Exploring the Coral Reef Destruction in Boracay using System Dynamics Simulation

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Abstract: A recent survey of the coral reefs in Boracay Island indicated that as much as 70 percent have been destroyed in just 23 years. The main cause identified for this deterioration was the increase in the number of tourists visiting the island and worsened by sand erosion, worsening water quality from waste disposal, bad fishing practices as well as climate change, among other causes. This study offers a dynamic perspective into problem of coral degradation as it relates the factors and simulates the interactions over time. The study identifies the feedback loops that complicates the problem and leads to difficulties in improving the sad conditions of Boracay coral reefs. The simulations show that feedback loops related to increasing tourist arrivals have been found to be difficult to manage and control, as they are necessary for local government revenues and island economy. Indeed, the socio-economic factors effect on the problem increase as the number of tourists is controlled. The study attempts to identify possible interventions first, to control the exponential growth of the confounding factors and second to sustain the success of these interventions. The analysis of the coral reef problem suggests that the solution lie mainly in the proper community development and planning.

Key Words: Coral Reefs; Causal Loop Diagram; Stella; Vensim; System Dynamics

1. INTRODUCTION

The deterioration of Coral Reefs in the Philippine Sea, especially near the areas of Boracay, caught the attention of the scientists and experts. According to the local news, 70% of the Boracay Coral Reefs were depleted after 23 years (Ordinario, 2015). A study conducted by Japanese and Filipino Marine Biologists during 2010 to 2015 indicated that the deterioration of Coral reefs greatly increased, with the increase of tourists visiting Boracay (Ordinario, 2015). Besides coral degradation, there are also reports regarding the hazards of the beaches in Boracay. The shrinking of the beach area, sand erosion, and the dangerous water quality of the beaches were also reported.

The different kinds of waste that were discharged directly into the ocean affects the quality of the water, and promotes coral deterioration (Ordinario, 2015).

To further understand the deterioration of coral reefs in Boracay, it is better to understand the causes of the deterioration of coral reefs in Boracay, and evaluate whether the number of tourist entering Boracay is related to the sudden decrease of coral reefs. There are several factors and activities that cause the deterioration of coral reefs in the area. International Coral Reef Information Network (n.d.) released nine factors that affect the death rate of coral reefs. These are Water pollution and sewage, sedimentation, coastal development, destructive fishing practices, coral mining, careless recreation, global warming, coral bleaching, carbon dioxide, and ozone depletion. These variables will be further discussed later on the major variables. Upon further investigation, there are several other variables that could explain the deterioration of coral reefs in Boracay, such as the different activities of the tourist in the area, the number of tourist entering Boracay, the logging activities near Boracay, and the different livelihood businesses that depends on coral reefs. These variables will be also discussed further in detail. The birth rate of Coral reefs will also be included in the list of variables.

2. METHODOLOGY

Intensive data gathering and literature reviews related to the study were conducted to support the main idea of the study. The definition of selected major variables used in the study will be shown in this section

2.1 Definition of Variables

2.1.1 Number of Coral reefs

The number of coral reefs is our main problem variable. This represents the number of coral reefs in the Boracay area. Boracay is known to have wonderful beaches with great corals for tourists to view. In light of this, there is an issue where the corals have been declining. There is a decline of this variable over the years because the death rate of corals have been greater than the preceding years.

1.2 Objective of the Study

The objective of the system dynamics study are the following:
- To determine the behavior of the destruction of coral reefs in Boracay.
- To determine the true cause of coral reef decrease
- To understand the whole system and the relationship of each variable and how they contribute to the destruction of coral reefs
- To implement policies to solve the undesired behavior of the problem.

1.3 Audience

The target audience of the study are the local government officials, especially, in the officials in the Department of Environment and Natural Resources, Department of Tourism, and Bureau of Aquatic Resources. The study is relevant to them because they currently do not know the present and current behavior of the destruction of coral reefs in the Boracay. By informing the audience about the current behavior of the problem, it will open their eyes about what is really happening in the coral reefs in Boracay.

