How Does Water Temperature Affect Coral Reef Deterioration?

Expansion Of Dennis Hubbard's 'The Non-linearity of Environmental Change: A coral reef model'.

Beliz Pekkan, snr: 2066519

Jacob Bae, snr: 2074768

Marin Bourdon, snr: 2081204

Michael Pavlik, snr: 2070814

Pim van Bilsen, snr: 2081388

Sherwin Lee, snr: 2077086

Word Count: 1847 Words

Problem Statement

Coral reefs are arguably one of the essential fauna in our oceans. They help protect marine life by creating homes for millions of species, support healthy food webs and help protect the coastlines by reducing the power of the waves that hit the coasts. They, in turn, are responsible for maintaining and improving marine life and our lives.

However, we are not paying these magnificent creatures back. ‘Atmospheric carbon dioxide concentrations are projected to exceed 500 parts per million, and global temperatures are expected to rise by at least two °C between 2050 and 2100, well above levels seen in the past 420,000 years, during which most marine life has evolved’ (Hoegh-Guldber et al., 2007). These high temperatures will also bring out declining water quality and overexploitation of key species, leading to the tipping point for coral reefs which will become less and less functioning.

According to PNAS, the Great Barrier Reef lost 50.07% of its initial coral cover from 1985 to 2012 (De’ath et al., 2012). This is just one example of many ecological catastrophes around the marine world. With our model, we would like to simulate how fast the corals deteriorate to create a visual connection with real-world situations.

With all the data in mind, as conscious beings, we want to model this phenomenon to attract more attention to the problem. We are curious as to how these elements all interact with each other, especially water temperatures rising due to climate change. In the end, we came to the question, ‘How does water temperature affect the deterioration of the corals?’.

Model Description

Our model is based on a model we found that simulated coral-reef growth by Dennis Hubbard and Oberlin College, called ‘The Non-linearity of Environmental Change: A coral reef model’. This model aims to simulate the relationships between nutrients in the water environment, encouraging reef algae and grazers that consume them and reproduce.

The original model we found utilized fishes, corals, algae, and urchins. We dismissed urchins as their effect on the environment is not trivial, and thus would not contribute to the goal of our research question. We changed the code to simulate humans' adverse effects on the environment together with global warming, which leads to warmer and more acidic waters. Alongside that, we wanted to see if simulating such effects would affect the corals.

To model the deterioration of the corals, we must understand why and how the process of deterioration happens. With the water temperature increase, the pH levels decrease, and corals start the bleaching process. This process turns the corals into white, skeleton-based corals. This stage is the last phase before the death of the coral. This happens due to several factors.

In our model, the three most important agents are fish, corals, and algae. Fish agents in our model have the properties of ***fishenergy*** and ***fishstomach***. Fishenergy is created to control how many fish live inside our model, as well as a way to keep track of a fish's energy levels. ***Fishstomach*** is a constantly changing variable that keeps track of the "fullness" of each fish, of which they will be "full" after eating two algae. To ensure that the fish does not always eat more algae when they're full, the variable ***tickcounter*** was implemented. Once the ***fishstomach*** hits 2, ***tickcounter*** will start counting up by 1 for each tick. Once it hits 2, both ***fishstomach*** and ***tickcounter*** will be reset to 0. Fish agents can also swim randomly in the model environment, which will deduct ***fishenergy*** by 5. If the fish is in the eating range, then they have the option to eat one alga to regain energy. To reproduce fish in the environment, the total number of fish must be less than 4 times the total number of algae.

Coral agents exhibit such behavior that one coral agent dies if conditions are met. If there are fewer than 3 coral agents, one new coral agent is created. In case there is no coral agent left, the corals all die off. These attributes are controlled by ***corallife*** property, of which we have set the lifespan of the corals to be 125 ticks. For every tick, ***corallife*** is deducted by 1. The action of the coral agent is determined by its environment. After the agents spawn, they check if there is an algae agent within 3.5 spaces in the environment. If an algae agent exists within that range, the coral agent dies off (Bergstrom, 2007).

