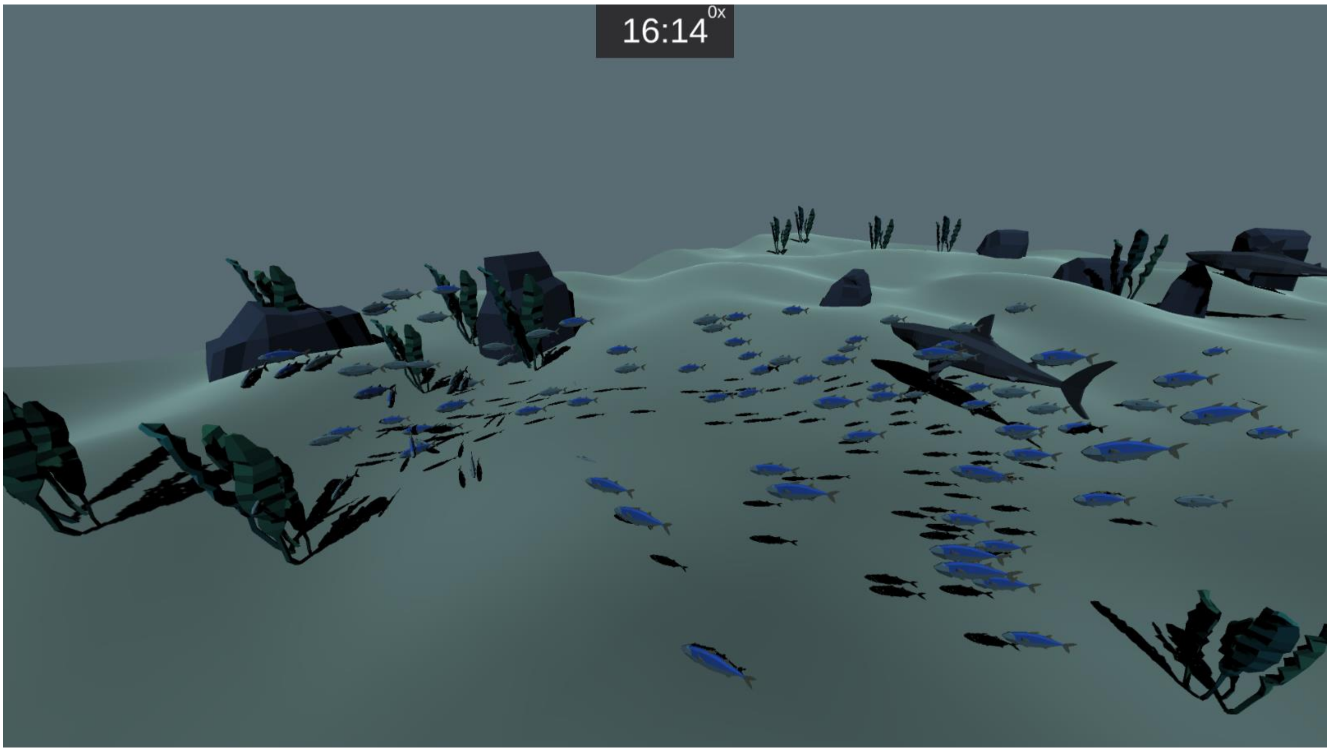
Comprehensive Creative Technologies Project: Simulation of Predator-Prey Relationships in a Marine Environment

Harry Newton
harry3.newton@live.uwe.ac.uk
Supervisor: Simon Emberton

Department of Computer Science and Creative Technology
The University of the West of England
Coldharbour Lane
Bristol BS16 1QY



Abstract

The simulation discussed in this report aims to, as accurately as possible, simulate the predator-prey relationships between three unique populations within a marine environment; using their real-world behaviours of as inspiration.

Keywords: predator-prey simulation, marine environments, simulated behaviours

Brief Biography

As a final year Games Technology student, my primary focus throughout my studies has been in the field of gameplay programming. Seeing a project such as this as an opportunity to broaden my knowledge within the overall games development landscape, I chose a topic that would introduce me to new techniques and systems I had yet to encounter before. In doing so, I have greatly improved my knowledge and understanding of a variety of topics and tested my capabilities as a developer more than ever before.

More of my work can be found online at: http://www.hnewtongd.co.uk

How to Access the Project

GitHub: https://github.com/HJNewton/CCTPProject

The repository on GitHub contains all of the code produced for this project.

