GAMBUSIA AND SYSTEMS THINKING

Cara Bergamo, Jarrett Cato, Samira Farouk, Lisa Halbsgut, Jennifer Lee, Andrea Miltiades, Paul Morrison, David Page, Eugenia Shmidt, Pranava Upadrashta

Advisor: Michael T. Roche

Teaching Assistant: Matthew Singer

ABSTRACT

The team challenge involved performing fieldwork to obtain data related to daily fluctuations in dissolved oxygen levels within a natural system (Long Pond at Drew University). Once these patterns were discerned, the team designed and conducted laboratory experiments for estimating oxygen production and consumption by certain biotic factors. The main subjects of these tests were *Gambusia affinis*, mosquito fish, and *Elodea densa*, common aquarium plants. The focus of these experiments resulted in estimates of the amount of oxygen taken in or produced per gram of organism per hour both in light and dark conditions. With this information, the computer program Stella modeled a "break even" system, which represented a perfect environment. Ultimately, the team wanted to suggest the proper ratios required to design a miniature closed system in which *Gambusia* could be sustained for extended periods of time.

It was determined that Long Pond was not a productive system during the trial period. Obtained lab data suggests that *Gambusia* consume more oxygen, or respire more, in the presence of light. Also, the results of the test conducted showed that dissolved oxygen levels peaked at midday. Following this, levels began to steadily decline, reaching lowest amounts during early morning hours (4:30). It was also determined that *Gambusia* do not directly obtain oxygen from the atmosphere. Laboratory results suggested that the proposed equilibrium for the Stella model use 0.38 grams of *Gambusia* with 3.4 grams of *Elodea* to maintain a sustained system with respect to dissolved oxygen.

INTRODUCTION

In nature, there exists a variety of ecosystems which would not be productive without the successful interaction of each of their components. These components include differing biotic and abiotic factors. To understand the interaction between these components, we chose to analyze some of the biotic and abiotic factors found within the ecosystem of Long Pond at Drew University. Along with the studies of Long Pond, we also chose *Elodea densa*, a water plant, and *Gambusia affinis*, a small predatory fish, to take a closer look at the interaction between these biotic factors in a simple ecosystem. In the ecosystem, abiotic aspects include oxygen, sunlight and water. By investigating these components, we gain a better understanding of ecosystems and the way certain factors interact in order for the environment to be productive. With this information we are able to design experiments to test for the necessary conditions of the ideal ecosystem in which *Elodea* and *Gambusia* could be sustained.

The aim of this project was to use modeling software to design a closed system which would model patterns in nature related to dissolved oxygen as observed in Drew University's Long Pond. To do so, we were required to take pH, temperature, and dissolved oxygen readings from Long Pond and design experiments to estimate oxygen production and consumption by these organisms.. Ultimately, we wanted to create a miniature closed system in which *Gambusia* could be sustained for extended periods of time.

Gambusia affinis

Gambusia affinis, a member of the fish family Poecilidae, is commonly used as a biological method of mosquito control. Although widely introduced as mosquito control agents, recent critical reviews on mosquito control have not supported the view that *Gambusia* are particularly effective in reducing mosquito populations or in reducing the incidence of mosquito-borne diseases [1]. As opposed to having positive effects, the fish often have negative effects on other fish in the same ecological system. *Gambusia* are ideally suited to stock ponds, ornamental ponds, golf courses, canals, creeks and lakes [2]. They prefer the shallow vegetated areas near the shore that are also the preferred habitat of mosquito larvae. Being self-feeding and self-sustaining, they require virtually no maintenance, though they like to be in water with a pH of 7 to 8 and a temperature of 21° to 25° Celsius [3]. *Gambusia* can withstand shifts in water temperature, salt levels, diminished food supply, low dissolved oxygen levels, organic pollution, and overcrowding. *Gambusia* are one of the most widely distributed freshwater fish in the world due to their ability to adapt to a variety of environments [2]. Because of their ability to tolerate low dissolved oxygen levels, the *Gambusia* were ideally suited for our investigations.

Gambusia can grow to be 1-2 inches in length and can weigh up to 1 gram [5]. Lacking color and having similar form, *Gambusia* have often been compared to guppies. The basic body form of the female is much like the wild-type female guppy, though they can be distinguished without too much practice. The male is much slimmer than the male wild-type guppy, and the gonopodium, a modified anal fin, is much more evident [6]. This fin is also more visible in the male species than in the female. *Gambusia* have a flattened head and protrusible dorsally oriented mouths which help them with surface eating. They are highly fertile fish because the female can store sperm after mating. They are live-bearing fish which is an advantage for them in that the young are better developed and have a higher survival rate than fish that hatch from eggs. Their diet consists of mainly phytoplankton, zooplankton, algae, and aquatic insects, but they are not limited by this—they will eat basically anything, and they choose food sources that are easily accessible. They are tempted by moving prey, which is the reasoning behind their appetite for baby fish and other moving objects [3].

Figure 1 *Gambusia affinis* [4]

Elodea densa

Elodea densa is a very common aquarium plant. It grows best in temperatures of 10° to 25° Celsius and at pH levels of 6.5 to 7.5 [7]. It needs minimal to medium light (2-3 watts) and prefers hard water [8]. *Elodea* will root if the shoots are buried in the gravel. The leaves branching off the *Elodea* are about 1-3 cm long and 5 mm across, and they come in groups of four to eight. *Elodea* are leafy and bright green. They grow until they reach the water surface [9]. When they reach the surface, they form dense beds. Because of this, *Elodea* often become a nuisance. They restrict water movement, cause fluctuations in water quality, and trap organisms and sediment underneath [10]. *Elodea* spread rapidly through fragmentation, and therefore they will easily propogate in the laboratory.

Figure 2 *Elodea densa* [7]

Importance of Oxygen within the Ecosystem

Photosynthesis is the driving mechanism behind the productivity of ecosystems. Sunlight is absorbed by plants and utilized to produce glucose. The plants release oxygen through this process, which is then taken in by animals, such as fish. Oxygen absorbed into the animal body allows respiration, or the breakdown of glucose and other energy rich carbohydrates. Not only do animals absorb oxygen, but aerobic bacteria also consume oxygen during decomposition of organic matter. Oxidative respiration is the most efficient means of extracting energy from food available to animals. Moreover, animal metabolic rates are dependent on many factors including size, oxygen availability, respiration efficiency, activity level, food quality and metabolism. The more productive the environment, the better the quality and availability of oxygen within an ecosystem. Also, the ability of the plant organisms within the ecosystem to produce a significant amount of oxygen allows respiration to be more efficient.

