Modelling Potential Effects Of Climate Change On Marine Food Chain and Marine Mammals with NetLogo

Qi-fan Wu

2700280@student.vu.nl

ABSTRACT

Climate change has several influences on marine ecosystems including increasing seawater temperature, extreme climatic events, rising sea levels and decreasing sea-ice amount. These impacts can lead to direct and indirect effects toward marine mammals as well as the entire marine food chain. The rising seawater temperature will lead to the huge decline of zooplanktons such as krill, and ultimately, the decreasing of krill could cause extinction of species and destroy the whole ecosystems through affecting the reproductive success and survival probability of marine mammals, hence have different consequences for their group populations. While the low seawater temperature which might occur because of extreme climatic events such as El Niño could also lead to diseases among marine mammal species and make their populations decrease. Cetaceans, which often play roles as predators have constrained distribution patterns with limited opportunity for population expansion would be particularly vulnerable toward effects of climate change. The potential effects of climate change on marine mammals and marine food web will be simulated to create a simplified model of marine ecosystem, and several experiments will be conducted to verify related hypotheses and answer the research question.

Author Keywords

Agent-based modeling; NetLogo; Project Socially Aware Computing; Oceanography and Marine Biology; Marine ecosystems.

CSS Concepts

• **Agent-Based Modeling and Simulation**; Modeling and simulation; Model development and analysis.

INTRODUCTION

Climate change can affect marine ecosystems. The potential impact of climate change such as patterns of wind and ocean circulation, temperature of seawater, reduced sea ice and rising sea levels, acidification, changing oxygen and salinity levels can for example disrupt the habitat of marine fauna, and affect the whole marine ecosystem directly and indirectly [1]. The risk of climate change on Cetaceans such as dolphins and whales, which always act as predators, are increasing. Whereas zooplankton such as krill are also an important component of the marine ecosystem and play an important role in the marine food web as well [2].

The main societal challenge of climate change on marine ecosystems includes bringing extra stresses that might push marine social–ecological systems beyond the ranges of past variability to which humans have become adapted, and increasing the amount of extreme events and uncertainties that humans might need to face in the future [3]. Through simulating this challenge, there might be improvement toward conservation and legislation related to marine mammals so that they provide better protections to threatened species. Non-climate change threats and pressures toward marine ecosystems such as fisheries, boat strikes, heavy metals and oil pollution, habitat disturbance and degradation could also be reduced by international treaties and conservation agreements that are based on scientific research. In conclusion, simulating the potential effects of climate change on marine food chain and marine mammals can not only display the relationship between different elements of marine ecosystem more directly and clearly, but also help improve conservation and legislation to regulate human behaviors so that give marine ecosystem better protections as well as minimize the non-climate change threats that mainly caused by human activities [4].

RESEARCH QUESTION / HYPOTHESIS

The research question is about how different impacts of climate change, might lead to different population of four representative species in marine food chain, which are krill, fish, dolphins and whales, and how these influences effect the balance of local marine ecosystem. So the research question is: *"How climate changes affect the survival of Cetaceans directly and indirectly and how climate changes affect the balance of the local marine ecosystem?"* The hypothesis of this research question is that compare to the default value of this model, which the whole ecosystem is not affected by climate change and relatively balanced, the higher the water temperature that caused by climate change, the faster the marine ecological equilibrium being disturbed, and the extinction of predators would also be accelerated, while another hypothesis is that low water temperature will accelerate the extinction of dolphins, maintain the ecological balance for a longer time compare to the high seawater temperature and increase the population of fish during certain time period, but will still result in the mass extinction of the study area at the end.

MODEL DESCRIPTION AND CHOICES

In order to simulate the marine environment and test the hypothesis, a new model in NetLogo will be created. The world is set to wrap in both dimensions and adjust the size of the world to 80 by 80 with the middle coordinate 0.

Turtles (and Breeds)

Four representative species from different level of food chain are chosen to be modeled, which are krill (primary consumers), fish (secondary consumers), dolphins (tertiary consumers) and whales (apex predators). Shapes of these animals are set to one of their families that has representative and highly recognizable appearance.

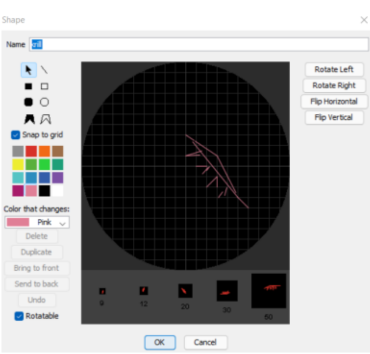

Figure 1. Shape of krill in the NetLogo model.