Built Project on Google Drive:
https://drive.google.com/file/d/1cTU7T0WxhrgDNujD7ynopjsIxyiTQnAm/view?usp=sharing

To access the built project, download the `.zip` file from the Google Drive link above. Once installed, unzip the file into a new folder and run the `.exe` file.

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1. Introduction

Simulations depicting predator-prey relationships have existed for decades now. Within these simulations, these unique behaviours can be observed; displaying how each population affects the next until they reach an equilibrium with one another or go extinct (Laura R. Prugh et al., 2009). Shodor (1997), for example, simulates an ecosystem displaying the relationships between grass, rabbits, and wolves.

In the past, simulations such as the one seen in CLE (2012) and Darkow (2019) have been used as educational tools, providing an opportunity to teach students about the impacts of overpopulation, behaviours of animals, and food pyramids within the natural environment.

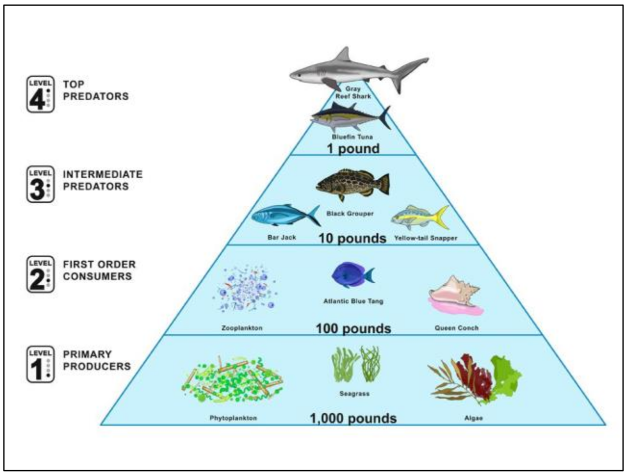


Fig. 1: Marine food pyramid detailing different trophic levels in the environment. (Gunther, T. 2018)

This project primarily focused on improving upon previous simulations, such as the ones seen in Shodor (1997) and Darkow (2019), in three distinct areas. Firstly, introducing more complex behaviours to the simulation components, such as schooling behaviours. Secondly, presenting the simulation in a 3D environment to enhance the user experience. Finally, providing more user control over the outcome of the simulation by implementing a series of tools that allow users to edit the population behaviour and sizes before a simulation starts.

Within this simulation, three unique populations are presented, inspired by three trophic layers of the marine food pyramid shown in Figure 1. The primary producers in the form of plants on the ocean floor, first-order consumers in the form of fish, and top predators in the form of sharks. Each population has their own unique behaviour that affects and justifies their position within the simulation by having a direct impact on the simulation results.

A common theme occurs amongst these kinds of simulations, Lague (2019) and Shodor (1997) for example, where they are set within forest-like environments. To differentiate this project from others of its kind, the decision was made to set it in a unique environment that would provide the opportunity to develop and implement the aforementioned complex behaviours.

To complete this project, several key tools were used. Unity 3D version 2020.1.3f1 was utilised alongside Visual Studio 2019 for the key implementation process. GitHub was used as a version control software and online backup for the project.

Project Objectives:

- Implement a customisable and functional predator-prey simulation within a marine environment.
- Display the simulation to users in a clear and realistic manner.

Deliverables:

- A built project containing the completed simulation, including the customization tools required to allow users to edit the simulation.
- User-facing information to inform changes to the simulation through the diversion from the default simulation settings.

2. Literature Review

Before delving too far into the implementation process, it is essential that the key literature surrounding this topic is reviewed and the best possible practices for certain aspects are uncovered. This ensures that the most efficient methods are used to create the final product.

2.1 Avoidance Behaviour for First-Order Consumers

Podila (2019) discusses the use of various manoeuvres used by fish to avoid an attack, each of which is dynamically chosen depending on the direction of attack from a pursuing predator. Manoeuvres such as the 'fountain manoeuvre', 'flash manoeuvre' and 'split manoeuvre' are used by Podila (2019) to effectively allow the first-order consumers to avoid attack in a more realistic manner.

2.2 Shark Activity in Relation to the Time of Day

Research was conducted into the patterns of sharks relevant to the time of day and how this affected their feeding habits. According to ISAF (2019), sharks primarily feed at low tide which, typically, occurs at dusk and dawn. Additionally, this opens up the opportunity to explore more complex behaviours for the sharks during periods when they are not feeding.

