THE EFFECTS OF DEPTH, pH, DEPTH OF LIGHT PENETRATION, AND AREA ON BACKSWIMMER (HEMIPTERA: NOTONECTIDAE) DISTRIBUTION IN SEASONAL PONDS OF THE FLORIDA SCRUB

BY
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THE EFFECTS OF DEPTH, pH, TURBIDITY, AND AREA ON BACKSWIMMER (HEMIPTERA: NOTONECTIDAE) DISTRIBUTION IN SEASONAL PONDS OF THE FLORIDA SCRUB

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New College of Florida, 2003

Abstract

Backswimmers (Hemiptera: Notonectidae) are small, predacious Hemipterans. It is not known what factors affect the distributions of the five species of Notonectidae present at Archbold Biological Station in Lake Placid, Florida. Depth, pH, the depth of light penetration, and area are known to influence Notonectidae distribution among lakes and ponds in different locations throughout the world. This thesis shows that each of these factors influence only one of the species of Notonectid studied. Other factors, such as vegetation density, may play a role. Competition within the ponds may also be reduced by other mechanisms such as size differentiation.

Dr. Elzie McCord

Division of Natural Sciences

Introduction

A pond is defined as a small, shallow body of water that usually supports aquatic plant life from shore to shore and lacks a thermocline (Usinger, 1971). Not all ponds have a well defined basin. Some exist in marshes, some in the shallow water on the windward side of a lake, and some in the oxbows or lazy meanders of rivers. These areas are referred to as palustrine ecosystems by wetland ecologists (Caduto, 1990).

Even in the same area, no two ponds are exactly alike. Microhabitats and water quality in ponds vary according to pond size, shape, and depth, the persistence of the pond throughout the year, and local soil type, topography, and climate (Caduto, 1990). Available nutrients are very important in determining the pond environment. Nitrogen in the form of nitrate and ammonia and phosphorus in the form of phosphate are the two most important nutrients. Nitrogen levels affect the growth of green plant tissue while phosphorus promotes green plant reproduction (Odum, 1971). Iron, needed for respiration, calcium, needed for bone growth in vertebrates, and silicon, which is the major element in the frustules of diatoms are other important dissolved nutrients. Many of these nutrients tend to be more available for growth at certain pH and dissolved oxygen levels and temperatures. Other nutrients can act as pH buffers (Caduto, 1990).

Though autotrophic bacteria and photosynthetic plants are the primary producers in ponds (Odum, 1971), some nutrients also enter from outside the pond in the form of plant debris, via migrating animals and insects, and through soil erosion. Most of the nutrients present in a pond cycle within that pond. However, birds and other animals remove some nutrients from the ponds by feeding there and then leaving (Caduto, 1990).

Many microscopic and macroscopic organisms live in ponds. Bacteria are most numerous in ponds with fertile waters and organic bottoms. Fungi are important decomposers in ponds. Some are parasitic. Microscopic algae are the most important pond producers. Cyanobacteria, often called blue-green algae, are important producers along with green algae. Diatoms are common in moderately fertile ponds (Caduto, 1990; Odum, 1971).

Macrophytic plants grow where their needs for light, water clarity, and depth are met. Ponds generally consist of three plant zones: the emergent zone and shoreline, the floating-leaved zone, and the submergent zone. (Caduto, 1990 and Odum, 1971). Rooted plants with leaves extending above the water's surface characterize the emergent zone. Water lilies characterize the floating-leaved zone in the Eastern United States, although water hyacinth is most commonly seen in this habitat in Florida. As its name implies, plants that are completely or almost completely submerged occupy the submerged zone (Odum, 1971). Some deeper ponds have a deep-water zone where no rooted plants grow. There is usually a mosaic of these zones in a pond and not all of the zones are present in every pond (Caduto, 1990).

A large number of animal fauna are present in ponds. Zooplankton inhabits open water and provides food for many aquatic organisms. Invertebrates inhabit many pond microhabitats (McCafferty, 1981). Ponds are home to many vertebrates, also, including frogs, fish, and salamanders. Turtles and snakes live in and around the marginal zone of ponds. Many birds and mammals feed on pond organisms (Caduto, 1990).

Many species of insects are also present in ponds. Water striders, marsh treaders, and whirligig beetles live on the surface of the water. Water boatmen, backswimmers, water scorpions, giant water bugs, and other hemipterans as well as many aquatic beetles are fierce pond predators. Many insect larvae also live in ponds, including midge and other fly larvae, dragonfly and damsel fly naiads, mayfly naiads and others. They are often the dominant form of life (Usinger, 1971; McCafferty, 1981).

Ponds are created in many ways. Ponds in northern regions sometimes rest in kettle holes left by glaciers. Landslides create ponds by damming streams. Strong winds can scour out holes that then fill with water. In the tundra, very shallow depressions can become ponds because water cannot penetrate the permafrost (Caduto, 1990).

Rivers can create ponds when they change course. When a river erodes its outer bank and eventually joins a channel downstream, a pond or lake is left in the old channel called an oxbow lake or pond (Odum, 1971). Scroll ponds are created when a river gradually erodes its outer bank and deposits sediments on the inside of the bend. Eventually the channel moves towards the outside of the bend and a pond or lake forms on the inner edge. Ponds can also be formed by sediment deposit in deltas (Caduto, 1990).

Animals and even human beings also create ponds. Beavers create ponds in northern areas (Odum, 1971). American alligators hollow out small ponds in southern wetlands. Humans create ponds for wastewater and irrigation purposes as well as during construction and mining (Caduto, 1990). Farm ponds or managed fish ponds are also common (Odum, 1971).

Seasonal ponds, often called vernal, ephemeral, or temporary ponds, are wet for only part of the year. Seasonal ponds are a favorable habitat for many organisms because intraspecific competition and predation are reduced (Odum, 1971). They are present in many ecosystems throughout the world. They flood in different seasons depending on regional climatic patterns. Some flood only once in a year while others flood and dry many times within a single year. This depends in part on the pond’s size and basin characteristics. Seasonal ponds range in size from small pools that hold only a few liters of water to large lakes or wetlands that cover hundreds of hectares (Graham, 1997). Most are less that one hectare in size. Their small size results in high perimeter to area ratios. These high ratios may increase the exchange of energy, organisms, and materials with the adjacent ecosystem (Palik et al, 2001).

Though environmental conditions found in seasonal ponds throughout the world vary considerably, there are some patterns in invertebrate community structure found in these ponds. The invertebrates either inhabit both temporary and permanent bodies of water or are adapted completely for living in the seasonal ponds (Graham, 1997 and Odum, 1971). Insects generally leave the pond for more permanent water before it dries up (Graham, 1997). Many have adaptations such as a ready means of dispersal (wings) and short life cycles (Usinger, 1971). Pond invertebrates that do not leave seasonal ponds when they dry up possess adaptations to survive the dry period(s). These adaptations generally fall into one of two types. Some organisms resist desiccation during part of their life cycle. Snails and some mites burrow into the substrate before the pond completely dries up and seal their bodies with a water impervious layer. Other organisms produce a desiccation resistant stage, usually the egg or a cyst. In this stage, the organism can lose up to 92% of its body water and still survive. This is called cryptobiosis (Graham, 1997). In insects, this type of dormancy is referred to as Aestivation, and is most often observed in eggs. Larval aestivation is found in some species of aquatic Diptera, stonefllies, and fishflies (McCafferty, 1981).

Ostracods and small planktonic crustaceans are common seasonal pond inhabitants. Branchipods live almost exclusively in temporary bodies of water (Graham, 1997). Fairy shrimps are another common temporary pond inhabitant. Their eggs can survive in dry soil for months (Odum, 1971).

Many insects live in seasonal ponds. Waterboatmen, backswimmers, and other aquatic Hemipterans, various families of aquatic beetles, and Dipteran larvae, Odonate and mayfly naiads are usually present. The specific genera and species present depend upon the characteristics of the pond, including its hydroperiod, its nearness to permanent water, and the abundance of prey such as other invertebrates (Graham, 1997; McCafferty, 1981; Usinger, 1971).

Plants growing in seasonal ponds must be able to survive the dry periods. Some plants only inhabit the ponds when they are flooded, others only inhabit the ponds when they are dry. Often, the seeds remain in the soil while the pond is dry (or flooded) and sprout when the pond floods (or dries out). Other plants inhabit the ponds year round. Most of these are emergent species (Abrahamson et al. 1984).

The southern Lake Wales Ridge in Florida is pockmarked with seasonal ponds. Little is known about the ecology of the invertebrates that inhabit them. My thesis examines some of the characteristics of these ponds and the affect of these characteristics on the distribution of backswimmers, a family of aquatic Hemipterans common in seasonal ponds on the southern ridge.

Chapter 1: Seasonal Ponds of the Southern Lake Wales Ridge

The Lake Wales Ridge is the topographic crest of the central and south–central peninsular region of the state of Florida (Fig. 1.1) (Abrahamson et al. 1984). It extends over 85 miles in a southeasterly direction from a point north of the intersection between Polk, Osceola, Orange, and Lake Counties to the southern end of Highlands County. It reaches a maximum elevation of 300 feet above sea level in some places (White, 1958).

Residual sandhills, relic beach ridges, and palio dunes characterize the ridge. It, along with the other high ridges in central Florida, is a remnant of a once larger upland preserved from a time of much higher sea level (White, 1958). A valley that averages 3 km in width and contains numerous solution lakes occupies the central part of the southern ridge (Abrahamson et al. 1984). Because of its previous isolation, a large number of endemic plant and animal species and subspecies occur there (Lohrer, 1992).

Archbold Biological Station (Fig. 1.2) is located on the Southern Lake Wales Ridge in Highlands County 12 km south of the town of Lake Placid. Its area encompasses most of the geologic and topographic features associated with the ridge. Its area includes the eastern crest of the ridge, the southernmost portion of the aforementioned intraridge valley, and part of the western side of the ridge (Abrahamson et al. 1984).

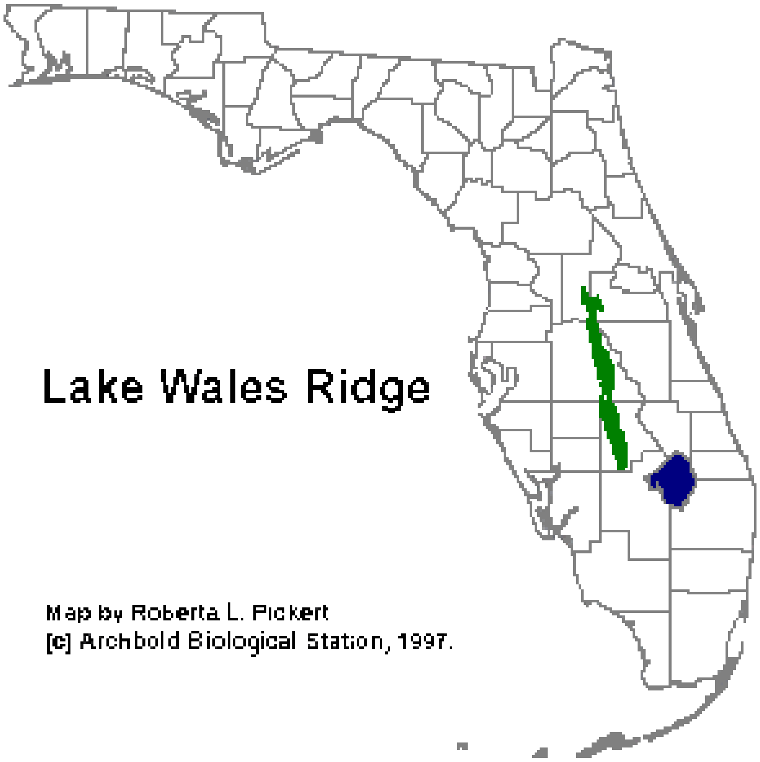


Fig. 1.1: The Lake Wales Ridge

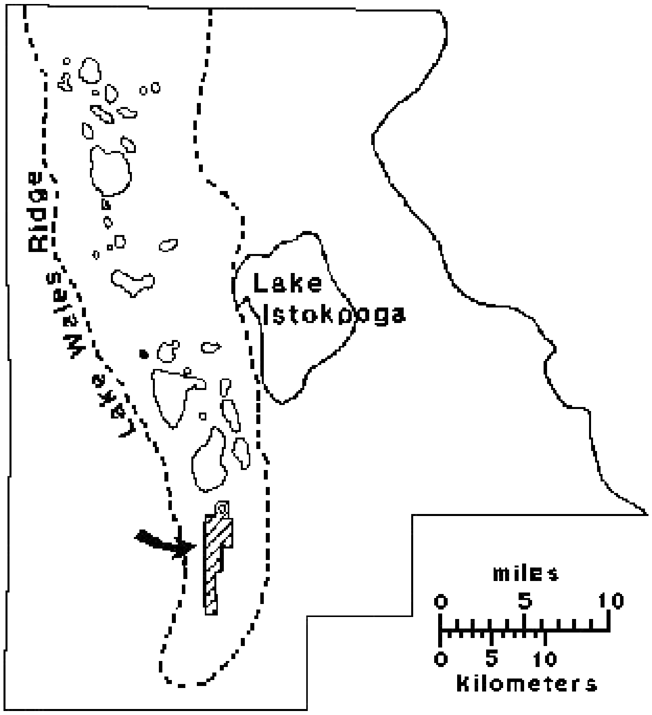


Fig. 1.2: Location of Archbold Biological Station (Drawn by Edwin Rivera [c] Archbold Biological Station 1984.)

There are three permanent bodies of water present on the station (Fig. 1.3). One is Lake Annie, which is located at the north end of the station property. It is the southernmost of the many small sinkhole lakes that dot the Lake Wales Ridge and more northern areas for 200 miles. It covers an area of 90-acres and is 68 ft (20.7 m) deep (Lohrer, 1992). The barrow pit near the center of the station property is a small, permanent pond only a few meters wide. The last of the three is the sinkhole pond. It is farther south than the barrow pit and it covers an area of about 500 m^2. All of the other ponds present on the station are seasonal, although the deepest zone in the larger ponds can stay flooded for long periods of time.

There are hundreds of seasonal ponds spread throughout the Archbold Biological Station area (Fig. 1.3). They are concentrated in the intraridge valley portion of the station and vary greatly in shape and size. Some are flooded every summer and into the fall and even later in the wettest years. Other ponds flood only in the wettest years. There are many types of vegetation present in the ponds, often in zones (Abrahamson et al. 1984).

The most common zonation from center to edge encountered in deeper ponds is maidencane (*Panicum hermitomon* Schult), *Hypericum edisonianum* Adams & Robson, cutthroat grass (*Panicum abcissum* Swallen). In shallower ponds, the zonation is often either *Hypericum edisonianum*, broomsedge (*Andropogon spp.*) or pure cutthroat grass (Abrahamson et al. 1984 and Landman and Menges, 1999). Cutthroat grass can form dense monocultures in shallow seasonal ponds (Yahr et al. 2000).

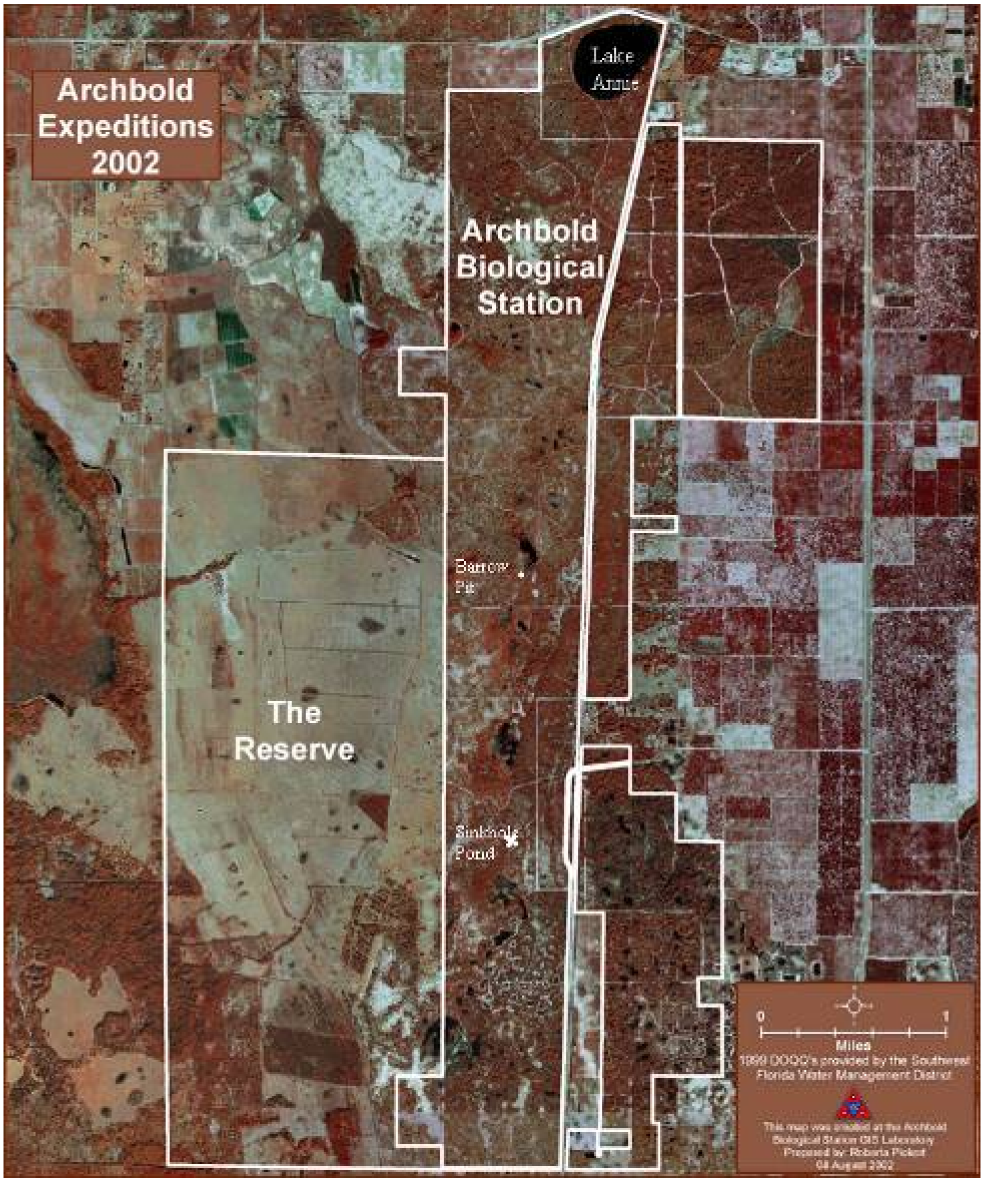


Fig. 1.3: Location of permanent bodies of water on Archbold Biological Station. All of the other irregularly shaped dark areas are seasonal ponds.

There is no emergent vegetation in the center of the deepest ponds. This zone is often flooded well into the dry season (Abrahsmson et al. 1984). The next deepest zone is usually at least moist during the dry season. A sparse strand of maidencane generally dominates it (Yahr et al. 2000). Mosses often forms a continuous ground cover in this zone. Redroot (*Lachmanthes carolinana* (Larn) Dandy) dominates this zone in some ponds (Abrahamson et al. 1984). The rhizomatous *Hypericum edisonianum* characterizes the next zone (Yahr et al. 2000). This zone is almost always dry during the dry season. *Hypericum edisonianum* forms nearly pure strands in the deeper end of this zone but is often replaced by a species of yellow-eyed grass (*Xyris elliottii* Chapm) or blue maidencane (*Amphcarpon muhlenbergianum* (Shult) Hitch) in the shallower end of the zone. Tall cordgrass (*Spartina bakerii* Merr) occurs in the drier portions of this zone (Abrahamson et al. 1984). The shallowest zone, the marginal zone, is dominated by either a mat of cutthroat grass (Yahr et al. 2000) or by a strand of broomsedge and small herbs (Abrahamson et al. 1984). For details about the various pond plants, see appendix A.

Invertebrate communities quickly establish themselves after seasonal ponds have flooded. The development, composition and abundance of species are often very heterogeneous within the same pond. These invertebrate communities are affected by the duration, timing, and frequency of flooding (De Szalay and Resh, 2000).

Both submersed and emergent aquatic plants affect the residing invertebrates and their population abundance. Submersed vegetation provides the invertebrates with shelter from predators, spawning sites, perches for sit-and-wait predators, and sometimes food (Hann, 1995). Many aquatic fly larvae, certain aquatic beetles (water scavenger beetles, aquatic leaf beetles, water weevils), and other aquatic insects are herbivorous. Water scorpions are an example of a sit-and-wait predator (McCafferty, 1981). The grazing invertebrates, in turn, may prevent algal blooms, allowing the submersed vegetation to persist. Different plants can create microhabitats that should result in different assemblages of invertebrates. Plant morphology, surface texture, epiphytic algal growth and community composition, nutrient content of the plant tissues, and the presence or absence of defensive chemicals can all affect the invertebrate community structure associated with a specific plant (Hann, 1995).

Emergent vegetation also provides shelter, spawning sites, perches for sit-and-wait predators, and food. Emergent vegetation can also influence the distribution of aquatic invertebrates because of these factors (Hann, 1995). Invertebrate diversity is often higher in vegetated areas than in open water. De Szalay and Resh (2000) examined invertebrate communities of saltgrass in seasonal wetlands in California. They found that diversity was lowest in low plant cover areas.

A striking feature of the seasonal ponds on the ridge is the distinct boundary between them and the surrounding vegetation communities. Most of the ponds are ringed by saw palmetto. The horizontal stems of the palmettos often grow down the slope from flatwoods communities to the seasonal ponds. They then stop to form an abrupt ecotone between the two communities. This suggests that there is little interaction between the species present in the two communities. However, this is not the case. *Hypericum edisonianum* and other pond species often invade flatwoods. Also, certain flatwoods species like *Pinus elliottii* var. *densa* Little & Dorman (south Florida Slash Pine) are often found in ponds. These rapid invasions suggest a dynamic equilibrium exists between the two communities (Abrahamson, 1991).

Few slash pine seedlings survive to maturity in the ponds. Abrahamson (1991) found that slash pine invasion is checked primarily by periods of high water level. Mortality may also be influenced by fire dependent factors such as fuel loads, plant size, pre- and post-fire precipitation, and water table conditions pre- and post-fire.

Over time, seasonal ponds are invaded by bayheads and transition from herbaceous pond vegetation to the woody vegetation characteristic of bayheads. Landman and Menges (1999) found two distinct patterns of this invasion. First, Bayhead invader species prefer the most shallow pond zones. Second, the geographic distribution of vegetation at the landscape level influences bayhead invasion of ponds; i. e. ponds closer to bayheads tend to have higher densities of woody bayhead individuals. Fire and fire suppression may also play a role.

I examined twelve seasonal ponds spread throughout the Archbold Biological Station Area (Fig. 1.4). While I was conducting my study, two other interns were conducting studies involving the seasonal ponds. I utilized ponds from both of their studies so that multiple data could be obtained on individual ponds. One intern was looking at fish populations. Six of the ponds from her study were included in my study. They are numbered E1-E6, E being the first initial of her name. The other intern was monitoring malaise traps in ten different ponds. Four of these ponds were used in my study. They are numbered J1-J4, J being the first initial of his name. There was one pond being used in both studies. I used it in my study also and numbered it JE1. The last pond in my study was not being used in either of the other two studies. It was numbered L1. I chose the ponds so that as wide an area as possible was covered in my study. The ponds are of varying area and depth with differing vegetation communities.