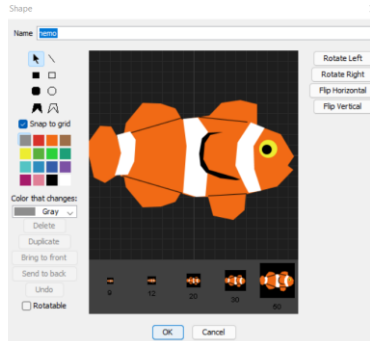

Figure 2. Shape of fish in the NetLogo model.

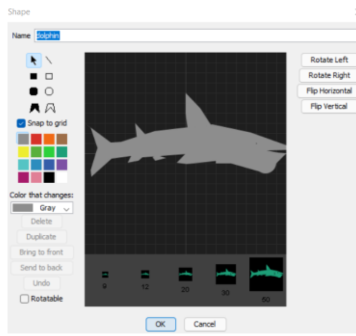

Figure 3. Shape of dolphin in the NetLogo model.

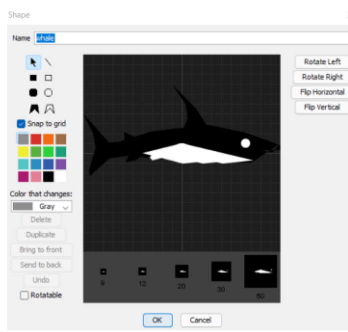

Figure 4. Shape of whale in the NetLogo model. Killer whale or Orca (*Orcinus orca)* is chosen to represent the apex predator in the model: whales.

The sizes of these breeds in the model depends on their body size in real life, same as their movement speed and energy consumed/expended. While in order to make them easier to see, their sizes only vary from big to small, but disproportionate. Krill, fish and dolphins will flock as what they do under the natural environment, and they will also apply three rules: avoid the nearest neighbor if it is too close, else align with the average direction of its neighbors, and they will move towards other same species nearby (unless they are too close). Whales in this model tend not to flock.

When these animals get prey they will gain a certain amount of energy from food, and every time they move they will also expand a certain amount of energy. The fertility rate of each species in the model relies on their fertility and time period in real life situations. Both krill and fish will have a random chance to spawn every tick, each krill who lay eggs will have 42 survival offspring and fish will have 6 survival offspring. For dolphins and whales, they have a relatively small chance to give birth every three ticks, and dolphins could have three cubs whereas whales can only have one cub. When fish, dolphins and whales have offspring, their energy would be equally divided by the amount of their offspring. When the energy of consumers <1, they will die.

Patches

In the attached model *Marine – Basic.nlogo*, patches are set as blue gradient colors. The seawater temperature are random distributed and the patches with color light cyan (pcolor = 87) represent the warmest part, the cyan represent the water with middle temperature, and the patches with color sky represent the seawater with lowest temperature. The probability of getting the middle water temperature is the highest while the probability of getting the low water temperature is the lowest.

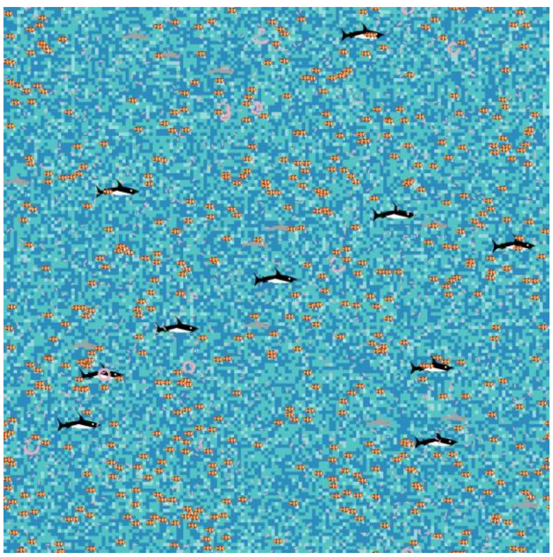

Figure 5. In the default model *Marine – Basic.nlogo*, patches in the background have randomized blue gradient colors, which represent different seawater temperatures.

