Bivalve Population in Newport Back Bay

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Abstract

Bivalve population has been decreasing over the last 50 years in the Newport Back Bay. There are very few wetlands left in California and their unique environment is home to many endangered species, including different bivalve species. State agencies and environmental groups have shown a keen interest in the restoration of the ecology in the back bay. The project focused on determining the limiting factors of bivalve growth and searching the possible correlations between bivalve population and other factors such as salinity, pollution and amount of nutrients (i.e. nitrogen). Phytoplankton is a critical component of bivalve ecology because they are the bivalves' primary food source. We also considered the effects of phytoplankton concentration on bivalve population. Also we formulated models used predict future effects on bivalve population due to salinity and competition with other bivalve species.

Introduction

Newport Back Bay is an important habitat for wildlife in Southern California. Anecdotal evidence shows that bivalve populations are declining [1]. This implies that the ecosystem productivity is below the normal level. Recently, a variety of local state agencies and environmental groups have become interested in the restoration of the ecosystem [1]. Studies have been done on the health of the ecosystem in back bay. In 2003, a shellfish resource survey was done by Kinnetic Laboratories, Inc. [2]. It was determined that the three most abundant species of bivalves throughout the bay were *Protothaca stamina* (Pacific Little Neck Clam), *Chione undatella* (Frilled Venus Clam), and *Tagelus* *affinis* (Jackknife Clam) [2].

In order to understand bivalve population, we needed to understand growth rate. Hence, we began by studying the *Logistic Growth Model.*The growth rate of any species of bivalves can be expressed by the *Logistic Growth Model.*

$$\dot{N} = Nr\left(1 - \frac{N}{k}\right)$$

Where N represents the bivalve population size, r is the growth rate of the bivalve population, and k is the carrying capacity for the bivalve population. **Figure 1-1** shows the behavior of this model.

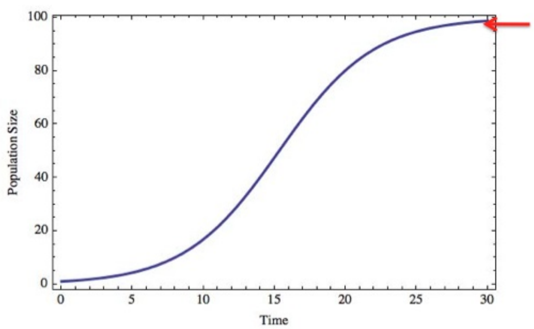

Figure 1-1

In **Fig.1-1**, the red arrow points to the carrying capacity for the population. All species survive depending on how long the ecosystem can "support" the population. If the resources run out, then it is intuitive that the population would decline. If there is a small population and abundant resources, it can be said that the population will thrive. The *Logistic Growth Model* describes this behavior. It also shows how a population reaches an equilibrium point at the carrying capacity value, k and stabilizes as it reaches it.

Some assumptions of the model are that the carrying capacity remains constant, there is unlimited space, and there are no other effects on population size such as death rate, competition and predation from other species.

These assumptions make the model unrealistic for bivalve population interpretation. In the back bay ecosystem, different types of bivalves compete for resources. There are other factors besides competition on bivalve population size, such as the conditions of the water. Water salinity, temperature, pH levels, and percent dissolved oxygen quantities believe to play a significant role in bivalve population size.

In this paper, we will discuss the competition between two species of bivalves for phytoplankton and the effect of water quality on bivalve population. Also, we focused on building a realistic model involving different components that affect their survival, for bivalve population in the back bay.

Materials and Methods

In order to get an estimation of the overall health of the bay, we took water and soil samples at the back bay. To collect data, a group of $6-8$ people went to Newport Back Bay and collected data throughout the entire bay over a span of eight weeks (via canoes and a motor boat). **Figure 1-2** shows a satellite image of the Newport Back Bay and Newport Harbor. Data was collected from both the Upper Newport Bay and around Newport

Harbor. We went to different sties and collected small amounts of water, about $20-40$ milliliters, using 50 mL vials and containers.