All of the seasonal ponds present on the Archbold Biological Station property have an official number. The numbers look like this: 6-12. The first part of the number is the study tract number. The second part of the number is the pond’s number. Therefore 6-12 would be pond twelve in study tract six. Below is a table correlating my pond numbers with the official station numbers (Table 1.1). Ponds E5 and E6 are two halves of the same pond. A raised road cuts this pond in half. Even when the water in the pond is high, there is little contact between the two halves.

Table 1.1 My study pond numbers, their official numbers, and the approximate maximum area of each pond.

Official Pond Number	My Number	Approximate Surface Area (m^2)
7-47	E1	1650
7-64	E2	2731
18-15	E3	9744
18-23	E4	9663
30-5 (south half)	E5	8213
30-5 (north half)	E6	2025
6-9	J1	962
7-57	J2	1257
19-19	J3	1988
30-33	J4	1606
6-32	JE1	5095
7-75	L1	6912

I calculated the area of each pond using the vegetation map. There is a map ruler in the key that I used this to estimate various lengths, widths, or radii (depending upon pond shape) in each of my study ponds. I used these measurements to estimate area. The area is the approximate maximum area of the pond. The purpose of the calculation is to give an idea of each pond’s size relative to the other ponds.

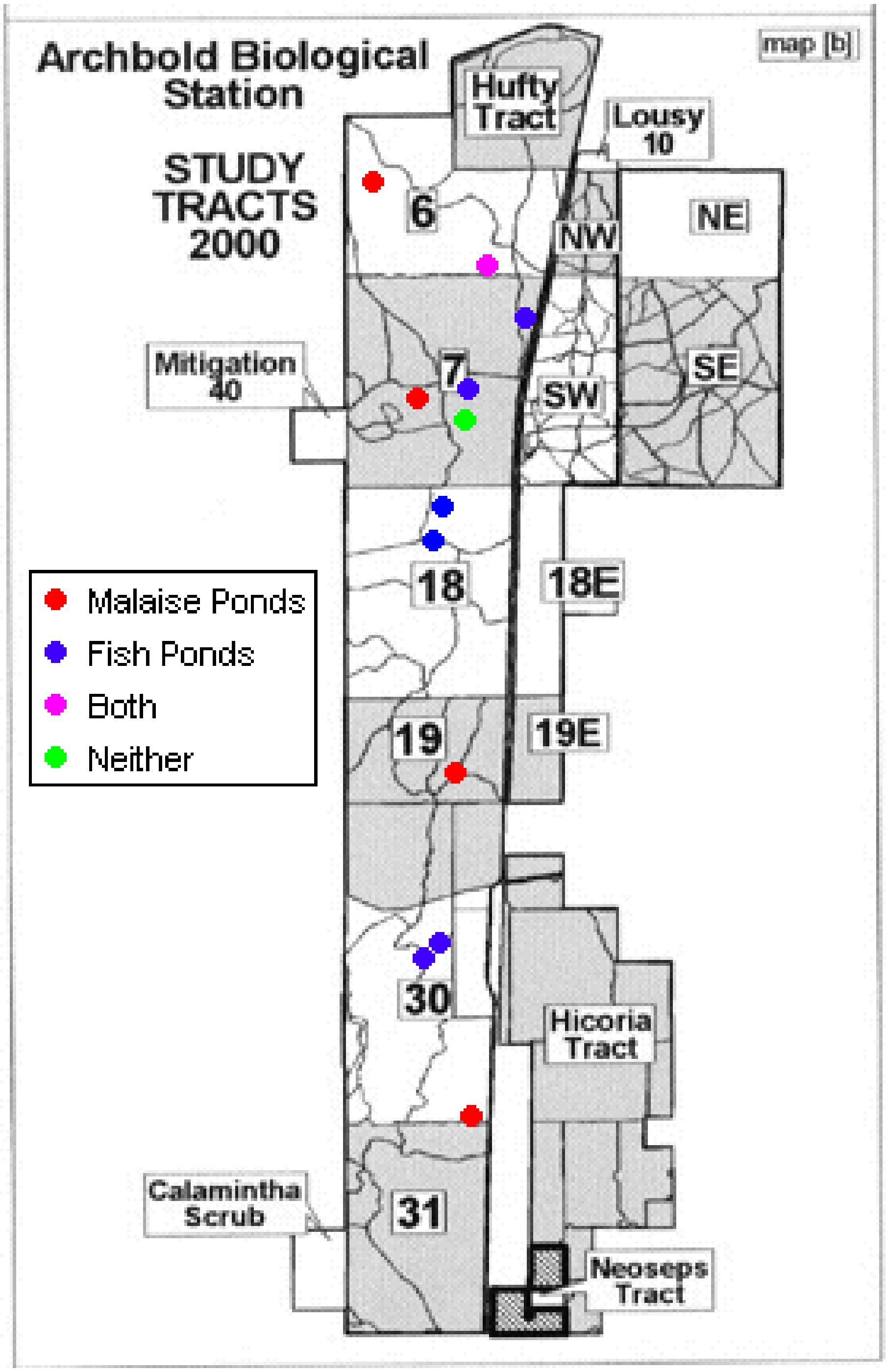


Fig. 1.4: Pond Locations.

Pond J1 (fig. 1.5a) is shaped like a lower case b lying on its back. There are large patches of hypericum (*Hypericum edisonianum*) and broomsedge (*Andropogon sp.*)

present in this pond. No roads pass close enough to the pond to affect it. This pond is unusual in having extremely clear water.

Pond J2 is shaped like a fat L. *Hypericum edisonianum* and maidencane (*Panicum hemitomon*) are the dominant emergent vegetation types. A road passes near the north end, but the road does not pass close enough to have an impact.

Pond J3 is shaped like a woman's high-heeled boot. Spartina (*Spartina bakerii*) dominates the center of the pond. Patches of hypericum and maidencane surround the spartina. A road passes through the southeast end of the pond cutting off the high-heel of the boot.

Pond J4 (Fig. 1.5b) has an oval, almost egg shape. It is one of the deeper ponds and there is a large area in the pond with no emergent vegetation. There is a large patch of hypericum in the center of the pond and other small patches near the edge. Broomsedge and spartina surround the edge of the pond. A road passes through the southernmost tip of the pond.

Pond JE1 is shaped like a scalene triangle with rounded corners. There is a large patch of hypericum in the center. This patch is surrounded by cutthroat grass (*Panicum abscissum*). A road passes through the entire southern edge of the pond.

Pond E1 (Fig. 1.5c) is square shaped. The dominant emergent vegetation is cutthroat grass. There are also several adult slash pines growing in this pond. A road passes through the entire eastern edge of the pond.

Pond E2 (Fig. 1.5e) is the smallest pond in this study (see Table 1.1). It is roughly circular in shape. The dominant emergent vegetation is redroot. A road passes quite close to the north end.

Pond E3 is also roughly circular in shape. The dominant emergent vegetation is cutthroat grass. A road passes close to the west side of the pond.

Pond E4 is oblong, shaped like an oval that has been pinched in the middle. Patches of hypericum and redroot grow in the pond, which is dominated by cutthroat grass. A road cuts through the middle of the pond.

Pond E5 is shaped like half of an oval. Hypericum and maidencane dominate this pond. A raised road forms the northern edge.

Pond E6 is shaped like an oval with a kink in it. The southern edge is flat. It is also dominated by hypericum and maidencane. The raised road forms the southern edge of this pond.

Pond L1 (fig. 1.5d) is long and narrow. Its dominant emergent vegetation is maidencane. There are also several large patches of hypericum in this pond. No main roads pass near this pond but an ATV trail passes through the pond slightly north of the center of the pond.

a b

c d

e

Fig. 1.6: Ponds J1 (a), J4 (b), E1 (c), L1 (d), and E2 (e).

Chapter 2: Depth, pH, Conductivity, and Depth of Light Penetration

Introduction

Seasonal ponds found in the same area can differ markedly in physical and chemical characteristics. This can have an impact on what organisms live in a particular pond. Depth is important in determining how long a seasonal pond will stay flooded. The depth of light penetration can affect the predation strategy of organisms living in a seasonal pond. On the other hand, the types and numbers of organisms living in a pond can affect the depth of light penetration. Conductivity and pH, two important chemical factors, can also have an affect on organisms living in seasonal ponds.

The amount of rainfall and depth are important in determining which ponds will stay flooded longer. Shallower ponds tend to dry up faster then deeper ponds. This is very important to organisms that must reach a particular stage before the pond dries up (Graham, 2002).

Different species of plants live at different depths. This creates zones within ponds. Deeper ponds have more zones than shallower ponds and thus tend to have more diverse plant life (Abrahamson, 1984).

Ponds could be defined as small bodies of water existing wholly within the photosynthetic zone, although they often vary in turbidity (Usinger, 1971). Seasonal ponds are no exception. In most seasonal ponds, turbidity determines the depth of light penetration. Turbidity is a function of three main variables: dissolved chemicals, suspended particles, and the density of microbial organisms. Examples of dissolved chemicals include tannins, acids, and salts. Soil particles such as silt and clay as well as organic matter are examples of suspended particles (Brower et al. 1998). Tannins cause much of the turbidity in the seasonal ponds at Archbold Biological Station. The depth of light penetration affects the distribution and amount of photosynthesis in seasonal ponds (Brower et al. 1998). The depth of light penetration also affects the visibility in ponds. This could have an impact on organisms that utilize their sense of sight to capture prey.

Conductivity is a measure of the salinity or the amount of soluble salts present in soil or water. The more dissolved ions present in the water, the easier it conducts a current (Brower et al. 1998). The body fluids of freshwater organisms are hypertonic to the surrounding water. Insects and other aquatic organisms compensate for this by excreting a very dilute urine and reabsorbing some ions in the gut (Odum, 1971). Aquatic insects also possess adaptations for the active absorption of ions. Most freshwater insects can adapt well to decreases in salt concentration, but cannot adapt well to increases in concentration (McCafferty, 1981).

The hydrogen ion concentration or pH of soil or water is one of the most important chemical factors of a habitat (Brower et al. 1998). In an aquatic ecosystem, it is a function of the dissolved carbon dioxide content of the water (Odum, 1971). It determines the nature of many chemical reactions that take place in the habitat. It can also have a direct impact on the distribution and diversity of organisms in a habitat (Brower et al. 1998). Some organisms can tolerate a wide range of pH, but many can only survive in a limited range.

In this part of my study, the depth, depth of light penetration, conductivity, and pH of the twelve different ponds were measured to determine if these characteristics differ significantly between the ponds. It is already known that the ponds are of differing depth. The depth of light penetration may differ because vegetation type and vegetation density differ between ponds. Also, the ponds are adjacent to different habitats. Conductivity and pH may differ because of differing soil types and differing types and densities of vegetation in the different ponds.

As noted in the previous chapter, roads pass near most of the ponds and even pass through several of them. These roads are cleared paths through the scrub for the research vehicles to travel on. They can also serve as firebreaks during controlled burns. The presence of roads would not have an affect on depth and would probably not significantly affect pH. However, the presence of the roads could affect the depth of light penetration by increasing turbidity. Since little plant life grows in the roads, the soil is easily stirred up. Also, when a vehicle is driven through a pond, pollutants from that vehicle get washed into the pond.

The depth of light penetration could also be affected by the size of the ponds. Dissolved particles and microscopic life can spread more in larger ponds. They could become less concentrated, reducing the turbidity. This would increase the depth of light penetration. Or, more space could allow for the growth of more organisms, which could lead to an increase in turbidity and a decrease in the depth of light penetration. The size of the ponds will probably not have a large impact on the depth of light penetration because most of the turbidity in the station's ponds is due to tannic acid, not dissolved particles or microscopic life.

Materials and Methods

Both the center depth and average depth of each of the ponds was measured. All of the ponds were measured on the same day so the data would be comparable. Center depth was measured at the approximate center of the pond using a meter sick. Average depth was measured by taking depth measurements at five points in each pond and averaging all six collected depth measurements. The five different depth measurements were taken so that at least one depth measurement was taken in each vegetative zone. Points were chosen to get a good sampling of the depth profile of each pond.

To determine the pH of the ponds, three water samples were taken randomly at different places in each pond, two near the surface and one near the bottom. I collected the samples in small vials. To collect a sample at the surface, I dipped the vial into the pond and let it fill with water. To collect a sample near the bottom, I held my thumb over the top of the vial until I lowered it to near the bottom of the pond and then I released my thumb and let the vial fill with water. I again covered the top with my thumb to bring the vial back up to the surface of the pond. All of the water samples were collected during the morning on the same day. A pH meter in the station's chemistry laboratory was used to measure the pH of the samples. I calibrated the pH meter using a two-point calibration with pH 7 and pH 4 buffers. The average of the three pHs was then calculated. The pH was measured the day after the samples were collected.

The water samples used to measure the pH were also used to measure conductivity utilizing a conductivity meter. The meter had been previously calibrated. The three values were then averaged to get average conductivity.

The depth of light penetration was measured using a Secchi disk (Fig. 2.1). It is slowly lowered until no longer visible. The depth at this point is recorded. The disk is lowered further and then slowly raised until it can just be seen again. The depth at this point is recorded. I measured the depth using a small, plastic ruler (Fig. 2.2). Once I could no longer see the disk, I held the cord at the point where it entered the water. I then raised the disk and measured the depth with the ruler. I then carefully lowered the disk back to into the water. I raised the disk to where I could just see it and measured the depth in a similar manner. The mean of these two depths is the depth of light penetration. This procedure was repeated three times in each pond and the three values were averaged. Turbidity measurements were taken over a period of two weeks between 1:30pm and 2:30pm.

Fig. 2.1: A secchi disk

Fig. 2.2: Measuring the depth of light penetration

To determine if the presence of roads impacts the depth of light penetration of the ponds, I used Linear Regression and Correlation analysis. First, I gave each pond a number from zero to three. Ponds that never come in contact with a road were designated as three. Ponds near enough to a road that the pond water could come in contact with the road were given a two. A one was given to ponds that have roads passing through the edge of them. Ponds with a zero had roads passing through the middle of them. I called this the nearness to a road value. I used these values along with the average depth of light penetration in the analysis.

There are three different ways of measuring the size of a pond: depth, area, and volume. I measured the depth of the ponds. The area was calculated from the vegetation map as discussed in the previous chapter. I calculated volume by multiplying the area by the average depth. I used correlation analysis to see if pond size had a significant impact on the depth of light penetration.

Results and Discussion

Unsurprisingly, depth varies considerably between ponds (Table 2.1). Pond J4 is the deepest of the twelve with a center depth of 87.0 cm. The shallowest pond, E5, has a center depth of only 11.1 cm. Interestingly, the center depth was not always the deepest depth.

Table 2.1: This table shows the center depth, the average depth, and the deepest recorded depth.

Pond	Center Depth	Average Depth	Deepest Depth
JE1	72.0cm	44.1cm	72.0cm
J1	35.9cm	27.9cm	38.8cm
J2	74.9cm	48.6cm	74.9cm
J3	21.9cm	30.5cm	42.0cm
J4	87.0cm	59.9cm	87.0cm
E1	54.5cm	41.8cm	54.5cm
E2	54.4cm	41.9cm	54.4cm
E3	20.2cm	18.7cm	25.0cm
E4	26.4cm	21.9cm	31.0cm
E5	11.1cm	10.2cm	11.1cm
E6	23.1cm	19.6cm	27.7cm
L1	45.7cm	46.5cm	66.9cm

Archbold Biological Station has been taking depth measurements of some of its seasonal ponds since 1989. The data can be found in Appendix B. The data show how unpredictable the length and intensity of the wet and dry seasons are. In 1993 and 1995 most of the ponds stayed wet throughout the year. Two thousand and two was also a very wet year. In contrast, in 1997 and 2000, most of the ponds were flooded for only a few months and some were never flooded.

The conductivity in all the ponds averaged either 30.8 or 30.9 µMHOS (Table 2.2). Either all of the ponds have the same conductivity or the meter was not calibrated correctly.

Table 2.2: Conductivity measurements from each pond and average conductivity.

Pond	Sample 1	Sample 2	Sample 3	Average
JE1	30.8	30.8	30.7	30.8
J1	30.7	30.8	30.8	30.8
J2	30.8	30.7	30.8	30.8
J3	30.8	30.7	30.8	30.8
J4	30.8	30.9	30.7	30.8
E1	30.8	30.8	30.8	30.8
E2	30.8	30.8	30.7	30.8
E3	30.8	30.8	/	30.8
E4	30.8	30.7	30.8	30.8
E5	30.8	30.8	30.7	30.8
E6	30.9	30.8	30.7	30.8
L1	30.7	/	30.8	30.8

Average pH ranged from 4.3±0.2 in pond E2 to 5.7±0.3 in pond J1. The pH values within the same pond sometimes varied considerably as did average pH values between ponds (Table 2.3). The samples were collected on one day and the pH was measured the following day. This may have allowed organic matter in the samples to decompose altering the pH of the sample. This could account for the variability of the pH measurements within the same pond. The main point of interest is that ponds J1 and J3 were the only two ponds with a pH greater than 5 in all three samples. The low pH is not surprising because there is a high concentration of tannic acid in most of the ponds. Pond J1, the least acidic pond, has a low concentration of tannic acid in its waters.

Table 2.3. pH values obtained from each sample and average pH for each pond. Two values were not recorded because those samples spilled.

Pond	Sample 1	Sample 2	Sample 3	Average± SD
JE1	5.546	5.171	4.253	4.9±0.7
J1	5.559	5.538	6.081	5.7±0.3
J2	4.676	4.525	4.792	4.7±0.1
J3	5.646	5.022	5.466	5.3±0.3
J4	4.858	4.588	4.627	4.7±0.1
E1	4.154	4.469	4.991	4.5±0.4
E2	4.581	4.177	4.159	4.3±0.2
E3	4.982	4.367	/	4.7±0.4
E4	4.874	4.421	4.424	4.6±0.3
E5	4.568	4.239	4.454	4.4±0.2
E6	4.335	4.09	4.904	4.4±0.4
L1	4.250	/	4.724	4.5±0.3

Measurements of pH taken earlier in the winter were lower (Table 2.4). This is most likely due to the fact that there was little water in the ponds at that time. These data show that the pH of the ponds fluctuates throughout the year and that it can get very low.

Table 2.4: pH measurements taken in several ponds in late fall and winter 2001/2002. (Courtesy of Nancy Deyrup, Education Coordinator Archbold Biological Station)

Pond #	11/9/2001	12/14/2002	1/11/2001	2/1/2001	2/28/2001	Average
750	3.730	3.412	/	/	/	3.571
753	3.772	3.552	3.817	4.035	3.687	3.773
756	3.405	3.529	3.527	3.688	3.381	3.506
757W	3.763	3.55	/	/	/	3.657
774	3.643	3.664	3.613	3.669	3.599	3.683
784	3.683	3.557	3.522	3.623	3.609	3.599
1837	3.668	3.645	3.741	3.641	3.72	3.683
1924	3.546	3.555	3.636	/	/	3.579
3035	3.681	3.498	/	/	/	3.590
3113G	3.778	3.658	3.576	/	/	3.671
3116	3.712	3.573	3.623	/	/	3.636
3149	3.677	/	/	/	/	3.677
sinkhole	3.414	3.381	3.402	3.347	3.364	3.364

Pond J1 had the greatest depth of light penetration, having unusually clear water. This clarity was due to a lack of tannins in this pond. Pond J1 is in an area that was burned more recently than the areas surrounding any of the other ponds in this study, which could account for the lack of tannins. Pond E4, with an average depth of light penetration of only 19 cm, was the most turbid pond. Ponds E3, E5, and E6 had dried to a point where they were too shallow to take measurements in. There was some variation within ponds as well as between them (Table 2.5).

Table 2.5. Average depth of light penetration per sample and per pond.

Pond	Sample 1	Sample 2	Sample 3	Average± SD
JE1	24cm	36cm	38cm	33±8cm
J1	>39cm	>39cm	>39cm	>39cm
J2	37cm	28cm	36cm	34±5cm
J3	24cm	31cm	29cm	28±4cm
J4	30cm	31cm	36cm	32±3cm
E1	30cm	32cm	29cm	30±2cm
E2	34cm	36cm	35cm	35±1cm
E3	/	/	/	/
E4	19cm	20cm	18cm	19±1cm
E5	/	/	/	/
E6	/	/	/	/
L1	41cm	29cm	33cm	34±6cm

Neither area ($r = 0.05$, $p = 0.9031$) nor volume ($r = 0.16$, $p = 0.6796$) has any impact on the depth of light penetration in the ponds. There is a slight correlation between depth and depth of light penetration (Average Depth of light penetration vs. Average Depth: $r = 0.43$, $p = 0.2501$; vs. Deepest Depth: $r = 0.41$, $p = 0.2779$). However, as can be seen from the regression graphs (Fig. 2.3 & 2.4) there is no clear relationship between the two characteristics. Because most of the turbidity in the seasonal ponds is due to tannins, it is not surprising that the size of the ponds has little effect on the depth of light penetration.

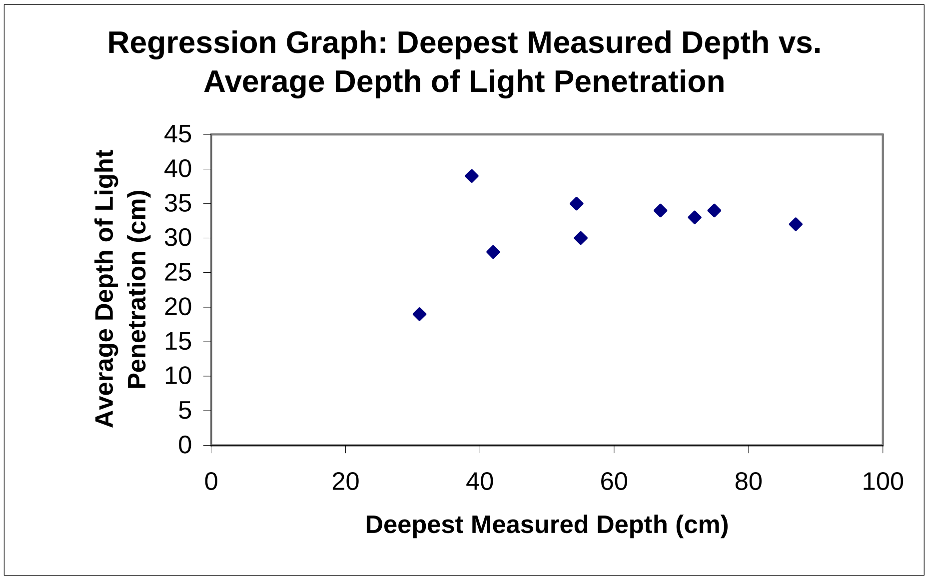


Fig. 2.3: Regression graph of Average Depth vs. the Depth of light Penetration.

