie**					
HEMIPTERA	Belostomatidae	*Belostoma* spp.	+	+	**P** (**Pi)**, some are **C.**	**He**, uni- , bi- and multivoltine. Belostomatids are non-seasonal. ♀ oviposit at warm ponds on the back of ♂. Gerrids, corixids and notonectids oviposit during spring-summer. Some notonectids insert eggs in plants and some corixids oviposit in other organisms (Merritt & Cummins, 1996).	**Low** Tolerate wide ranges of pH and DO. Life doesn't depend entirely on water quality. Some remain under water by controlling air bubbles retained in the abdomen. Notonectidae have hemoglo-bin.
	Corixidae	*Centrocorisa nigripennis*	-	+	**P** (**Pi)** of chironomids larvae and Oligochaeta. **D** + **Sc** of algae and microorganisms. Some **CG** as early instars (Merritt & Cummins, 1996).		
		Trichocorixia sp.	-	+			
	Gerridae	*Limnogonus* sp.	-	+	**P** (**Pi)**.		
	Mesoveliidae	*Mesovelia* sp.	-	+	**P** (**Pi)** + **Sv**.		
	Veliidae	*Microvelia* spp.	+	+	**P** (**Pi)** of live and dead arthropods.		
	Saldidae	*Saldula* sp.	-	+	**P** (**Pi)** + **Sv**		
	Notonectidae	*Buenoa* spp.	-	+	Violent **P** (**Pi**) Detect prey with compound eyes. Feed of ephemerid, chironomids, larva and adult mosquitoes and other hemipteran. Some are **C** (Bay, 1974; Merritt & Cummins, 1996).		
		Notonecta sp.	+	+			
	Pleidae	*Paraplea* sp.	-		Prey microcrustacea by **Pi**.		
	Miridae	Species 1	-	+			
COLEOPTERA	Dytiscidae	*Celina* sp.	-		**P** + **Pi** larva and adult. Feed mainly of mosquitoes and chironomids. Inject prey with proteolytic enzymes (Peckarsky et al. 1990). *Laccophilus* sp. is one of the most significant predators of Hemiptera.	**Ho**, mainly univoltine. Oviposit during May-Aug.	**Low** Somewhat tolerant. Breathe atm. O_2.
		Desmopachria sp.	-				
		Hydrovatus sp.	-				
		Laccodytes spp.	-				
		Laccophilus proximus	-	+			
		Matus sp.	-				
		Megadytes cf. fraternus	-	+			
		Pachydrus sp.	+	+			
		Termonectus cf. margineguttatus	+	+			

Table 1.3 Continuation

Insects collected at Laguna Cartagena from May/3/03 to March/25/04			Reported before at L. Cartagena	Reported before at Puerto Rico	Feeding habits	Life cycle	Indicator value
Order	**Family**	**Genus/specie**					
COLEOPTERA	Hydrophilidae	*Berosus* sp.	+	+	**P** larva and **H** adult. Larvae feed mainly of chironomids, crustaceans and mosquitoes (Bay, 1974). Also **Sh** or **CG** (Merritt & Cummins, 1996).	**Ho**, bi- and trivoltine. Oviposit mainly on eutrophic ponds with some vegetation (some build cases of vegetation), during early mid-summer.	**Low** Somewhat tolerant. Some species tolerate brackish and eutrophic water.
		Enochrus ochraceus	+	+			
		Helobata larvalis	-				
		Hydrochara sp.	-				
		Laccobius sp.	-				
		Paracymus subcupreusus	-	+			
		Tropisternus lateralis	+				
	Helodidae	*Prinocyphon* sp.	-		**Sc**, **H** and **CG**.	**Ho**, univoltine	
	Carabidae	Species 1	-	+	**P** (**E**)		
	Curculionidae	Species 1	-	+	**Sh**, **H**	**Ho**, univoltine	
	Sphaeridiinae	Species 1	-	+			
	Scarabidae	Species 1	-	+			
	Staphylinidae	*Stenus* sp.	-	+	**P** (**E**).		
ODONATA	Aeshnidae	*Aeshna* spp.	-	+	**Larvae** are **P** (**G**). **E** and **S** prey (Dip, Col., Eph). **C** is rare but has been reported in *Tramea spp.* **Adults** feed on living prey, predominantly flying insects (Corbet, 1980).	According to Corbet, 1980, Merritt & Cummins, 1996: **He, Long** (10-15 instars). Mainly univoltine. Oviposition occurs during May-Aug. Growth is controlled by temperature and photo-period (altitude and latitude). In cold regions one generation could take 3-4 years and in tropical regions and temporary ponds larval maturity could take 2 month or less.	**Low** Somewhat tolerant. Quite tolerant of salinity. Tolerate [DO] of 4-8 mg/L.
		Anax sp.	-	+			
		Oploaeshna sp.	-				
	Corduliidae	*Epicordulia* sp.	-				
	Libellulidae	*Brechmorhoga* sp.	-				
		Crocothemis servillia	-				
		Idiataphe sp.	-				
		Libellula sp.	-				
		Nannothemis sp.	-				
		Micrathyria cf. aequalis	-				
		Perithemis cf. domitia	-	+			
		Sympetrum cf. vicinum	-				
		Tramea cf. onusta	+	+			
	Coenagrionidae	*Nehalennia* sp.	-		**Larvae** are **P** (**G**). **Adults** often capture immobile prey (Corbet, 1980).		**Low** Somewhat tolerant.
	Lestidae	*Lestes* sp.	+	+			

Table 1.3 Continuation

Insects collected at Laguna Cartagena from May/3/03 to March/25/04			Reported before at L. Cartagena	Reported before at Puerto Rico	Feeding habits	Life cycle	Indicator value
Order	**Family**	**Genus/specie**					
EHEMEROPTERA	Baetidae	*Centroptilum* sp.	-	+	**Adult** mayflies do not feed. Most **nymphs** are **CG** (detritus, diatoms) and **Sc** of periphyton (Wallace and Merritt, 1980; Brittain, 1982; Merritt & Cummins, 1996). Some are **Sh** and **P**, but is rare (Brittain, 1982).	H e. Oviposits more than 1000 eggs during spring-fall. Nymphal life span varies from 3-4 weeks to about 2½ yrs. Adults live from 1-2 hrs to 14 days. Have two winged instars, subimago and imago (Brittain, 1982; Merritt & Cummins, 1996).	**High** Sensible to pollution. Affected by eutrophic-cation and low pH. Many tolerate salinity. Need high % DO for gonad maturation and emergence. Baetidae are among the most tolerant. Moderately low concentrations of O_2 (Brittain, 1982).
DIPTERA	Chironomidae	Species 1	-		Most are opportunistic **O**, others are **F**, **CG**, **Sc**, **P**, mixed feeders and few are parasites (Pinder, 1986; Wallace & Merritt, 1980).	Uni-, bi-, mero- or multivoltine. 4 life stages (egg, larva, pupa and adult). Slower develop at decreasing temp. Oviposits in May, July-Sept. (Merritt & Cummins, 96').	**High** Tolerate pH from 6.0-9.0, heavy metals, oil Have hemoglobin which helps tolerate low DO (Pinder, 1986).
DIPTERA	Chironomidae	Species 2	-				
DIPTERA	Chironomidae	Species 3	-				
DIPTERA	Chaoboridae	*Mochlonyx* sp.	-	+	**P** (**Pi** or **E**). Adult do not feed.	Uni-, semi- or bivoltine	**High** Preferred low DO
DIPTERA	Ceratopogonidae	Species 1	-	+	**P** (**E**), **CG**.	Uni- or multivoltine	
DIPTERA	Culicidae	*Culex* sp.	-	+	**F**, **CG**, **D** (Wallace & Merritt, 1980).	Multivoltine,Oviposit spring-late autumn.	**Low** Breath atm. O_2
DIPTERA	Empididae	Species 1	-	+	**P** (**E**) of mosquito larvae (Bay, 1974). Some **CG**.	Univoltine (Merritt & Cummins, 1996)	
DIPTERA	Stratyomyiidae	*Odontomyia* sp.	-	+	**CG**		Breath atm. O_2 or DO
DIPTERA	Tabanidae	*Tabanus* sp.	-	+	**P** (**Pi**)	Oviposit Jun-Oct.	Breath atm. O_2 or DO

Table 1.4 Previous reports of non-insects invertebrates collected at Laguna Cartagena from May/3/03 to March/25/04 and their feeding habits

Other macroinvertebrates Collected at Laguna Cartagena from May/3/03 to March/25/04				Recorded before from L. Cartagena	Recorded before from Puerto Rico	Feeding habits
Class	**Order**	**Family**	**Genus/specie**			
Gastropoda		Ampullaridae	*Marissa* sp.	+	+	Scrapers of algae and organic matter
		Thiaridae	*Tarebia* sp.	+	+	Scrapers of algae and organic matter
Hydrozoa	Hydroida	Hydridae	*Chlorohydra* sp.	-	+	Predator (crustaceans, aquatic insects, aquatic worms, flatworms).
Ostracoda	Cypridoida	Cyprinae	*Chlamydotheca* sp.	-	+	Filter feeders
			Other sp.	-		Filter feeders
Copepoda	Cyclopida		*Macrocyclops* sp.	-	+	Predator (plankton, bacteria, mosquito larvae, protozoan, other crustaceans and green hydra).

Table 1.5 Previous reports of vertebrates collected at Laguna Cartagena from May/3/03 to March/25/04 and their feeding habits

Vertebrates Collected at Laguna Cartagena from May/3/03 to March/25/04				Reported before at L. Cartagena	Reported before at Puerto Rico	Feeding habits
Class	**Order**	**Family**	**Genus/specie**			
Osteichthyes		Ciclidae	*Oreochromis mossambicus*	+	+	Omnivore
		Poeciliidae	*Gambusia affinis*	+	+	Omnivore (mainly predator)
Amphibia	Anura	Bufonidae	*Bufo marinus*	+	+	Predators

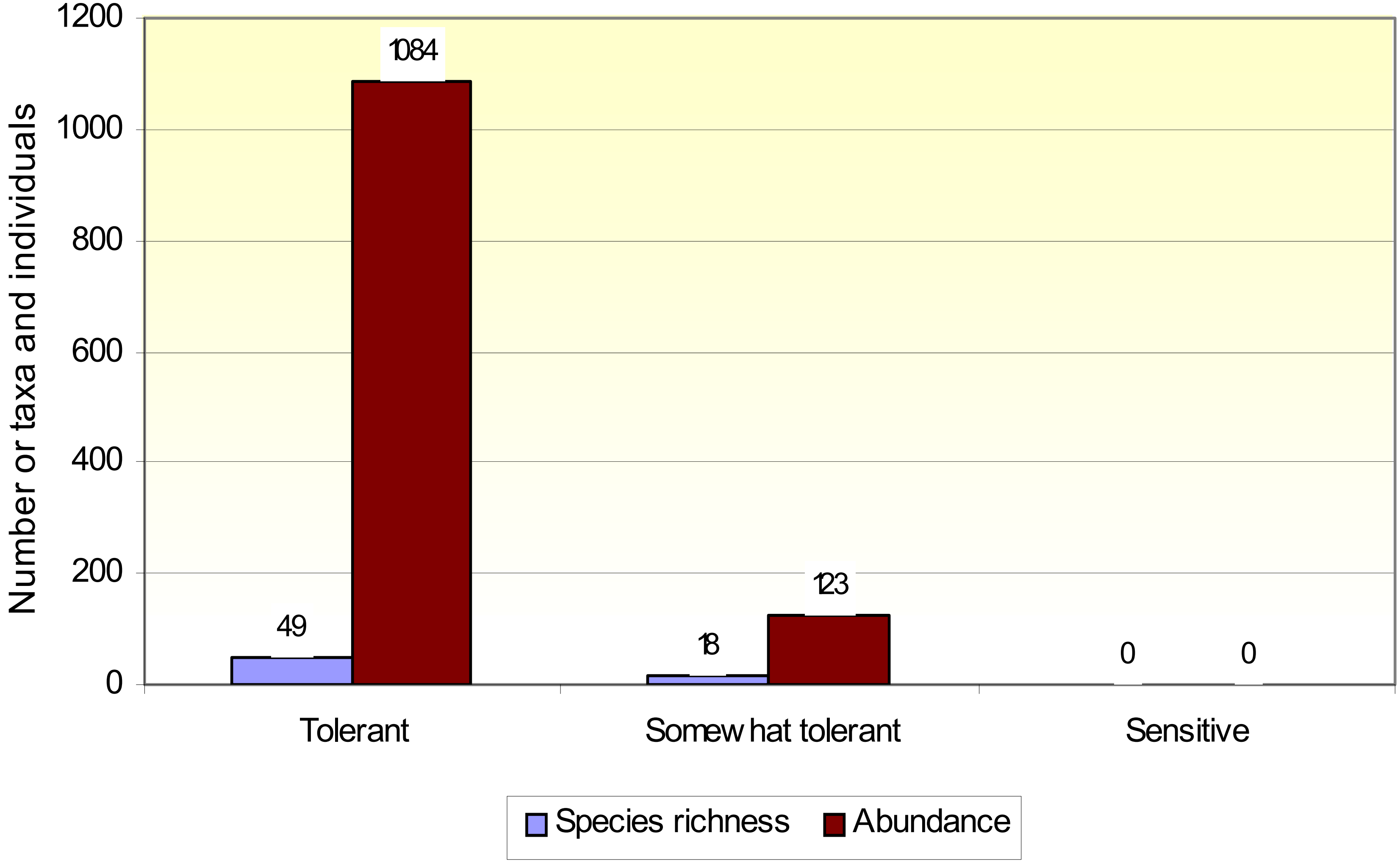

Figure 1.2 Diversity and abundance of insects tolerant, somewhat tolerant and sensible to physical environmental disturbances.

Diversity indices between the two sites were similar. At site 1 overall Simpson index (Dsp) was 0.067 (1/Dsp = 14.86) and Shannon-Wiener (H') was 3.21. At site 2 Dsp was 0.083 (1/Dsp = 12.03) and Shannon-Wiener (H') was 2.88. Results expressed by sampling month are shown in figures 1.3 and 1.4. Jaccard Index similarity dendogram (figure 1.5) shows a closer relation between successive months. Results on Hutchinson T-test (1970) for Shannon-Wiener biotic index were, |t obs| > t α = | -2.551| > 1.965 (0.05).

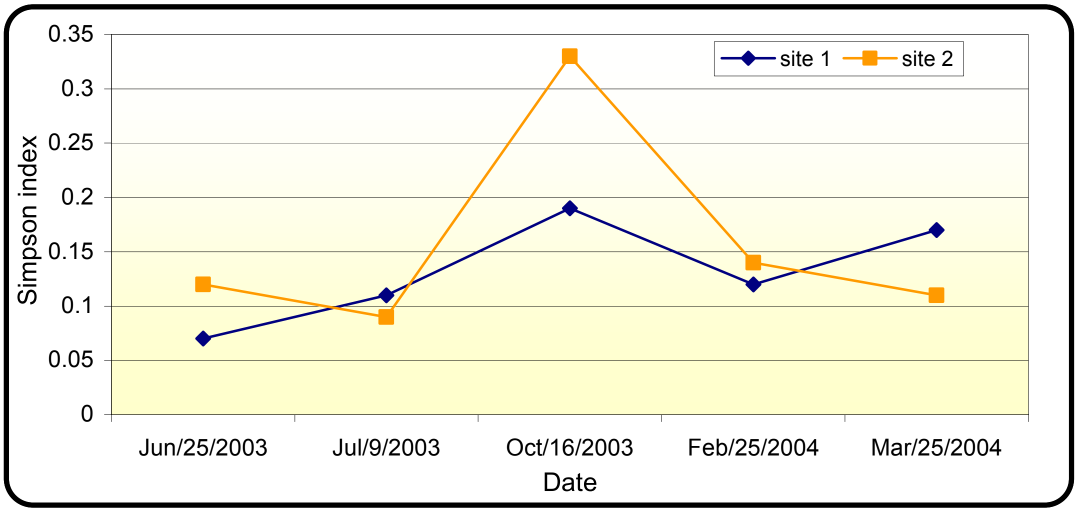

Figure 1.3 Simpson index of dominance at sampling sites1 and 2 of Laguna Cartagena.

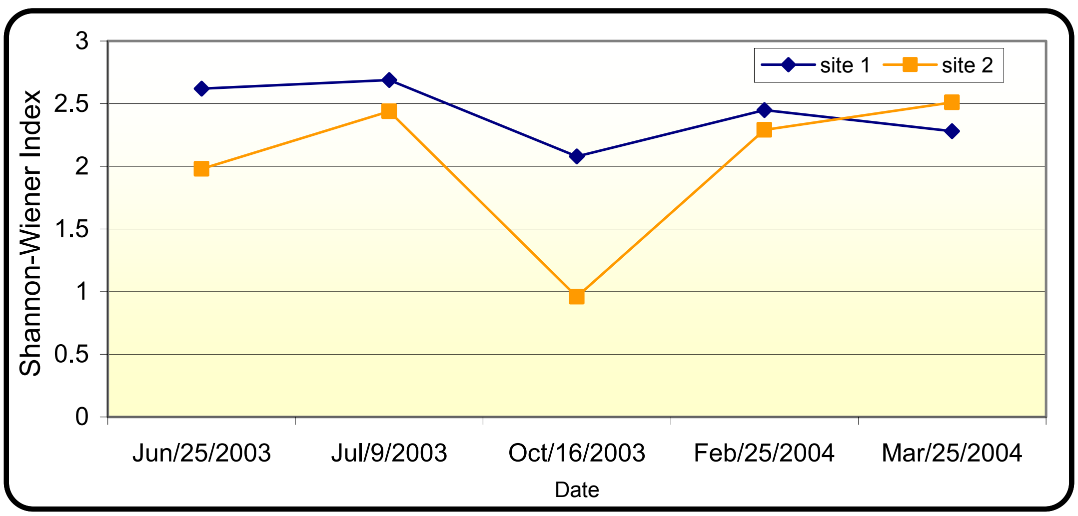

Figure 1.4 Shannon-Wiener diversity Index at sampling sites 1 and 2 of Laguna Cartagena..

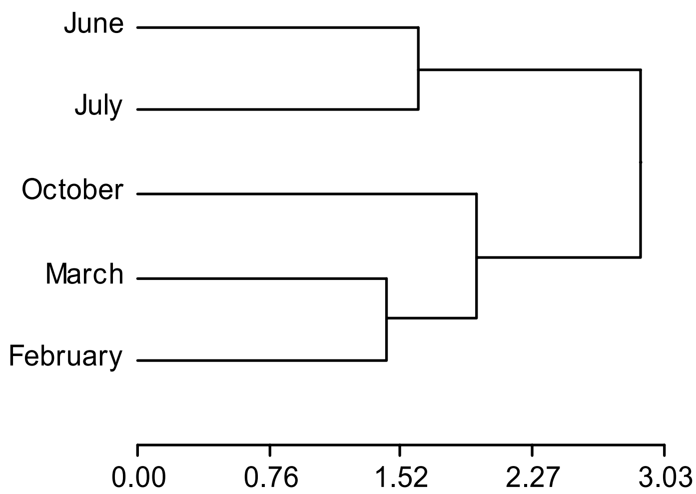

Figure 1.5 Jaccard Index of similarity dendogram (Ward: Euclidean distance).

AQUATIC INSECTS OF LAGUNA CARTAGENA
Pictures and Diagnostic Characteristics

COLEOPTERA

According to Merritt and Cummins, 1996; Arnet *et al*., 1980; Pennak, 1978; Young, 1954

Head: Chewing and biting mouthparts; visible mandibles. Antennae usually 11-segmented or less; its pattern and design are commonly used in identification.

Thorax: Two pairs of wing pads, fore wings hard (elytra), hind membranous. Number of tarsal segment its essential in identification to family.

Abdomen: Normally only abdominal sternites are visible. Some families like Dytiscidae have the coxae greatly enlarge.

Dytiscidae

Figure 1.6 *Thermonectus cf. margineguttatus* female dorsal view.

Figure 1.7 *Thermonectus cf. margineguttatus* female ventral view.

Figure 1.8 *Thermonectus cf. margineguttatus* male dorsal view.

Figure 1.9 *Thermonectus cf. margineguttatus* male ventral view.

Figure 1.10 *Thermonectus cf. margineguttatus* male fore tarsus.

Small beetles, approximately 10-11 mm long. Dorsal surface of hind tarsus bare, except for marginal cilia. Outer spur at apex of hind tibia blunt, more or less emarginated (Fig. 1.47). Suction disk of male protarsus with a few large and many small suction cups (Fig. 1.49). Elytra black with yellow maculae or transverse bands, or yellow with black spots; middle tarsi of male simple; elytra of female with sculpture of many short grooves.

Figure 1.11 *Laccodytes pumilio* (Le Conté) dorsal view.

Figure 1.12 *Laccodytes pumilio* ventral view.

Figure 1.13 *Laccodytes* sp. dorsal view.

Figure 1.14 *Laccodytes* sp. ventral view.

Figure 1.15 *Laccodytes pumilio* spur on hind legs.

Fore and middle tarsi 5 segmented. Scutellum covered by pronotum. Spines of hind tibia simple and acute (Fig. 1.42). Apical third of prosternal process somewhat diamond-shape (Fig. 1.43).

Figure 1.16 *Laccophilus proximus* (Say) dorsal view.

Figure 1.17 *Laccophilus proximus* ventral view.

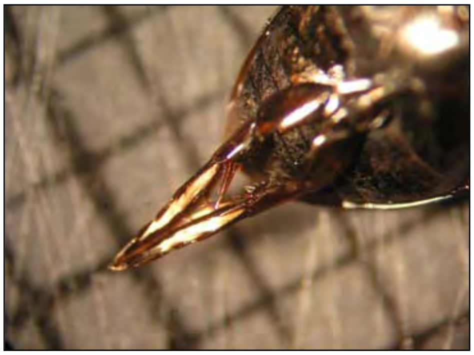

Figure 1.18 *Laccophilus proximus* spur on hind legs.