In the attached model *Marine - Climate Change.nlogo*, effects of climate changes on marine ecosystems are simulated and applied. When the water temperature is too high (> 18 °C and ≤ 21 °C), the water with highest temperature, which represents by patches with color pale cyan, which be randomly selected and turned to orange, and krill at these orange patches will die because zooplankton like krill are sensitive to the water temperature and water temperature that is too high would lead to the decline of krill populations [5]. When water temperature is > 21 °C and ≤ 23 °C, randomly selected patches with color cyan will also turn to orange, and when water temperature is > 23 °C, randomly selected patches with color sky will turn to orange and lead to the death of krill as well.

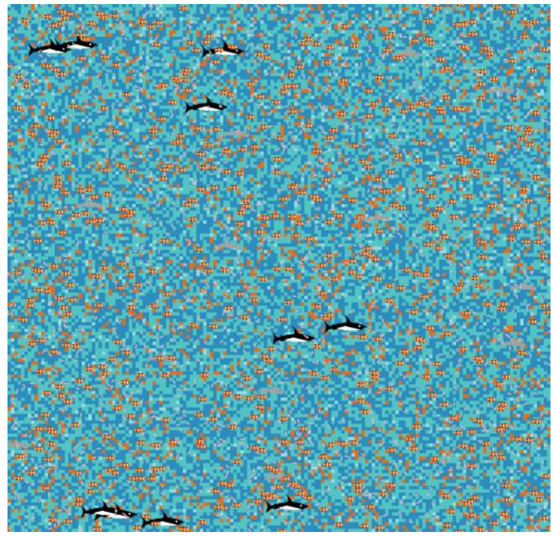

Figure 6. In the model *Marine - Climate Change.nlogo*, when seawater temperature is too high, patches in the background might be randomly selected and turn to orange, which lead to death of krill.

While it should be mentioned that low water temperature which might cause by extreme climatic events would also result in low salinity in certain area, and low salinity have been discovered that it can lead to higher skin lesion prevalence and severity, and it is considered that such conditions might affect the epidermal integrity or produce more general physiological stress, potentially making the marine mammals, especially dolphins, more vulnerable to natural infections or anthropogenic factors and indicating more potential diseases [6]. So when the water temperature is lower than 16, dolphins will have certain probability to die every 10 ticks after 80 ticks in this model.

Overview

Overall, the default value of krill population is 1500, fish population is 550, dolphin population is 12, whale population is 10. The energy that fish can gain from food is 2, dolphin can gain from food is 10, whale can gain from food when eating fish is 6, whale can gain from food when eating dolphin is 20. For each tick, krill can forward 0.1 and repeat this movement 5 times, fish can forward 3 and cost 1 unit energy, dolphin can forward 20 and cost 1 unit energy, whale can forward 8 and cost 6 unit energy. To keep the ecological equilibrium, krill will only hatch when krill population is less than 7 times fish population, and fish will only hatch when krill population is larger than 5 times fish population, the reason of this setting is because of limited oxygen amount, although the oxygen amount is not included in this model.

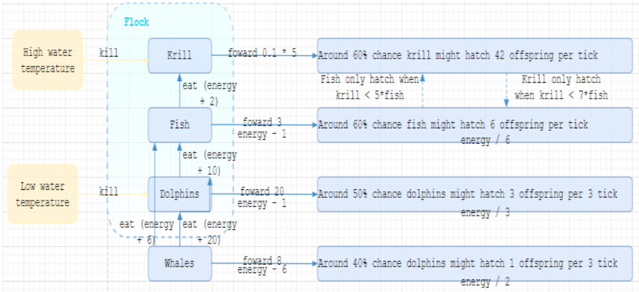

Figure 7. The overview chart of the model, the larger graph would be attached in the same folder.

EXPERIMENT / METHOD

Measurements and Results

In order to test the hypothesis, a series of experiments will be taken place. The *Marine - Climate Change.nlogo* model will be used as the starting point, and four scenarios : water temperature > 18 °C and ≤ 21 °C, water temperature > 21 °C and ≤ 23 °C, water temperature > 23 °C, water temperature < 16 °C.

The first experiment is to test whether the higher the water temperature that caused by climate change, the faster the marine ecological equilibrium being disturbed, and the extinction of predators would also be accelerated. For each scenario there would be 10 repetitions, and mean time of fish (secondary consumers) die out would be calculate to see how sea water temperature affect the extinction of predators. The code “if ticks = 200 [stop]” is added to the go function to stop the simulation at exactly 200 ticks.