Further research discovered that during the periods between feeding times sharks rest in primarily two different ways. Firstly, many species of sharks tend to rest in a process known as 'yoyo diving'. Burgess (2017) explained that certain species of sharks will rest by swimming to the surface and resting as they descend towards the seabed, when they descend low enough, they then swim back up to the surface and repeat the process. However, Kelly M, L et al. (2019) explains how other species, such as the nurse shark, can rest by remaining stationary on the ocean floor and force water over their gills using 'spiracles', an external opening to the trachea (Editors A, 2009), in a process known as 'buccal pumping' (MCC, 2015).

2.3 Energy Transfer within a Marine Food Pyramid

As is evident in Figure 1, each trophic level of the pyramid contains a different value for the amount of relative biomass within that level. The change in biomass between levels remains consistent at around 10% of the energy transferred, this means that if, for example, a creature on the 2nd trophic level consumes a plant on the 1st then that fish will only receive 10% of the plant's total energy afforded by its biomass. As the trophic level increases, less energy is transferred due to the biomass decreasing. As discussed by Wilkins, et al. (2015), due to this lack of energy, there are generally fewer creatures at the higher trophic levels.

2.4 Efficacy of a 3D Predator-Prey Simulation

Throughout the research period, very few examples of 3D predator-prey simulations were found. In a video by Lague (2019) he simulates an ecosystem that involves a predator-prey relationship between plants, rabbits, and foxes; although this simulation is titled *'Simulating an Ecosystem'*, the primary focus of the video is on the predator-prey relationships involved. Referenced in the video by Lague (2019) is a video by Primer (2019) in which two populations, hawks and doves, compete for food, with the hawks acting as a predatory species. Both Lague (2019) and Primer (2019) prove that it is possible and effective to represent these relationships within a 3D environment.

3. Research Questions

After reviewing pre-existing simulations of the proposed kind and key literature on the topic, several questions arose:

How can the imitation of real-life behaviour impact the outcome of the predator-prey simulation?

Is it possible to simulate predator-prey relationships, accurately and effectively, within a 3D space?

Can a simulation of this type inform users and improve their knowledge of the topic at hand?

4. Research Methods

To conduct the most effective initial research possible for this project, the decision was made to primarily focus on secondary research. Sites such as Google, Google Scholar, and YouTube were effectively used to find relevant materials concerning the topic. Using these search methods, sufficient information was gathered regarding the real-life behaviour of the concerned populations and the efficacy of a 3D simulation (further discussed in Section 6). Searching primarily for information regarding feeding behaviours, schooling behaviours, energy transfers within environments, and predator-prey relationships assisted in achieving a successful research outcome.

Alongside this secondary research, in the latter stages of the project, a period of primary research in the form of user-testing took place. This user-testing was initially planned to provide feedback on certain aspects of the project, that feedback then being used to improve and make changes. However, due to certain aspects of the project overrunning, this feedback instead diverged towards determining the success of the project and its informational value.

During this period of user-testing, 4 different users spent time with the project and, once complete, answered a questionnaire on Google Forms. The questionnaire put forth a series of questions regarding the key aspects of this project and requested users to input, using a Likert Scale (Contributor, 2021), how clear the purpose of each was. This research was key in understanding whether the project was a success and answering some of the research questions proposed in Section 3. The results of the user test are further discussed in Section 8 of this report.

It is highly unlikely there was any bias in neither the secondary nor primary research conducted. All secondary research was conducted purely objectively, and the users who took part in the primary research were informed to answer in a completely honest fashion.

5. Ethical and Professional principles

Due to the nature of the primary research that was conducted, it was imperative to ensure that all aspects of it were handled ethically and professionally.

Before engaging in the user-testing period, all participants were sent an information sheet. This information sheet informed them of the purpose behind the user testing, what would be expected of them, and what would happen to the information they submitted. Additional information regarding the use of user data was provided through a research privacy notice.

No user data was collected during this period of primary research. All user consent forms were stored on a password protected OneDrive account.

The information sheet allowed for each user to give informed consent to submit to the user-testing by completing a consent form.

The information sheet, consent form, and research privacy notice can all be found in Appendix D of this document.

Several assets produced by other people have been used in this project. Although many are under the CC0 license, several are assigned a CC-BY license meaning credit has to be attributed to the creator. All credit for these assets can be found in Appendix C of this document.

