For office use only	Team Control Number	For office use only
T1 ________________	**5689**	F1 ________________
T2 ________________		F2 ________________
T3 ________________	Problem Chosen	F3 ________________
T4 ________________	**C**	F4 ________________

2009 Mathematical Contest in Modeling (MCM) Summary Sheet

As you read this paper, the Earth's human population is rapidly growing. That growth is coupled with demand for better quality health and nutrition, which can only be met by improved food production practices. Children in the developing world don't receive enough animal protein early in life to mature fully. Demand for animal protein is the root problem the people of Bolinao, Philippines have experienced over the last 15 years. Past solutions focused on harvesting large quantities of one type of fish using large cages. Unfortunately this approach failed to meet the demand for protein, ruined local water quality and destroyed coral reef.

Yet, this problem is solvable. Future technological innovations like self powered fish cages, algae based biodiesel fuel and radio frequency identification tracking offer great potential for waste reduction and improved results from open water fish harvesting in years to come. However, the people of Bolinao cannot wait for the future. Change must begin now. We must assist the transition to more economically viable and environmentally friendly fishing techniques. Ultimately, the people of Bolinao are the greatest stakeholders in the future quality of life there. Math based models show the various stages of this deterioration by demonstrating how the ecosystem in Bolinao once functioned before demand for fish grew dramatically in the early 1990s. We demonstrate the dangers to water quality created by the current practice of producing only milkfish in the region. Finally we attempt to show how introducing other species back into the commercial fish pens will allow equilibrium to recur, reducing levels of waste in the water and allowing coral reef (a catalyst for growth) to return. Combining the balanced ecosystem with market pricing formulas demonstrates how different alternative fish harvesting practices will lead to higher overall profits for the local population providing them with the protein that they need while offering them more money to better their quality of living in other ways. By implementing many of the practices which help produce the balance our models suggest is necessary, the people of Bolinao can effectively reduce the levels of particulate waste present in their water in less than a few years while allowing coral reef to grow again.

Fish is the most efficient source of animal protein for humans because it requires less food to obtain the same amount of protein as chicken, beef or pork. It is no surprise malnutrition reduction has focused on harvesting fish. While one key limit of our models was the ability to compile an large enough data set to gain accurate pricing estimates and precise ratios of different species necessary to recreate the type of balanced ecosystem that previously existed, our results still demonstrate to the Bolinao people both the environmental and economic value of transitioning from producing only milkfish to a more diverse aquaculture. Finally, we suggest policy changes designed so that the people of Bolinao don't have to choose between getting enough food to eat now and having a healthy environment in the future.

TABLE OF CONTENTS

Abstract	i
Table of Contents	0
Table of Symbols	1
Table of Formulas	2
Table of Figures	2
Problem Restatement	3-4
Problem Approach	4-5
Problem Assumptions	5
Task 1: Modeling Water Quality before Mass Farming of Milkfish Disruption	6-8
Task 2: Modeling Water Quality of Current Milkfish Monoculture	8-10
Task 3: Modeling Water Quality of an adjusted Polyculture	10-12
Task 4: Valuing Polyculture for Human Consumption	12-13
Task 5: Return to Balance: Maximizing Bioproduce while Maintaining Water Quality	14-15
Task 6: Recommending Changes to Reestablish a Balance to Bolinao	15
Conclusion	15-17
Bibliography	18-21
Appendix A: Polyculture Population Model of Acceptable Ratios for Water Quality	22
Appendix B: Formulas for Levels of Contaminants Affecting Water Quality	23
Appendix C Letter to Pacific Marine Fisheries Council	24-26

Table of Symbols

Symbols used for quantities referring to each species are taken from the following key:
(S refers to starfish, T to Giant Tiger Prawn, M to Milkfish, R to rabbitfish, L to Blue Mussels)

P_m Current population of milkfish

P_{my} Current population of juvenile (young) milkfish

P_{mo} Current population of breeding (old) milkfish:

P_x Current population of specie X(S refers to starfish, T to Giant Tiger Prawn, M to Milkfish, R to rabbitfish, L to Blue Mussels)

P_{x-1} Population of specie X from the previous month

B_x Birth rate of specie X

S_x Survivability rate of specie X (Where Survivability=Growth rate minus the death rate)

G_x Growth rate of specie X

D_x Death rate of specie X

E_x Rate at which specie X is eaten by a predator (found with factor of P_y the population of the predator)

C_d Level of Carbon dissolved

N_d Level of Nitrogen dissolved

Chl Level of Chlorophyll

C_p Level of particulate Carbon

N_p Level of particulate Nitrogen

W_x Level of bacteria created by individual Specie X

M_x Market Price for Specie X

Table of Formulas

Current population of juvenile (young) milkfish: $P_{my} = B_m P_{mo-1} + 0.066 P_{my-1}$

Current population of breeding (old) milkfish: $P_{mo} = S_m P_{mo-1} + .0166 P_{my-1}$

Current population of rabbitfish: $P_r = S_r P_{r-1} - E_r P_{m-1}$

Current population of giant tiger prawn: $P_t = S_t P_{t-1} - E_t P_{m-1}$

Current population of starfish: $P_s = S_s P_{s-1}$

Current population of algae: $P_a = S_a P_{a-1} + .E_a P_{r-1}$

Current population of mussels: $P_l = S_l P_{l-1} + E_l P_{s-1}$

Level of Carbon dissolved: $C_d = Y_m P_m + Y_t P_t - Y_l P_l$

Level of Nitrogen dissolved: $N_d = Y_m P_m + Y_r P_r - Y_l P_l - Y_a P_a$

Level of Chlorophyll: $Chl = Y_a P_a$

Level of particulate nitrogen: $N_p = Y_m P_m + Y_t P_t - Y_a P_a$

Level of particulate carbon: $C_p = Y_m P_m + Y_r P_r + Y_s P_s - Y_l P_l$

General formula for population growth of specie X: $P_x = P_{x-1} + (P_{x-1} G_x) - (\sum E_y P_y) - P_{x-1} D_x$

General formula for particulate waste level: $\sum all(P_x W_x)$

Value of the ecosystem for a ratio of species:

$D_p = M_m P_m + M_r P_r + M_s P_s + M_l P_l + M_t P_t + M_a P_a - input \cos ts$

Formula assumed as a conversion factor for particle and dissolved waste to bacteria level:

Table of Figures

Figure 1.1 Problem Solving Process Diagram 6
Figure 1.2 Change in Rates Due to Population 7
Figure 2.1 Food Web of Polyculture Ecosystem 8
Figure 2.2 Water Quality When Only Milkfish are Present 9
Figure 3.1 Water Quality With Mussels 11
Figure 4.1Optimal Polyculture Ration (without Algae) 13

*All graphs created from data obtained from internet sources cited in Bibliography and based on assumptions of the authors.
*All diagrams the original work of the authors.

Problem Restatement

The past thirty years has experienced a global population explosion while simultaneously undergoing a growing demand for a higher quality of living. Increased global trade and technological innovations has helped raise billions out of poverty. The goal of alleviating malnutrition in rising population created a push in the 1970s to expand the use of aquaculture to help alleviate this growing demand for animal protein in human diet.

The most efficient source of animal protein for humans is fish of which 65% of the raw weight is edible compared to 50% of chicken weight. Both of these animals require must less grain resource input to obtain the same level animal protein as beef or pork. Chicken and fish require 2 kg of grain for 1 kg of meat, whereas, beef requires 7 kg and pork 4kg. It is no surprise that this effort to reduce malnutrition has focused on greater harvesting of fish. However, human demand for fish has outpaced the natural rate of growth of wild fish which has led to overfishing, reducing the naturally found stock of fish in ocean waters. To alleviate this growing demand as well as create price stability, humans have turned to aquaculture as a solution. By creating large pens and cages of fish in contained spaces and forcing spawning with fish feed engineered to yield bigger fish, farmers have been able to reduce the cost of fish and meet growing demand for animal protein. However, this solution to world hunger has created other ecosystem concerns as the byproducts of the fish farms like uncontrolled waste have created an imbalance in local ecosystems leading to the destruction of other marine wildlife including coral.

In the Bolinao region of the Philippines, the overproduction of Milkfish has helped meet local demand for animal protein but has destroyed local ecosystems and coral by reducing the water quality. With a growing global population natural resources become increasingly valuable with food and water being most important. Mass Fish farming solves the problem of malnutrition and can increase the economic exports of an area but has the detrimental effect of increasing water pollution and through this disruption, limiting the amount of marine life over the long term.

Task 1 involves modeling of the ecosystem before the mass farming of milkfish was introduced in order to understand the natural interaction amongst varying species in the ecosystem and how they created growth while maintaining water quality.