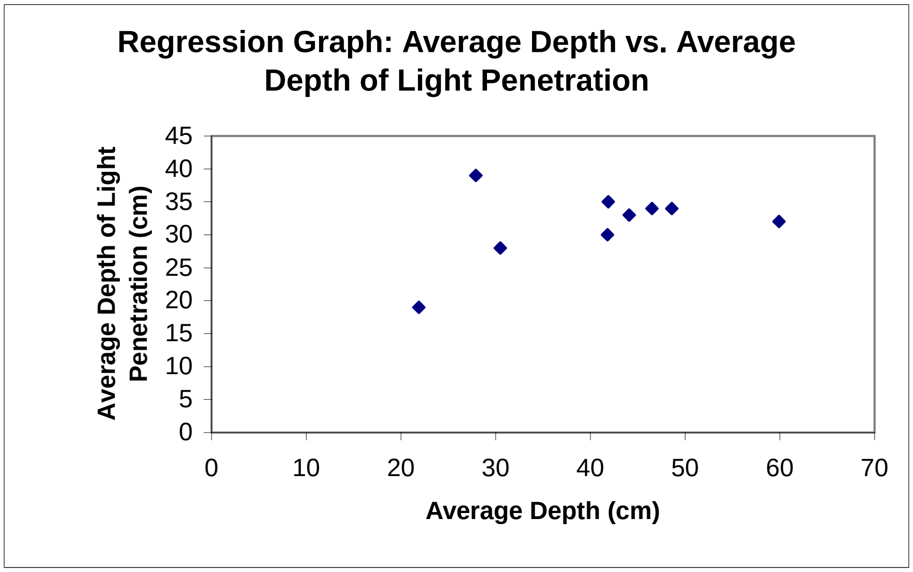


Fig. 2.4: Regression graph Deepest Measured Depth vs. the Depth of light Penetration.

The presence of roads in the ponds, however, does have a significant affect on the depth of light penetration (r = -0.83, p = 0.0058). The relationship is a linear one (Fig. 2.5). The closer the ponds are to a road (i. e. the lower the nearness to road value (see p.

23), the shallower the depth of light penetration is. Of course, this is a very preliminary look at this relationship. Altering the numbering system can make the correlation less significant. For example, if ponds with no road passing through them are labeled one (previously two and three) and ponds with a road passing through them are labeled zero (previously zero and one), r = -0.68 and p = 0.0428. The correlation is still significant, but not nearly as significant as it was with the first numbering system. It would be interesting to look into this relationship in more detail.

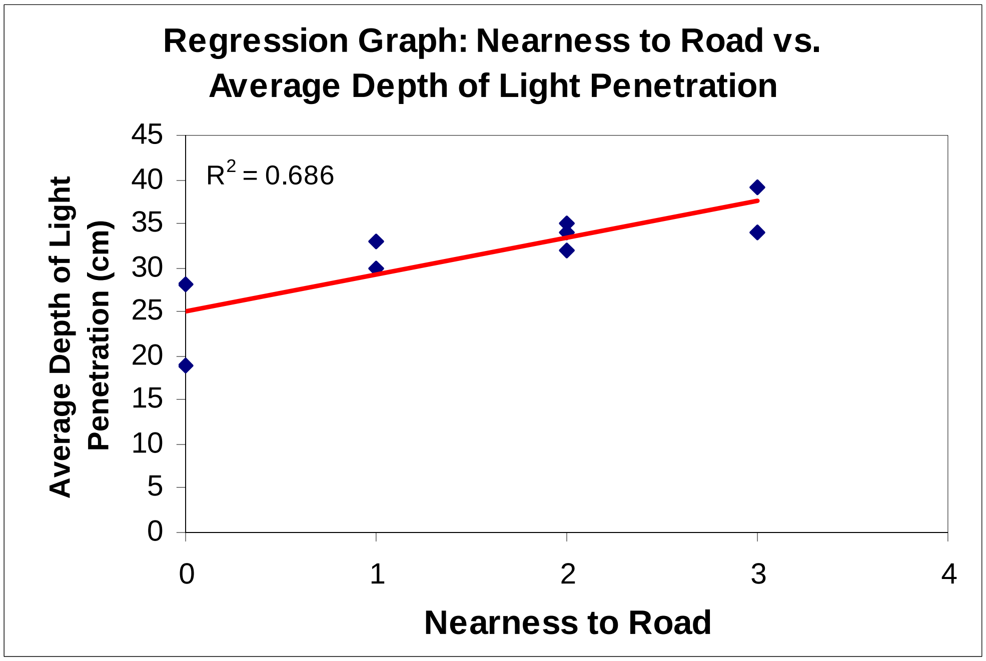


Fig. 2.5: Regression graph of nearness to road value (see p. 22) for the explanation of this value) vs. average depth of light penetration.

Chapter 3: Backswimmer (Hemiptera: Notonectidae) Distribution Among the Seasonal Ponds

Introduction

The backswimmers (Hemiptera: Notonectidae) are one of the sixteen families of Hemiptera that occur in, on, or near the water. Others include the water boatmen (Corixidae), the water scorpions (Nepidae), the giant water bugs (Belostomatidae), the toad bugs (Gelastocoridae), the shore bugs (Salidae), several families of water striders, and a few others. The common name of backswimmer was given to the Notonectidae because they swim with their ventral side facing upward. They use their long, oar-like hind legs to propel themselves through the water. Their forelegs are raptorial. Their ventral side is generally lightly colored while their dorsal side is usually black. This helps the backswimmers avoid predators (Borror et al. 1976). Backswimmers can be found in most lakes, ponds, and small pools throughout the world.

Notonectids, like many aquatic insects, must come to the surface of the water at intervals to replenish their air supply. The tip of the abdomen is thrust through the surface film. Air enters the abdominal trough and diffuses forward to the subelytral air spaces. This forms a layer of air that is enclosed by rows of small hairs. Oxygen passes from this layer to the ventral and thoracic spiracles. (Usinger, 1971; Wellfleet Bay Wildlife Sanctuary, 2000)

Backswimmers are fierce predators. The naiads feed on small crustaceans including water fleas, seed shrimp, copepods, and smaller insects. Adults prey upon anything smaller than themselves including other insects, tadpoles, and small fish. Some species will even eat their own larvae if other prey is scarce (Borror et al. 1976). They capture prey from the water surface, from underwater perches, or while swimming; grasping them with the first two pairs of legs (Streams, 1987a). Backswimmers are equipped with piercing-sucking mouthparts. They inject digestive enzymes into their prey and suck out the resulting liquid. They often attack animals larger then themselves. Their bite is quite painful; it feels much like a bee sting (Borror et al. 1976).

Backswimmers are, in turn preyed upon by other aquatic inhabitants. Other aquatic insect predators prey upon Notonectidae naiads. The adults are preyed upon by fish and larger insect predators such as water scorpions and giant water bugs (Wellfleet Bay Wildlife Sanctuary, 2000).

Many aquatic insects are known to use chemical defenses. Eight families of aquatic Hemipterans have specialized glands that emit pungent, protective secretions against potential predators. In adult Hemipterans, these glands are located in the metasternal region of the prothorax. Paired glandular lobes are attached to a saclike reservoir through a connecting duct. Other connecting ducts lead to lateral orifices. The defensive chemical(s) ooze from these ducts onto the cuticuler surface and then either along grooves or into patches of bristles. In nymphs, the glands are located dorsally in the abdominal region Each gland opens through two pores located near the intersegmental membranes (Rhodes, 1994).

Backswimmers possess such glands. Their secretions are brownish in color and odorless. They are characterized by two major components: p-hydroxy-benzaldehyde and methyl-p-hydroxybenzoate. Whether these compounds are truly defensive or not is not yet known (Rhodes, 1994).

The family Notonectidae is one of three within the superfamily Notonectoidea. The other two are Pleidae (pygmy backswimmers) and Helotrephidae, both of which contain a few genera of very small backswimmers. There are two subfamilies within the family Notonectidae: Notonectinae and Anisopinae. The genus *Notonecta* in the Notonectinae and the genus *Buenoa* in the Anisopinae are the only two genera present in Florida (Williams and Feltmate, 1992).

The genus *Notonecta* includes the larger (8-17mm in length), more commonly seen species. Five species are known to occur in Florida. Two, *Notonecta indica* L. and *Notonecta undulata* Say are present in the station's ponds (Fig. 3.1). The adults of both species are about 10mm in length. The scutellum is usually dark and both species generally have dark wing markings, although there is a pale form of both species. The scutellum of *N. undulata* individuals is always in part black, even in the pale form. The dark wing markings of *N. indica* are often more fully developed then those of *N. undulata* (Slater and Baranowski, 1978). *Notonecta undulata* has the widest distribution of any of the American species and therefore, it must be able to adapt itself to a variety of ecological conditions. In the south, it is replaced by *N. indica* and grows less abundant (Rice, 1954). The naiads of both species are also very similar.

Blaustein (1998) studied the predatory habits of *Notonecta maculata* F. on pool communities. Taxa richness vs. *N. maculata* densities were determined in a natural pool survey and in an outdoor artificial pool experiment. He also preformed a laboratory prey preference experiment. He found that *N. maculata* is an important predator of pool communities because it structures the community by selectively preying upon certain sizes of pelagic species (Blaustein, 1998). Other species of *Notonecta* may play a similar role. It is well known that species of *Notonecta* are important mosquito larvae predators.

Fig 3.1a: *Notonecta indica* (Actual size ~ 1.1 cm in length)

Fig 3.1b: *Notonecta undulata* (Actual size ~ 1.0 cm in length)

Species in the genus *Buenoa* are 5-9 mm in length and more slender. Seven species are known to occur in Florida. *Buenoa artafrons* Truxal, *Buenoa confusa* Truxal, and *Buenoa scimitra* Bare are the only three species found in the station's ponds (Fig. 3.2). *Buenoa artafrons* range in length from 5.20 mm to 5.98 mm and in width from 1.49

mm to 1.75 mm. Most individuals are sordid white in color, but this varies. Sometimes the scutellum has an orange apex and two anterolateral black areas (Truxal, 1953). *Buenoa confusa* is a small species, ranging from 4.16 mm to 5.78 mm in length and 1.10 mm to 1.49 mm in width. Females can be larger. They are usually sordid white in color with a black band extending along the anterior margin of each hemelytron for about a quarter of its length (Truxel, 1953). *Buenoa scimitra* varies considerably in size from 5.46 mm to 6.50 mm in length and 1.36 mm to 1.82 mm in width. Females can be larger. They are also sordid white in color with an orange to reddish yellow scutellum sometimes with black anteriolateral portions (Truxel, 1953).

Hampton et al. (2000) studied the effects of second and forth instar *Buenoa macrotibialis* Hungerford on the zooplankton assemblage in a pond in Vermont in which this *Buenoa* commonly occurs. They found that these naiads feed primarily on cyclopoid copepods and large rotifers in the open water of the pond. By this direct suppression of the copepods, the immature *Buenoa* indirectly release small rotifers from either predation by the copepods or competition with them (Hampton et al. 2000). They note that, in general, *Buenoa* species seem to be primarily open-water foragers.

In 1922, Hungerford discovered that the red color visible through the thin bodies of *Buenoa* species is due to the presence of hemoglobin. In 1928, Bare found that this hemoglobin is present in large cells that surround the tracheae in abdominal segments 3-7. The *Buenoa* species store oxygen in these cells, thus allowing them to stay submerged for much longer periods than *Notonecta* species (Usinger, 1971; Wellfleet Bay Wildlife Sanctuary, 2000). This allows them to inhabit the mid-water of ponds, a habitat with abundant prey and few other insects (Gittelman and Bergtrom, 1977), although this habitat does not occur in shallower ponds.

Fig. 3.2: The three species of *Buenoa*present in the station's ponds. From bottom to top: *Buenoa artafrons* (~ 0.7 cm in ength)l, *Buenoa confusa* (~ 0.5 cm in length), and *Buenoa scimitra* (~ 0.6 cm in length).

Many species of *Buenoa* are known to stridulate. Hungerford first recorded chirping sounds made by *Buenoa* species in 1924. In 1928, Bare described several structures as possible stridulatory organs. One is the stridulatory comb on the base of the male tibia. A second is the rostral prong with its file-like teeth that stands in opposition when the forelegs are brought up to the head. The third are the fine sclerotized ridges on the inner face of the fore femur (Usinger, 1971).

Adult Notonectidae colonize seasonal ponds during the wet season. Most species of *Notonecta* deposit their eggs on vegetation or on rock surfaces while all species of *Buenoa* and some species of *Notonecta* deposit their eggs within plant stems. The eggs of both genera are white and spindle shaped. *Buenoa* eggs possess a distinct anterodorsal cap that *Notonecta* eggs lack. All studied species pass through five larval instars before becoming mature adults. These naiads are wingless (Usinger, 1971; Wellfleet Bay Wildlife Sanctuary, 2000). Because the naiads cannot fly, the adults take a risk when laying their eggs in a particular pond. If the pond dries up before the nymphs mature, they die.

Niche separation between species of *Notonecta* is accomplished by many subtle isolation mechanisms that allow the different species to coexist, possibly by reducing competition among them (Gittleman, 1975). Studies of groups of Notonectidae have shown that some combinations of species rarely occur together, although individual species often show overlap in their geographical distribution. There is also evidence for species segregation by habitat type. This partitioning of available habitats may indicate competitive or other interactions between species, although other factors that influence habitat selection in *Notonecta* may also influence distribution patterns (Briers and Warren, 1999). A wide range of factors could potentially influence the distribution of Notonectidae among ponds (Bendell, 1986).

Gittelman (1975) found that the two genera present in Costa Rica, *Martarega* and *Buenoa* are separated almost completely by habitat selection. *Martarega* is found in slowly moving rivers because the temperature is cooler and more constant. Also, *Martarega* prefer prey that fall into the water from vegetation or the shore. Such prey is more available in the rivers. In contrast, *Buenoa* are found in static waters because they can tolerate the higher temperatures and they are more active hunters.

Interestingly, Gittelman (1975) found no habitat separation between the four species of *Buenoa* present in Costa Rica. However, he did observe that there was no overlap in body size of any of the species collected in the same pond. He suggests that competitive interactions select for different body sizes so that each species can hunt different prey.

Briers and Warren (2000) looked at two species of *Notonecta*, *Notonecta obliqua* Gallen and *Notonecta maculata* F. as examples of a field metapopulation. Their study was based on the assumption that the ponds form discrete patches of habitat that are close analogues of the island-like patches used in most metapopulation models. They showed that population turnover is an important component of the regional population dynamics of *Notonecta* in dewponds. As would be predicted from standard metapopulation models, the level of occupancy of both species was fairly stable over the study period despite minor pond fluctuations. However, they also discovered that, contrary to the assumptions made by standard metapopulation models, both pond occupancy and population turnover are influenced by habitat conditions. The habitat conditions that are important in occupancy patterns may reflect the oviposition site preferences of the two species.

In a previous study, Briers and Warren (1999) noted that competition and other interactions between the immature stages of notonectids could play an important role in determining distribution patterns. Using a combination of laboratory and field mesocosm experiments, they examined the influence of habitat complexity on the outcome of competition between the naiads of two *Notonecta* species, *Notonecta obliqua* and *Notonecta maculata*. They found that the outcome of competitive interactions between the naiads of the two species can be altered by differences in environmental complexity. However, they noted that differences in preferences of the adults for various habitat characteristics such as oviposition substrates could reduce the potential for competition among naiads by allowing the partitioning of pond occupancy over an area or habitat partitioning in individual ponds. They concluded that the distribution patterns they observed in the dewponds are probably the result of habitat selection modified by competitive interactions between naiads where the two species occur together.

Svensson et al. (2000) collected data on the life history, distribution, and coexistence of the five common species of *Notonecta* present in Sweden. They showed that some of the species differed in their habitat preferences. *Notonecta glauca* L. had the widest distribution pattern. *Notonecta obliqua* was present in deeper pools with higher vegetative diversity. *Notonecta lutea* Muller and *Notonecta reuteri* Hungerford were found only in ponds with high vegetative diversity and high vegetation cover along the shoreline, which are found predominantly on the mainland. *Notonecta maculata*, on the other hand, was found in smaller pools with sparse vegetation cover and low vegetative diversity that occur on exposed islands. They do not know whether these patterns are the result of habitat preference or competition between species. They note that size, species, and sex may affect competitive abilities.

In a study of *Notonecta undulata* and *Notonecta insulata* Kirby in a small pond in Connecticut, Streams (1987b) found that the two species maintain large spatial separations during the breeding season. *Notonecta insulata* occurs in the center of the pond where it may have a competitive advantage or refuge from competition. *Notonecta undulata* may have a similar advantage or refuge in shallow water. *Notonecta undulata* prefers densely vegetated microhabitats for oviposition and during early development, which may account for its higher densities in shallower water. However adults and fourth and fifth instars can also survive in deeper waters.

In a study of two *Notonecta* species in ponds in Connecticut, Streams and Shubeck (1982) found that the density of the two species usually decreased with increasing depth. However, in laboratory studies they showed that the two species prefer deeper depths. They proposed two hypotheses to explain this discrepancy. The first one suggests that prey may be more available in shallower water. The second suggests that predation on backswimmers may increase with increasing depth. From their observations, they believe the first is the more likely explanation.

Bendell (1986) studied the effects of fish and pH on backswimmer populations in lakes in Ontario, Canada. He found large populations of Notonectids in fishless lakes and very small or nonexistent populations in lakes with fish. In fishless lakes, he found a minimum density of *Buenoa* species at an intermediate pH (about 5.6). He found no relationship between *Notonecta* densities and pH.

Gittelman and Bergtrom (1977) examined the microhabitat separation between two species of *Buenoa*, *B. confusa* and *B. margaritacea* Torre-Bueno, in Connecticut. They found that *B. margaritacea* swim at a deeper depth than *B. confusa*. They also found that, in general the earlier instars swim at shallower depths. The two species are separated horizontally, also, making the separation three-dimensional. They note that the two species might occur in different ponds due to their preference for different water depths.

In a study of three *Notonecta* species in ponds in Great Britain, Giller and McNeil (1981) showed that predation strategy is a very important factor in habitat selection among the three species. They predicted habitat selection based on the predation habits of the three species. Their prediction fit very closely with the actual selection found in nature. The few anomalies in their prediction suggest that other factors such as pH and oviposition sites may be involved.

Streams (1987a) compared basic aspects of foraging behavior among the six species of *Notonecta* found in Connecticut. His study supports Giller's and McNeill's (1981) conclusion that differences in predation strategy among species of *Notonecta* are adaptations for feeding in different habitat types. He also identified constraints on foraging behavior that limit the potential for species of *Notonecta* to adapt to different types of habitats. While the risk of predation favors more passive foraging (sit an wait), larger species may have to adopt more risky, active foraging strategies to meet the energy needs required by a larger body size. Differences in swimming ability also help to explain the observed differences in predation strategy and differences in habitat usage among notonectids.

It is not known what factors affect the distribution of Notonectidae species in Florida. The purpose of this study was to look at possible factors that could affect the distribution of the five Notonectidae species present at Archbold Biological Station. From the previously mentioned studies, I decided to look at the depth, pH, depth of light penetration, and area of the ponds as possible factors. From the Streams and Shubeck (1982) study and one of Stream's (1987b) later studies, I hypothesized that depth may effect *Notonecta* distribution. The Svensson et al. (2000) study also supports this hypothesis. The Gittelman and Bergtrom (1977) study suggests that depth may also affect *Buenoa* distribution. Bendell's (1986) study suggests that pH may affect *Buenoa* distribution, but will probably not affect *Notonecta* distribution. The depth of light penetration could impact the predation strategies of the various *Notonecta* species.

According to Giller and McNeil (1981) and Streams (1987a), this could also affect *Notonecta* distribution. The study of Svensson et al. (2000) suggests that area may affect *Notonecta* distribution.

Methods

The relative population of Notonectidae per pond was determined using a dip netting procedure. An aquatic net was used to take twenty sweeps in each pond. The samples were taken by dragging the net through the water for ten seconds (Fig. 3.3). Sampling was done in various pond microhabitats including in and around vegetation, in open water, near the shore, and along the bottom. In each pond, I took three samples in different spots along the edge of the pond. The rest of the samples were taken to maximize the number of different microhabitats sampled.

The samples were sorted in a larval pan (Fig. 3.4). The white pan makes it much easier to see, and thus collect, aquatic specimens. The Notonectidae present in each sample were collected in a small vial.

I brought the vials back to the laboratory and counted the number of Notonectidae present in each. I then put the Notonectidae into two vials, one for species of *Notonecta* and one for species of *Buenoa*. The two genera are not difficult to tell apart; the two species of *Notonecta* are much larger. They were preserved in 80% ethanol. I labeled each vial with the date collected and the pond number. Later, I pinned and labeled the adults of both genera. Because of their size, the *Buenoa* had to be point mounted.

Fig 3.3: Taking a sample.

Fig. 3.4: The larval pan.

Both adults and naiads of the two *Notonecta* species were identified and counted, while only the adult *Buenoa* could be identified. The early instars of the two *Notonecta* species can be distinguished by the presence or absence of conspicuous bands on the legs (Rice, 1954). The later instars can be separated by the shape of the head, as can the adults. In *N. indica*, the median length of the head is greater than the maximum distance between the eyes while the two distances are subequal in *N. undulata* (Slater and Baranowski, 1978). Because of this, *N. undulata* individuals appear to have a shorter head (Fig. 3.5).

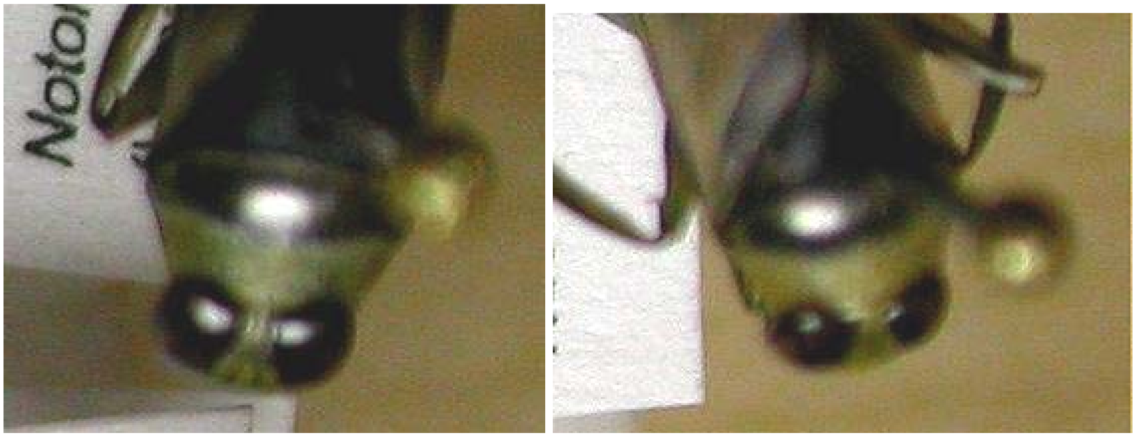


Fig. 3.5: Comparison of the heads of *N. indica* (on the right) and *N. undulata* (on the left).

Males of the three species of *Buenoa* can be identified by the stridulatory ridges on their forelegs. I carefully removed one of the forelegs of each adult *Buenoa* and glued them to the point so I could easily see the stridulatory ridges. *Buenoa scimitra* got its name from the scimitar shaped series of stridulatory ridges present on its forelegs (Fig. 3.6a). Both *Buenoa artafrons* and *Buenoa confusa* have a much smaller series of ridges. The ridges are oriented in a similar shape in both species, but in *B. confusa*, there are fewer ridges (Fig. 3.6b,c) (Truxel, 1954).