Alongside this, all information gathered through the process of secondary research was sourced through ethical means, from ethical sources. All information was fact-checked against multiple sources to ensure its accuracy.

6. Research Findings

The research phase of this project provides a clear opportunity to plan additional features that will enhance the overall simulation.

6.1 Avoidance Behaviour for First-Order Consumers

Ensuring that the first-order consumers avoid predators in the most realistic manner, as discussed in Section 2.1, is vital to not only the visual aspect of the simulation but also the outcome. If the fish are not properly manoeuvring the space then they may become too difficult or too easy for the sharks to catch and consume. Emulating the behaviours discussed by Podila (2019) would aid in avoiding these kinds of issues.

6.2 Shark Activity in Relation to the Time of Day

Accurately representing the research of Section 2.2, in regard to the resting behaviour of various sharks, will quite drastically impact the entire simulation. Currently, the behaviour of the top predators within the simulation revolves entirely around consumption with no alternative behaviour. Syncing up the sharks' ability to feed to the times discussed in Section 2.2 (low-tide) on an in-simulation clock will afford a great deal more in terms of realistic behaviour. Additionally, the behaviours discussed by Kelly M, L et al. (2019) surrounding stationary rest in certain species of sharks or the "yoyo diving" discussed by Burgess (2017), if successfully implemented, would provide a much-needed alternative behaviour to feeding and would allow the simulation to run for a longer period.

6.3 Energy Transfer within a Marine Food Pyramid

As previously discussed in Section 2.3, consumption is not very efficient – only around 10% of biomass is transferred as energy. Using this information, it is possible to put together a system where by each unique creature and plant in the simulation is afforded its own biomass value that can be used to calculate the amount of energy to transfer to the predator creature that is consuming it. This would affect the simulation quite drastically as populations would maintain more realistic levels due to dependence on the prevalence of members of the trophic levels below them.

6.4 Efficacy of a 3D Predator-Prey Simulation

Using the findings of Section 2.4, aspects of the examples shown by Lague (2019) and Primer (2019) will be effectively implemented to allow for a 3D predator-prey simulation to be achieved; placed within the unique environment of a marine ecosystem.

7. Practice

The three core elements of this project were the primary producers, first-order consumers, and top predators: kelp, fish, and sharks, respectively. The first-order consumers were the initial focus of this project, followed by the primary producers and top predators. These components were developed in this order due to their impact on the outcome of the project.

The three aforementioned groups were chosen based on the marine food pyramid found in Figure 1. The decision to not include the intermediate predators within the simulation was made early on in planning so as not to push the scope of the project too far.

7.1 Primary Producers

Fig. 2: Example of a primary producer.

To provide the first-order consumers with the required nutrients to reproduce, the primary producers were implemented. Within the simulation, they can be seen as the kelp on the ocean floor. Primary producers can grow and be consumed by first-order consumers. The number of primary producers in the scene fluctuates depending on the predetermined respawn rate of primary producers and the number of first-order consumers in the scene.

Each primary producer is assigned an integer, `timesToBeConsumed`, on instantiation that determines how many first-order consumers it can provide nutrients to before it is depleted and destroyed.

Each time a first-order consumer interacts with a particular primary producer a secondary integer, `nutrientsToProvide`, is used to assign additional nutrients to the interacting creature. These nutrients directly affect the future behaviour of the first-order consumer that receives them, allowing them to reproduce or simply to not starve to death.

Initially, it was planned that each time a primary producer was consumed, it would transfer 10% of its total available nutrients, such as occurs in nature (Wilkins, D. et al, 2015), however, this proved to not translate well into the simulation space. There were far too few nutrients available using this system to sustain any substantial population of first-order consumers. Instead, after testing several systems, the consuming creature is provided 2/5 of their total biomass. This allows for reproduction to occur and the population to sustain itself.

Once a primary producer has been completely depleted, it is then destroyed and removed from the scene.

7.2 First-Order Consumers

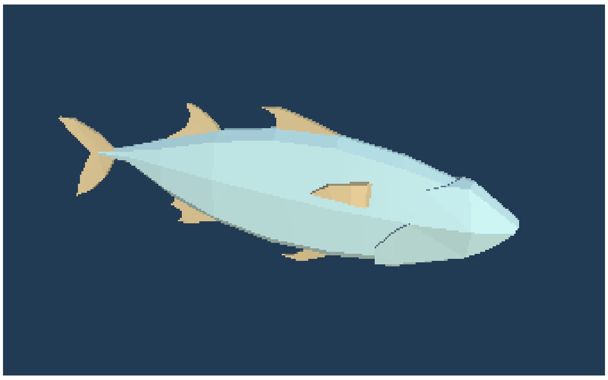


Fig. 3: Example of a first-order consumer.