Task 2 demonstrates the danger of an aquaculture based entirely on milkfish and algae. Ultimately the milkfish fecal waste and the overgrowth of algae create an imbalance that destroys coral which prevents the ecosystem of producing as much fish as it could otherwise. Task 2 then asks for a model of the current populations of the ecosystem based on the known water quality to understand the conditions from which the ecosystem is beginning.

Task 3 examines what populations of various marine species would be required in order to achieve an acceptable level of water quality and to restart the growth of coral reefs. Coral growth increases biomass production and improved water quality allows more species to grow. Both conditions ultimately achieve the largest value of sellable marine produce.

Task 4 requires criteria to determine how different parts of the ecosystem out to be valued.

Task 5 looks at the multiple solutions of populations of different species from the model in part 3 that can achieve the acceptable constant level of water quality. It then requires examining which solution for the model in part 3 yields the highest economic value of the whole ecosystem based on those criteria determined as part of Task 4.

Task 6 requires explaining to the Pacific Marine Fisheries council what changes to the biodiversity of the marine ecosystem of the Bolinao region are required to produce the maximum economic value for the local population and achieve the desired level of water quality that will allow coral growth which further increases the produce of the aquaculture.

The domination of aquaculture in the Bolinao region of the Philippines by milkfish has created an imbalance which threatens the long term sustainability of the local marine life and human population. The long term sustainability of this system can be achieved by improving water quality and allowing coral reef to grow again. By transitioning from a milkfish monoculture to a balanced polyculture, the biodiversity can meet the increased demand for animal protein while increasing overall economic value while maintaining a stable system for both the long and short term.

Problem Approach

Task 1: To model water quality before Milkfish dominated the local ecosystem we created formulas that modeled the interaction between the various species present to the ecosystem. This model focused on obtaining a solid state equilibrium of water quality by first establishing a formula for determining how to measure the change in water quality based on the sum of the products of the waste of each individual species. Some species like the blue mussel which consumes the waste of other species contributes negative waste and thus helps clean improve water quality. It was then necessary to develop an effective function that described the population of each individual species at any given time as the population at that time would determine the waste produced by that species and thus the water quality. The general formula for each species population calculated the overall change to the population by adding the number of new species based on the determined growth rate and subtracting the number of that species eaten by each of the other species as well as the number of that species that died naturally. This equation allowed us to determine the population of the species which was a required input to determine the water quality at that time. It is then possible to determine a steady state by running the whole model for several iterations until the level of the water quality of the current iteration remains the same as the previous one. Adjusting the number of each species in the system while keeping the ratio of each species to one another constant should allow for the model to predict what population level of each species existed before the disruption of overfishing which led to the commercial milkfish monoculture addressed in Task 2.

Task 2: We then set the populations for all those species except Milkfish and algae to zero and ran the model to determine the effects on water quality. Based on the known current water quality we attempted to determine what the current populations of a variety of species might be

Task 3: By setting the water quality to an acceptable desired constant we ran simulations of adjusting the populations of other species in different combinations that would reestablish an equilibrium polyculture. This polyculture would consume the waste products of the milkfish and keep the growth of algae under control. By examining the difference from the results of model 2b and model 3 we would expect to be able to determine different combinations for how many of various species needed to be introduced to the sites in the Bolinao region in order to reestablish acceptable water quality and create coral growth.

Task 4: By examining existing data on the dollar value of various marine species we could determine values for each type of species in the system. Certain fish are worth more than others and algae and fish waste can be used as alternative products.

<u>Task 5:</u> Based on the values of these individual products from Task 4 it is possible which combinations from model 3 are likely to create the most economic value for owners.

<u>Task 6:</u> We will address some of the policy changes that the Pacific Marine Fisheries Council can assist the government of the Philippines implement in order to help ensure the long term viability of what should become a self sustaining ecosystem. These policies center on harvesting all species at rates that allow the systems to keep the milkfish population under control and thus maintain the polyculture. These policy changes comprise a diverse set of ideas that center on local policing and enforcement, education, and location selection of the aquaculture farming cage sites. We also seek to mention some technological innovations that will potentially reduce current issues that affect water quality and coral reef growth.

Assumptions

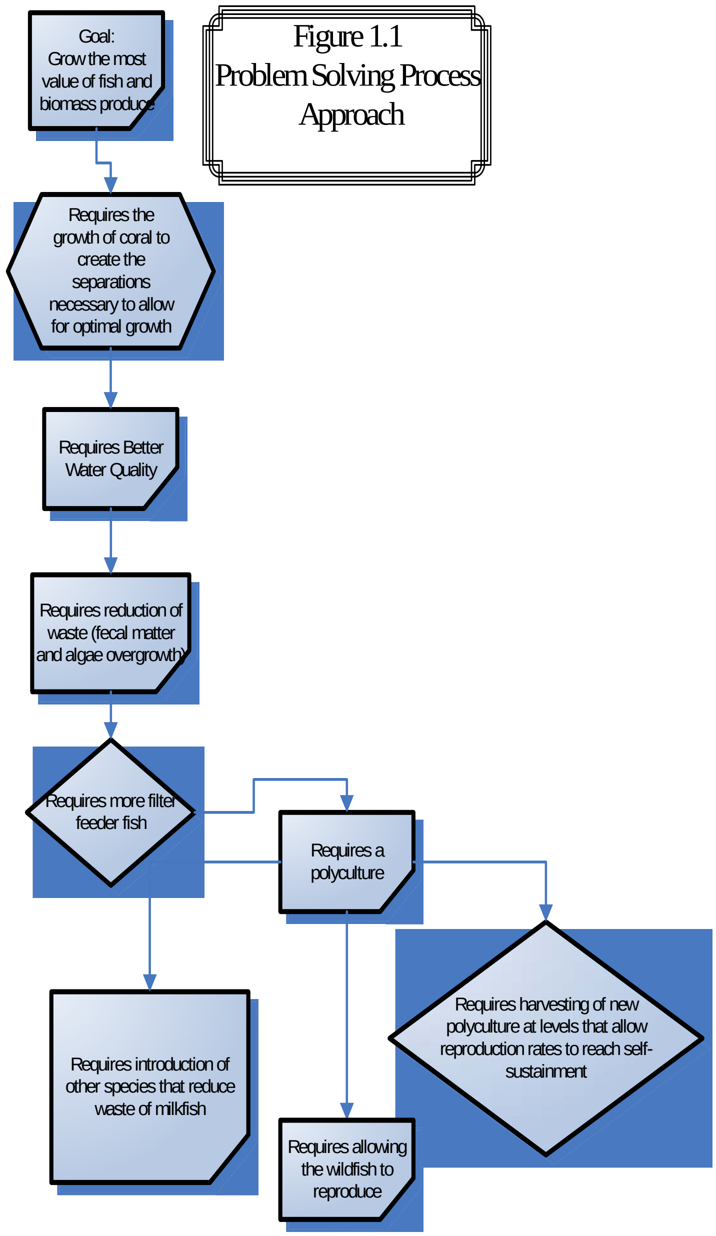
Through the course of this project our group made several assumptions in order to simplify the modeling process. The accuracy of any model decreases as more assumptions are made. However, without certain assumptions it would be impossible to provide useful conclusions because of the large number of unknown values for known variable. The assumptions we made are included below and addressed in more detail in the appropriate headings for the tasks under which they were assumed. Many of these assumptions were based on a lack of published or consistent data.

These assumptions include that the growth rates of species were constant. Variability of amount of eggs laid by species was normally distributed. Humans are the only predator of the Milkfish population. The channel is not a closed system. Excess population can immigrate to other reef locations. The algae are a mix of Cyan bacteria and Red varieties in order to provide more realistic results. Milkfish stop being omnivores after they mature and only eat other animals. It takes 5 years for Milkfish to become sexually mature (FishBase). An adult Milkfish is capable of eating an adult Rabbit fish. The fish pens currently hold approximately 58,500,000 fish. Milkfish weigh about 500 to 600 grams (Milkfish).

None of the other 5 species in the ecosystem model eat the Sea Stars. Rabbit fish waste has the same composition. The prices listed in Task 4 are estimates assumed from solitary sources. Giant Tiger Prawn spawn nightly at a rate of 7.6 to 9% but only 50% of these spawn hatch (Bray). Giant Tiger Prawn has a mortality rate of 10 to 40% and an average weight of 106 grams (Food and Agriculture Organization of the United Nations). Rabbit fish double in population every 1.4 to 4.4 years. Prawns excrete 0.028 milligrams of ammonia per gram of body weight per hour (Burford). Mollusks urinate up to 45% of their body weight per day. Each year 55% of blue mussels die. Female mussels release 1 million eggs semi-annually, of which 30% hatch. Japanese starfish release 10 million to 25 million eggs per year. Starfish has an average lifespan of 3 years. A starfish eats 36 grams of mussel each month.