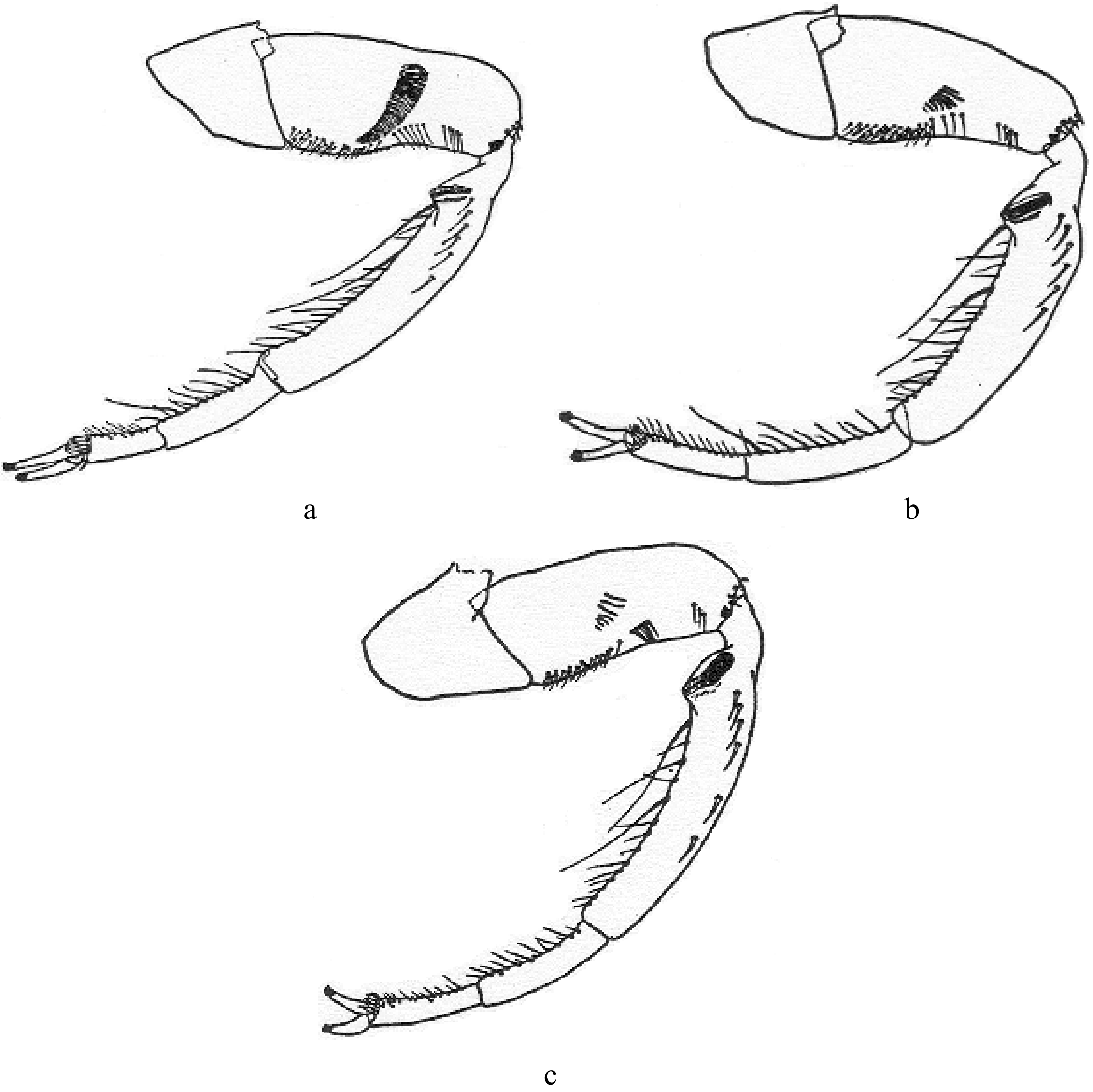


Fig. 3.6: Male *B. scimitra* (a), *B. artafrons* (b), and *B. confusa* (c) forelegs. (From Truxel, 1954).

The females were more difficult to identify. Female *B. confusa* have a black band on each hemelytra, like the males of the species. Neither of the other two species have this band. Female *B. scimitra* have a narrower head than female *B. artafrons*. In *B. scimitra*, the greatest width of the head is five to five and a half times that of the anterior width of the vertex. In *B. artafrons*, the width of the head is seven times this length (Truxel, 1954).

This method of sampling and counting gives relative population. Relative population is a way to compare populations between different habitats without counting every single individual. Absolute population can be calculated from relative population. One method of doing this involves a simple proportion: relative population over total sample volume is equal to absolute population over total pond volume (Southwood, 1966).

I explained how I calculated pond volume in the previous chapter. To calculate my sample volume, I first found the area of the face of the dip net. Next, I measured how far I walked when I took a sample. Multiplying these two values gave me the volume of a single sample. I multiplied this volume by twenty (the number of samples I took) to get the total sample volume. I then used the proportion to estimate the absolute population of backswimmers in each of the ponds in my study. I calculated the absolute population of both genera.

Both linear regression and correlation analyses were used to determine if the distribution of any of the five species is affected by pond depth, pH, turbidity, or area. Analyze-it®, a statistics program that works with Microsoft Excel was used to do the analysis.

Results

All five species of Notonectidae found on the station were present in at least some of the ponds sampled. Only a few *N. undulata* and *N. indica* individuals were present in the ponds where they were found. *Buenoa confusa* adults were present in most of the ponds in moderate numbers. *Buenoa artafrons* adults were present in five ponds, while *Buenoa scimitra* adults were present in only two ponds.

The backswimmers were present in nine different combinations in the twelve ponds. All five species were present together in pond J3. Ponds J2 and J4 had four of the five species present: *N. indica*, *N. undulata*, *B. confusa*, and *B. artafrons*. Ponds E6 and E2 each had three different species present. *Notonecta indica*, *N. undulata*, and *B. confusa* were found in pond E6. *Notonecta indica*, *B. artafrons*, and *B. confusa* were found in pond E2. Five of the ponds had combinations of two species present. Ponds E1 and E3 had *N. indica* and *B. confusa* present. *Notonecta undulata* and *B. confusa* were found together in pond L1. *Notonecta undulata* and *B. scimitra* were found together in pond J1. *Buenoa artafrons* and *B. confusa* were found together in pond JE1. There were no *Notonecta* and no *Buenoa* in pond E5.

There are several interesting patterns in this distribution. First, no species occured by itself in a pond. At least one other species was also present. Second, there was always at least one species of *Buenoa* present when one or both species of *Notonecta* were found in a pond. However, species of *Buenoa* do occur in ponds where neither species of *Notonecta* occur. Lastly, it is interesting to note that all five species occurred together in one of my study ponds.

It is interesting to note that distribution within a single pond is not uniform (Table 3.1). As can be seen in the table, there were many samples with no backswimmers in them and other samples in which many backswimmers were present.

Table 3.1: Total number of Notonectidae (larvae and adults) collected in each of the twenty samples taken in each pond.

	Pond Number											
Sample Number	JE1	J1	J2	J3	J4	E1	E2	E3	E4	E5	E6	L1
1	0	1	1	7	4	1	2	0	1	0	0	1
2	1	0	2	0	2	0	2	1	0	1	1	1
3	1	1	0	3	0	1	0	1	0	0	0	0
4	0	1	3	1	10	0	1	0	0	0	2	1
5	0	0	5	0	3	7	2	1	2	0	0	0
6	0	0	6	2	9	0	1	0	0	0	3	1
7	1	0	2	2	1	6	2	0	0	0	1	1
8	0	1	1	0	2	0	0	0	1	1	2	0
9	1	0	0	1	0	0	0	0	0	0	0	2
10	2	0	2	1	4	4	4	0	0	0	0	3
11	0	0	1	2	1	0	1	0	0	0	0	1
12	0	1	3	4	10	3	0	2	0	0	0	2
13	0	0	1	0	4	0	1	1	0	0	0	6
14	1	1	6	6	5	6	0	0	0	0	0	1
15	0	0	5	3	1	7	1	2	0	0	0	3
16	0	4	0	0	0	0	4	4	1	0	0	2
17	0	1	4	7	1	0	0	0	0	0	3	1
18	7	0	4	4	1	0	0	0	0	0	0	3
19	0	0	0	1	1	14	3	0	0	0	0	4
20	0	0	12	7	9	16	0	0	0	0	0	6

The absolute populations of both genera vary greatly between ponds (Table 3.2). The estimates are high because they are based on the assumption that the backswimmers are distributed uniformly throughout the ponds, which they are not. Though the estimates are high, they do give an idea of the numbers of backswimmers present in each pond.

Table 3.2: Estimates of the absolute population of backswimmers in each pond.

Pond #	***Notonecta*** **Relative Population**	***Notonecta*** **Absolute Population**	***Buenoa*** **Relative Population**	***Buenoa*** **Absolute Population**
JE1	0	0	14	2953
J1	2	442	9	1988
J2	4	5491	54	74122
J3	7	5980	44	37588
J4	5	2789	63	35145
E1	3	736	52	12758
E2	1	117	23	2687
E3	2	136	10	681
E4	1	126	4	505
E5	0	0	2	95
E6	7	2026	5	1447
L1	1	932	38	35401

Pearson correlation analysis is used to examine the strength of the correlation between two sets of data. The closer the r (coefficient of correlation) value is to 1 and the closer the p value is to 0, the stronger and more significant the correlation between the two data sets is (Brower et al. 1997 and Southwood, 1966). The correlation is considered to be significant if $p < 0.05$.

Linear regression analysis is used to determine if one data set varies linearly with another. The R^2 value shows how much the distribution of the dependent variable (x) is affected by the independent variable (y) (Brower et al. 1997 and Southwood, 1966). A t-test is often used to determine the significance of a linear relationship.

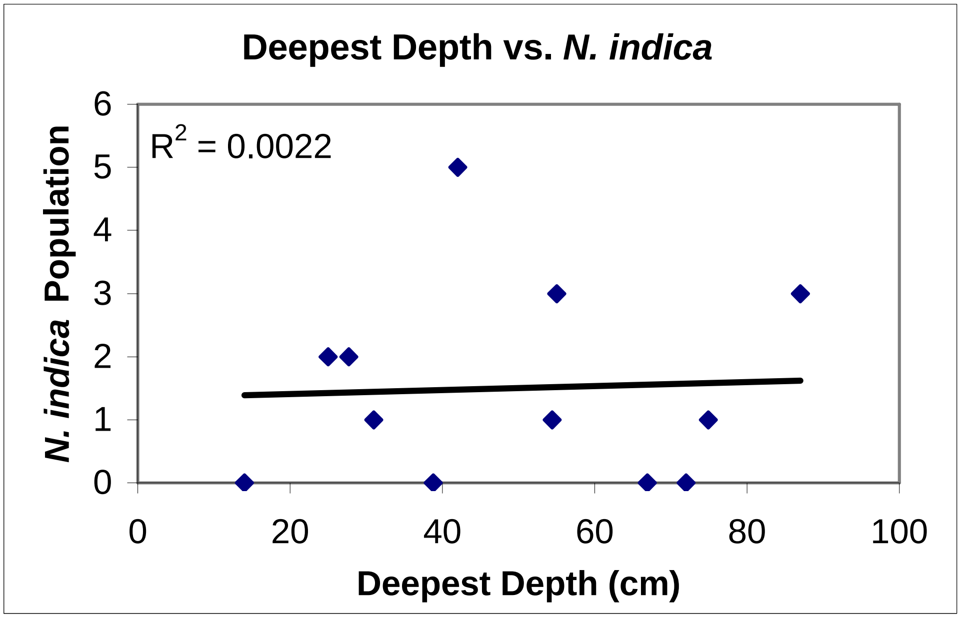
Neither *N. undulata* nor *N. indica* distributions appear to be affected by depth, pH, or the depth of light penetration (Table 3.3 and Figs. 3.7 and 3.8). However, this may be due to the low number of individuals found in each pond. The distribution of *N. undulata* is, however, affected by area.

Table 3.3: Linear Regression and Correlation Data for the genus *Notonecta*

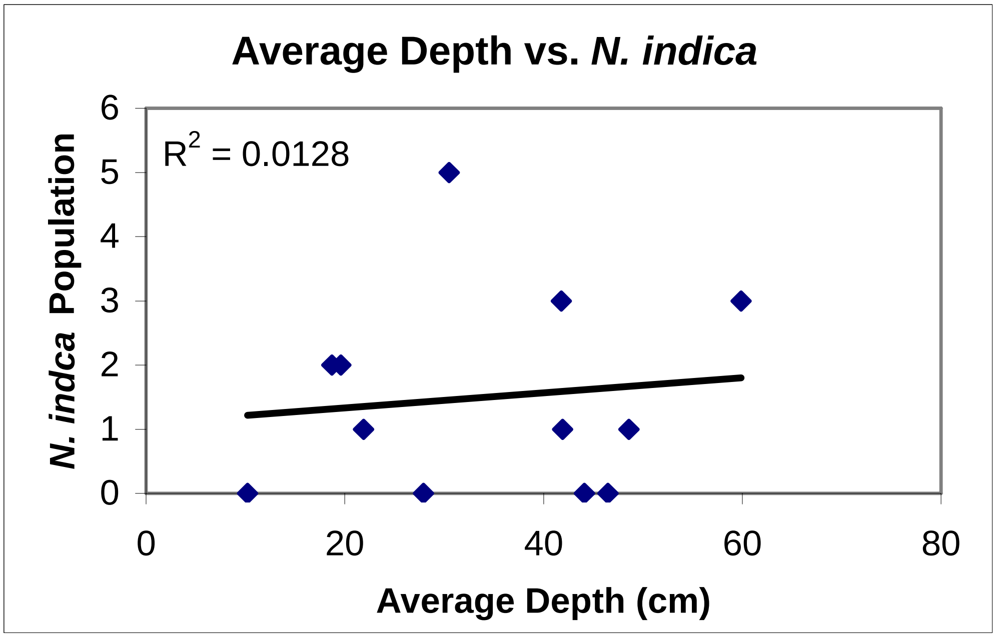
	R^2	**t**	**r**	**p**
N. indica vs. Deepest Measured Depth	0.0022	0.15	0.050	0.881
N. indica vs. Average Depth	0.0128	0.36	0.1131	0.726
N. indica vs. Average pH	0.0090	0.30	0.0950	0.769
N. indica vs. Average Depth of Light Penetration	0.1235	1.00	-0.3540	0.350
N. indica vs. Approximate Area	0.1205	1.42	0.3500	0.2689
N. undulata vs. Deepest Measured Depth	0.0015	0.12	-0.0400	0.9059
N. undulata vs. Average Depth	0.0037	0.33	-0.0607	0.851
N. undulata vs. Average pH	0.0672	0.84	0.2592	0.416
N. undulata vs. Average Depth of Light Penetration	0.1382	0.28	0.3717	0.325
N. undulata vs. Approximate Area	0.3843	2.02	0.6199	0.0315

Relationship is linear if $t \geq 2.23$ (2.36 for average depth of light penetration)

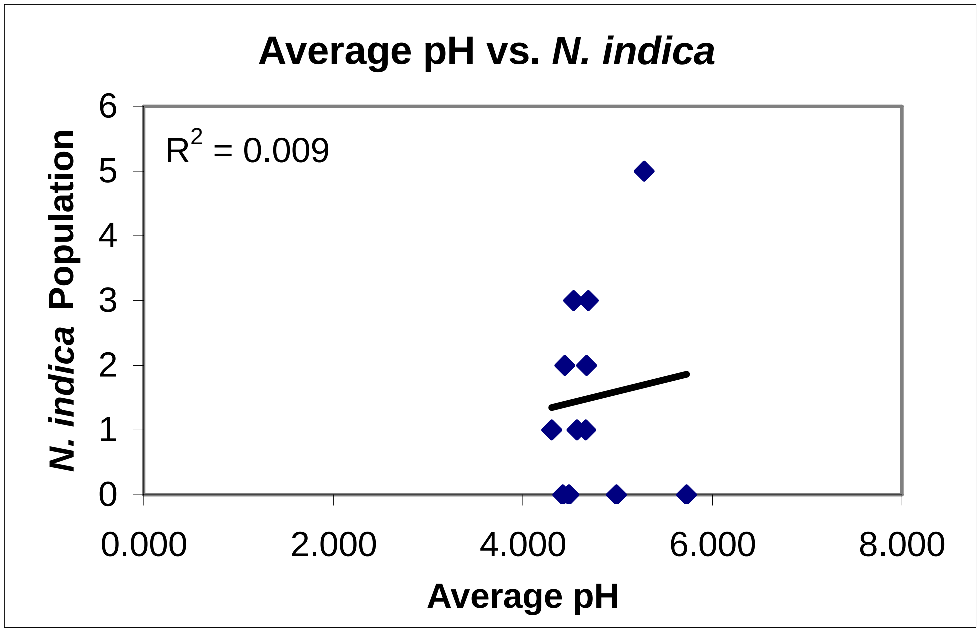
Notonecta undulata distribution correlates with the approximate area of the pond. They are present in ponds with an approximate maximum area greater than 2000 m^2 (Fig. 3.8e). There appears to be a slight correlation between *N. indica* and approximate area, also. However, there is no discernable trend in the data (Fig. 3.7e).



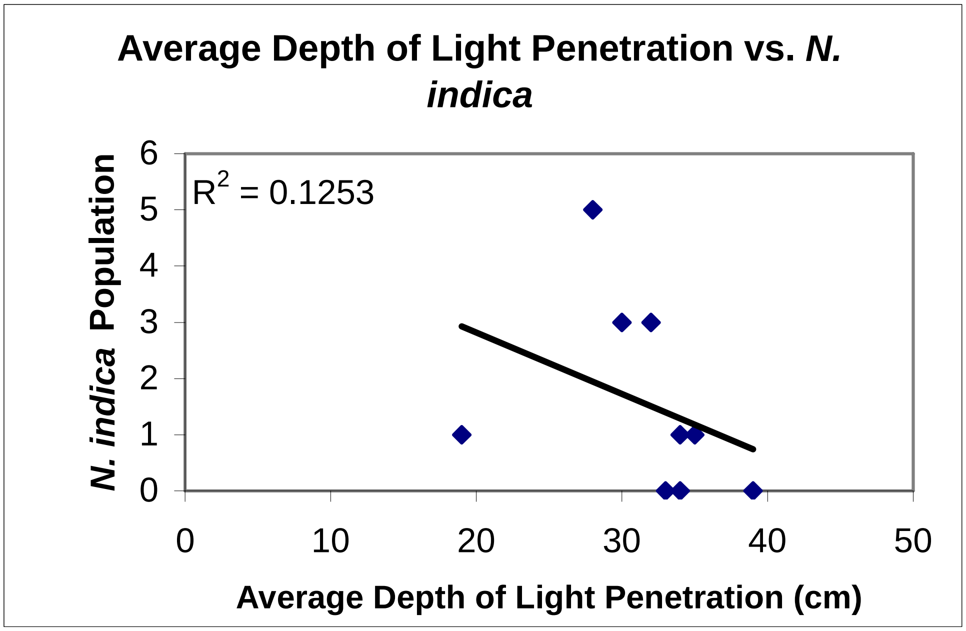
a


Average Depth vs. *N. indica*
R² = 0.0128
6
5
4
3
2
1
0
0
20
40
60
80
N. indca Population
Average Depth (cm)

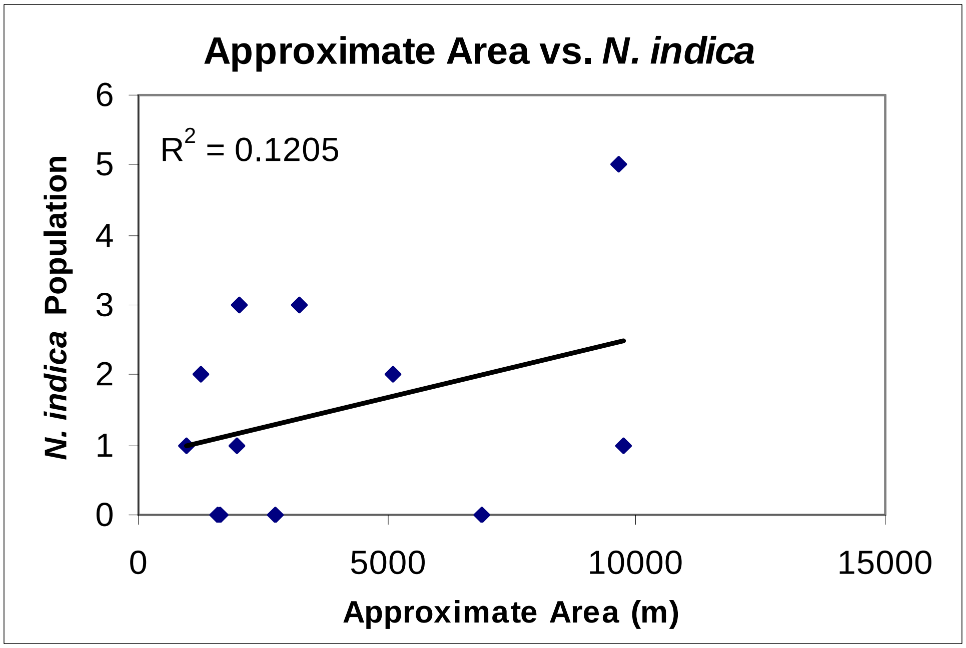
b


Average pH vs. *N. indica*
R² = 0.009
6
5
4
3
2
1
0
0.000
2.000
4.000
6.000
8.000
N. indica Population
Average pH