For our experiment, we studied the production and consumption of oxygen by *Elodea* and *Gambusia*, respectively. Dissolved oxygen was a key aspect of our project as levels can often change within minutes from optimum to lethal. Such changes occur according to the time of day, weather, and temperature. The dissolved oxygen concentration can be one indicator of the health of the ecosystem. While concentrations can range from 0 to 18 parts per million, healthy aquatic ecosystems may contain 5 to 6 parts per million. No other variable in a fish culture is as dynamic. Because oxygen is not very soluble in water, water has a limited capacity for oxygen. While the rate of oxygen use by organisms in a pond can be very high, oxygen diffuses very slowly from the atmosphere into the water. Oxygen is also added to the water when photosynthesis occurs. This is because plants release oxygen after the intake of water and carbon dioxide from the environment and perform metabolic processes. The combination of these factors causes the rapid changes within the ecosystem [11].

Stella

An integral part of this team project is the Stella model, which was created to represent a closed system using a computer program called Stella. Stella uses a method of modeling that it calls "systems thinking." The purpose of this program with respect to this particular project is to be able to plug in a hypothetical scenario into a template and have the program predict the results. To use this software, it is necessary for the creator of the program to carefully consider what variables affect what aspects of a closed system. For example, photosynthesis increases the amount of oxygen, whereas cellular respiration decreases the amount of oxygen.

The Stella software allows the creator of a program to use 4 main representations. These are the stocks, flows, converters, and connectors. The stocks are the focus of the closed system. In this model, the *Elodea* and *Gambusia* are shown as stocks. A stock, by definition, is "how things are" [12]. In contrast, a flow is, by definition, "how things change" [12]. In our Stella model, the flows are photosynthesis and respiration. Converters are then factors that impact the flows. For example, in our model, the sunlight is a converter that affects the rate of photosynthesis, which is a flow. The program allows us to graph the relative amounts of sunlight available at different times of the day. Connectors function just as they sound – they link one aspect of the model to the other, so there can be a functioning cycle. For example, the *Elodea* stock must be connected to photosynthesis as well as respiration. [12]

Introduction of experiments

The rate of oxygen consumption (respiration) and rate of oxygen production (photosynthesis) is needed to construct the computer model and to further understand the system. Once we understand patterns of productivity by examining data collected from the pond, we were then able to begin constructing miniature simple systems in a laboratory using *Gambusia* and *Elodea*. The *Gambusia* constantly consume oxygen while the *Elodea* both produce oxygen and consumes oxygen. Light intensity affects the rate of oxygen production and consumption. Experiments were conducted in both light and dark settings. Closed chambers of water were constructed containing *Gambusia*, *Gambusia* and *Elodea*, *Elodea* and solely water, as a control. The dissolved oxygen content of the water in each of the chambers was measured before and after a set period of time. The net difference was divided by the time run of the experiment and the mass of the experimental organism. The resulting number was the rate of oxygen production, or consumption in a light or dark setting per gram per hour.

Another aspect of the closed system that we believed might have been crucial to the amount of oxygen intake and dissolved oxygen within the environment was whether *Gambusia* was able to attain a significant amount of oxygen from the air itself by going to the surface. Because *Gambusia's* jaw is angled upward, we thought it might be possible that the fish can take in some of its oxygen from the atmosphere. We proceeded in experimenting with this idea by comparing three man-made environments: one where *Gambusia* was able to come to the surface, one with a net to inhibit the surfacing of *Gambusia*, and a control with a net but no *Gambusia*. The data that we obtained enabled us to examine whether a significant portion of *Gambusia*'s oxygen intake came from surfacing.

MATERIALS AND METHODS

The Pond and Constructing the Raft

We chose Long Pond, located in Drew University's Zuck Arboretum, as the site of our environmental testing because it had been studied previously. Our group deployed a rowboat (and eventually a student designed logging platform) equipped with several different sensors to monitor the natural conditions of the pond. These sensors included a surface and underwater light sensor, a dissolved oxygen sensor, a pH sensor, and air temperature sensor. We anchored the rowboat in the middle of the pond and activated the sensors to begin taking readings at 3:00 PM on July 22, 2002. We decided to run the sensors for three days, until 3:00 PM July 25, 2002.

Our group ran a second test of the natural conditions from 4:30 PM August 5 until 3:00 PM August 8 due a faulty battery connection during the first run. Also, in this second run, we felt we needed to construct a special platform that would be less cumbersome than the rowboat. Use of the rowboat, which we covered with a tarp to protect the valuable equipment, may not have been the best idea, as the tarp may have shifted its position during the three days and impeded the correct operation of some of the sensors. In addition, the water probes (dissolved oxygen, pH, water temperature, deep water light) were attached to the side of the rowboat with duct tape, which may not have held them in a secure position. Thus, our group spent time engineering a raft/logging platform designed to efficiently and safely hold our equipment and aid in taking more accurate and easier readings.

This raft was designed with a PVC pipe frame that we encased partially with hollow polyethylene swimming pool "noodles". The base of the raft was a rectangular piece of Styrofoam which was attached to the pipe frame. On top of the platform, there was a styrofoam box that encased all of our sensor computers (YSI 610 DM Logger, LI-COR, LI-1000, and Palm Pilots IIIc). The sensors/probes that needed to be in the water were attached to the PVC frame and dangled off the side of the raft. The surface sensors (air temperature, surface light) sat on top of Styrofoam box held in position by Velcro attachments. This raft met all of the design criteria, namely, it was easy to deploy, inexpensive to construct of all waterproof floating materials, and effective in protecting the sensors.

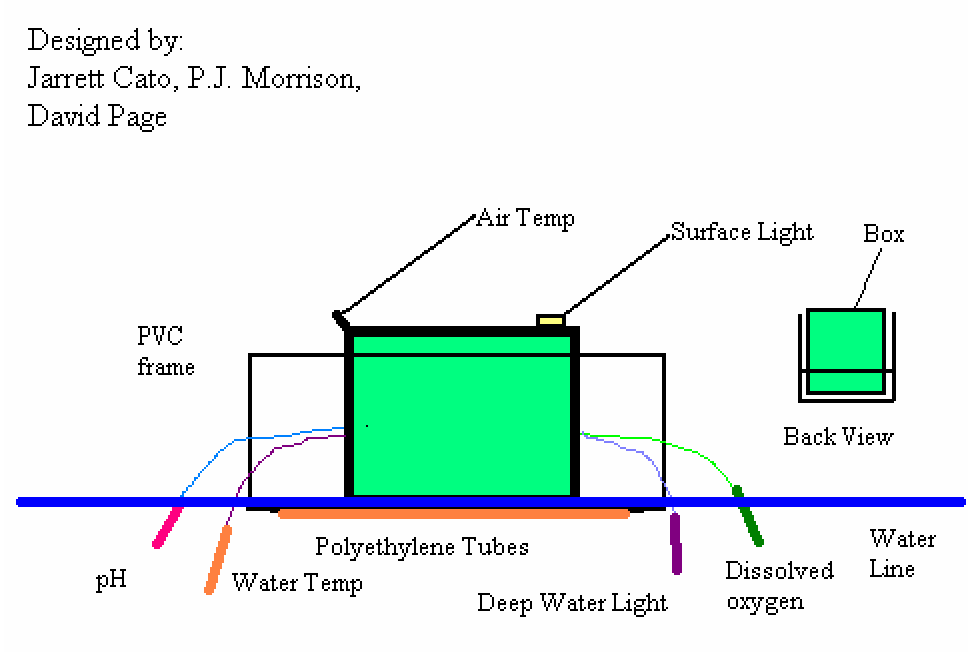

Figure 3 A diagram of the raft we built to deploy the probes with.