Task 1: Modeling Water Quality before the Mass Farming of Milkfish Disruption

Every civilization wants to be able to provide for the basic needs of its children and elderly. The people of the Philippines are no different and have been fishing the local waters for centuries to put food on their tables. For a long time the amount of fish in the area was more than adequate to meet the needs of the population. However, as people sought better nutrition by eating more fish protein, the people fished more until the local population of wild fish was no longer large enough to sustain itself. To resolve this problem people developed various techniques like dynamite explosions and the distribution of sodium cyanide to catch ever more elusive remaining fish. These techniques killed off not only milkfish but other species that kept the ecosystem in balance. The resulting uncontrollable growth of algae in combination with the destruction that explosives caused destroyed parts of the coral reef by depriving it of the nutrients and sunlight it needed to grow. The people built the milkfish population back up by introducing them in large numbers and keeping them in large cages where they could be fed until they were large enough to harvest.



Using better quality fish feed allowed the milkfish population to grow more quickly but also increased the levels of pollution in the local waters as a result of the fish waste. Previously other species like the blue mussel mollusk (which feed on the waste of milkfish) and other species kept the water pollution level in check. Other herbivorous fish like the rabbitfish and echinoderms like the starfish helped contain algae growth. The starfish also ate the blue mussels. As seen in Figure 1.2, the food web of this ecosystem allowed for different species to coexist in certain ratios to one another which kept the water clean and allowed the coral reef to grow. Additional coral reef further increased the overall population growth. By allowing for special feed to replace the natural diet of the milkfish, the people unknowingly depleted the quality of the local water supply in the Bolinao area while simultaneously destroying the coral reef. This coral reef had served as a catalyst for the growth of the overall system by providing shelter for certain species from their predators. By modeling the previous stability it is possible to show what levels of different populations were previously required to maintain a balanced ecosystem. These ratios can then serve as a helpful starting point for reestablishing a new balance within commercial milkfish farms.

To produce this model we researched the relationships between the various species and determined appropriate rates of population growth patterns. The general formula: $P_x = P_{x-1} + (P_{x-1}G_x) - (\sum E_y P_y) - P_{x-1}D_x$ calculated the current population of the species X, given the population of X from the previous month, adding the growth rate G_x, while subtracting for the decline to the population as a result of the death rate D_x, and the amount of the X eaten by each of the other species in the system $(\sum E_y P_y)$.

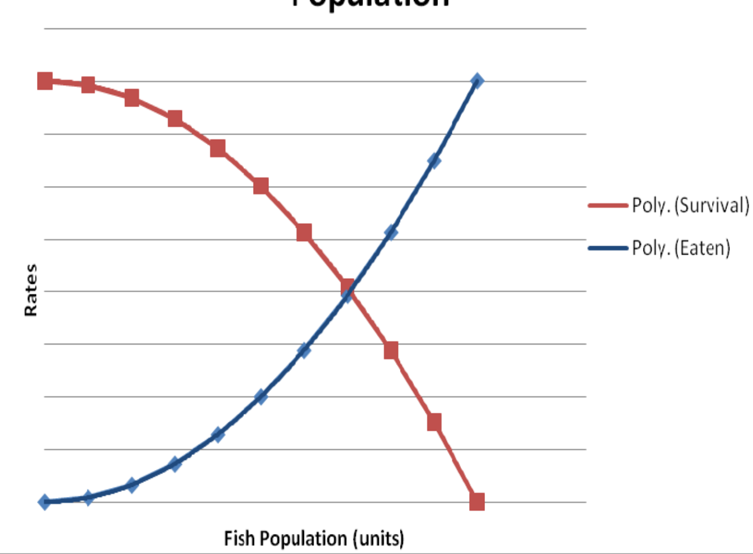
Knowing the population of each species allowed us to multiply the population P_x by the rate of bacteria waste production W_x. Taking the sum of the products of the bacterial waste for all of the species in the system, it was then possible to determine the overall bacteria level in the water. This process could be conducted for each type of waste product C_d, N_d, Chl, C_p, N_p and compared to the acceptable levels of these contaminants present at site A in the problem statement to determine if the water quality was acceptable or not.

Once overall system of equations (our model) was ran for enough iterations it should have been possible to demonstrate that at a certain point the level of each contaminant in the water reached a constant level. By maintaining the ratio of the species present at this level of water quality and reducing the overall number of each species a similar equilibrium should be been obtainable that achieved the allowable level of the water quality.

However, our model was unable to ever achieve this steady state level of water quality for several reasons. The main reason was that our model considered the growth rate G_x, Death rate D_x, and survivability rate S_x (Growth rate minus the death rate), to remain constant which does not occur in nature due to the conservation of mass. An example of the more natural trend of this relationship is depicted in Figure 1.2. As the fish population increases the rate at which they are eaten increases. As the fish population increases the rate at which they survive decreases.

In any closed system the overall mass of the system must stay the same. Thus, the addition of any new member of a population of one species to the overall system precludes the growing of something else either immediately or in the future. An example is that when the fish population is larger the death rate should be greater at some point because fish are more easily caught by their predators. Our model did not include any

Figure 1.2 Change in Rates due to Population



upper limit on the population of any of the species within the ecosystem and so over time the population of all organisms continued to grow at similar rates and water quality never reached an equilibrium value. In reality there has to be a natural limit to the system if for no other reason than eventually if the fish waste grows uncontrollably it occupies all of the space killing any new fish that would grow by choking of nutrient access to them.

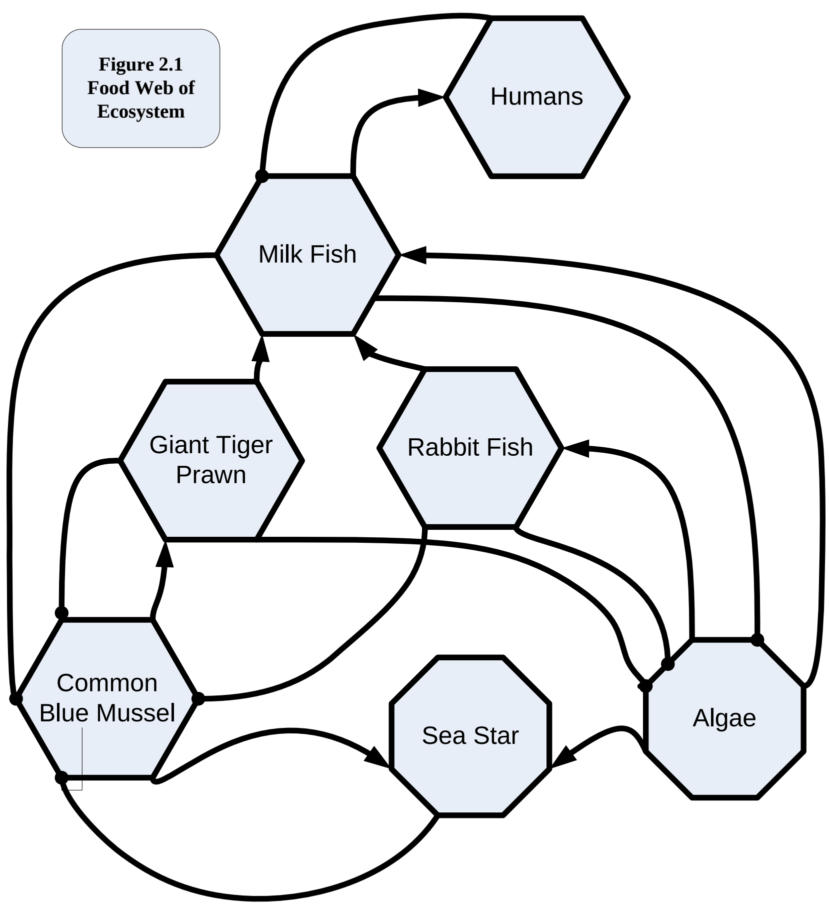
One possibility would have been to introduce an assumed limit to the ecosystem by confining the space to the Bolinao region. We were able to find source which estimated the water area of Bolinao to cover 1170 hectares. Based on the limit in the problem that the farmers currently use about 50,000 milkfish to a pen and operate about 10 pens per hectare, it is possible to assume a natural limit on the milkfish population of 585,000,000 milkfish (500,000 milkfish per hectare multiplied by 1170 hectares). This assumption is reasonable because the farmers want to grow as many fish as possible without sacrificing any fish. Given that they only produce one type of fish and demand is greater than what they can supply, they should grow as many milkfish as the ecosystem will support. By assuming this upper equilibrium it is then possible to base the growth rate off a factor of the difference between the current population of milkfish P_m, and the upper limit of 585,000,000 to produce a formula of ($G_x(585{,}000{,}000 - P_m)$.