Figure 1-2

We also used the *Eureka Sub 3 Water-Quality Multi-probe*. This probe collected data for temperature, dissolved oxygen, conductivity, pH levels, time of record, and depth. The probe was taken to specific areas of the bay and lowered, 1 foot at a time, to the bottom of the bay. The probe collected data in $20-60$ second intervals for that specific spot. The probe was connected to a hand-held PDA device, where it accumulated all the data mentioned earlier. The probe was also left underwater to record data for $24-72$ hour periods at a set depth. It was then synced to a desktop on the UCI campus and data was exported on spreadsheets for analysis.

Figure 1-3

Figure 1-3 is an image of the *Eureka Sub 3 Water-Quality Multi-probe* used for data collection.

Population size was obtained from an older study done by Kinetic Laboratories, Inc [2]. The amount of bivalves found throughout the bay were recorded by Kinetic Laboratories and we were allowed access. We used the data from the probe, soil and water samples, and the survey from Kinetic Laboratories to find any correlation between salinity, dissolved oxygen, pH levels, and bivalve population. **Figure 1-4** shows an example of the data provided by Kinnetic Laboratories. This map shows the quantitative survey Kinnetic Laboratories developed throughout the bay.

In order to model the bivalve population growth, we used the *Lotka-Volterra Equations*. We derived our own model for bivalve population with a combination of a *predator-prey model* and a *competition model*. We also used *MatLab and Simulink* to simulate the behavior of bivalve population.

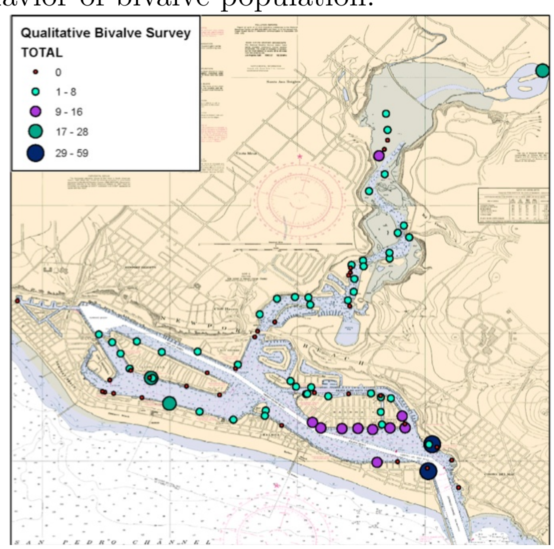

Figure 1-4

Correlations

In order to find correlations between water quality and bivalve population we began by studying the population data provided.

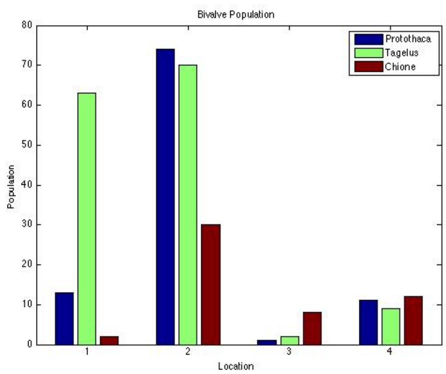

Figure 1-5

Figure 1-5 shows the bivalve population according location.

The x-axis of **Figure 1-5** represents the location as follows:

1. North Upper Bay

2. Balboa Island

3. Lido Island

4. South Upper Bay

We can see in **Figure 1-5**, that bivalve population is lowest in Section 4 - Lower Bay. **Figure 1-6** shows the different sections of the bay.

Lido Island makes up a part of the Lower Bay section. We studied this part of the bay in more detail and compared it to the other parts of the bay like Balboa Island, since Balboa Island has a larger amount of population compared to Lido Island. **Figure 1-6** shows the location of Lido Island and Balboa Island.

We first took a look at the temperature changes in Lido Island. The temperature in Lido Island is slightly higher than in Balboa Island. This could be due to the location of Lido Island. The fact that Lido island is in a stagnant location could be causing the temperature to increase. Further studies are required to determine how much impact temperature in Lido Island affects bivalve population. **Figure 1-7** shows the temperature changes in Lido Island. The temperature starts in the upper right-hand corner of Lido Island and travels counter-clockwise around the island. The blue line represents the temperature, the dashed blue line represents the average temperature of Lido Island, and the red dashed line represents the average temperature of Balboa Island. We can see that the temperature in Lido Island is slightly higher than in Balboa Island. This could be a factor of bivalve population.