2.1.2 Birth rate of Coral reef.

The birthrate of coral reefs represents the reproduction rate of the corals. According to Coral reef Alliance (n.d), the birth rate of coral reefs takes of the things that occur in the island. The reason for the recent developments of Boracay was to attract more tourists. Also, tourists also take part in the many recreational activities that are available in Boracay

2.1.3 Tourist activities

The different tourist activities mentioned previously greatly affects the corals, when these activities are not performed with the corals in mind. Activities such as scuba diving, boat anchoring, and other tourist related activities could harm the physical component of the corals.

2.1.4 Destructive Fishing practices

Destructive fishing practices are methods of fishing that cause deterioration of coral reefs in Boracay. Cesar (2000) presented and mentioned different kinds of destructive fishing practices that could harm the coral reefs. These are poison fishing, Muro-ami, and blast fishing. Poison fishing is used to capture more fish and fast moving fishes using cyanide that could paralyze their movement, so that they can be easily caught by the hunters. Murro-ami fishing method is the method that use divers, especially kids to dive and look inside the corals whether there are fish species inside, and caught them. Lastly, Blast fishing is a method of fishing that uses dynamite and explosion to catch more. With the explosion, the coral reefs were being affected by it.

2.1.5 Sedimentation

Sedimentation is one of the primary causes that reduce the number of coral reefs in the ocean. Dudley (2003) conducted a study about coral reef sedimentation, and its effects to the coral reefs. Dudley (2003) mentioned in his study that sedimentation could also kill and damage the corals and other organism because sediments blocked the passageway of sunlight to the symbiotic algae, an organism inside the coral reefs that help in producing food. Without food, the corals could die due to famine caused by sedimentation. Sediments came from sand erosion that was caused by the logging activities near the area.

