Introduction

Recently, there has been considerable news coverage of ”the Great Pacific Ocean Garbage Patch”[2]. Based on recent scientific researches in the Pacific Ocean Gyre, a wide variety of technical and scientific problems associated with this plastic debris are coming to light. Many biologists point out that plastic debris would create many potential threats on marine eco-system, and ultimately jeopardize human beings. Many biologists have pointed out that plastic granules appeared in the digestive system of the seabirds and other animals,but the path of the particles in the marine ecosystem and the concentration of plastic in different species is poorly understood.

As the backgrounds noted above, this article mainly draws together to address the circulation of plastic pollution in the eco-chain and its impacts on the local eco-system. So our goal is pretty clear:

- Model the original circulation of marine eco-system.
- Model the concentration of plastic in different species.
- Model the circulation of plastic pollution with increasing plastic pollution.
- Model the impacts on the survival of species.
- Take the factor of cleaning up into consideration to get a revised model.
- Put forward the government policies and practices that should be implemented to ameliorate its negative effects.

Step1: A Simple Biomagnification Model Based On The Eco-Chain

There’re a wide variety of biological species surviving in the Pacific Ocean and therefore the marine ecosystem is very complex. To simplify the model, typical species were chosen to make up the marine eco-chain[3] shown as Fig1. When the plastic pollution enter the marine environment, they are attached to the plankton or just free in the ocean, fish consume contaminated plankton.[4] Concentration of plastic debris increases up along the eco-chain.[5] Meanwhile, the plastic debris return into the ocean through the excrement and corpses of organisms.

In this step, we consider how the plastic debris transmit along the eco-chain,with different concentration of plastic in different species . To study this problem, we construct a model to gain the concentration of plastic population in each species due to biomagnification.

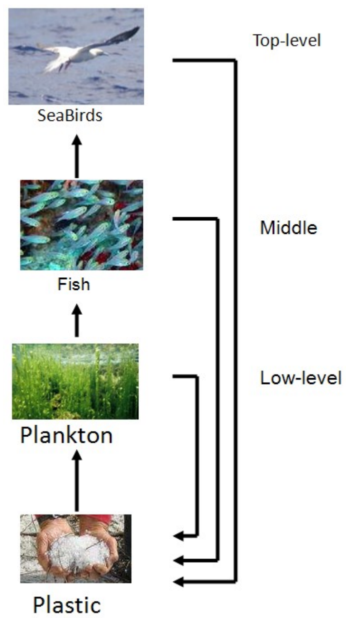

Fig 1: The marine food chain

1. Assumptions

- Species in the marine ecosystem has a uniform distribution and a relatively stable population;

- Species in higher level mainly feed on species in lower level,and we omit the impacts of other predation approach;
- species are attributed to the eco-chain in the sea;
- The Concentration of plastic pollution has not reached the threshold of death.

2. Terms and Definitions

Terms	Definitions
$x_(i)$	population of the species in the ith trophic level
N_i	the plastic amount in the ith trophic level
ξ_i	transmission ratio from the ith to the (i+1)th trophic level
$C_(i)$	the concentration of plastic pullution in the ith trophic level
σ_i	plastic transmission ratio renturned to the Ocean from the ith trophic levels

3. Model Construction

Fig2 shows the transitive relation between the ocean and each trophic level. Therefore, we can build differential equations to describe the relationship.

$$\begin{cases} \frac{d_{N_1}}{d_t} = N_4\sigma_4 + N_3\sigma_3 + N_2\sigma_2 - N_1\xi_1 \\ \frac{d_{N_2}}{d_t} = -N_2\xi_2 - N_2\sigma_2 + N_1\xi_1 \\ \frac{d_{N_3}}{d_t} = -N_3\xi_3 + N_2\xi_2 - N_3\sigma_3 \\ \frac{d_{N_4}}{d_t} = N_3\xi_3 - N_4\sigma_4 \\ C_i = \frac{N_i}{x_i} \end{cases} \tag{1}$$

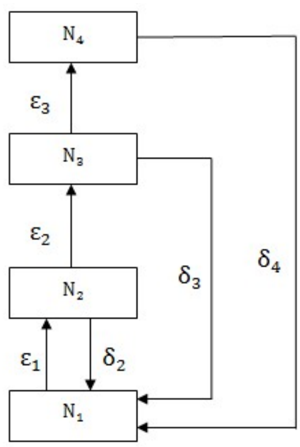

Fig 2: Model diagram

4. Model Solutions

Due to the complexity of the analytical solution and the difficulty to obtain the real data, we use simulation data to solve the model constructed above. The number of consumers at each level decreases significantly, so that a Single top Consumer, will be supported by a million separate producers[6].

