An Empirical Approach to Remotely Sensing Marine Plastics

Ethan Estess
EESS 141
March 17, 2010

Abstract

This study takes an experiment-based approach to determining if it is possible to remotely sense marine plastic debris directly using ocean color satellites. An original experiment was conducted which determine the optimal wavelength for remotely sensing plastics in water to be near 768nm. This result was extrapolated to a remote sensing application in the Great Pacific Garbage Patch and then to regions of high sailing vessel concentration, both with negative results. This method has been empirically shown to be ineffective, and further studies should seek out new approaches for locating regions of high plastic concentrations in the ocean to guide future cleanup efforts.

Introduction

The waters of the North Central Pacific Ocean contain an immeasurably enormous quantity of floating plastic debris in a region known as the Great Pacific Garbage Patch (**Figure 1**), and this mass of pollution stems from humanity's widespread use of this cheap and functional material. Plastic pollution's negative effects on marine life through ingestion and entanglement are widely documented (Donohue et al. 2007), and the harmful impacts of chemicals associated with plastic such as Bisphenol A and other Persistent Organic Pollutants (POP's) have been observed but are under-studied (Moore et al. 2001). Many expert scientists acknowledge the reality and severity of the marine plastics problem, yet few have proposed solutions. It is argued that any solution to plastic pollution of the ocean must come from the supply side of the equation- that any attempt to pick it up would be futile and costly.

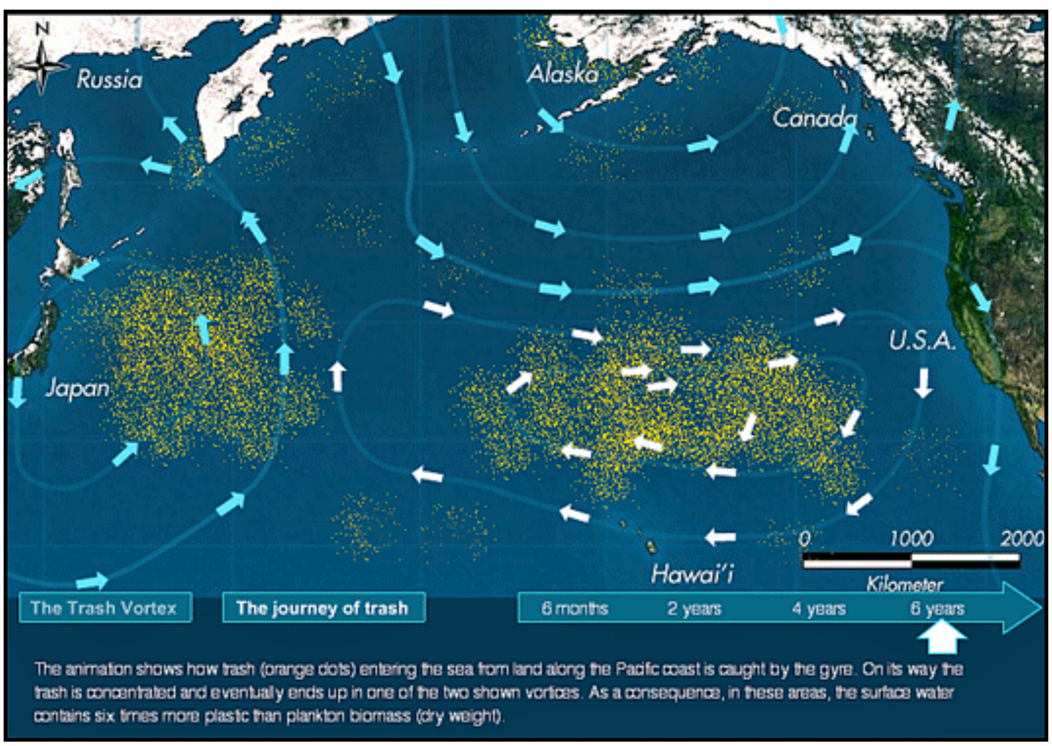

Figure 1: Location of Great Pacific Garbage Patch, divided into the Eastern and Western Garbage Patch

This author disagrees with this assumption, on the basis that a system could be designed which maximizes the amount of plastic removed and operates in a sustainable cycle. Nearshore cleanup projects have been successful in the Northwest Hawaiian Islands where the Garbage Patch has been documented to deposit large quantities of plastic (Boland 2006), but the time has come to focus on developing an open ocean cleanup system. A crucial element to this system would be reducing the search time for a vessel trying to harvest the plastic, and this could potentially be facilitated on some scale by the use of remote sensing. Most media articles covering this issue contain the disclaimer that the Garbage Patch is made up of small particles which are too finely dispersed over a large area to be imaged by satellites. At the same time, a review of the scientific literature did not return any studies which actually attempted to locate plastic directly using ocean color satellites. Other projects for example, the Ghost Net Project, have used satellite imagery to locate convergence zones where plastic may accumulate, but to the author's knowledge no studies have attempted to directly sense plastic by satellite. This represents a major void in our understanding of this serious environmental problem, and this project is designed to attempt to bridge this gap.

This study takes an empirical approach to remotely sensing marine plastics to determine if it is a feasible concept. A spectroradiometer was used to determine the optimal wavelength for measuring plastics suspended in water. An original experiment was designed and conducted to compare the signal strength and pattern from water without plastic in it to water with a known quantity of floating plastic pieces. The quantity of plastic was changed from one test to the next, and the Radiance (Lu) signal yielded from the plastic and the Downwelling Irradiance (Ed) signal were measured for each test. From this data, the particular wavelength at which plastic yielded the most distinct Remote Sensing Reflectance (Rrs) signal was determined. It is this author's hypothesis that this represents the optimal wavelength for sensing marine plastics by satellite.

Ocean color satellite imagery was then observed at the experimentally determined optimal wavelength to test the feasibility of remotely sensing plastic in the open ocean. To do this, dates and GPS coordinates of encounters with large amounts of plastic debris from several separate scientific expeditions to the Great Pacific Garbage Patch were collected. In addition, dates and GPS coordinates of high concentrations of plastic sailing vessels in a large open ocean race were gathered to determine if very large (>10m) pieces of plastic gave off a signal. SeaWiFS L1A images which lacked cloud cover from the regions and times of interest were collected and processed without an atmospheric correction to observe raw radiance at the experimentally determined optimal wavelength. The exact region of high plastic concentration were viewed with a Zoom feature, and by rescaling the color bar differences in radiance were accentuated to determine if the plastic debris could be imaged.

