Can the Great Pacific Garbage Patch be Eliminated With Plastic-eating Microbes?

Team: 7

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Abstract

This paper explores the modeling of the interaction between plastic-eating microbes and plastic found in the Great Pacific Garbage Patch (GPGP). The GPGP also known as "Trash Island" or "Garbage Island," is a gyre (vortex) of plastic located in the Pacific Ocean. The plastic originates from trash being dumped or simply finding its way into the ocean from every continent as well as from ocean-faring ships. The plastic is known to be hazardous to wildlife and possibly humans as we ingest plastic-contaminated seafood. Our model was designed to determine whether the plastic-eating (plastic-degrading) microbes could eventually eliminate the GPGP completely. If not, could the plastic-eating microbes reduce the size or prevent the GPGP from growing larger?

Our results showed that the plastic-eating microbes and the continuous supply of plastic being added to the GPGP eventually reach a symbiotic relationship. That is, the plastic-eating microbes and their offspring consume the plastic at a rate that prevents the GPGP from growing larger. Our model also demonstrated that the GPGP can never be completely eliminated by the plastic-degrading microbes because as the plastic supply decreases, the plastic-eating microbe population dies off rapidly thus preventing a complete degradation of the plastic. Also, there is a continuous supply of plastic from humans thus preventing a complete elimination of the GPGP.

Can Plastic-eating Microbes Eliminate the Great Pacific Garbage Patch?

Introduction

What is the Great Pacific Garbage Patch?

The GPGP is an area in the Pacific Ocean where oceanic currents formed a circular rotating gyre of trash (Lindstrom, 2011). Actually there are several gyres within the GPGP mostly made up of tiny pieces of plastic 1-5 mm in diameter or smaller referred to as confetti by marine biologists, (Mincer, 2013). The GPGP also contains larger debris like fishing nets and a chemical sludge of some sort. The GPGP is located in the central North Pacific Ocean roughly 135 degrees W to 155 degrees W and 35 degrees N and 42 degrees N, (Dautel, 2009) (see Fig. 1).
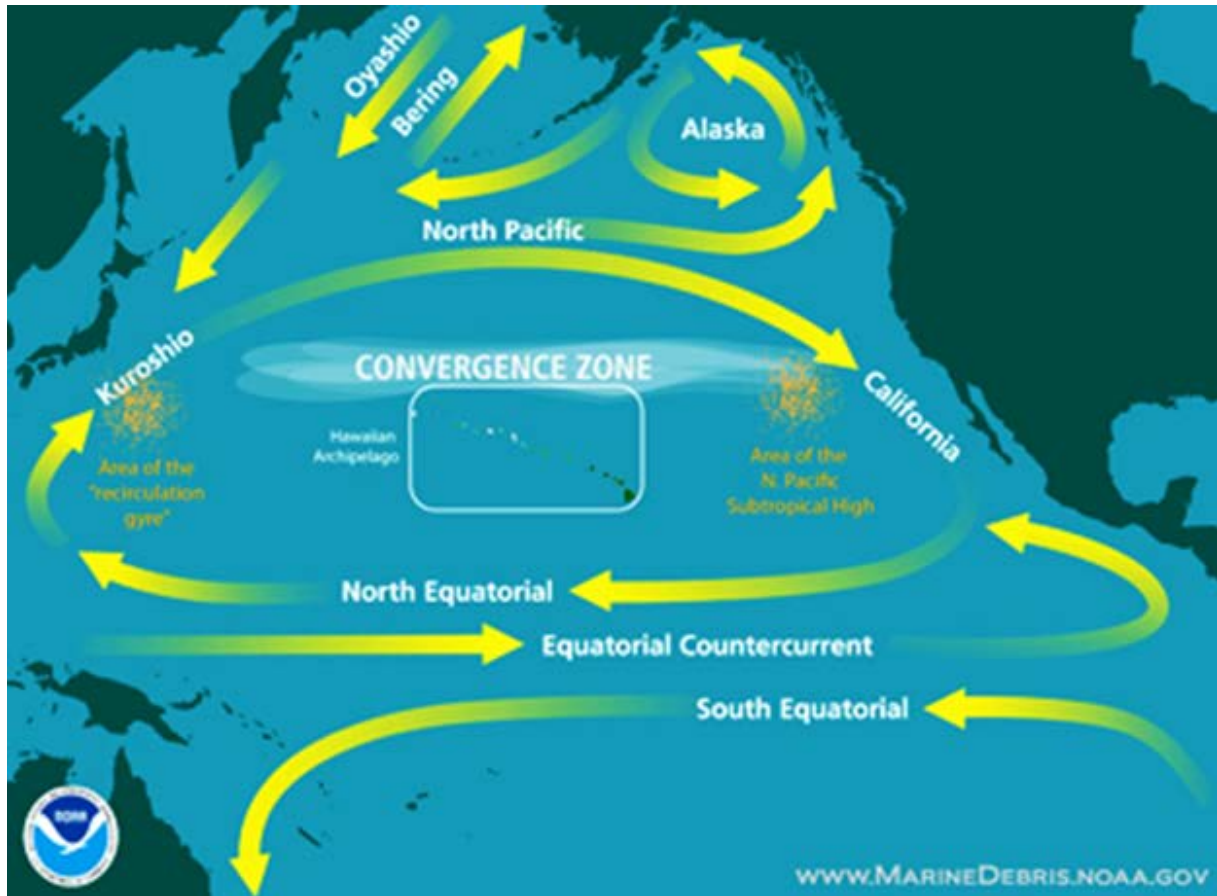

Figure 1 Ocean currents forming the convergence zone where the GPGP is located (Sheavly, 2010).

How big is it?

The size of the GPGP is hard to define. There have been estimates ranging from the size of Texas to the size of a continent. There is almost no way to accurately measure the size of the GPGP since the GPGP consists of several gyres over a huge area in the Pacific Ocean. The area of the GPGP is estimated to cover 17 million square miles in the Central Pacific Ocean (Casey, 2010).

Where did the trash come from?

Marine debris is generally classified as either land-based or ocean-based. The United Nations Joint Group of Experts on the Scientific Aspects of Marine Pollution estimated that around 80% of marine debris is land-based leaving 20% coming from sea-faring ships (Sheavly & Register, 2007). Greenpeace estimated that 100 million tons of plastic are produced every year and about 10% of that ends up in the ocean. The largest source of the plastic entering the ocean are polluted rivers around the world that empty into the oceans.

The Citarum River in Indonesia (see Fig. 2) and the Ganges River in India, are examples of major sea pollution sources, (Spooky, 2013). The major rivers of Bangladesh, Nigeria, and other developing nations collectively provide another example of marine-pollution sources. It has been noted that the levels of pollution in and around these rivers constitute a major health hazard to people living and doing business around the water.