We assume that the initial values shown below

Symbols	$N_1(0)$	x_1	x_2	x_3	x_4	ξ_1	ξ_2	ξ_3	σ_2	σ_2	σ_2
Initial values	600	10^{12}	10^{10}	10^9	10^7	0.001	0.01	0.008	0.005	0.005	0.005

Using the simulation data, although we can not get an accurate value, we can predict the trendency of the plastic concentration in the ocean and different species as shown in Fig3,4.

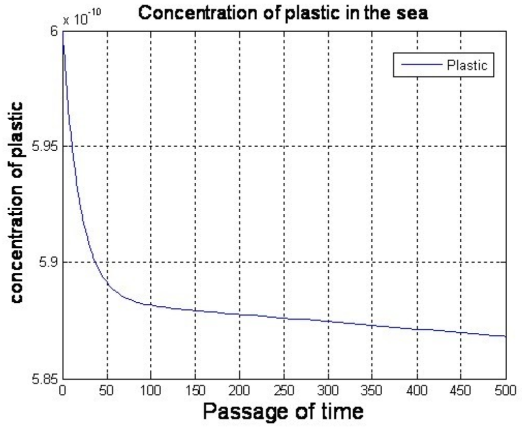

Fig 3: **Concertration of plastic in the sea**

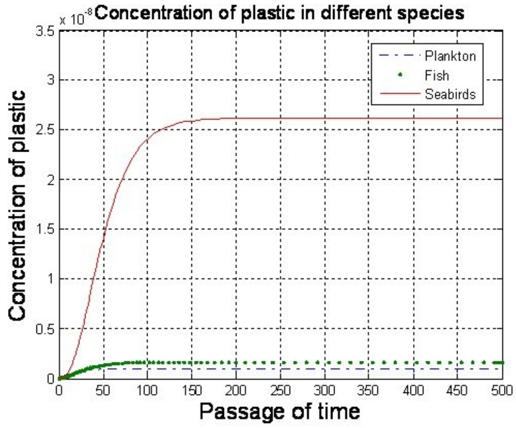

Fig 4: **Concertration of plastic in different species**

From two figures above, we can see that the plastic concentration in the sea would gradually decrease to a stable value, and plastic concentration in different species would increase and finally reach to a stable state.

We can also get another conclusion that the concentration of species in upper level is much higher than that in the lower levelbesides, the population of species in upper level is very small compared with that in lower level.[6] So the concentration of species in the upper level is always much higher than that in lower level. This also confirms the role of biomagnification in the eco-chain,which has been confirmed by many biologists.

Step2: Taking The Real Environment Into Account

1. Model Construction

Through the simple mathematical model above, we can obtain the concentration of plastic particles in each layer due to biomagnification. But the reality is often not so simple, so we often have to take the emissions from the environment each year and Self-purification capacity of the ocean into account. Therefore, in the actual process, we need to amend our model as follows:

$$\begin{cases} \dfrac{d_{N_1}}{d_t} = N_4\sigma_4 + \sigma_3 N_3 + N_2\sigma_2 - N_1\xi_1 + C - \beta N_1 \\ \dfrac{d_{N_2}}{d_t} = -N_2\xi_2 - N_2\sigma_2 + N_1\xi_1 \\ \dfrac{d_{N_3}}{d_t} = -N_3\xi_3 + N_2\xi_2 - N_3\sigma_3 \\ \dfrac{d_{N_4}}{d_t} = N_3\xi_3 - \sigma_4 N_4 \\ C_i = \dfrac{N_i}{x_i} \end{cases} \tag{2}$$

where β means self-purification factor; C means the amout of the plastic pumped into the ocean , to simplify the model, we assume C is a constant here.