By locating large (~1m) pieces of plastic debris by satellite, it may be possible to guide clean up efforts to regions of higher abundance of plastic particles. This is an acceptable assumption considering that marine flotsam and jetsam of all sizes are known to accumulate together along current lines and at convergence zones (Ghost Net Project). For this reason, this study represents an important step in moving towards real solutions to marine plastic pollution.

Methods

A HydroRad 2 spectroradiometer was utilized to determine the optimal wavelength for measuring plastics in water. All radiance measurements were recorded simultaneously with irradiance measurements from the sky. Known quantities of plastic were incrementally added to the water for each successive test and data was recorded. Certain tests were repeated several times with different varieties and concentrations of plastic to see if the color, concentration, or type of plastic changes the results.

This experiment was conducted during the time interval of 11am to 1pm PST in February at approximately 37° N. The experimental design involved using a fresh water pool with a dark blue bottom and an approximate water depth of 1.5 meters. The sample location was in a large open area to prevent light contamination. The plastics samples consisted of pieces of assorted size, color, type, and degree of photodegradation which were collected from streets, water sheds, garbage cans, and beaches. Only medium sized plastic pieces (roughly 0.5cm to 2.5cm) that float in fresh water were used in this study. Plastic samples were rinsed with fresh water to clean off debris prior to the experiment. Both Ed and Lu sensors were mounted on a PVC pipe frame extending over the water, with the radiance sensor pointing straight down at the water surface and the irradiance sensor straight up at the sky (See **Figure 2**). The radiometer was connected to a PC with the program Radsoft installed on it. The experiment began by pointing both the radiance and irradiance sensors at the sky to see if their measurements were in accordance. A series of other calibration samples were conducted with the radiance sensor pointing down to see if it the instrument was functioning properly.

The first test measured the radiance from the surface of the water. A fishing line grid was then added to keep the plastic samples in the area of view of the radiance sensor, which was calculated to be approximately 14cm x 14cm, given a sensor altitude of 1m and a Field of View in air of 8°. The next test involved placing one small plastic particle in the water in the area of view before recording the signal. This process was repeated with 2, 4, 8, 16, 32, and 64 pieces of plastic, with several tests repeated for data quality control purposes. Each step of the experiment was photographed for record-keeping.

Figure 2: Photograph of experiment setup with radiometer on ground and sensors mounted on the PVC frame

The remote sensing aspect of this experiment entailed finding latitudinal and longitudinal coordinates and dates of vessels in an open ocean sailing race and of sightings of marine plastic debris in the open ocean (See **Figures 3 and 4** for sample locations). The Scripps Institute of Oceanography's recent research expedition to the Garbage Patch, called SEAPLEX, provided the necessary information for locating known quantities of plastic. Also, the 2006 Newport-Bermuda Ocean Race website possessed a sailing vessel tracking feature which was also very useful. The NASA Ocean Color Homepage was utilized to download L1A swaths from SeaWiFS containing the site in question on the specific date. Filed were loaded into SeaDAS with Pixel and Line Sample Rates of 1, and displayed at the experimentally determined optimal wavelength. A standard Chlorophyll a color scheme was loaded and the Cursor Position and Zoom functions used to locate test sites. If the image lacked obstructive cloud cover, the radiance counts were rescaled to determine if any discernible features became viewable at the site. A lack of any visible signal indicated either that there was no plastic at that location and time or that the plastic which was recorded to have been present at the site did not provide a strong enough signal to be remotely sensed. If it was uncertain whether there was a signal or not due to cloud cover or errors in the data, no significant conclusions could be drawn from the image.

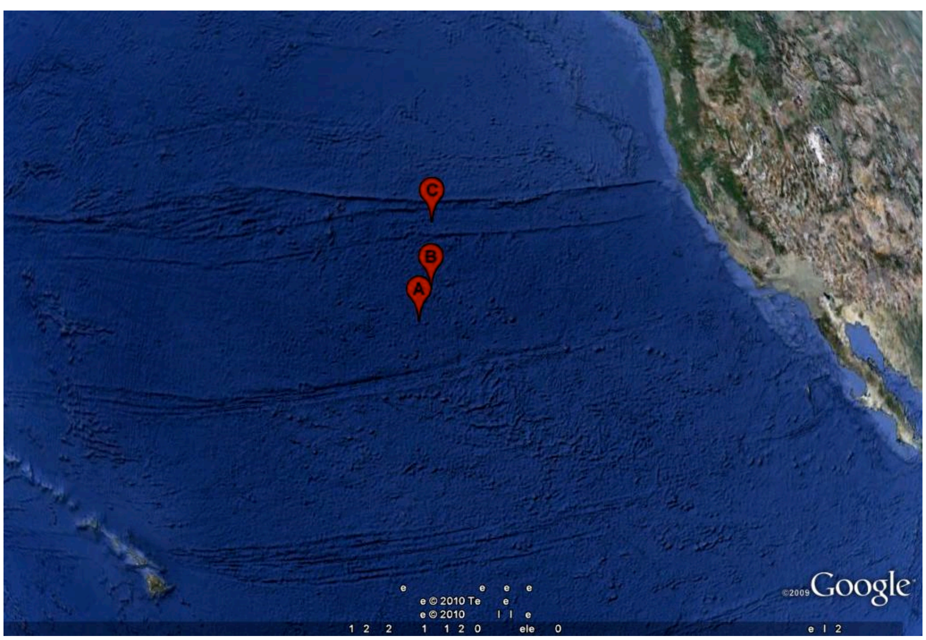

Figure 3: Sites of plastic observation from Scripps SEAPLEX project: A: 8-6-09 (34°23'60"N, 140°41'W), B: 8-17-09 (35°53'60"N, 140° 1'48"W) and C: 8-22-09 (39°N, 140°W)