The first-order consumers were represented in the simulation as the fish, making up the largest population within the simulation. Implementation of this population was critical due to the fact it directly interacted with all other elements of the simulation; being consumed by top predators and consuming primary producers. Failure to accurately depict first-order consumers would likely have resulted in a much less effective or failed outcome.

7.2.1 Movement of First-Order Consumers

To accurately depict the schooling behaviour (Editors B, 2013) required for the first-order consumers in this simulation, it was decided that implementation of the Boids (Reynolds, C. W. 1987) algorithm would be used. This would allow for the first-order consumers to move as a group throughout the simulation space.

To start, the implemented algorithm populates a list of all the first-order consumers in the scene. This list is then iterated over for each member, using their own position to determine the separation distance they should maintain from their local neighbours.

Using the number of local neighbours found, the average centre and speed of the group are calculated to determine where the first-order consumers should steer towards to maintain their position in the group, this forms the cohesion aspect of the Boids algorithm. This average centre is constantly moved towards the direction in which the first-order consumers should move, allowing each to align themselves in a common direction. This direction is towards a target that moves randomly around the scene at a speed slightly faster than the group.

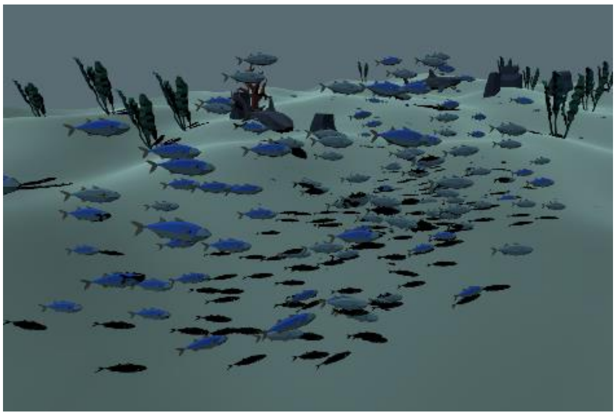


Fig 4: First-order consumers with Boids rules applied.

Every time the `ApplyBoidsRules()` method is called, the separation, cohesion, and alignment values are reapplied to each first-order consumer based on the new values presented, meaning they always maintain consistent schooling behaviour, as can be seen in Figure 4. To improve the performance of the simulation, these rules are only applied every 15 frames.

7.2.2 Obstacle Avoidance and Simulation Space Containment

To prevent the first-order consumers from becoming stuck on, or passing through, objects in the scene, some degree of obstacle avoidance was implemented. Utilising the built-in Raycast system (Unity, 2020) within Unity, each first-order consumer casts out a ray in front of them to check for obstacles. If an obstacle is detected within the predetermined `obstacleAvoidanceRange`, then the first-order consumer will be reflected away where it is free to then re-join the school.

Several scenarios may arise in which a first-order consumer could become separated from their group, causing them to potentially roam out of bounds of the simulation. To avoid this, a set of bounds are used which each first-order consumer checks their position against and, if they are found to be out of bounds, moves back towards the simulation space.

7.3 Top Predators

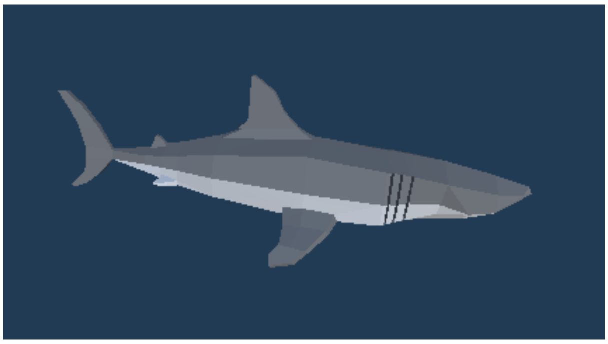


Fig. 5: Example of a top predator.

Top predators form the highest level of the simulation. Through their feeding and reproductive behaviours, they have a significant impact on both other populations; first-order consumers and primary producers.