Figure 2 Citarum River, Indonesia. One of the most polluted rivers in the world.

How much trash is there?

The total average abundance of plastic at and below the surface was estimated to be over 334,000 pieces per square kilometer and the density of plastic was approximately 6 times that of plankton in the water (Moore, Lattin & Zellers, 2001).

The most recent and most substantial study on the amount of oceanic trash came from a paper written after a SEAPLEX expedition in 2009. The SEAPLEX expedition was conducted by a group of researchers from Scripps Institution of Oceanography. According to the lead researchers from the expedition Miriam Goldstein, Marci Rosenberg and Lanna Cheng (2012) "Plastic pollution in the form of small particles (diameter less than 5 mm) — termed 'microplastic' — has been observed in many parts of the world ocean. They are known to interact with biota on the individual level, e.g. through ingestion, but their population-level impacts are largely unknown. One potential mechanism for microplastic-induced alteration of pelagic ecosystems is through the introduction of hard-substrate habitat to ecosystems where it is naturally rare. Here, we show that microplastic concentrations in the North Pacific Subtropical Gyre (NPSG) have increased by two orders of magnitude in the past four decades…"

Are there environmental impacts?

Environmental impacts of the plastic in the ocean have direct and indirect effect on the environment. Some of the plastic from the GPGP is mistaken for food by marine birds and animals and fed to their young, (Moore, 2003). A study done on the Midway Islands found that of the 1.5 million Laysan Albatrosses that inhabit Midway almost all of them have plastic in their digestive systems (Jordan,2009).

Ingestion of plastic by marine animals can cause internal injuries, blockage of nutrients from being absorbed and infections (see Fig. 3). Some of the plastics are like sponges which soak up toxins from the surrounding waters. Some plastics were found to contain certain chemicals up to one million times the amount found in surrounding water (Moore, 2008).

Figure 3 Sea turtle's body grossly deformed from plastic ring.

Another problem that results from marine plastic is entanglement. Volunteers from the 2008 International Coastal Cleanup (ICC) found 443 animals trapped by marine debris. The ICC estimates that those animals found make up a miniscule percentage of the total damage done to marine and terrestrial organisms every year by trash, (ICC Report, Ocean Conservancy, 2008).

"Marine life can become entangled in marine debris causing serious injury or death. Entanglement can lead to suffocation, drowning, increased vulnerability to predators, or other injury. Marine debris can constrict an entangled animal's movement which results in exhaustion or development of an infection from deep wounds caused by tightening material," (EPA, "Marine Debris Impacts, n.d.").

Figure 4 Seal entangled in fishing net.

If plastic is non-biodegradable, how will we ever remove the plastic?

In the very beginning of our project, our team was brainstorming about how to remove or eliminate the plastic floating in the GPGP. We eventually came up with the idea of introducing plastic-eating microbes from timed-released capsules. We assumed there *had* to be microbes that digested plastic not realizing that the rest of the scientific and environmental world firmly believed that was not the case. In our research to find these microbes we found that not only were there plastic-eating microbes but they were already in the GPGP! They are the main reason the plastic is degraded into small confetti-like pieces (Mincer, 2013).

Who discovered plastic-eating microbes?

In May 2008, Daniel Burd then a high school student at Waterloo Collegiate Institute won the Canada-wide Science Fair with his discovery of plastic-eating (degrading) microbes. Daniel was able to isolate two types of bacteria each able to degrade plastic at a relatively rapid rate. One bacteria strain was found to belong to the genus Pseudomonas and the second bacteria strain belonged to the genus Sphingomonas. Daniel experimented with ways to speed up the degradation including changing temperature, combining the bacteria and adding sodium acetate (Burd, 2008).

Tracy Mincer Associate Scientist at the Woods Hole Oceanographic Institute, after an expedition to the GPGP, was able to identify bacteria on plastic samples taken from the GPGP under an electron microscope. On the plastic pieces were spherical bacteria 1-2 microns in diameter that can associate in lines across a plastic surface in fields of 100 or more cells (sometimes up to 10% of the surface of the plastic). Mincer thinks that the bacteria may significantly accelerate the perforation of the plastic into confetti-like pieces in combination with weathering and UV light.

Problem Statement

Our goal of this project was to answer the following questions: (1) Can the plastic-eating bacteria completely eliminate the plastic in the GPGP? (2) Can the plastic-eating bacteria slow the growth of the GPGP? (3) Can the plastic-eating bacteria shrink the GPGP? (4) How accurately can this be modeled? The modeling program we used was NetLogo. NetLogo is a multi-agent programmable modeling environment.

Methods

We will have to make certain assumptions in our model: (1) we assumed the bacteria ate the small plastic pieces instantly (2) the bacteria were distributed randomly based on a uniform distribution by the computer at the beginning of each simulation.

NetLogo Code

NetLogo is a programmable modeling environment that is well suited for complex systems that evolve in time. This programming environment enables exploration of macro-level patterns that emerge from micro-level behavior of individuals called agents. The NetLogo programming environment allows the programmer to formulate the instruction set for thousands of agents all

operating independently of one another. The objective of the NetLogo model is to develop code providing instructions for individual bacterium that drive their behavior and interaction with their local environment. The local environment is assumed to consist of discrete particles of plastic suspended in water distributed randomly throughout a 2-dimensional area subject to a uniform probability density function. Initially we considered two different types of plastic with color attributes of violet and green however to reduce the behavior space size we limited the model to a single type of plastic.

The discrete plastic particles were coded as patches within the NetLogo modeling environment representing the fundamental quantity of interest to the team. The quantity of plastic was tracked during the evolution of the system to address the question of whether it is possible to eliminate the plastic which forms the great pacific garbage patch. Next, bacteria were introduced within the model system and coded as agents capable of performing actions on the distribution of plastic particles. Principally the bacteria agents eat the plastic thereby eliminating plastic from the environment. We defined an energy attribute for each bacterium which enables each bacterium to move, eat and reproduce if the bacterium has sufficient energy for these actions. If a bacterium's energy drops to zero the bacterium dies and is removed from the population of bacteria. If the total population of bacteria drops to zero the simulation stops. Bacteria acquire energy by consuming plastic particles that are in close proximity to their location. The amount of energy gained from consuming the plastic is a variable controlled by a slider bar on the interface screen much like calories gained by an individual that consumes food. Initially the team introduced an additional agent breed called parasites for future consideration of predator-prey phenomena within the system model. This predator-prey complexity was inhibited for the initial behavior space simulations via an on/off switch placed on the interface screen. Other variables set by slider bars on the interface screen are the initial number of bacteria, birth threshold energy, and the plastic growth rate representing the growth of the bacteria food supply due to plastic dumping and eventual consolidation of plastic into the great pacific garbage patch.