Fore and middle tarsi 5 segmented. Scutellum covered by pronotum. Spines of hind tibia notched or bifid apically (Fig. 1.44). Apical third of prosternal process lanceolate (Fig.1.45).

Figure 1.19 *Desmopachria aspera* (Young) dorsal view.

Figure 1.20 *Desmopachria aspera* ventral view.

Ventrally convex beetles. Fore and middle tarsi each 4-segmented. Scutellum covered by pronotum. Metepisternum reaching mesocoxal cavity and apex of prosternal process reaching metasternum. Hind coxal process not divided into three parts, without lateral lobe and base of hind trochanter entirely free. Hind tarsal caws unequal. Middle coxae separated by about ½ width of middle coxae (Fig. 1.39). Prosternal process rhomboid, apex acute.

Figure1.21 *Pachydrus* sp. larva.

Figure1.22 *Pachydrus* sp. larva head.

Head with frontal projection constricted at the base and spatulate at apex with lateral branch of frontal projection short; maxillary palpus 3 segmented (Fig. 1.40-1.41).

Hydrophilidae

Figure 1.23 *Enchorus ochraceus* (Melsheimer) dorsal view.

Figure 1.24 *Enochrus ochraceus* ventral view.

Figure 1.25 *Enochrus ochraceus* larva dorsal view.

Adult: Elytra with at least a sutural stria (Fig. 1.53). Maxillary palp slender, much longer than antennae, last segment as long as or longer than penultimate segment. All tarsi 5 segmented. Curved pseudobasal segment of maxillary palp convex anteriorly (Fig.1.54).

Larva: Mandibles asymmetrical, the right with 2 inner teeth and the left with only 1. Abdomen with prolegs on segments 3 through 7.

Figure 1.26 *Helobata larvalis* (Horn) dorsal view.

Figure 1.27 *Helobata larvalis* ventral view.

Elytron with at least a sutural stria. Maxillary palp slender, much longer than antennae, last segment as long as or longer than penultimate segment. All tarsi 5-segmented. Curved pseudobasal segment of maxillary palp convex posteriorly. Labrum concealed beneath clypeus that project laterally in front of eyes (Figs. 1.56-1.57)

Figure 1.28*Tropisternus lateralis* (Say) dorsal view.

Figure 1.29 *Tropisternus lateralis* ventral view.

Figure 1.30 *Tropisternus lateralis* larva dorsal view.

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Figure 1.31 *Tropisternus lateralis* larva dorsal view of head.

Adult: First segment of hind tarsi shorter than 2nd (Fig. 1.48). Antennae about same length of maxillary palp (Figs. 1.51-1.52). Mesosternum and metasternum with a continuous median longitudinal keel prolonged posteriorly into a spine between the hind coxae (Fig. 1.46). Rarely exceeding 12 mm. Prosternum sulcate (Fig.1.50). **Larva:** Head subcuadrangular, mandibles asymmetrical, lateral abdominal gills with setae.

Figure 1.32 *Paracymus subcupreusus* (Say) dorsal view.

Figure 1.33 *Paracymus subcupreusus* ventral view.

First segment of hind tarsi shorter than 2nd. Antennae shorter or only about same length of maxillary palp. Mesosternum and metasternum without a continuous spine. Elytra with at least sutural stria. Maxillary palp a short and stout, about same length as antenna, last segment as long as or longer than penultimate segment. Small species, not more than 3 mm long. Prosternum longitudinally carinate.

Figure 1.34 *Berosus* sp. larva dorsal view.

Figure 1.35 *Berosus* sp. larva head.

Eight complete abdominal segments, segments 9 and10 reduced. Labium and maxillae inserted at anterior margin of ventral side of head. First 7 abdominal segments with long tracheal gills.


Figure 1.36 *Hydrochara* sp. dorsal view


Figure 1.37 *Hydrochara* sp. ventral view.

First segment of hind tarsi shorter than 2nd (Fig. 1.48). Antennae about same length of maxillary palp. Mesosternum and metasternum with a continuous median longitudinal keel prolonged posteriorly into a spine between the hind coxae. Greater than 13 mm. Prosternum carinate. Clypeus truncate. (Figures 1.61-1.63)

Helodidae


Figure 1.38 *Prinocyphon* sp. dorsal view.


Figure 1.39 *Prinocyphon* sp. ventral view.

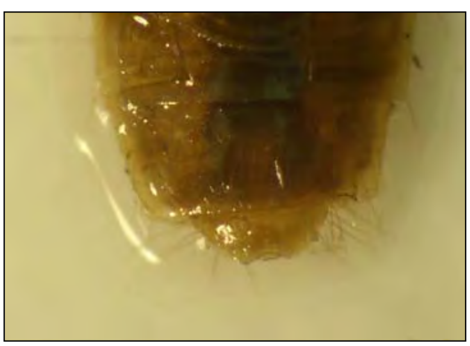
Figure 1.40 *Prinocyphon* sp. terminal segment.

Antennae longer than thorax. Abdominal segment not pilose or spinous. Eight abdominal segment rounded.

COLEOPTERA

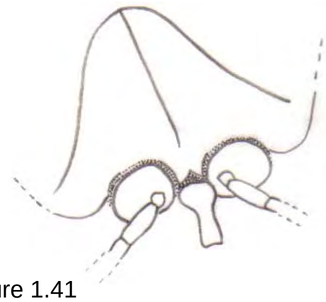

Figure 1.41

Figure 1.42

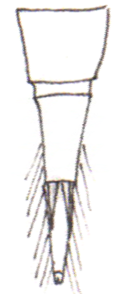

Figure 1.43

Figure 1.44

Figure 1.45

Figure 1.46

Figure 1.47

Figure 1.41 *Desmopachria aspera* fore Coxa.

Figure 1.42 *Pachydrus* sp. larva head.

Figure 1.43 *Pachydrus* sp. larva terminal segment

Figure 1.44 *Laccodytes* sp. hind leg.

Figure 1.45 *Laccodytes* sp. prosternum.

Figure 1.46 *Laccophilus proximus* hind leg.

Figure 1.47 *Laccophilus proximus* prosternum.

COLEOPTERA


Figure 1.48

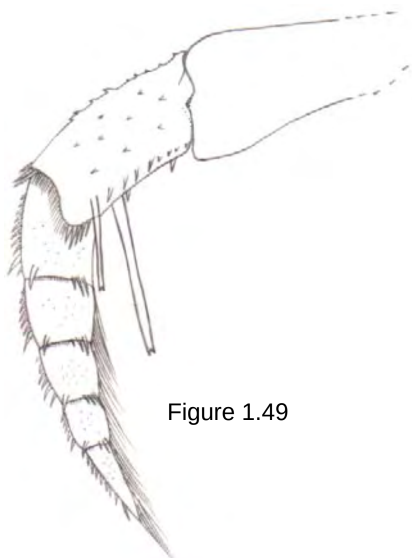
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Figure 1.50


Figure 1.53

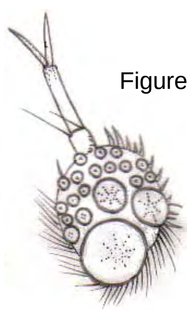
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Figure 1.51

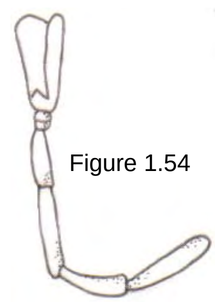


Figure 1.54

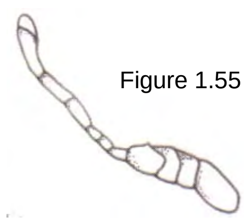


Figure 1.55

Figure 1.48	*Tropisternus lateralis* median keel.	Figure 1.52	*Thermonectus cf. margineguttatus* ventral view of male fore tarsi.
Figure 1.49	*Thermonectus cf. margineguttatus* hind leg.	Figure 1.53	*Tropisternus lateralis* sulcate prosternum.
Figure 1.50	*Tropisternus lateralis* hind leg.	Figure 1.54	*Tropisternus lateralis* labial palpus.
Figure 1.51	*Thermonectus cf. margineguttatus* dorsal view of male fore tarsi.	Figure 1.55	*Tropisternus lateralis* antennae.

COLEOPTERA

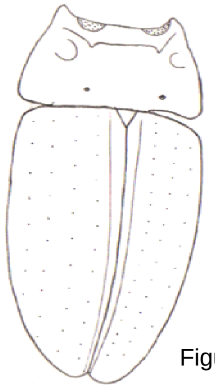


Figure 1.56

Figure 1.57

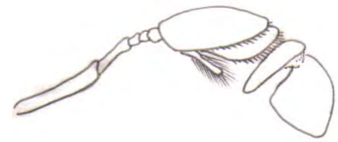


Figure 1.58

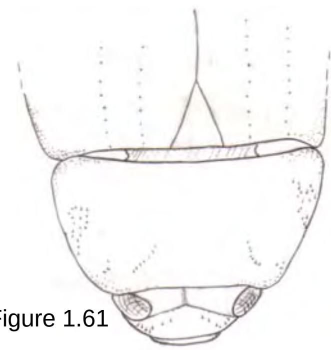


Figure 1.61

Figure 1.59

Figure 1.60

Figure 1.62

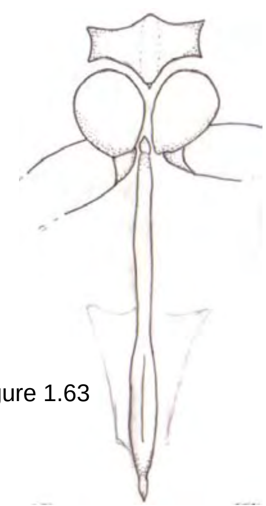


Figure 1.63

Figure 1.56 *Enochrus ochraceus* elytra.

Figure 1.57 *Enochrus ochraceus* antennae.

Figure 1.58 *Hydrochara* sp. antennae.

Figure 1.59 *Helobata larvalis* dorsal view of head and elytra.

Figure 1.60 *Helobata larvalis* antennae.

Figure 1.61 *Hydrochara* sp. dorsal view of head and elytra.

Figure 1.62 *Hydrochara* sp. hind leg.

Figure 1.63 *Hydrochara* sp. median keel and prosternum.

HEMIPTERA

According to Merritt and Cummins, 1996; Pennak, 1978; Drake and Hussey, 1955

Head: gular region not hidden. Eyes usually prominent and well developed. Mouth parts modified for sucking and piercing; is either three or four segmented.

Thorax: three segmented. Legs consist of coxa-trochanter-femur-tibia-tarsi-claw. Hind wings are membranous, whereas the hemelytra have a leathery base and a thin membranous portion apically.

Abdomen: it bears the spiracles and genitalia. In Corixidae the last few segments are symmetrical in males and asymmetrical in females.

Belostomatidae

Figure 1.64 *Belostoma bossi* dorsal view.

Figure 1.65 *Belostoma bossi* ventral view.

Figure 1.66 *Belostoma minor* dorsal view.

Figure 1.67 *Belostoma minor* ventral view.

Genus: Antennae shorter than head. Beak triangular and very short. Apex of abdomen with respiratory appendages (Fig. 1.91). Tibia and tarsus of middle and hind leg similar. Membrane of hemelytron not reduced (Figs. 1.92-1.93). Length 26 mm or less. Identified to species level by comparison with previously collected specimens at Laguna Cartagena (S. Ramos collection, at UPRM).

Notonectidae

Figure 1.68 *Buenoa cf. macrophtalma* dorsal view.

Figure 1.69 *B. cf. macrophtalma* ventral view.

Figure 1.70 *B. cf. pallipes*

Figure 1.71 *B. cf. albidus*

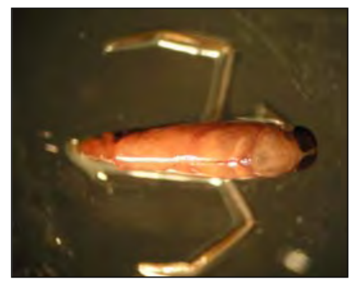


Figure 1.72 *B. cf. femoralis*

Genus: Hemelytral commissure with a definite hair-lined pit at anterior end; antennae 3-segmented (Fig. 1.95, 1.104-1.108). Identified to species level by comparison with previously collected specimens at Laguna Cartagena (S. Ramos collection, at UPRM).

Figure 1.73 *Notonecta undulata* (Say) dorsal view.

Figure 1.74 *Notonecta undulata* (Say) ventral view.

Hemelytral commissure without a definite hair-lined pit at anterior end (Fig. 1.94); antennae 4-segmented. Eyes separated dorsally. Intermediate femur with a pointed protuberance before apex; anterolateral margins of prothorax with a deep impression.

Corixidae

Figure 1.75 *Centrocorisa nigripennis* dorsal view.

Figure 1.76 *Centrocorisa nigripennis* ventral view.

Rostrum with transverse striations; nodal furrow present. Fore tarsus with spine like apical claws resembling those along lower margin of palm; pala not digitiform. Eyes not protuberant, inner anterior angles acute. Fore tibia of male not produced over base of pala (Fig. 1.98). Purinose area at base of clavopurina broadly rounded, subequal to postnodal purinose (Fig. 1.103). Pronotum and clavus only faintly rugulose. Male fore tarsus expanded. None of the species have a longitudinal groove on the ventral surface of middle femora.

Figure 1.77*Trichocorixia cf. reticulata* dorsal view.

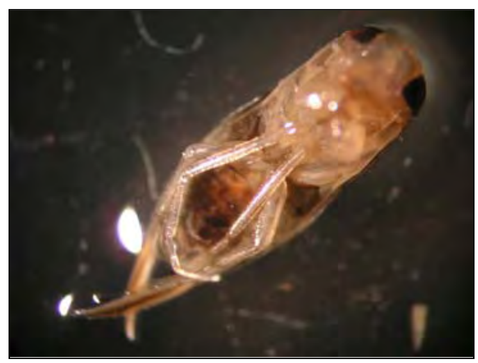


Figure 1.78 *Trichocorixia cf. reticulata* ventral view.

Rostrum with transverse striations; nodal furrow present. Fore tarsus with spine like apical claws resembling those along lower margin of palm; pala not digitiform. Eyes not protuberant, inner anterior angles acute. Fore tibia of male produced over base of pala (Figs. 1.97, 1.102). Identified to species level by comparison with previously collected specimens at Laguna Cartagena (S. Ramos collection, at UPRM).

Gerridae

Figure 1.79 *Limnogonus cf. franciscanus* dorsal view.

Figure 1.80 *Limnogonus cf. franciscanus* ventral view.

Inner margin of eyes concave behind the middle. Body long and narrow. Pronotum shiny. Fore lobe of pronotum with pair of long, pale lines (Fig. 1.101). Identified to species level by comparison with previously collected specimens at Laguna Cartagena (S. Ramos collection, at UPRM).

Mesoveliidae

Figure 1.81 *Mesovelia cf. muslanti* (Bush) dorsal view.

Figure 1.82 *Mesovelia cf. muslanti* ventral view.

Claws of legs inserted at tip of tarsi. Body stout; tarsi 3-segmented. Inner margin of eyes converging anteriorly (Fig. 1.100).

Veliidae

Figure1.83 *Microvelia cf. robusta* dorsal view.

Figure 1.84 *Microvelia cf. robusta* ventral view.

Middle tarsi not deeply cleft and without plumose hairs arising from base of cleft. Tarsal formula 3:3:3. Middle tarsi with narrow claws arising from cleft (1.96). Identified to species level by comparison with previously collected specimens at Laguna Cartagena (S. Ramos collection, at UPRM).

Figure 1.85 *Microvelia cf. capitata* dorsal view.

Figure 1.86 *Microvelia cf. capitata* ventral view.

Middle tarsi not deeply cleft and without plumose hairs arising from base of cleft. Tarsal formula 3:3:3. Middle tarsi with narrow claws arising from cleft. Guérin's (1857, cited in Drake and Hussey, 1955) description of *M. capitata*: "Fuscous; head fulvous; neck, spots on thorax, sides of abdomen and legs fulvous; hemelytra white spotted. Very close to *M. pulchella* but differ by its smaller size and by the coloration of the body. Specimen compared with previously collected specimens at Laguna Cartagena (S. Ramos collection, at UPRM).

Saldidae

Figure 1.87 *Saldula* sp. dorsal view.

Figure 1.88 *Saldula* sp. ventral view.

Hemelytra with short embolar fracture. Second segment of tarsi subequal to 3rd segment. Tubercular appendices at dorsum (Fig. 1.108)

Pleidae

Figure 1.89 *Paraplea* sp. dorsal view

Figure 1.90 *Paraplea* sp. ventral view.

Body form ovoid. All legs similar, hind tarsus with 2 well developed claws. Anterior tarsi each with two segments (Fig. 1.99); abdominal carina on ventrites 2-6.

HEMIPTERA

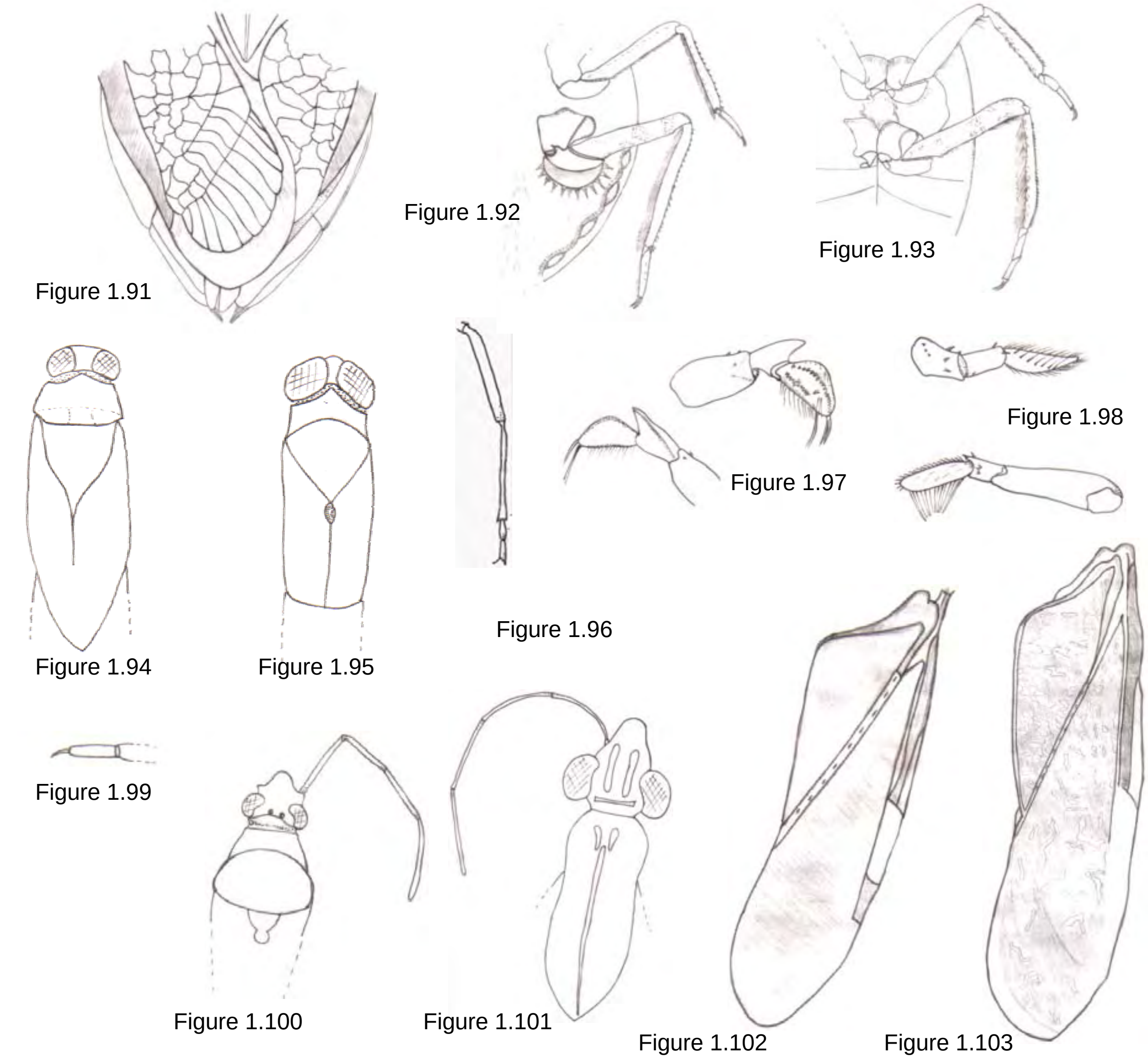
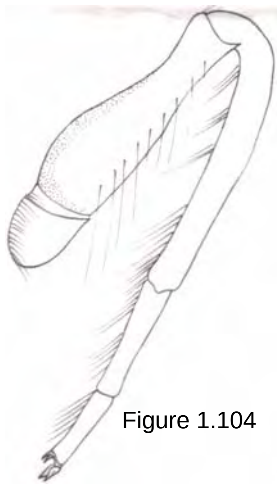


Figure 1.91	*Belostoma bossi* wing membrane.
Figure 1.92	*Belostoma minor* middle and hind leg; air strap.
Figure 1.93	*Belostoma bossi* middle and hind leg.
Figure 1.94	*Notonecta undulata* head and thorax dorsal view.
Figure 1.95	*Buenoa cf. macrophtalma* head and thorax dorsal view.
Figure 1.96	*Microvelia cf. robusta* hind leg.
Figure 1.97	*Trichocorixia cf. reticulata* fore tarsi.
Figure 1.98	*Centrocorisa cf. nigripennis* fore tarsi.
Figure 1.98	*Pleidae* sp. fore tarsi.
Figure 1.100	*Mesovelia cf. muslanti* dorsal view of head and prothorax.
Figure 1.101	*Limnogonus cf. franciscanus* dorsal view of head and thorax.
Figure 1.102	*Trichocorixia cf. reticulata* wing.
Figure 1.103	*Centrocorisa cf. nigripennis* wing.

