Simulation of Habitat Degradation on Marine Ecosystems

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INTRODUCTION

While Earth continues to evolve through time, global warming continues to threaten the growth of its species, especially in marine environments. 14% of coral reefs around the world have died. Then, as coral reefs continue to experience coral bleaching, the question of how coral habitat loss affects marine species arises. In other words, how will species interact with each other? How will species continue to survive when threats such as carrying capacity, overcrowding, and other species interactions, are present? Will certain species thrive while others go extinct? Will cooperation strategies survive?

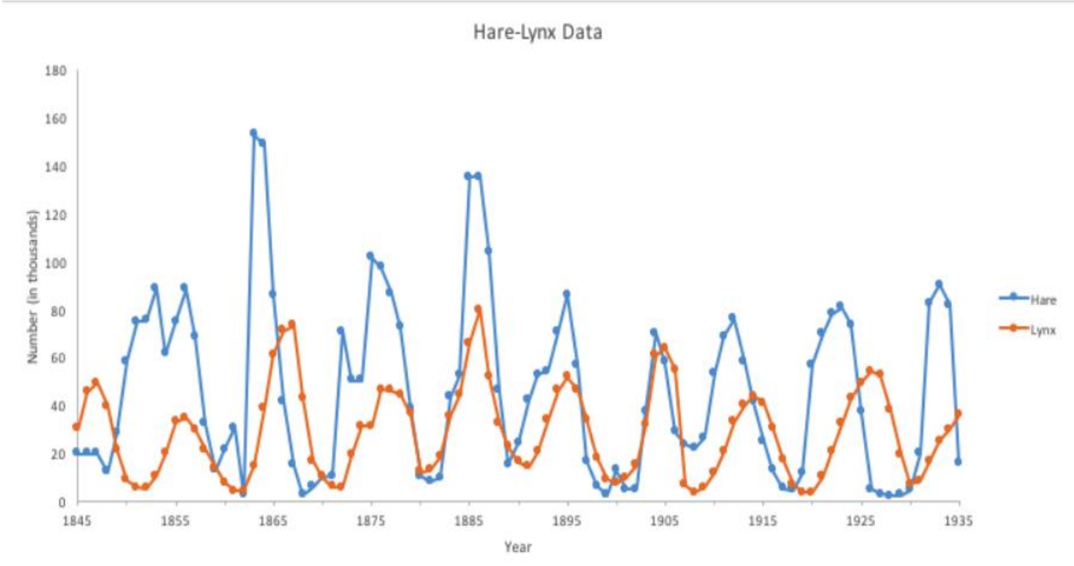
In this project, we decided to create a simulation with different species interacting over a stretch of territory, using an evolutionary-game-theory setup. We will then degrade or remove some territory and see the effects on the populations over time.

SIMULATION SET-UP

- We focused on two species interaction such as fish and sharks. We also considered Prisoner's Dilemma as a related and well-known example.
- Interactions take place in each square of a (n x n) grid. The grid size can also be changed.
- Each square has a limited carrying capacity, noted as m, for each species (fish or sharks), which can also be inputted manually. We normally start the simulation will all nodes at capacity.
- The simulation chooses a random player. Then, with some probability, they will play some player or attempt to move to a different node. The probability depends on how crowded the node is.
- The interacting players play a game using a matrix modeled by the game Prisoner's Dilemma. They usually play a player at their own node but may play players at adjacent nodes. Depending on the payout, the player may die, reproduce, or nothing may happen.
- If the initial player moves to a different node, they have a probability to die or successfully make it to that node. Probability depends on how crowded the nodes are.
- To simulate habitat loss, random nodes are selected and set to capacity 0. Consequently, these nodes can no longer maintain population. Just because, with the simulation we actually use, players can survive (briefly) at "deleted" notes.