The secondary consumer fish is chosen to examine the result because the extinct of fish is caused by the decreasing of primary consumers, and would certainly lead to the extinction of its predators.

	Baseline model (mean of 10 repetitions)	Proposed model (mean of 10 repetitions)
water temperature > 18 °C and ≤ 21 °C	Fish did not die out. Fish population :342	Fish died out 8 times. Mean no fish time: 147 ticks
water temperature > 21 °C and ≤ 23 °C	Fish did not die out. Fish population :342	Fish died out 10 times. Mean no fish time: 98 ticks
water temperature > 23 °C	Fish did not die out. Fish population :342	Fish died out 10 times. Mean no fish time: 67 ticks

Table 1. <Different levels of high water temperature> for the baseline and proposed model per scenario.

The second experiment is to analyze whether water temperature that is too low, that can cause diseases among dolphins, will maintain the ecological balance for a longer time compare to the seawater temperature higher than normal and increase the population of fish at certain time period, but will still result in the mass extinction of the study area at the end. This time the code “if ticks = 200 [stop]” is added to the go function to stop the simulation at exactly 200 ticks, it should be noticed that the diseases that caused by low temperature only begin to lead deaths after 80 ticks.

	Baseline model (mean of 10 repetitions)	Proposed model (mean of 10 repetitions)
water temperature > 18 °C and ≤ 21 °C	Fish did not die out. Fish population :342	Fish died out 8 times. Mean no fish time: 147 ticks
water temperature > 21 °C and ≤ 23 °C	Fish did not die out. Fish population :342	Fish died out 10 times. Mean no fish time: 98 ticks
water temperature > 23 °C	Fish did not die out. Fish population :342	Fish died out 10 times. Mean no fish time: 67 ticks
water temperature < 16 °C	Fish did not die out. Fish population :342	Fish died out 10 times. Fish population: 708

Table 2. <Different levels of high water temperature and water temperature that is too low> for the baseline and proposed model per scenario.

While to test whether low water temperature will still result in the mass extinction of the study area at the end, the code “if ticks = 200 [stop]” will be deleted and replaced by “if not any? fish [stop]”. The mean time that all fish died out is after 947 ticks.

Result Analysis

Descriptive statistics would be applied to analyze the data. Through comparing the mean of fish extinction time and fish died out probability, several facts could be concluded. Graphs below illustrate relationships between variables and population of turtles.

The figure 8 shows the relationship between different levels of water temperature that are considered to be too high to make krill survive and the fish extinction time. The water temperature that is too low also joins the analysis. According to the data, the first hypothesis that compared to the default model, the higher the water temperature caused by climate change, the faster the marine ecological equilibrium being disturbed, and the extinction of predators would also be accelerated is verified. Climate change could lead to higher seawater temperature, and the higher seawater temperature would make the amount of zooplankton decline, which will disturb the ecological balance and cause a series of chain reactions: the extinction of secondary, tertiary and apex predators. Part of the second hypothesis could also be verified, which is "low water temperature will accelerate the extinction of dolphins, maintain the ecological balance for a longer time compared to the high seawater temperature". According to the data, low water temperature would postpone the fish extinction time and maintain the marine ecological equilibrium for a relatively longer time.

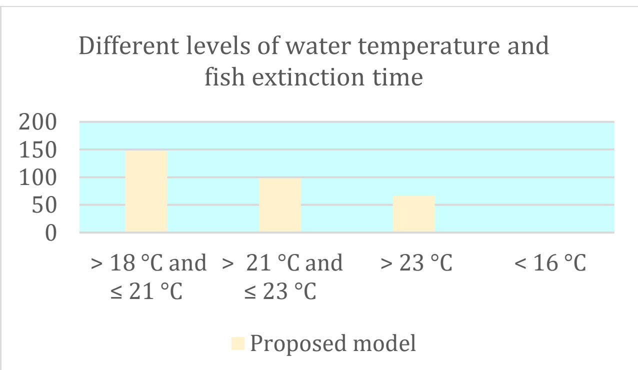

Figure 8. The bar chart shows the relationship between different levels of water temperature and extinction time of fish within 200 ticks.