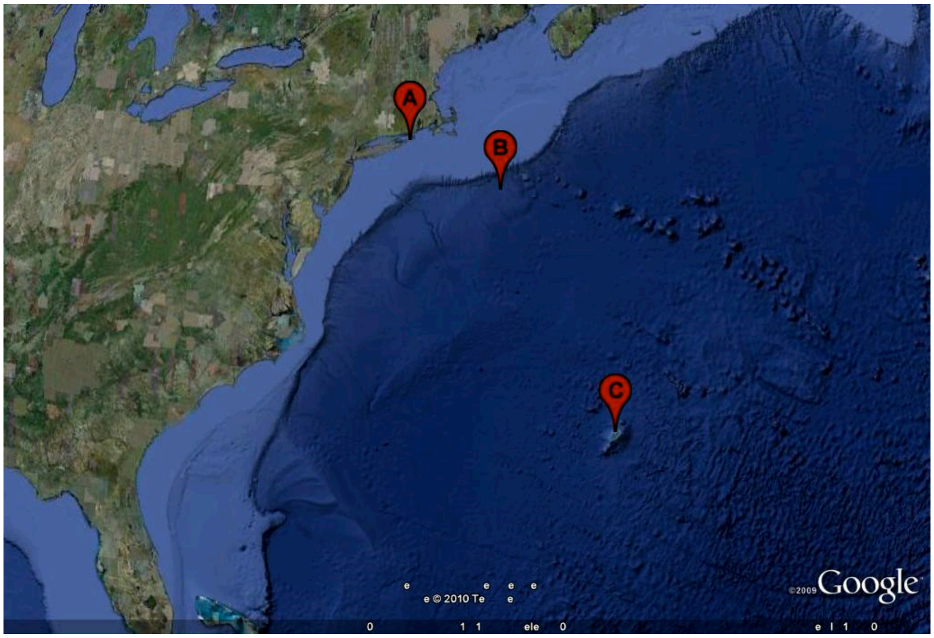

Figure 4: Sites of large (>10m) plastic sailing vessels in the 2006 Newport-Bermuda Ocean Race: A: 6-16-06 (41° 8'57.78"N, 71°45'57.17"W), B: 6-17-06 (39°38'33.59"N, 68°24'15.47"W), and C: 6-21-06 (32°30'41.75"N, 64°47'58.74"W)

Results

Data was collected for the spectroradiometer experiment and was subsequently analyzed. The first step was to adjust and align the wavelengths from the separate Radiance and Irradiance samples for each test, as the device logged samples at slightly different wavelengths for each sensor. This introduced a source of error, but it is definitely minor considering that before adjusting the data the wavelength measurements were off by as much as 10nm and after the greatest difference was 0.5nm- not a significant error for the level of accuracy required for this research question. The next step was to remove variations in Lu due to changes in Ed from solar angle and cloud cover by dividing Lu by Ed. This gave Remote Sensing Reflectance (Rrs) in units of Sr^-1. Rrs values were graphed with wavelength for all tests, with examples seen in **Figures**

5 through 8. It became evident at this stage that the wavelength of the absolute peak in signal strength did not vary significantly between tests with plastic and without, with the average peak in the range of 440nm. What was also obvious, though, was that the signal pattern was changing dramatically in the higher wavelengths when plastic was added. To better observe this part of the signal, Rrs values were smoothed using an 11 point smoothing technique and scaled to 440nm such that the Rrs value at 440nm for all tests was equal to 1. By graphing these smoothed and scaled Rrs values with wavelength on the same plot (**Figure 9**) it was possible to clearly determine at what wavelength the Rrs signal with plastic differed most from the signal without plastic.

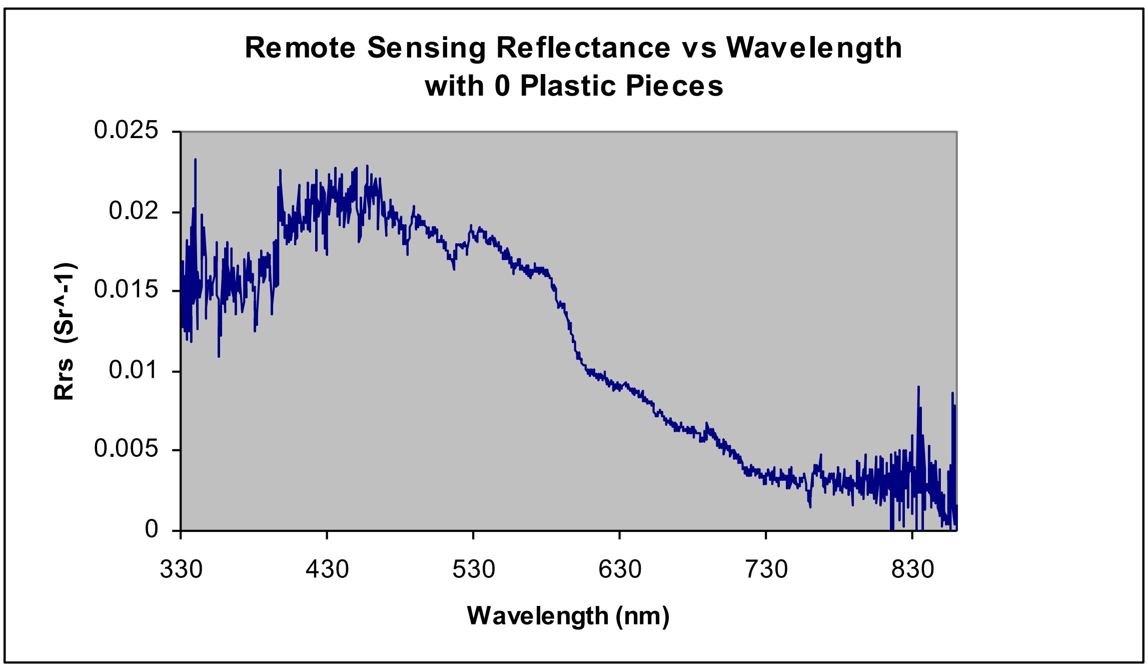

Figure 5: Graph of Remote Sensing Reflectance from control (water without plastic)