Closed light/dark biological systems and DO relationships

200 mL of de-chlorinated tap water were placed into each of seven 250 mL bottles. The dissolved oxygen concentration of this water was measured with self-filling ampoules for photometric analysis. Two bottles contained only one fish; the next two contained only *Elodea*; another contained a fish and *Elodea*. A seventh bottle containing only 200 mL of distilled water was used as a control. All bottles were sealed with a pacifier top through which a metal couplet was passed. A flexible plastic tube was attached to the other end of the couplet and was positioned along the side of each bottle with a rubber band. All bottles were vertically suspended on clamps with the nozzles down. The masses of all of the plants and fish were recorded.

All specimens were subjected to a three hour period of daylight in a 20 degrees Celsius environmental chamber after which the DO concentration was measured. A second group of biological systems was assembled and was identically prepared as the first but was exposed to darkness instead. The DO concentration was measured at the termination of three hours.

Determination of possible atmospheric oxygen uptake by *Gambusia* in the laboratory

In order to determine whether Gambusia draws a significant amount of its oxygen from the surface, we decided to simulate a simple, closed system in which the fish were restricted from reaching the surface. We inhibited oxygen intake from the surface by placing a piece of wire screen netting in a beaker of water. We also set up two other beakers. One simply contained water and a fish, and a control consisted of water and a piece of netting. We measured the dissolved oxygen concentration of each system before adding the fish and three hours after the fish were added to the beakers. Two trials were conducted. In one, the systems were kept in lighting, and in the other, the beakers were kept in the dark. We varied the amount of lighting to determine whether the time of day dictates the intake of oxygen by the fish. Dissolved oxygen concentrations were measured using Vacu-vials ®. See figure 4.

After a sample of water is taken from the system and placed in the vial, the ampoule (self-filling reagent) is snapped, mixed, developed, and finally read. Readings are taken by a mini-spectrophotometer which is designed to display oxygen measurements in parts per million. Oxygen changes the color of the liquid inside of the Vacu-vials from yellow to blue. Therefore, if the water contains more dissolved oxygen, it turns a deeper blue color. The spectrophotometer passes light through the sample. Light is absorbed by the liquid, but also transmitted through to the other side. This transmitted light determines the dissolved oxygen concentration reading. The amount of light transmitted through the ampoule is inversely proportional to the dissolved oxygen concentration.

a b c

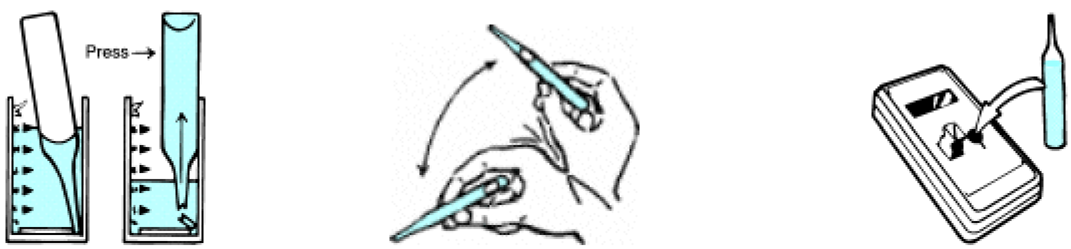

Figure 4 The Vacu-vials® Test Procedure [13] **:** a. Snap; b. mix; c. take reading with spectrophotometer.

Simulation of the laboratory system using Stella Systems Thinking

Our model began with dissolved oxygen as the first stock. The flow that came into this stock was photosynthesis because photosynthesis increases the dissolved oxygen. The flow that came out of this stock was cellular respiration because respiration decreases the amount of available oxygen. The sunlight was added as a converter because sunlight allows photosynthesis to take place. Consumption of oxygen by both the Gambusia and the Elodea were converters, and oxygen production by the Elodea was also a converter. Elodea was added as a stock and connected to the photosynthesis and respiration converters, and the Gambusia was added as a stock and connected to the respiration converter.