NEW PLASTIC ENTERING THE GPGP

NEW PLASTIC

PLASTIC

REDUCED AMOUNT OF PLASTIC

EAT

GAIN ENERGY FOR REPRODUCTION

PLASTIC-EATING BACTERIA
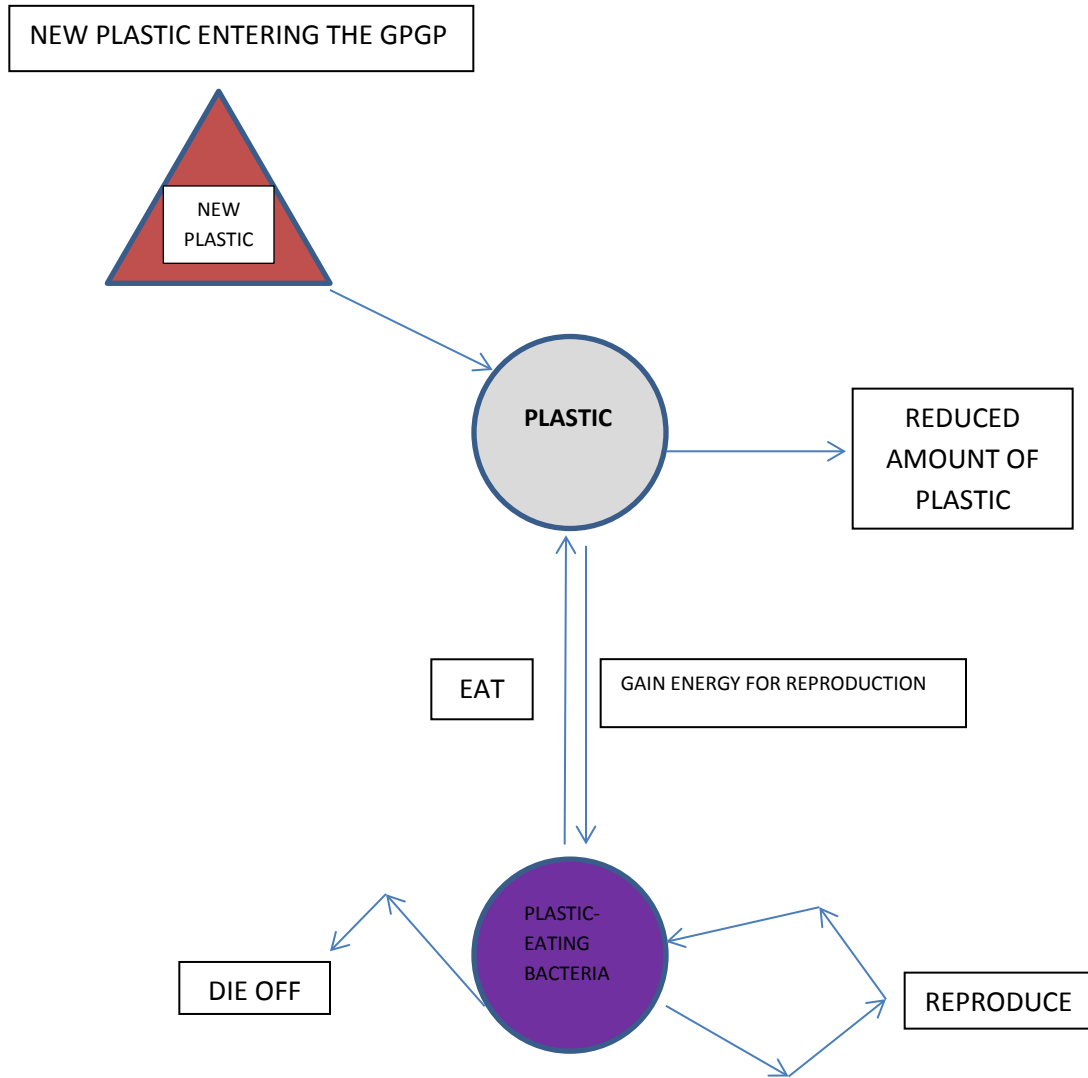
DIE OFF

REPRODUCE

Figure 5 Graphic image of our model

Behavior Space

Simulations were run using the BehaviorSpace tool provided in the NetLogo modeling environment as depicted in figure A. Initially the set of simulations were much too extensive, resulting in massive data files and excessive computer runtimes. Data file size was a strong function of the number of changing variables, variable increment size, repetitions and time limit and whether or not the "Measure runs at every step" box was checked in the BehaviorSpace input screen (as it was in the example depicted in figure A). The NetLogo CSV data file format provided each time-increment as a row in EXCEL and the number of columns as the number of runs or different configurations requested in the BehaviorSpace input screen. Thus the number of columns is actually provided by NetLogo in the action window as depicted in figure B multiplied by the number of reporters requested (which is 1 in figure A).
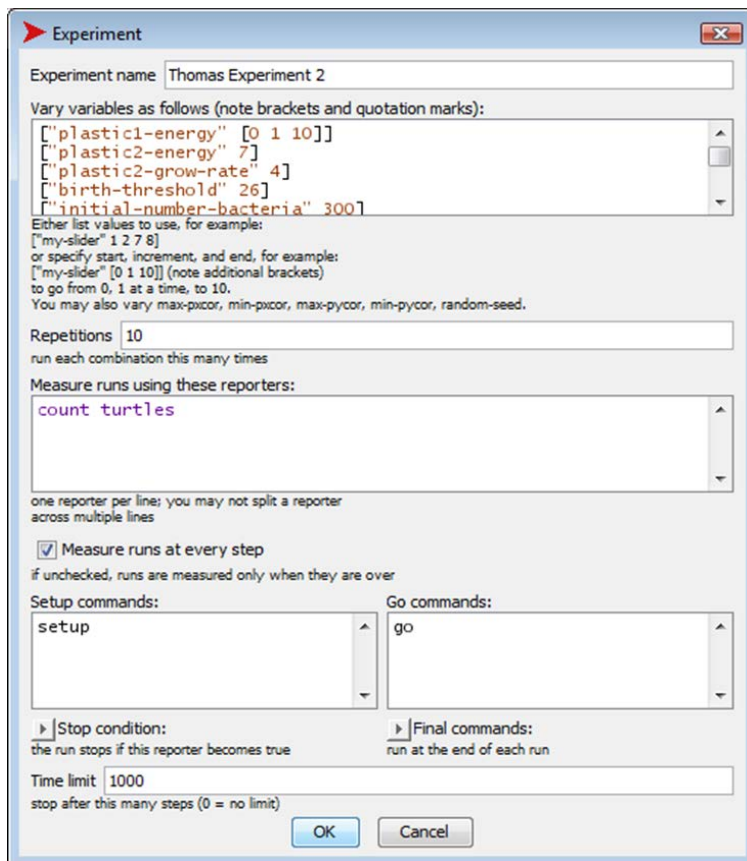
Figure 6 Snapshot of the BehaviorSpace screen used to set-up the simulations performed in NetLogo based on the sensitivity analysis of interest as captured in the master table AA.
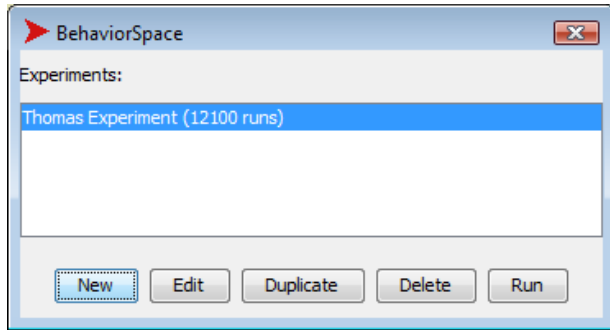
Figure 7 Each set of simulation results represents an experiment with the number of runs displayed next to the experiment name.