2.1.6 Urban Pollution

Urban pollution is caused by the developments in Boracay. Some examples of developments are hotels, resorts, restaurants and other places tourists can stay. The developments have a downside because of the pollution it brings. Debris from construction and waste can cause the water to have worse quality. The corals will suffer because the poor water quality will make the water have reduced oxygen and an increase in nutrients. The increase in nutrients could cause enhanced algal growth and make the corals crowded in an area. The poor water quality will also reduce the capability to reproduce and grow. Under urban pollution, fertilizer run-off, solid waste and sewage disposals were added in the model. Urban Pollution was broken down into these components that affect the quality of water. Poor quality of water contributes to the deterioration of coral reef covers. These wastes came from the restaurants, hotels, and from the farms in the nearby areas.
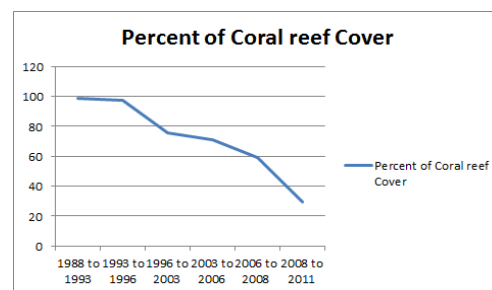
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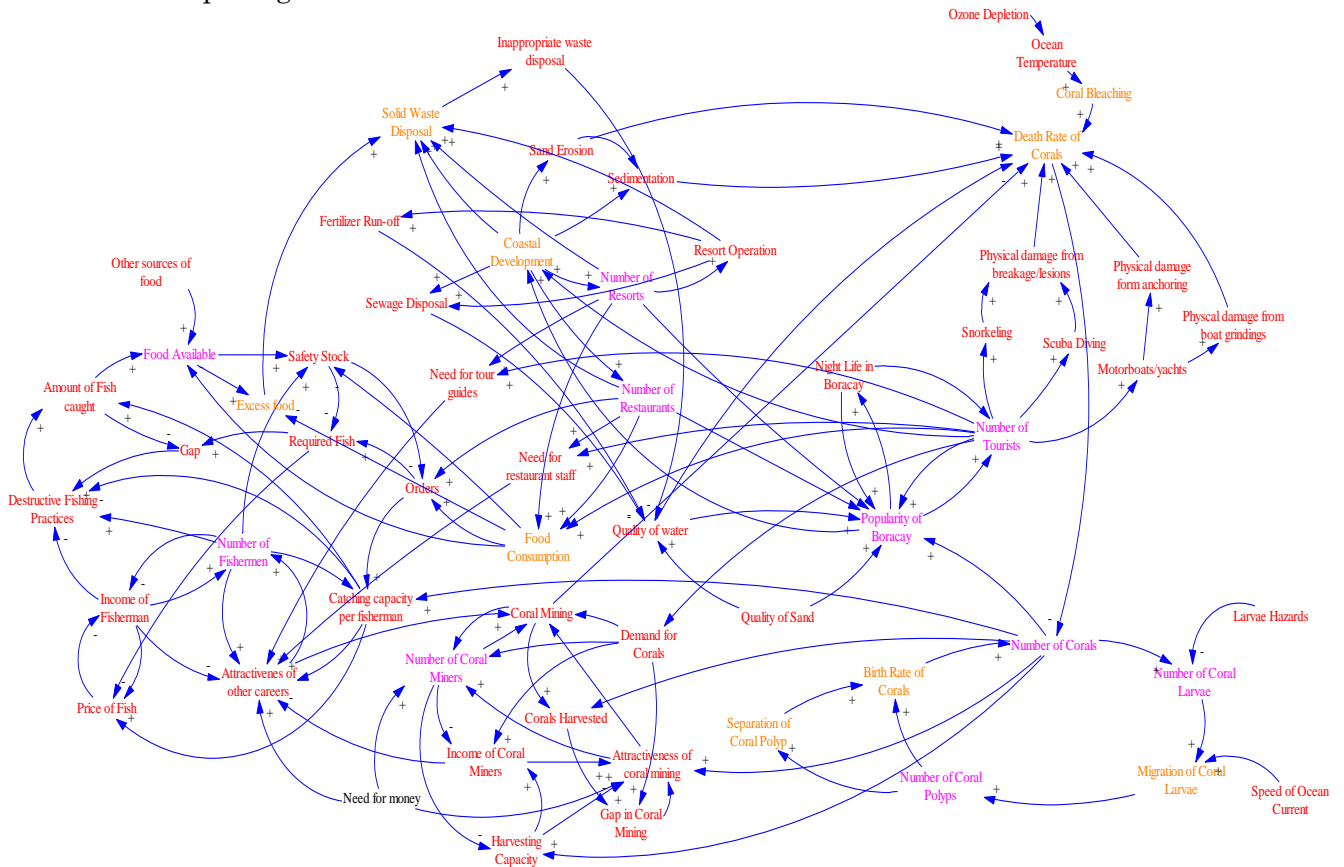

Figure 1. Reference Mode

2.3 Causal Loop Diagram

Figure 2. Causal Loop Diagram

3. RESULTS AND DISCUSSION

Using the Causal Loop Diagram Shown in *Figure 2*, a Stock Flow Diagram was constructed to simulate and show the initial simulation of the model. The initial simulation of the model is shown below.
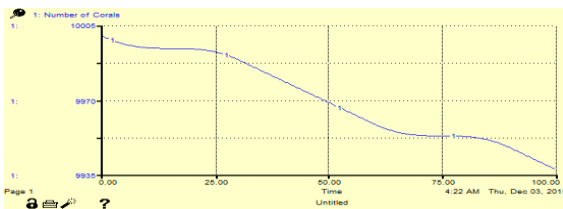

Figure 3. Initial Simulation Run

3.1 Parameter Sensitivity

There are seven levels identified in the model that affect the number of coral reefs in Boracay. The important levels in the model are the number of tourist going to Boracay, number of coral polyps, and Number of coral larvae. Each of the level will be justified as to why they were selected to conduct the parameter sensitivity analysis of the model.