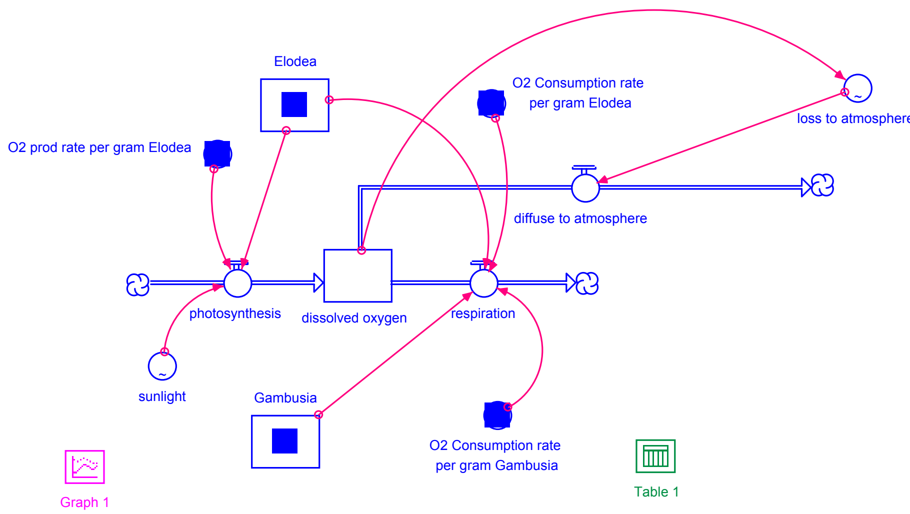

Figure 5 Stella model used to diagram a simple aquatic sytem

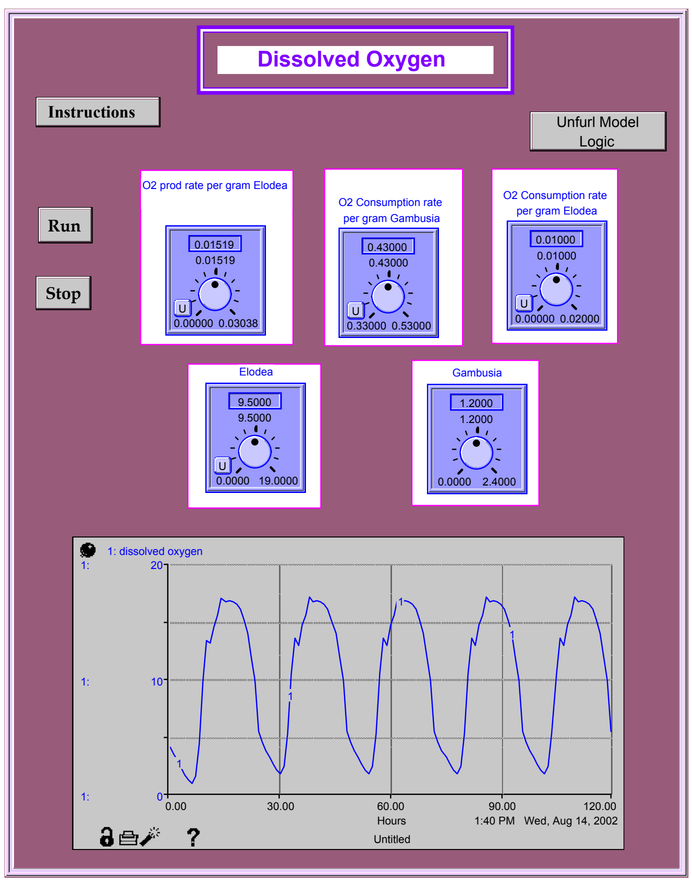

Figure 6 Stella user interface for predicting productivity in our closed system

RESULTS

Closed light/dark biological systems and DO relationships

The dissolved oxygen concentration in the chambers with *Gambusia* and *Elodea* changed more when exposed to light than when not exposed to light. The dissolved oxygen concentration of the chamber with solely *Elodea* decreased when exposed to darkness and increased when exposed to light.

Table 1 Closed light/dark biological systems and DO relationships

	O2/g (mg/L)	Mass (g) Fish	Mass (g) Elodea	Initial DO (ppm)	Final DO (ppm)	DO*(f)* - DO*(i)*	Time (h)	date
Fish only	- 0.33	0.45		8.90	6.70	-2.20	3.0	8/1/02
Fish only	-0.53	0.60		8.90	4.10	-4.80	3.0	8/1/02
Elodea only	0.01		4.58	8.90	9.90	1.00	3.0	8/1/02
Elodea only	0.02		4.90	8.90	10.70	1.80	3.0	8/1/02
Fish + Elodea		0.38	3.40	8.90	8.90	0.00	3.0	8/1/02
Fish + Elodea		0.78	3.46	8.90	7.00	-1.90	3.0	8/1/02
Dark Fish	-0.06	0.96		9.00	7.80	-1.20	4.5	8/5/02
Dark Elodea	-0.01		3.58	9.00	8.10	-0.90	4.5	8/5/02
Water (control)				9.00	8.80	-0.20	4.5	8/5/02

An estimation of DO consumption/production per gram of *Gambusia* or *Elodea* was calculated using Dorfman's protocol:

Dissolved Oxygen per Gram= $\frac{\Delta DO(v)}{Tm}$

ΔDO: difference in dissolved oxygen levels ($DO_f - DO_i$)
v: volume of water in liters (.20 L)
t: time in hours of test run
m: mass of *Gambusia* or *Elodea*

Table 2 Summary of dissolved oxygen consumption/production

Test subject	Environmental condition	O2/g in mg/L
Gambusia	Light	-0.33
Gambusia	Light	-0.53
Gambusia	Absence of Light	-0.06
Elodea	Light	0.01
Elodea	Light	0.02
Elodea	Absence of Light	-0.01

Determination of possible atmospheric oxygen uptake by Gambusia in the laboratory

From the chart, it is apparent that the net decreased the oxygen intake of the fish. Without the net, the fish consumed more oxygen. The larger fish was kept in both trials in the beaker with the net. The data also suggests that fish consume more oxygen, or respire more, in the presence of light. In the control beaker, the dissolved oxygen concentration increased by the same amount in both trials. In essence, the larger fish consumed more oxygen than the smaller fish, but consumption per gram biomass was less.

Table 3 Determination of possible atmospheric oxygen uptake by Gambusia

	O_2/gram (mg/L)	Mass of fish (g)	Initial DO (ppm)	Final DO (ppm)	DO*(f)* -DO*(i)*	Run time
Fish with net (light)	**0.26**	0.70	9.10	5.90	-3.20	3:30
Fish without net (light)	**0.38**	0.33	9.10	6.90	-2.20	3:30
Water with net (light)		0.00	9.10	9.60	0.50	3:30
Fish with net (dark)	**0.09**	0.70	8.40	7.30	-1.10	3:30
Fish without net (dark)	**0.14**	0.33	8.40	7.60	-0.80	3:30
Water with net (dark)		0.00	8.40	8.90	0.50	3:30

The Pond

After reviewing the data collected from the pond ecosystem, mainly dissolved oxygen levels, a relatively consistent trend was revealed. The results of the test conducted showed that dissolved oxygen levels peaked at midday. Following this, levels began to decline exponentially, reaching lowest amounts during early morning hours (4:30). The general graph of the results are bound between these two points, with a continuous sinusoidal fluctuation.

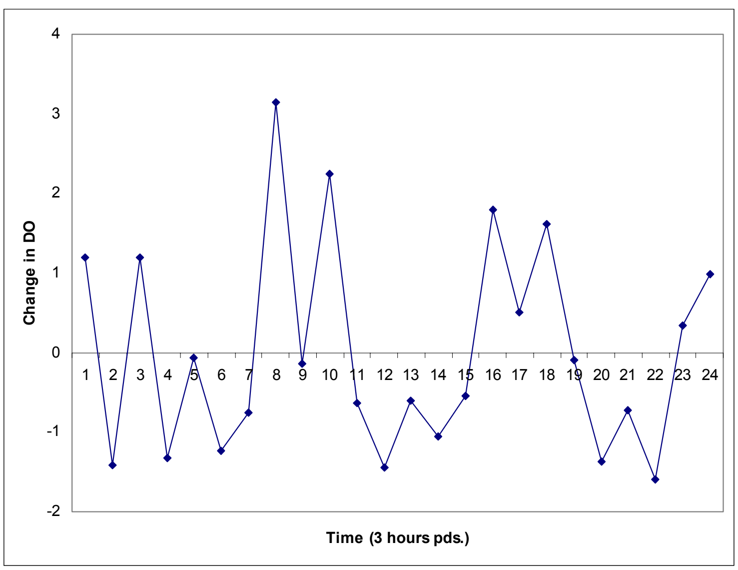

Figure 7 1995 Change in Dissolved Oxygen Levels over Three Hour Intervals, Long Pond, Zuck Arboretum, Drew University