We can say that temperature may be an important factor in bivalve population. Further studies of Lido Island are required before stating that temperature is, for sure, a limiting factor. It is also important to study other water quality factors like pH levels and dissolved oxygen.

Figure 1-6

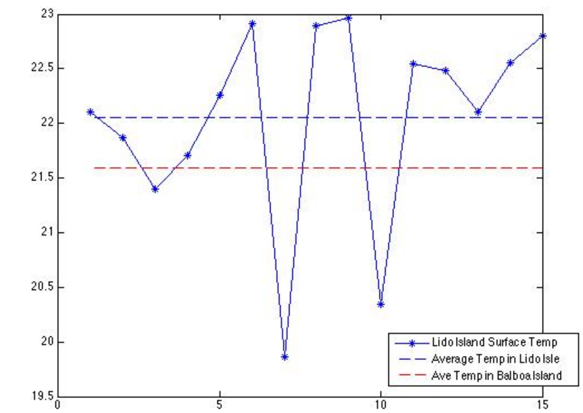

Figure 1-7

Mathematical Modeling

Lotka-Voltera Predator-Prey Model

Specifically to our system, we examined the *Lotka-Volterra equations*, which are also known as the *predator-prey equations* by applying it to the relationship between the phytoplankton and the different species of bivalves in the bay. The most basic model being:

$$\frac{dN}{dt} = N\left(a - bP\right)$$
$$\frac{dP}{dt} = P\left(cN - d\right)$$

Multiplying out, we get

$$\frac{dN}{dt} = aN - bNP$$
$$\frac{dP}{dt} = cNP - dP$$

N and P denote the populations of the prey (phytoplankton) and the predator (bivalves) respectively at a certain time t. Physically, aN represents the rate of growth of the prey population and bNP represents the rate of consumption of the prey by the predator. cPN represents the growth of the predator which is affected by the prey population. dP represents the death rate of predator. [4] However, the model assumes:

- There are unlimited resources and space for the prey and the predator.
- The prey population grows exponentially in the absence of any predators.
- It assumes that predator's only food supply is the prey.
- The predator dies exponentially in the absence of prey.

Because of the simplicity of the behavior of the equations due to these assumptions, these equations are not a suitable model for the ecological system we are observing. [4] However, it serves as a good basis for our understanding of population growth and decay.

So to better fit our purposes, we use this modified model:

$$\frac{dN}{dt} = N\left[r\left(1 - \frac{N}{K}\right) - \frac{kP}{N+D}\right]$$

$$\frac{dP}{dt} = P\left[s\left(1 - \frac{hP}{N}\right)\right]$$

Which takes into account limited resources with the carrying capacity (K). It also creates a carrying capacity for predators dependent on the prey population ($\frac{N}{p}$). Also, the consumption rate of the predators $\frac{kPN}{N+D}$ is more accurately depicted since it eventually evens out due to the $\frac{N}{N+D}$ term. Taking these equations as a basis, we can expand it to n predators, or three in our case for the three species of bivalves:

$$\frac{dN}{dt} = N_i r_i\left(1 - \frac{N_i}{K_i}\right) - \frac{k_1 PN}{N+D_1} - \frac{k_2 QN}{N+D_2} - \frac{k_3 RN}{N+D_3}$$

$$\frac{dP}{dt} = P\left[s_1\left(1 - \frac{h_1 P}{N}\right)\right]$$

$$\frac{dQ}{dt} = Q\left[s_2\left(1 - \frac{h_2 Q}{N}\right)\right]$$

$$\frac{dR}{dt} = R\left[s_3\left(1 - \frac{h_3 R}{N}\right)\right]$$

Here, we can see that in order to take into account the consumption by each species of bivalves, similar terms of consumption are added to the rate of growth for the phytoplankton. Also, we can see that each species hold different carrying capacities as well as different growth rates. This set of equations best serves as our basis for out model of the ecology of the back bay.