7.3.1 Movement of Top Predators

Although similar in requirements to the movement behaviour of the first-order consumers, the top predators did not require any of the Boids behaviour as they do not school. This meant that the implementation of sufficient movement behaviour was simple.

Similar to the target which the school of first-order consumers follows, each top predator is assigned their own movement target when they are spawned, this target then moves randomly around the scene. Using this target, each individual determines and moves in, the direction they should be moving based on their current position and the target's position.

7.3.2 Obstacle Avoidance and Simulation Space Containment

To avoid obstacles and remain within the predetermined simulation space, top predators use an identical system to that used by first-order consumers.

7.4 Reproduction, Feeding, and Death

Fig. 6: In-simulation graph displaying the population history of first-order consumers.

During the initial planning stages, it was decided that three key behaviours would need to be present: feeding, reproduction, and death. Each of these behaviours has a direct impact on the prevalence of each population and the overall outcome of the situation. As can be seen in Figure 6, the populations are significantly affected by the aforementioned behaviours. Significant spikes in population can be seen in Figure 6 which indicates a large number of the population has reproduced, this is, expectedly, followed by a dramatic decrease in numbers either due to starvation or top predators feasting on the abundance of available first-order consumers. Similar graphs exist within the simulation depicting the population history of both primary producers and top predators.

7.4.1 Feeding Behaviours of First-Order Consumers and Top Predators

Only two of the three populations within the simulation feed; first-order consumers and top predators, both of which have unique behaviours regarding seeking out sources of nutrients and consuming them.

As detailed in Figure 1, each population consumes the members of the trophic level below them. In the case of this simulation, the top predators consume the first-order consumers, and the first-order consumers consume the primary producers.

For the first-order consumers to seek out primary producers to consume, it must be determined whether or not the individual requires extra nutrients.

Once the current amount of nutrients drops below the threshold, the individual's state will be changed to 'Feeding'. Once their state is changed, the first-order consumer will check its current position against the available food sources in the scene to determine which is closest to them. Once this check is complete and a suitable source is found, the first-order consumer will break off from the main group and move towards their new target.

If the first-order consumer successfully increases their nutrient level back above the threshold, they will seek to re-join the group and, if they have the requirements, reproduce.

Much like the first-order consumers, the top predators base their feeding habits on a drop in nutrients. Once this is detected they enact a change in states that commences the feeding behaviour.

Initially, the top predators chose their targets based upon an 'outlier' system. This system detected which first-order consumer was most vulnerable based on its distance from the rest of its local group. This system was effective and realistic; however, it produced an issue wherein all top predators would target the same first-order consumer when hungry. To replace this, the same approach previously discussed, wherein the top predators would find the closest first-order consumer to them then target them, was implemented. Attempts were made to combine the two systems so outliers within a certain radius around each top predator would be selected; however, more often than not, the top predators would starve before they found a suitable target.

7.4.2 Reproductive Behaviours of Each Population

All three populations present in the simulation replenish their numbers through some form of reproduction. The primary producers grow up from the ground, meanwhile, the first-order consumers and top predators reproduce with one another to produce offspring.

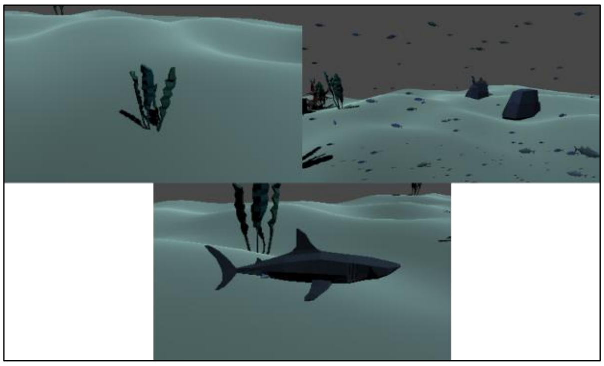


Fig. 7: Examples of all three populations in their infant stages

To display the reproduction systems, each member of a population will grow from an infant stage, as can be seen in Figure 7, all the way up to an adult size; Figures 2, 3, and 5. Whenever reproduction occurs, the newly spawned element will randomly choose its final size from between a range, which it will then grow to. In the case of first-order consumers and top predators, once they reach their final size, they are considered adults and can begin reproducing. Adding this slight randomisation to the scale of each member of a population allows for a more realistic looking outcome, particularly in the schools of first-order consumers such as in Figure 4.