The interface screen for the NetLogo model is shown in (see figure 7) depicting the variables (slider bars), setup and go buttons to perform single experiments, switch to turn on and off the parasites and running population counts for bacteria, plastic1, plastic2, parasite populations. In addition, a 2-dimensional view of the locations of plastic types, bacteria and parasites (if engaged) is provided in the window at the right side of the screen.
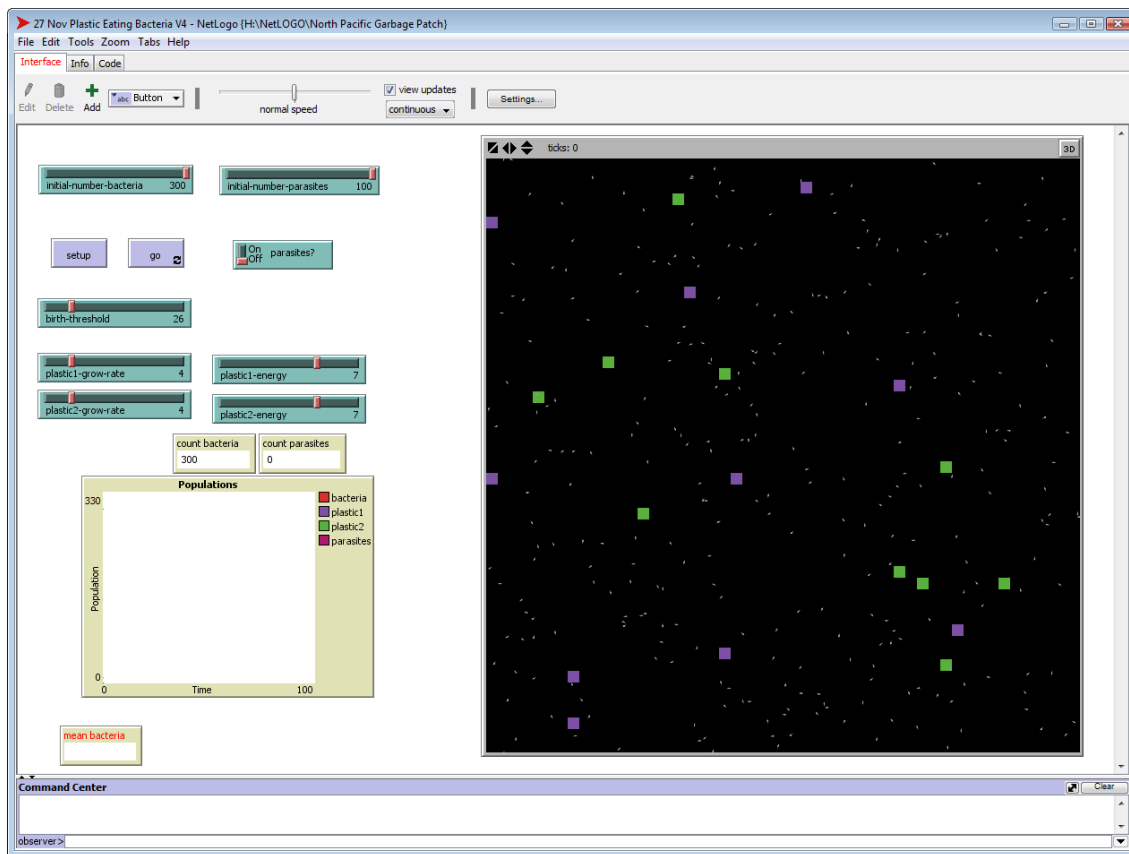
Figure 8 Snap shot of the NetLogo interface screen for the plastic-eating bacteria model.

SLIDER VARIABLE	MINIMUM VALUE	MAXIMUM VALUE	INCREMENT VALUE	Nominal setting for other slider variables that you are NOT changing
P1 - growth	0	20	2	4
P2 - growth	0	20	2	4
Birth threshold	8	100	10	26
P1 - energy	0	10	1	7
P2 - energy	0	10	1	7
Initial bacteria	0	300	50	300

Figure 9 Master table of all behavior-space experiments partitioned to enable team members to perform the simulations on their home computers.

	P1 - growth	P2 - growth	Birth threshold	P1 - energy	P2 - energy	Initial bacteria
P1 - growth						
P2 - growth	Nam					
Birth threshold	Megan	Nam				
P1 - energy	Tom	Moira	Megan			
P2 - energy	Grace	Grace	Andreana	Moira		
Initial bacteria	Tom	Andreana	Tom	Tom	Nam	

Figure 10 Assignment table for team members providing individuals responsible for running different sensitivity experiments associated with the NetLogo plastic-eating bacteria model.

Results

Employing the BehaviorSpace tool found under the tool tab in the NetLogo modeling environment, all combinations of variables were explored along with statistical measures of plastic and bacteria populations resulting from these simulations. The resulting data were captured in a comma-delimited file format enabling post-processing and analysis in either EXCEL or MATLAB. The NetLogo code was distributed to each of the team members along with assignments and responsibility for portions of the partitioned behavior space simulations (see Figure 10). The resultant data files were collected and integrated into a single master data file containing all variations of model space variables along with the resulting population distribution statistics. Some analysis was performed in EXCEL however due to the size of the master data file the analysis proved challenging and EXCEL 2010 limited the number of columns that could be captured within a worksheet to 16,384 which resulted in truncation of a portion of the runs captured in the comma-delimited format (CSV). MATLAB did not have these limitations and therefore became the preferred analysis environment.