Algae agents are also responsible for maintaining the control of coral and fish numbers. On their own, they do not have any actions rather than spawn based on the ***AlgaeReproduction*** slider determined by the user. In their natural environment, they suffocate corals as well as take nutrients away from the corals. To replicate that in our model, corals that spawn too close to algae die off.

The ***Temp*** slider is responsible for changing the temperature of the water. The user can choose the value between 10 and 30 degrees by 10 (10,20,30). In the code, the variable ***Temp*** represents the water temperature. If the temperature is not 20 degrees, which is the natural temperature of the water in the ocean, it changes pH from its natural level of 8.1. Every time the temperature increases or decreases by 10 degrees, there is a 0.2 change in the pH of the water (Gillespie', 2019). With higher temperatures, the pH gets lower, which makes the water more acidic. In contrast, when the water temperature decreases, the pH increases, making the water more basic. Such changes in pH can directly affect algae growth, as they thrive in certain environments. However, even though pH was not implemented in the code due to severe implementation complications, the variable ***Temp*** was then used to affect algae growth which indirectly affects corals.

Results

In our research, we have used 3 datasets, each containing 25 sets of 30,000 ticks of our model. This means each dataset contains 750,000 values. Each dataset is only different in temperature, using either 10, 20, or 30 degrees Celsius as temperature.

When looking at the number of corals, we have found that the mean of the count decreases whenever the temperature increases. The 10 degrees Celsius result shows a mean of 80.62, whereas the 20 degrees Celsius result shows a mean of 63.64. The 30 degrees Celsius result shows a mean of 15.19, which is significantly lower (Fig 1.0).

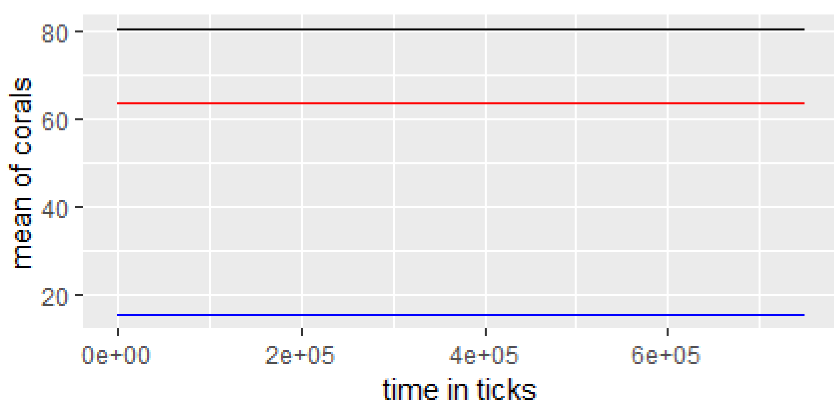

Fig 1.0: Mean of coral counts. Blue = 30 degrees, Red = 20 degrees, Black = 10 degrees.

The amount of algae increases whenever the temperature increases. These tests show values of 4.005, 26.58, and 122.9, respectively.

While comparing the 10 degrees Celsius and 20 degrees Celsius datasets, after performing a Welch Two Sample t-test, we can conclude that the water temperature indeed affects the number of corals in our model ($p = 2.2e-16$, $t = 461$). The 10 and 30 degrees Celsius datasets show a similar result. ($p = 2.2e-16$, $t = 3434$). Finally, the 20 and 30 degrees datasets Celsius also follow the same pattern ($p = 2.2e-16$, $t = 1352$). The higher t-values with higher temperatures show that the number of corals are indeed affected by temperature.

On those different line graphs, we can see how corals (blue lines) and algae (red lines) are evolving during the time in ticks compared to the temperature of the water in degrees Celsius. For every graph about corals, the starting value is 48, and for the graphs about algae, the starting value is 45.