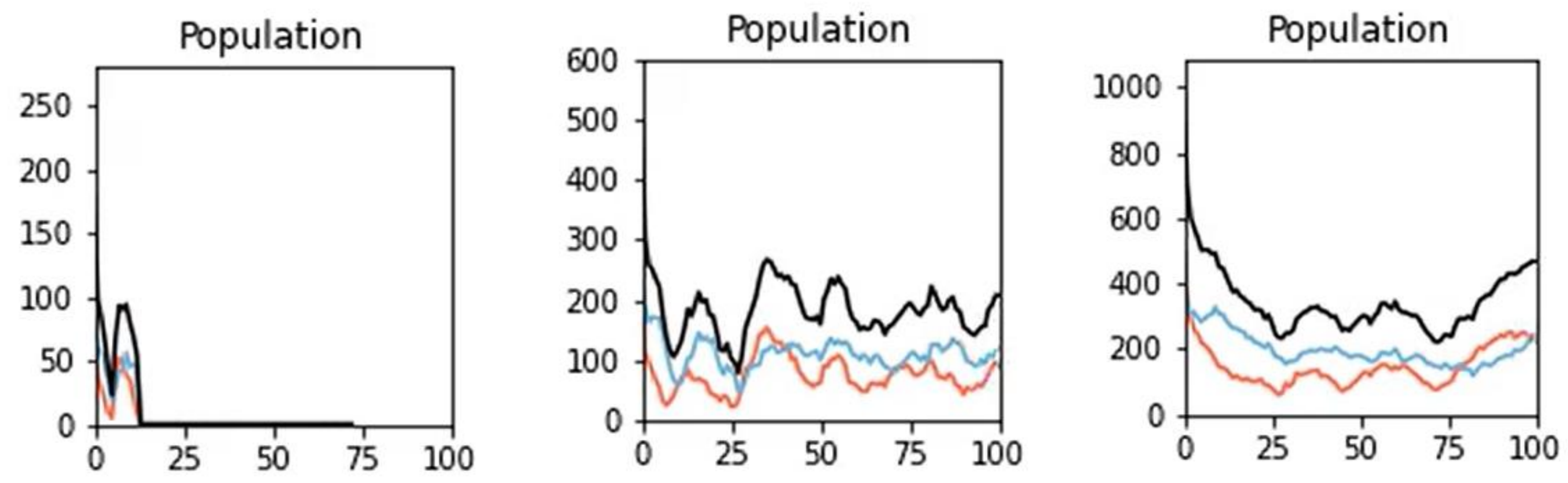
The LYNX/HARE PREDATOR/PREY RELATIONSHIP

Predators and prey impact each other in number: predators eat their prey, but in turn, predators may die of starvation if prey populations become small. Sometimes, this results in cyclic patterns of predator and prey populations, "where prey increase in number and then with abundant food, predator number increases until the predators begin to suppress prey numbers and then decrease as well," (Northern Arizona University, n.d.) From 1845-1935, the Hudson Bay Company carried out a study of lynx and snowshoe hares, comparing the number of populations over time. When graphed, we see the predator/prey cyclic patterns. This is just one interesting example of a predator/prey relationships.



WHAT HAPPENS TO COOPERATION OVER GENERATIONS?

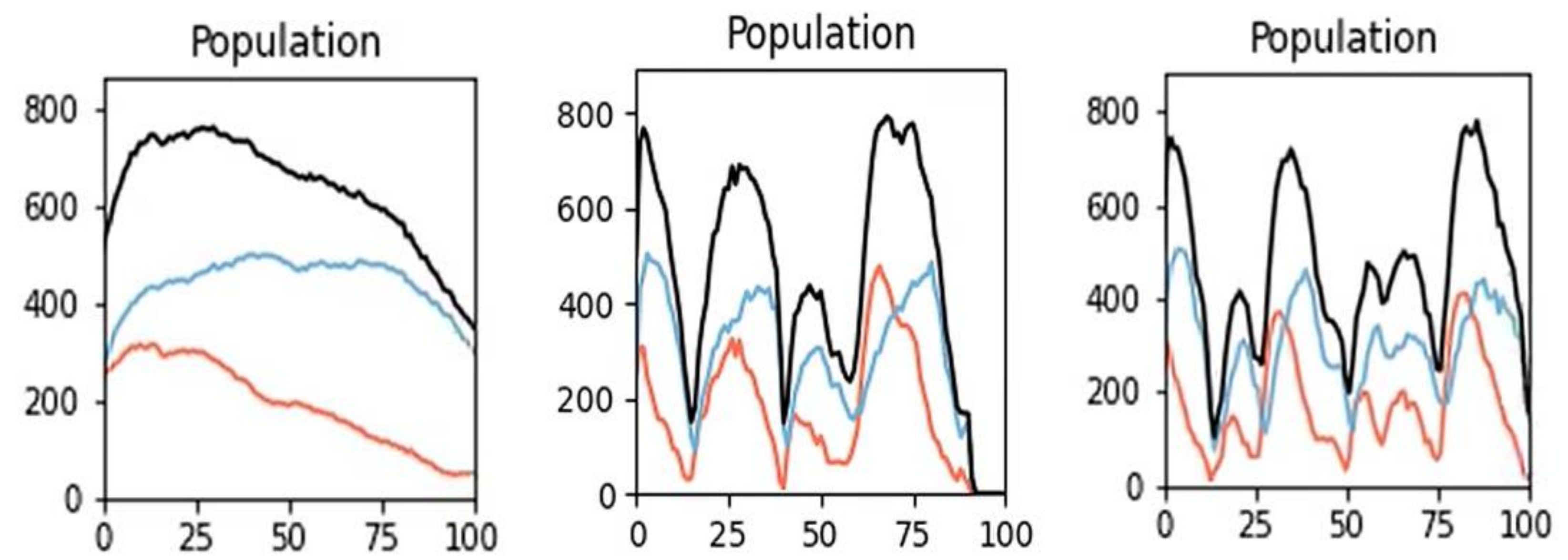
Using the prisoner's dilemma matrix, we run various simulations with varied grid sizes and capacities.