HEMIPTERA



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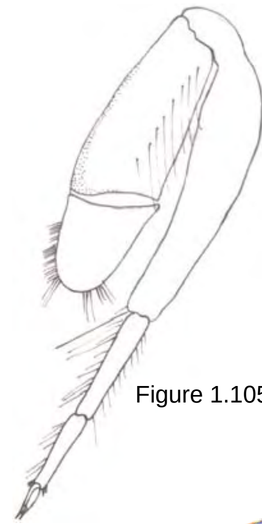

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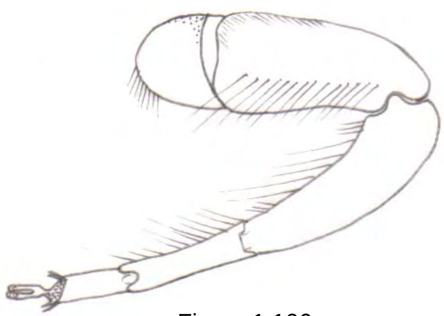

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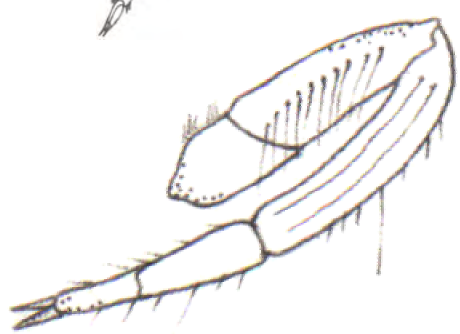


Figure 1.107

Figure 1.108

Figure 1.104 *Buenoa cf. pallipes* fore leg.

Figure 1.105 *Buenoa cf. albidus* fore leg.

Figure 1.106 *Buenoa cf. femoralis* fore leg.

Figure 1.107 *Buenoa cf. macrophtalma* fore leg.

Figure 1.108 *Saldula* sp. terminal segment.

DIPTERA (larva)

According to Merritt and Cummins, 1996 and Pennak, 1978

Critical to the identification of the families of Diptera larva is:

Head:

- extent of development of the head and whether head is exposed or retracted into the thorax

Thorax:

- body shape
- location and number of prolegs
- presence and location of spiracles

Abdomen:

- presence of terminal appendages which sometimes serve a respiratory function.

Chironomidae

Figure 1.109 Chironomidae sp. 1 pupa.

Figure 1.110 Chironomidae sp. 1 larva.

Figure 1.111 Chironomidae sp. 2 larva.

Figure 1.112 Chironomidae sp. 3 larva.

Prothorax with a pair of prolegs; abdominal segments without prolegs. Head capsule lacking labral fans. Respiratory system apneustic. Body segments lacking prominent dorsal tubercles and setae.

Culicidae

Figure 1.113 *Culex* sp. larva.

Siphon with a pectin, and with several pairs of siphonal tufts (Fig. 1.121).

Figure 1.114 Empididae?

Head with suction disc (Fig. 1.120) and body with creeping welt.

Figure 1.115 *Odontomyia* sp. larva.

Mandibles moving parallel one another in vertical plane. Hooked spines in abdominal sternites 6 and 7 (Fig. 1.119).

Figure 1.116 *Tabanus* sp. larva.

Posterior spiracle. Body integument with longitudinal striations. Intestine visible through integument. It moves by contraction and expansion (Figs. 1.117-1.118).

DIPTERA

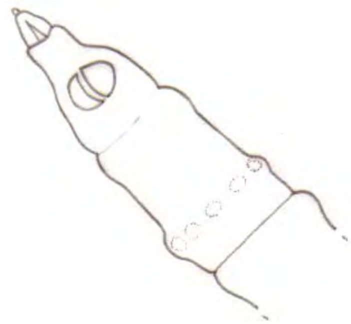
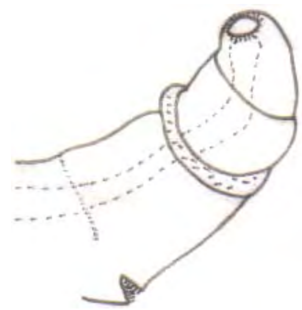


Figure 1.117

Figure 1.118

Figure 1.119



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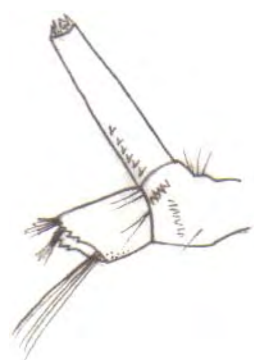


Figure 1.121

Figure 1.117	*Tabanus* sp. terminal segments.
Figure 1.118	*Tabanus* sp. head.
Figure 1.119	*Odontomyia* sp. terminal segments.
Figure 1.120	Diptera: Empididae head
Figure 1.121	*Culex* sp. siphon.

ODONATA (nymph)

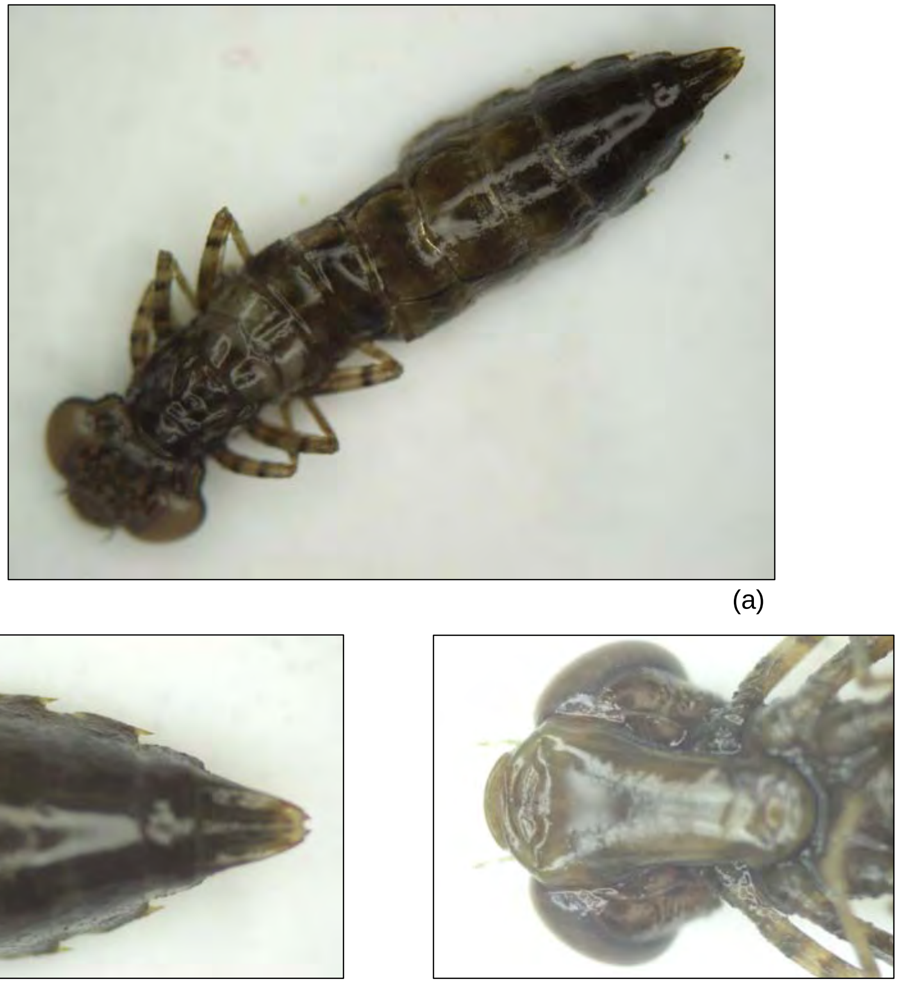
According to Needham *et al*. 2000; Merritt and Cummins, 1996; Pennak, 1978

Head: The food-getting apparatus is called the labium. It consists of a pair of palpal lobes outfitted with hooks, spines, teeth and raptorial setae that differ with family and genus.

Thorax: The prothorax is freely movable as in the adult. The mesothorax and metathorax are solidly fused to form the synthorax. Legs are usually short and robust.

Abdomen: The terminal area of Anisoptera is composed of an epiproct (superior), 2 paraproct (inferior) and 2 cerci (lateral). In the Zygoptera the epiproct and 2 paraprocts are modified to form the 3 gills (one median and two laterals).

Aeshnidae



(a) (b) (c)

Figure 1.122 *Aeshna* sp.1 (a) dorsal view, (b) terminal segments, (c) proboscis.

Palpal lobes of labium without stout raptorial setae on dorsal surface (Fig. 1.145). Prosternal margins of head rounded. Antennae about half as long the head length. Compound eyes white and shorter than their greatest width. Lateral spines present on segments 6-9. Paraprocts shorter than abdominal segments 8 + 9. Epiproct almost as long as paraprocts (Fig. 1.139).

(a)

(b)

(c)

Figure 1.123 *Aeshna* sp. 2 (a) dorsal view, (b) proboscis, (c) terminal segments.

Palpal lobes of labium without stout raptorial setae on dorsal surface (Fig. 1.145). Prosternal margins of head rounded. Antennae about half as long the head length. Compound eyes shorter than their greatest width. Lateral spines present on segments 7-9. Paraprocts shorter than abdominal segments 8 + 9 but about equal to 9 + 10. Epiproct about 2/3 paraprocts (Fig. 1.146). Mesothorax and segment 8 brighter, inner borders of eyes also brighter.

(a)

(b) (c)

Figure 1.24 *Aeshna* sp. 3 (a) dorsal view, (b) proboscis, (c) terminal segments.

Palpal lobes of labium without stout raptorial setae on dorsal surface (Fig. 1.141). Prosternal margins of head rounded. Antennae about half as long the head length. Compound eyes shorter than their greatest width. Tip of paraprocts straight. Lateral spines on abdominal segments 7-9. Paraprocts shorter that abdominal segments 8 +9 and 9 +10. Epiproct about equal to paraprocts (Fig. 1.142).

Figure 1.125 *Anax* sp. (a) dorsal view, (b) proboscis, (c) terminal segments.

Palpal lobes of labium without stout raptorial setae on dorsal surface (Fig. 1.144). Prosternal margins of head rounded. Antennae about half as long the head length. Compound eyes as long as their greatest width. Lateral spines on segments 6-9. Paraprocts about as long as abdominal segments 8 + 9. Epiproct about 5/6 paraprocts (Fig. 1.140). Thorax brighter, inner borders of eyes also brighter. A line of black dots at both sides of abdomen (dorsally).

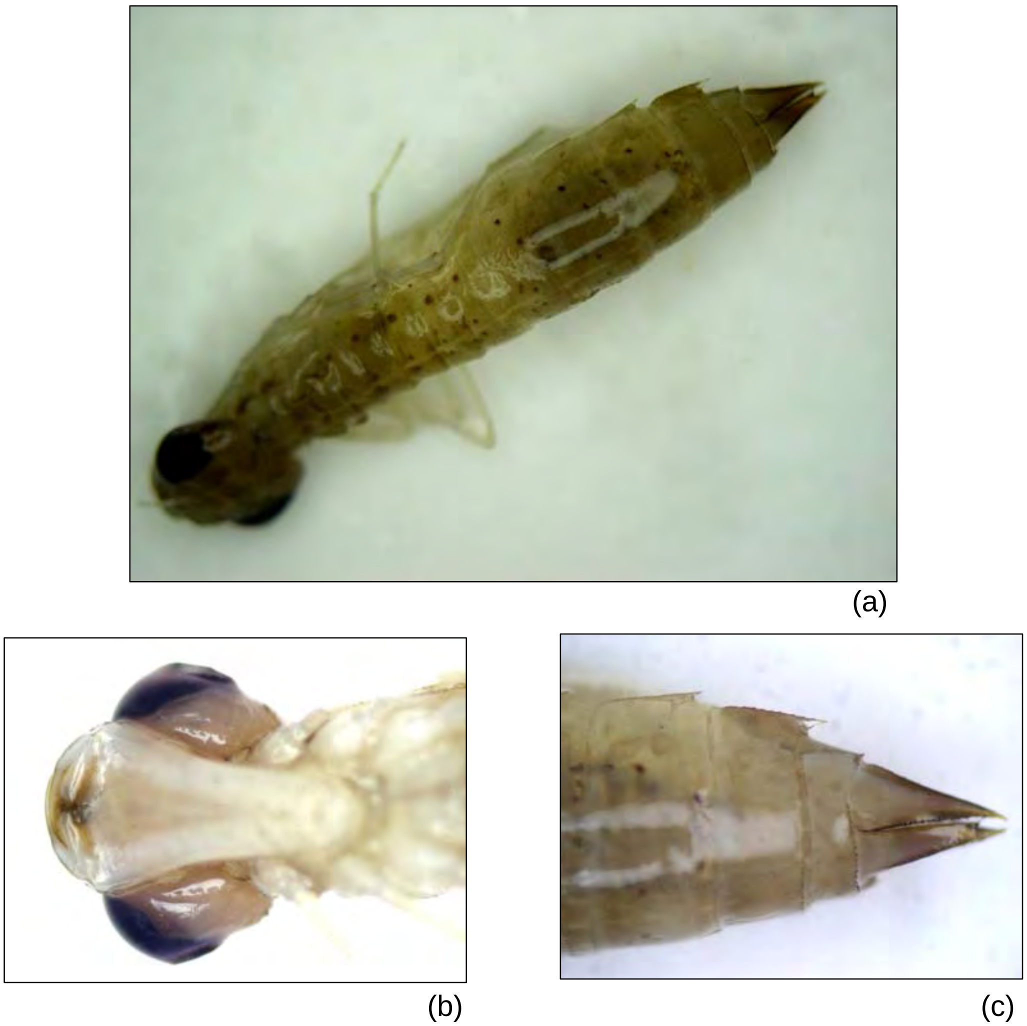


Figure 1.126 *Oploaeshna* sp. (a) dorsal view, (b) proboscis, (c) terminal segments.

Palpal lobes of labium without stout raptorial setae on dorsal surface (Fig. 1.147). Prosternal margins of head rounded. Tips of paraprocts strongly incurved. Lateral spines well developed on abdominal segments 5-9. A line of black dots at both sides of thorax and abdomen (dorsally). Epiproct about 5/6 paraprocts. (Fig. 1.143)

Libellulidae


(a)


(b)

Figure 1.127 *Brechmorhoga* sp. (a) dorsal view, (b) proboscis, (c) terminal segments.

Eyes occupying about ½ the length of head. Dorsal hooks present on abdominal segments 4-9, upright, spinelike. Epiproct slightly longer than its basal width but shorter than dorsal length of abdominal segments 8 + 9. Crenulations of distal margin of each palpal lobe evident; 7 palpal setae; outermost premental setae set apart from others and almost at a right angle to them (Figs. 1.148-1.149)

(a)

(b)

(c)

Figure 1.128 *Crocothemis servillia*, Drury *(*a) dorsal view, (b) proboscis, (c) terminal segments

Eyes occupying about ½ the length of head. Dorsal hooks, spines or knobs absent on abdominal segments5-9. Dorsum of abdominal segments 1-5 conspicuously pale, segments 6-10 much darker. Lateral margins of abdominal segments 8 and 9 somewhat concave, each bearing 15-16 spinules; legs faintly banded (1.171-1.172).

Figure 1.129 *Idiataphe* sp. *(*a) dorsal view, (b) proboscis, (c) terminal segments.

Eyes occupying about ½ the length of head. Dorsal hooks present on abdominal segments 6-9, low and blunt. Epiproct twice as long as its basal width. Cerci about 1/5 as long as epiproct; lateral spine of abdominal segment 9 about ½ length of lateral margin of segment 9; 6 palpal setae (Figs. 1.153-1.155).

(a)

(b)

(c)

Figure 1.130 *Libellula* sp. (a) dorsal view, (b) proboscis, (c) terminal segments

Eyes confined to anterior ¼ of head. Anterior margin of prementum straight on each side of median line, finely crenulate, and bases of spinulose setae not in notches between crenulation.

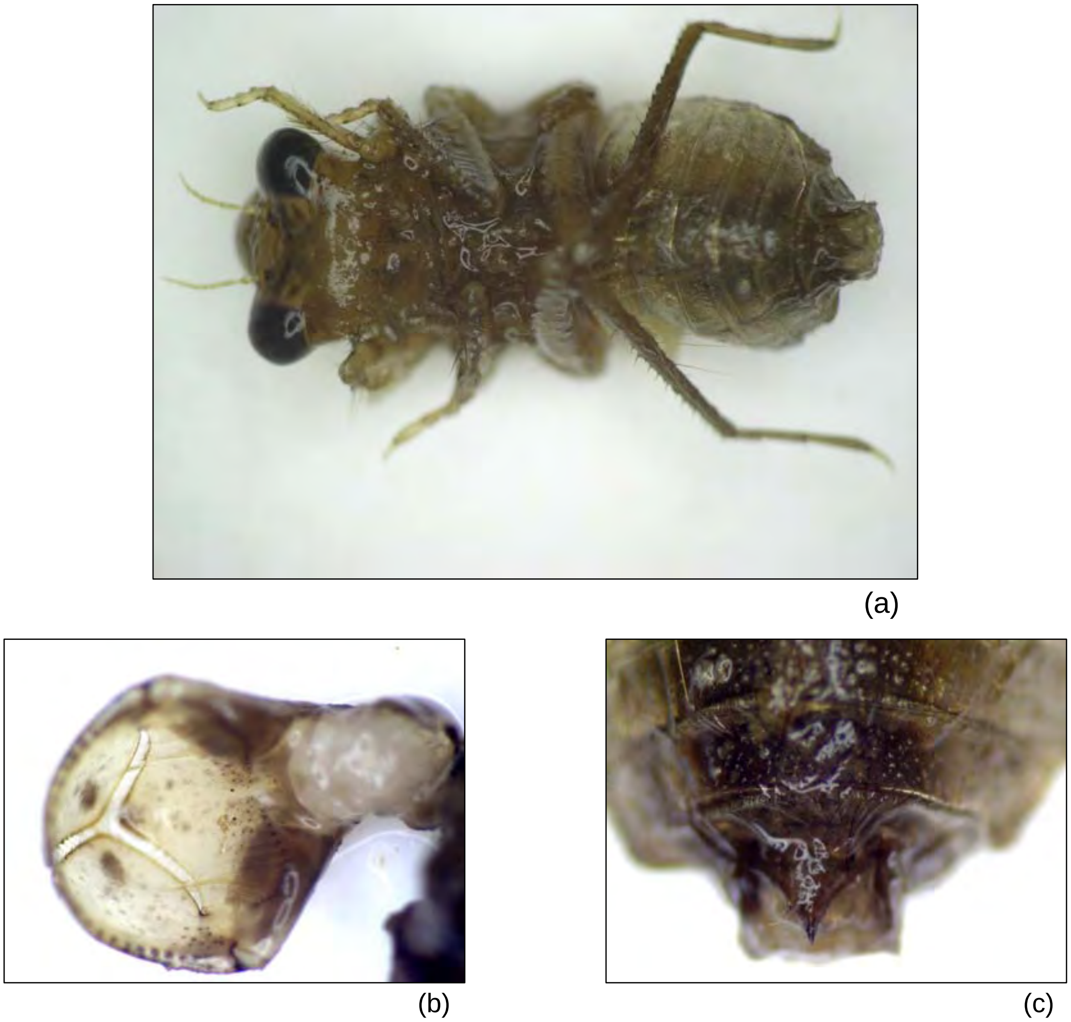
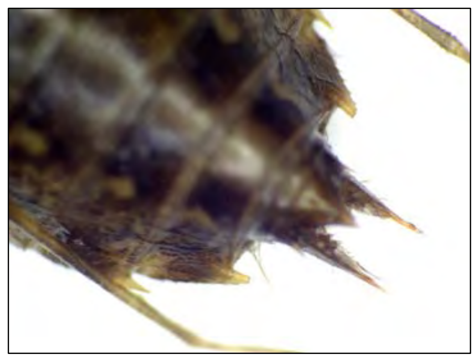


Figure 1.131 *Nannothemis* sp.? (a) dorsal view, (b) proboscis, (c) terminal segments.

Large eyes; abdomen relatively short and blunt and without dorsal hooks. According to Merritt and Cummins (1996) and Needham *et al*. (2000) it should have lateral spines on segments 8-9, but it does not (Figs. 1.173-1.174).

(a)

(b)



(c)

Figure 1.132 *Micrathyria* cf. *aequalis* (Hagen) (a) dorsal view, (b) proboscis, (c) terminal segments.

Eyes occupying about ½ the length of head. Dorsal hooks, spines or knobs absent on abdominal segments 5-9. Lateral spines of abdominal segment 9 not longer than its middorsal length (Fig. 1.152). 6 palpal setae (Figs. 1.150-1.151). Dorsum of abdominal segments 1-5 conspicuously pale, 6-10 much darker. Lateral margins of abdominal segments 8 and 9 straight, each bearing 5-6 stout spinules, interspersed with long, thin hairs. Legs strongly banded.