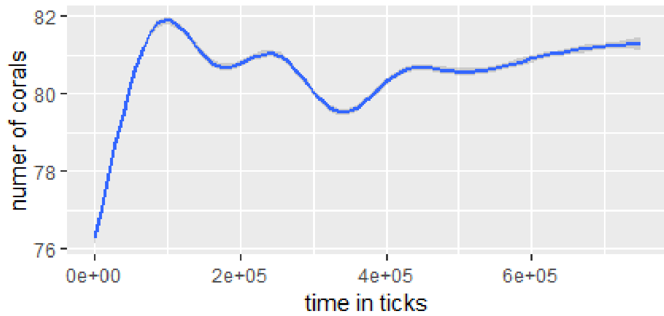

Fig 1.1: Fluctuation of coral counts at 10 degrees.

We can see that for the coral, at 10 degrees, it sharply increases to around 80 corals at 100,000 ticks and decreases slightly, then increases slightly near the end of the run. (Fig 1.1)

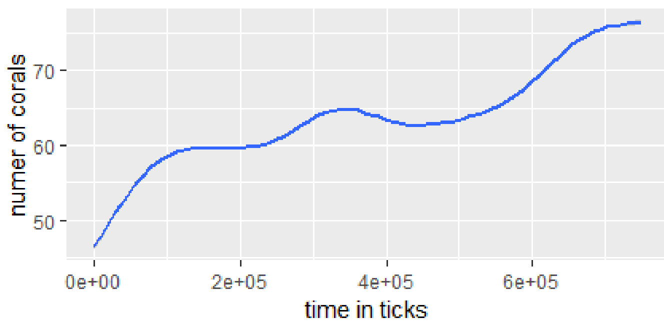

Fig 1.2: Fluctuation of coral counts at 20 degrees.

At 20 degrees, the number of corals increases relatively linearly on average, increasing from 48 and hitting 80, around 700,000 ticks. (Fig 1.2)

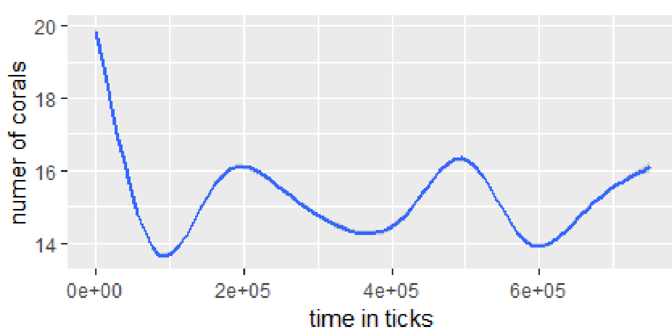

Fig 1.3: Fluctuation of coral counts at 30 degrees.

At 30 degrees, the number of corals sharply decreases at the start, hitting a low of 14 entities at around 100,000 ticks. The number of corals will then continue to fluctuate between 14 and 16 entities till the end. (Fig 1.3)

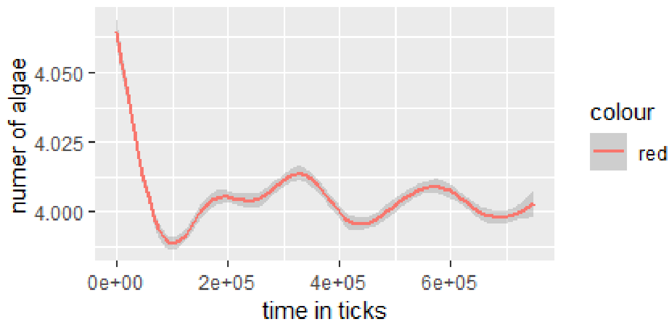

Fig 1.4: Fluctuation of algae counts at 10 degrees.