3.1.1 Number of Tourist

The number of tourist should be included in the parameter sensitivity of the model because the number of tourists is connected to several sectors in the model such as the food requirement,

coastal development, tourist activities and coral reef business in the area. Determining the number of tourist is important because it affects the sector of tourist activities. The higher the number of tourist will be, the tourist activities will be also high, as well as the food requirement, and Coastal development. These sectors affect the number of corals, coral polyps and coral larvae in the seashore.
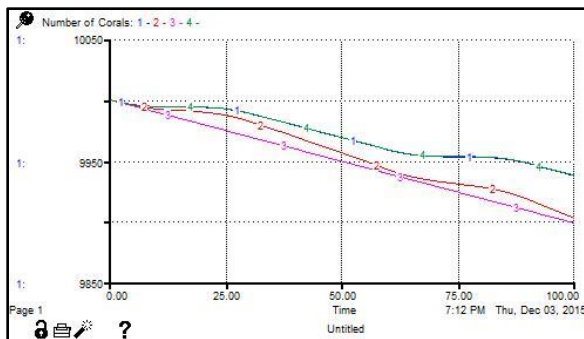
3.1.2 Food Available

Figure 5.Number of Coral reefs with combination parameter sensitivity on Predators and Urban Pollution

Coral Polyps are a necessary inclusion in the parameter sensitivity because the number of corals depends on the number of coral polyps. Based on the stock flow of the model, Coral polyps were transforming into coral reefs after growing in certain time. It is important to know what will happen to the problem if the number of coral polyps will increase or decrease the number of corals if parameter sensitivity will be conducted.

3.1.3 Popularity of Boracay

The coral larvae originate from the parental coral reefs which serve as the start of the reproduction of corals. The number of coral larvae depends on the number of corals in the area because the only sources of larvae are only the coral reefs. It is also possible that the larvae originates from a different area, but this scenario is not considered in the model. After conducting the

parameter sensitivity analysis for the number of coral larvae, it is important to know the behavior of
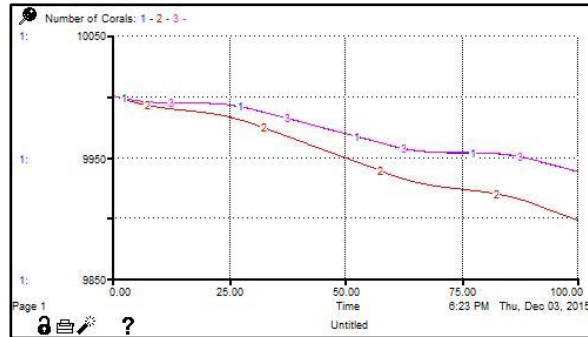

Figure 4.Parameter sensitivity (Number of Tourist)

the number of corals after applying this increase and decrease on each level.

3.2 Solution Design

3.2.1 Government Intervention on Incoming Tourists

Government Intervention is one way to control the increasing death rate in Boracay. The government has several options available to them. One alternative for the government to do is to limit the number of tourists that enter the island. This will reduce the overcrowding that occurs in the island. The tourist activities will be less populated which would decrease the likelihood of accidents. There would also be less garbage to collect because there would be less people in the beach. The food consumption would be reduced as well, which would lessen the demand for fish. Destructive fishing would not be needed if that were the case.
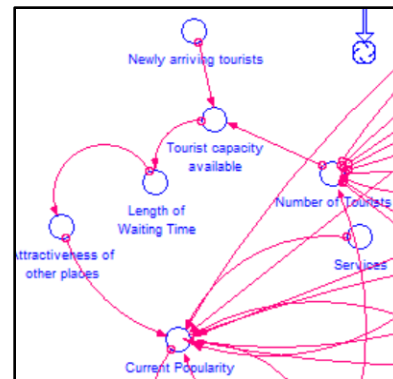