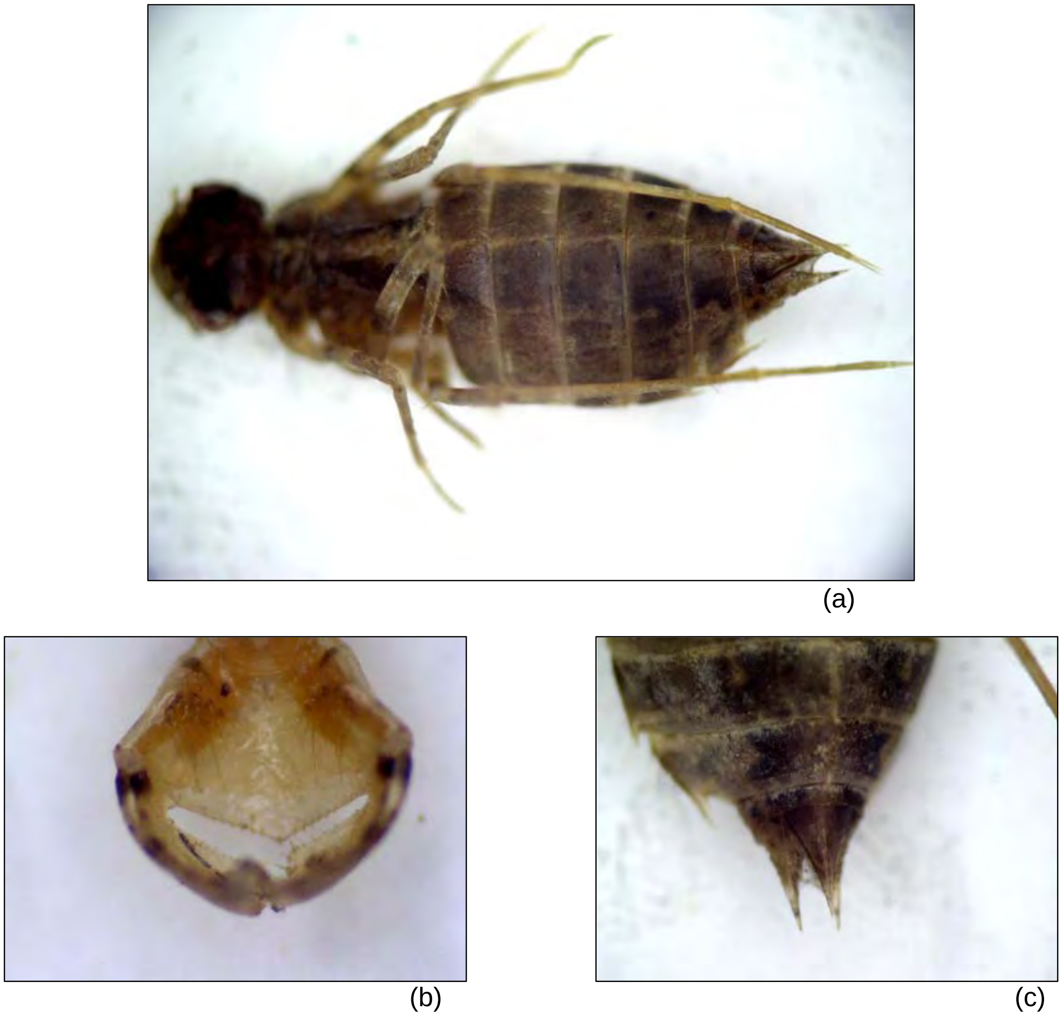


Figure 1.133 *Perithemis cf. domitia* (Drury) (a) dorsal view, (b) proboscis, (c) terminal segments.

Eyes occupying about ½ the length of head. Dorsal hooks, spines or knobs present on abdominal segments 5-9. Dorsal hooks of abdomen cultiform, like teeth. Crenulations of distal margins of each palpal lobe deep; 6 palpal setae (Figs. 1.156-1.157).

(a)

(b)

(c)

Figure 1.134 *Sympetrum cf. vicinum* (Hagen) (a) dorsal view, (b) proboscis, (c) terminal segments.

Eyes occupying about half the length of head. Dorsal hooks, spines or knobs present on abdominal segments 6-9. Dorsal hooks upright, spinelike. Epiproct not longer than its basal width (Figs. 1.158-1.160).

(a)

(b)

(c)

Figure 1.135 *Tramea cf. onusta* (Hagen) (a) dorsal view, (b) proboscis, (c) terminal segments.

Eyes occupying about ½ the length of head. No dorsal hooks. 9 palpal setae. Epiproct 2/3 as long as paraproct (Figs. 1.161-1.162).

Corduliidae

(a) (b) (c)

Figure 1.136 *Epitheca* sp. (a) dorsal view, (b) proboscis, (c) terminal segments.

Middorsal hooks present on abdominal segments 6-9. Crenulations on distal margin of palpal lobes shallow. Lateral spines on abdominal segment 9 about twice as long as those on abdominal segment 8. (Figs. 1.163-1.165).

Lestidae

(a)

(b)

(c)

Figure 1.137 *Lestes* sp. (a) dorsal view, (b) proboscis, (c) terminal segments.

Prementum distinctly petiolate and spoon-shaped (Fig. 1.167-1.168). Distal margin of each palpal lobe divided into 4 processes (3 sharp hooks and a short serrate and truncate projection (Fig. 1.169).

Coenagrionidae

(a) (b) (c)

Figure 1.138 *Nehalennia* sp**.** (a) dorsal view, (b) proboscis, (c) terminal segments.

Prementum subquadrate (Fig. 1.166). Lateral caudal gill 3 times longer than wide and terminal angle of about 60º (Fig. 1.170).

ODONATA

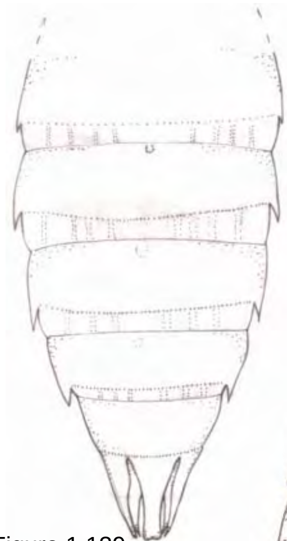


Figure 1.139

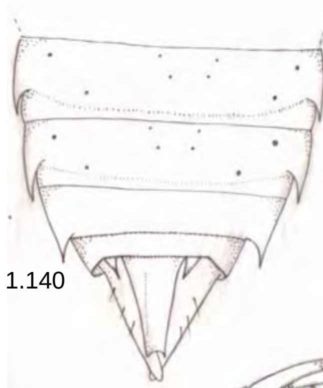

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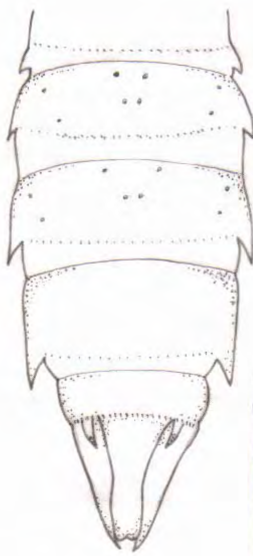
Figure 1.141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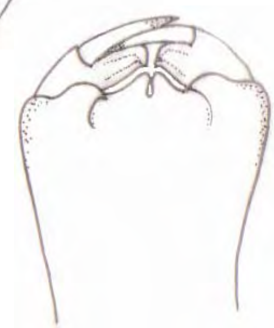
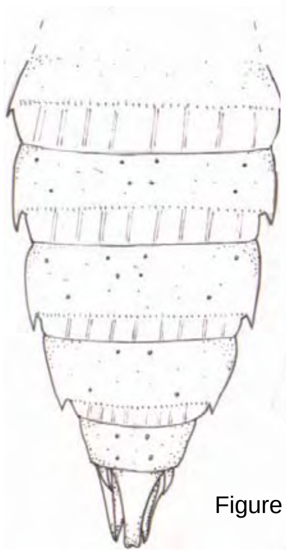


Figure 1.144


Figure 1.145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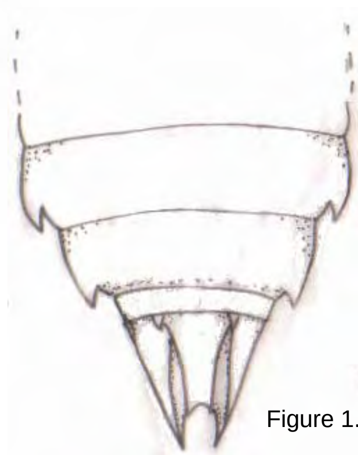


Figure 1.146


Figure 1.147

Figure 1.139 *Aeshna* sp. 1 terminal segments.

Figure 1.140 *Anax* sp. terminal segments.

Figure 1.141 *Aeshna* sp. 3 proboscis.

Figure 1.142 *Aeshna* sp. 3 terminal segments.

Figure 1.143 *Oploaeshna* sp. terminal segments.

Figure 1.144 *Anax* sp. proboscis.

Figure 1.145 *Aeshna* sp.1 and 2 proboscis.

Figure 1.146 *Aeshna* sp. 2 terminal segments.

Figure 1.147 *Oploaeshna* sp. proboscis.

ODONATA

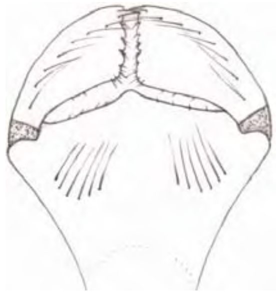
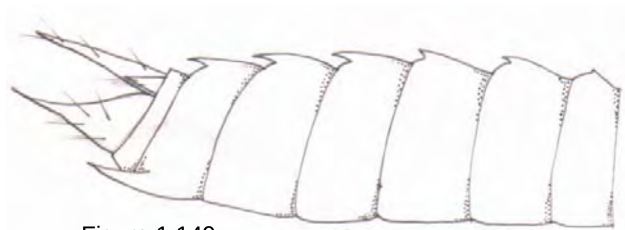


Figure 1.148



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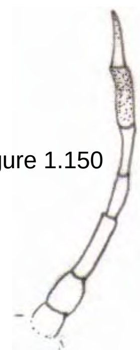


Figure 1.150

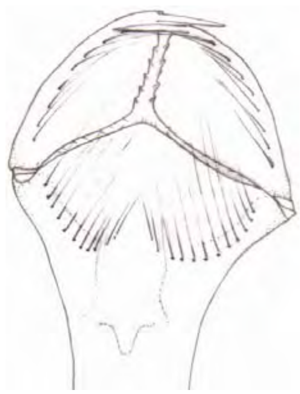
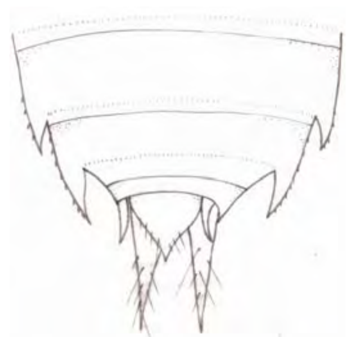


Figure 1.151



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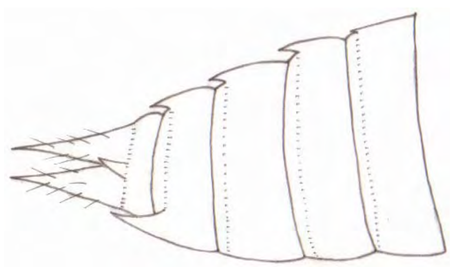


Figure 1.154

Figure 1.155

Figure 1.148 *Brechmorhoga* sp. proboscis.

Figure 1.149 *Brechmorhoga* sp. terminal segments.

Figure 1. 150 *Micrathyria cf. aequalis* antennae.

Figure 1.151 *Micrathyria cf. aequalis* proboscis.

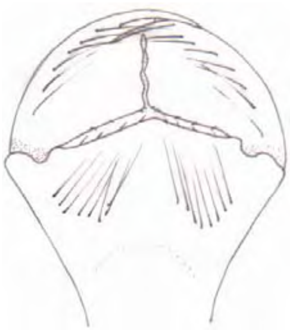
Figure 1. 152 *Micrathyria cf. aequalis* terminal segment.

Figure 1.153 *Idiathape* sp. proboscis.

Figure 1.154 *Idiathape* sp. lateral view of terminal segments.

Figure 1.155 *Idiathape* sp. dorsal view of terminal segments.

ODONATA



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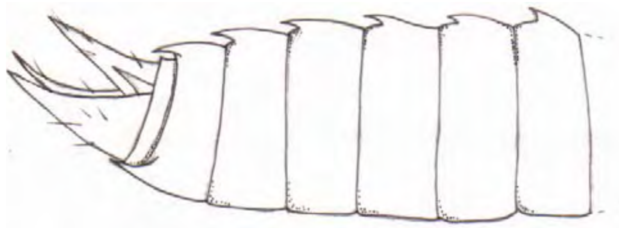

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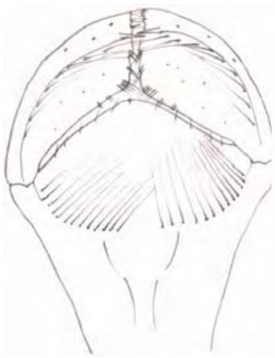

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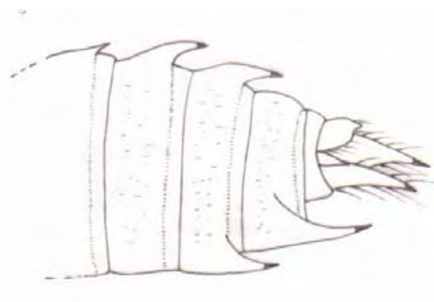

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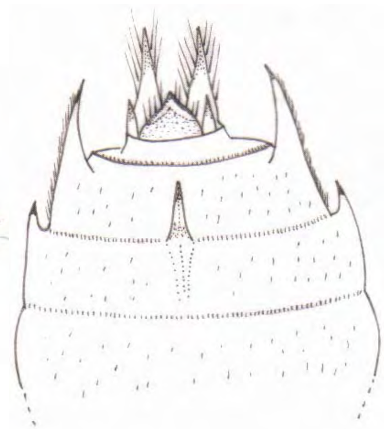

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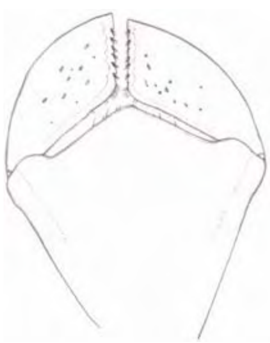

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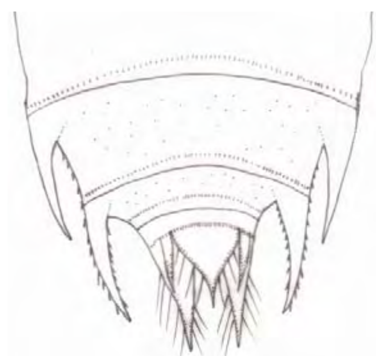
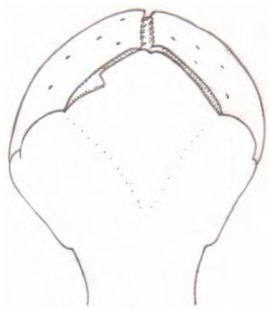


Figure 1.162

Figure 1.156	*Perithemis cf. domitia* proboscis.
Figure 1.157	*Perithemis cf. domitia* terminal segments.
Figure 1.158	*Sympetrum cf. vicinum* proboscis.
Figure 1.159	*Sympetrum cf. vicinum*. lateral view of terminal segments.
Figure 1.160	*Sympetrum* sp. dorsal view of terminal segments.
Figure 1.161	*Tramea cf. onusta* proboscis.
Figure 1.162	*Tramea cf. onusta* terminal segments.

ODONATA



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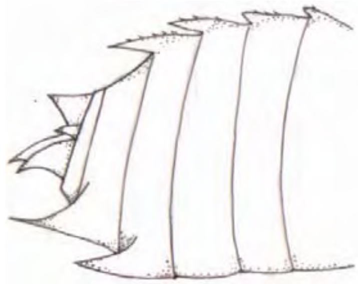

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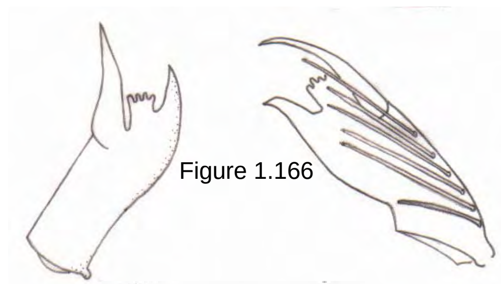

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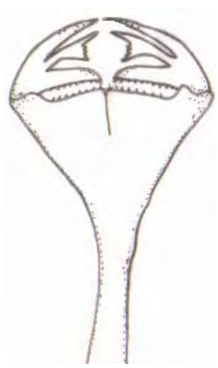

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Figure 1.168

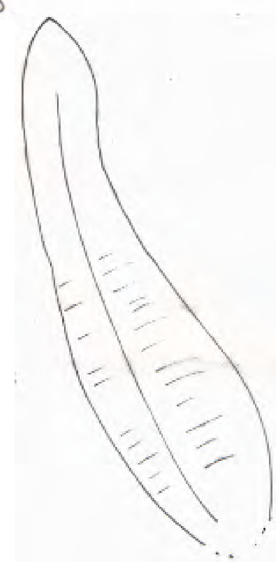

Figure 1.169

Figure 1.170

Figure 1.163 *Epitheca* sp. ventral view of proboscis.

Figure 1.164 *Epitheca* sp. lateral view of terminal segments.

Figure 1.165 *Epitheca* sp. dorsal view of terminal segments.

Figure 1.166 *Nehalennia* sp. prementum.

Figure 1.167 *Lestes* sp. complete proboscis.

Figure 1.168 *Lestes* sp. part of proboscis.

Figure 1.169 *Lestes* sp. lamella.

Figure 1.170 *Nehalennia* sp. lamella.

ODONATA

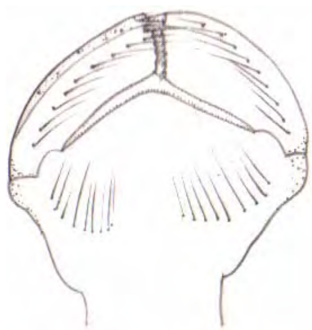

Figure 1.171

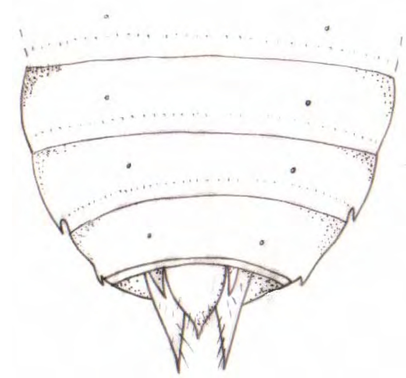

Figure 1.172

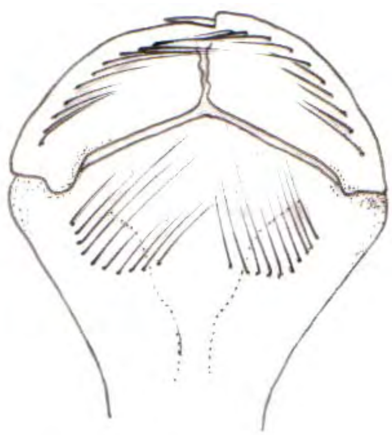

Figure 1.173

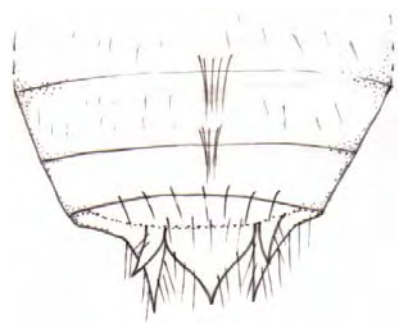

Figure 1.174

Figure 1.171 *Crocothemis servillia* proboscis.

Figure 1.172 *Crocothemis servillia* terminal segments.

Figure 1.173 *Nannothemis* sp. proboscis.

Figure 1.174 *Nannothemis* sp. terminal segments.

EPHEMEROPTERA
According to Heckman, 2002; Merritt and Cummins, 1996;
Berner and Pescador, 1988; Pennak, 1978

Head: prominent antennae, large compound eyes and vestigial mouthparts.

Thorax: large mesothorax and slender and weak legs.

Abdomen: have 2-3 segmented filaments at the end of the abdomen.

Baetidae

Figure 1.175 *Centroptilum* sp. lateral view of body.

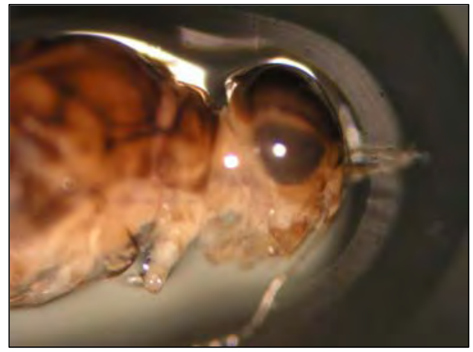

Figure 1.176 *Centroptilum* sp. lateral view of head.

Figure 1.177 *Centroptilum* sp. gills.

Figure 1.178 *Centroptilum* sp. filaments.

Claws sharply pointed. Labrum with small median notch along anterior margin. Apices of filaments without bristles; gills simple and present on abdominal segments 2-7.

TERRESTRIAL INSECTS OF LAGUNA CARTAGENA
Pictures


Figure 1.179 Sphaeridiinae dorsal view.


Figure 1.180 Sphaeridiinae ventral view.


Figure 1.181 *Stenus* sp. dorsal view.


Figure 1.182 *Stenus* sp. ventral view.


Figure 1.183 Carabidae dorsal view.


Figure 1.184 Carabidae ventral view.


Figure 1.185 Curculionidae dorsal view.


Figure 1.186 Curculionidae ventral view.


Figure 1.187 Scarabidae dorsal view.


Figure 1.188 Scarabidae ventral view.


Figure 1.189 Miridae dorsal view.


Figure 1.190 Miridae ventral view.

Laguna Cartagena Vegetation

Figure 1.191 *Pistia stratiotes* (water lettuce)

Figure 1.192 *Eichhornia crassipes* (water hyacinth)

Figure 1.193 *Typha dominguensis* (cattail)

Figure 1.194 *Cypreus* sp. (sedge)

Figure 1.195 NI shrub with white flowers

Figure 1.196 *Phyla nodiflora* (cape-weed)

Laguna Cartagena Vegetation


Figure 1.197 *Prosopis pallida*


Figure 1.198 NI shrub with brown seeds.