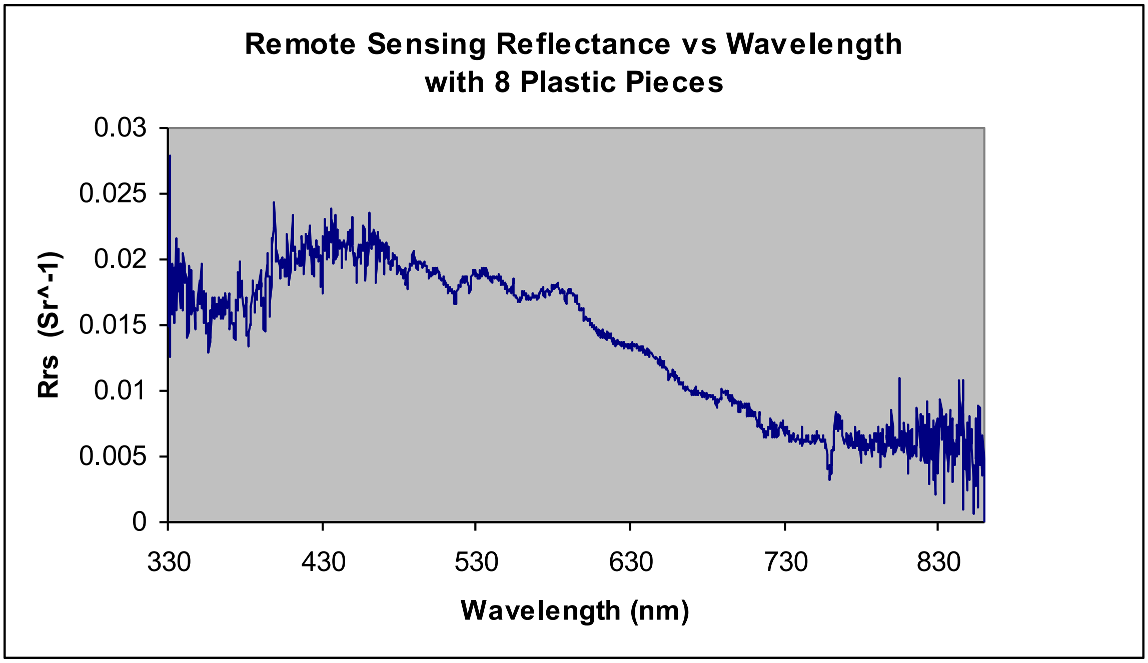

Figure 6: Graph of Remote Sensing Reflectance from water with 8 pieces of plastic

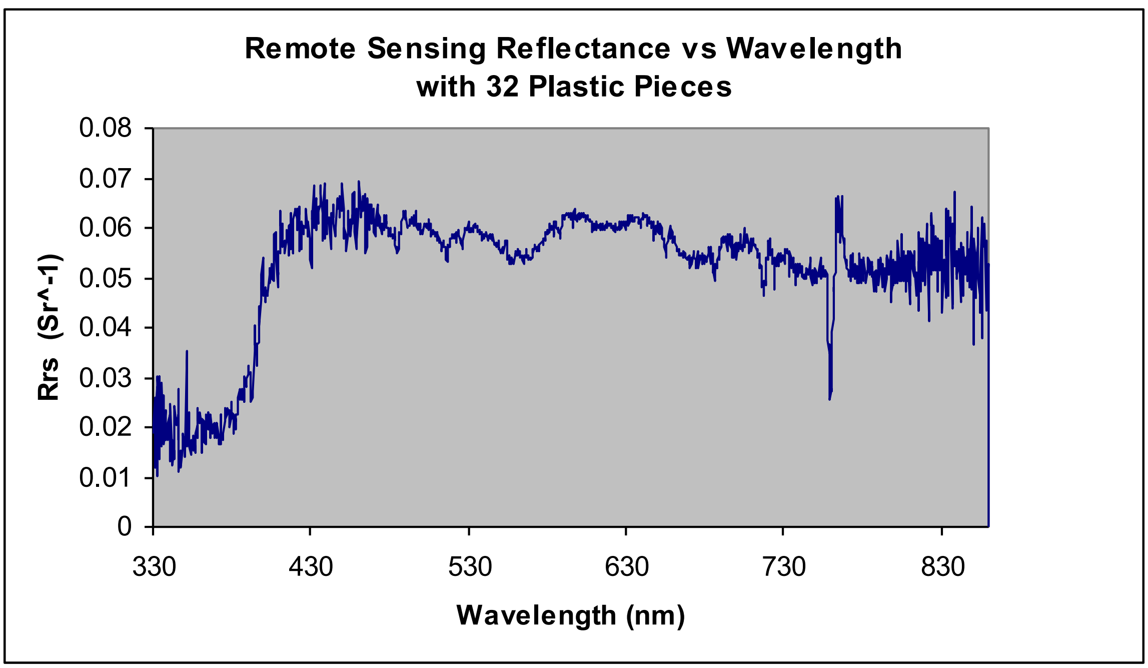

Figure 7: Graph of Remote Sensing Reflectance from water with 32 pieces of plastic