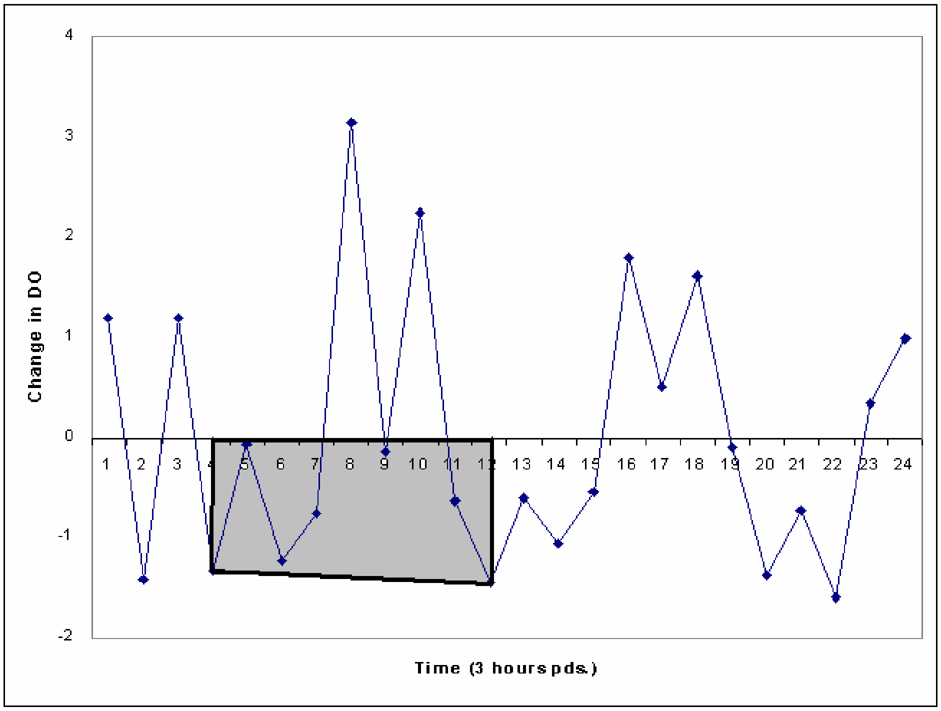

Figure 8 1995 Change in Dissolved Oxygen Levels over Three Hour Intervals with Community Respiration Over 24 Hours Marked, Long Pond, Zuck Arboretum, Drew University

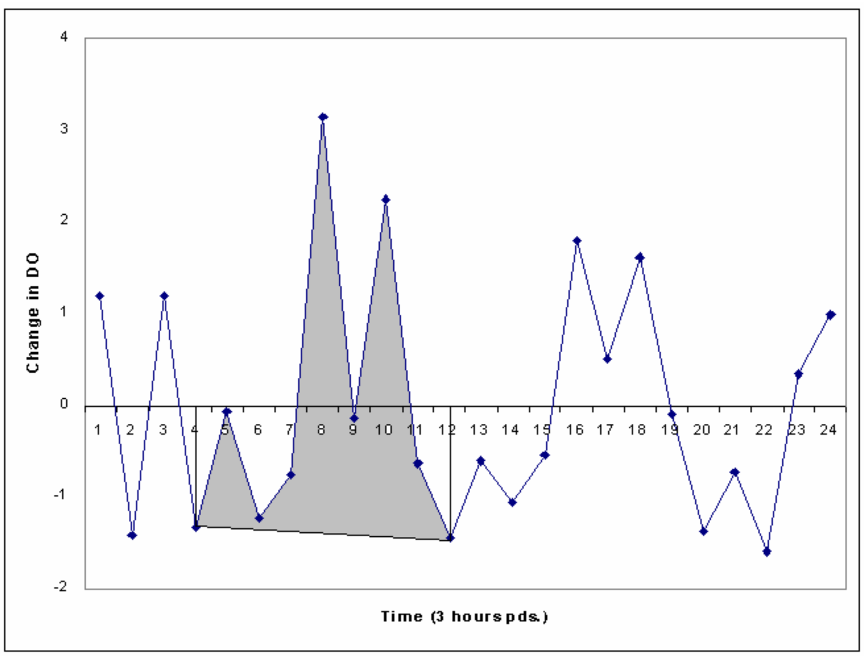

Figure 9 1995 Change in Dissolved Oxygen Levels over Three Hour Intervals with Photosynthetic Production Over 24 Hours Marked, Long Pond, Zuck Arboretum, Drew University

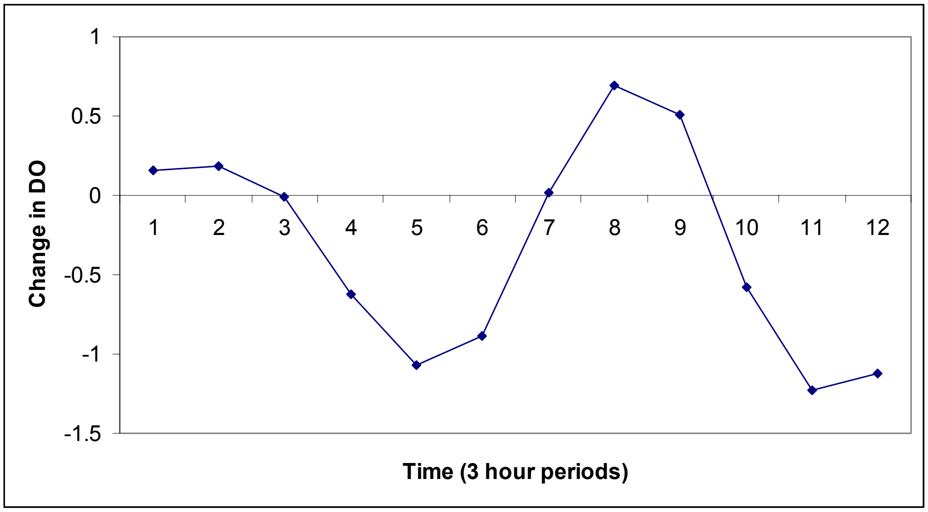

Figure 10 2002 Change in Dissolved Oxygen Levels over Three Hour Intervals, Long Pond, Zuck Arboretum, Drew University