Despite the difficulty in achieving steady state equilibrium of water quality we were still able to produce a model that demonstrates the general trend that should have been present in the ecosystem that existed before the introduction of only mass farming milkfish (See Figure 1.3).

Task 2: Modeling Water Quality of Current Milkfish Monoculture

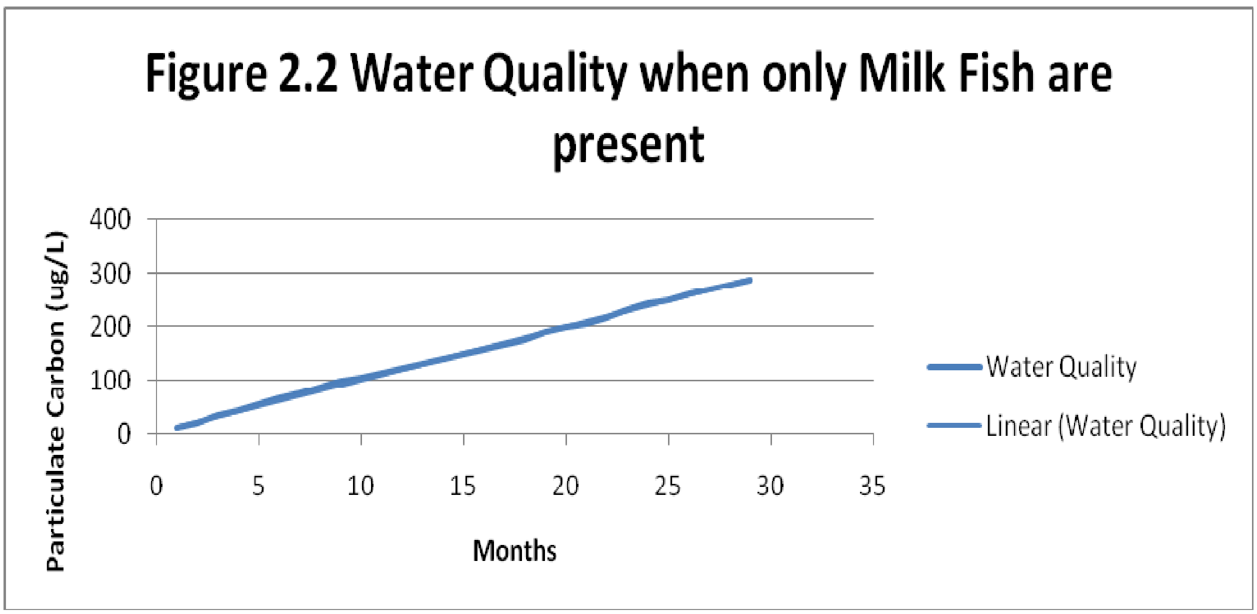
Poor water quality and the destruction of coral reef don't really seem like problems for people who are trying to meet their basic needs and keep their children healthy. It is difficult to show people how their actions now are ultimately leading to greater problems for them and their children in the future. The current thought process is that growing one type of fish, milkfish and feeding them specially formulated fishmeal creates the larger amounts of fish necessary to meet growing demand. It also doesn't require the sustenance of a variety of different creatures. Why is it not possible to simply apply modern agriculture methods

Figure 2.1
Food Web of Ecosystem



to aquaculture? Why shouldn't Filipinos continue to increase the yield of milkfish with specially designed fishmeal the way a farmer in America's Midwest increases the yield of his soybean or corn harvest by using specially formulated seed and fertilizer? Initial observations may lead to the conclusion that such an approach is both viable and desirable. After all, why not simply remove the excess fish waste and sell it as fertilizer for local farmers? This might be possible. However, just like land farmers eventually realized that growing certain crops year after year led to decreased yields because of nutrient depletion in the soil, fish farmers encounter the threat of decreased overall yield because only growing milkfish in the same area depletes the water quality by causing algae and waste to grow uncontrollably. The excess algae reduce coral growth in the same way that lack of crop rotation depletes soil of nitrogen. Both conditions appear to offer better results in the short term but in both cases the repetitive use of either method destroys the longer term viability of the system.

Still, for people to change behavioral practices, it is important to be able to demonstrate the limiting effects of the current system to address their problem in a continual way. For our model this requires first demonstrating that the current system of only farming milkfish actually causes water quality and the amount of harvestable fish to decline. To model the current system we took our model from part one and set the values for the populations of everything but milkfish and algae to zero. As demonstrated in Figure 2.1, it is possible to show the decline in water quality over time and the rise of the algae population which in excess chokes off the viability of the milkfish because of increased amount of oxygen demanded by the algae and the decreased quantity available to the fish.



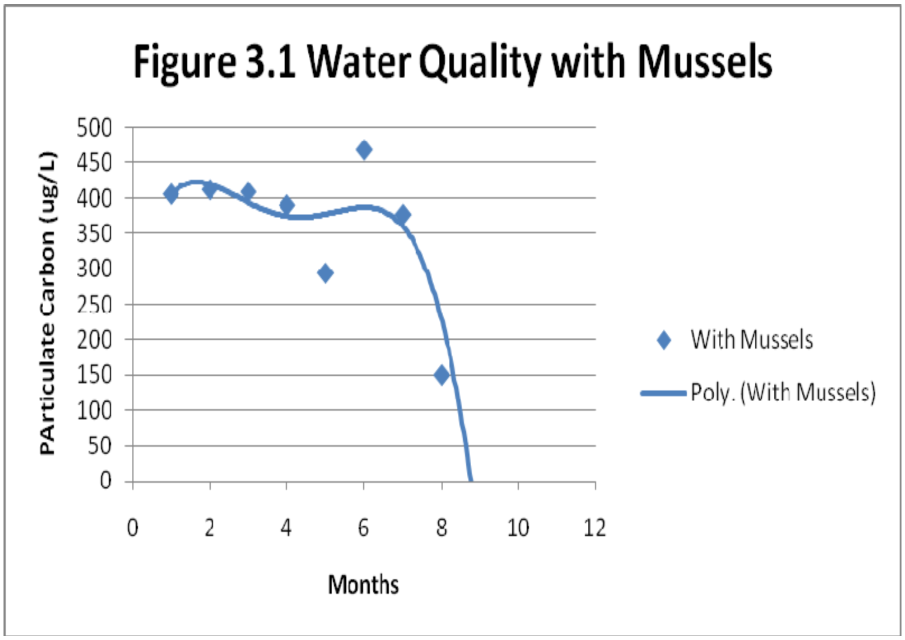
However, it is unrealistic to assume the current system consists only of milkfish and algae. We know that the current system has a water quality of 10 million bacteria per milliliter and 15 micrograms of chlorophyll per liter both of which are much greater than the suggested 0.5 million to 1 million bacteria per milliliter and 0.25 micrograms of chlorophyll suggested to be acceptable for adequate coral growth. This coral growth acts like a skyscraper in that it allows more fish to grow in a given space through vertical partitioning. Therefore, we gradually adjusted the populations of the various species in our model to achieve the level of current water pollution in Bolinao. By conducting this process it is possible to exam how these populations might be altered in order to help achieve the desired levels of water quality which allow coral and the overall fish population to grow over the long term; growth that is more than it is able to when the environment is almost exclusively dominated by the farming of milkfish alone.

Again, our model was unable to produce a steady state equilibrium of water quality when the ecosystem consists of only milkfish and algae because the algae do not entirely dispose of the waste from the milkfish and without another species like blue mussels to reduce the waste of the milkfish, the milkfish growing uncontrollably over time even if the twenty percent of young one that mature each year to level at which they can breed are removed by humans. If the humans harvest those milkfish aged less than the age of five years at which they can reproduce the level of milkfish will drop below its own level of sustainability until those milkfish left able to reach the age at which they can reproduce. This human harvesting can reduce the level of waste in the water somewhat although it is insufficient to achieve a steady state because there is still nothing to reduce the waste except the algae (which will grow uncontrollably to consume the milkfish waste which raise the level of chlorophyll above acceptable levels which chokes off the sunlight and nutrients needed for the coral reef to grow) (Environmental Protection Agency). Our model of bacteria waste levels in the water quality when the ecosystem consists only of milkfish and algae is depicted in Figure 2.2. While possible to reduce the levels of waste through harvesting this will only reduce the rate at which the waste level of bacteria grows (a more gradual slope), not cause it to decline.