As the amount of the plastic reduced with the ocean's self-purification ability is far less than that pumped into the ocean each year, we can almost ignore the role of the ocean's self-purification ability.

2. Model Solutions

Using appropriate simulation data, we can also draw out the trend of the plastic content in the ocean as well as each trophic level.

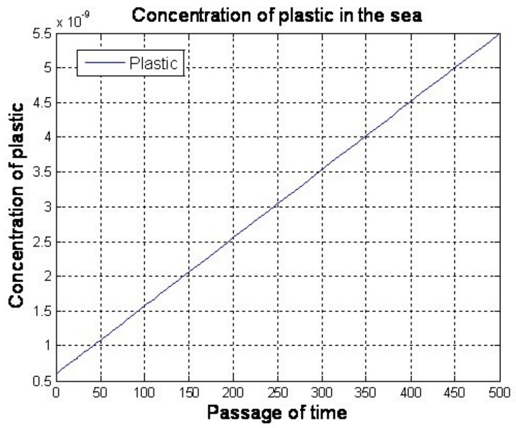

Fig 5: **Concertration of plastic in the sea**

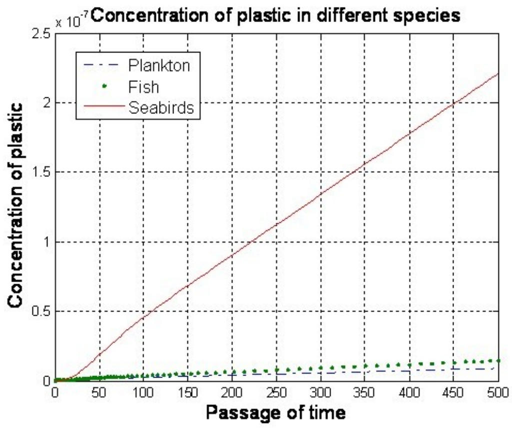

Fig 6: **Concertration of plastic in different species**

The two figures above show that the concentration of plastic pollution in the ocean would grow unlimitedly, and besides, plastic in some species may grow unlimitedly either.

Step3: How The Concentration Of Plastic Threats On The Survival Of Species[7]

As the results shown above, we find that when the plastic pollution effects the marine eco-system, they would accumulate in different species. Too much plastic beyond the limits of a certain concentration would pose a threat on the survival of species. Therefore, to study how the concentration of plastic pollution threats on the survival of species is necessary.

Terms and Definitions

Terms	Definitions
$x(t)$	population of the species
$C_E(t)$	the concentration in the environment
$C_0(t)$	the concentration in the Organism

1. Impacts Of Pollution On The Single Species

First,We can establish a Logistic model in the normal environment without plastic pollution:

$$\frac{d_x}{d_t} = x[b - d - fx] \tag{3}$$

Where b and d is constants, stands for the birth rate and the death rate; $\frac{b-d}{f}$ stands for the carrying capacity of the environment; f stands for the density-dependent factor.

Second, in the condition of plastic pollution,as the growth rate $r = b - d$ will decrease with the increasing density and mass of pollution,we add the impact of pollution to the growth rate to get a revised growth rate:

$$r = r(C_0) = r_0 - H(C_0) \tag{4}$$

Where $H(C_0)$ stands for the pollution level,$H(0) = 0$,and $H(C_0)$ increases with the environmental deterioration. We regard $H(C_0)$ as the function of pollution, It should satisfy the following equation:

$$H(C_0) = r_1 C_0 \tag{5}$$

Where r1 stands for the scaling factor, C_0 stands for the density and mass of plastic in biotic population, we regard it as a function as follows:

$$\frac{d_{C_0}}{d_t} = kC_E - gC_0 \tag{6}$$

Where kC_E stands for the ingestion by the species, gC_0 stands for the emissions by the species.

$$\frac{d_{C_E}}{d_t} = -hC_E + u_t \tag{7}$$

Where $-hCe$ stands for the decrement by the self cleaning capacity, $u(t)$ stands for the increment by pollution.