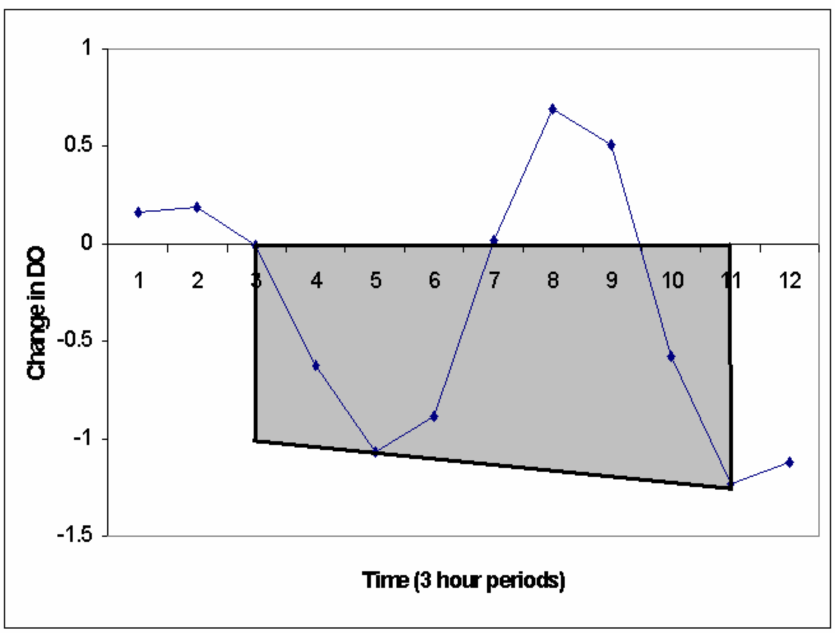

Figure 11 2002 Change in Dissolved Oxygen Levels over Three Hour Intervals with Community Respiration Over 24 Hours Marked, Long Pond, Zuck Arboretum, Drew University

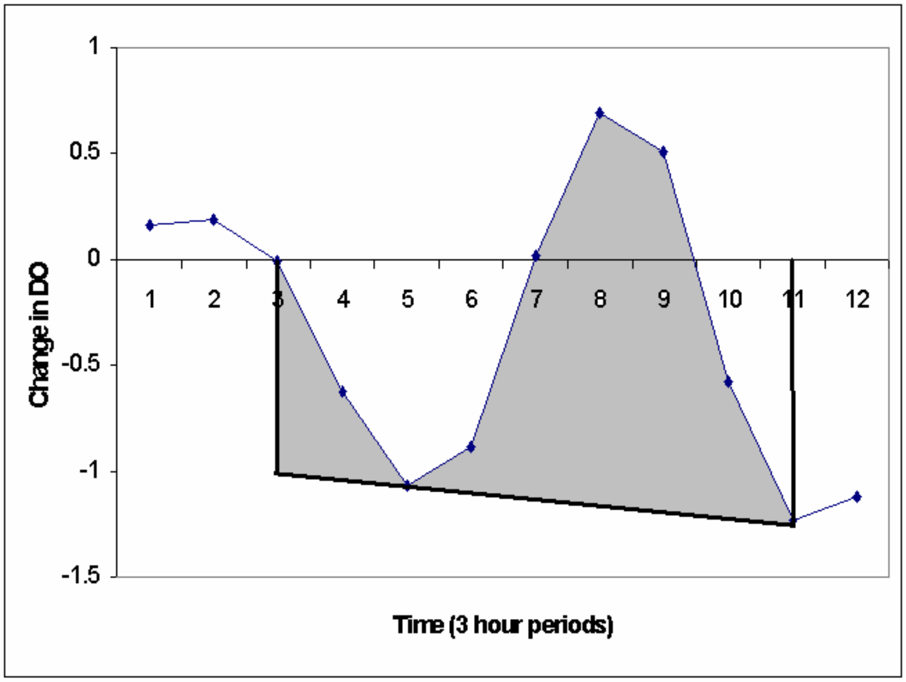

Figure 12 2002 Change in Dissolved Oxygen Levels over Three Hour Intervals with Photosynthetic Production Over 24 Hours Marked, Long Pond, Zuck Arboretum, Drew University

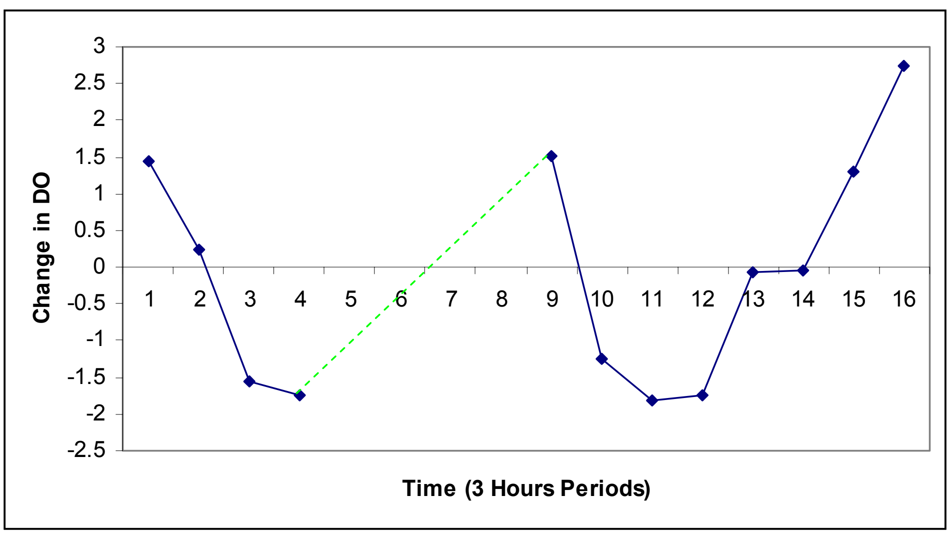

Figure 13 2002 Lab Data – Change in Dissolved Oxygen Levels over Three Hour Intervals with 23 grams of Elodea and 2.3 grams of Gambusia (Graph was incomplete due to computer failure; predicted values added) Scale: 1 equals 1:30 P.M. August 6, 2002, 2 equals 4:30

Graphical analyses of controlled laboratory experiments using techniques applied to pond

The difference in dissolved oxygen concentration of the closed system containing 23 grams of *Elodea* and 2.3 grams of *Gambusia* was graphed. Difference in dissolved oxygen level was plotted, the distance between points represents a three hour period. The same method of analysis was used on the closed system data that was used to analyze the pond data. It was found that the relative area of the rectangle figure is 14.4 and the area under the peaks is 10.4, suggesting that this ratio of *Elodea* to *Gambusia* would not be able to sustain the system.