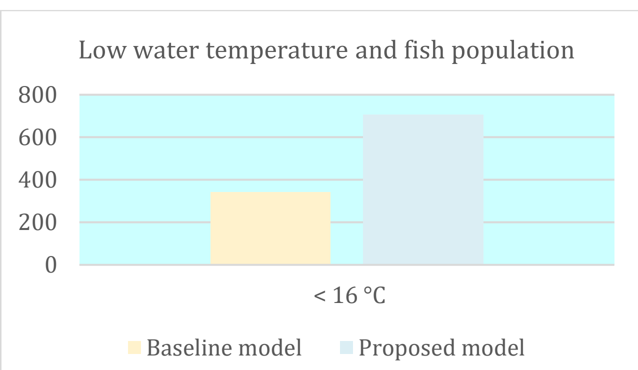

Figure 9. The bar chart shows the relationship between low water temperature and fish population within 200 ticks.

Figure 9 shows the differences of fish population between baseline model and model with low water temperature. The other part in the second hypothesis "low water temperature can increase the population of fish during a certain time period" could also be verified. According to the experiment the low water temperature would also lead to the mass extinction is also verified while compared to the first hypothesis and the first part of the second hypothesis, the reason behind it is more complicated and would be discussed in the later part of this paper.

DISCUSSION

The reasons why the increase of sea water temperature will cause the extinction of marine animals might be when water temperature is increased, the warmest part in the previous condition would become above the preference temperature of krill first. And when the water temperature is higher than certain thresholds, the middle temperature areas and cool temperature areas in the previous environment will also be heated and no longer suitable for the survival of krill. The huge decline of krill will result in the food shortage of fish and speed up their extinction, and the enormous decreasing and extinction of fish will certainly cause the extinction of its predators.

For the low water temperature that is also caused by climate change, the low temperature could cause the death of dolphins slowly after a certain time but the decreasing of dolphins will lead to the increasing fish amount because of less predators. So after dolphins die out the amount of fish increases and the fish population is around 2 times larger compared to the baseline model at the 200th tick. Because the default amount of dolphin is relatively small and although their hunting range is the widest among these four species, they can only eat one fish at each tick, so the extinction of dolphin did not cause huge damage to the ecological balance within the study area, while the decline of dolphin will have large effect on the whale because fish could not provide enough amount of energy to the whale, and the decreasing of whale will make the amount of fish increase, and result in the huge decrease of krill, and disturb the natural balance at the end.

While it should not be ignored that this model is an extremely simplified model so that it could only simulate the marine ecosystems and food chain roughly, there are still many elements and variables are needed to be quantified and modeled, and a large amount of further researches are needed in order to simulate the realistic marine ecosystem. The fraud and limitations of this model is that it can only keep ecological equilibrium under strict conditions, and it needs to implement more rules in order to accord with reality. In order to verify whether low water temperature will still result in the mass extinction of the study area, the fish population turn out to be zero at the end, while there are still certain chances that the fish population in the default model will turn to zero because of randomization of this model, and also because of lacking several prerequisites such as oxygen levels, ocean acidification, natural and accidental deaths of marine animals, phytoplankton (also producers) such like algae and human activities. To make this model more accurate, several databases should be included, also wind and ocean circulation, upwelling and downwelling should be considered and modelized. Moreover, different species from the same family have different behaviors and habits, to make the model more realistic, a huge amount of research and observation are required.

CONCLUSION

In conclusion, climate change will fundamentally alter the structure of oceans and impact marine ecosystems. The rising seawater temperature would affect the population of krill and result in increasing risks for dependent predators, and abnormally low seawater temperature which might be caused by extreme climatic events that related to climate change could also disturb the balance of marine ecosystems and food chain. The research question about how climate changes affect the survival of Cetaceans directly and indirectly and how climate changes affect the balance of the local marine ecosystem might be answered based on several experiments. Climate change makes the food sources of Cetaceans decrease so that reduce their survival chances indirectly, and climate change could also cause diseases among certain species of Cetaceans and lead to potential death of them directly. And the extinction of one species could damage the ecological equilibrium, and finally cause mass extinction.

This model is a simplified model that could only simulate the marine ecosystem roughly. To make it more accurate and applicable, further research is necessary. For example, ArcGIS and Google Earth Engine could be applied for mapping the study areas, and several databases could be imported to the NetLogo model to make it more accurate and realistic. The dynamic modeling of how climate change affects the sea levels, sea-ice cover, seawater acidification, salinity, prey distribution, and animal migrations patterns should also be included in the further research.

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