The analysis proceeded in a staged fashion due to the large number of variables and range of variables incorporated into the NetLogo system model.

The first stage, which we named the "quick-look" stage, spanning the full parameter space but with very limited fidelity (step size). The simulations were run based on a behavior-space as specified in (see Figure 11).

Variable	Min. Value	Max. Value	Step Size	Nominal Value
Birth-Threshold				0
Initial-Number-Bacteria	0	400	200	
Plastic1-Energy	0	10	2	
Plastic1-Growth-Rate	0	20	2	

Figure 11 Behavior space for "quick-look" analysis with limited fidelity specifically targeted to identify phenomena of interest for later-stage, higher fidelity behavior space simulations and analysis.

A higher fidelity, stage-2 behavior space was also generated as depicted in figure 12 however, the resulting data file exceeded the column capability of EXCEL limiting the ability to use EXCEL to peruse the full set of simulation results.

Variable	Min. Value	Max. Value	Step Size	Nominal Value
Birth-Threshold	0	40	5	
Initial-Number-Bacteria	0	1000	200	
Plastic1-Energy	0	10	2	
Plastic1-Growth-Rate	0	20	2	

Figure 12 Behavior space for stage-2 analysis with expanded fidelity specifically targeted to explore the dependency of plastic remaining as a function of the birth-theshold variable.

Additional behavior spaces were run at extreme fidelity with many repetitions and extended time to ensure that the final value of the plastic1 population was stable and not experiencing transient oscillations of sizable magnitude. Unfortunately the data file resulting from these simulations were on the order of 300 MB and not viewable in their entirety by EXCEL. Results from one of the early runs (see Figure 13) provides insight into the final state populations of plastic types and bacteria count at the end of 1000 time steps clearly showing that the major population transients have damped out leaving only small residual oscillations in the plastic and bacteria populations.
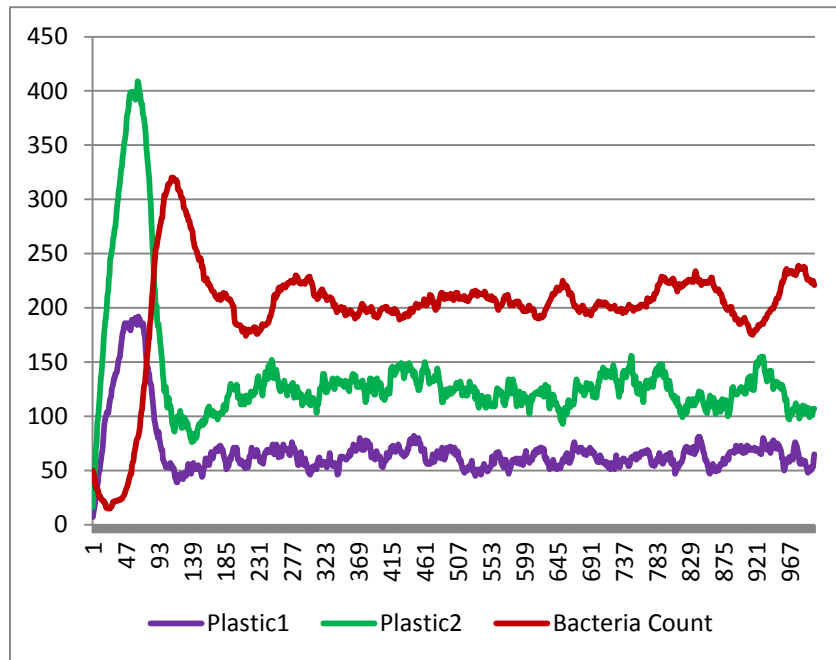
Figure 13 Plots of the plastic and bacteria populations as a function of increasing time increment demonstrating that 1000 time increments is sufficient for transients to damp out.

The results in figure 13 provide visual confirmation that we can reduce the number of time steps from $1000 \Rightarrow 500$ and be confident that statistical averages of these populations out past 300 provide reasonable confidence in the stability of the final-state population values.