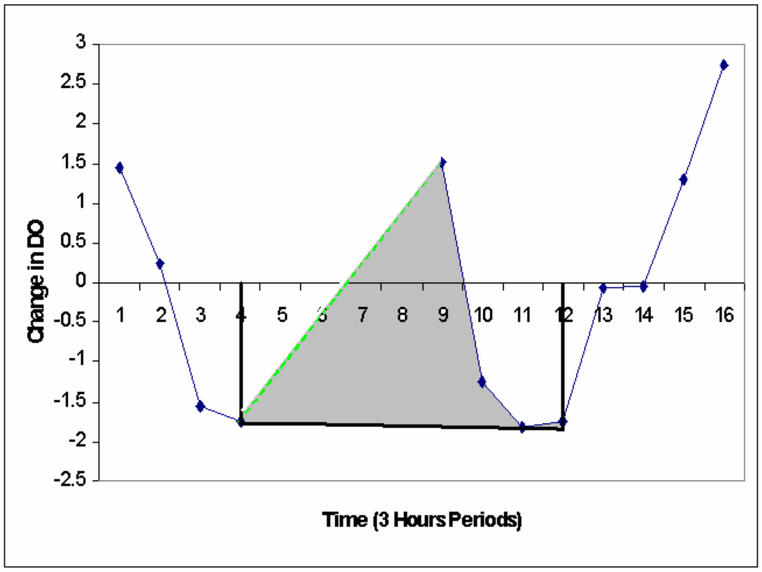

Figure 14 2002 Lab Data – Change in Dissolved Oxygen Levels over Three Hour Intervals with Community Respiration Over 24 Hours Marked with 23 grams of Elodea and 2.3 grams of Gambusia (Graph was incomplete due to computer failure; predicted values added) Scale: 1

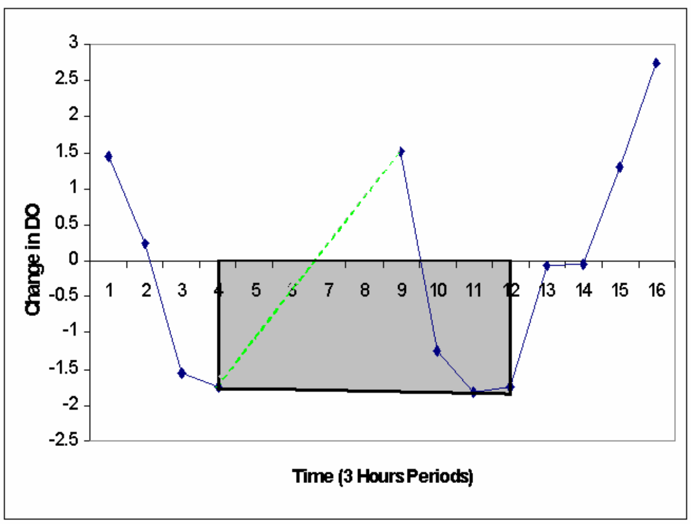

Figure 15 2002 Lab Data – Change in Dissolved Oxygen Levels over Three Hour Intervals with Photosynthetic Production Over 24 Hours Marked with 23 grams of Elodea and 2.3 grams of Gambusia (Graph was incomplete due to computer failure; predicted values added) Scale: 1 equals 1:30 P.M. August 6, 2002, 2 equals 4:30 P.M. August 6, 2002, and continuing in three hour intervals

DISCUSSION

The pond ecosystem

The main objective of the data collection at the pond was to gain an understanding of the pond's natural ecosystem. To do so required measurements of various aspects of the pond's natural state, including dissolved oxygen concentration, temperature, intensity of light, and pH, using the methods previously mentioned in the paper. Of all of these readings, the dissolved oxygen reading was the one of primary importance; dissolved oxygen was the primary factor we concerned ourselves with in designing our ideal *Gambusia* system. The other readings, such as pH, were helpful in giving our group a better general sense of the pond environment. Unfortunately, due to a number of probe failures and extremely shallow and drought induced water levels, we were unable to obtain a good "picture" of what was happening this month with respect to productivity in Long Pond, and we did not have time to take these readings again.

Using the dissolved oxygen readings, we hoped to evaluate whether or not the pond's ecosystem was "productive," "break even," or "unproductive." "Productive" means that more oxygen is produced in the pond than the consumer organisms need; "break even" means that the oxygen in the pond is sufficient for the fish, and "unproductive" means that the oxygen in the pond is insufficient for the consumer populations. Essentially, this test helped us to understand how a natural ecosystem uses its oxygen resources, which greatly helped us in constructing a model environment for the *Gambusia* in the laboratory.

The three graphs we created use plots of differences in dissolved oxygen readings taken over three hour time intervals. Using this data, we can assess whether an ecosystem is in one of the three aforementioned states with respect to its state of oxygen exchange.

How can we determine the state of oxygen exchange? We can analyze the graphs of the data as follows: (14)

1) Draw a line between the two lowest points on the graph in a 24-hour period (negative baseline).
2) Erect a perpendicular from these two points and draw this line until it crosses the *x-axis*. This yields a rectangular polygon, whose area is representative of the amount of oxygen consumed by its inhabitants. This is such because *x-axis* of plot of change in DO represents no oxygen respired, and the two lowest points represent the maximum oxygen respired.
3) To find the amount of oxygen produced, one must find the area under the graph (starting from the negative baseline) of the change in DO.

Two of the three graphs presented are use data from Long Pond, one from 1995 and the other from 2002. We were able to analyze each of these graphs for productivity using the methods described above. In the 1995 graph, the area under the curve is much larger than the area in the rectangle, suggesting a productive environment. However, the graph based off the 2002 data shows the area under the rectangle to be much bigger than the area under the curve, which implies a non-productive environment. This makes sense considering the current condition of the pond, which is extremely low as a result of the hot and dry conditions. This method of graphical analysis also proved to be very useful in analyzing data from laboratory setups, which is described later.

In conclusion, the information we gathered from the pond was very helpful in giving a concept of how oxygen exchange works in a pond ecosystem. We learned from our mistakes in setting up the experiments, especially with respect to using the rowboat. Engineering the raft proved to be a valuable experience, as it enabled us to conduct tests much more easily. Simply, the pond tests we a success in helping the project understand how nature truly functions.

Closed light/dark biological systems and DO relationships

Since the rectangular figure has a larger area, it can be concluded that the closed ecosystem is functioning at a deficit. The amount of oxygen consumed is larger than the amount of oxygen produced. Oxygen consumption to fuel respiration of *Gambusia* and *Elodea* exceeded the oxygen production of the *Elodea*. A more desirable situation would be for the two areas to be equal; an ecosystem whose production and consumption levels are equal.