c

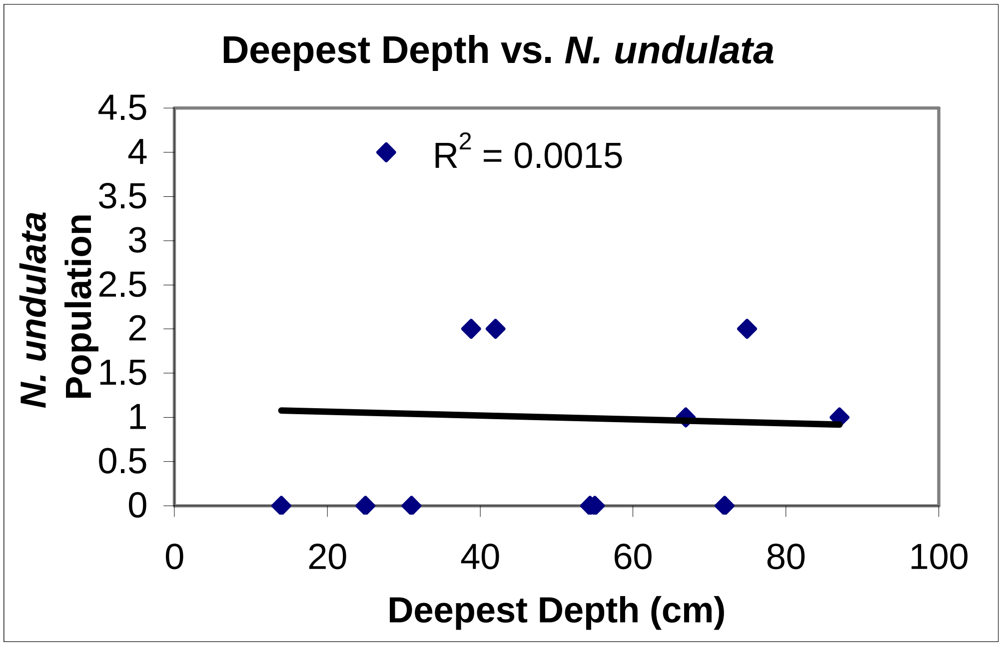


d

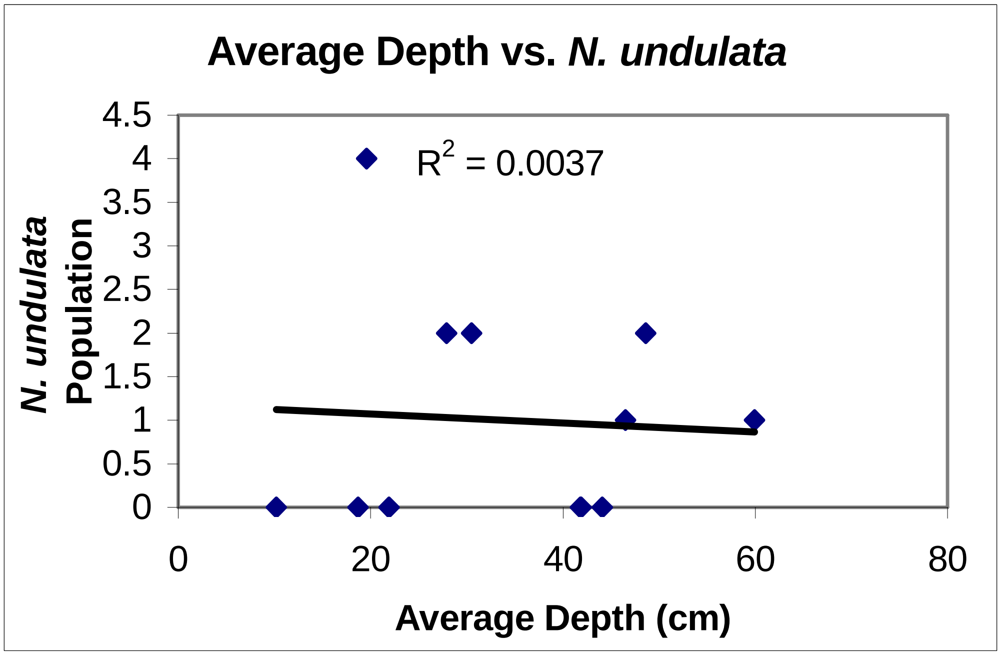


e

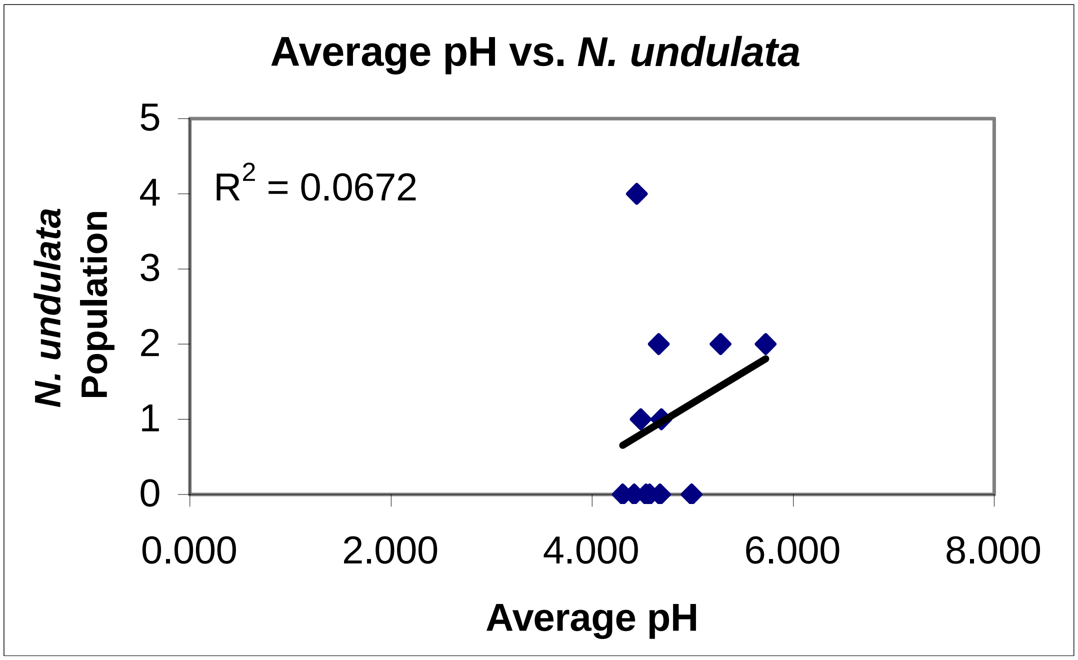
Fig. 3.7: Linear Regression graphs of a) deepest measured depth, b) average depth, c) average pH, d) average depth of light penetration, and e) approximate surface area vs. *N. indica* population.


Deepest Depth vs. N. undulata
R² = 0.0015
N. undulata Population
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
Deepest Depth (cm)

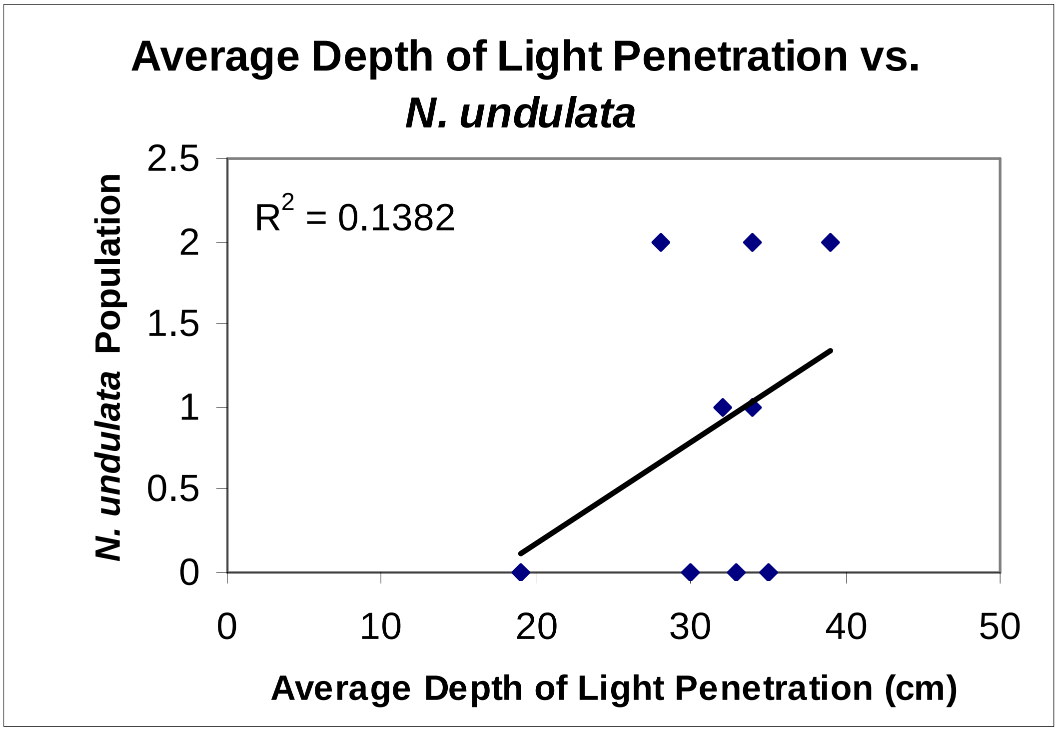
a


Average Depth vs. N. undulata
R² = 0.0037
N. undulata Population
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
Average Depth (cm)

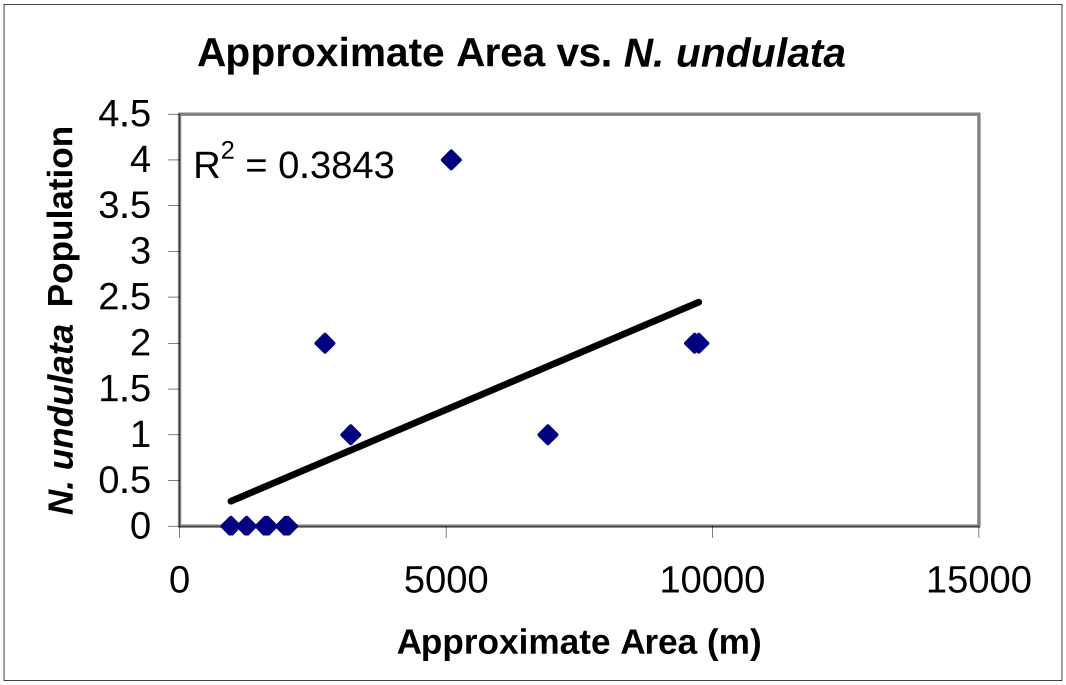
b


Average pH vs. *N. undulata*
N. undulata Population
Average pH
R^2 = 0.0672
0
1
2
3
4
5
0.000
2.000
4.000
6.000
8.000

c


Average Depth of Light Penetration vs. *N. undulata*
N. undulata Population
Average Depth of Light Penetration (cm)
R^2 = 0.1382
0
0.5
1
1.5
2
2.5
0
10
20
30
40
50

d



e

Fig. 3.8: Linear Regression graphs of a) deepest measured depth, b) average depth, c) average pH, d) average depth of light penetration, and e) approximate surface area vs. *N. undulata* population.

There is another trend that may bear further study. The average depth of light penetration vs. *N. indica* data set is better fit by a curve (Fig. 3.9). The curve for average depth of light penetration vs. *N. indica* shows a possible trend towards more individuals in ponds with an intermediate level of light penetration. However, the trend is not that strong ($p = 0.142$).

The average depth of light penetration vs. *N. undulata* correlation results are similar to those of *N. indica*. However, as can be seen on the graph (Fig. 3.8d), there are no discernable trends.

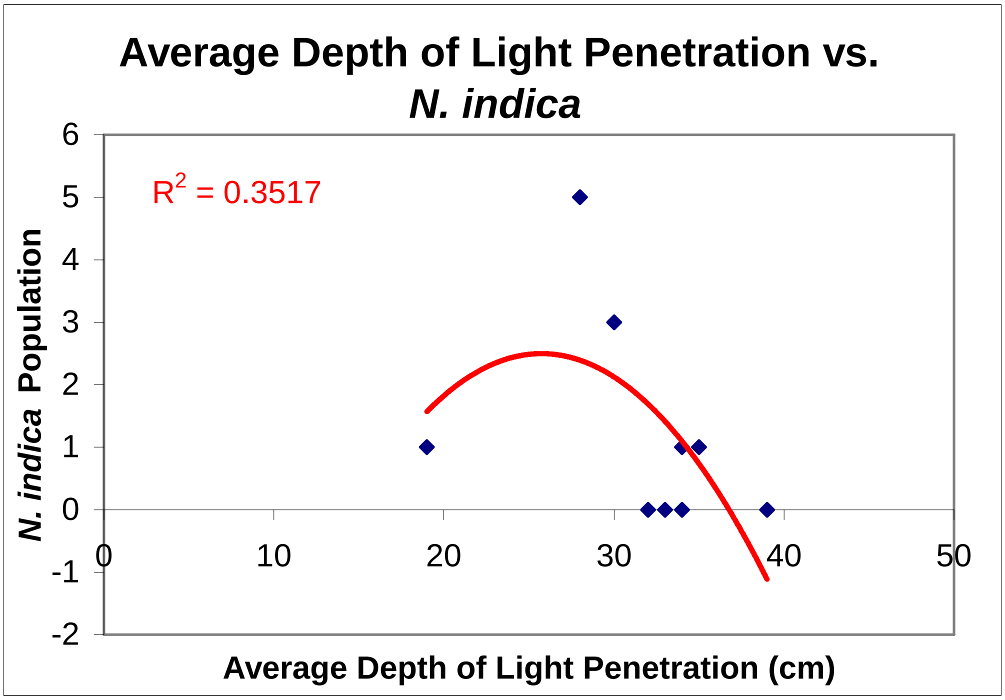


Fig. 3.9 Curvilinear Regression Graph of Average Depth of Light Penetration vs. *N. indica*.

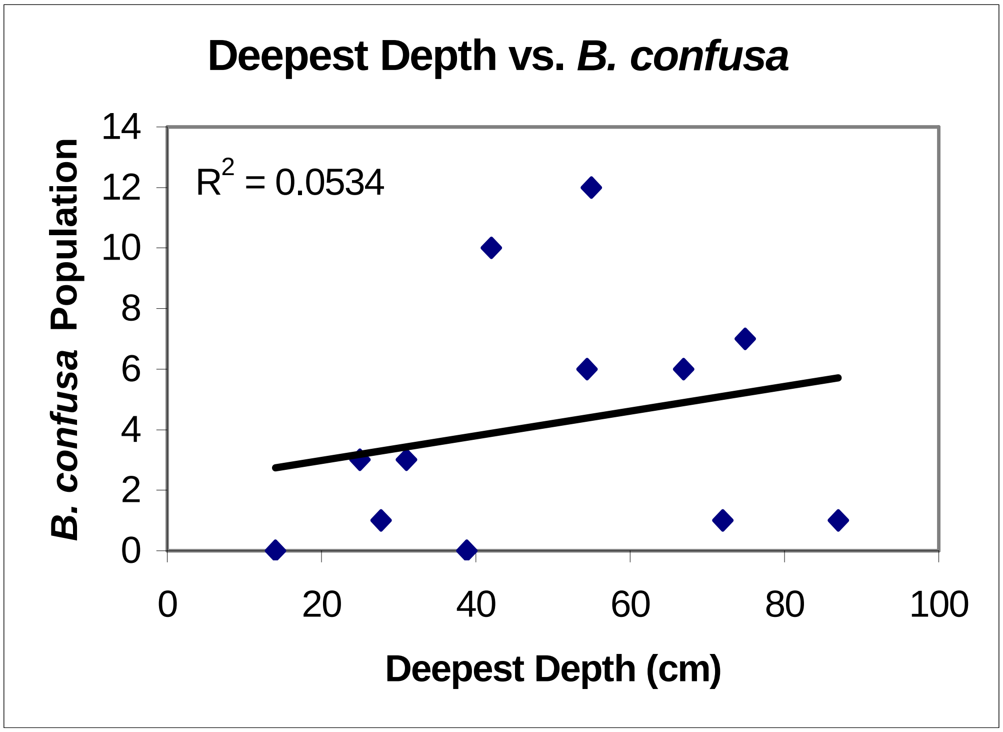
Buenoa confusa distribution does not show an affect from any of the four factors in this study (Table 3.4 and Fig. 3.10). The deepest measured depth vs. *B. confusa* and average depth vs. *B. confusa* data sets look like they might fit a curve, but the relationships are not significant (deepest depth vs. *B. confusa*: $R^2 = 0.40$, $p = 0.0989$; average depth vs. *B. confusa*: $R^2 = 0.3565$) (Fig. 3.11).

Of the three factors, only depth shows an effect on the distribution of *B. artafrons* (Table 3.3 and Fig. 3.12). The graphs of deepest measured depth vs. *B. artafrons* and deepest measured depth vs. *B. artafrons* show more individuals in deeper ponds (Fig. 3.12a & b).

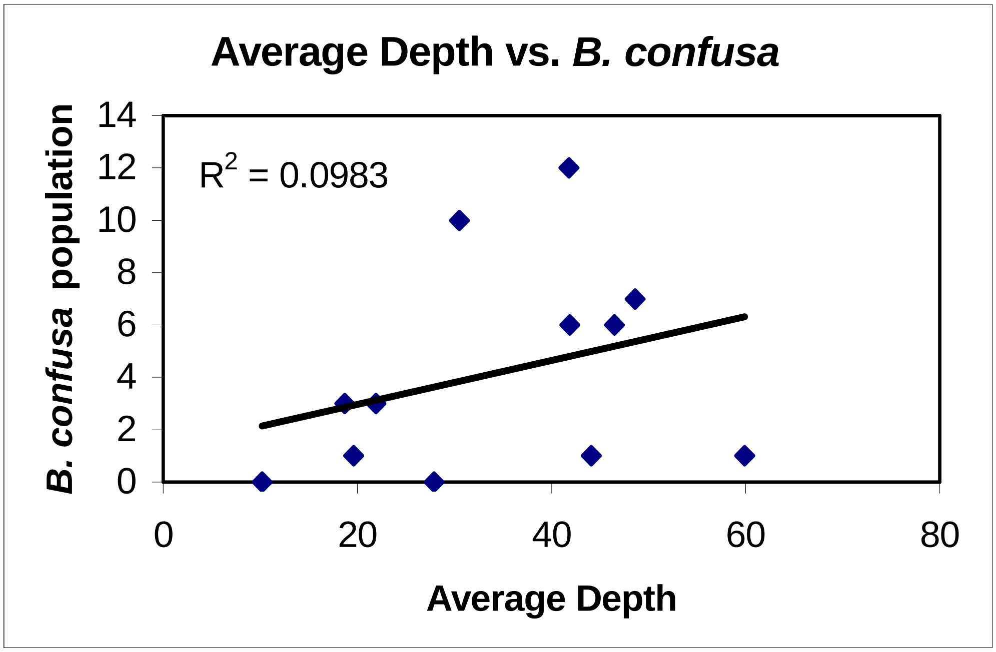
Table 3.4: Linear Regression and Correlation Data for the genus *Buenoa*.

	R^2	t	r	p
B. confusa vs. Deepest Measured Depth	0.0534	0.96	0.33	0.4697
B. confusa vs. Average Depth	0.0983	1.67	0.3135	0.3210
B. confusa vs. Average pH	0.0137	0.37	0.1171	0.7170
B. confusa vs. Average Depth of Light Penetration	0.0032	0.09	-0.1984	0.6090
B. confusa vs. Approximate Area	0.1849	1.23	0.43	0.1629
B. artafrons vs. Deepest Measured Depth	0.4369	2.79	0.6600	0.0193
B. artafrons vs. Average Depth	0.4153	2.67	0.6444	0.0240
B. artafrons vs. Average pH	0.0096	0.31	0.0982	0.7600
B. artafrons vs. Average Depth of Light Penetration	0.0394	1.14	0.0569	0.8840
B. artafrons vs. Approximate Area	0.0007	0.1411	0.0300	0.9365

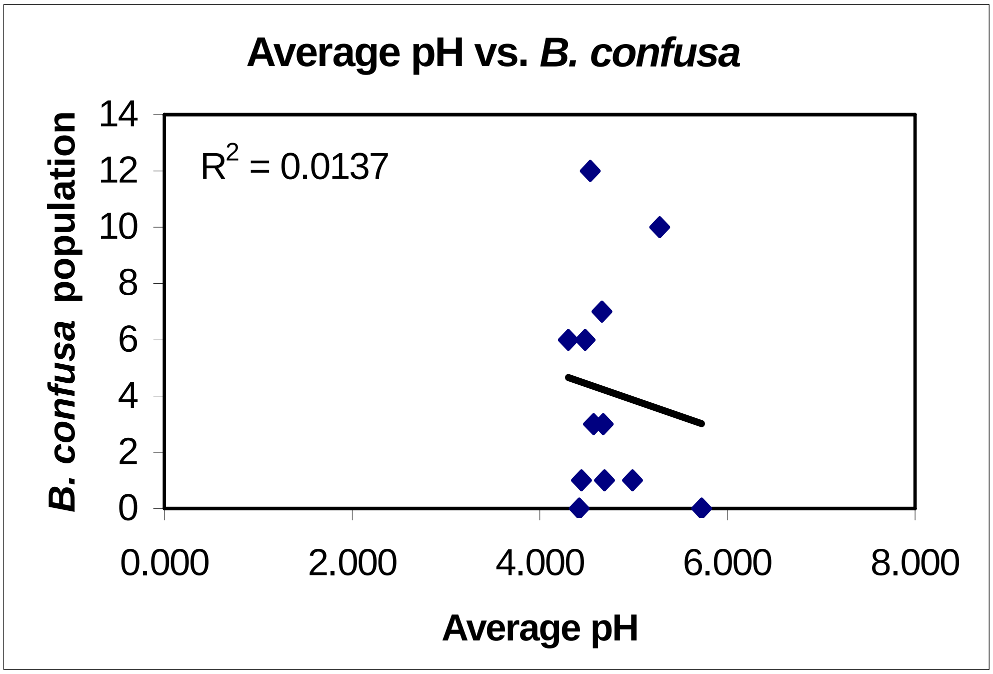
Relationship is linear if $t \geq 2.23$ (2.36 for average depth of light penetration)



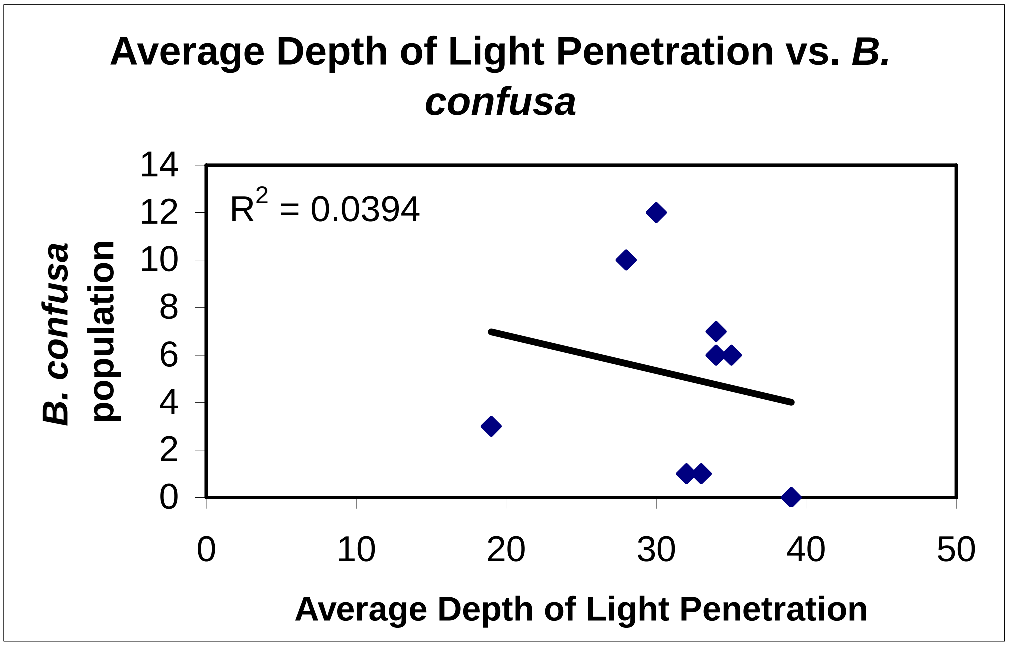
a


Average Depth vs. *B. confusa*
$R^2 = 0.0983$
B. confusa population
0
2
4
6
8
10
12
14
0
20
40
60
80
Average Depth