In contrast, at 10 degrees, for the algae, the opposite can be observed. The algae decrease to around 4 at 100,000 ticks, then fluctuates.(Fig 1.4)

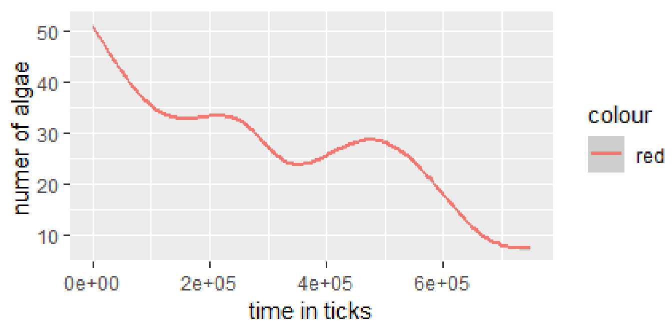

Fig 1.5: Fluctuation of algae counts at 20 degrees.

At 20 degrees, the number of algae still decreases, but more slowly and linearly to get around 10 entities at 700,000 ticks. (Fig 1.5)

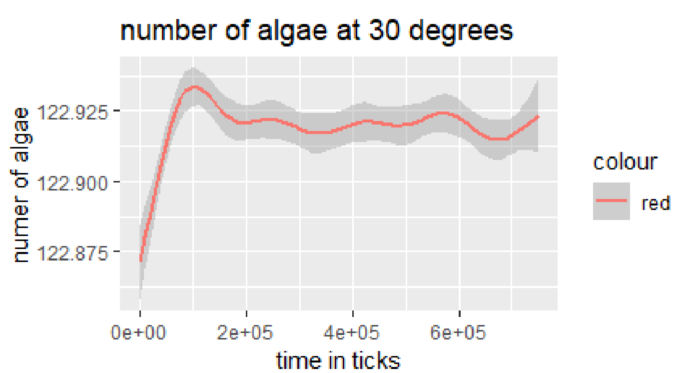

Fig 1.6: Fluctuation of algae counts at 30 degrees.

At 30 degrees, we can see that the number of algae sharply increases to reach 122 around 100,000 ticks and will barely deviate from this number. (Fig 1.6)

Overall, we can see that the change in the water's temperature impacts the number of algae and the number of corals but in opposite ways, as seen by the count of both corals and algae. When the temperature of the water goes up, the number of algae increases, but the algae are killing the corals, so their number drastically reduces. The opposite can be observed with lower water temperatures.

Discussion

As the temperature goes up, the pH level decreases, which leads to coral reefs dying. Consequently, with the death of coral reefs, algae reproduction is left unchecked. However, if the temperature decreases, it will have the opposite effect. If it decreases, there will be more coral reef expansion and a decrease in algae populations.

As global warming and pollution increase the ocean water will become more acidic. This leads to an overall algae population increase, which throws the balanced ecosystem out. The model does not count for other factors such as pollution, over-poaching, type of fauna and flora, etc. This fact makes our model less accurate in comparison to real-world scenarios. However, this model can be simply implemented to more complex models, which would count for different types of fish, algae, and environment.

In addition, the water temperature itself does not have a large impact on coral life, but it affects the number and type of fish and plants that are present in the environment. We implemented the acidity of the water with the change of ph. The problem we encountered was that for 10 degrees difference, the pH only changed by 0.2. This change affects many different variables but not at the level expected, so we decided to focus on the effects of the water's temperature instead.

We believe this model is a great step forward to explore and simulate this topic more scientifically. Our approach can be expanded upon to draw more attention to this ecological crisis we are undertaking and may be used to model for solutions as well.

References

Bergstrom, C., McKeel, C., & Patel, S. (2007). Effects of ph on algal abundance: A model of Bay Harbor, Michigan. Retrieved November 20, 2022, from https://deepblue.lib.umich.edu/bitstream/handle/2027.42/57443/Bergstrom_McKeel?sequence=1

Corals and Climate | Center for Science Education. Center for Science Education. (n.d.). Retrieved November 14, 2022, from https://scied.ucar.edu/learning-zone/climate-change-impacts/corals-and-climate

De'ath, G., Fabricius, K. E., Sweatman, H., & Puotinen, M. (2012). The 27–year decline of coral cover on the Great Barrier Reef and its causes. Proceedings of the National Academy of Sciences, 109(44), 17995–17999. https://doi.org/10.1073/pnas.1208909109