Compartmental Model

In our examination of the bay, we saw that depending on the location, the conditions such as differing amounts of conductivity, which is related to salinity and temperature, as well as temperature, pH, and dissolved oxygen. These conditions have an effect on certain bivalve species. For example, a certain species of bivalves may prefer a saltwater environment, while another prefers freshwater. Therefore, we have decided to divide the bay into compartments depending on what the conditions are. The following set of equations is an altered model that takes into account this compartment.

$$\frac{dN_i}{dt} = N_i r_i \left(1 - \frac{N_i}{K_i}\right) - \frac{k_{1i} P_i N_i}{N_i + D_{1i}} - \frac{k_{2i} Q_i N_i}{N_i + D_{2i}} - \frac{k_{3i} R_i N_i}{N_i + D_{3i}} - \sum_j f_{ij} N_i + \sum_j f_{ji} N_i$$

$$\frac{dP_i}{dt} = P_i \left[s_{1i} \left(1 - \frac{h_{1i} P_i}{N_i}\right)\right] - \sum_j a_{ij} P_i + \sum_j a_{ji} P_i$$

$$\frac{dQ_i}{dt} = Q_i \left[s_{2i} \left(1 - \frac{h_{2i} Q_i}{N_i}\right)\right] - \sum_j b_{ij} Q_i + \sum_j b_{ji} Q_i$$

$$\frac{dR_i}{dt} = R_i \left[s_{3i} \left(1 - \frac{h_{3i} R_i}{N_i}\right)\right] - \sum_j c_{ij} R_i + \sum_j c_{ji} R_i$$

Here, i=1,..,n compartments and similarly for j as well. The last two terms of each equation ($\sum_j f_{ij} N_i + \sum_j f_{ji} N_i$ in the phytoplankton case) represent the transfer of species between two adjacent compartments. The a_{ij} for example in the phytoplankton equation, takes a value from a n by n matrix A which represents contains values describing the rate of exchange between two adjacent compartments where n denotes the total number of compartments in the ecological system. Generally, we would want to define $a_{ij} > a_{ji}$, since it would be more difficult for the bivalves and phytoplankton to travel against the flow of water. This occurs similarly for the other terms in the $\frac{dP}{dt}$, $\frac{dQ}{dt}$, and $\frac{dR}{dt}$. This transfer occurs due to the flow of water from the San Diego Creek, to the Newport Harbor and eventually the ocean, as well as because of the general movement of the species itself to possibly move to a more suitable environment.

Effect of Salinity on Growth Rates

As discussed before, certain types of bivalves most likely prefer a certain amount of salinity compared to others. This may cause differing growth rates of the same species depending on their specific location in the bay. To exhibit this, we created equations for the

s_{ik}:

$$Freshwater : s_{ki} = \overline{s_k}\left(\frac{M_k^2}{M_k^2 + salt(i)^2}\right)$$

$$Saltwater : s_{ki} = \overline{s_k}\left(\frac{salt(i)^2}{M_k^2 + salt(i)^2}\right)$$

Here, k denotes the *kth* predator. M_k is a positive constant along with $\overline{s_k}$ both of which affect the growth rate of the predator. The most essential part to this is the *salt(i)* function which is $salt(i) = \frac{i-1}{n-1}$. Here, i denotes the current compartment where n is the total number of compartments. By assuming that the first compartment is the near the San Diego Creek and that each subsequent compartment gradually makes its way down to the ocean, we can assume a gradient of increasing salinity throughout the bay. The following figure (Figure 2-1) depicts the changes of growth rate with respect to compartment:

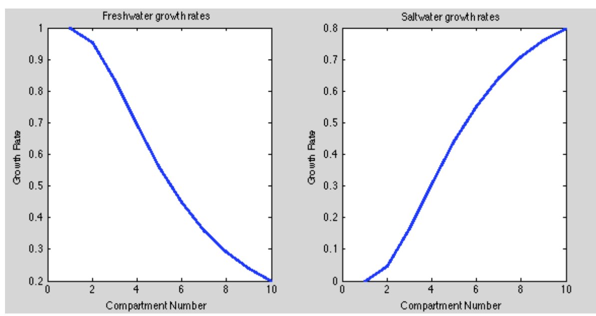

Figure 2-1

The first graph depicts the growth rates of the freshwater bivalves and the second graph depicts the growth rates of the saltwater bivalves. This implementation would ideally alter the growth rates of each predator for each compartment, causing species to congregate at one compartment ideal for its survivability. With more data on bivalve populations and the water quality, we would be able to construct a much more accurate model for these growth rates so that they take into consideration pH, temperature, pollutants, and so on. After modeling these equations in Matlab, we are able to create visual representations of these systems by use of an ordinary differential equation solver by plotting the solution with respect to time. The following graph (Figure 2-2) depicts an example system with random parameters. Note that not all systems may have oscillations, however it is shown here to exhibit one possibility of a predator-prey system.