Finally,We can get a "single species" model in a polluted eco-system:

$$\begin{cases} \frac{d_x}{d_t} = x[r_0 - r_1 C_0 - fx] \\ \frac{d_{C_0}}{d_t} = kC_E - gC_0 - mC_0 \\ \frac{d_{C_E}}{d_t} = -hC_E + u_t \end{cases} \tag{8}$$

and initial conditions $x(0) > 0, 0 \le C_0(0) \le 1, 0 \le C_E(0) \le 1$.

In order to compare the impacts on a single species model in different conditions ,we carried simulation data to indicate the impacts of pollution on single-species ,we use Matlab to implement the model, with the results of Figure bellow,where we see that can see that with the passage of time in the condition of varied $C_0(t)$;

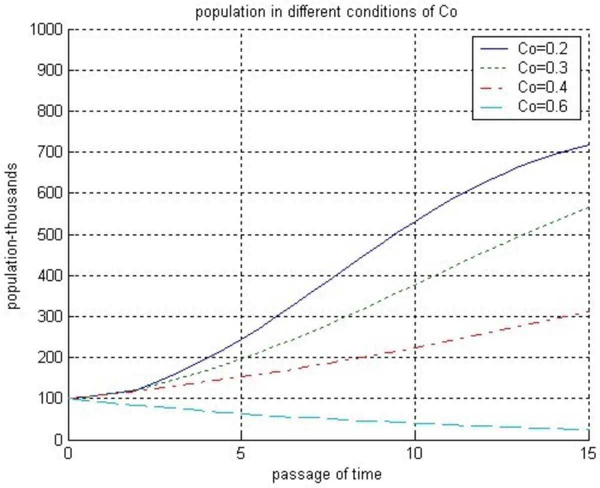

Fig 7: population in different conditions of C_0

As we can see from the figure, population still increase in the condition of low pollution level, When the pollution level increased to a certain value, population will decrease gradually, if no effective measures are taken, population would face the danger of extinction.

2. Try To Find The Prerequisites To Keep Eco-Balance

Further , we try to explore the value which determines the key factor of species development , here , we give different conditions of C_0 in the model as follows:

(1) Density of pollution has a upper limit:

a) if $\langle C_0 \rangle_* < \dfrac{r_0}{r_1}$,then any species with a initial number $x_0 > 0$ can keep a low developing state in the condition.

b) if $\langle C_0 \rangle_* > \dfrac{r_0}{r_1}$, then any species with a initial number $x_0 > 0$ would face the danger toward extinction.

(2) Density of pollution increase all the way

In this condition, when pollution become serious, then $C_0 > \frac{r_0}{r_1}$, that is, any speciecs would face the danger of extinction in future.

From the above analysis, in future, we can monitor the density of plastic to evaluate the impacts of pollution on the species developing, besides, in terms of environmental protection and animals protection, if we can calculate some important parameters of local eco-system by further experiment or research, with the above analysis, we can establish a plastic pollution schedule to protect local environment, which provides a good method for protecting local environment.

3. Impacts On Multi-Population

We have discussed impacts of plastic pollution on single-population, likewise ,we can also get the impacts and the threshold on multi-population, here we omit the process of modeling , reference[6] can provide the modeling process.

Step4: Simulating A Cleaning-up Plan

Analysis above show that if we don't take mesures to control the situation, the concentration of the plastic pollution in the ocean would increase all the way. And species suffer from great concentration of plastic pollution, which would cause great harm on each species along eco-chain. therefore it is high time we should take effective measures to address this problem, take the factor of removing plastic into the model mentioned above, we could get a amended model as follows:

$$\frac{d_{N_1}}{d_t} = N_4\sigma_4 + N_3\sigma_3 + N_2\sigma_2 - N_1\sigma_1 - \alpha N_1 \tag{9}$$

Where α stands for the removing proportion of plastic every year.

1. $\alpha = 1\%$

We use this amended differential equation to predict the trend of eco-system developing, as we can see from the figure8 and figure 9, the effects of plastic pollution would be limited in a low state compared with the precious one, on the contrary, the situation would still deteriorate in future, which shows that the removing proportion is not big enough.