Figure 1.199 Mix grasses


Figure 1.200 NI shrub with yellow flower.


Figure 1. 201 *Echinochola* sp.


Figure 1.202 NI shrub with white and yellow flower.

NI: not identified

Discussion

Factors that affect distribution, abundance and community composition of aquatic macroinvertebrates include: hydroperiod (wet and dry cycles), habitat complexity (presence or absence of littoral vegetation), fire frequency, presence of vertebrate predators (fish), trophic status (oligotrophy vs. eutrophy) and surface water quality (last two will be discussed in Chapter 2). Asymmetry of organisms can be another character to examine when determining environmental pollution.

Hydroperiod and insect communities

The hydrologic regime is the most important factor determining the function of a wetland; it also affects plant composition, water quality and wetlands diversity (Zack and Román, 1988). Laguna Cartagena is a temporal water ecosystem, and its intermittent flooding and drying influence drastically the insect communities; in which efficient colonizers have an advantage (Wiggins *et al.* 1980). Evans (1966) mentioned that inundation of marshes after "dried out" is usually followed by an increase in macroinvertebrate populations (Evans *et al.* 1999). This was observed in Laguna Cartagena during February and March of 2004, when total insects collected increased 2-3 times after the flooding of November 2003.

The most frequently cited advantage for invertebrates of breeding in temporary waters is the rich detrital resource and low predation pressure (Neckles et al., 1990). When recently flooded, Laguna Cartagena is quickly (about one week) colonized by detritivores, like mayflies of the family Baetidae; this could be due to the high amount of algae and decaying plant matter accessible (de Szalay *et al.*, 1999); predators like dytiscids, hydrophilids larvae, odonates, notonectids and herbivores like adult hydrophilids raise afterward as their food resources become available (de Szalay and Resh, 1997 cited in Rader, 1999). Even though all insect orders in Laguna Cartagena showed an increase during flooded months (February and March), succession of insects could not be established. Although the lagoon begun to inundate during November's rains (sum precipitation = 19.04 cm), samplings could not be made until February.

According to Ward (1992) changes in water level directly affect entomofauna by shaping the littoral zone (where most aquatic insects reside); and indirectly influence them by reducing or eliminating macrophytes and altering chemical parameters. As a consequence, in order to achieve reproductive success, temporary water invertebrates have developed structural, behavioral, and physiological adaptations to irregular drought and refolding (Neckles *et al.*, 1999). Aquatic invertebrates in temporary habitats can be classified either as residents, adapted to endure during the dry season or adapted to colonize during the wet season (Batzer and Wissinger, 1996; Taylor *et al.*, 1999). Wissinger (1997) suggests that some of the most successful invertebrates in temporary water wetlands can not tolerate drought but instead employ fairly predictable migrations between temporary and permanent waters; he refers to them as "cyclic colonizers".

According to Pinder (1986) non-biting midges are often the most abundant and widespread, given that both the egg and larva can be desiccation resistant and are also the most rapid aerial colonizers. However non-biting midges were the second most abundant family in the lagoon. In contrast, in wetlands handled as waterfowl habitat, beetles (dytiscids and hydrophilids), and hemipterans (corixids) colonize by immigrating from near aquatic habitats rather than by means of dehydration resistant stages; allowing them to benefit from available aquatic food resources (Batzer and Wissinger, 1996). This could be the case of notonectids and corixids, which were the most and third most abundant families, respectively, collected at the lagoon. These families can be classified as cyclic colonizers. In the other hand, odonates have to deposit eggs and immatures must develop before they can exploit food resources (Batzer and Wissinger, 1996). Residual pools (pockets of water) in Laguna Cartagena serve as refuge for invertebrates during the months of drought (June-August).

In accordance with Ward (1992) droughts and floods also influence life cycles of resident insects. Occurrence, abundance and distribution of invertebrates with longer life cycles and metamorphosing larva may be influenced directly by span as well as timing of the hydroperiod (Taylor *et al.*, 1999). Laguna Cartagena is an intermittently flooded marsh, and it is inundated approximately 75% of the year. As a result the lagoon has a community of insects with both long (Coleoptera, Odonata, and Hemiptera) and short (Diptera) life cycles (Table 1.3), but has a higher representation of insects with long life cycles (joined). According to Evans *et al.* (1999) beetles and hemipterans have the characteristics of successful opportunists regardless of their relatively long life cycles; being the most abundant and diverse orders, respectively, collected at the lagoon. Results also goes along with Mc Clure (1994) observations, in which he found that bays with intermittent hydrology were dominated by multivoltine species with rapid larval development (dipterans), while bays with constant water were dominated by univoltine species with low development (odonates, hemipterans, coleopterans) (Taylor *et al.*, 1999).

Hydroperiod at Laguna Cartagena changes seasonally, which may well promote the development of different community structures. According to Magee *et al.* (1999) the greater the range of hydrological regimes within a wetland complex the greater the assortment of invertebrates. Short-term hydrology (annual precipitation) influences the microdistribution and abundance of invertebrates locally (Reid, 1985; cited in *Magee et al., 1999*). Some invertebrate taxa may be reliable indicators of wetland hydrological regimes (Evans *et al.*, 1999). For example, *Desmopachria* sp., which is found in Laguna Cartagena, is commonly found in temporarily flooded marshes. Other studies indicate that larvae of the beetle *Berosus* sp. were practically the only macroinvertebrates found before a lake dried out (Ward, 1992). *Berosus* sp. larvae were only collected at Laguna Cartagena during June, when the lagoon was almost dry.

Wetlands insect diversity is typically lower than lakes, rivers and streams, possibly because of the stressful environments created in these ecosystems. However, Williams (1996) "disputes the conception that drought is a major barrier to the success of insects in temporary waters. He described how almost all of the aquatic insect orders have some species able to live in habitats that are only temporary flooded, and many are well represented. He suggested that exploiting temporary waters may not be particularly difficult for invertebrates to accomplish and that the concept of faunas being constrained by temporary water conditions may exist more as a human perception than as a biological reality".

Habitat complexity (emergent vegetation)

Freshwater wetlands are usually characterized by their large number of plant species that forms a mosaic of communities (Bacon, 1988). Laguna Cartagena is an herbaceous wetland dominated by cattail and water hyacinth (Figures 1.192 and 1.193). According to Owen (1999) dominance of *Typha* sp. over other plants may be explained by the deterioration of water quality.

Macroinvertebrate assemblages appear to be mostly influenced by vegetation (Battle *et al.*, 2001). Aquatic macroinvertebrates are associated to benthic sediments, emergent vegetation, submerged vegetation, and open water habitats. Although, during almost one year of sampling, site 1, which has an approximate depth of 15 cm, a smaller area and more emergent plants than site 2, showed a higher abundance (~ twice) and diversity (21 more species) than site 2. According to Reid (1983, cited in Magee *et al*., 1999) and Helgen (2002), water areas with emergent vegetation and water column filled with a complex plant arrangement had greater richness when judged against open water areas. The habitat created by the combination of emergent plants and open water are very prolific areas for insects development (Magee *et al.*, 1999), since apart from providing habitat, decaying plant material supplies food for aquatic detritivores (some midges and mayflies), and enhance availability of refuge, allowing successful avoidance of predation in vegetated areas (Evans *et al.*, 1999). According to a study of carbon flow through food webs at a vegetated and an unvegetated Florida lake, made by Hoyer *et al.* (1997), phytoplankton was the most important carbon source in the unvegetated lake, while periphyton was the main source in the vegetated lake (Scheffer, 1998).

During the survey species from Odonata, Ephemeroptera and some Coleoptera (mostly Hydrophilidae) seemed to prefer vegetated areas; meanwhile, hemipterans like corixids, notonectids and belostomatids, and some dytiscids were more abundant at open water areas of site 1. According to Ward (1992) true aquatic hemipterans are strong swimmers, thus it is common to find them at open water areas.

Fire relation to wetlands ecology

According to Lee *et al*. (1995) and Ponzio *et al*. (2004) prescribed fire is a very important tool used to maintain the overall ecology of marshes; being currently used to manage vegetation patterns and succession. However, its impact on plant and animal communities is related to hydroperiod and nutrient concentrations (Lee *et al.*, 1995).

Laguna Cartagena vegetation was accidentally burned during July 2003, though dominant vegetation (*Typha dominguensis* and *Eichhornia crassipes*) recovered rapidly (in approximately two months), and augmented on following months. Studies done at St. Johns River Basin Marsh at Florida showed that some plant species may disappear after a fire and some others like *Typha domingensis* might be beneficiated (Lee *et al.*, 1995). Subsequent studies made by Ponzio *et al.* (2004) in the same river showed that *Typha* sp. density doubled at prescribed burn sites after one or two years, whereas no change in *Typha* sp.

density was reported at the control site. However, studies by Urban *et al.* (1993) showed that density of *Typha* sp. in subsequent years could also be influenced by hydroperiod (Ponzio *et al.*, 2004). Increasing soil nutrient availability due to fire could also be the cause of an increase of invasive plant species at Laguna Cartagena.

Fire can influence invertebrate distribution and abundance (Magee *et al.*, 1999). The fire of July did not seem to diminish the diversity of insects at the lagoon. On the contrary, it appeared to increase, given that seven more families of macroinvertebrates (two of them terrestrials insects) were collected in relation to June samplings. During the post-fire period beetles were the order with higher abundance, representing 42% of total organisms collected. This could be attributed to the shield that provides their coriaceous wings and their nutritional habits; since by being scavengers they can feed on those organisms that did not tolerate the fire.

Even though fire did not affect immediately the abundance and diversity of invertebrates at the lagoon, October samplings showed a drop of ten families of macroinvertebrates with respect to July samplings. However, other factors could have been the cause of this reduction, such as dissolve oxygen depletion as a result of the excess of organic matter produced by the fire (this will be discussed in Chapter 2).

Functional groups and their responses to human impairment

Wetlands, especially marshes, support a diverse and abundant invertebrate community consisting of aquatic, semiaquatic and terrestrial species (Battle and Golladay, 1999). Laguna Cartagena is characterized by a diverse fauna of different functional groups (Table 1.3). It is dominated mainly by insects (Hemiptera, Coleoptera, Diptera, Odonata and Ephemeroptera) but microcrustaceans (*Chlamydotheca* and *Macrocyclops*), gastropods (*Marissa* and *Tarebia*), annelids (oligochaetes) and cnidarians (*Chlorohydra*) can also be found.

Generalists, like hemipterans, coleopterans and odonates, dominate the functional feeding groups in Laguna Cartagena. This group can use a variety of food resources including detritus, plants, epiphytic algae and other organisms (Leslie et al., 1999), however the majority are mainly predators. Additionally, generalists are able to resist disturbance when food resources change. In contrast, specialists eat by selecting feeding, which involves the rejection of some available food substances (Cummins, 1973). A community with a high proportion of wetland specialists is thought to reflect more competition and evolution of specialists (decrease with increasing disturbance), whereas one with a high proportion of generalists may indicate less competition and more use of the same resources. A community with a high abundance of generalists, like the one at Laguna Cartagena is representative of a disturbed environment. According to Kerans and Karr (1994) grazers and predators decrease with human impairment, meanwhile filter feeders increase.

Fish are usually the top carnivorous, nevertheless species like *Oreochromis* sp. and *Gambusia* sp. are found at Laguna Cartagena only during long periods of inundation. Instead Laguna Cartagena is dominated by predatory insects (more than 75%) like juvenile and adult aquatic beetles and hemipterans, and odonate larva. As a consequence, of short term flooding, predation pressure is lower in Laguna Cartagena. Overall community structure at the lagoon does not seem to show any major problem although changes in abundance and diversity are clearly the consequence of its many environmental disturbances.

Aquatic insects also have trophic connections with terrestrial consumers like insectivorous birds (detailed information in Danforth, 1926) and bats, which give them a higher consideration for the management of the lagoon as a wildlife refuge. For example, water birds select high protein insects over low protein plant food during the breeding season due to the increasing demands of egg lying and gonads development (Murkin and Wrubleski, 1988).

Abnormally dry seasons may favor food acquisition by water birds and terrestrial predators, whereas long hydroperiod and deeper water favor invertebrates.

Asymmetry

S. Hardensen (2000) suggests that evolutionary ecology and behavior interfere with the suitability of fluctuating asymmetry in mature damselflies as a biomonitoring tool and conclude that fluctuating asymmetry in emerging adults should be much more appropriate as a bioindicator; however Zygoptera adults were not collected during our survey. Although pollution due to agricultural discharges can cause deformities on dragonflies, during the present survey only one dragonfly, *Epitheca* sp., showed a malformation in the labrum (Fig. 1.163). Deformities on larval mouthparts of Chironomids have also been reported in response to contaminants (various authors cited in Pinder, 1986), but mouthparts of chironomids were not studied in detail.

Tolerance Values

Laguna Cartagena has a higher abundance (90%) and diversity (73%) of tolerant insects, which can be divided into three categories: those that can tolerate environmental disturbances (some Diptera), those that prefer degraded conditions (some Diptera) and those that do not depend entirely on water quality to survive (Hemiptera and Coleoptera). Somewhat tolerant species, like Odonata, account for 6.7% of the total abundance and 24% of the diversity. Although sensitive insects were not reported at the lagoon (according to literature), there was one species of Ephemeroptera, *Centroptilum* sp., that was only abundant during periods of high oxygen concentration. This "sensitive" organism accounted for 3.3 % of the total abundance and 3% of the diversity. Although ephemeropterans were only abundant during periods of high oxygen concentration, Baetidae is one of the most tolerant families of Ephemeroptera.

Statistical analysis

Both Simpson and Shannon-Wiener indexes showed the same pattern. Dominance was higher (lower diversity) on October and lower on those months with higher diversity (June, February and March). Although in March I collected 13 species more than in June, diversity indexes showed that June had the highest diversity in relation to total insect abundance. Hutchinson t-test for Shannon-Wiener biotic index indicates that there was a significant difference in aquatic insect diversity between site 1 and site 2, which means that diversity of insects expressed differently at each site when influenced by climate and physical-chemical changes in water. Site 1 showed the highest diversity (higher values) and site 2 showed more variability.

Jaccard index similarity dendogram showed a closer relationship between successive months June-July (lagoon was almost dry) and February-March (lagoon was full and shallow). Since I have seen that abundance and diversity of insects can be affected at Laguna Cartagena by changes in the environment, I assume that resemblance between sampling months are also related to these changes.

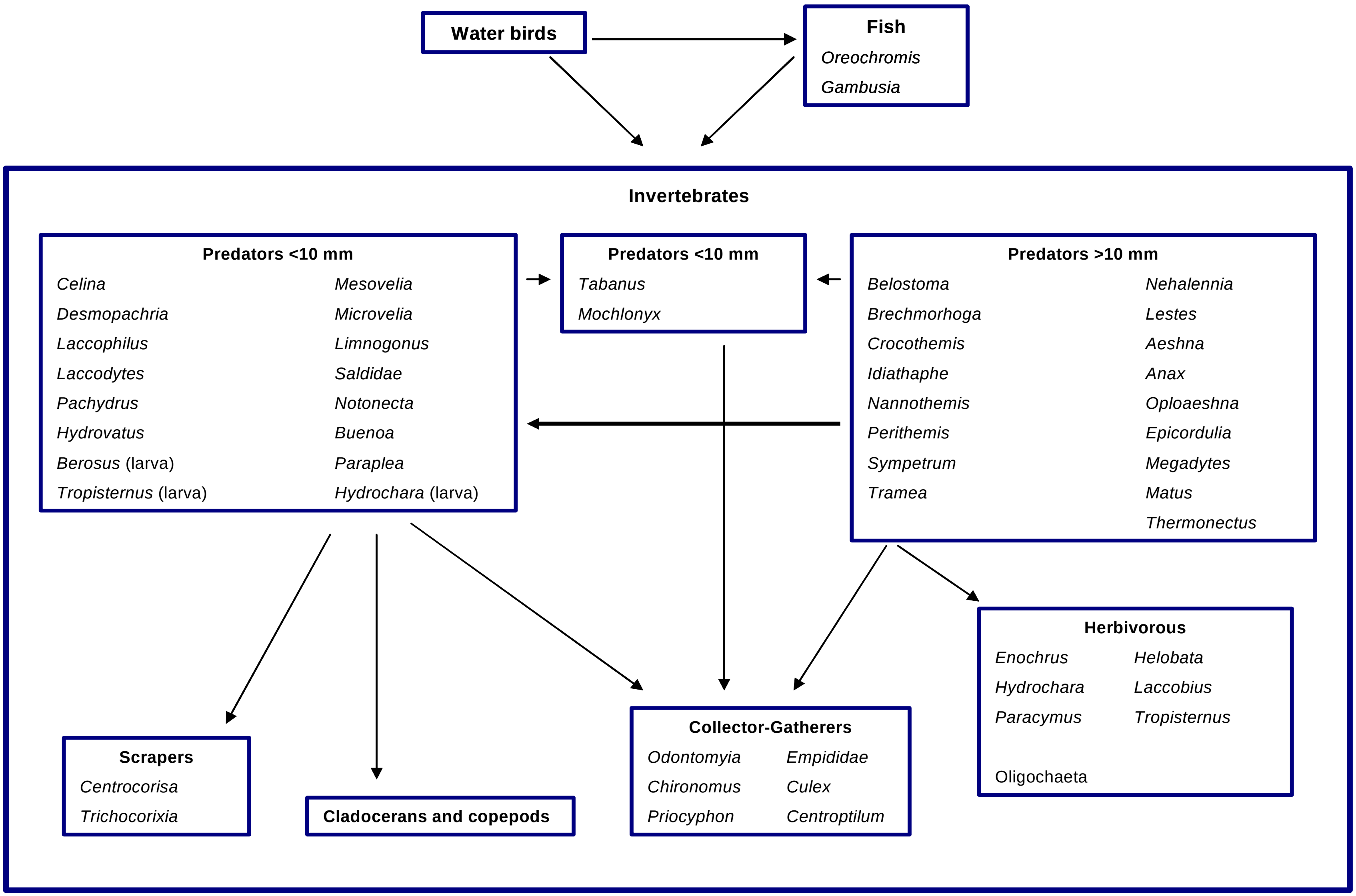

Figure 1.203 Laguna Cartagena: open-water food web. Species were grouped based on size and prey preference/functional feeding group classification based on Rader (1999).

Conclusions and Recommendations

1. During the year of sampling macroinvertebrates at Laguna Cartagena responded to environmental disturbances with comparable ways to macroinvertebrates from Southeastern USA wetlands and other intermittent ecosystems. Yet, subsequent studies should be done to validate this data.

2. Insects at Laguna Cartagena confirmed that are sensible indicators of physical changes (hydroperiod, vegetation). However subsequent studies involving macroinvertebrates as environmental disturbance indicators should be done at Laguna Cartagena and other wetlands in Puerto Rico to facilitate the development of confident biotic indices for these water resources.

3. According to biological data (aquatic insects) and the Shannon's diversity index, Laguna Cartagena has a fair water quality.

4. There is little information on the abundance and distribution of insects in freshwater wetlands in Puerto Rico; therefore it is necessary to make continuous censuses and make publications so they can be accessible for scientists that are interested in developing management plans to protect wetlands.

5. There is few published information about the effects of fire on wetlands ecosystems (Lee et al., 1995). Since FWS scientists are considering to use fire as a management tool in Laguna Cartagena, studies should be conducted on the effects of fire frequency.

Research Needs

1. Species of the same genus may require different habitats or food supplies; therefore it is necessary to develop taxonomic keys to species level in order to know the exact community structure at the lagoon and their habitat requirements.

2. Aquatic insect ecology should be explored further including: diet, food web, nutrient cycling, habitat preferences, and migration patterns.

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CHAPTER 2: Physical and chemical parameters at Laguna Cartagena and their influence on aquatic macroinvertebrates communities

Insects as bioindicators of water quality

Introduction

Water quality can fluctuate widely in wetlands, both over the course of a day and over seasons. To define the overall condition of the studied site, not only at the sampling time but also over time, physical and chemical parameters should be taken at the same time biological monitoring is being effectuated.

Physical and chemical parameters

Physical and chemical characteristics of water are responsible for the existence of aquatic systems, and changes on those parameters are responsible for the existence of the different plant and animal communities within that environment, having a major effect on community composition.

The temperature of surface waters can be influenced by geographical position, season, time of day, sun exposure, aeration, and the flow and depth of the water body. The surface temperature of a shallow pool will have little variability with air temperature. The smaller the water volume, the greater the diurnal variation and the higher the maximum temperature. As water temperature increases, the rate of chemical reactions increases, along with evaporation and volatilization of substances from the water. Increased temperature also decreases the solubility of gases in water, such as O_2, CO_2, N_2, CH_4, and others.

The metabolic rate and growth of aquatic organisms is also related to temperature, including some organisms that appear to be limited by variations in temperature. In warm waters, respiration rates increase, leading to increased oxygen consumption and increased decomposition of organic matter. According to Cummins (1973), feeding rate is also temperature dependant.

DO indicates the concentration of oxygen available in the water. There are several environmental factors that affect the oxygen content of natural waters; these include temperature, salinity, turbulence, concentration of organic matter, amount of nutrients, atmospheric pressure, photosynthetic activity of algae and plants, and the type and number of organisms in the water body. However, its solubility in freshwater is mostly determined by water temperature. Measurement of DO can be used to indicate the degree of pollution by organic matter, the rate of decomposition and the level of self-purification of the water. Saturation concentration of oxygen at 30ºC is 7.48 mg/L and just over half of it at 0ºC. Therefore, the smaller the volume of water, the more abrupt will be the fluctuations in the oxygen concentration.