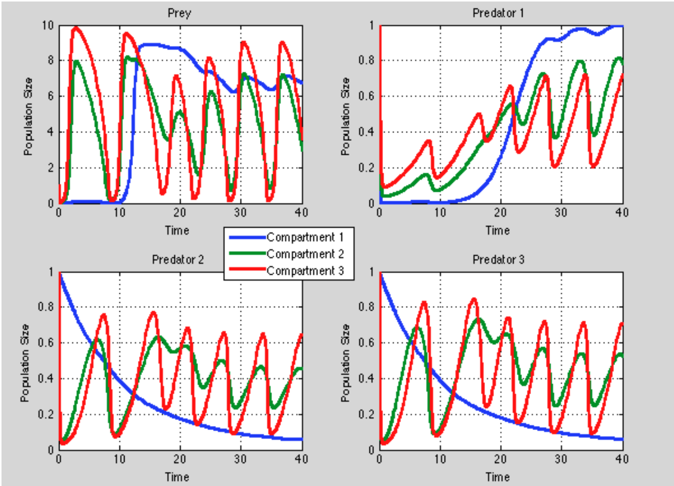

Figure 2-2

Here, we can see that in the upper right graph that the bivalves prefers freshwater because the population is growing most quickly in the first compartment. The two bottom graphs show bivalves that prefer water with higher salinities, as the population in the first compartment is declining. With further data on the phytoplankton and bivalve populations, we could estimate the parameters to create an accurate representation of the bivalve population and its interaction with each other and the phytoplankton population.

Model in progress

After taking into account the altered growth rates in the compartmental model, we noticed that our model still exhibited growth in all compartments even if conditions were not ideal for that particular species of bivalves. So, we created a new model that included a new term:

$$\frac{dN_i}{dt} = N_i r_i \left(1 - \frac{N_i}{K_i}\right) - \frac{k_{1i} P_i N_i}{N_i + D_{1i}} - \frac{k_{2i} Q_i N_i}{N_i + D_{2i}} - \frac{k_{3i} R_i N_i}{N_i + D_{3i}} - \sum_j f_{ij} N_i + \sum_j f_{j_i} N_i$$

$$\frac{dP}{dt} = P_i \left[s_{1i} \left(1 - \frac{h_{1i} P_i}{N_i}\right)\right] - \sum_j a_{ij} P_i + \sum_j a_{j_i} P_i - g_{1i} P_i$$

$$\frac{dQ}{dt} = Q_i \left[s_{2i} \left(1 - \frac{h_{2i} Q_i}{N_i}\right)\right] - \sum_j b_{ij} Q_i + \sum_j b_{j_i} Q_i - g_{2i} Q_i$$

$$\frac{dR}{dt} = R_i \left[s_{3i} \left(1 - \frac{h_{3i} R_i}{N_i}\right)\right] - \sum_j c_{ij} R_i + \sum_j c_{j_i} R_i - g_{3i} R_i$$

Effectively, the new $g_{1_i}P_i$ term for the first predator, for example, should be able to keep the growth rates relatively stable after a certain point. This however, is not concrete and may require more revision in the future. One possible solution to this problem may be to change the carrying capacity of the predator depending on the compartment. This, with more time, should be implemented and tested. The following set of graphs (Figure 2-3) are a simplified example of the new model in Matlab:

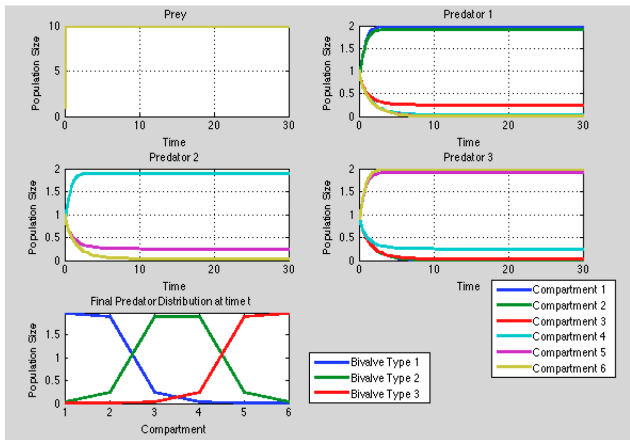

Figure 2-3

The first four graphs show the population graphs for the prey, and 3 species of predators, or bivalves over time. The last graph depicts the final predator distribution. It depicts the populations of each bivalve species after a certain point in time, when the populations reach equilibrium. As you can see, the blue line depicts a freshwater bivalve, the green line shows a species of bivalve which prefers water with moderate salinity, and the red line shows a saltwater bivalve. Again, this was made with random parameters and with better sampling data, a more accurate model can be constructed to fully model the ecological system.