Due to the limitations of EXCEL to handle the large NetLogo data files we shifted to using MATLAB and plotted the results for the behavior-space experiments as shown in figures 14-19 below.
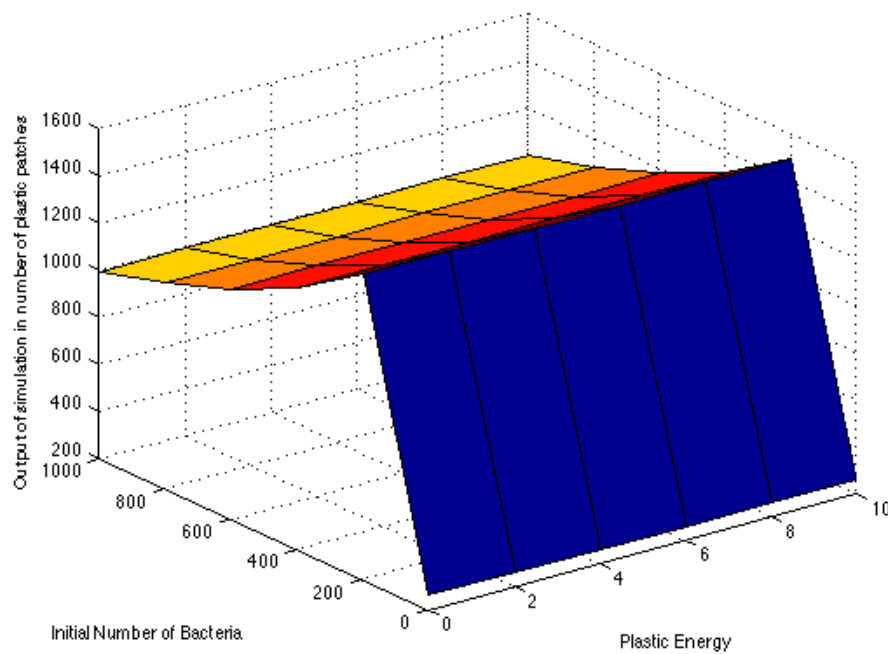
Figure 14 Sensitivity of the plastic1 population of patches as a function of the initial-number-of-bacteria variable and the energy-gained (calories) by the bacteria from consuming plastic1 particles.
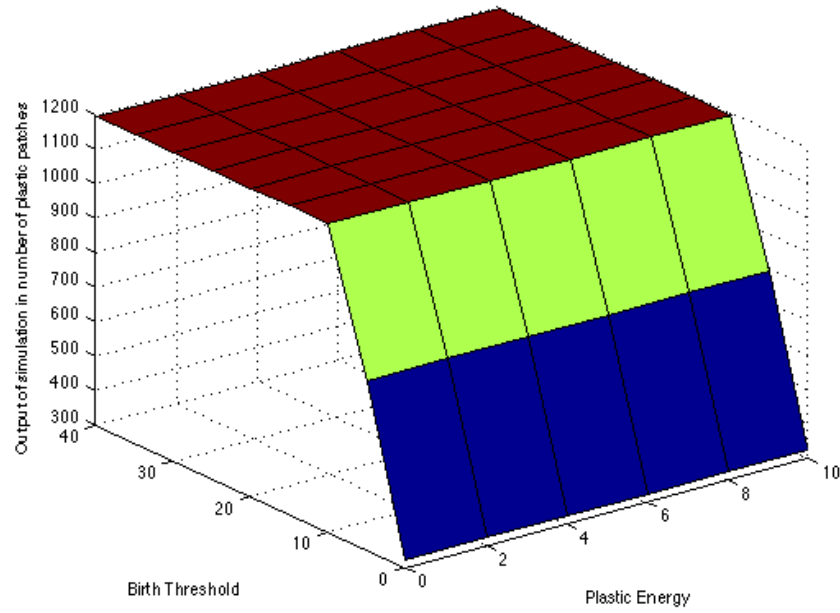
Figure 15 Sensitivity of the plastic 1 population of patches as a function of birth-threshold (binary fission) variable and the energy-gained (calories) by the bacteria from consuming plastic 1 particles.
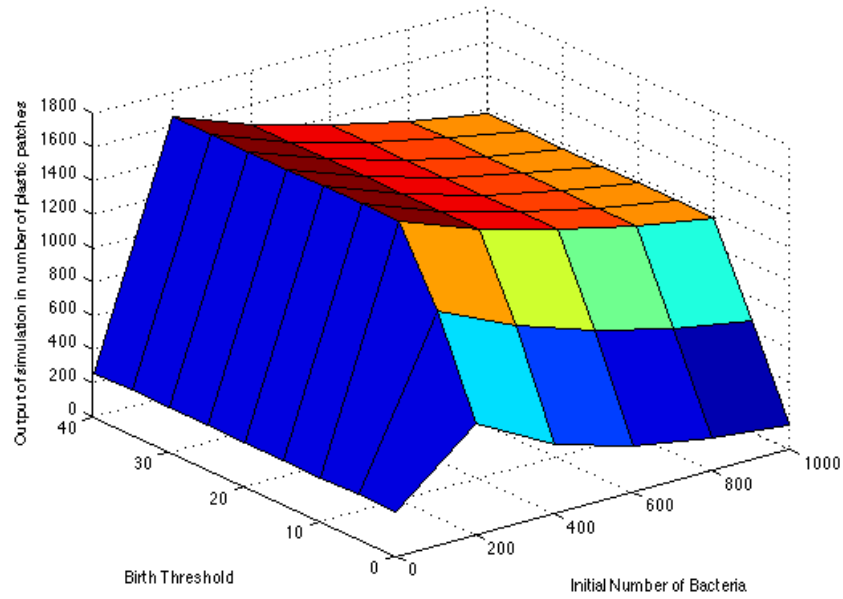
Figure 16 Sensitivity of the plastic 1 population of patches as a function of birth-threshold (binary fission) variable and the initial-number-of-bacteria variable.
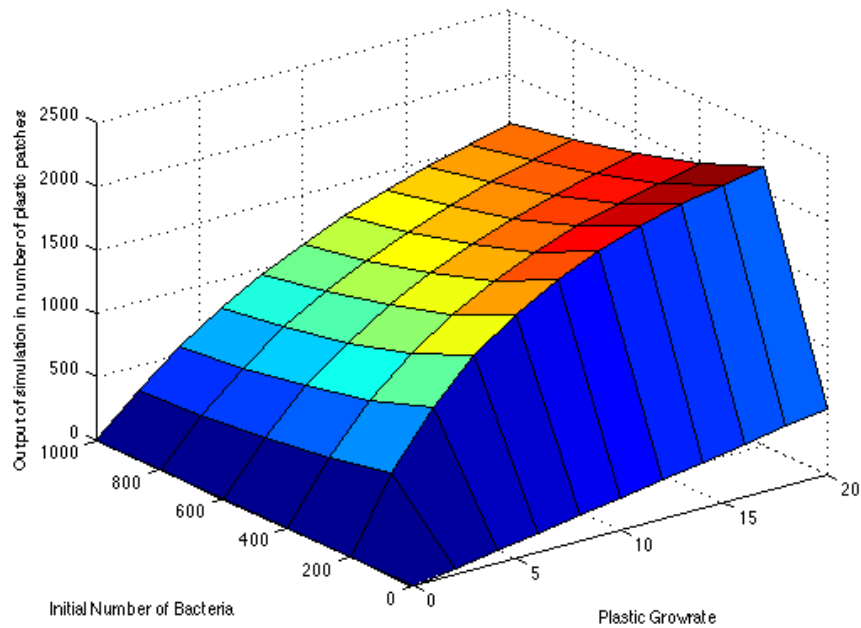
Figure 17 Sensitivity of the plastic 1 population of patches as a function of the initial-number-of-bacteria variable and plastic-growth-rate variable.
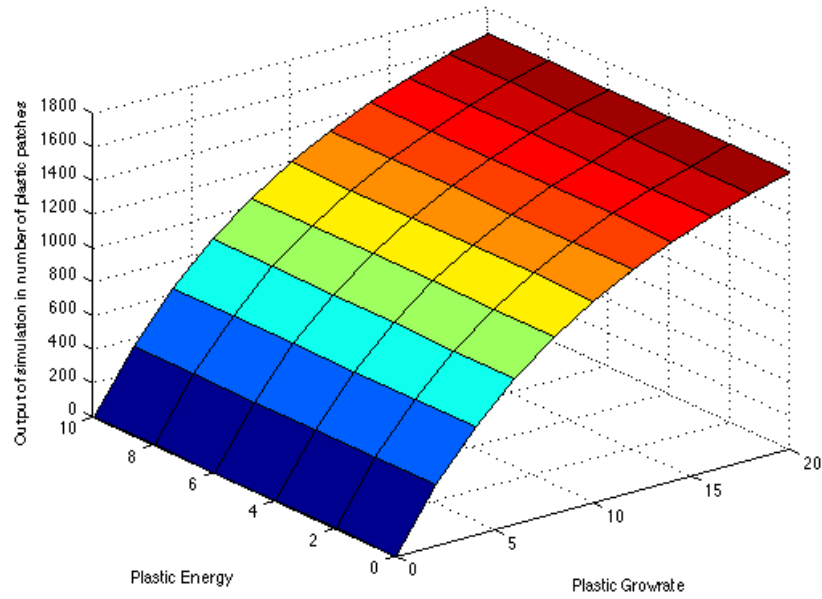
Figure 18 Sensitivity of the plastic 1 population of patches as a function of the energy gained (calories) by the bacteria from consuming plastic 1 particles and plastic 1-growth-rate variable.
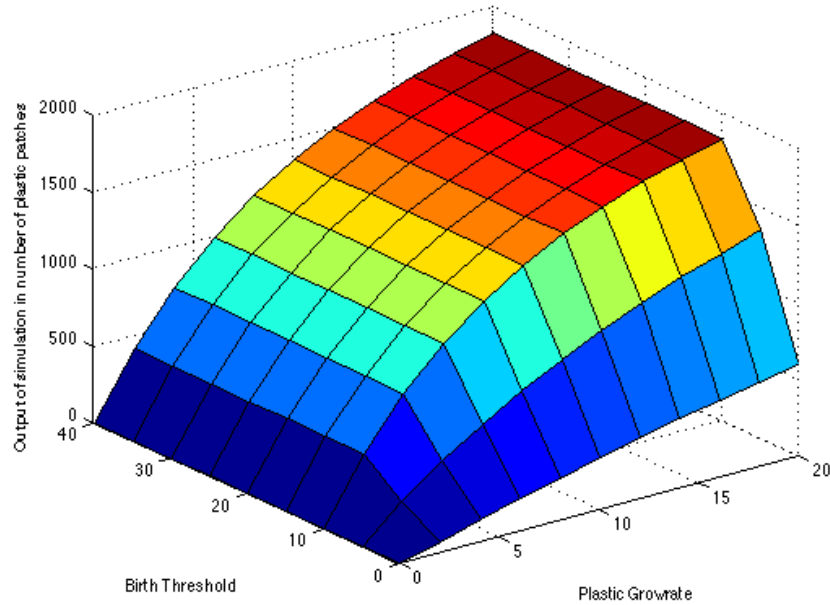
Figure 19 Sensitivity of the plastic 1 population of patches as a function of the birth-threshold (binary fission) variable and plastic 1-growth-rate variable.