Oxygen is an important wetland parameter because it is essential for most forms of biological life and it determines population size and community composition. However, it is difficult to establish water quality standards to prevent mortality because required concentrations vary among species and for the different life stages (Kalff, 2002). Freshwater insects can be divided into those that must come to the surface to obtain gaseous oxygen (Hemiptera and Coleoptera) and those that can obtain oxygen from solution (Ephemeroptera, Diptera and Odonata). Among dissolved oxygen dependant organisms, Ephemeroptera are the most sensitive. Some families of Diptera, like chironomids, can live without oxygen for a period of time because they can respire anaerobically (fermentation) or have hemoglobin, an oxygen transporting agent that allows them to tolerate low concentrations. Usually concentrations below 5 mg/L may adversely affect the functioning and survival of biological communities and below 2 mg/L may lead to the death of most invertebrates. However, Kalff (2002) mentioned that some fish species can tolerate 2-5 mg/L DO. Some cichlids can tolerate oxygen below 2 mg/L for extended periods. According to a study made by NOAA, too much oxygen can also be unfavorable for aquatic biota.

At a given temperature, pH indicates the intensity of the acidic or basic character of a solution. Diel variations in pH can be caused by the photosynthesis and respiration cycles of algae in eutrophic lakes. The pH of most natural waters is between 6.0 and 8.5, although lower values can occur in dilute waters high in organic content, and higher values in eutrophic waters, ground water brines and salt lakes. According to Kalff, (2002), there are insects such as *Chironomus* spp., water boatmen, and damselflies that are only slightly affected by acidification, perhaps because of reduced predation from fish; whereas others like mayflies are acid-sensitive.

Nutrients

Nutrient levels are critical to the ecology of wetlands. Nitrogen and phosphorus mostly influence plant and algal growth. Nitrogen is present in aquatic environments in several forms, including ammonia, nitrates and nitrites.

Ammonia (NH_3) occurs naturally in different water ecosystems in equilibrium with the ammonium ion (NH_4^+). Ammonia comes from the decomposition of organic and inorganic matter, excretion by biota, and reduction of the N_2 by microorganisms (Horne and Goldman, 1994; Kalff, 2002). Because ammonia is a gas, it can be released to the atmosphere. The absorption of NH_3 is dependant on the temperature, pH, and total ammonia concentration. At certain pH levels, high concentrations of NH_3 are toxic to aquatic life and therefore detrimental to the environment. Of all freshwater organisms, fish and shrimp, especially post larval shrimp, are generally considered the most sensitive to ammonia. Surface waters have ammonia concentrations that are typically less than 0.2 mg/L NH_3 – N; the maximum acceptable concentration assuming a pH value of 7.0 and a temperature of 25 ºC is 1.24 mg/L NH_3 – N. However, values may reach 2-3 mg/L NH_3 – N in wetlands. Higher concentrations might be a sign of organic contamination, for example, domestic sewage, industrial waste, and/or fertilizer run-off. Anoxic soils may also have high ammonia concentrations. Therefore, ammonia concentration can be used as an indicator of water pollution.

The nitrate ion (NO_3^-) is the common form of nitrogen in the aquatic environment (Horne and Goldman, 1994; Kalff, 2002). Surface waters that have been disturbed by man normally contain from 1-5 mg/L NO_3-N. Contamination by wastes or fertilizer run-off can raise concentrations higher than 5 mg/L, and occasionally reaching 200 mg/L. In lentic systems, levels of nitrate higher than 0.2 mg/L tend to stimulate algal growth which can be used as an early indication of eutrophication. Nitrate can be reduced to nitrite under anaerobic conditions (denitrification). Freshwater usually contain 0.001 mg/L NO_2^--N, and rarely higher than 1 mg/L. Determination of nitrate plus nitrite gives a general indication of the nutrient status and level of organic pollution.

Phosphorus (P) occurs mostly as dissolved orthophosphates. It is considered a limiting nutrient for algae and macrophytes and since it is actively taken up by plants, is usually found at low concentrations (Horne and Goldman, 1994). Undisturbed waters usually have from 0.005 to 0.020 mg/L; or as low as 0.001 mg/L in freshwaters and as high as 200 mg/L in some saline waters. Since P input is the major cause for eutrophication, the management of aquatic ecosystems (lake, wetland or reservoir) requires knowledge of the levels of phosphate to prevent and/or control excess algal growth.

High concentrations of P could also affect diversity and abundance of invertebrates. This could happen in three ways: reduction of food availability, alteration of the macrophyte community, resulting in a diminution or elimination of the open water, and/or reduction of oxygen content due to shading. Some plants like cattail develop rapidly in P rich wetlands, especially during periods of continuous inundations. According to Rader (1999), cattails are perhaps the most inhospitable habitat for some benthic invertebrates because of the thick anaerobic layer produced by cattail decomposition. However, some fish reach their highest levels in enriched cattail habitats (Jordan, 1996 cited in Rader, 1999). In order to maintain P unavailable, it is necessary to sustain aerobic conditions.

Metals and heavy metals

The concentration of heavy metals is commonly studied to determine water quality. According to Kennish (1992), living organisms require trace amounts of some heavy metals like cobalt, copper, iron, molybdenum, vanadium, strontium, manganese or zinc to regulate many biochemical processes; however excessive levels of essential metals can be detrimental to organisms. Previous research has shown that aquatic plants and bivalves are not able to successfully regulate metal uptake (Connell and Miller, 1984). For this reason, bivalves are often used as biomonitor organisms in areas of suspected metal pollution (Kennish, 1992). On the contrary, chironomids of the subfamily Chironominae can tolerate contamination by heavy metals, although there are some exceptions (Pinder, 1986).

Water pollution by heavy metals resulting from anthropogenic impact is causing serious ecological problems in many parts of the world. Therefore, the assessment of metal pollution is an important aspect of most water quality assessment programs (Global Environmental Monitoring Systems, US Environmental Protection Agency). Non-essential heavy metals of particular concern to surface water systems are cadmium, chromium, mercury, lead, arsenic and antimony.

Connell and Miller (1984) suggested that behavior of metals in natural waters is a function of substrate sediment composition, the suspended sediment composition, and the water chemistry. Metals may become more soluble if water increases in salinity, decreases in redox potential, or decreases in pH.

Purpose

In this chapter, I will compare values of physical-chemical parameters, nutrients and metals found in Laguna Cartagena with those ranges established and permitted by the Puerto Rico Environment Quality Board and the US Environmental Protection Agency. The values obtained during the survey will be correlated with abundance and diversity of aquatic insects during the same dates to validate the use of aquatic macro-fauna as biological indicators for the water quality determinations within a single system.

Materials and Methods

I. Methodology:

A. Sampling locations and schedule:

Water samples were taken at three sites on the southwestern section of the lagoon (Figure A-2). Sampling sites were chosen by the Fish and Wildlife Service by accessibility and lagoon receives water inputs at those areas. Five samplings were made during a period of ten months (June 25, 2003 – March 25, 2004). Two sampling months (February and March) were during the dry season and the other three sampling months (June, July and October) during the rain season. All samples were made between 1030 and 1330 hr.

B. Physical and Chemical Parameters

Dissolved oxygen (DO) was measured in situ with a DO meter (model YSI 55®); pH and temperature were measured in the field using a pH/ºC meter (OAKTON®). Electrodes were calibrated according to the manufacturer before and after field use. Depth was measured with a calibrated rod.

C. Water Samples

At each sampling site, two duplicate water samples of approximately 500 ml were taken immediately below the water surface with a glass dipper. For heavy metal analyses, duplicate samples of 500 ml of water were poured from the glass dipper into sterile glass bottles with 0.5 ml of nitric acid and placed on ice until arrival to the laboratory. The other two samples of 500 ml were used for nutrient analyses.

- **Nutrients**

Nitrate, nitrite, orthophosphate, and ammonia were measured in the laboratory by colorimetric analysis using a LaMotte® Water Pollution Detection Kit (Smart 2). Each determination was conducted in duplicate.

- **Heavy Metals**

Cadmium, lead, zinc, and cobalt were determined in water samples using a Perkin Elmer ® Atomic Absorption spectrophotometer, model Analyst 100©. Analyses were performed by extraction procedures in duplicate.

Samples digestion was performed as follows: 3.0 mL of HNO_3 concentrated were added to 500 mL of water sample. Water was evaporated, without boiling, to 15-20 mL. Once cool, an additional 3.0 mL of HNO_3 concentrated were added to the sample; then it was heated, allowing reflux. The remaining was filtered and washed with 10% HCl and completed to 50 mL with 10% HCl.

D. Statistical Analysis

To determine how biological indicators (Chapter 1) relate to physical and chemical parameters, correlation analyses were performed on transformed (log (X+1)) biotic index data. Linear regressions were used to analyze parameters related one to another, using the equation:

$$\hat{Y} = \beta_0 + \beta_1 + \varepsilon, \text{ where}$$

β_0 = intercept

β_1 = slope

ε = aleatory error

Interval estimates were calculated using a level of confidence of 0.95 ($\alpha = 0.05$).

Results

Table 2.1 Weather and physical parameters at the lagoon from June 25, 2003 to March 25, 2004.

Date	Weather	Mean Max. Temp. ºC	Mean Min. Temp. ºC	Precipitation during month (Sum)	Water Depth	Other Events
Jun/25/03	Sunny	32.9	21.0	4.95 cm	Shallow, ~ 11 cm.	
Jul/9/03	Sunny	33.9	20.6	5.26 cm	Almost dry, < 5 cm.	The lagoon was burned.
Oct/16/03	Sunny	32.5	21.4	18.70 cm	Site 1 ~ 1.9 m and site 2 ~46 cm.	Water emanated decaying odor.
Feb/25/04	Sunny	30.8	16.6	4.98 cm	Full, site 1 (15 cm) and 2 (30 cm) connected.	Flood events during November 12-14 of 2004.
Mar/25/04	Cloudy, rainy	30.9	17.1	7.52 cm	Site 1 with various pools of ~15 cm and site 2 ~ 15 cm.	

Table 2.2 Physical and chemical parameters measured at sampling sites of Laguna Cartagena from October 16, 2003 to March 25, 2004.

Site	Sampling Date	Air Temperature (ºC)	Water Temperature (ºC)	DO (mg/L)	pH
1	Oct/16/03	35.4	29.1 (28.6-29.7)	0.34 (0.31-0.42)	-
2	Oct/16/03	34.7	29.8 (29.1-31.0)	0.57 (0.52-0.59)	-
1	Feb/25/04	28.3	33.3 (32.9-33.8)	7.98 (7.43-8.20)	7.39
2	Feb/25/04	30.4	31.4 (31.0-31.5)	6.58 (6.31-7.42)	7.57
1	Mar/25/04	30.0	32.0 (31.7-32.4)	8.56 (7.99-8.63)	7.45
2	Mar/25/04	29.4	32.6 (32.1-33.3)	5.81 (5.23-6.12)	7.52
Water Quality Standards PREQB (1978)			< 32.2	> 5.0	7.30-8.50

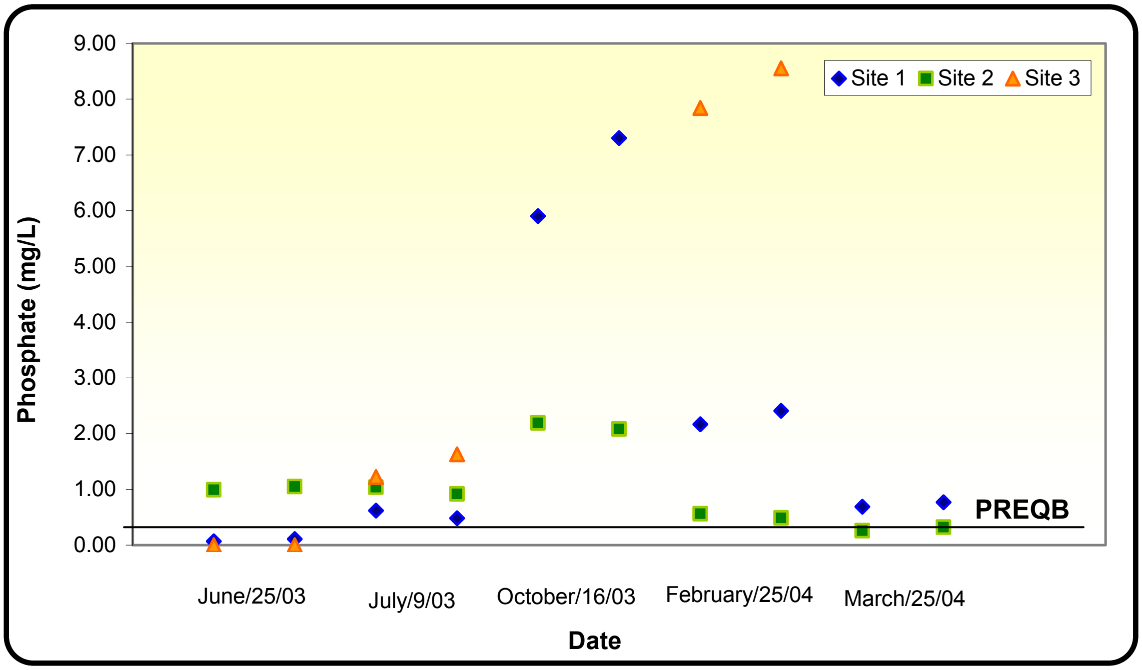

Figure 2.1. Phosphate concentration from June 2003 to March 2004 at the three sampling sites.

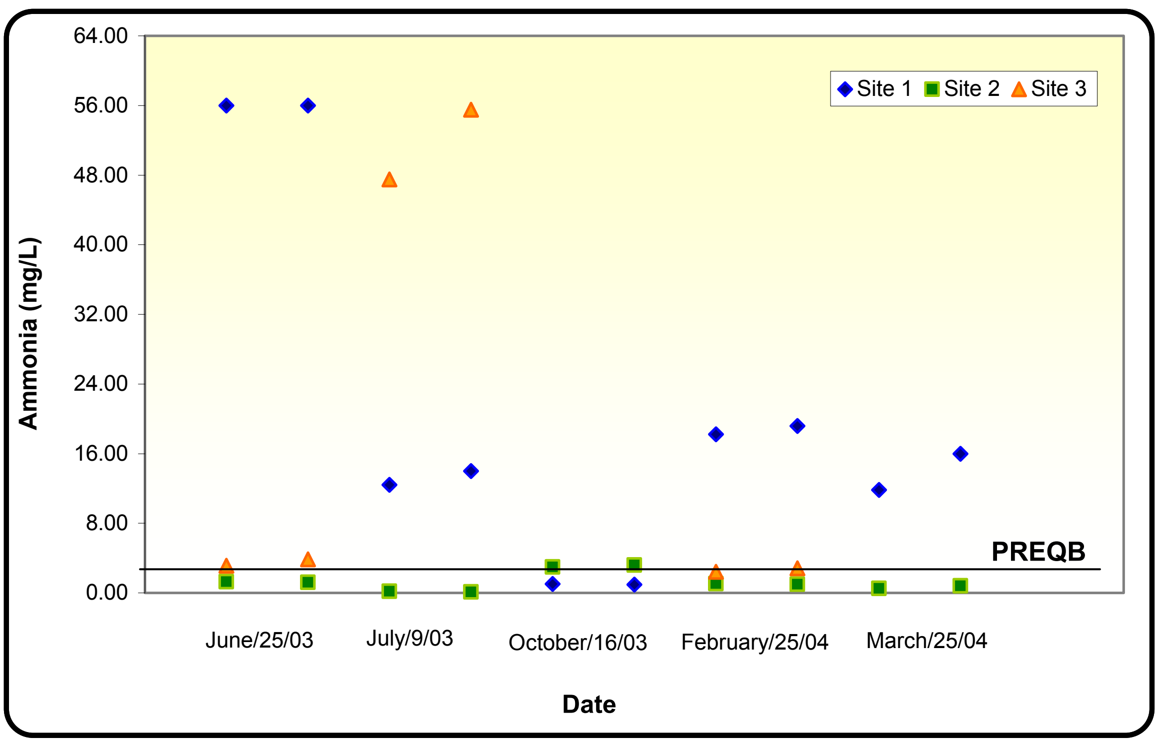

Figure 2.2. Ammonia concentration from June 2003 to March 2004 at the three sampling sites.

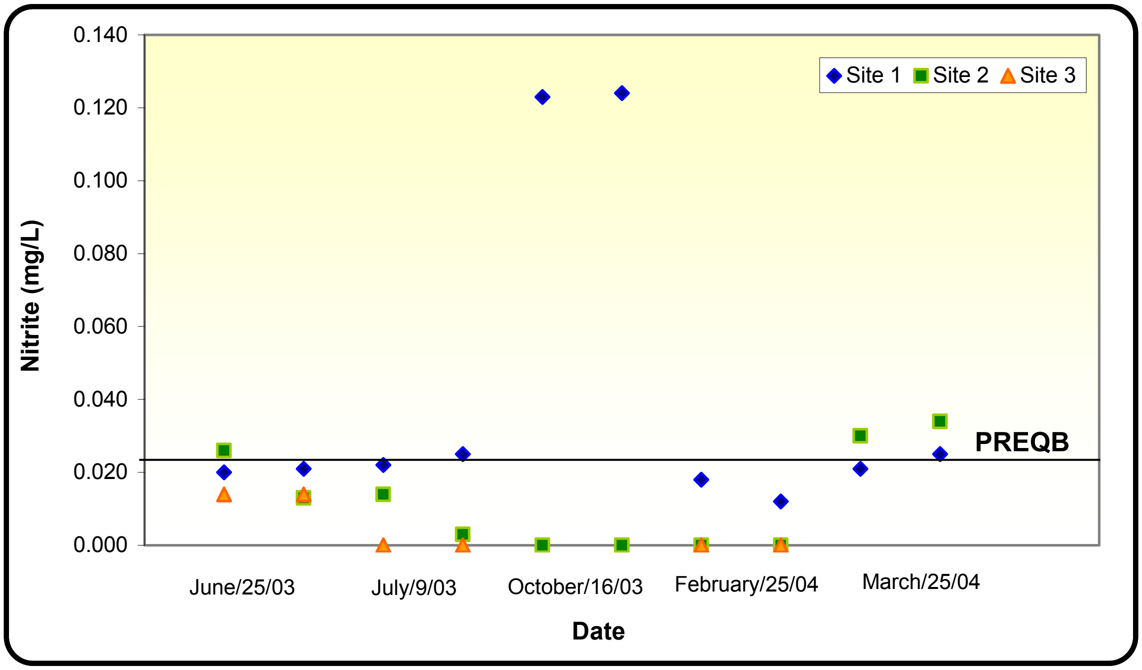

Figure 2.3. Nitrite concentration from June 2003 to March 2004 at the three sampling sites.

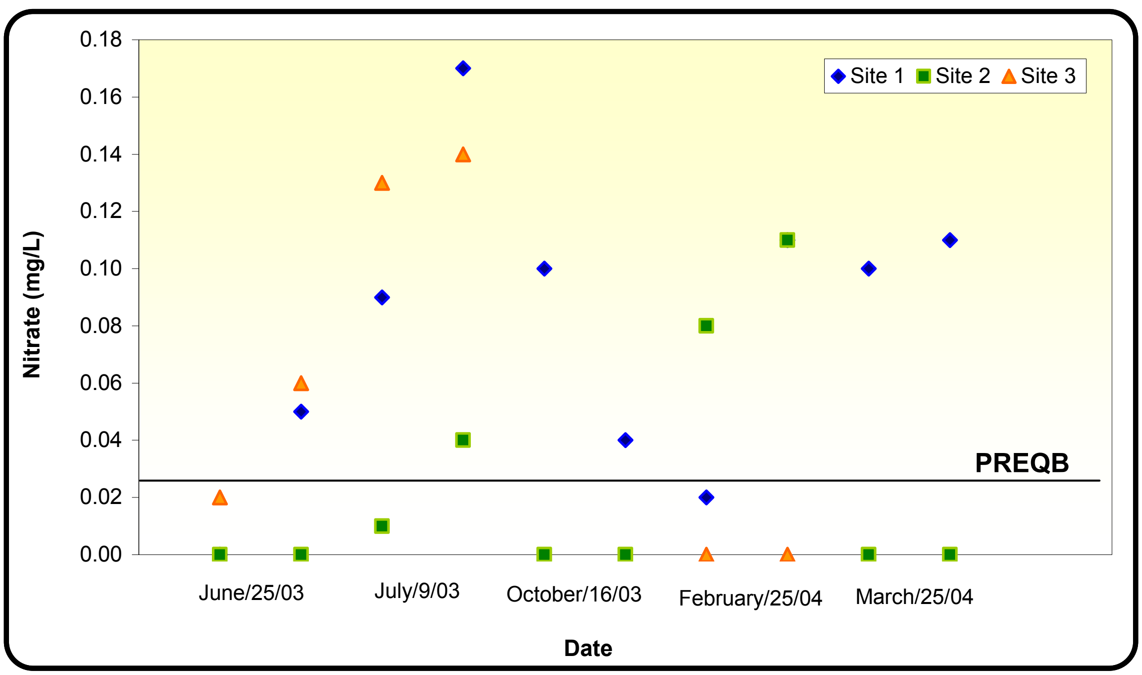

Figure 2.4. Nitrate concentration from June 2003 to March 2004 at the three sampling sites.

Table 2.3 Mean metal concentration in water samples from three localities at the southwestern section of Laguna Cartagena.

Site	Sampling date	Metals (ppm)			
		Co	Zn	Pb	Cd
1	Jun/25/03	0.0005	0.0200	n/d	n/d
2	Jun/25/03	n/d	0.0250	n/d	n/d
3	Jun/25/03	0.1080	0.2312	n/d	n/d
1	Jul/9/03	0.0005	0.0247	n/d	n/d
2	Jul/9/03	n/d	0.0278	n/d	n/d
3	Jul/9/03	0.1120	0.2338	n/d	n/d
1	Oct/16/03	-	-	-	-
2	Oct/16/03	-	-	-	-
3	Oct/16/03	-	-	-	-
1	Feb/25/04	0.0010	0.0262	n/d	n/d
2	Feb/25/04	0.0005	0.0297	n/d	n/d
3	Feb/25/04	0.1150	0.2412	n/d	n/d
1	Mar/25/04	0.0015	0.0324	n/d	n/d
2	Mar/25/04	0.0010	0.0316	n/d	n/d
3	Mar/25/04	0.1164	0.2486	n/d	n/d

n/d = not detected

Table 2.4 Correlations between aquatic insect data and water physical-chemical parameters.