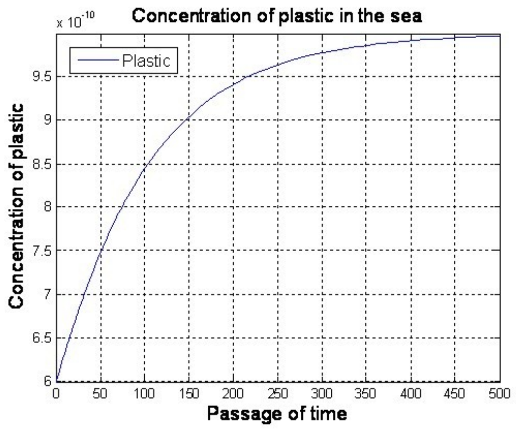

Fig 8: **Concertration of plastic in the sea**

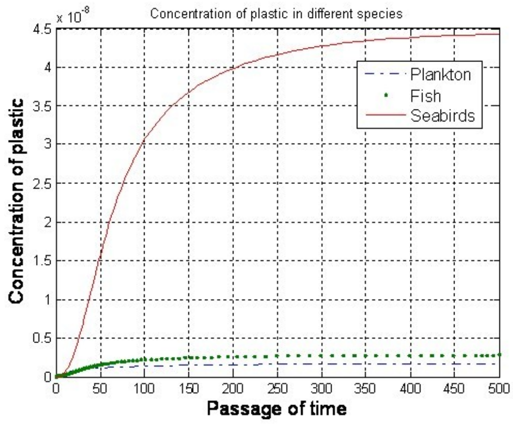

Fig 9: **Concertration of plastic in different species**

2. $\alpha = 1.65\%$

We get the following diagram shown in Fig9,10.

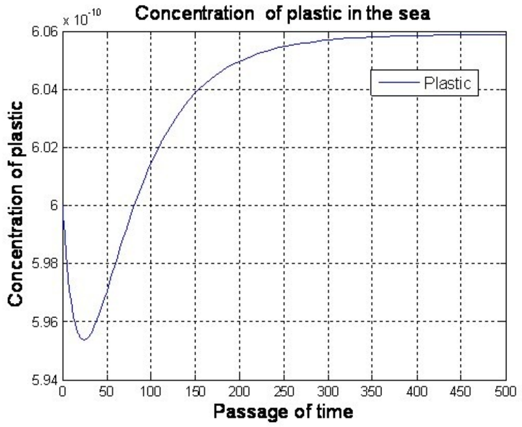

Fig 10: **Concertration of plastic in the sea**

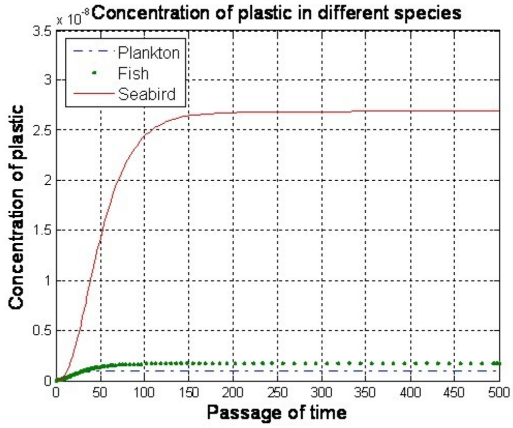

Fig 11: **Concertration of plastic in different species**

It shows that after fluctuating in a period of time, the concentration of the plastic pollution eventually stabilizes at the initial value. That proves at such governce intensity, the plastic concentration of the entire system maintains previous level. Neither deteriorated nor turn for the better. Therefore, this value is the threshold.

3. $\alpha = 10\%$

Likewise, we can get figure14 and 15, we can have a conclusion that with a removing proportion of 10%,the concentration of plastic pollution decreases gradually and finally reaches to a tiny state, at the same time, the concentration of different species would increase first and reach the peak but decrease gradually, which shows that if we can take a cleaning-up plan to remove 10% proportion of plastic every year, we can have a steady process to minimize the impacts of plastic and restore the balance of local eco-chain.