Eventually when we have more time and more data of bivalve samples, we can create more accurate models of this ecosystem and analyze this data to find which conditions are most suitable for certain bivalve species. This in turn can help us create a more suitable environment for these species which are essential to the ecosystem of the Newport Back Bay.

Results

Bivalve Sampling

In order to get a clear indication of this, we believe a quantitative and qualitative analysis of the bivalve population throughout the back bay would allow us to determine the condition of Newport Back Bay. The bivalve species represent as the primary species of the ecosystem due to their unique filtration ability. Bivalves are fresh and marine mollusks ranging from clams, oysters and mussels. Because of their filtering mechanism, they serve as the filters for the back bay and in keeping the community of the bay safe for species to live. Bivalves have these structures called siphons, where they essentially intake water containing any other chemicals through the inhalant siphon then exert the filtered water to the environment through the exhaling siphon [3]. We went out in the morning when the tide was at the lowest of the month and sampled for bivalves throughout the lower back bay from the Back Bay Science Center (BBSC) and around Lido Island. We used shovels to dig up a cubic foot deep of sediment and then sieved the debris to extract bivalves. We then sorted the bivalves out and identified the type of bivalves recovered. In **Figure 2-4** are some bivalves collected by the members of the research team that participated in the bivalve survey along with Dr. Peter Bryant, a retired UC Irvine professor from the Department of Developmental and Cell Biology that has a close relationship with the Back Bay Science Center in observing the behavior of bivalve species in the bay.

Figure 2-4

In order to sample bivalves, we needed Dr. Bryant to be with us since he possessed the Fish and Game license. The bivalve sampling however was insufficient and not as productive as planned. The time constraints we had for this project in a 8-week span also added extra pressure as well. The ideal time for sampling bivalves were during the lowest tides, but they only occur twice a month, which would not be sufficient data to develop a concrete conclusion between bivalves and several factors such as salinity, pH, temperature, oxygen consumption and possibly pollutants. This project would require extra time for a more appropriate quantitative survey of bivalves.

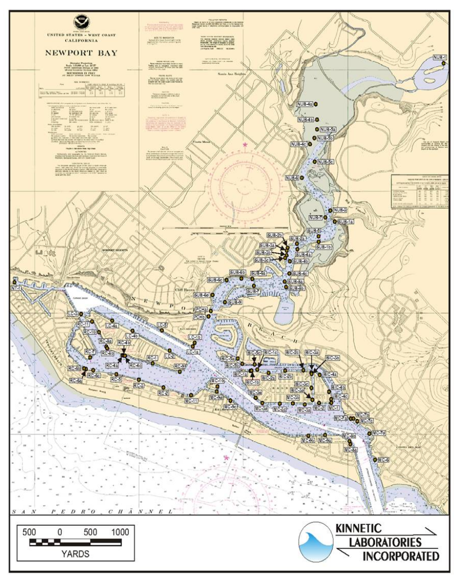

Figure 2-5

These issues led us to reference to a bivalve survey done in 2003 throughout the

Newport Back Bay by the Kinnetics Inventory Inc. The figure in **Figure 2-5** shows a map of the Newport Back Bay and the different stations the team had sampled [2]. We cross referenced with their the population data with the water quality data we collected from the refractometer and multi-probe.