Parameters	PO4		NO3		NO2		NH4		DO		pH		Temp		Depth	
	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p
Abundance	-0.05	0.89	0.72*	0.02	0.25	0.49	0.10	0.78	0.69*	0.13	-0.54	0.46	0.54	0.27	-0.09	0.80
Family Diversity	-0.20	0.57	0.52*	0.11	0.27	0.46	0.02	0.99	0.64*	0.16	-0.52	0.67	0.54	0.26	-0.24	0.50
Species diversity	-0.20	0.59	0.64*	0.05	0.27	0.47	0.16	0.65	0.65*	0.16	-0.82	0.21	0.56*	0.24	-0.22	0.53
Simpson	0.48	0.16	-0.15	0.68	0.12	0.75	-0.40	0.25	-0.77*	0.07	0.87*	0.13	-0.69	0.13	0.58*	0.08
Shannon-Wiener	-0.42	0.22	0.42	0.23	0.10	0.79	0.22	0.54	0.70*	0.12	-0.33	0.67	0.62	0.19	-0.41	0.24

* High correlation

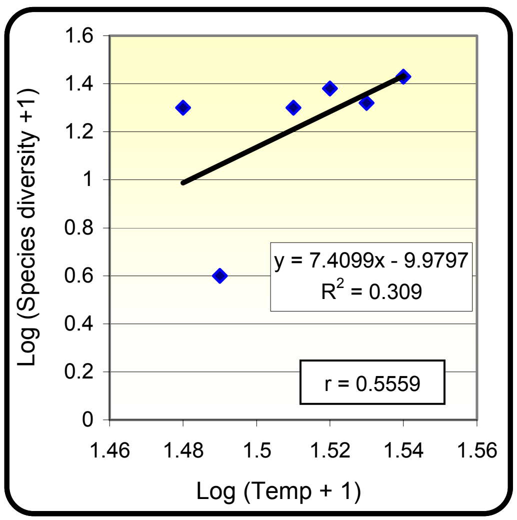

Figure 2.5 Correlation between temperature and species diversity (log transformed data).

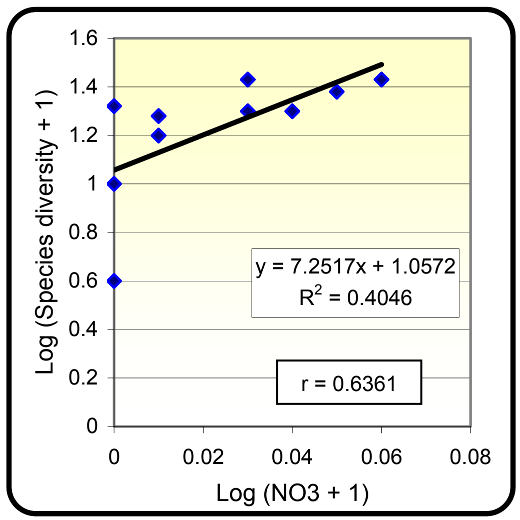

Figure 2.6 Correlation between nitrate and species diversity (log transformed data).

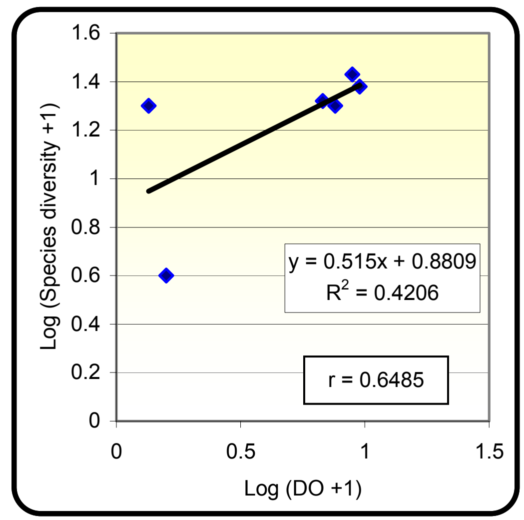

Figure 2.7 Correlation between DO and species diversity (log transformed data).

Discussion

Physical and Chemical Parameters

Among physical and chemical parameters measured at the lagoon, only DO and depth had significant fluctuations, meanwhile temperature and pH remained within acceptable ranges for the PREQB (Table 2.1 and 2.2) . Dissolved oxygen (r = 0.6485), nitrate (r = 0.6361) and temperature (r = 0.5559) had a significant correlation with insect diversity (Figures 2.5 to 3.7). Fluctuations in parameter values were not entirely related to dry and rainy season but to diameter and depth of open water, amount of vegetation, and contribution of organic mater.

Changes of physical environmental factors seem to shape the species assemblages of invertebrates at Laguna Cartagena more than biological relationships such as competition, predation and parasitism; this follows studies reported by Schoener (1986, cited in Dufrene and Legendre, 1997).

The depletion of oxygen in water and soil that is associated with flooding is perhaps the most important chemical feature of wetlands. Although shallow and running waters generally remain well oxygenated, isolated and deeper ones may become stagnant and oxygen depleted. This goes along with the obtained values, given that oxygen concentrations during October, when the lagoon showed its maximum depth and denser vegetation, were low (ca. 0.34 mg/L). Oxygen depletion during October could also be the result of an excess organic matter caused by the fire of July 2003, since decomposition is an oxygen consuming process.

Throughout October, the lagoon also had the lowest abundance and species diversity. Although oxygen concentrations below 2 mg/L may lead to the death of most invertebrates, during this time Laguna Cartagena was dominated by Coleoptera and other insects like Hemiptera (which breathe atmospheric air or do not depend entirely on water quality to survive). According to Sharitz and Batzer (1999), “the majority of air breathing aquatic invertebrates (most beetles, hemipterans and fly larvae) periodically venture to the water surface to replenish their oxygen supply”. These surface breathing insects are much more conspicuous in wetlands than in lakes, rivers or streams.

Only October values for DO were below those permitted by PREQB. Subsequent samplings (February and March) showed a saturated concentration of oxygen expected for the water temperature. This could be due to November rains and cattail removal which enlarged the open water area, allowing continual aeration of the lagoon and promoting an increase in oxygen concentrations for several months. As a consequence, abundance and diversity of species increased, including some sensitive organisms like Ephemeroptera. These observations are supported by correlations of log-transformed data, which showed a positive and significant relation between DO and abundance and diversity of insect species (Figure 2.7).

Dissolved oxygen plays a major role in spatiotemporal distribution patterns of aquatic insects. “Responses include, but are not limited to microspatial positioning, depth distribution, migratory behavior and predatory-prey interactions” (Ward, 1992). Vertical migration of species from the family Chaoboridae, like the one found at Laguna Cartagena (*Mochlonyx* sp.) is regulated mainly by DO (LaRow, 1970; cited in Ward, 1992). They preferred waters with low oxygen concentration, therefore remained under the substrate and only underwent vertical migration to the water column when DO saturation declined. As a result, *Mochlonyx* sp. was only collected during October, when lower oxygen concentrations were reported. Affecting the position of organisms at the water column will also affect the predatory pray interactions among generalists.

Many aquatic invertebrates in wetlands can tolerate stressful levels in water quality parameters other than just oxygen (Sharitz and Batzer, 1999), for example water temperature and pH. Water temperature affects not only range, but the time of emergence (for some species, like Ephemeroptera), the rate at which invertebrates feed, and the efficiency of digestion. In a study by Pacaud (1948), invertebrates like *Notonecta* sp. increased the rate of feeding (chironomids) with increasing temperature. Water temperature was higher than air temperature during February and March, however the difference was only about 2-3ºC. Although water temperatures of 25-30ºC are generally more appropriate for invertebrate development, according to Ward (1992) some species tolerate water temperatures above 40ºC; these include notonectids, corixids, *Chironomus*, *Tabanus*, *Culex*, *Enochrus*, *Microvelia*, *Helochares*, *Hydroscapha*, stratiomyids, saldid, libellulids and the gastropod *Physa*. According to a study made by NOAA, there are also some fishes, like the mosquito fish and tilapia which are found at Laguna Cartagena, that are tolerant to wide ranges of temperature and low DO, among other parameters. In relation to pH, the average values for both sampling areas fall within the standard pH range for fish and invertebrates (Bambaradeniya *et al.*, 2002).

Depth also has some influence in the community structure of wetland ecosystems. Invertebrate species richness is correlated with pool size (Taylor *et al.*, 1999). Studies done in Missouri's wetlands showed that greater water depth were associated with lower invertebrates abundance and greater abundance coincided with depth of 11-20 cm and temperatures of 27 ºC (Magee, 1989 cited in Magee, 1999), suggesting that the size of the pond has a small influence in the number of species (de Szalay *et al.*, 1999). Higher abundance and diversity in the lagoon also coincided with depths around 15 to 30 cm (Table 2.1). However, this could be due to a concentration "effect" of organisms.

Nutrients

Laguna Cartagena is a marsh perturbed by agricultural activities. High levels of nutrients in the form of nitrogen (nitrate, nitrite and ammonia) and phosphorus from fertilizers and waste waters can be the trigger for eutrophication. For example, as little as 0.015 mg/L total P can accelerate plant growth and large algal blooms. According to Battle et al. (2001), disturbed marshes have approximately five-fold higher PO_4-P concentrations than undisturbed wetlands. Laguna Cartagena showed PO_4-P values ~7 times above those permitted by the PREQB (Figure 2.1). In addition to runoff from uplands, elevated phosphate could be due to inputs from an irrigation canal that connects with the Maguayo community. As a result of long term eutrophication, overall diversity will be reduced while the abundance of some species will increase. Ammonia was also found in higher concentrations (Figure 2.2) with values of almost 60 times above those permitted by PREQB; although higher values were recorded when the lagoon was being used as a pasture by cattle, probably because of excretion inputs from these animals. High concentrations of DO are required to oxidize ammonia to nitrite and nitrate; however, ammonia was usually high and significant concentrations of nitrite or nitrate was never recorded during the survey (Figures 2.3 and 2.4). A small layer of oxidized soil, sometimes only a few mm thick usually remains at the soil-water interface, this thin layer is often important in the chemical transformations that occur in wetlands.

Metals and heavy metals

Measurements of metals and heavy metals where made at the three sites for four sampling months (June, July, February and March). Heavy metals like Pb and Cd were not detected by the equipment. Zn and Co showed concentrations of "not detected" to 0.1164 ppm and from 0.0200 to 0.2486 ppm, respectively. According to PREQB and EPA, these values are not toxic to aquatic life.

Consequences of deterioration of water chemistry

Changes in land use and land management frequently result in alterations of the hydrology and water chemistry of wetland areas (Owen, 1999). Altered wetlands often become dominated by non-native or invasive plant species which can lower the biodiversity of the ecosystem, decrease its functional value for humans and other species, and even result in complete wetland loss (Reed and Cahoon, 1992; cited in Owen, 1999). Dominance of *Typha* sp. over other plants in the lagoon may be explained by the deterioration of water quality. Remnant populations reflect the hydrologic conditions of an earlier era and which are now being out-competed by exotic and more common species. Restoration of native vegetation may be possible in some areas, but in most parts where invasive species dominate, the physical conditions can no longer support native species (Owen, 1999). However, protection of high diversity sites does not guarantee effective conservation of rare or spatially restricted organisms (Dufrene and Legendre, 1997). Ecological results reinforce the opinion that disturbed as well as undisturbed wetland habitats are worthy of protection (Taylor *et al*., 1999).

Conclusions

1. During the hydrological survey, plant arrangement and insect communities at Laguna Cartagena were influenced by climate (season).

2. Results showed that dissolved oxygen was the chemical parameter with the strongest influence on community structure at Laguna Cartagena. When concentrations were below 1 mg/L, the lagoon was dominated by air breathing insects, while concentrations above 5 mg/L promoted the higher abundance and diversity of aquatic insects in the lagoon.

3. Representatives of aquatic insect families like Notonectidae, Corixidae (Hemiptera), and Dytiscidae (Coleoptera) were considered wetland specialists in Laguna Cartagena.

4. Invertebrates like microcrustaceans, most midge larvae, and naiads flourish in Laguna Cartagena despite possessing fairly rudimentary structures to absorb oxygen.

5. Aquatic insects were sensitive indicators of changes in water parameters at Laguna Cartagena.

6. According to chemical data Laguna Cartagena has a moderate water quality (mesotrophic-eutrophic).

Recommendations

1. Develop alternatives for the restoration of Laguna Cartagena natural hydroperiod.

2. Laguna Cartagena should maintain contact with adjacent streams and canals to allow seed dispersion and exchange of invertebrate and vertebrate species between systems.

3. Farmers and agriculturists must be made aware of the importance of the lagoon and the effects of agricultural procedures and cattle grazing; management plans should minimize such impacts.

Research Needs

1. Since most wetland plants obtain their nutrients from the sediments, the concentration of plants should be determined.

2. Given that primary producers are the base of the food web, concentration of metals and heavy metals should be determined within Laguna Cartagena macrophytes.

3. More research is needed concerning the role of invertebrates (nutrient cycling, bioaccumulation) in the Laguna Cartagena ecosystem.

4. Determine (up-date) the amount of nutrient inputs from agricultural and cattle practices.

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APPENDIX

List A-1. Aquatic insects collected by Danforth at Laguna Cartagena on his ornithological study of 1926.

Odonata
Dragonfly
Damselfly

Diptera
Chironomidae

Coleoptera
Dytiscidae
Hydrocanthus iricolor Say
Pachydrus globosus Aubé

Hydrophilidae
Berosus interstitialis Knisch (= *B. tesselatus* Fletiaux & Sallé)
Enochrus nebulosus Say

Hemiptera
Plecoris femoratus

List A-2. Aquatic insects collected by Dr. Julio García-Díaz at Laguna Cartagena

Coleoptera
Dytiscidae
Laccophilus proximus Say
Thermonectus basilaris Harris,
T. circumscripta Latreille
T. margineguttata Aubé

Hydrophilidae
Tropisternus lateralis F. (= *T. nimbatus* Say)
Enochrus ochraceous Melsheimer

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Table A-1. Number of individuals within each Hemiptera family collected at sites 1 and 2 in samplings from June 25, 2003 to March 25, 2004.

			Hemiptera								
Date	Site	Total	B	C	G	Me	Mi	N	P	S	V
6/25/2003	1	47	1	9	-	2	-	11	7	-	17
6/25/2003	2	12	1	-	-	3	-	2	-	-	6
7/9/2003	1	30	6	6	-	1	-	11	1	-	5
7/9/2003	2	20	-	2	-	6	-	2	8	-	2
10/16/2003	1	47	1	-	-	-	45	1	-	-	-
10/16/2003	2	1	-	-	-	-	-	1	-	-	-
2/25/2004	1	189	4	20	2	8	-	146	1	-	8
2/25/2004	2	140	23	12	5	7	-	89	0	-	4
3/25/2004	1	127	5	67	3	4	-	17	29	-	2
3/25/2004	2	51	-	3	3	10	-	2	21	2	10
sum		664	41	119	13	41	45	282	67	2	54
percent			6.2	18.3	1.4	5.5	6.9	43.4	10.3	0.3	7.8

B=Belostomatidae; C=Corixidae; G=Gerridae; Me= Mesoveliidae; Mi=Miridae; N=Notonectidae; P=Pleidae; S=Saldidae; V=Veliidae

Table A-2. Number of individuals within each Diptera family collected at sites 1 and 2 in samplings from June 25, 2003 to March 25, 2004.

			Diptera									
Date	Site	Total	Ch	Cho	Cl	Ct	E	St	T	M	M_1	M_2
6/25/2003	1	1	1	-	-	-	-	-	-	-	-	-
6/25/2003	2	0	-	-	-	-	-	-	-	-	-	-
7/9/2003	1	11	10	1	-	-	-	-	-	-	-	-
7/9/2003	2	5	4	-	-	-	-	1	-	-	-	-
10/16/2003	1	23	21	-	-	-	-	1	-	1	-	-
10/16/2003	2	0	-	-	-	-	-	-	-	-	-	-
2/25/2004	1	66	64	-	-	1	-	1	-	-	-	-
2/25/2004	2	45	43	-	1	-	1	-	-	-	-	-
3/25/2004	1	85	74	-	-	-	2	4	5	-	-	-
3/25/2004	2	17	14	-	-	-	-	-	-	1	1	1
sum		253	231	1	1	1	3	7	5	2	1	1
percent			91.3	0.4	0.4	0.4	1.2	2.8	2	0.8	0.4	0.4

Ch=Chironomidae; Cho=Chaoboridae; Cl=Culicidae; Ct=Ceratopogonidae; E=Empididae; St=Stratiomyidae; T=Tabanidae; M=Muscidae; M_1 y M_2=mosquitoes

Table A- 3. Number of individuals within each Coleoptera family collected at sites 1 and 2 in samplings from June 25, 2003 to March 25, 2004.

			Coleoptera							
Date	Site	Total	Ca	Cu	D	He	Hi	Sc	Sp	St
6/25/2003	1	21	-	-	6	-	15	-	-	-
6/25/2003	2	2	-	-	1	-	1	-	-	-
7/9/2003	1	56	1	-	15	30	9	-	-	1
7/9/2003	2	7	-	-	3	-	4	-	-	-
10/16/2003	1	34	-	1	4	-	17	1	11	-
10/16/2003	2	0	-	-	-	-	-	-	-	-
2/25/2004	1	5	-	-	1	-	4	-	-	-
2/25/2004	2	3	-	-	1	-	2	-	-	-
3/25/2004	1	30	-	-	0	-	30	-	-	-
3/25/2004	2	8	-	-	3	-	5	-	-	-
sum		166	1	1	34	30	88	1	11	1
percent			0.7	0.7	23.2	19.9	53	0.7	7.3	0.7

Ca=Carabidae; Cu=Curculionidae; D=Dytiscidae; He= Helodidae; Hi=Hydrophilidae; Sc=Scarabidae; Sp= Sphaeridiinae; St=Staphylinidae

Table A-4. Number of individuals within each Odonata family collected at sites 1 and 2 in samplings from June 25, 2003 to March 25, 2004.

			Odonata				
Date	Site	Total	A	Ce	Cr	Le	Li
6/25/2003	1	3	2	-	-	1	-
6/25/2003	2	1	-	-	-	1	-
7/9/2003	1	9	-	-	-	1	8
7/9/2003	2	2	-	-	1	1	-
10/16/2003	1	13	7	-	-	-	6
10/16/2003	2	5	-	-	-	-	5
2/25/2004	1	11	1	5	-	2	3
2/25/2004	2	6	1	3	-	-	2
3/25/2004	1	23	1	-	-	10	12
3/25/2004	2	9	1	-	-	2	6
sum		82	13	8	1	18	42
percent			15.9	9.8	1.2	21.9	51.2

A=Aeshnidae; Ce=Coenagrionidae; Cr=Corduliidae; Le=Lestidae; Li=Libellulidae

Table A-5. Number of Ephemeroptera collected at sites 1 and 2 in samplings from June 25, 2003 to March 25, 2004.

			Ephemeroptera
Date	Site	Total	Baetidae
6/25/2003	1	1	1
6/25/2003	2	1	1
7/9/2003	1	1	1
7/9/2003	2	1	1
10/16/2003	1	0	-
10/16/2003	2	0	-
2/25/2004	1	31	31
2/25/2004	2	5	5
3/25/2004	1	0	0
3/25/2004	2	1	1
sum		41	41
percent			100

Table A-6. Number of specimens within each order of insects collected at Laguna Cartagena for each order of insects at sites 1 and 2 in samplings from June 25, 2003 to March 25, 2004.

Date	Site	Total	Hempitera	Diptera	Coleoptera	Odonata	Ephemeroptera
6/25/2003	1	73	47	1	21	3	1
6/25/2003	2	16	12	0	2	1	1
7/9/2003	1	105	30	10	55	9	1
7/9/2003	2	34	20	5	6	2	1
10/16/2003	1	121	47	24	37	13	-
10/16/2003	2	7	2	0	0	5	-
2/25/2004	1	308	193	66	5	13	31
2/25/2004	2	199	140	45	3	6	5
3/25/2004	1	261	123	85	30	23	0
3/25/2004	2	83	50	17	8	7	1
sum		1207	664	253	167	82	41
percent			55.2	21	13.5	6.8	3.4

Table A-7. Diversity and abundance of insect species collected at two sites of the southeastern section of Laguna Cartagena from May 3, 2003 to March 25, 2004.