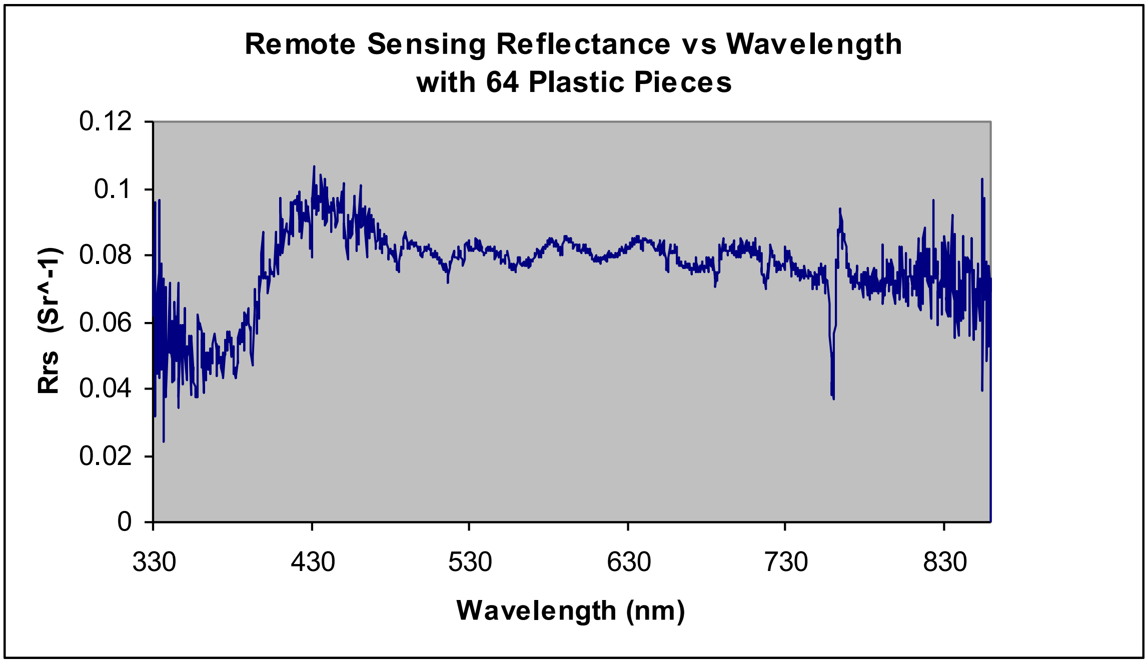

Figure 8: Graph of Remote Sensing Reflectance from water with 64 pieces of plastic

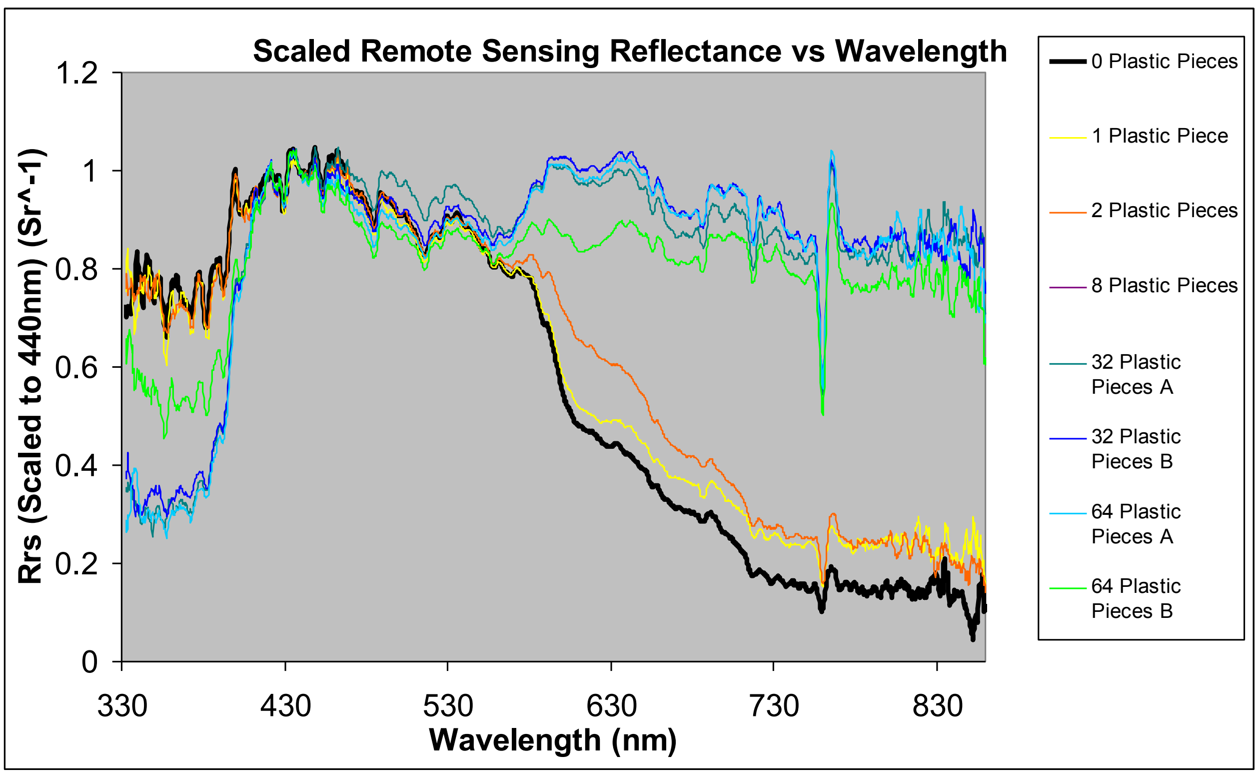

Figure 9: Graph of Remote Sensing Reflectance scaled to 440nm against wavelength

The optimal wavelength for measuring plastics in water was experimentally determined to be 768 nm. At this wavelength, the Remote Sensing Reflectance signal for all tests with plastic in them was most divergent from the tests without plastic. It was interesting that the signal from certain tests in the 330-390nm range was also very divergent for the plastic tests, but this study chose not to focus on this element of the data because there is no SeaWiFS channel below 410nm. The 768nm wavelength provides the strongest, most discernible signal from plastic in calm, fresh water, and this result was extrapolated to a remote sensing application.

The closest SeaWiFS channel to the 768nm signal peak is the 765nm channel, so satellite images were processed at this channel. Images from the Great Pacific Garbage Patch were created to test if plastic was viewable at the 765nm channel. Image sites were known to contain plastics from a range of sizes and varieties, from large discarded fishing nets to small particulate plastics dispersed throughout a large area. **Figure 10** represents an area at which a small discarded fishing net and other small forms of debris were found by the 2009 SEAPLEX project. There is a signal at the sample site, yet this it is impossible to know whether this is the result of the plastic at the site or of cloud cover. Cloud cover represented a great challenge in this project because of the resolution of data being used, and most images of sites with high plastic concentrations were unusable due to clouds. To overcome this, the focus shifted from looking at exact coordinates to larger, cloud free regions known to be within the Garbage Patch. This effectively removed cloud cover as a variable and made it possible to see if plastic debris actually was distinguishable in a large scale image of the sea surface. **Figures 10 and 11** show cloudless images scaled to very low Radiance values which lack any distinguishable characteristics resulting from plastic or other sources.