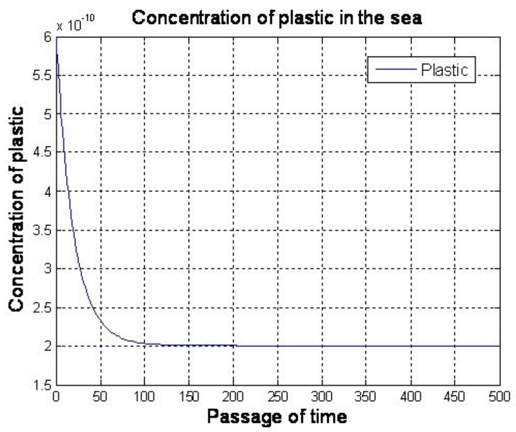

Fig 12: **Concertration of plastic in the sea**

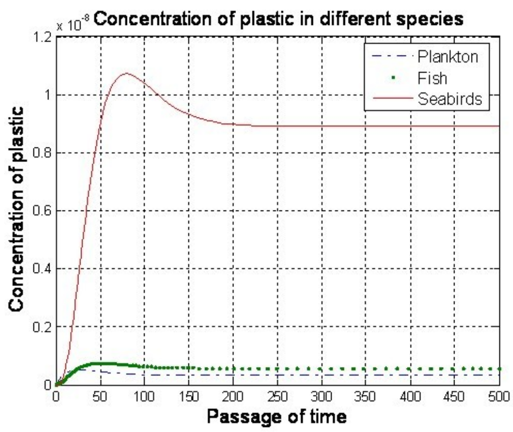

Fig 13: **Concertration of plastic in different species**

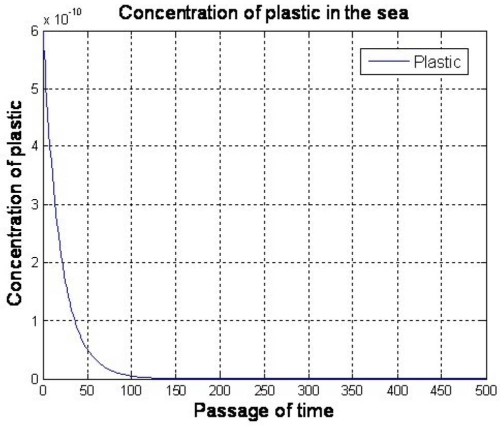

Fig 14: **Concertration of plastic in the sea**

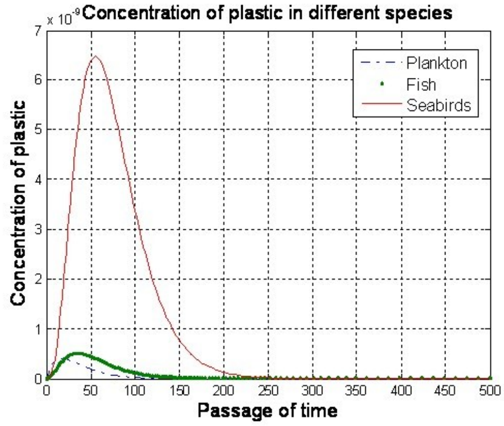

Fig 15: **Concertration of plastic in different species**

Using our simulation data, we can see that if we can remove 10 million tons of plastic a year, then, together with the self-purification capacity it takes about 100 years to completely eliminate pollution of plastic polution. Besides that from the chart, we can see that, after a certain amount of volatility in the food chain for each layer, the amount of plastic have tended to zero, and thus prove that this methods is appropriate and effective. In this way, we can stop the plastic's influence on the ecosystem.

Strengths And Weaknesses

In this article, we aim to establish a model to simulate the circulation of plastic pollution between different kinds of species along the food chain, and through it, we want to evaluate the impacts of plastic on the marine ecosystem. The strengths and weaknesses of model can be included as follows:
Strengths:

- We focus on the entire marine ecosystem, taking the consideration of impacts on polluted district. which has a comprehensive understanding of behavior about eco-system.
- With the help of our model, we can get a conclusion that the concentration of plastic pollution will increase along the eco-chain, which has been approved by other biologist.
- In model three, we get a boundary value of pollution level theoretically, with further information of local marine species, which can give us some information to improve this situation before it worsens.
- In the end , we point out that when we take measures to remove and clean up those plastic, the impacts of plastic pollution would be limited for example, if plastic decrease in a stead speed (5%), the impacts would be limited to a better situation.