Florida Keys National Marine Sanctuary. (2011, April 4). Pollution can smother coral reefs, lower water quality, and make corals more susceptible to disease. How does pollution impact corals? Retrieved November 14, 2022, from https://floridakeys.noaa.gov/corals/pollution.html

Gillespie, C. (2019, March 2). The effects of temperature on the ph of water. Sciencing. Retrieved November 18, 2022, from https://sciencing.com/effects-temperature-ph-water-6837207.html

Hoegh-Guldberg, O., Mumby, P. J., Hooten, A. J., Steneck, R. S., Greenfield, P., Gomez, E., Harvell, C. D., Sale, P. F., Edwards, A. J., Caldeira, K., Knowlton, N., Eakin, C. M., Iglesias-Prieto, R., Muthiga, N., Bradbury, R. H., Dubi, A., & Hatziolos, M. E. (2007). Coral reefs under rapid climate change and ocean acidification. Science, 318(5857), 1737–1742. https://doi.org/10.1126/science.1152509

Appendix - Netlogo Code

```
;; CORAL DETERIORATION MODEL (revision 3)
;; Done for Multi-Agent Systems.
;; Group members: Beliz Pekkan, Michael Pavlik, Sherwin Lee, Marin Bourdon,
Jacob Bae, Pim van Bilsen
;; model referenced: "The Non-linearity of Environmental Change: A coral reef
model" (Hubbard & College, 2012)


;; general explanation for our model:
;; The majority of the reused code from the original model were used for model
setup.
;; Reused/revised/referenced code will be cited accordingly.
breed [fishes fish]
```

```
breed [corals coral]
breed [algae alga]
breed [nutrients nurtient]

fishes-own [fishenergy fishlife fishstomach tickcounter]
corals-own [spawnclock corallife]

;; to setup was partly taken from the Coral Reefs Model (Hubbard & College,
2012)
;; The urchins code block was removed in our model as we did not require it.
;; The "algae" shape was replaced with one done by our group.
to setup
  __clear-all-and-reset-ticks
  ask patches [set pcolor 39]

  create-algae numalgae[
    set color green
    set shape "algae"
    set size 2
    setxy random-xcor random-ycor]

  create-corals numcoral[
    set color [153 50 204]
    set shape "coral"
    set size 2
    set spawnclock 0
    set corallife 125
    setxy random-xcor random-ycor]

  create-fishes numfish[
    set color red
    set shape "fish"
    set size 2.5
    set fishenergy 75
    set fishstomach 0
    set tickcounter  0
    setxy random-xcor random-ycor]

  create-nutrients NutrientLoad
  [set color 20]
```

```
  display-labels
  update-plot
end

;; to go was partly taken from the Coraf Reefs Model (Hubbard & College, 2012)
;; The code was used in the "ask fishes" and "ask corals" code block, as well as
the plots and labels.
;; Some numbers were also tweaked to fit our needs better.
to go
  if count corals = 0 [stop]

  ask fishes ;;This block of code will ask 10% of fishes to die every 10 ticks.
This was done for balancing purposes.
  [if (ticks mod 10 = 0)[
    ask n-of (count fishes * 0.1) fishes [die]
    ]
  ]

  ask fishes
  [
    degrade
    swim
    ifelse count algae > 4 [fishdie eat repro][repro fishdie]
  ]

  ask algae
  [spawnalgae]

  ask corals
    [set corallife (corallife - 1)
    if count corals < 3 [hatch 1 set corallife 100]
    if (distance one-of algae < 3.5) [die]
    if corallife < 1 [die]
    set spawnclock (spawnclock + 1)
    if spawnclock > 25 [spawn]
    if spawnclock > 25 [set spawnclock 0]
    if count corals < 1 [stop]
    ]
```

```
  tick
  update-plot
  display-labels
end

;; FISHES
;; to swim was taken from Coral Reefs Model (Hubbard & College, 2012)
to swim
  let dice random 3
  let fishchange (dice - 1)