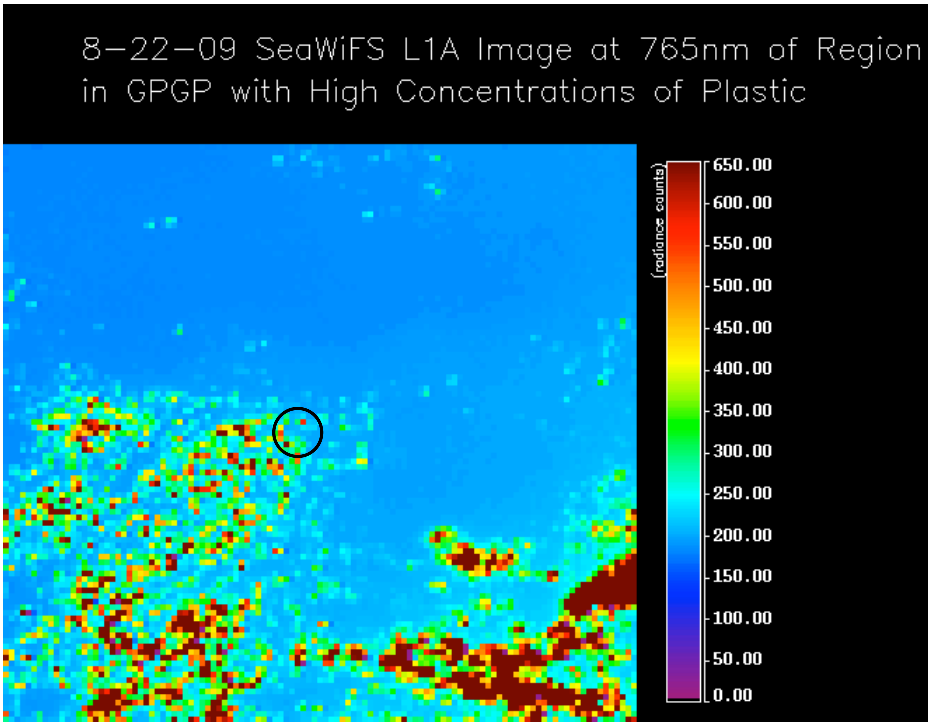

Figure 10: Site from Great Pacific Garbage Patch where SEAPLEX located discarded fishing gear and other plastic debris.

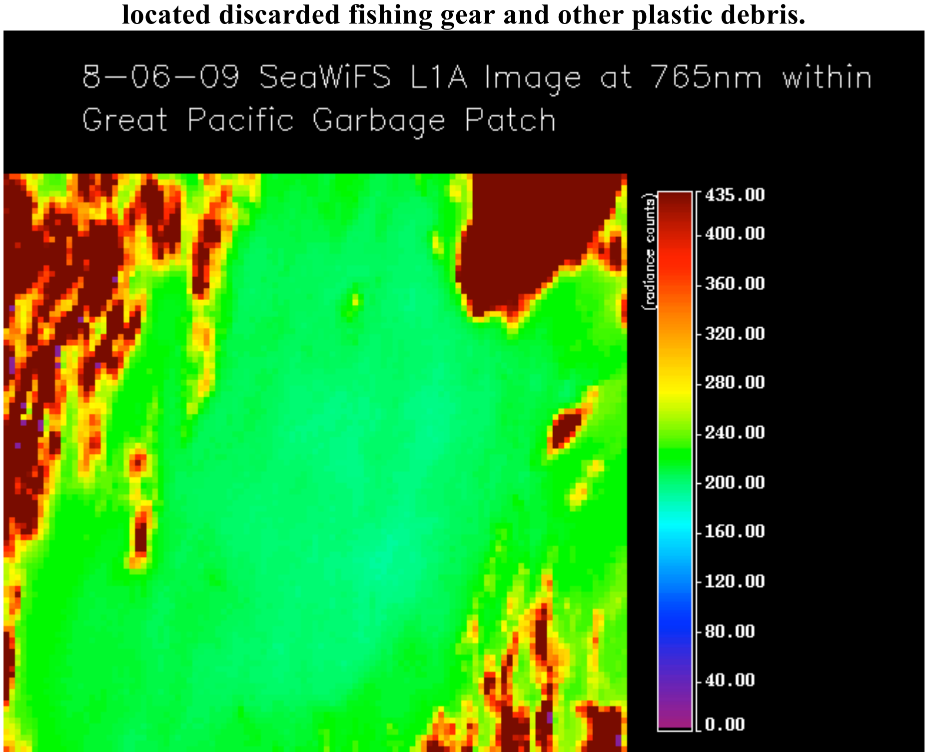

Figure 11: An almost cloudless region within the Great Pacific Garbage Patch

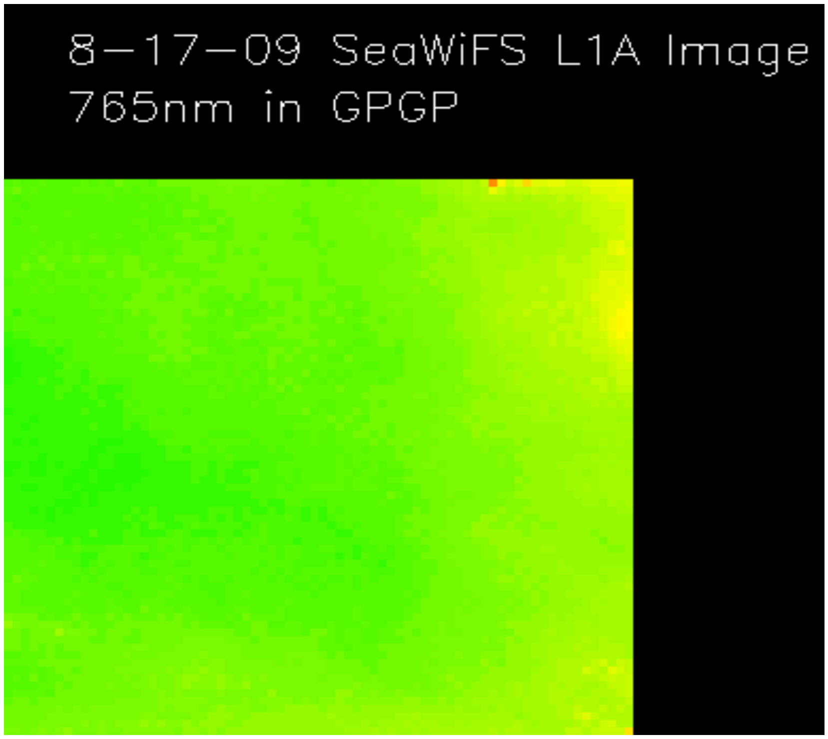

Figure 12: A cloudless region within the Great Pacific Garbage Patch. Note the lack of a signal from plastic or biota. (scaled to 335 Radiance Counts)