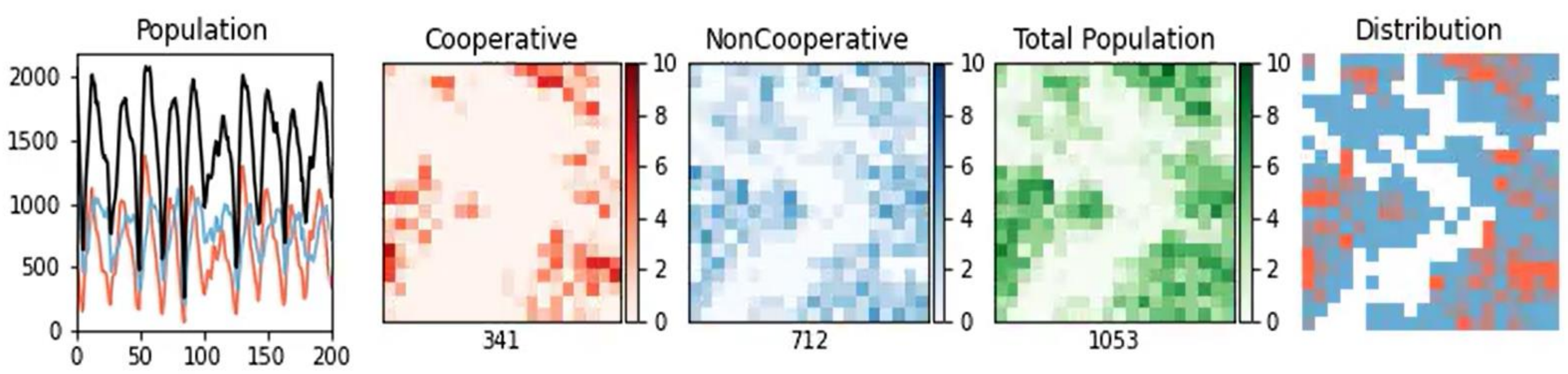
Graphs of populations for 10,000 iterations per initial population with m=3, when n=6, 10, and 14, respectively. Here we see populations go extinct when n=6 but survive and become steadier in population totals by n=14. At 10,000 iterations per initial population, populations are displaying surviving, more stable lynx/hare predator-prey relationships.

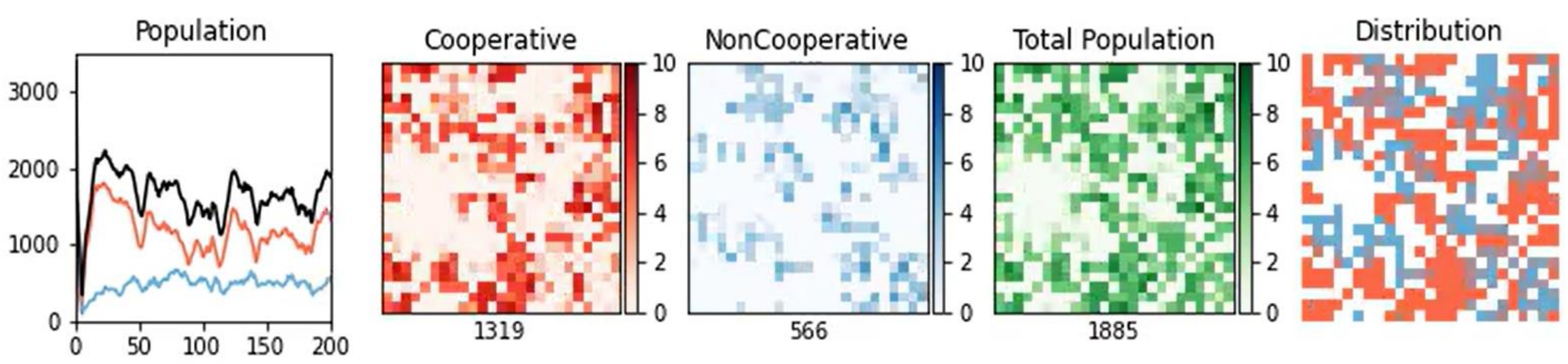
10000 generations	Size									
Capacity	2x2	4x4	6x6	8x8	10x10	12x12	14x14	16x16	18x18	20x20
2	<500	<500	200	1500	700	10000+	10000+	10000+	10000+	10000+
3	<500	500	1500	1000	10000+	10000+	10000+	10000+	10000+	10000+
4	<500	500	1000	5000	2000	10000+	10000+	10000+	10000+	10000+
5	<500	<500	2000	2000	7000	10000+	10000+	10000+	10000+	10000+
6	<500	500	500	1200	2000	7500	10000+	10000+	10000+	10000+
7	<500	300	500	1000	10000	2500	2500	2500	5500	5500
8	<500	<500	500	500	2000	2000	9500	3500	5500	5500
9	<500	300	500	700	1500	2000	2500	3000	5500	5500
10	<500	<500	<500	1300	1500	7000	9000	5000	5000	5500