<u>Task 3: Modeling Water Quality of an adjusted Polyculture</u>

Before the farming of massive quantities of milkfish in pens, there was a balanced ecosystem of a variety of species that coexisted in ratios that allowed the waste of certain animals to serve as the food for others. However, the demand for milkfish led to a disruption of this balance which required still more milkfish which led to the creation of the massive milkfish farms.

The ecosystem is not as ideal as it once was as we modeled in Task 1. However, it is not as bleak a situation as the milkfish monoculture we modeled in Task 2. There are other species that exist in current system although in limited quantities. They include mollusks like blue mussels, echinoderms likes starfish, herbivores like rabbitfish, and crustaceans like giant tiger prawn. However, as demonstrated in the second model for Task 2 the quantities of these other species are insufficient to reach the established levels of water quality. These levels will maximize the value of biomass available for harvest by restoring the natural catalyst of coral growth. The coral serves as protective shelter for all of these species, which is required in order for them to reach their optimal growth. Coral grows very slowly, on average only 80 millimeters per year (Roth). However, by determining the quantities of these species required to reach the desired water quality of 0.5 million to 1 million bacteria per milliliter and 0.25 micrograms of chlorophyll per liter, it is possible to increase the overall yield of fish available for harvest while recreating a polyculture that is sustainable. Through modeling this process we determined how to recreate the previous stable ecosystem that was once naturally present before commercial milkfish farming. This process will also reduce the cost of overall feed for the milkfish as they can eat certain quantities of the other species. By fixing the goals of acceptable water quality as the output of this model we were able to determine what combinations of populations of the various species could be self sustaining. Still this practice requires some guidelines for harvesting only a portion of any species so as to prevent recreating the overfishing problem that was the original cause for the rise of commercial fish farming that created the issues with water quality and coral reef destruction in the first place.



Reestablishing the balance that occurred in the region under the conditions present in the model from part 1 is a difficult Task. It requires introducing other species into the commercial fish pens that help to keep the other populations under control. However, our model was able to effectively demonstrate the pattern of what would occur to waste levels over time if such a combination was attempted. This process was possible by taking data from internet sources to determine sustainability rates S_x for each of the species and then adjusting the populations of each species in relation to one another in order to achieve the desired water quality levels. These results of this model rely heavily on increasing the population of blue mussel in order to control the waste levels of bacteria from the growing milkfish population. This downward trend in the level of bacteria present in the water is depicted in figure 3.1. In the span of less than a few years the population of blue mussels almost entirely eliminates the level of bacteria waste. In a similar manner the rabbitfish reduces the level of chlorophyll through its consumption of the algae, a process that provides more sunlight and nutrients for coral to grow again (FishBase). The milkfish keeps the rabbitfish population under control and the population of tiger prawn provides the milkfish an alternative feed source so that the milkfish don't wipe out the rabbitfish population. Similarly the starfish consumes the mussels to keep them from growing uncontrollably. As part of the process of setting the inputs of growth rate for the starfish the reproductive rate can vary widely which if an overpopulation of starfish occurs in early months before the blue mussel can grow sufficiently, the waste levels of bacteria can grow upward exponentially because the blue mussel is not yet able to sustain its own survivability. Thus the process requires a reduced presence of starfish early in the biodiversity effort and a greater number of blue mussels. After about six to eight months the mussels have grown enough that more starfish can gradually be introduced. If the starfish reproduce too quickly early it may be necessary to added more blue mussels to the system periodically because there is no effective control in our model on the starfish population.

Our model ultimately required the introduction of certain quantities of starfish, rabbit fish, blue mussels, and giant tiger prawn in order to reestablish a sustainable polyculture that would support the milkfish while improving the water quality and coral growth. The overall cost of introducing these changes was… It also requires the establishment of certain harvesting guidelines so that the system is allowed to maintain itself naturally. The goal is to keep those harvesting guidelines above the demand for milkfish so that overfishing would become economically undesirable because it would only create excess supply above the natural level of demand. In order to make these guidelines more enforceable a combination of community based policing standards as well as law enforcement officials paid for by fishing licensing fees would be desirable. For specific equations used in order model to determine the water quality levels at given times please refer to Appendix B. Such guidelines are addressed in more detail in our report to the Pacific Marine Fisheries Council as part of Task 6.

Task 4: Valuing Polyculture for Human Consumption

Being able to show how a current fishing system monoculture based exclusively on the harvest of milkfish is undesirable for the long term is an insufficient argument to change a local population's practices. That argument must also demonstrate how it benefits the population economically to make changes to those practices now.

As part of Task 3 we were able to model and demonstrate what types of input quantities of certain other species would be required to establish a self sustaining polyculture yielded more harvestable biomass over the long term. However, those inputs came at short term up front monetary costs in addition to longer term costs in the form of restrained harvesting guidelines in order to allow the system to remain at equilibrium. Harvesting different quantities of different species at different rates of time could be achieved loosely through enforcement of simple harvesting guidelines.

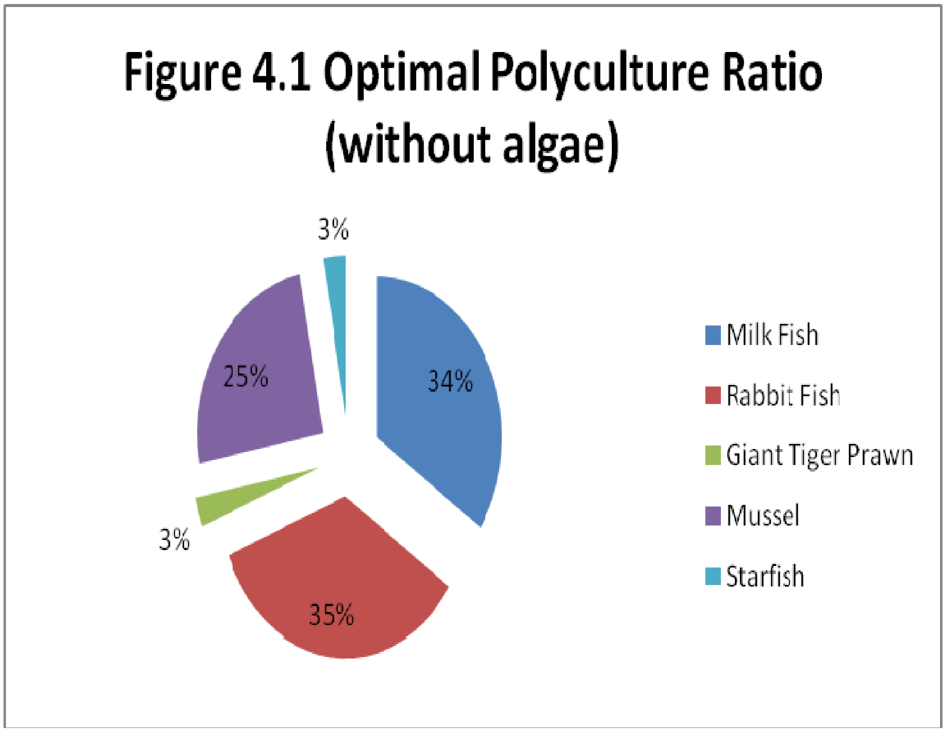
However, demonstrating the costs of changing the system doesn't get people excited if they are unable to see the economic benefit these changes will mean for them in both the short and long term. In order to demonstrate the benefits of these changed practices it is important to clarify the time required for water quality to improve and coral to grow again. It is also necessary to demonstrate how this growth will lead to more money for the population than continuing to only farm milkfish. This process requires setting a value on coral growth as well as the harvestable fish in the system.

As we know from the initial cause of the problem, animal protein from fish is more desirable to not only the local population but also to a global population of consumers who are increasingly demanding better quality of health and nutrition for themselves and their children. The harvesting of different combinations of the various species discussed in Task three could still produce the same desired level of water quality through reduced fish waste and the same desired coral growth through the decreased abundance of chlorophyll. However, certain species produce a different value on the market than others.

We therefore sought to explain the different value for different types of species in the system and why these various species as a whole could produce a greater overall value of income for the population than simply growing milkfish. On the simplest level, besides being unsustainable over the long term because of depletion of the natural resources in an area, growing only milkfish is undesirable because an excessive supply of milkfish only makes the value of each additional fish worth less. By harvesting a polyculture of species with economic value to both the local and global population, the people of the Bolinao region have the potential to make more money and raise their standard of living over both the short and the long term.

This policy through diversification of risk also reduces the likelihood of a farmer losing his entire stock to disease.