Satellite images from the Great Pacific Garbage Patch did not give sufficiently strong evidence to conclude if plastic debris is detectable, so images of a large, high density group of >10m sailing vessels created to see if more conclusive results could be generated. **Figure 13** possesses what appears to be cloud cover directly over a site of very high vessel concentration, but this is not necessarily the case because it is possible that the radiance signal from the boats looks very much like clouds. **Figure 14** also shows a patch of what appears to be cloud cover directly over another site of very high vessel concentration as the boats were arriving at the race finish line off Bermuda. It is very likely that these last two images actually represent cloud cover which happened to be over the boats and not a signal from the boats themselves for two reasons. First, the area over which the signal is seen is far too large to represent the group of vessels. The second reason is that **Figure 15** represents a negative result as a significant concentration of vessels should be present in the cloudless region of the image, yet none are seen. This image clearly shows that the large mass of boats that were present in the region were not sensible by SeaWiFS. There is a possibility that due to the time of day that the image was taken, the vessels may have been further south than predicted and thus not been visible in the image, but this is very unlikely. This body of evidence stands to suggest that it this technique of remotely sensing marine plastic debris is not functional.

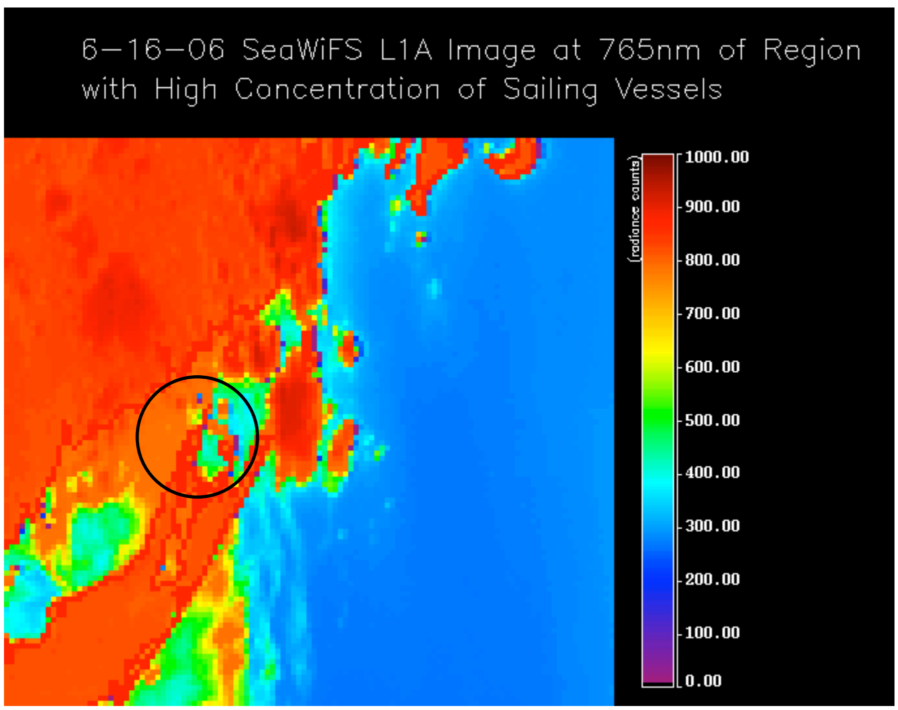

Figure 13: Site of high sailing vessel concentration off Newport, Rhode Island at the start of the 2006 Newport-Bermuda Ocean Race. Note the coastline in bright red and strong signal within sample area

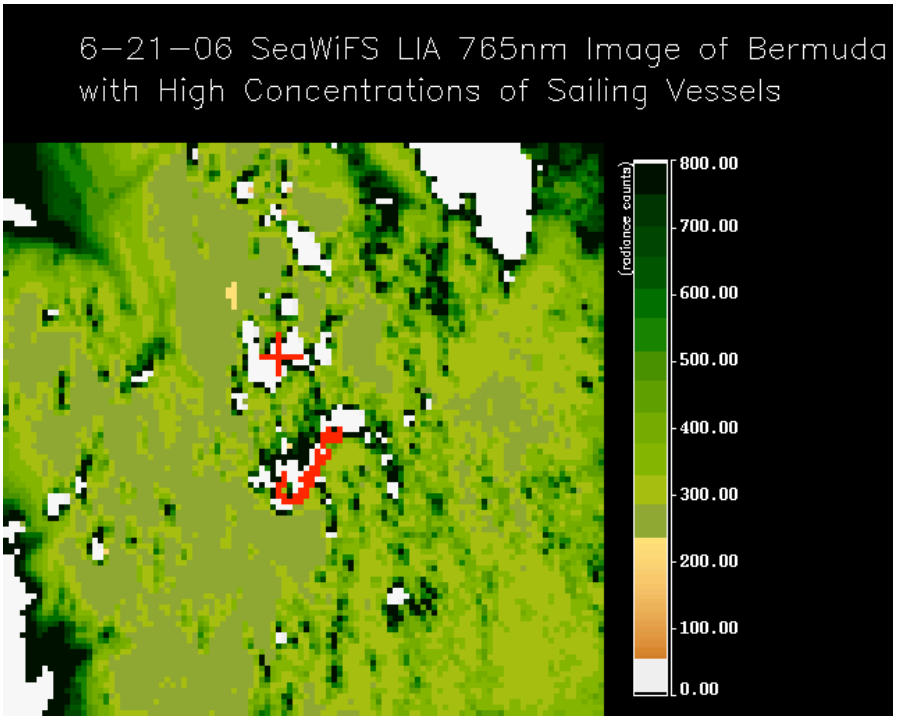

Figure 14: Bermuda (in red) at the end of the 2006 Newport-Bermuda race. High concentrations of vessels were present at the indicated location, as well as off the northern and western sides of the island.