Although the plastic1 population was of primary interest to the team the bacteria population was directly responsible for the evolutionary nature of the plastic1 population count. So to understand the cause-and-effect relationships we need to analyze the bacteria population with respect to the plastic1 population. Initial study of the relationship between the two populations (plastic1 and bacteria) were explored in a limited fashion with some results provided below in figures 20-23 showing the repeatability of the populations after 1000 time steps.
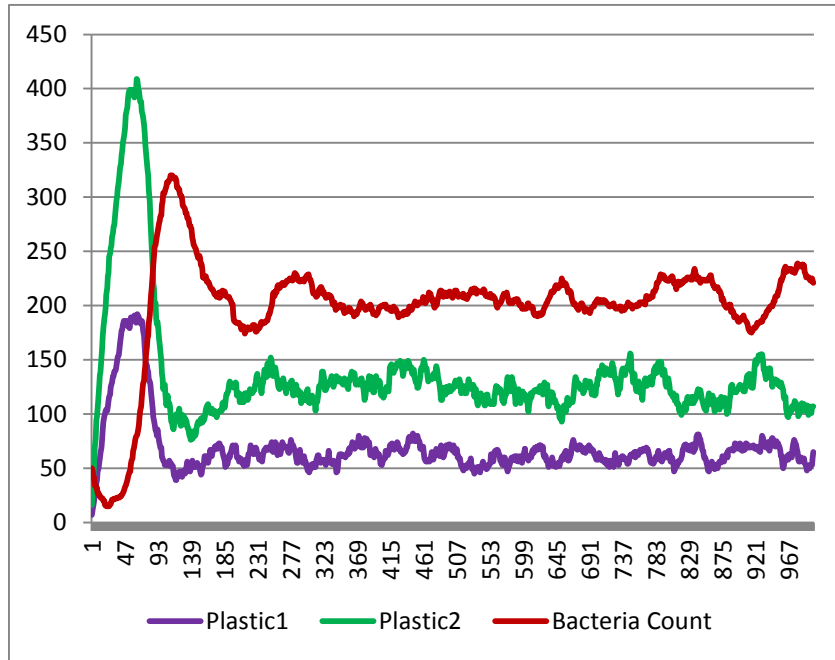
Figure 20
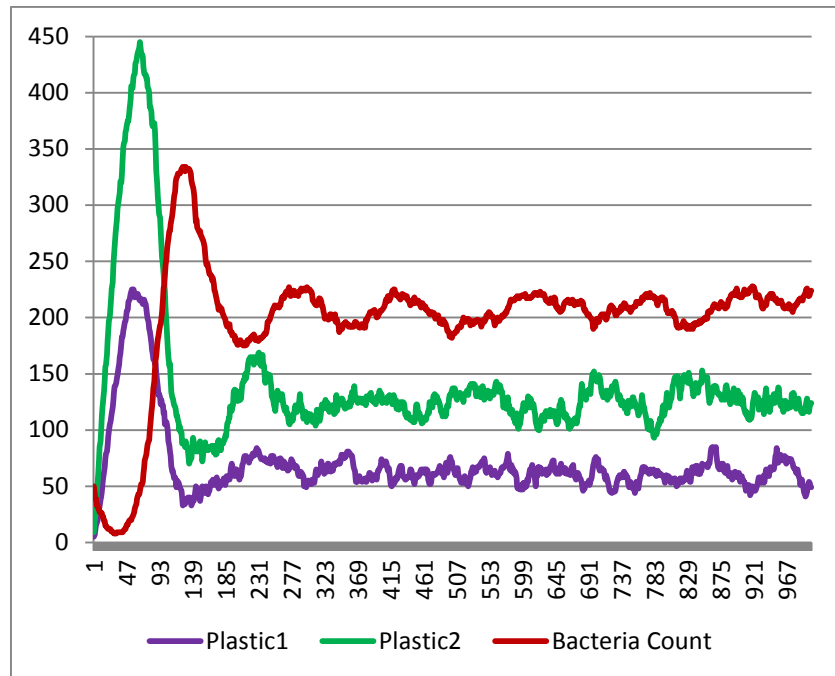
Figure 21
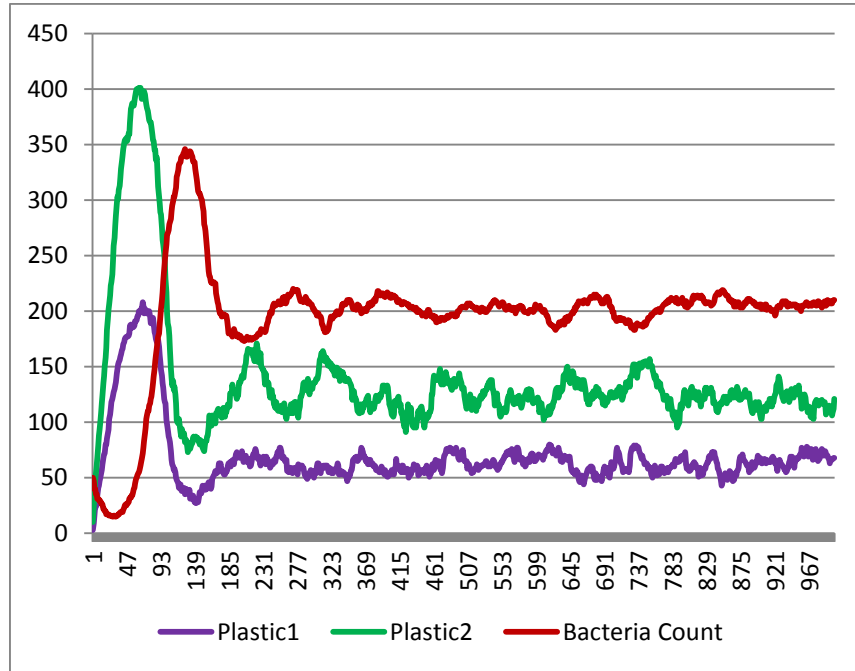
Figure 22
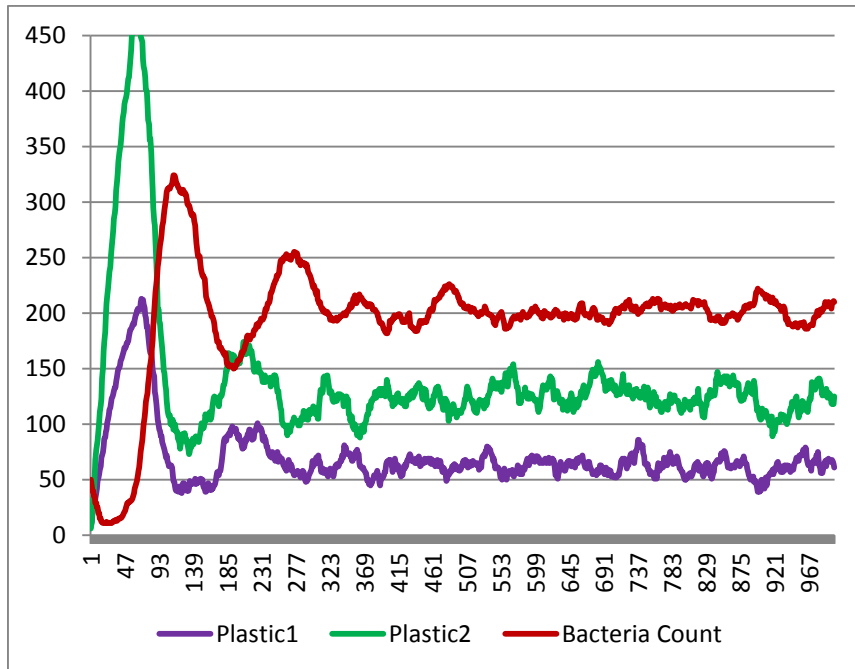
Figure 23