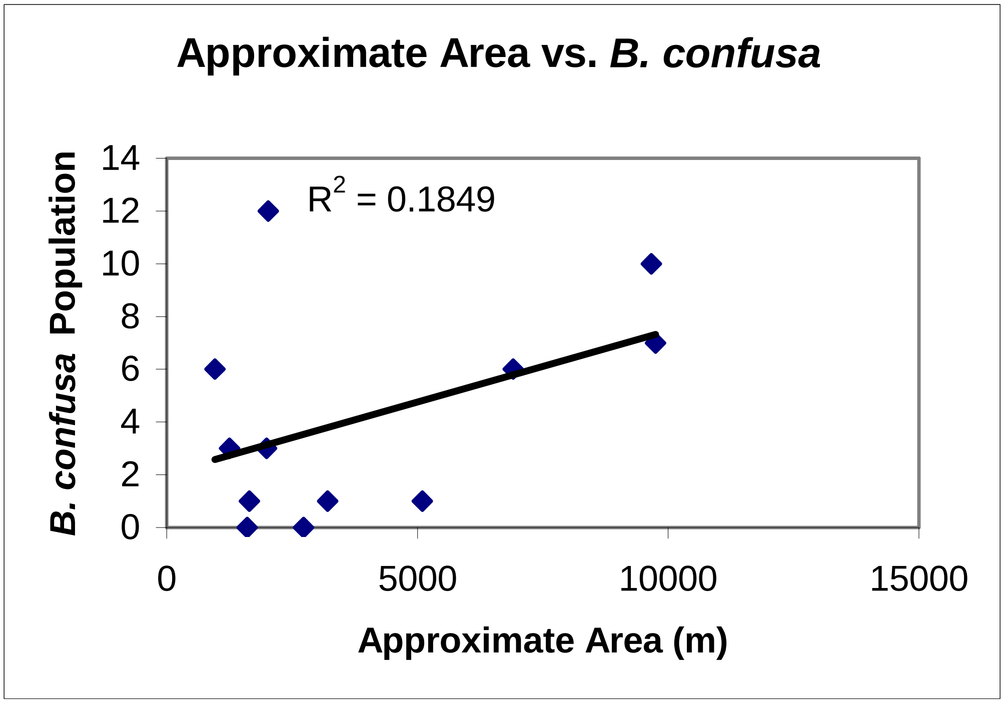
b


Average pH vs. *B. confusa*
$R^2 = 0.0137$
B. confusa population
0
2
4
6
8
10
12
14
0.000
2.000
4.000
6.000
8.000
Average pH

c

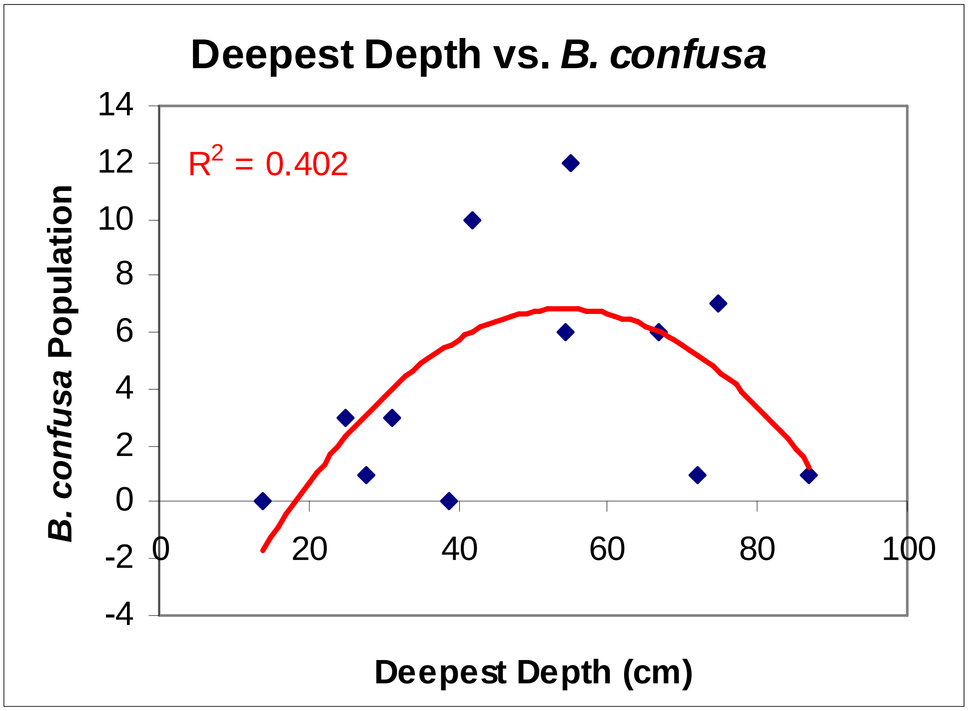


d

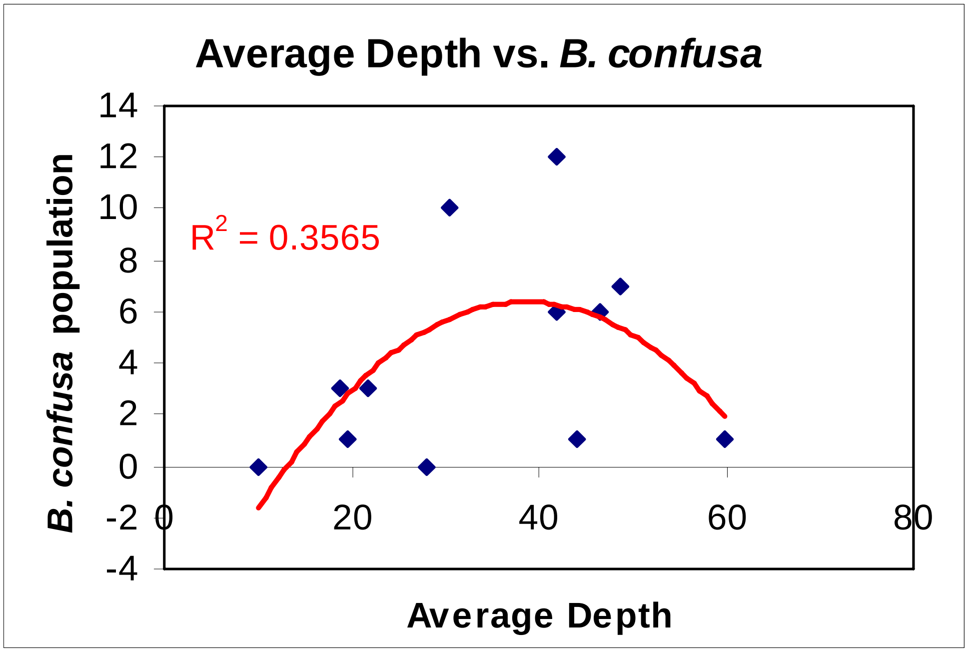


e

Fig. 3.10: Linear Regression graphs of a) deepest measured depth, b) average depth, c) average pH, d) average depth of light penetration, and e) approximate surface area vs. *B. confusa* population.

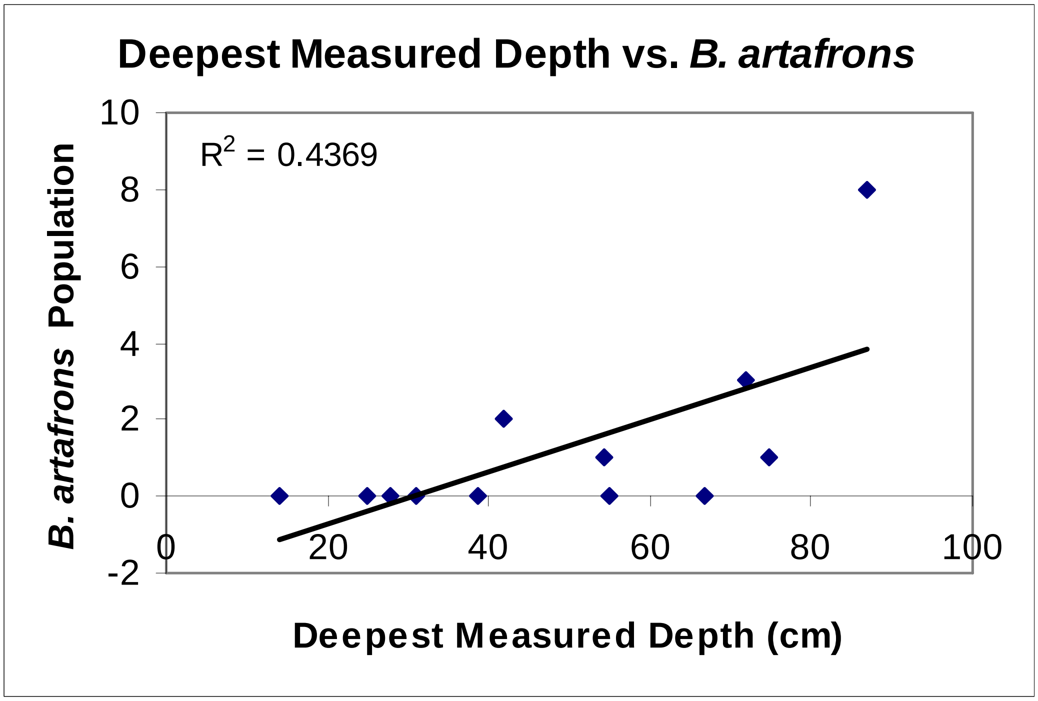


a

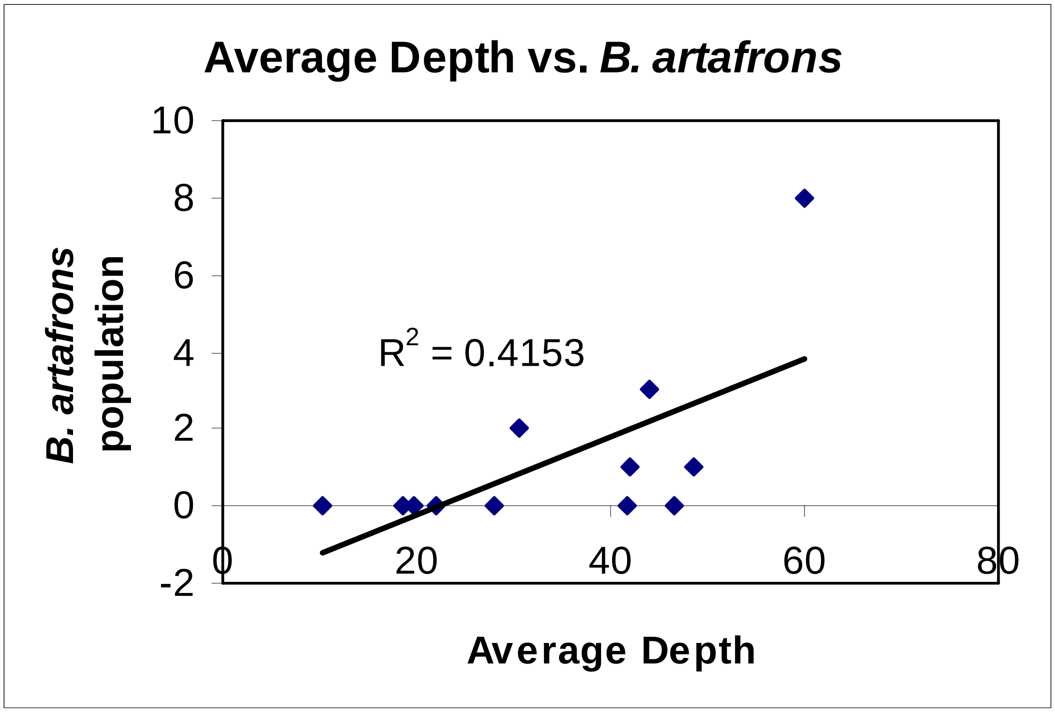


b

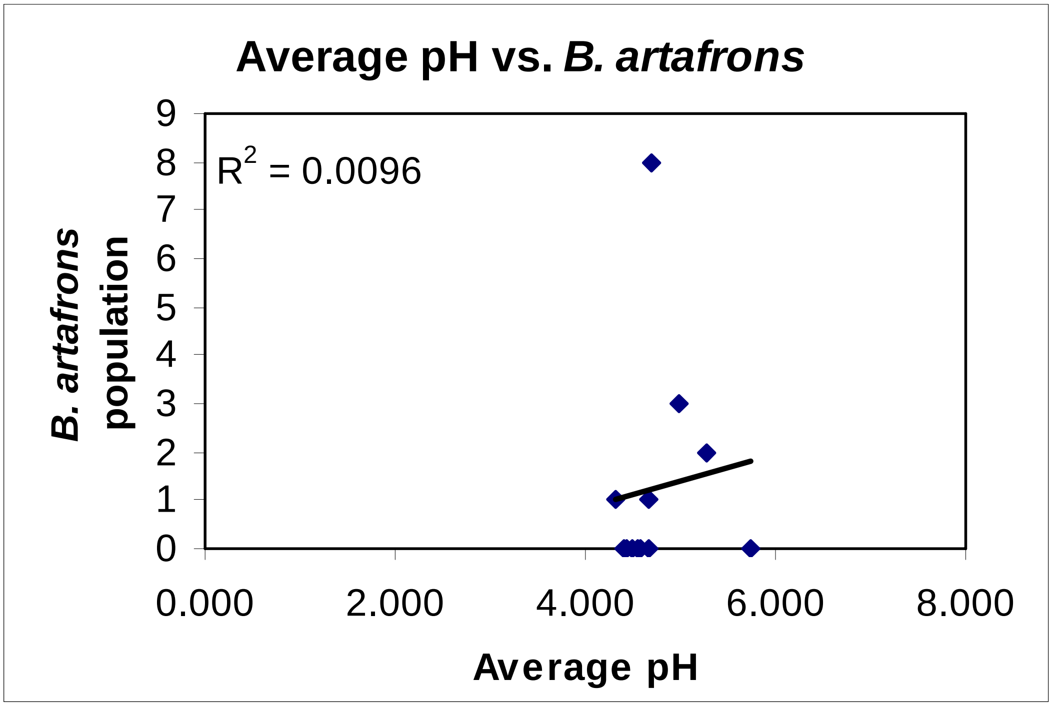
Fig. 3.11 Curvilinear Regression graphs of a) deepest measured depth and b) average depth vs. *B. confusa* population.


Deepest Measured Depth vs. *B. artafrons*
$R^2 = 0.4369$
10
8
6
4
2
0
-2
0
20
40
60
80
100
B. artafrons Population
Deepest Measured Depth (cm)

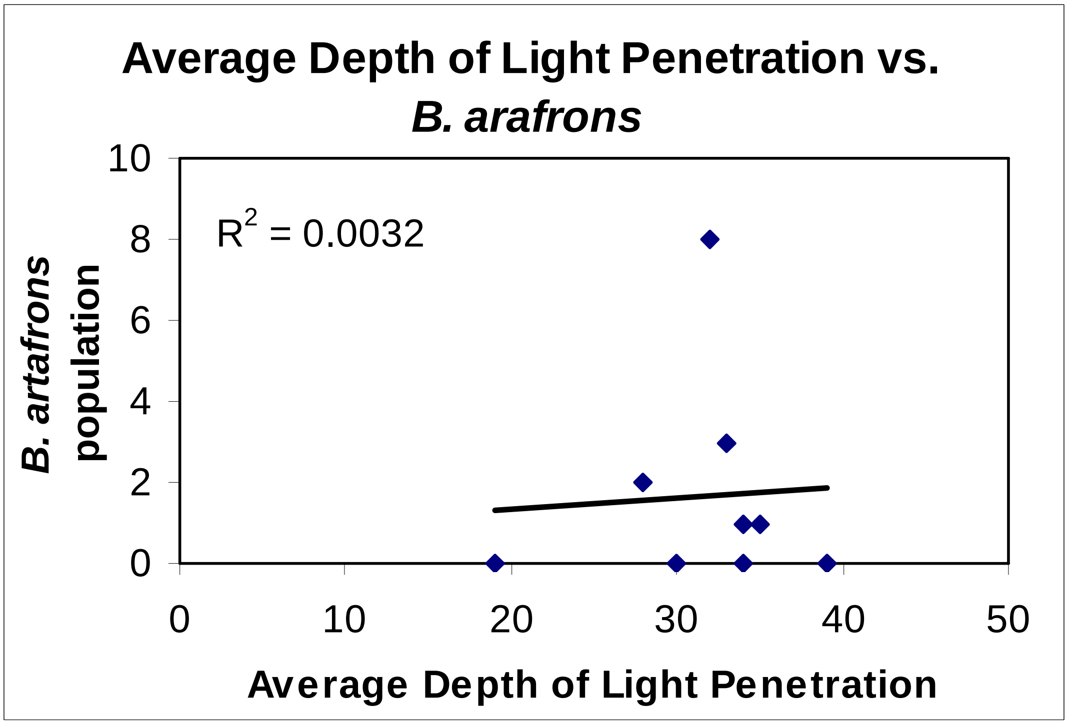
a


Average Depth vs. *B. artafrons*
$R^2 = 0.4153$
10
8
6
4
2
0
-2
0
20
40
60
80
B. artafrons population
Average Depth

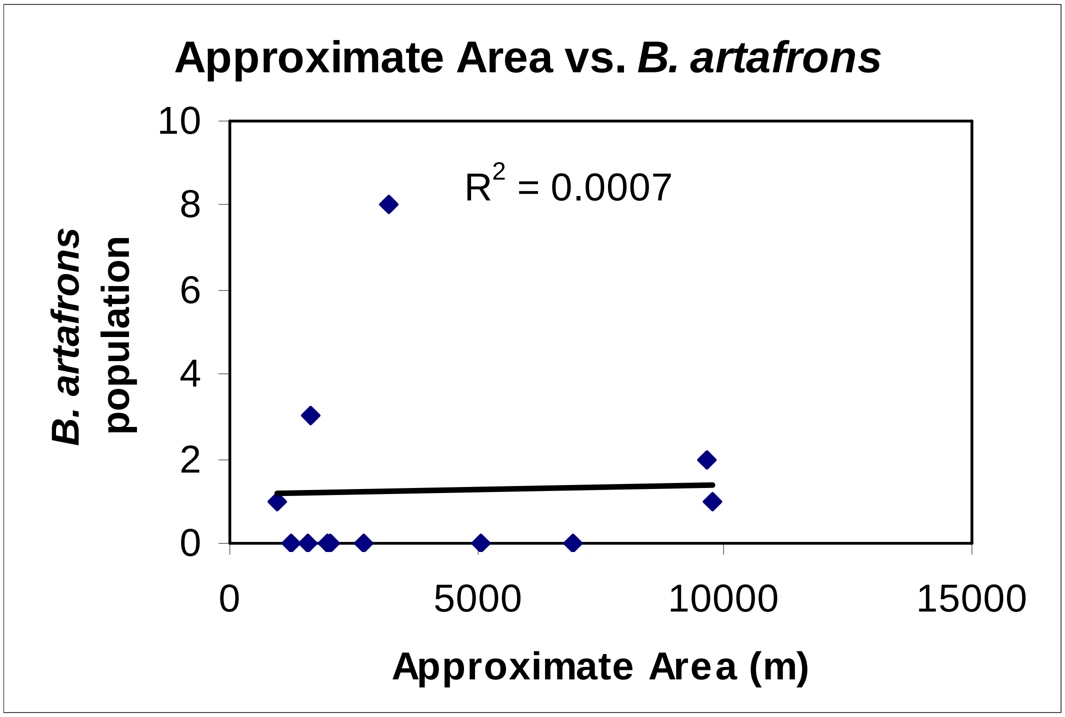
b


Average pH vs. *B. artafrons*
B. artafrons population
Average pH
R^2 = 0.0096
0
1
2
3
4
5
6
7
8
9
0.000
2.000
4.000
6.000
8.000

c


Average Depth of Light Penetration vs. *B. arafrons*
B. artafrons population
Average Depth of Light Penetration
R^2 = 0.0032
0
2
4
6
8
10
0
10
20
30
40
50

d



e

Fig. 3.12: Linear Regression graphs of a) deepest measured depth, b) average depth, c) average pH, d) average depth of light penetration, and e) approximate surface area vs. *B. artafrons* population.

There were not enough *B. scimitra* adults collected during sampling on which to perform data analysis. However, the two ponds where the adults were collected were the only two ponds with a pH greater than 5. Most of the other ponds had a pH of approximately 4.5.

Discussion

Neither depth nor pH showed a significant effect on the distribution of either *N. indica* or *N. undulata*. This concurs with Bendell's (1986) finding that there is no relationship between pH and *Notonecta* density. Streams and Shubeck (1982) found a higher number of *Notonecta* in shallower depths. However, their study looked at distribution within, rather than between, ponds. My data show that depth does not affect the distribution of *N. indica* or *N. undulata* between different ponds. However, it could affect their distribution within the same pond. Also, the other studies that noted depth as a factor were conducted on the European species of *Notonecta*.

The depth of light penetration in the ponds does not show an effect on *N. undulata* distribution. This implies that the depth of light penetration does not have a large impact on the predation strategy of this species. *Notonecta undulata* is a highly adaptable species (Rice, 1954), which may explain why the depth of light penetration does not have a large impact on its predation strategy. However, the *N. indica* vs. light penetration data show a weak trend towards more individuals in ponds with an intermediate depth of light penetration. Perhaps there is a balance. The light penetration needs to be great enough so that *N. indica* individuals can hunt but not great enough for them to become easy targets for predators.

Svensson et al. (2000) found that area was an important factor in the distribution of the five common European species of *Notonecta*. The area of the ponds does not show an effect on *N. indica* distribution.

However, the area of the ponds does show an effect on *N. undulata* distribution. *Notonecta undulata* were only found in ponds with an approximate maximum area greater than 2000 m^2. Streams (1987b) noted that *N. undulata* prefers densely vegetated microhabitats for oviposition. Perhaps vegetation density is higher in larger ponds.

Buenoa confusa distribution does not show an effect from any of the four factors studied. Bendell (1986) found a significant relationship between *Buenoa* densities and pH. However, *B. confusa* was not examined in his study. It is not surprising that not all species of *Buenoa* are affected by pH. The distribution of *B. confusa* was not affected by depth as suggested by Gittelman and Bergtrom. However, depth could still play a part in its distribution within individual ponds.

Buenoa artafrons distribution does not show an effect from pH, the depth of light penetration, or area. However, my data does show a trend of more individuals in deeper ponds. Perhaps competition for prey and space is less in deeper ponds. The studies of both Truxal (1954) and of Hampton et al. (2000) note that most members of the genus *Buenoa* inhabit open waters. There are generally larger areas of open water in deeper ponds (Abrahamson et al. 1984). This could also explain why there is a trend of larger numbers of *B. artafrons* in deeper ponds.