Weakness:

- We consider the Great Pacific Ocean Garbage Patch as a relative stable environment, which is an ideal condition.

- Although we can obtain qualitative value but can't obtain these accurate data or parameters to get the exact value.

Direction in further research

- In order to further research, we suggested that we should obtain these parameters of local eco-system. by the way of experiments on local environment.
- Taking other factors such as climate changes into this eco-system can be a more comprehensive model.
- Having a further research on the mutually-species of different populations, try to find a more typical condition that meets local marine eco-system.

Call To Action: A Report To The Expedition Leader

Dear leader,

As we all know, there're a wide variety of species surviving in the Pacific Ocean. These species are interdependent and competing together to form a relatively balanced marine ecosystem. And for pollution with a certain limit, the marine ecosystem can maintain stability through self-purification ability. But now, with waste pumped into the ocean for many years, much of the debris (plastics, in particular) is accumulating in high densities over a large area of the Pacific Ocean.

By studying,we have had some findings from the food chain biomagnifications model, as well as the discovery of racial survival. Some important findings and conclusions can be summarized as follows

- When the plastic debris enter the marine system, they will biomagnificate and eventually enter different populations along the food chain, we find out that when pollution lasts for a long time, the density of pollution in different species would reach a steady state , and furthermore, they will finally enter our human body.
- We take the factor of cleaning up plastic into consideration and find that if we can remove 2 percent of plastic every year and then the impacts of plastic would be limited to a better situation.
- When the density of plastic pollution reaches threshold, it would have a great impact on the survival of species. With the threshold, we can monitor the density of plastic pollution to evaluate the impacts on the eco-system.

The situation at present is very serious, so we have to take measures before the tragedy happens. Since the main purpose of our measures is to clean up the plastic debris in the Pacific Ocean, we can take action from the following three aspects.

- The most urgent thing we need to do is to deploy aircraft with special sensors to the convergence zones to pinpoint the location of debris. Then, great deals of manpower and material resources have to be spent in cleaning up the plastic debris in the Pacific Ocean.

- In the long term, we must reduce the plastic amount pumped into the ocean. Government needs to issue a number of acts as an economic lever to limit emissions from factories. Meanwhile, the public should raise environmental awareness, and consciously reduce the use of plastic products. Furthermore, some new easy-to-degradable materials need to be developed to replace the use of plastic.
- At the same time, the level of plastic processing must be enhanced. We can seek to reduce emissions of plastics and increase plastic recycling levelssuch as garbage into biodiesel or power generation. Some additives like photosensitizer can also be added to alter the characteristics of plastic, then the decomposition rate of the plastic can be greatly developed.

We sincerely hope that our research can help bring governance to the plastic pollution and the Pacific Ocean can get free of the plastic debris sooner!

Yours sincerely,
All member of team 6312

References

[1] Michelle Allsopp, Adam Walters, David Santillo, and Paul Johnston, "Plastic Debris in the Worlds Oceans", http://newsgroups.derkeiler.com/Archive/Soc/soc.culture.greek/2009-09/msg00030.html

[2] http://en.wikipedia.org/wiki/Great Pacific Garbage Patch

[3] http://en.wikipedia.org/wiki/Foodchain

[4] Charles J. Moore1, Shelly L. Moore, Molly K. Leecaster2,and Stephen B. Weisberg, "A comparison of plastic and plankton in the North Pacific central gyre", Marine Pollution Bulletin Vol.42

[5] Cecilia Eriksson, Harry Burton, "Origins and Biological Accumulation of Small Plastic Particles in Fur Seals from Macquarie Island", Royal Swedish Academy of Sciences 2003

[6] Merchant, Carolyn, "The Columbia Guide to American Environmental History", Columbia University Press. P. 169. ISBN

[7] Zhien Ma, "Mathematical Modeling and Research on Population Ecology(chinese)", 1996,(169 180)