Genus/species	25/Jun/03		9/Jul/03		16/Oct/03		25/Feb/04		25/Mar/04		Total
	Site 1	Site2	Site 1	Site2	Site 1	Site2	Site 1	Site2	Site 1	Site2	
Belostoma bossi	1	1	6	0	1	0	4	18	5	0	36
Belostoma minor	0	0	0	0	0	0	0	5	0	0	5
Centrocorisa nigripennis	3	0	4	0	0	0	20	12	67	3	109
Trichocorixia cf. reticulata	6	0	2	2	0	0	0	0	0	0	10
Limnogonus cf. franciscanus	0	0	0	0	0	0	2	5	3	3	13
Mesovelia cf. muslanti	2	3	1	6	0	0	8	7	4	10	41
Microvelia cf. robusta	9	5	5	2	0	0	8	4	2	6	41
Microvelia cf. capitata	8	1	0	0	0	0	0	0	0	4	13
Saldula sp.	0	0	0	0	0	0	0	0	2	0	2
Buenoa cf. pallipes	8	2	10	2	1	2	10	28	0	0	63
Buenoa cf. macrophtalma	3	0	1	0	0	0	55	48	0	0	107
Buenoa cf. albidus	0	0	0	0	0	0	4	9	0	2	15
Buenoa cf. femoralis	0	0	0	0	0	0	67	0	0	0	67
Notonecta undulata	0	0	0	0	0	0	14	4	12	2	32
Paraplea sp.	7	0	1	8	0	0	1	0	28	20	65
Miridae species 1	0	0	0	0	45	0	0	0	0	0	45
Dytiscidae sp.	0	0	0	0	2	0	0	0	0	2	4
Agabus sp.											0
Celina sp.											0
Derovatellus sp.	0	0	0	0	0	0	0	0	0	1	1
Desmopachria aspera	0	0	5	2	1	0	0	0	0	0	8
Hydrovatus sp.											0
Laccodytes sp.	0	1	0	0	0	0	0	0	0	0	1
Laccodytes pumilio	0	0	2	2	0	0	0	0	0	0	4
Laccophilus proximus	6	0	5	0	0	0	0	0	0	0	11
Matus sp.											0
Megadytes cf. fraternus											0
Pachydrus sp.	0	0	0	0	1	0	0	0	0	0	1
Thermonectus cf. margineguttatus	0	0	3	0	0	0	1	1	0	0	5

Table A-7. continuation

Genus/specie	25/Jun/03		9/Jul/03		16/Oct/03		25/Feb/04		25/Mar/04		Total
	Site 1	Site2	Site 1	Site2	Site 1	Site2	Site 1	Site2	Site 1	Site2	
Hydrophilidae species 1	0	0	0	0	1	0	0	0	0	0	1
Berosus sp.	0	0	4	0	0	0	0	0	0	0	4
Enochrus ochraceus	3	0	2	2	7	0	2	0	17	3	36
Helobata larvalis	0	0	2	0	0	0	0	0	1	0	3
Hydrochara sp.	0	0	1	0	0	0	0	0	0	0	1
Hydrophilus sp.											0
Laccobius sp.	0	1	0	0	0	0	0	0	0	0	1
Paracymus subcupreusus	8	0	0	2	0	0	0	0	0	0	10
Tropisternus lateralis	4	0	0	0	9	0	2	2	12	2	31
Prinocyphon sp.	0	0	30	0	0	0	0	0	0	0	30
Carabidae species 1	0	0	1	0	0	0	0	0	0	0	1
Curculionidae species 1	0	0	0	0	1	0	0	0	0	0	1
Scarabidae species 1	0	0	0	0	1	0	0	0	0	0	1
Sphaeridiinae species 1	0	0	0	0	11	0	0	0	0	0	11
Stenus sp.	0	0	1	0	0	0	0	0	0	0	1
Aeshna sp. 1	1	0	0	0	0	0	1	0	1	0	3
Aeshna sp. 2	0	0	0	0	6	0	0	1	0	1	8
Anax sp.	1	0	0	0	0	0	0	0	0	0	1
Oploaeshna sp.	0	0	0	0	1	0	0	0	0	0	1
Epicordulia sp.	0	0	0	1	0	0	0	0	0	0	1
Brechmorhoga sp.	0	0	0	0	0	0	0	0	2	0	2
Crocothemis servillia	0	0	0	0	6	4	1	0	0	0	11
Idiataphe sp.	0	0	0	0	0	0	0	0	2	0	2
Libellula sp.	0	0	1	0	0	0	0	0	0	0	1
Nannothemis sp.	0	0	0	0	0	0	0	0	2	0	2
Micrathyria cf. aequalis	0	0	3	0	0	0	2	0	3	0	8
Perithemis cf. domitia	0	0	1	0	0	0	2	2	0	0	5

Table A-7. continuation

Genus/species	25/Jun/03		9/Jul/03		16/Oct/03		25/Feb/04		25/Mar/04		Total
	Site 1	Site2	Site 1	Site2	Site 1	Site2	Site 1	Site2	Site 1	Site2	
Sympetrum cf. vicinum	0	0	0	0	0	0	0	0	1	4	5
Tramea cf. onusta	0	0	3	0	0	1	0	0	2	0	6
Nehalennia sp.	1	1	1	1	0	0	5	3	10	2	24
Lestes sp.	0	0	0	0	0	0	2	0	0	0	2
Centroptilum sp.	1	1	1	1	0	0	31	5	0	1	41
Pseudocentroptiloides sp.					0						0
Chironomidae species 1	1	0	10	4	21	0	48	43	74	14	215
Chironomidae species 2	0	0	0	0	0	0	12	0	0	0	12
Chironomidae species 3	0	0	0	0	0	0	4	0	0	0	4
Mochlonyx sp	0	0	0	0	1	0	0	0	0	0	1
Ceratopogonidae species 1	0	0	0	0	0	0	1	0	0	0	1
Culex sp.	0	0	0	0	0	0	0	1	0	0	1
Empididae species 1	0	0	0	0	0	0	0	1	2	0	3
Muscidae species 1	0	0	0	0	1	0	0	0	0	1	2
Mosquito species 1	0	0	0	0	0	0	0	0	0	1	1
Mosquito species 2	0	0	0	0	0	0	0	0	0	1	1
Odontomyia sp.	0	0	0	1	1	0	1	0	4	0	7
Tabanus sp.	0	0	0	0	0	0	0	0	5	0	5
Species Abundance	**73**	**16**	**106**	**36**	**118**	**7**	**308**	**199**	**261**	**83**	**1207**
Family diversity	**12**	**8**	**15**	**12**	**14**	**2**	**17**	**15**	**17**	**17**	
Species Diversity per site	**18**	**9**	**26**	**15**	**19**	**3**	**27**	**19**	**25**	**20**	
Species diversity per date	**21**		**30**		**20**		**31**		**34**		
Species in common	**6**		**11**		**2**		**15**		**11**		

Note: Shadowed organisms were collected only during a pre survey in May 3, 2003 and are not used for abundance and diversity purposes, although are reported.

Table A-8. Other invertebrates collected at sites 1 and 2 in samplings from June 25, 2003 to March 25, 2004.

		Ostracods		Gastropods		Copepods	Hydrozoa
Date	Site	*Chlamydotheca*	Species 1	*Marissa*	*Tarebia*	*Macrocyclops*	*Chlorohydra*
6/25/2003	1	1	-	-	-	-	-
6/25/2003	2	-	-	-	-	-	-
7/9/2003	1	5	-	-	-	-	-
7/9/2003	2	1	-	1	1	-	-
10/16/2003	1	-	-	-	1	-	-
10/16/2003	2	-	-	-	-	-	-
2/25/2004	1	37	-	4	-	4	-
2/25/2004	2	61	14	17	-	92	3
sum		105	14	22	2	96	3

– = absent

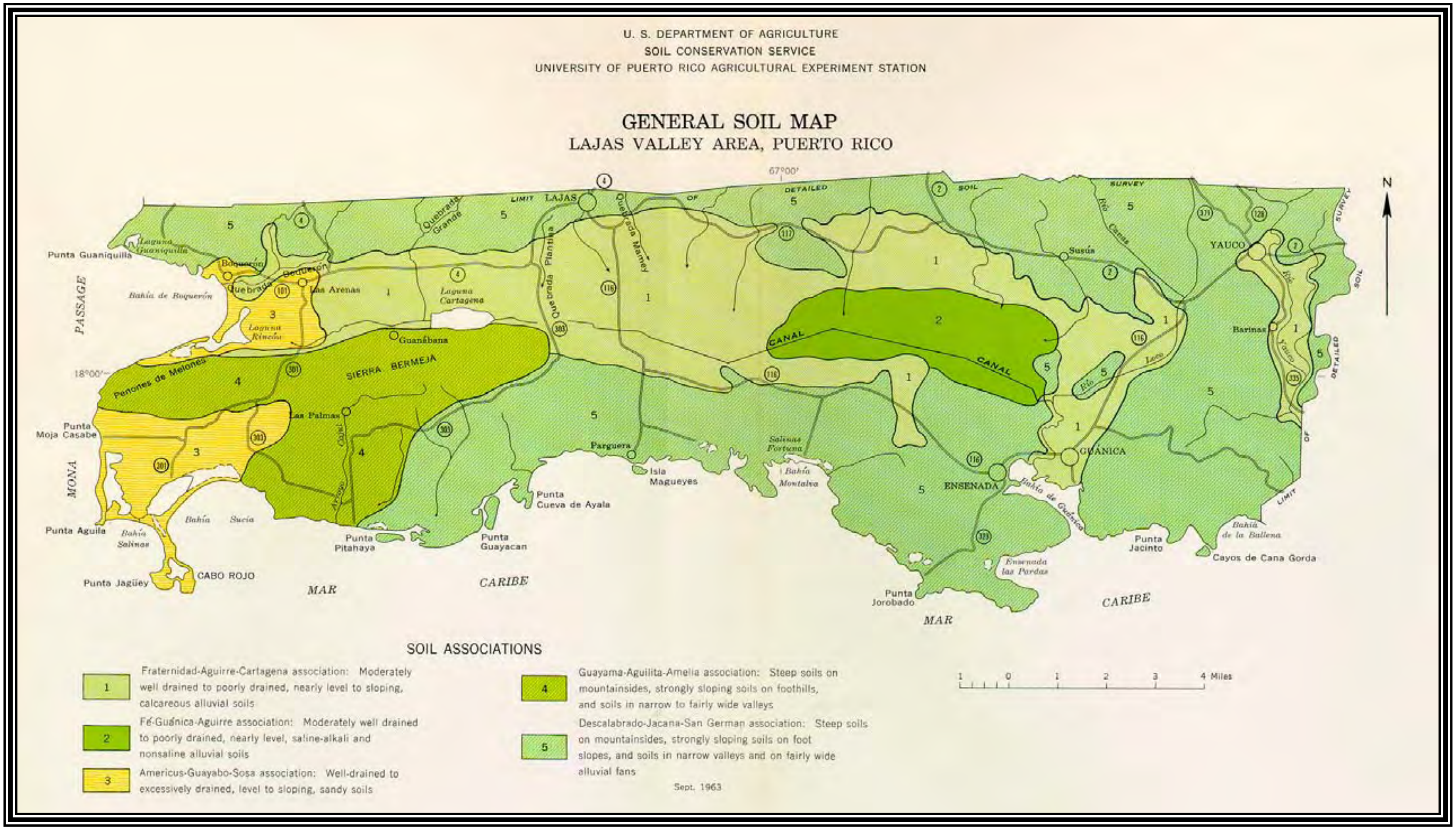

Figure A-1. General Soil Map from the Lajas Valley Area, Puerto Rico.

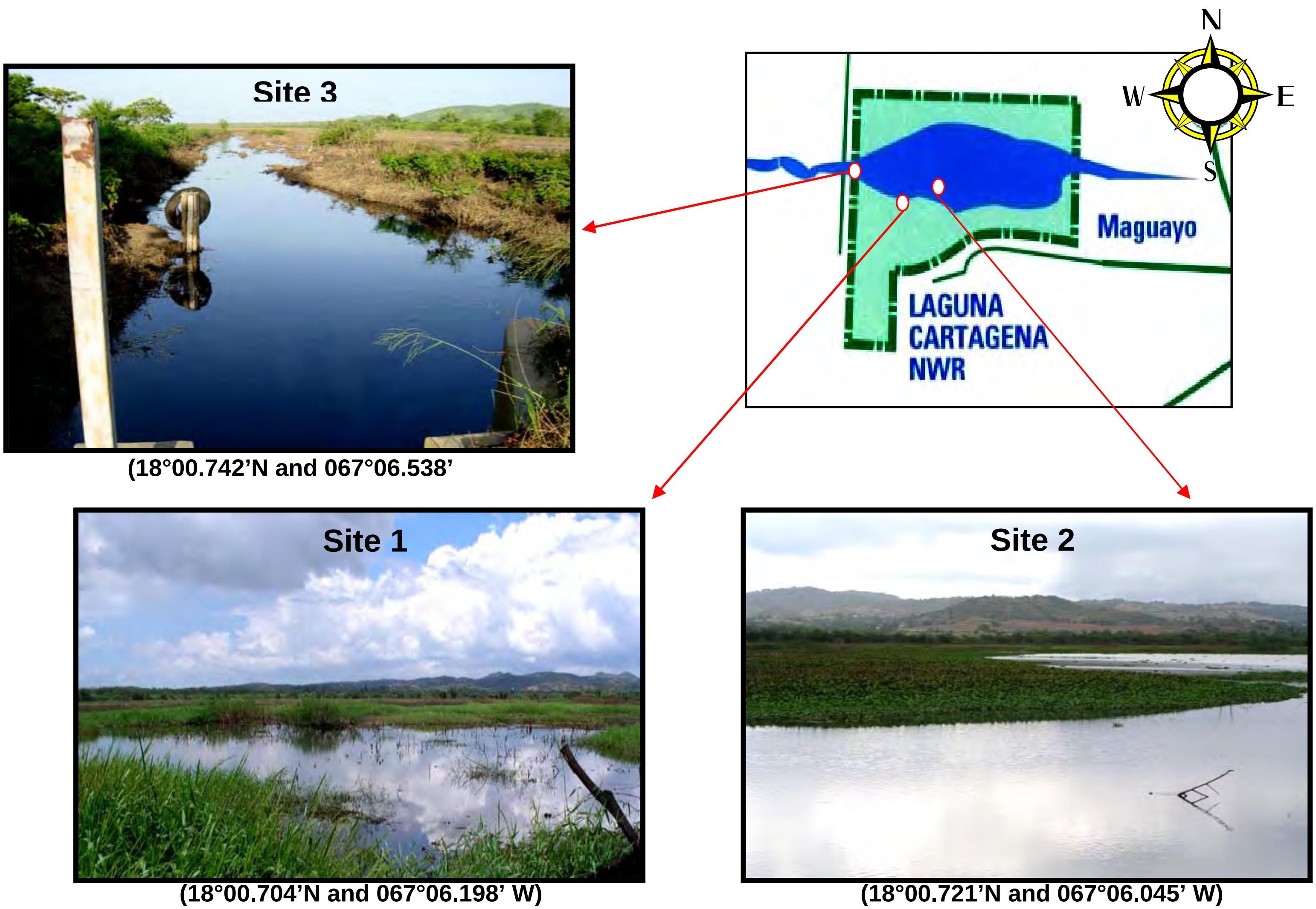

Figure A-2. Study sites at Laguna Cartagena

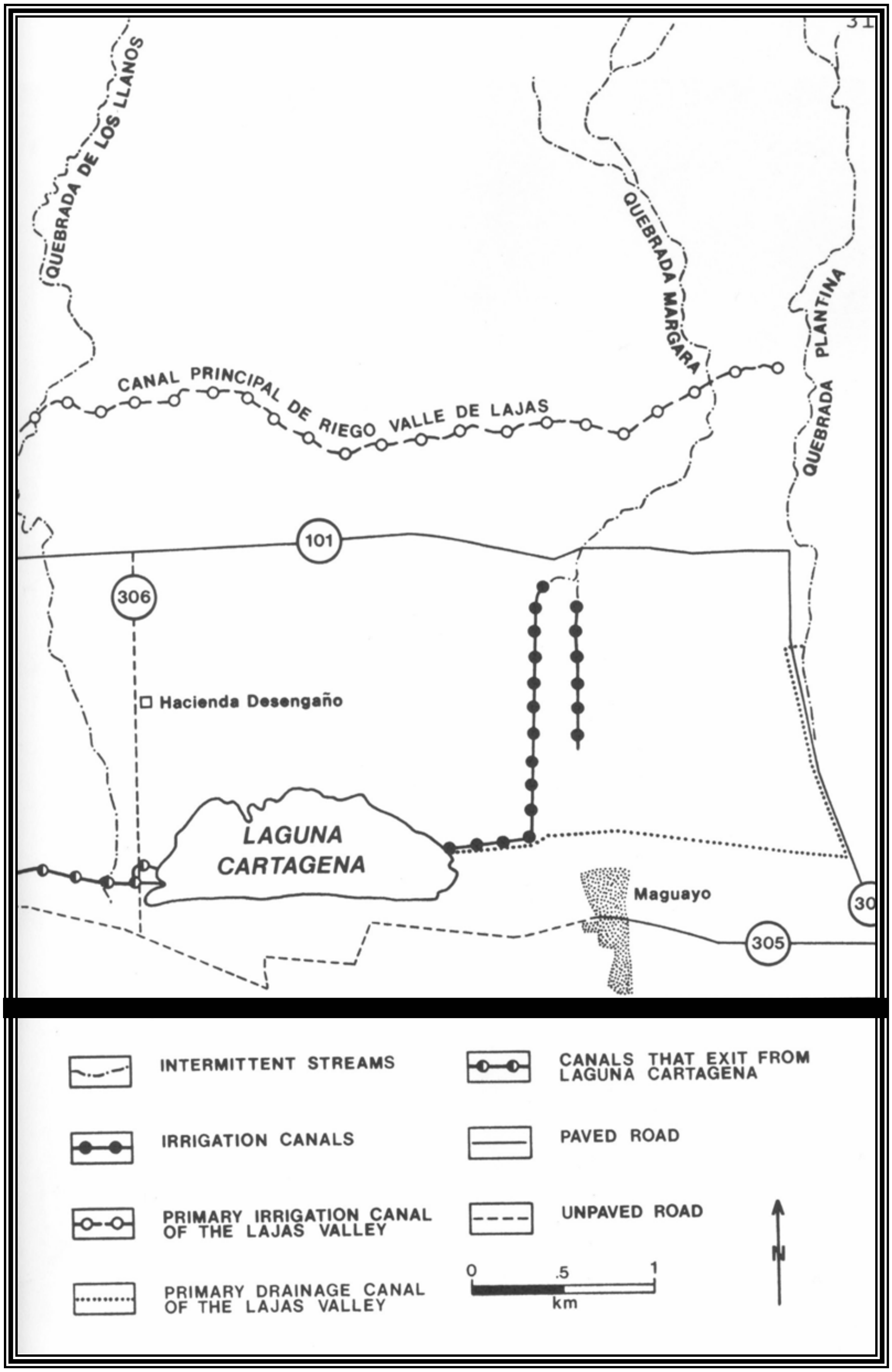

Figure A-3. Water inputs and outputs at Laguna Cartagena.

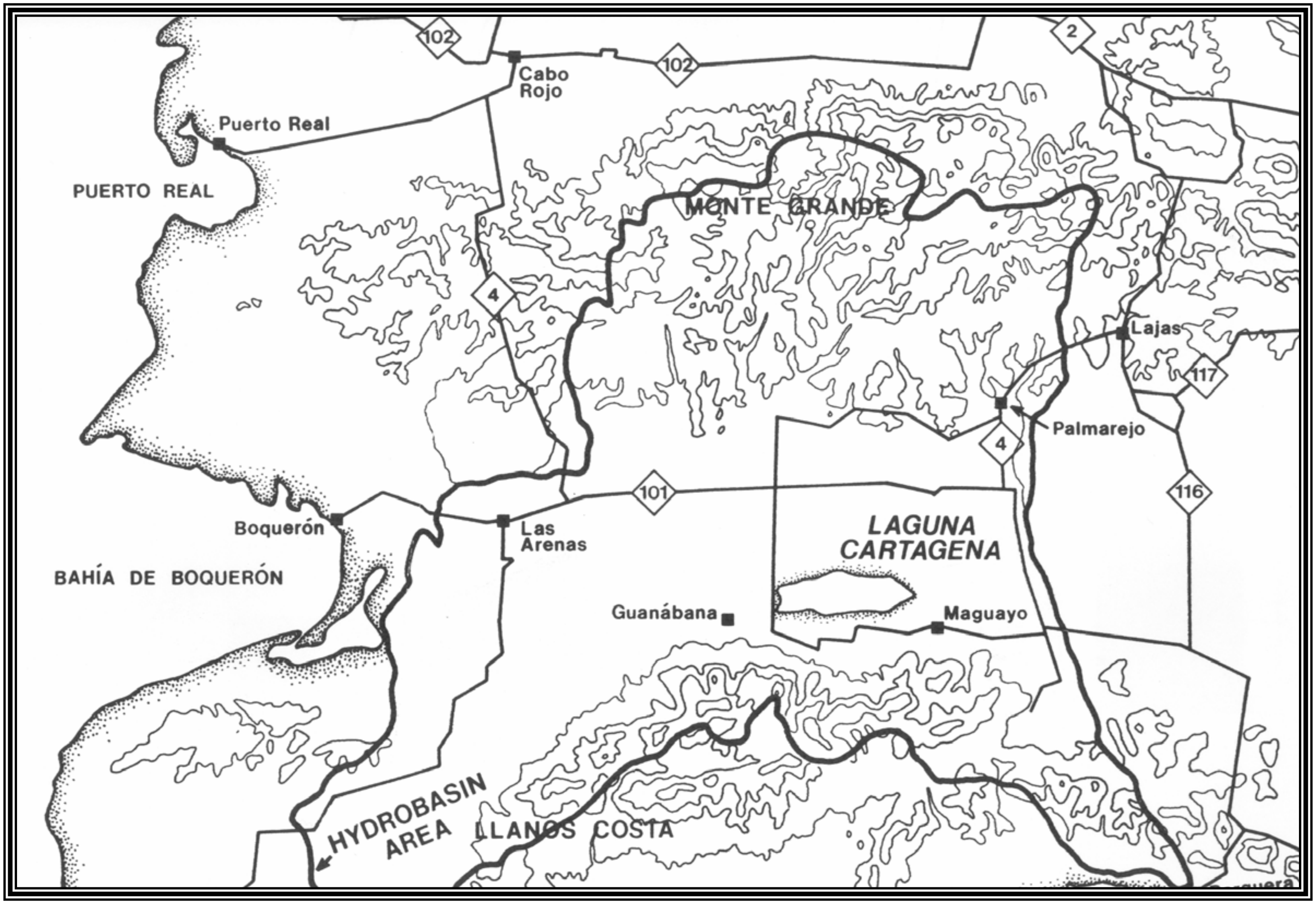

Figure A-4. Laguna Cartagena Hydrobasin