Buenoa scimitra prefers ponds with a pH above 5. This is almost the opposite of the species Bendell studied, which were least abundant at a pH of about 5.6. However, his study was done in Canada, so it is not surprising that the relationships are different.

There are two other interesting points. Data on pH collected in the late fall and winter of 2001/2002 show pH measurements around 3.7. With the exception of *B. scimitra*, the backswimmers in the station's ponds appear to be able to tolerate fairly low pH levels. It would be interesting to see how the pH levels fluctuate over time and the reactions of backswimmers and other pond organisms to these fluctuations.

Depth data collected from several different ponds from 1989 to the present show that the duration and intensity of the wet and dry seasons fluctuate greatly. This poses an interesting question. Are there some years in which the backswimmers cannot utilize the ponds and, if so, where do they lay their eggs? This could be a particular problem for *B. artafrons*, because they were found more often in deeper ponds.

It is interesting to note that the R^2 values for the significant trends are relatively small (Approximate Area vs. *N. undulata* $R^2 = 0.3843$, Average Depth vs. *B. artafrons* $R^2 = 0.4461$, Deepest Measured Depth vs. *B. artafrons* $R^2 = 0.4368$). Clearly there is another factor or factors affecting the distribution of these species and possibly the other species among ponds.

Vegetative type, vegetative density, or both could affect Notonectid distribution. A common method of catching prey used by some species of Notonectids is to cling to a piece of submerged vegetation and wait until prey swims past. The Notonectid then drifts up under its unsuspecting meal (Borror et al. 1976). The type and/or density of vegetation present in a pond could have an effect on the predation strategy of some of the Notonectidae species living in that pond. Giller and McNeil (1981) found that predation strategy is a very important factor in the habitat selection among the species they studied. Svensson et al. (2000) found that both vegetative density and diversity are important factors affecting the distribution of the European *Notonecta* species. Streams (1987b) found that *N. undulata* prefers densely vegetated microhabitats during oviposition. The studies of Hampton et al. (2000) and of Truxel (1954) noted that many species of *Buenoa* prefer open water. This implies that they would be found less frequently in ponds with a high density of vegetation. This hypothesis merits further study.

Unlike the two genera present in Costa Rica, the two genera present at Archbold Biological Station do not appear to be separated by habitat selection. I found both genera present together in most of my study ponds. Gittleman (1975) noted that competition between species of Buenoa was reduced by size differentiation. He observed that no two species in the same pond were the same size. In the ponds at Archbold Biological Station, *Notonecta* and *Buenoa* are distinctly different in size. The two species of *Notonecta* measure about 1 cm in length while the three species of *Buenoa* measure from 0.5-0.7 cm in length. This could allow the two genera to hunt different prey, if available prey is a limiting factor, and thus reduce competition between them.

The different species in each genus are also different sizes. *Notonecta indica* is 0.1 cm longer than *N. undulata*. *Buenoa artafrons* is the largest *Buenoa* with both males and females measuring 0.7 cm in length. *Buenoa confusa* is the smallest with both males and females measuring 0.5 cm in length. *Buenoa scimitra* males measure 0.6 cm in length, though the females measure only 0.5 cm in length. Whether this size differentiation is enough to reduce competition between the species is not known. It would be interesting to look into this further.

Streams (1987b) showed that differences in microhabitat preference seemed to play a major role in separating *N. undulata* and *N. insulata* populations within his study pond. He notes that spatial separation within species assemblages may come about through interaction between species, i. e. interspecific competition and predation, or without significant interaction through differences in microhabitat selection. My data (Table 3.1) indicate that the Notonectidae species in the station's ponds may prefer different microhabitats. This is something that could be looked into further.

Conclusion

Depth, pH, depth of light penetration, and area each affect the distribution of only one of the five species of Notonectidae present in the seasonal ponds of Archbold Biological Station. Pond depth is highly variable both between ponds and over time. *Buenoa artafrons* was found more often in deeper ponds. It, like many species of *Buenoa*, may prefer open water areas that are larger and more common in deeper ponds.

Buenoa scimitra individuals were only found in the two ponds with a pH greater than 5. The pH of the ponds, due in large part to tannic acid, can drop to below 4. The other four species appear to be fairly tolerant of low pH.

The depth of light penetration had the least impact on the distribution of the five species. My data show a weak trend of more *N. indica* in ponds with an intermediate depth of light penetration. This suggests that the depth of light penetration may have an impact on this species' predation strategy.

The roads that pass through some of the ponds may increase the turbidity of these ponds, decreasing the depth of light penetration. It is not known what effect this might have on various pond organisms. My data show that the presence of roads would not greatly affect the backswimmers.

Notonecta undulata was found only in ponds with an approximate maximum area greater than 2000 m^2. This could be due to the amount or type pf vegetation present in this size pond.

Other factors could influence Notonectidae distribution between ponds. Many species of *Notonecta* use sit-and-wait predation strategies and species of both genera use vegetation for oviposition sites. Therefore vegetation type and/or density could influence distribution.

Both genera occur together in most of my study ponds. The size difference between the two genera could reduce interspecific competition. The size differences of the various species could serve the same purpose.

Interspecific competition could also be reduced by differences in microhabitat selection. My data show that the Notonectids are not evenly distributed within the ponds.

There are still many areas of backswimmer ecology in Archbold Biological Station's ponds that have yet to be explored. One unanswered question is: where do the backswimmers go when the ponds are dry? Though all four factors in this thesis have some influence on distribution, they are only a small part of the many isolation mechanisms that allow the different species of Notonectidae to coexist.

Appendex A: Common Types of Pond Vegetation in the Seasonal Ponds of Archbold Biological Station

(Plant information from www.archbold-station.org.)

Deepest zone: no emergent vegetation.

Next deepest:

Maidencane
Panicum hemitomon
Schult

Maidencane is perennial, flowering in March and April. It is a rhizomatous grass common in the wettest seasonal ponds and along lake margins.

Panicum hemitomon
Photo by Ann Murray
Copyright 1998 University of Florida

Maidencane in pond L1

Xyris fimbriata Ell

Xyris fimbriata is a species of yellow-eyed grass. It is a perennial that blooms in the summer and fall. It is a tufted cryptophyte common in seasonal ponds.

*

Xyris fimbriata in pond J4

Bachelor's Buttons
Eriocaulon decangulare L

Bachelor's buttons are perennial moneocious plants. They are a rare plant found in seasonal ponds and in low flatwoods. They are not present in any of my study ponds, but they are present in other ponds on the station.

*

Redroot *Lachnanthes caroliniana* (Larn) Dandy

Redroot, also called bloodroot, is a perennial that flowers in the summer from May to August. It is a rhizomatous herb common in seasonal ponds and other shallow, mucky habitats.

*

Redroot in pond E4

Third deepest:

Edison’s Hypericum
Hypericum edisonianum
Adams & Robson

Edison’s hypericum is a perennial that flowers almost year round. It is a clonal shrub common in seasonal ponds with sandy bottoms.

*

Edison’s Hypericum in pond J4

Xyris elliottii Chapm

Xyris elliottii is another species of yellow-eyed grass. It is a perennial flowering from April to October. It is a tufted grass common on the margins of seasonal ponds.

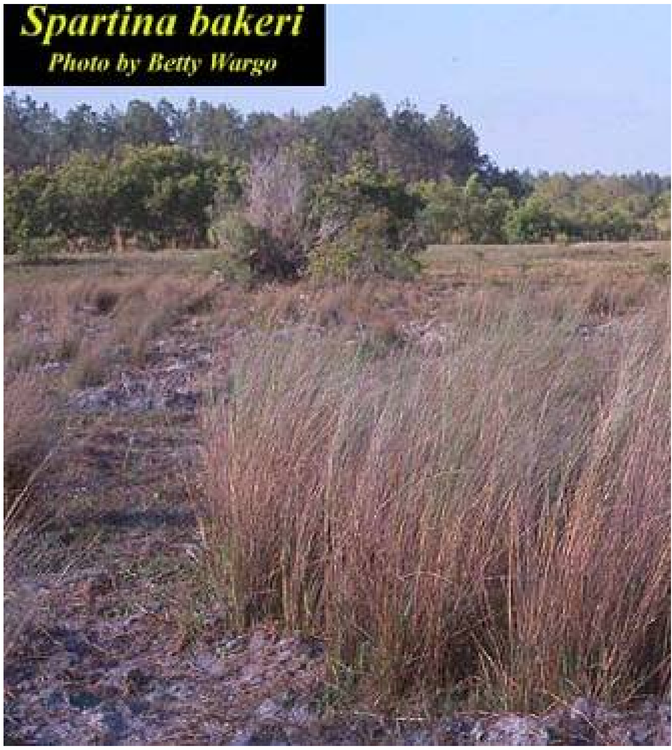
Xyris elliottii in pond

Blue Maidencane
Amphicarpum muhlenbergianum
(Shult) Hitch

Blue maidencane is a perennial that flowers from June to September. It is an amphicarpic plant common in disturbed scrub. It is not present in any of my study ponds.

Sand Cordgrass
Spartina bakeri Merr

Sand cordgrass is a perennial that flowers from January to May. It is a clump-forming grass common in some seasonal ponds and along the sandy shores of lakes.



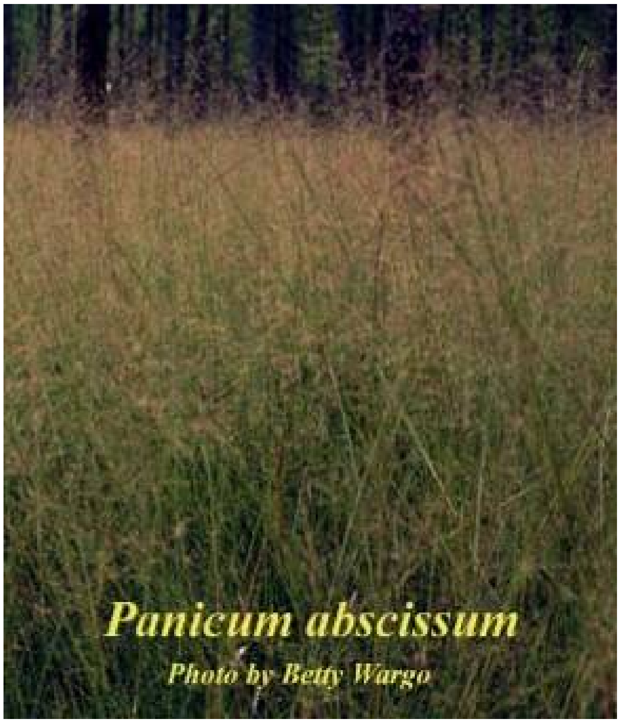
*

Sand Cordgrass in Pond J3

Marginal zone:

Cutthroat Grass
Panicum abscissum
Swallen

Cutthroat grass is a perennial that flowers from May to August. It is stimulated to flower by fire. It is common in seasonal ponds.



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Cutthroat grass in pond E4

Broomsedge *Andropogon spp.*

There are several species of broomsedge present in the station's seasonal ponds: *Andropogon brachystachyus* Chapman (not shown), *Andropogon glomeritus* (Elliott) C. Mohr, and *Andropogon virginicus* C. S. Campb. They are perennial and flower in October. They are cespitose plants common in seasonal ponds.

[*]

[+]

Broomsedge in pond J1

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[*] Photograph from Atlas of Florida Vascular Plants, Institute for Systematic Botany, University of South Florida, Tampa.

[+] Photograph from Aquatic, Wetland, and Invasive Plant Particulars and Photographs, University of Florida Center for Aquatic and Invasive Plants.

Appendix B: Pond Depth Data From 1989 to 2002

(Courtesy of Jeff Hutchinson, Land Manager, Archbold Biological Station)

1989

Tract #			7	7	7	7	7	7	7	7	7	7	7	7	7	7	18	18	18	19	30	30	31	31	31	31	31
Pond #			14	50	53	64	56	57W	61S	60	62E	62W	72	74	84	97	6	15	37	24	16	35	13S	13G	16	45	49
y	m	d																									
89	5	25	/	0	/	0	/	/	/	/	/	/	0	0	0	0	/	0	0	0	0	0	0	0	0	0	0
89	6	9	/	0	/	0	/	/	/	/	/	/	0	0	0	0	/	0	0	0	0	0	0	0	0	0	0
89	6	23	/	0	/	0	/	/	/	/	/	/	0	0	0	0	/	0	0	0	0	0	0	0	0	0	0
89	7	5	/	0	/	0	/	/	/	/	/	/	0	0	0	0	/	0	0	0	0	4	0	0	6	0	0
89	7	21	/	0	/	0	/	/	/	/	/	/	0	0	0	0	/	0	0	0	0	0	0	0	0	0	0
89	8	4	/	0	/	0	/	/	/	/	/	/	0	0	0	0	/	0	0	0	0	0	0	0	0	0	0
89	8	18	/	5	/	0	/	/	/	/	/	/	15	8	12	2	/	0	0	0	3	0	0	0	0	0	0
89	9	1	/	0	/	0	/	/	/	/	/	/	5	0	5	0	/	0	0	0	0	0	0	0	0	0	0
89	9	15	/	2	/	0	/	/	/	/	/	/	15	7	10	0	/	0	0	0	0	3	0	0	1	0	0
89	9	28	/	13	/	20	/	/	/	/	/	/	23	33	34	30	/	30	36	0	5	0	0	0	1	0	0
89	10	13	/	20	/	40	/	/	/	/	/	/	30	35	45	35	/	18	70	5	10	0	0	0	1	0	0
89	10	28	/	3	/	21	/	/	/	/	/	/	20	12	28	18	/	4	58	0	0	0	0	0	0	0	0
89	11	10	/	0	/	10	/	/	/	/	/	/	20	12	15	10	/	0	40	0	0	0	0	0	0	0	0
89	11	14	/	0	/	6	/	/	/	/	/	/	0	8	10	6	/	0	30	0	0	0	0	0	0	0	0
89	12	4	/	0	/	2	/	/	/	/	/	/	0	6	5	2	/	0	15	0	0	0	0	0	0	0	0

1990

Tract #			7	7	7	7	7	7	7	7	7	7	7	7	7	7	18	18	18	19	30	30	31	31	31	31	31
Pond #			14	50	53	64	56	57W	61S	60	62E	62W	72	74	84	97	6	15	37	24	16	35	13S	13G	16	45	49
y	m	d																									
90	1	5	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
90	1	19	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
90	2	2	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
90	2	16	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
90	3	2	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
90	3	16	/	0	/	0	/	/	/	/	/	/	0	0	0	0	/	0	0	0	0	0	0	0	0	0	0
90	4	13	/	0	/	0	/	/	/	/	/	/	0	0	0	0	/	0	0	0	0	0	0	0	0	0	0
90	4	30	/	0	/	0	/	/	/	/	/	/	0	0	0	0	/	0	0	0	0	0	0	0	0	0	0
90	5	11	/	0	/	0	/	/	/	/	/	/	0	0	0	0	/	0	0	0	0	0	0	0	0	0	0
90	5	25	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
90	6	8	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
90	6	22	/	0	/	0	/	/	/	/	/	/	0	0	0	0	/	0	0	0	0	0	0	0	0	0	0
90	7	6	/	0	/	0	/	/	/	/	/	/	0	0	0	0	/	0	0	0	0	0	0	0	0	0	0
90	7	20	/	20	/	20	/	/	/	/	/	/	40	30	30	10	/	0	50	0	0	0	0	0	0	0	0
90	8	7	/	15	/	15	/	/	/	/	/	/	20	15	28	10	/	3	50	10	10	0	0	0	0	0	0
90	8	17	/	15	/	15	/	/	/	/	/	/	25	20	30	10	/	3	55	15	15	15	5	10	15	0	0
90	8	31	/	20	/	25	/	/	/	/	/	/	30	30	35	15	/	3	80	30	25	30	5	10	15	0	0
90	9	14	/	0	/	0	/	/	/	/	/	/	10	10	15	5	/	0	30	15	10	10	0	0	10	0	0
90	9	28	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
90	10	12	/	0	/	0	/	/	/	/	/	/	10	10	10	0	/	0	55	20	10	28	10	15	20	0	0
90	10	26	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
90	11	9	/	0	/	0	/	/	/	/	/	/	0	0	0	0	/	0	16	0	0	0	0	0	5	0	0
90	11	25	/	0	/	0	/	/	/	/	/	/	0	0	0	0	/	0	0	0	0	0	0	0	0	0	0
90	12	7	/	0	/	0	/	/	/	/	/	/	0	0	0	0	/	0	0	0	0	0	0	0	0	0	0
90	12	21	/	0	/	0	/	/	/	/	/	/	0	0	0	0	/	0	0	0	0	0	0	0	0	0	0

1991

Tract #			7	7	7	7	7	7	7	7	7	7	7	7	7	7	18	18	18	19	30	30	31	31	31	31	31
Pond #			14	50	53	64	56	57W	61S	60	62E	62W	72	74	84	97	6	15	37	24	16	35	13S	13G	16	45	49
y	m	d																									
91	1	4	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	1	16	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	2	1	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	2	15	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	3	1	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	3	15	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	3	29	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	4	12	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	4	26	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	5	10	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	5	24	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	6	7	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	6	21	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	7	5	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	7	19	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	8	2	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	8	16	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	8	30	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
91	9	6	/	4.06	0	7.11	/	/	/	/	/	/	34	17	31	23.9	/	3.05	72.9	0	13	14	0	10.9	22.1	0	0
91	9	20	25.4	2.54	0	11.4	/	/	/	/	/	/	38.1	20.3	29.2	17.8	/	0	66	0	20.3	5.08	0	8.89	15.2	0	0
91	10	4	24.1	1.27	0	8.89	/	/	/	/	/	/	33	17.8	27.9	22.9	/	2.54	61	10.2	26.7	12.7	5.08	14	22.9	0	1.27
91	10	18	27.9	2.54	53.3	5.08	25.4	0	38.1	30.5	58.4	33	33	17.8	27.9	15.2	/	0	61	0	24.1	1.27	0	10.2	17.8	0	0
91	11	1	11.4	0	40.6	0	8.89	0	25.4	17.8	38.1	20.3	17.8	8.89	10.2	1.27	36.8	0	36.8	0	16.5	0	0	0	0	0	0
91	11	15	1.27	0	29.2	0	0	0	14	7.62	16.5	7.62	5.08	0	0	0	/	0	0	0	7.62	0	0	0	/	0	0
91	11	29	0	0	16.5	0	0	0	0	0	3.81	0	0	0	0	0	/	0	0	0	2.54	0	0	0	0	0	0
91	12	13	0	0	5.08	0	0	0	0	0	0	0	0	0	0	0	/	0	0	0	0	0	0	0	0	0	0
91	12	27	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/

1992

Tract #			7	7	7	7	7	7	7	7	7	7	7	7	7	7	18	18	18	19	30	30	31	31	31	31	31
Pond #			14	50	53	64	56	57W	61S	60	62E	62W	72	74	84	97	6	15	37	24	16	35	13S	13G	16	45	49
y	m	d																									
92	1	3	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
92	1	17	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
92	1	31	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
92	2	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	2	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	3	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	3	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	4	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	4	24	0	0	0	0	0	0	0	0	0	0	0	0	30	0	20	0	0	0	0	0	0	0	0	0	0
92	5	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	5	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	6	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	6	19	0	0	15	0	0	0	0	0	0	0	0	0	22	0	15	0	0	0	11	0	0	0	14	0	0
92	7	3	50	40	70	30	30	0	40	50	40	45	45	30	70	35	45	10	80	30	35	40	25	30	35	20	25
92	7	17	49	23	65	22	37	0	39	53	47	50	42	31	66	27	33	1	65	20	20	31	22	27	36	5	15
92	7	31	17	17	55	17	24	0	36	28	36	35	52	27	53	22	28	0	43	0	15	17	4	16	21	0	1
92	8	14	53	46	93	47	63	48	54	56	78	62	71	45	84	48	52	25	72	12	24	39	25	28	38	18	25
92	8	21	68	64	94	63	68	102	57	61	87	69	76	50	105	60	53	32	83	37	31	60	39	41	52	30	38
92	8	28	67	56	89	56	66	95	54	58	82	68	69	50	103	56	54	25	75	37	30	57	36	40	52	25	36
92	9	11	56	43	79	50	58	94	50	50	75	58	62	41	94	43	39	12	65	29	22	48	26	33	41	17	25
92	9	25	69	55	99	54	65	96	55	56	80	67	68	46	98	49	50	22	76	28	27	34	20	29	38	14	21
92	10	9	70	49	97	52	66	88	56	54	81	65	65	46	93	48	47	17	77	31	25	39	20	27	39	10	20
92	10	23	63	30	86	38	59	66	47	40	64	51	56	40	75	30	46	3	67	15	19	24	1	13	25	0	1
92	11	6	49	18	77	29	49	31	42	35	52	45	47	29	64	18	40	0	49	0	12	18	0	7	15	0	0
92	11	20	48	10	69	20	36	15	41	32	41	40	36	24	55	12	35	0	32	0	10	11	0	0	6	0	0

1993

Tract #			7	7	7	7	7	7	7	7	7	7	7	7	7	7	18	18	18	19	30	30	31	31	31	31	31
Pond #			14	50	53	64	56	57W	61S	60	62E	62W	72	74	84	97	6	15	37	24	16	35	13S	13G	16	45	49
y	m	d																									
93	1	15	39	11	70	23	40	14	42	31	46	46	45	27	57	15	40	0	33	1	21	10	0	1	13	0	0
93	1	28	42	22	78	30	47	17	46	36	54	48	48	31	66	27	44	4	46	14	24	30	10	16	27	0	0
93	2	11	33	7	65	18	34	8	36	24	41	41	38	27	53	13	38	0	34	0	20	18	1	9	15	0	0
93	2	26	33	15	68	22	37	9	37	30	43	43	40	27	58	22	40	0	31	0	22	22	4	11	19	0	0
93	3	12	24	3	58	11	24	0	33	20	33	35	30	19	48	8	34	0	18	0	20	18	1	10	15	0	0
93	3	26	51	32	84	38	56	39	47	40	66	52	54	40	77	34	49	7	76	40	37	56	34	36	46	16	21
93	4	9	39	18	73	28	45	14	37	30	53	49	44	32	67	24	40	0	69	36	30	45	26	31	36	1	6
93	4	23	35	17	71	26	39	11	35	26	48	43	44	30	62	21	41	0	64	32	25	41	19	25	30	0	0
93	5	7	21	1	65	11	25	0	22	19	31	32	31	20	47	7	26	0	46	15	20	26	1	12	16	0	0
93	5	21	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
93	6	4	0	0	34	0	0	0	0	0	2	12	6	0	24	0	13	0	0	0	3	1	0	0	0	0	0
93	6	18	13	7	66	12	20	0	22	24	28	28	30	16	44	13	25	0	22	2	16	21	0	0	14	0	0
93	7	1	3	0	57	0	3	0	7	10	13	21	13	0	30	0	19	0	0	0	17	17	5	4	16	0	0
93	7	16	26	25	84	28	33	9	36	40	42	45	43	30	62	29	47	4	30	0	16	20	0	7	18	0	0
93	7	3	32	20	80	23	30	0	32	35	40	40	41	25	57	25	46	0	0	0	14	18	0	7	15	0	0
93	8	12	23	9	60	11	22	0	20	12	30	30	30	15	48	2	23	0	0	0	0	4	0	0	2	0	0
93	8	27	16	1	49	1	16	0	19	7	17	25	18	9	34	0	20	0	0	0	0	0	0	0	0	0	0
93	9	10	27	16	61	12	23	0	32	24	28	35	28	20	54	17	33	0	31	10	24	10	0	0	13	0	0
93	9	23	30	13	63	16	23	0	33	24	34	33	37	19	52	14	36	0	26	4	23	6	0	0	4	0	0
93	10	7	21	6	54	13	18	0	33	22	28	35	28	16	49	18	35	0	21	9	25	8	0	0	9	0	0
93	10	21	34	24	65	25	30	6	36	32	45	45	43	29	56	25	43	0	39	7	25	19	1	4	12	0	0
93	11	5	32	14	59	20	28	1	35	32	42	42	40	29	58	24	45	0	41	7	25	23	2	9	18	0	0
93	11	18	18	3	46	9	17	0	19	16	28	32	27	15	47	6	32	0	24	0	21	9	0	0	4	0	0
93	12	3	5	0	43	0	3	0	19	7	13	18	11	4	34	0	22	0	0	0	16	1	0	0	0	0	0
93	12	17	0	0	34	0	0	0	9	0	1	12	3	0	29	0	14	0	0	0	4	0	0	0	0	0	0
93	12	30	0	0	28	0	0	0	7	0	0	9	0	0	20	0	14	0	0	0	2	0	0	0	0	0	0