In our research we established that coral reef growth created a value of $52,000 a square kilometer and that each square kilometer of coral reef could produce 20 tons of fish biomass overall (Alcala). Looking at individual species we were able to estimate market values for each type of species in the polyculture. Many of them are worth more than milkfish. Some are worth less. The value of Giant Tiger prawn shrimp was estimated to be worth $6400 per ton (Aquaculture). Blue mussel yielded much less at $1000 a ton. Starfish was estimated to yield $2200 a ton and is considered a delicacy in some areas of Southeast Asia. Rabbit fish was estimated to offer about $4600 a ton although it is difficult to believe that it as an herbivorous fish would be more valuable than the $1280 a ton offered for milkfish. Unfortunately, the pricing of most of these products was very difficult to obtain and varied greatly.



Our model from part three was only able to yield general combinations of the ratios which would be required in a biologically diverse polyculture ecosystem. A pie chart of the combination that worked well to achieve acceptable water quality is depicted above in Figure 4.1. Therefore it is difficult to produce the exact optimal market value of the new system and thus conclusively show the desirability of transitioning from the current system. However the high price of giant tiger prawn over milkfish makes it an attractive alternative to grow more of. Growing additional blue mussel, while it may not be worth as much as milkfish alone is desirable because the reduction in waste levels it creates allows for more milkfish to be grown in the same area. Algae can be sold in smaller quantities to produce what is now $18 to $30 a gallon biodiesel (Morton). However, by assisting the research in that area now, farmers would be guaranteeing a future decline in the price obtainable for algae but would be creating greater future profits by increasing the future demand in the marketplace for this product.

Hopefully, the global production of a wider variety of seafood produce would create pressure for a more transparent and standardized market for seafood commodities similar to the markets that already exist for cattle and grain, which would allow for better research of the desirability of making certain adjustments to various species.

<u>Task 5: Return to Balance: Maximizing Bioproduce while Maintaining Water Quality</u>

One of the great difficulties in getting the population of Bolinao and the commercial fish farmers to make changes to their milkfish based monoculture is to tangibly show how a polyculture of different complementary species would not only be good because it would improve water quality and coral growth, but would also leave them with more money in their pockets. By setting values for the different species that would exist in the proposed polyculture, it is possible to show how one type of fish is more desirable to rise compared to another. However, while different combinations of the populations of various species in a polyculture may produce the same water quality, they are not all equal in terms of their economic value because certain species will produce a better price at market.

Part of the difficulty in maximizing the overall value obtainable for the fish farmer requires providing accurate values for each of the different species and how they might continue to be valued over time. In Task 4 we researched and established estimates for each species in the polyculture. By taking different combinations of these populations from the model in part three and multiplying the harvestable population of each species by the price we researched in Task 4 it is possible to create an estimate of the revenue the farmer could receive from that ratio of polyculture. By subtracting the associated input costs for establishing that polyculture, it is then possible to compare the various polyculture combinations that meet the desired water quality levels and choose the option that ultimately maximizes profit for the fish farmer.

Provided that profit is greater than what the farmer currently receives from raising the monoculture of only milkfish, it should be an easy persuasion to convince him or her not only of the environmental benefit of sustainability that switching to a polyculture would provide, but also the economic benefit that such a transition would bring. Unfortunately, although we were able to develop such a model, it is somewhat questionable in terms of the accuracy of its results because it is very difficult to provide accurate market prices that a fish farmer is likely to receive for the various species being produced as part of the desired polyculture.

Hopefully, one of the positive side effects of this increased production of a variety of seafood species would be the creation of a more standardized seafood commodities market for the region. Such price transparencies associated with a system would allow farmers to plan and optimize the species ratios of their polycultures better as well as providing consumers with a better understanding of what their costs will be. Ultimately such transparency should lead to better prices and reduced the waste of unsold or unused fish.

With greater price transparency and consistency it would then be possible to more accurately model which harvesting strategies and levels of milkfish feeding produce the highest level of water quality per unit of harvest value in the short term so that the overall yield of harvest will be greater in the long term because of improved water quality and coral reef growth associated with the development of that polyculture combination.

Recognizing that a major inadequacy of the results of our model results from the inability to obtain accurate pricing data, our model indicates that the maximum value of harvest for the given requirement of water quality occurs when the farm produces a combination of (insert numbers of different species) which is better than when the farm produces a combination of (insert other numbers of different species) which has a lower overall profit even though it results in the same level of water quality.

Ultimately with greater understanding of price changes and levels of pollution at different sites, it is possible to use our models from part 3 to determine what the most optimal harvest strategy is to achieve a unit of water quality. Because water quality is a product of both the level of bacteria and the level of chlorophyll, certain sites may produce more value when the combination of different species is tailored to reduce more of one of those two water contaminants. We recognize that the applicability of our model is in many ways limited by the information available on the value of different species and the variability associated with the pollution of different sites. No model is perfect. However, our model achieves the basic purpose of providing fish farmers in the Bolinao region of the Philippines an accurate estimate of the profit increase they are likely to see by transitioning from a monoculture of farming only milkfish to a polyculture. Such a transition provides more overall value while reducing the levels of fish waste and chlorophyll in the region. This reduction improves water quality and the restoration of coral reef growth which acts as a catalyst for further increased yield of a variety of species (Precht).

Task 6: Recommending Changes to Reestablish a Balance to Bolinao

While the our model was never able to achieve a steady state equilibrium of water quality, there are still several policy recommendations that will help the people of Bolinao achieve the better water quality, coral reef growth, and better economic opportunity that they desire. All of our policy recommendations are the result of the understanding of how the various inputs in the biologically diverse polyculture ecosystem we developed interact. Principles like the inclusion of additional blue mussel to reduce waste levels are helpful to improve initial conditions and reduce waste. Even if the Bolinao people ultimately reject a transition to a polyculture at the very least they should attempt to manually improve the water quality of the milkfish pens by using commercial scoops to remove fish waste which can be recycled and sold to local land farmers. Simple ideas and principles like the value of local community based education and policing efforts are helpful in improving local quality of life for all Filipinos regardless of the approach they choose. We have highlighted many of these pragmatic practices in a letter address to the Pacific Marine Fisheries Council whom we believe is the best avenue to suggest these ideas to the people in the region. For a copy of this letter see Appendix C.

Conclusion

At first glance, Bolinao appears to have a problem of coral reef destruction and water quality deterioration based on the overproduction of a single type of fish. However, when examined more closely the real issues are much more personal. Filipinos are not simply farming large amounts of milkfish because they seek to destroy their living environment. Their monoculture milkfishing practices stem from a growing need for animal protein of which fish is the most economical and accessible source for the people in their country to produce. Fish offers the highest yield of food for raw weight at 65% while simultaneously requiring the lowest amount of feed input to achieve a kilogram of animal protein when compared to beef or pork. What Bolinao is really struggling to deal with is the very human problem of meeting a growing need for better nutrition and quality of life for their children.

In order to break this cycle of short term economic gain at the expense of gradual environmental destruction of both accessible water quality and coral growth (which has the added benefit of helping protect coastal integrity from tropical storms (United States Agency International Development), it must be demonstrated to local farmers that their current milkfish monoculture does more harm than good and that an alternative polyculture offers not only a better long term stability for the environment in the Bolinao region (through improved water quality and coral growth) but also a better economic situation for the local population that will allow them to feed their children and offer both current and future generations of Filipinos a rising standard of nutrition and better quality of life.

Our solution involved a series of models to explain the past system, the current system, and what a transition in aquaculture practices could create if a future system is adopted. It then focused on explaining the economic value of the current system and comparing it to the better potential economic value of a polyculture system based on the harvesting of a variety of species as opposed to the current monoculture focused on harvesting only milkfish.

Our solution offers the double benefit of a more sustainable ecosystem that reduces bacteria and chlorophyll to more acceptable levels while allowing for greater coral growth and economic benefit to the local population through the better prices received for the variety of species harvestable from a polyculture. At first glance a monoculture of milkfish seems to the type of specialization that offers the highest economic profit for fish farmers by reducing the unit cost of each fish. However, the long term sustainability cost of the byproduct waste of a milkfish monoculture is not taken into consideration. Neither is the greater profit that can be obtained through the introduction and harvesting of other species that naturally reduce the economic cost of raising milkfish by reducing the effect of their waste and creating more space to grow additional fish. These other fish eat the byproduct of the milkfish which provides more harvestable biomass produce per unit of effort. Finally, a variety of combinations of ratios of different populations in a polyculture produce the same level of water quality. However, they don't all yield the same economic profit for the farmer because certain fish offer a better profit than others and can be raised in larger quantities than in other scenarios. While our model was unable to demonstrate multiple scenarios that provide great economic profit than the current system such scenarios do exist and could be demonstrated by our model given a larger data set.