  set heading (90 + ((random-float 50) * fishchange)) ;; subtracts 1 from the
dice roll to get +1 or -1.
  forward 2.5 ;; swim forward
end

to fishdie ;; the code was implemented so that it is never possible to have no
fishes in the model.
  if (fishenergy <  0) and (count fishes > 1)  [die]
end

to degrade
  set fishenergy fishenergy - 5
end

;; to eat was partly taken from "to bitealgae" in  the Coral Reefs Model
(Hubbard & College, 2012)
;; some new code was added and tweaked to the original model, most notably the
implementation of fishstomach and tickcounter.
to eat
  let current-fish self
  let food one-of algae with [distance current-fish < (1 + (count algae / 5.0))]

  ;; Using ticks to determine the fullness of the fish, in order to prevent the
fish from eating algae at every possible tick.
  if (fishstomach < 2) and (food != nobody) [
    ask food [die] set fishenergy fishenergy + 10 set fishstomach fishstomach +
1]
  if fishstomach = 2[
    if (tickcounter > -1) or (tickcounter < 2) [set tickcounter tickcounter + 1]
    if tickcounter = 2 [ set fishstomach 0 set tickcounter 0 ]
```

```
  ]
  if fishenergy < 75 [set fishenergy 75]
end

;; to repro was partly taken from "to makenewfish" in the Coral Reefs Model
(Hubbard & College, 2012)
;; a line of code was added to prevent a situation where all fish dies, which
would create a unusable dataset.
to repro
  if count fishes = 0 [hatch 1 rt random-float 360 fd 10 set fishlife 100]
  if count fishes < (4 * count algae) [if (random FishReproduction > (350 +
count fishes)) [hatch 1 rt random-float 360 fd 10] set fishlife 100]
end

;; CORALS
;; to spawn was taken from the Coral Reefs Model (Hubbard & College, 2012)
to spawn
  if random 100 < (RecruitProb * 2) [hatch 1]
  set corallife 125
  setxy random-xcor random-ycor
  if (distance one-of algae < 3) or (random 250 < count corals) [die]
end


;; ALGAE
;; The inclusion of nutrientload from the original model was carried over, but
only alongside the implementation of Temp.
;; Temp was included to determine the rate of which algae was reproducing.
to spawnalgae
  if Temp > 20 [if random 50 < AlgalReproduction [Ifelse count algae >
(nutrientload * 2.7) [if random 500 < nutrientload [die] ] [if random 250 <
(nutrientload + (1.2 * count algae)) [hatch ((Temp - 20) / 5) + 1 setxy
random-xcor random-ycor]]]]
  if Temp = 20 [if random 50 < AlgalReproduction [Ifelse count algae >
(nutrientload * 2.7) [if random 500 < nutrientload [die] ] [if random 250 <
(nutrientload + (1.2 * count algae)) [hatch 1 setxy random-xcor random-ycor]]]]
  if Temp < 20 [if random 50 < AlgalReproduction [Ifelse count algae >
(nutrientload * 2.7) [if random 500 < nutrientload [die] ] [if random 250 <
(nutrientload + (1.2 * count algae)) [hatch (Temp / 20)  setxy random-xcor
random-ycor]]]]
```

```
end


;; PLOTS AND VALUES
;; both to update-plot and to display-labels were taken from the Coral Reefs
Model (Hubbard & College, 2012)
to update-plot
      set-current-plot "Reef-Community Structure"
      set-current-plot-pen "Fish"
      plot (count fishes) * 1.5
      set-current-plot-pen "algae"
      plot count algae
      set-current-plot-pen "Corals/SqMt"
      plot count corals
      set-current-plot "Percent Cover"
      set-current-plot-pen "CoralColony"
      plot (count corals) / (count corals + count algae + 40) * 100
      set-current-plot-pen "AlgaePercent"
      plot (count algae) / (count corals + count algae + 40) * 100
end

to display-labels
  ask turtles [set label ""]
end
```