The analyses of our results regarding dissolved oxygen determination of closed light/dark biological systems revealed notable conclusions. Photosynthesis and respiration are the processes that are attributed to oxygen fluctuations in biological systems. The primary objective of our experiments was to study the relationship between the masses of *Gambusia* and *Elodea* as they relate to the organisms' oxygen uptake and release in a closed biological system.

Mathematical analyses were performed in order to determine the amount of oxygen consumption/production per gram of *Gambusia* or *Elodea.* The consumption of oxygen by *Gambusia* in darkness was significantly lower than when exposed to light, indicating these fish are diurnal. Based on our estimates, a proposed equilibrium was suggested. We observed that 0.38g *Gambusia* in conjunction with 3.4g *Elodea* seems to be necessary to maintain the initial dissolved oxygen concentration in a closed biological system exposed to light. The oxygen consumption of *Gambusia* in our trials was calculated as 0.33 mg O_2 / g fish . Our data is supported by the oxygen consumption calculated in a separate study, 0.35 mg O_2 / g fish [15], which was discovered in our descriptive research.

Our calculated values were entered into the Stella modeling software. The software was used to model a closed system in order to predict dissolved oxygen concentrations under various mass relationships between *Elodea* and *Gambusia.* These models were constructed using our results and helped us better understand how the two organisms affect each other.

Determination of possible atmospheric oxygen uptake by Gambusia

From Table 3, we see that more oxygen is consumed per gram of *Gambusia* when the fish are free to access the surface for oxygen. With the net as an inhibitor, the fish pulled less oxygen from the water. Thus, the fish are less active with the net over them, suggesting that the fish may feel comfort with a "shelter", or cover, above them, such as a net. This assumption leads us to believe that *Elodea* may act as a type of "shelter" as does the net. Without the net, the fish consumed more oxygen from the water. Therefore, the data tends to suggest that *Gambusia* do not consume oxygen from the surface. Contrastingly, they pull more oxygen from the water when they are not restricted from the surface. We also notice that more oxygen is consumed when the systems were kept in light rather than in darkness. From this observation, we are led to believe that the fish are more active in the day. Because the dissolved oxygen concentrations of the control systems did not change significantly, we can assume that the net did not have a substantial impact on our readings.

CONCLUSION

The purposes of our experiments were to obtain a data set of environmental conditions affecting Long Pond, estimate oxygen uptake of *Gambusia* and *Elodea* and use Stella software to construct a model of a simplified closed ecosystem. Current data from the pond was not obtained due to difficulties with the probing equipment and this summer's drought-like conditions. Oxygen uptake of *Gambusia* and *Elodea* was estimated based on the two trials we conducted. Results may have been better supported if more trials could have been conducted. However, the Stella model was constructed successfully based on data obtained from the dissolved oxygen experiments.

Our product, the simplified model pertaining to dissolved oxygen provides a solid foundation for the study of many other abiotic and biotic components that influence the productivity and sustainability of ecological systems. If this project were to be furthered, more factors should be taken into consideration, like temperature, pH, soil and biotic activity. The effect of these factors on the dissolved oxygen levels would make a more lifelike model. Activity of *Gambusia* when placed in an environment with a covering, like the net experiment, also is a topic for future research. The effect of placing a covering on the ecosystem could be incorporated to the Stella model. *Gambusia* and *Elodea* are the two species which we chose to study because *Elodea* produces a lot of oxygen and *Gambusia* can survive in a variety of conditions. However, the relationship of oxygen consumption and production of other species of plants or fish would also be a useful tool in truly understanding the relationship of the ecosystem. Applying the scenario from the Stella model to an aquarium would be a confirmation of the validity of the results. It would show that virtual systems thinking can pertain to real life applications.

As Lorenz [16] stated, "The aquarium is a world; for, as in a natural pond or lake, indeed as all over our whole planet, animal and vegetable beings live together in biological equilibrium."

WORKS CITED

[1] Western Mosquitofish. Hawaii Biological Surveys. 9 Aug 2002. <http://hbs.bishopmuseum.org/good-bad/gambusia-full.html>

[2] Mosquito Fish. Fattigfish. 8 Aug 2002. <http://www.fattigfish.com/mosfish.htm>

[3] Livebearers - Poeciliidae. 1994. Mongabay. 9 Aug 2002. <http://www.mongabay.com/fish/poeciliidae.htm>

[4] Nonindigenous Fishes- *Gambusia affinis*. Sept 2001. USGS. 10 Aug 2002. <http://nas.er.usgs.gov/fishes/accounts/poecilii/ga_affin.html>

[5] Mosquito Fish - Gambusia affinis. 8 Aug 2002. <http://www.scbass.org/sc_fish/mosquito_fish.html>

[6] Biologybase: Keeping Gambusia affinis, the Western Mosquitofish. Mar. 1995. Biology Base. 10 Aug 2002 <http://www.interaktv.com/fishanat/Gambusiaaffinis.html>

[7] *Elodea densa*. 9 Aug 2002. <http://www.dnr.state.md.us/bay/sav/key/e_densa_final.html>

[8] Anacharis (*Elodea densa*). 9 Aug 2002. Aquatic Plant Depot. http://www.aquaticplantdepot.com/anelden.html

[9] Non-Native Freshwater Plants: Brazilian Elodea. 9 Aug 2002. http://www.ecy.wa.gov/programs/wq/plants/weeds/aqua002.html>

[10] Anacharis, *Elodea densa*. 9 Aug 2002. Animal World. <http://www.exotictropicals.com/encyclo/fresh/plants/anacharis.htm>

[11] Hargreaves, John A. and Tucker, Craig S. Measuring Dissolved Oxygen Concentration in Aquaculture. Jan 2002. Southern Regional Aquaculture Center. 7 Aug 2002. <http://texaserc.tamu.edu/pubs/efish/4601fs.pdf>

[12]Richmond, Barry. (2001). An Introduction to Systems Thinking: Stella. Hanover,NH: High Performance Systems, Inc.

[13] Vacu-vials in Other Instruments. 14 Aug 2002. CHEMetrics, Inc. Analysis Systems. <http://www.chemetrics.com/otherinst.html>

[14] Pollock, L. W. "Bio 186 Freshwater Ecology." Drew University. B15.

[15] Weinkle, W. An Examination and Comparison of Oxygen Consumption Rates in Three South Florida Fishes During Exercise and Resting Trials. 6 Aug 2002. http://www.shadow.net/~wweinkle/Instar2001.htm

[16] Lorenz, Konrad. (1997). King Solomon's Ring. Plume: 30