Employing the figures above we can see that we achieved good repeatability across different repetitions resulting in a final-state bacteria count of ~200 for final-state plastic1 count of ~50 and plastic2 count of ~125. The configuration space associated with these repeated runs is provided in figure 24.

Variable Name	Value
Birth-threshold	26
Initial number of bacteria	50
Plastic2-energy	7
Plastic2-growth-rate	4
Plastic1-Energy	7
Plastic1-Growth-Rate	2

Figure 24 Values for variables within the NetLogo Plastic-eating-bacteria System Model corresponding to the population evolution plots provided in figures 20 - 23.

Conclusion

Our results showed that the plastic-eating microbes and the continuous supply of plastic being added to the GPGP eventually reach a symbiotic relationship. That is, the plastic-eating microbes and their offspring consume the plastic at a rate that prevents the GPGP from growing larger. Our model also demonstrated that the GPGP can never be completely eliminated by the plastic-degrading microbes because as the plastic supply decreases, the plastic-eating microbe population dies off rapidly thus preventing a complete degradation of the plastic. Also, there is a continuous supply of plastic from humans thus preventing a complete elimination of the GPGP.

Bibliography

Casey, Susan. "Plastic Ocean." Bowermaster, John. Oceans. Washington DC.: Island Press, 2010. 71-82

Dautel, Susan L., (2009)Transoceanic Trash: International and United States Strategies For the Great Pacific Garbage Patch, 3 Golden Gate U. Envtl. L.J.

Environmental Protection Agency, "Marine Debris Impacts." Retrieved April 1, 2013, from water.epa.gov/type/oceb/marinedebris/md_impacts.cfm

Goldstein, Miriam C., Rosenberg, Marci and Cheng, Lenna. (May 9, 2012) Increased oceanic microplastic debris enhances oviposition in an endemic pelagic insect. Biology Letters

International Coastal Cleanup Report (2008)

Mincer, Tracy, personal communication, March 30, 2013

Moore, Charles (November 2003). Across the Pacific Ocean, plastics, plastics, everywhere. Natural History Magazine

Moore, Charles (October 2008). Synthetic polymers in the marine environment: A rapidly increasing, long-term threat. Environmental Research vol 108, issue 2, pages 131-139

Sheavly, S. B.; Register, K. M. (2007). "Marine Debris & Plastics: Environmental Concerns, Sources, Impacts and Solutions". *Journal of Polymers and the Environment* **15** (4): 301–305. doi:10.1007/s10924-007-0074-3

Sheavly, S. (December 8, 2010). De-mystifying the "great pacific garbage patch". Retrieved from http://marinedebris.noaa.gov/info/patch.html

Spooky http://www.odditycentral.com/pics/sea-of-garbage.html (February 11, 2008)