1994

Tract #			7	7	7	7	7	7	7	7	7	7	7	7	7	7	18	18	18	19	30	30	31	31	31	31	31
Pond #			14	50	53	64	56	57W	61S	60	62E	62W	72	74	84	97	6	15	37	24	16	35	13S	13G	16	45	49
y	m	d																									
94	1	14	0	0	28	0	0	0	11	0	0	12	0	0	21	0	15	0	0	0	5	0	0	0	0	0	0
94	1	28	0	0	28	0	0	0	13	2	1	15	2	0	25	0	19	0	0	0	12	0	0	0	0	0	0
94	2	11	0	0	28	0	0	0	5	0	0	5	0	0	24	0	17	0	0	0	10	0	0	0	0	0	0
94	2	25	0	0	17	0	0	0	0	0	0	0	0	0	14	0	2	0	0	0	1	0	0	0	0	0	0
94	3	11	0	0	22	0	0	0	0	0	0	0	0	0	19	0	3	0	0	0	0	0	0	0	0	0	0
94	3	25	0	0	26	0	0	0	7	0	0	9	0	0	21	0	11	0	0	0	0	0	0	0	0	0	0
94	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	4	22	0	0	11	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
94	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	5	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	6	3	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	6	17	10	1	33	0	0	0	9	3	0	9	0	0	30	0	16	0	0	0	0	0	0	0	0	0	0
94	7	1	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
94	7	14	19	2	46	0	2	0	18	12	14	21	15	6	35	0	17	0	0	0	0	0	0	0	0	0	0
94	7	29	8	0	34	0	0	0	10	1	0	12	1	0	25	0	10	0	0	0	0	0	0	0	0	0	0
94	8	12	0	0	27	0	0	0	2	0	0	8	0	0	25	0	12	0	0	0	0	0	0	0	0	0	0
94	8	26	15	11	44	2	8	0	28	20	18	28	21	14	49	18	32	0	21	0	16	10	1	14	24	4	9
94	9	9	30	17	61	18	24	0	32	25	35	38	29	21	60	18	38	0	44	0	21	36	12	30	39	17	23
94	9	23	45	37	78	36	48	18	47	44	61	50	53	39	81	38	48	11	74	3	23	39	22	38	46	25	30
94	10	6	48	30	76	35	54	25	43	42	64	50	54	38	78	31	46	1	74	5	23	43	28	46	50	25	32
94	10	21	30	12	66	21	34	5	32	22	44	42	41	26	61	18	39	0	54	0	17	25	11	31	35	5	13
94	11	4	31	12	66	21	33	0	34	25	43	43	42	26	62	21	41	0	47	0	20	21	10	28	33	1	8
94	11	18	39	20	76	34	44	10	43	33	54	49	50	36	73	35	48	10	71	18	25	46	24	36	44	23	24
94	12	2	28	11	65	19	30	1	34	23	41	42	39	24	61	19	41	0	58	2	22	30	13	30	36	5	10
94	12	16	18	2	54	10	21	0	27	17	33	33	29	16	51	8	33	0	38	0	20	21	5	22	27	0	1
94	12	30	32	18	65	24	36	1	34	24	46	46	43	28	65	24	48	0	57	13	24	38	18	31	40	8	17

1995

Tract #			7	7	7	7	7	7	7	7	7	7	7	7	7	7	18	18	18	19	30	30	31	31	31	31	31
Pond #			14	50	53	64	56	57W	61S	60	62E	62W	72	74	84	97	6	15	37	24	16	35	13S	13G	16	45	49
y	m	d																									
95	1	12	23	7	62	16	27	0	34	20	43	41	38	21	57	17	40	0	46	1	22	33	12	26	32	1	4
95	1	27	23	8	61	16	25	0	32	20	36	35	35	24	56	16	40	0	44	1	22	27	13	26	32	1	5
95	2	13	14	1	53	8	16	0	29	18	27	32	26	16	48	9	36	0	27	0	19	17	3	18	22	0	1
95	2	24	34	21	69	25	37	2	36	32	46	46	42	28	63	24	43	0	35	1	23	21	9	20	27	1	2
95	3	13	24	4	58	13	22	0	26	21	35	36	30	18	52	11	36	0	1	0	18	10	1	13	18	0	0
95	3	24	38	26	74	30	43	9	40	36	53	48	47	33	68	28	45	3	53	18	24	35	24	27	35	4	11
95	4	7	42	30	77	35	45	12	43	38	57	49	49	36	73	33	51	12	58	21	25	30	21	26	33	3	8
95	4	21	27	8	62	17	28	0	26	20	38	38	37	22	56	17	36	0	41	1	17	15	10	15	19	0	0
95	5	5	23	11	66	22	29	6	28	27	38	41	38	24	54	24	40	0	30	0	18	9	4	9	16	0	0
95	5	19	6	1	45	2	10	0	22	20	20	25	21	9	39	0	23	0	0	0	2	1	0	0	1	0	0
95	6	2	0	0	32	0	1	0	7	1	3	11	4	0	24	0	7	0	0	0	0	0	0	0	0	0	0
95	6	16	0	0	26	0	0	0	2	0	0	3	1	0	22	0	6	0	0	0	0	0	0	0	0	0	0
95	6	29	27	20	60	20	28	0	34	32	36	40	36	23	60	23	38	0	18	1	19	14	1	5	17	0	0
95	7	13	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
95	7	27	27	15	61	19	27	0	35	34	37	42	37	24	62	23	40	0	24	0	10	0	0	0	4	0	0
95	8	11	41	24	75	25	42	9	34	32	53	54	52	33	73	32	46	0	53	0	17	5	0	1	6	0	0
95	8	25	62	43	93	48	56	39	55	52	73	73	72	47	90	48	63	28	67	22	27	26	9	18	21	13	9
95	9	8	/	59	/	/	66	102	/	/	84	/	/	45	/	/	/	/	81	/	/	29	/	/	34	/	18
95	9	22	66	41	90	45	64	82	50	45	75	58	60	41	89	42	49	13	79	25	20	15	0	10	22	1	3
95	10	6	71	59	104	60	69	105	54	50	86	71	73	47	95	52	62	30	82	27	23	17	1	10	24	9	11
95	10	20	73	68	108	62	70	106	61	57	85	70	73	53	102	58	72	45	90	64	42	65	41	45	63	42	45
95	11	3	63	51	99	53	65	98	57	52	81	68	70	43	91	47	66	25	80	49	34	27	32	37	56	31	35
95	11	18	50	34	85	38	61	75	45	39	68	57	58	39	85	34	50	6	73	53	23	38	22	35	44	9	18
95	12	1	56	23	78	32	52	50	39	34	59	51	51	34	70	24	44	0	66	44	21	28	12	26	34	1	6
95	12	15	46	12	68	23	41	28	37	29	46	46	46	27	61	18	38	0	55	33	20	17	1	17	24	0	1
95	12	29	38	3	63	15	31	14	37	26	38	38	37	19	54	11	35	0	44	20	16	8	0	8	13	0	0

1996

Tract #			7	7	7	7	7	7	7	7	7	7	7	7	7	7	18	18	18	19	30	30	31	31	31	31	31
Pond #			14	50	53	64	56	57W	61S	60	62E	62W	72	74	84	97	6	15	37	24	16	35	13S	13G	16	45	49
y	m	d																									
96	1	12	46	11	68	21	36	16	41	33	43	43	42	24	58	12	42	0	45	20	20	9	0	11	16	0	0
96	1	26	35	1	58	10	26	6	34	24	34	37	35	17	47	8	37	0	32	5	14	1	0	2	4	0	0
96	2	9	34	1	56	3	22	1	35	24	31	35	32	15	46	8	34	0	21	1	11	0	0	1	1	0	0
96	2	23	24	0	47	0	12	0	27	15	20	27	21	7	36	1	26	0	0	0	2	0	0	0	0	0	0
96	3	8	16	0	46	0	7	0	26	14	13	24	15	3	33	0	24	0	0	0	0	0	0	0	0	0	0
96	3	22	1	0	34	0	0	0	16	4	2	15	4	0	23	0	14	0	0	0	0	0	0	0	0	0	0
96	4	8	13	2	48	5	9	0	28	19	18	27	20	9	42	2	24	0	0	0	1	0	0	0	0	0	0
96	4	19	0	0	36	0	0	0	17	5	4	16	10	0	28	0	18	0	0	0	0	0	0	0	0	0	0
96	5	3	0	0	29	0	0	0	8	1	1	4	1	0	23	0	15	0	0	0	0	0	0	0	0	0	0
96	5	17	0	0	5	0	0	0	1	0	0	1	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0
96	5	31	23	14	51	14	18	0	36	32	28	37	28	18	52	23	37	2	12	0	0	0	0	0	0	0	0
96	6	17	41	31	67	30	36	11	47	42	48	50	47	33	67	37	53	22	57	14	22	0	1	1	10	0	0
96	6	28	/	30	/	31	/	14	/	37	58	/	/	35	67	35	52	13	76	23	30	31	19	20	30	1	12
96	7	15	/	44	/	/	62	63	/	50	77	62	/	/	89	/	/	33	88	50	/	53	/	/	48	/	31
96	7	29	/	21	/	/	45	17	/	/	54	47	/	32	/	/	47	6	67	/	/	33	/	27	31	/	9
96	8	9	/	46	/	49	58	33	43	41	71	56	58	43	98	42	53	20	70	42	32	44	24	30	37	6	15
96	8	23	39	25	77	34	44	14	38	25	53	47	50	33	88	31	44	1	55	30	25	25	14	19	24	0	1
96	9	6	25	11	62	20	26	1	25	13	37	32	35	22	56	13	28	0	38	20	24	19	13	19	26	0	1
96	9	23	2	1	48	3	7	0	15	2	18	22	19	10	40	1	22	0	6	1	13	4	1	15	9	0	0
96	10	4	0	0	33	0	1	0	5	0	5	9	4	1	29	0	20	0	0	0	3	0	0	1	2	0	0
96	10	18	12	6	49	7	9	0	23	14	20	28	22	12	46	12	32	0	0	9	25	17	15	15	25	5	7
96	11	1	1	0	33	0	1	0	7	1	5	8	5	1	29	2	21	0	0	0	16	4	3	5	11	0	0
96	11	18	0	0	15	0	0	0	0	0	0	0	0	0	14	0	6	0	0	0	1	0	0	0	1	0	0
96	12	2	0	0	13	0	0	0	0	0	0	0	0	0	9	0	1	0	0	0	0	0	0	0	1	0	0

1997

Tract #			7	7	7	7	7	7	7	7	7	7	7	7	7	7	18	18	18	19	30	30	31	31	31	31	31
Pond #			14	50	53	64	56	57W	61S	60	62E	62W	72	74	84	97	6	15	37	24	16	35	13S	13G	16	45	49
y	m	d																									
97	1	10	0	0	12	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0
97	1	24	0	0	11	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0
97	2	7	0	0	15	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0
97	2	20	0	0	12	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0
97	3	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	3	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	4	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	5	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	5	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	6	13	0	0	18	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0
97	6	27	0	0	11	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0
97	7	11	0	0	13	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0
97	7	28	0	0	8	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	6	0	0	0	0	0	0
97	8	8	0	0	2	0	0	0	0	0	0	0	0	0	12	0	2	0	0	0	9	0	0	0	0	0	0
97	8	20	0	0	20	0	0	0	0	0	0	0	0	0	24	0	18	0	0	0	16	0	0	0	6	2	0
97	9	5	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	9	0	0	0	0	0	0
97	9	19	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	11	0	0	0	0	0	0
97	10	7	2	1	39	0	0	0	21	13	8	19	12	7	44	1	26	0	37	14	22	9	6	20	28	6	16
97	10	17	0	0	24	0	0	0	4	0	0	1	1	0	29	0	13	0	10	0	17	0	0	11	17	0	1
97	10	31	0	0	12	0	0	0	0	0	0	0	0	0	16	0	5	0	0	0	10	0	0	2	5	0	0
97	11	17	0	0	25	0	0	0	6	4	0	2	0	0	29	10	19	0	0	1	22	1	12	15	24	4	9
97	12	1	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	0	0	0	21	0	7	12	17	0	1
97	12	12	0	0	32	0	0	0	12	9	1	15	2	1	36	15	24	0	17	0	23	0	11	16	22	0	3
97	12	30	21	20	55	16	17	0	36	30	30	37	31	21	61	26	44	1	68	41	40	32	39	39	48	30	33

1998

Tract #			7	7	7	7	7	7	7	7	7	7	7	7	7	7	18	18	18	19	30	30	31	31	31	31	31
Pond #			14	50	53	64	56	57W	61S	60	62E	62W	72	74	84	97	6	15	37	24	16	35	13S	13G	16	45	49
y	m	d																									
98	1	9	35	33	72	31	32	0	48	42	43	48	44	33	70	39	61	19	86	55	42	50	50	49	60	40	44
98	1	26	35	29	75	33	46	0	42	37	59	60	55	36	77	42	60	7	81	62	43	55	48	58	69	43	46
98	2	6	57	49	89	48	63	71	55	50	80	65	61	43	90	49	50	23	87	80	47	78	53	70	83	55	58
98	2	25	58	52	92	53	65	72	56	48	82	67	62	44	96	49	51	22	83	83	53	89	62	86	82	60	63
98	3	9	/	39	/	45	/	69	/	/	74	59	/	42	86	/	/	13	81	80	/	83	/	83	84	/	57
98	3	23	/	57	/	57	67	102	/	/	83	68	/	45	99	/	/	28	89	94	/	107	/	96	89	/	70
98	4	6	/	36	/	41	61	74	/	/	70	55	/	40	84	/	/	7	77	80	/	91	/	86	80	/	55
98	5	1	41	13	70	22	40	20	38	26	47	44	41	25	60	18	35	0	62	63	36	66	41	64	68	26	31
98	5	15	/	2	/	/	/	2	/	16	/	/	/	/	47	/	/	0	50	52	/	56	/	54	59	/	20
98	6	1	/	22	75	26	38	17	/	41	44	45	/	27	60	/	39	6	55	44	26	41	/	40	44	0	2
98	6	15	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	38	22	17	26	/	22	28	0	0
98	6	30	0	0	34	0	1	0	7	5	6	12	4	0	23	0	5	0	19	0	7	13	0	9	15	0	0
98	7	14	22	4	43	3	10	0	22	19	17	27	17	7	33	2	20	0	28	20	25	42	21	25	44	20	20
98	8	12	/	16	65	/	/	0	/	22	/	/	/	17	50	/	/	0	32	20	23	44	27	33	50	14	20
98	8	24	/	12	64	/	24	0	/	21	33	36	31	16	48	/	/	0	42	42	25	46	/	38	53	/	25
98	9	9	/	1	49	/	/	/	/	/	/	/	/	1	29	/	/	0	20	27	/	28	/	29	40	/	10
98	9	21	/	28	68	/	/	/	/	/	/	/	/	23	56	/	/	1	43	41	/	46	/	38	54	/	29
98	10	5	/	28	76	/	43	21	/	33	/	/	/	30	66	/	43	0	73	53	/	65	/	54	72	/	45
98	10	19	41	10	62	13	26	6	35	20	36	36	32	18	51	11	36	0	63	45	27	54	32	49	62	26	35
98	11	2	/	12	64	/	/	9	/	/	/	/	/	19	53	/	/	/	63	45	/	54	/	45	58	/	24
98	12	1	/	21	76	/	/	23	/	/	/	/	/	38	62	/	/	/	73	54	/	63	/	54	66	/	31
98	12	18	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	62	49	/	49	/	46	55	/	17
98	12	29	30	3	56	8	21	1	32	15	30	32	27	13	42	1	30	0	54	44	26	43	24	42	50	4	10

1999

Tract #			7	7	7	7	7	7	7	7	7	7	7	7	7	7	18	18	18	19	30	30	31	31	31	31	31
Pond #			14	50	53	64	56	57W	61S	60	62E	62W	72	74	84	97	6	15	37	24	16	35	13S	13G	16	45	49
y	m	d																									
99	1	13	/	1	53	/	/	0	/	/	/	/	/	11	40	0	/	0	49	38	/	38	/	37	44	0	4
99	1	25	/	1	48	1	/	0	/	/	/	/	/	8	36	0	/	0	41	32	/	33	/	32	38	0	1
99	2	9	/	0	37	0	/	0	/	/	/	/	/	0	24	0	/	0	25	19	/	21	/	20	25	0	0
99	3	8	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	3	0	0
99	3	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
99	4	7	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
99	4	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
99	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
99	5	18	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0
99	6	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
99	7	2	0	30	61	19	16	0	0	0	0	0	0	0	58	/	/	0	53	51	53	84	/	43	60	/	29
99	7	28	/	20	/	/	/	/	/	/	/	/	/	/	56	/	/	/	70	52	/	71	/	/	53	/	20
99	8	10	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	56	/	64	/	/	49	/	12
99	8	23	/	63	91	/	62	47	/	/	/	/	/	45	93	/	/	29	91	78	/	93	/	60	76	/	44
99	9	7	/	56	90	/	65	94	/	/	/	/	/	44	96	/	/	23	85	88	/	105	/	86	83	/	62
99	9	21	/	72	93	/	70	107	/	/	/	/	/	47	106	/	/	37	97	/	/	126	/	104	97	/	72
99	10	18	/	49	90	/	65	92	/	/	/	61	/	43	87	/	/	12	82	/	/	114	/	95	87	/	56
99	11	1	42	53	90	53	65	91	54	44	74	40	59	43	87	39	51	11	79	89	64	107	77	91	84	44	50
99	11	15	/	38	86	40	61	79	54	38	79	53	0	41	78	37	48	3	77	0	47	100	89	35	80	37	45
99	11	29	/	24	67	/	52	55	/	/	/	/	/	47	67	/	/	0	72	0	/	87	/	71	73	/	30
99	12	13	/	13	68	/	41	36	/	/	/	/	/	0	57	/	/	0	64	70	/	75	/	63	65	/	18
99	12	27	/	18	63	/	46	35	/	/	/	/	/	26	58	/	/	0	74	74	/	78	/	63	70	/	22

2000

Tract #			7	7	7	7	7	7	7	7	7	7	7	7	7	7	18	18	18	19	30	30	31	31	31	31	31
Pond #			14	50	53	64	56	57W	61S	60	62E	62W	72	74	84	97	6	15	37	24	16	35	13S	13G	16	45	49
y	m	d																									
2000	1	10	/	10	65	/	34	22	/	/	/	/	/	20	50	/	/	0	65	65	/	60	/	49	38	/	8
2000	1	31	/	4	57	/	23	9	/	/	/	/	/	13	42	/	/	0	60	59	/	53	/	43	50	/	0
2000	2	14	/	0	49	/	13	0	/	/	/	/	/	6	32	/	/	0	51	51	/	42	/	34	39	/	0
2000	2	28	/	0	38	/	1	0	/	/	/	/	/	0	24	/	/	0	40	42	/	32	/	22	26	/	0
2000	3	13	/	0	27	/	0	0	/	/	/	/	/	0	14	/	/	0	25	28	/	21	/	9	12	/	0
2000	3	27	/	0	21	/	0	0	/	/	/	/	/	0	12	/	/	0	14	16	/	22	/	7	12	/	0
2000	4	10	/	0	0	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0
2000	4	24	/	0	0	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0
2000	5	8	/	0	0	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0
2000	5	23	/	0	0	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0
2000	6	5	/	0	0	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0
2000	10	10	/	0	0	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0
2000	10	24	/	0	0	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0
2000	11	7	/	0	0	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0

2001

Tract #			7	7	7	7	7	7	7	7	7	7	7	7	7	7	18	18	18	19	30	30	31	31	31	31	31
Pond #			14	50	53	64	56	57W	61S	60	62E	62W	72	74	84	97	6	15	37	24	16	35	13S	13G	16	45	49
y	m	d																									
2001	1	15	/	0	0	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0
2001	2	15	/	0	0	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0
2001	3	15	/	0	0	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0
2001	4	15	/	0	0	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0
2001	5	15	/	0	0	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0
2001	6	15	/	0	0	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0
2001	9	4	/	26	53	/	48	4	/	/	/	/	/	25	50	/	/	0	60	10	/	0	/	11	6	/	0
2001	9	17	/	63	68	/	67	97	/	/	/	/	/	44	90	/	/	27	94	70	/	45	/	45	48	/	32
2001	10	12	/	41	65	/	69	66	/	/	/	/	/	41	74	/	/	6	75	69	/	47	/	48	53	/	29
2001	11	9	/	62	65	/	69	73	/	/	/	/	/	45	68	/	/	3	71	55	/	39	/	46	49	/	23
2001	12	14	/	9	44	/	42	13	/	/	/	/	/	21	40	/	/	0	46	33	/	14	/	22	23	/	0

2002

Tract #			7	7	7	7	7	7	7	7	7	7	7	7	7	7	18	18	18	19	30	30	31	31	31	31	31
Pond #			14	50	53	64	56	57W	61S	60	62E	62W	72	74	84	97	6	15	37	24	16	35	13S	13G	16	45	49
y	m	d																									
2002	1	11	/	0	29	/	21	0	/	/	/	/	/	6	16	/	/	0	27	8	/	0	/	4	6	/	0
2002	2	1	/	0	22	/	8	0	/	/	/	/	/	0	17	/	/	0	0	0	/	0	/	0	0	/	0
2002	2	28	/	0	30	/	8	0	/	/	/	/	/	4	26	/	/	0	15	0	/	0	/	0	0	/	0
2002	3	28	/	0	3	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0
2002	4	30	/	0	0	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0
2002	5	30	/	0	0	/	0	0	/	/	/	/	/	0	0	/	/	0	0	0	/	0	/	0	0	/	0
2002	6	28	/	69	78	/	68	83	/	/	/	/	/	33	88	/	/	28	72	19	/	5	/	3	19	/	0
2002	8	1	/	51	76	/	69	85	/	/	/	/	/	33	82	/	/	17	72	41	/	46	/	26	37	/	18
2002	8	30	/	63	72	/	75	99	/	/	/	/	/	41	86	/	/	41	98	75	/	62	/	43	57	/	36

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