We developed simulations to determine the varying water quality based on the conditions of different quantities of the various species and accounted for the harvesting rates required in order to make these polycultures obtainable. By applying population quantities for polyculture combinations that achieved the appropriate water quality levels to a formula that produced an profit value for that combination, we could have determined which polyculture could provide the most profit to the fish farmer for the desired level of water quality that would allow for successful coral growth and long term sustainability of the polyculture. Furthermore, this increased profit could then be used in global trade to create a wider variety of diet than would be otherwise available.

Ultimately our model could be improved through the use of a more complete data set to improve the ratio of relationship between the species to levels closer to what is observable in nature. A more developed data set would not fundamentally change any of the relationships between the variables in the models we developed. Additionally, more accurately accounting for the human population in the model and adjusting the harvesting rate of the milkfish based on this inclusion would also provide more accurate results than trying to extrapolate what the human population should harvest on a periodic base in order to bring the ecosystem back into balance. This inclusion of the human population into the growth model of the population of the milkfish is necessary because in our ecosystem, humans are the only predator of the milkfish thus making them a requirement for equilibrium to be achieved. Finally, our model of the economic benefits for the people of Bolinao would be more accurate if we had been able to obtain more complete and recent pricing data for the market value and cost inputs of introducing the other species into the commercial fish farms next to the milkfish.

Despite the shortcomings of our models, we were still able to adequately show the economic and environmental benefit to the region by transitioning from a monoculture of milkfish to a polyculture of biological diversity. One of the biggest contributors to changing this system and reducing bacterial waste was the growth of the blue mussel mollusks. Through this process our models should convince the people of the Bolinao region of the Philippines to transition from the current monoculture of raising and harvesting only milkfish to a polyculture where they raise and harvest a wider variety of species to obtain the maximum sustainable yield from the ecosystem. With this optimal combination, implemented through the introduction of better farming practices and other species of aquatic life, it is possible to achieve a better result for both the environmental and economic quality of life for the Bolinao people over both the short and long term.

Bibliography

Alcala, Ashley, Edgardo Gomez, Garry Russ, Alan White. 30 June 2006. 07 February 2009. <http://oneocean.org/download/db_files/Chap5.Phil.06.Book.pdf>.

Anchorage World. 02 January 2009. 07 February 2009. <http://www.anchorageworld.com/content/bolinao Marine World Database 01/02/09>.

Aquaculture Consultancy and Engineering. 07 February 2009. <http://www.ace4all.com/live200611/docs/P%20monodon.htm>.

Artificial Reef Pictures. 07 February 2009. <http://myfwc.com/marine/reefs_pics.htm>.

Bray, W.A. Igenta Connect. 01 January 2008. 07 February 2009. <http://www.ingentaconnect.com/content/els/00448486/1998/00000159/00000003/art00236>.

Bray, W.A. Texas Agriculture and Mechanical University. 07 February 2009. <http://cat.inist.fr/?aModele=afficheN&cpsidt=2302392>.

Burford, Michele. CSIRO Marine Research. 07 February 2009. <http://cat.inist.fr/?aModele=afficheN&cpsidt=1061076>.

Environmental Protection Agency. 07 Febraury 2009. <http://www.epa.gov/reg3wapd/tmdl/pa_tmdl/LakeOntelauneeTMDL/ontelaunee_TMDL_report_AppendixB.pdf>.

FishBase. 10 January 2008. 07 February 2009. < http://filaman.ifm-geomar.de/Summary/SpeciesSummary.php?id=4618>.

FishBase. 15 January 2009. 07 February 2009. <http://www.fishbase.org/Summary/SpeciesSummary.php?id=80>.

Fisheries Improved for a Sustainable Harvest. USAID. 07 February 2009. <http://www.oneocean.org/fish/the_project.html>.

Food and Agriculture Organization. Fisheries and Aquaculture Department, United Nations. 07 February 2009. <http://www.fao.org/docrep/w2333e/W2333E04.htm>.

Food and Agriculture Organization. Fisheries and Aquaculture Department, United Nations. 07 February 2009. <http://www.fao.org/fishery/culturedspecies/Chanos_chanos>.

Food and Agriculture Organization. Fisheries and Aquaculture Department, United Nations. 07 February 2009. <http://www.fao.org/docrep/field/003/AB736E/AB736E03.htm>.

Food and Agriculture Organization. Fisheries and Aquaculture Department, United Nations. 07 February 2009. <http://www.fao.org/docrep/007/y5501e/y5501e0w.htm>.

Food and Agriculture Organization. Fisheries and Aquaculture Department, United Nations. 07 February 2009. <http://www.fao.org/docrep/field/003/ab735e/AB735E06.htm>.

Green Biz. Business Week. 17 November 2008. <http://www.businessweek.com/magazine/content/08_46/c4108greenbiz184899.htm>

Locations of Artificial Reefs and Wrecks. 07 February 2009. <http://www.dnr.sc.gov/marine/pub/seascience/reefloc.html>.

Milkfish, Chanos Chanos. 07 February 2009. <http://www.aqua-information.ait.ac.th/aarmpage/pdf/hambrey_2000-coastal_aquaculture/03-milkfish.pdf>.

Morton, Steven. Modern Use of Cultivated Algae. 26 October 1998. 07 February 2009. <http://www.siu.edu/~ebl/leaflets/algae.htm>.

NIMPIS (2002). *Asterias amurensis* species summary. National Introduced Marine Pest Information System (Eds: Hewitt C.L., Martin R.B., Sliwa C., McEnnulty, F.R., Murphy, N.E., Jones T. & Cooper, S.). 07 February 2009. <http://crimp.marine.csiro.au/nimpis>.

NIMPIS (2002). *Asterias amurensis* reproduction & life cycle. National Introduced Marine Pest Information System (Eds: Hewitt C.L., Martin R.B., Sliwa C., McEnnulty, F.R., Murphy, N.E., Jones T. & Cooper, S.). 07 February 2009. <http://crimp.marine.csiro.au/nimpis>.

Precht, William. Coral Reef Restoration Handbook. 07 February 2009. <http://books.google.com/books?id=POaHRmQRNf0C&pg=PA68&lpg=PA68&dq=great+barrier+reef+restoration&source=bl&ots=6fCFbriGB3&sig=JhJLu1wqf3yO6644uS6TEeQv-vU&hl=en&ei=akSOScCmGo_ftgfxr_SgCw&sa=X&oi=book_result&resnum=5&ct=result#PPP1,M1>.

Roth, Ariel. 07 February 2009. <http://www.grisda.org/origins/06088.htm>.

Southest Asian Fisheries Development Center. Aquaculture Department, United Nations. 07 February 2009. <http://www.seafdec.org.ph/pdf/MILKFSH2.PDF>.

SpringerLink. 03 November 2004. 07 February 2009. <http://www.springerlink.com/content/m1022200153w10t5/>.

The Common or Blue Mussel (Mytilus Edulis). 07 February 2009. <http://www.weichtiere.at/english/bivalvia/common_mussel.html>.

United Kingdom Marine SACs Project. 07 February 2009. <http://www.ukmarinesac.org.uk/communities/biogenic-reefs/br4_4.htm>.

USAID. 07 February 2009. <http://oneocean.org/download/db_files/PCRA_lectures.pdf>.