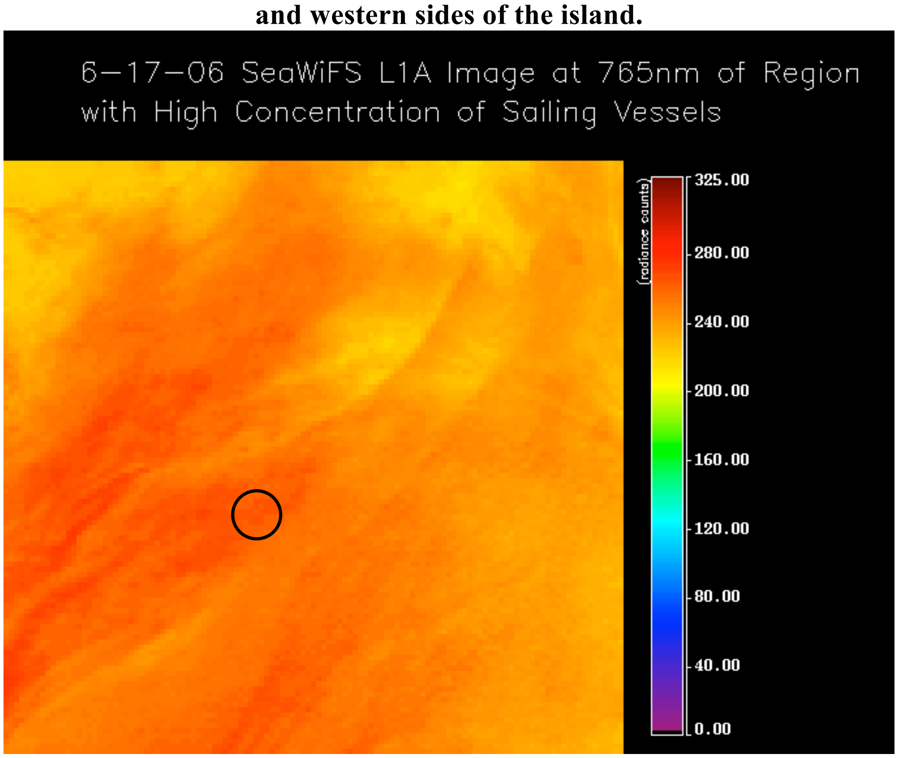

Figure 15: Northwest of Bermuda on a cloudless day. Note the lack of signal within or around the sample site.

Discussion

There were several technical difficulties associated with this project. First, identifying an exact site with a known presence of plastic debris in the open ocean is very challenging, considering GPS coordinates at the exact time that the satellite was overhead on a clear day paired with satellite photography of any cloud cover in the region are needed to be certain if any signal received is from something other than clouds. A potential technical shortcoming of the experimental component is that it was conducted in a shallow, sediment and algae free, fresh water pool and not in the open ocean. It is unknown to what degree the pool bottom effected the signal or how large a variation in signal strength and shape an experiment conducted in ocean water would result in. This study also operates under the assumption that the spectroradiometer was functioning properly and that the signal was not contaminated by the experimental design or by human interference. It is also unknown if water temperature plays an important role in this experiment.

Further studies could eliminate the technical challenges that faced this study. One potential solution would be for a vessel to tow a load of plastic debris (which would of course be secured in some way to the vessel to avoid losing it) to a particular location far offshore on a perfectly cloudless sky when the satellite is known to be overhead, log the GPS location, and then see if there is a signal from the known quantity of plastic. Repetition of the spectroradiometer experiment under different conditions could shed light on its accuracy and usefulness as a method for assessing the optical characteristics of plastic debris.

This study attempted to determine if it is possible to remotely sense marine plastics, and the evidence gathered suggests that it is not possible using this author's method. Results from the Great Pacific Garbage Patch were generally inconclusive, mainly because cloud cover was a pervasive element in all the images. **Figures 11 and 12** from the Garbage Patch which did lack cloud cover were clearly devoid of any signal, though, but because no exact coordinates of plastic within these images were known they were deemed inconclusive. **Figures 13 and 14** from the sailboat race sites were interesting because there were signals from the exact regions of very high sailboat concentration, but it is highly likely that these merely represent cloud cover over the sites in question and are therefore inconclusive. **Figure 15**, however, was also from a region of high sailboat concentration and it clearly shows that the boats at the site in question did not give off any observable signal, and due to the lack of cloud cover in the image it leads the author to conclude that this method of debris tracking is not feasible.

Conclusion

Regardless of this negative result, this is an effective and important study. The lack of scientific publications proposing techniques of locating marine plastic debris was shocking to this author, and this resulted in a sense of personal responsibility to add to the pool of knowledge for this subject. The idea of removing plastics from the sea is becoming increasingly realistic and new and improved remote sensing technologies may help it to become technologically and economically feasible. Somebody must take responsibility for the mess our species has made and is continuing to make in the Pacific and in other ocean basins, and the scientific community should spearhead this effort to ensure its sustainability and success. In regards to this study, it was recognized from the beginning that it is just as important to see if this method works as if it does not, as only by proceeding in this manner will humans make any progress towards mitigating marine plastic pollution.

A special thanks to Cpt. Jim Holms of the Clean Oceans Project and to the labs of Professor Raphael Kudela at University of California Santa Cruz and of Professor Kevin Arrigo at Stanford University

References:

2006 Newport-Bermuda Ocean Race Website
http://www.bermudarace.com/OntheRacecourse/RaceTracking/tabid/199/Default.aspx

Boland, Raymond. Zgliczynski1, Brian. Asher, Jacob. Hall, Amy. Hogrefe, Kyle. Timmers, Molly. *Dynamics of Debris Densities and Removal at the Northwestern Hawaiian Islands Coral Reefs* Marine Pollution Bulletin. 2006

Donohue, Mary J. Foley David G. *Remote Sensing Reveals Links Among the Endangered Hawaiian Monk Seal, Marine Debris, and El Nino* Marine Mammal Science 2007

Great Pacific Garbage Patch Image
http://students.umf.maine.edu/learykp/public.www/

High Seas Ghost Net Project Website
http://www.highseasghost.net/overview.html

Moore, C.J. Moore, S.L. Leecaster, M. Weisber S.B. A *Comparison of Plastic and Plankton in the North Pacific Central Gyre* Marine Pollution Bulletin 2001

SEAPLEX Project Website
http://sio.ucsd.edu/Expeditions/Seaplex/