Water Quality

From the Back Bay Science Center (BBSC), we split up into three groups where one group took water samples at intervals until reaching Lido Island, while the other two groups went towards the upper bay with the other group going past the "No Entry Sign." For each water sample we took, we recorded the time and pinpointed the exact locations using a GPS on a smartphone or a Newport Back Bay map. The water samples were quantified using a refractometer, which allowed us to determine the salt concentration (g/100g) and gave us a general idea of how the salinity levels varied throughout Newport Bay. We believed salt concentration would play a more significant role out of the rest of the factors in bivalve population due to their direct relationship with dissolved oxygen consumption rate. Dissolved oxygen rate also plays a significant role in where bivalves are significant in. Surprisingly, the conductivity displayed no variability in the harbor of the bay, but there was a significant difference in the upper bay from the science center to the natural preserve area of the back bay as expected. The upper bay consisted of more freshwater than the harbor due to the their relative distances to the main channel that leads to the ocean, where the influx of salt water is greater.

Multi-Probe Analysis

The probe output lists of data that measure various qualities of the water of the back bay. From this we analyzed it to find any correlations between the bivalve populations observed in the 2003 survey. The multi-probe became the main instrument used to conduct measurements of the bay with the conductivity data being the most interested. Conductivity is the measurement of electricity flow from ion to ion and sodium known in producing much conductance. The proportional relationship between conductivity and salt concentration gives us a numerical idea of the salt concentration throughout regions of the back bay. The probe was the main instrument used to measure the components of the back bay as compared to sampling water because of its reliability and efficiency in collecting measurements in the short period we had. In comparison to the measured salt concentration of the water samples using the refractometer and the probe, the results of both data sets agreed with each other with the overall conductivity greater in the harbor than the upper bay region. The data from the refractometer shows that the conductivity remained constant in the harbor at 3 g/100g, while the conductivity range varied from 1.6-3.0 g/100g in the upper bay region. The data collected from the probe supported this trend showing little conductivity change in the harbor and a slight difference from the BBSC to the preserve area in the uppermost bay. The data collected throughout the bay was taken every few seconds where the probe was dragged by a motor boat.

The other method we used to collect data with the probe was placing it at a specific location and allow it to collect data for 24-72 hours in five minute intervals. The depth remained constant which gave us a clearer idea of what factors fluctuated at the different locations. The probe was placed at the boat service center across Balboa Island, the yacht club across from Lido Island, the crab shack and at the "No Entry Sign" in the upper bay.

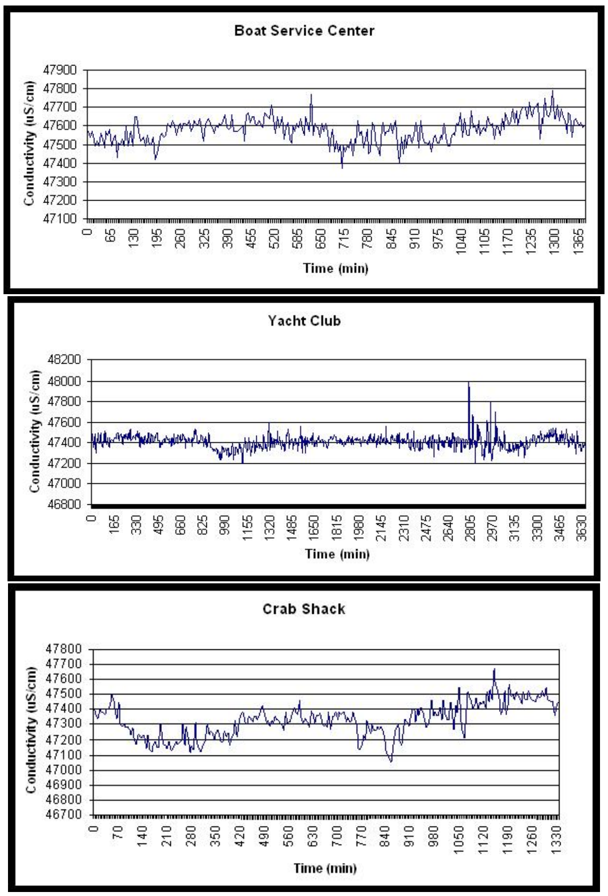

Figure 2-6

Figure 2-6 displays the conductivity trend over time at the boat service center, the yacht club and the crab shack. There appeared to be some fluctuation at the boat service center that must be caused by the incoming total waves from the ocean while there is little change at the yacht club on the Lido Channel. The constant conductivity may be due to the isolated location where a large scale of residents live with their boats parked throughout the middle of the Lido and Rhine channel of the harbor. However, the crab shack and the "No Entry Sign" locations expressed interesting conductivity trends over time. The magnitude of oscillations increased drastically from the boat service to the sign in the upper bay, where it was greatest.