Figure 6. Stock Flow Diagram for Government Intervention on Incoming Tourists

New Variables Introduced:

- Tourist capacity available
- New arriving tourists
- Attractiveness of other places
- Length of waiting time
- Leaving Tourists

A new loop was introduced in the stock flow diagram in order to control the factors that influence the death rate of corals. The problem at hand was the number of tourists that enter Boracay. Currently, there are a large number of tourists in the island, especially during its peak months. The government can control the amount of tourists entering to island by implementing a policy to have a limit for the tourists entering. Tourists limit variable decreases the amount of tourists entering the island.
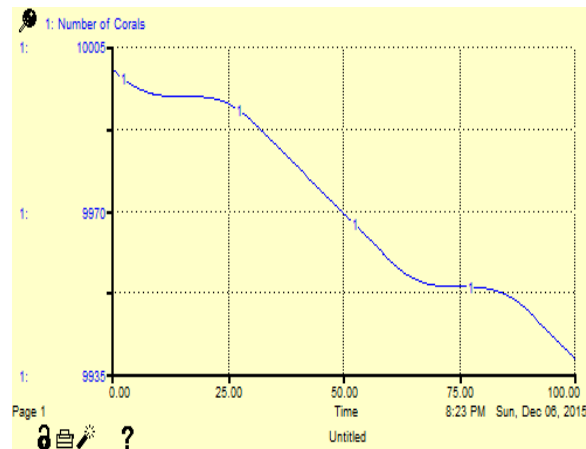
3.3 Simulation

Figure 7. Simulation of the solution (Government Intervention on Incoming Tourists)

The simulation shows the number of corals. As seen in the simulation above, there is no clear change in behavior even after the changes were made into the model. This indicates that the putting blame on the number of tourists entering Boracay would be true because the activities that threaten corals would still exist, which is not

solving the root cause of the problem. The behavior is similar because destructive fishing, reckless tourist activities, inappropriate waste disposal, and construction is still happening.

3.3.1 Coral Restoration

The second proposed alternative is to have a coral restoration activity in Boracay. Natives of the land could be paid to manually plant corals in favorable areas. This would also give jobs to those who are in need of money, which would decrease the amount of destructive fishermen and coral miners. One way to make use of the tourists in the island is to implement a coral planting activity for the tourists to engage in. This would net some income for the island while improving the state of the corals in the area.

Figure 8. Stock Flow Diagram (Coral Restoration)

New Variables Introduced:

- Coral Restoration
- Plantation Rate
- Number of Coral Planters
- Aspiring and Quitting Coral Planters

In this alternative, there were 4 variables introduced to simulate the implementation of coral restoration. The plantation rate is a new inflow attached to the number of corals level. It would increase the number of corals as long as there are people that would commit the act of coral restoration. Since that is the case, a coral planters level was also added. The open for a new occupation also affects the people in the island. There are people in need of money would not have to use illegal ways since there is a new job opening they could try. A new inflow and outflow was added to the coral planter level, which are the aspiring and quitting planters. The aspiring planters indicates the people who would join the existing coral planters. The quitting indicates the people who would leave the career for other endeavors. Lastly, the coral restoration variable is the activity that

influences the plantation rate. It is dependent on the number of coral planters.
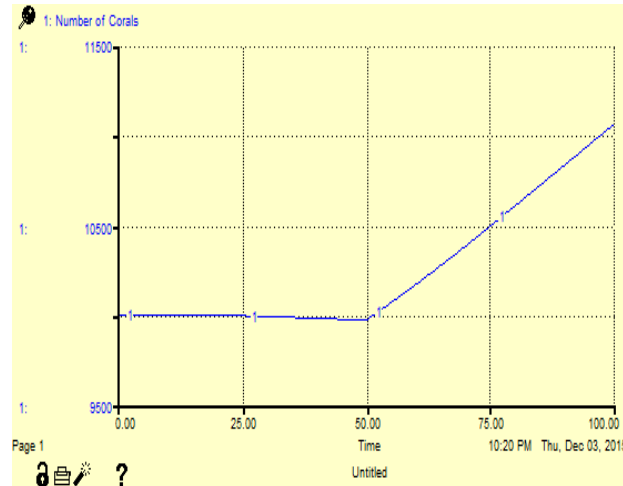
Simulation