The table above is data from a single typical run at a variety grid sizes and capacities. For large grid sizes at lower capacities, we tend to see the simulation settle into the Lynx/Hare pattern. Units are iterations per initial population. For small or large boards with too large capacities, populations are becoming extinct, and we see a survival stability curve appear, indicated in red above.



Here are three runs of the simulation for 10x10, capacity 7, which is a boundary case in the above table. In the first graph, this is 700,000 iterations. It shows the typical behavior we always see at the beginning of the simulation: populations briefly rise, with noncooperative rising faster. Then cooperative starts to drop, noncooperative follows suit, and there is a crash. The second and third graphs are 7,000,000 iterations. If the population makes it through the first crash, it often settles into the Lynx-Hare relationship (at least for a while).In the second graph, the population makes it through two large crashes until going extinct. This can happen and does quite often for these parameters. However, there exist cases, like populations in the third graph, that survive past 7,000,000 iterations. In this case, it went shortly extinct after the part shown. It needs larger boards to run indefinitely.





PRISONER'S DILEMMA

		PLAYER 2	
		C	NC
PLAYER 1	C	(4,4)	(-2,5)
	NC	(5,-2)	(-1,-1)

- This is the prisoner's dilemma matrix used for our simulation, with cooperate (C) and noncooperation (NC).
- The dilemma is: At any given moment, noncooperative players do better. But if noncooperative players take over in the population, they get negative payouts and eventually go extinct. If cooperative players take over, they do well. Is there a way for evolution to get around this dilemma?

LITERARY REVIEW

Evolutionary game theory in has become a growing concept in understanding and analyzing elements of biology. Martin Nowak, of Harvard University, utilized prisoner's dilemma to run computer simulations using large communities to watch as the strategies of the players went from defection to cooperation in cycles of population decline and growth. They found that in few generations, all the individuals were defecting in every round of the game, but in time, players developed new strategies by cooperating and mirroring their opponents' moves, quickly leading to areas being dominated by cooperators. Another study utilizes E. Coli with a growth advantage faced with overcrowding of wild-type populations to describe how the ideal free distribution displays the spatial distribution of selfish and cooperative individuals in spatially heterogeneous environments. Gregory M. Verutes and Amy Rosenthal have utilized a simulation game called Trade-off to preserve biodiversity and educate people about how their actions and communities lead to a cascade of impacts in marine environments. In a similar study, a Game Theory based Coevolutionary Algorithm (GCEA) was developed and tested using Multi-objective Optimization Problems by searching the evolutionary state strategies. When compared to other evolutionary optimization algorithms, the GCEA had a better performance. These few examples are only a small portion of all simulations conducted. There is a lot of literature in this area of study.

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- The first set of graphs shows a lynx hare relationship that runs for 2,000,000 iterations on a 20x20 grid and capacity 5.
- The second set of graphs shows a similar lynx hare relationship that runs for 2,000,000 iterations on a 25x25 grid, with 225 node capacities set to zero (degraded terrain) and capacity 5. The total capacity is similar.
- The second set of graphs includes cycles that have less drastic increases and decreases, highlighting its stability.
- This tells us that more spread out and varied terrain has better stability.
- The diversity in space and terrain is good (to a point).

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