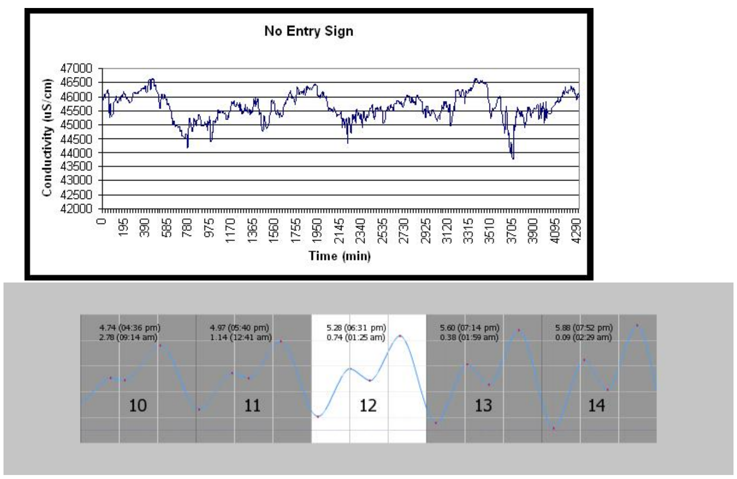

Figure 2-7

Surprisingly, the change in the conductivity at the sign closely resembled the oscillations of the tides observed (**Figure 2-7**) on the weekend the probe collected data. The greater change in the upper bay could possibly mean that there may be a large amount of freshwater influx coming from the San Diego creek and the proposed plan to increase the flux by ten times would cause a great deal of change in salinity distribution.

Conclusion

The project appeared to not have found a concrete answer to why certain bivalve species are present in certain parts of the bay. But based on some findings, we have concluded with some possible reasons for certain behaviors we noticed. The nonexistence of bivalve population other than a few Chione bivalves around Lido Island could possibly due to boats parked in the middle of Rhine Channel and at the docks. The conductivity appears to be relatively high near Lido and Balboa Island, but less bivalves around Lido Island. The scarce population of bivalves could possibly be due to the pollutants that the boats give off causing the overall temperature of the water to increase along with the toxins they emit to create an unsafe environment for bivalves.

We noticed that the Tagelus species appeared to be abundant near Balboa Island and in the upper bay while the Protothaca and Chiones are only seen near Balboa Island near the main channel. This could possibly mean that the Tagelus species may have developed an ability to live under fresh and saltwater in response to competition with other bivalve species in the past. The greater population of the Chione and Protothaca species in the lower back bay compared to the upper bay could possibly due to inability to live in freshwater and more favored under high salinity concentrations. These proposed explanations of the behaviors we witnessed still remain inconclusive, but with extra time spent on the project in the future, the reasoning behind certain behaviors of the bay will be much clearer.

Future Work

Possible projects entailed for the future include bivalve modeling for healthy bivalves instead of looking for factors that may hinder their living. The method of working backwards could be the key to finding why exactly the Chione and Protothaca species are more abundant near the main channel than the upper bay and the greater amount of Tagelus species in the upper bay. An investigation of identifying the most ideal conditions for bivalves could determine what factors contribute the most in their ability to sustain life and reproduce successfully over time. This project leads to another possible future work of having a portable tank that represents as a miniature model of the back bay and to manipulate certain factors and examine the bivalve population. The tank would include a fixed amount of phytoplankton and the factors looked at would be the amount of pollutants added, salinity concentration, temperature, a fixed amount of oxygen, and etc. A replica of the back bay can help monitor and possibly find solutions to the problem quicker as opposed to a bigger and complicated scale having to observe over the entire back bay.

Also a more expanded and developed form of the compartment model involving the salinity factors with the new term introduced along with more appropriate constants would be done. More realistic constants would allow us to display an accurate numerical description of the Newport Back Bay for us to anticipate certain bivalve populations given certain parameters. Another project would be to use more sophisticated equipment such as the mass spectrometer to identify the various metals or pollutants that could be floating around the back bay. Despite finding the possible reason of temperature difference, another project would be to determine why bivalves are nonexistent around Lido Island (along the Rhine and Lido channel) when compared to other regions of the bay.

References

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