Figure 9. Simulation of Solution (Coral Restoration)

A simulation was made showing the number of corals after the implementation of coral restoration. The solution is implemented at time = 50. As you can see, the number of corals immediately increased after time = 50 is reached. Coral restoration adds corals to an area, rehabilitates broken corals, and improves their health and reproductive system. This can also be offered as an activity for tourists to partake in. This solution takes time, but it is a good way to preserve the corals in Boracay, and involve the tourists in a great experience that helps the environment.

3.3.2 Fishing Patrol in fishery area

Even today, there are still those who commit destructive fishing practices in Boracay. This creates a threat to the corals because the blast created by using methods such as dynamite fishing damage the corals. One solution to this is to add fishing patrols in the fishing area to watch the fishermen in case they try anything illegal. A fine would be imposed to the fishermen if they get caught the first time. If they are to be caught again, they would be banned from fishing in Boracay.

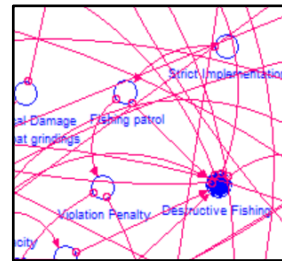Obviously this would require strict implementation in order to work properly.

Figure 10. Stock Flow Diagram (Fishing Patrol in fishery area)

New Variables Introduced:

- Fishing Patrol
- Violation Penalty
- Strict Implementation

There were 3 new variables introduced in model to implement this solution. The fishing patrol would decrease the amount of destructive fishing occurrences, but it would not eliminate it completely. The strict implementation is a multiplier that would increase the effectiveness of the fishing patrol. Lastly, the violation penalties would influence the quitting fishermen and the attractiveness of other careers because of the potential fine. There would be less fishermen in the system which would reduce the likelihood of destructive fishing practices.

The simulation that was run shows change in behavior in the number of corals. THis indicates that destructive fishing is a big part of the damage and deaths to corals. Addressing this issue would have a positive effect on the corals. One problem that this solution does not address is the attitude of the people. Even though you block this method, the people who use to do destructive fishing practices, would find another shady method to earn money.
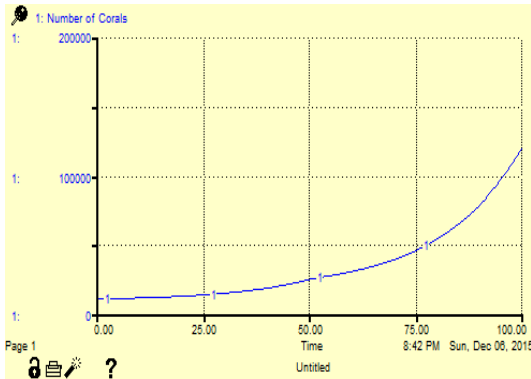
Figure 11 Simulation of solution (Fishing Patrol in fishery area)

4. CONCLUSION

After doing all the test and combination of variables to test whether the behavior of the problem variable, some insights and conclusions were made. Testing different variables to determine what will be the effect/s of these variables in a future setting. It is hard to pinpoint the most important variables in the mode because there are several factors that contributes to the whole problem. It is also better to know if the model could withstand the endogenous extreme variables input to the system. Increasing the level variables and important variables is a good parameter test to determine the change in the behavior of the problem. Parameter sensitivity is important to determine the reliability of the model to withstand exogenous factors. The solutions to address the problem of the destruction of coral reefs in Boracay were tested to determine how it will affect the current behavior of the system.

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