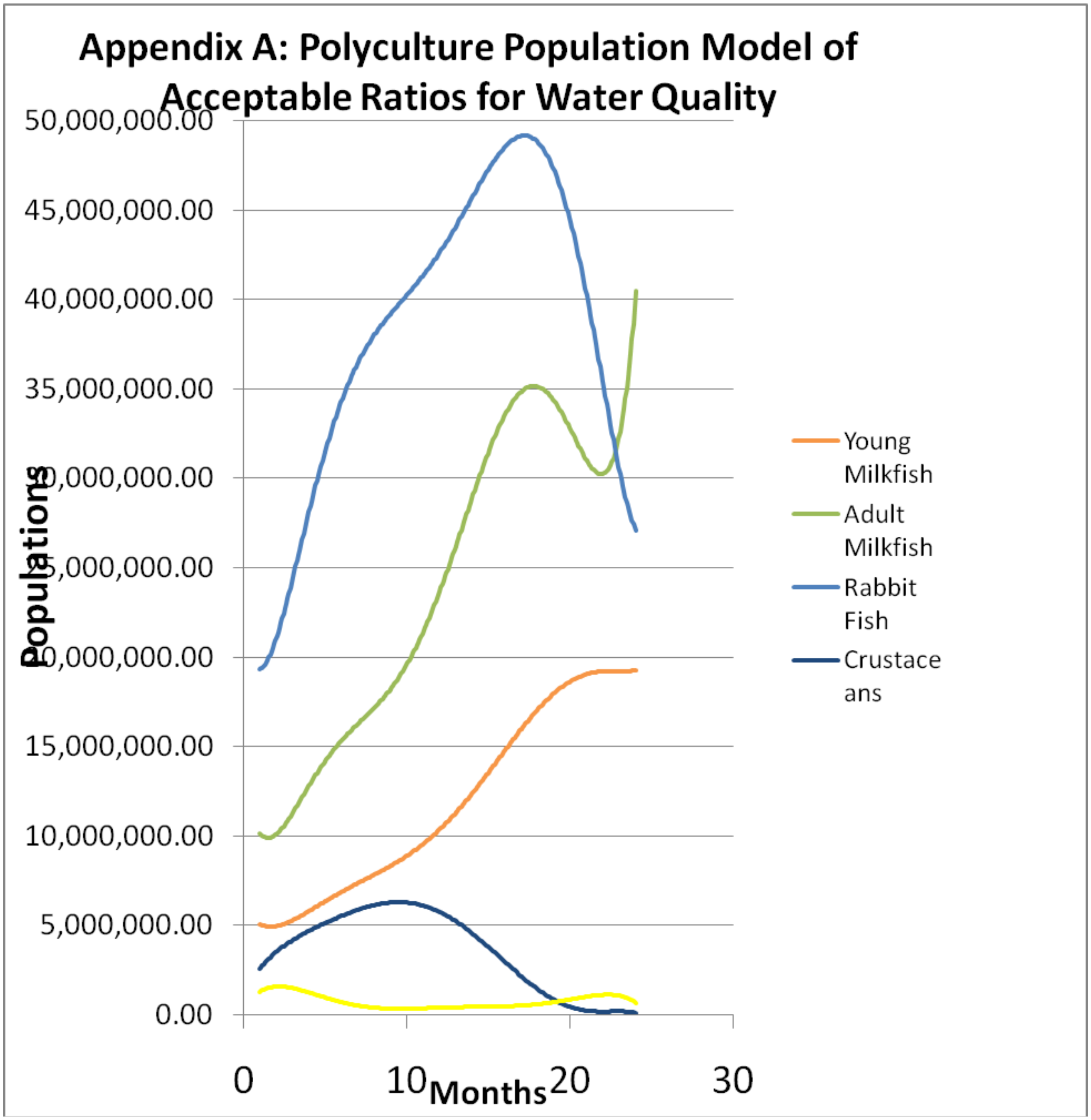
USAID. 07 February 2009. <http://oneocean.org/download/index.html>.

Van Dan, Le. 21 July 2008. 07 February 2009. <http://www.imolahue.org/pdf/p1-pilot6-en.pdf>.

Vennevig, Nielss. SINTEF Fisheries and Aquaculture. 07 Febraury 2009.

<http://eds.mofi.gov.vn/docs//norad/HTBien2006/MarketTrend_NielssVennevig.pdf>.

Appendix A: Polyculture Population Model of Acceptable Ratios for Water Quality



Appendix B: Equations for Calculation of Levels of Contaminants Affecting Water Quality

Level of Carbon dissolved: $C_d = Y_m P_m + Y_t P_t - Y_l P_l$

Level of Nitrogen dissolved: $N_d = Y_m P_m + Y_r P_r - Y_l P_l - Y_a P_a$

Level of Chlorophyll: $Chl = Y_a P_a$

Level of particulate nitrogen: $N_p = Y_m P_m + Y_t P_t - Y_a P_a$

Level of particulate carbon: $C_p = Y_m P_m + Y_r P_r + Y_s P_s - Y_l P_l$

Appendix C: Policy Recommendations to the Pacific Marine Fisheries Council

To the Pacific Marine Fisheries Council:

Increasing the biodiversity of the aquaculture in the Bolinao region of the Philippines will result in a more environmentally sustainable and economically desirable quality of life for the Filipino people. People in the region have been acting with intentions to provide their families with a better quality of life and higher standard of nutritional value in their diets by harvesting more fish. This overfishing of wild milkfish led to their depletion. More effort was required to find fewer fish and so techniques like using dynamite and sodium cyanide to kill or stun the fish destroyed other species in the ecosystem as well which allowed algae to grow uncontrollably reducing the nutrients available for coral growth. The desire for cheap animal protein led to the solution of commercial fish farming and harvesting of milkfish. This imbalance of a one species dominated monoculture resulted in stagnant fish waste and excess algae which deteriorated the water quality and choked off nutrients that coral needed to grow. Commercial fish harvesting seems to be a natural fact of life given the increased demand for animal protein. However, a multi-faceted approach can still be taken in order to allow commercial fish farming to continue in a manner that is both environmentally sustainable and economically productive for both the short and long term.

In order to achieve this combination of improved water quality, increased coral growth, and improved economic opportunity for the people of the Bolinao region, we propose the following changes. All of these improvements are contingent upon the principles of transitioning from the current monoculture of harvesting only milkfish to a more biologically diverse aquaculture that raises and harvests a variety of complementary species.

First it is important to spread out the area between fisheries in order to reduce fish waste from stagnating in very close areas. This allows for better water flow. Second, a fishing license system should be implemented with an associated fee being used to pay for the cost of enforcing certain laws governing the harvesting of certain types of fish at rates that allow local demand for animal protein to be met but which preserve the overall sustainable reproduction of all species in the polyculture. Third, a policy of educational efforts conducted at the local level is necessary to help people understand the value of good practices associated with effective coastal habitat management. The local population is the primary stakeholder in the long term sustainability of their environment and they should better understand the danger that practices like dynamite and cyanide fishing create for the stability of their own area.

Fourth, similar to the way agriculture farmers practice crop rotation in order to allow nitrogen and other nutrients to return to the soil, aquaculture farmers out to be instructed in how to better rotate the locations of their fish cages and pens away from coastal reefs so that those reefs can grow and allow wild species of fish to repopulate those areas while still meeting the demand for fish with the existing fish farms. This rotation will also reduce water quality issues associated with stagnant waste in one area. Fifth, creating a more biologically diverse aquaculture will reduce some of this waste because species like blue mussels and algae consume the leftover excrement (Common or Blue Mussel). Additional waste can be removed and recycled for use as fertilizer on local land based farms.

Sixth, allowing coral reef to repair through the seeding and elimination of excess algae in the area will help attract tourism. Furthermore, the improved water quality will actually make it desirable for people to go see the coral reef. Seven, where existing coral reef is not present old steel ships, armored military vehicles, subway cars, and aircraft can be seeded with live coral in order to promote the growth of artificial coral reef (Reefs and Wrecks). While not as biologically productive as natural coral reef, such artificial habitat can supplement the growth of a biologically diverse aquaculture and reduce the overall need for commercial fish farms while reducing the fish waste associated with them (Artificial Reef).

Finally, certain technological innovations offer promise for the alternative uses and practices of commercial fish harvesting and its biomass products in the future. Some companies are currently developing self-propelled alternative energy (solar and wave turbine) powered fish cages that could push further out to sea, thus reducing the damage caused by the stagnation of waste resulting from reduced water circulation near shore (Green Biz). They would still require the periodic refill of the fishmeal but would continue to offer the benefits of easily harvestable fish while allowing them to grow in a more natural environment. Another promising technological innovation, although too expensive to implement now is the use of radio frequency identification pills. These pills could be given to fish allowing them to grow out in the wild while periodically harvesting them with large fish scoops, scanning for the ones who have reached maturity while tossing back those who still need more time to grow. Finally, the demand for alternatives to crude oil based fuel products offers promise for innovations that will bring down the costs of algae as a biodiesel alternative fuel.

The combination of these changes in commercial fish harvesting practices as well as the eventual implementation of the technological innovations described above provide an effective foundation for the eventual resolution of all three aspects of the problem facing both the environment and the people of the Bolinao region. Implementing these best practices as well as reintroducing the appropriate ratios of certain species promises to create a sustainable biologically diverse aquaculture that will improve water quality, increase coral growth, and provide greater economic profit than the current milkfish based monoculture. We believe that your organization is best equipped to address these concerns and to suggest these practices to the Filipino government and to the local organizations in the Bolinao region that can most effectively implement them. The right to good nutrition is something that all Filipinos deserve. You as the people of the Pacific Marine Fisheries Council have the ability to help make that goal a reality over both the short and long term. Now is the time to act.