To replenish the population of primary producers, the `EnvironmentManager.cs` script constantly instantiates new prefabs at random locations in the simulation space dependant on the respawn speed the user selected at the start of the simulation.

Both the first-order consumers and top predators reproduce identically. Each member of these populations, on their instantiation, is assigned a gender, either male or female; in the `FishHealth.cs` and `SharkHealth.cs` scripts for first-order consumers and top predators, respectively. This gender will determine what role they play in the reproductive process. Female members are responsible for actually producing the offspring. Each time a reproductive process is set to occur, the members check whether they have sufficient nutrients to reproduce. If sufficient nutrients are present, reproduction will occur; if not then the member will seek out a source of food to consume.

During the process of reproduction, these females will check their surroundings for any male members of their population; one difference is: first-order consumers search their local group for a male, whereas top predators search the whole scene. If the female finds a suitable mate, they will then proceed to produce a predetermined number of offspring after a short period.

Reproduction within each population is vital to the outcome of the simulation. Without the ability to replenish populations, the simulation would provide a far less realistic depiction of predator-prey relationships.

7.4.3 End of Lifecycle Within the Simulation

To finalise the lifecycle for each population, each has a unique set of circumstances that can destroy the individual member.

Concerning the primary producers, their lifecycle ends once first-order consumers have completely consumed the nutrients they have to offer.

First-order consumers have a series of different scenarios in which they may be destroyed; starvation, being consumed, and natural causes. Starvation occurs when the first-order consumer has completely run out of nutrients. This commonly occurs if the population grows too large and competition for food sources is too high to sustainably maintain a steady population. Due to the fact first-order consumers are a prey creature, they are commonly consumed by the top predators. Finally, their lifecycle may also end if they grow too old. Each individual has a predetermined age they can live to and, if they reach this age, they will be destroyed.

Top predators share similarities to the first-order consumers in that they can also succumb to starvation and old age. Unlike first-order consumers, however, the top predators are, as the name suggests, at the top of the food chain within the simulation; so, there is no opportunity for them to be consumed by anything.

7.5 The Simulation Environment

For the most part, the simulation environment serves a purely visual purpose. However, providing a pleasing visual experience only served to improve the overall quality and feel of the simulation.

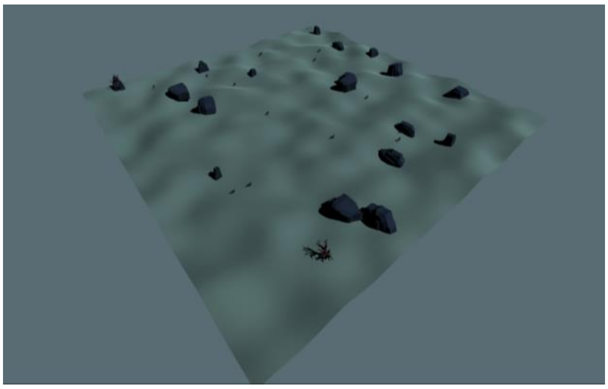
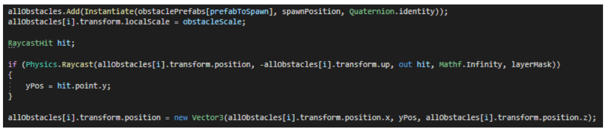


Fig. 8: An example of terrain formed by the mesh generator, populated with primary producers and objects.

To implement a realistic-looking ocean floor, a procedural mesh generator was created. This generator would create a flat plane from a series of vertices. The `y` position of these vertices would then be randomly manipulated through the use of Perlin noise. In doing so, bumps and divots would be formed in the terrain giving off the appearance of a sandy, ocean floor, the final result can be seen in Figure OCEANFLOOR. All the code for this generator and links to the tutorials used can be found in the `MeshGenerator.cs` script.

To further improve the ocean floor, various objects were scattered randomly about the space. Included amongst these objects were the primary producers, rocks, and coral. The rocks and coral primarily served the purpose of obstacles for the first-order consumers and top predators to avoid.



```
allObstacles.Add(Instantiate(obstaclePrefabs[prefabToSpawn], spawnPosition, Quaternion.identity));
allObstacles[i].transform.localScale = obstacleScale;

RaycastHit hit;

if (Physics.Raycast(allObstacles[i].transform.position, -allObstacles[i].transform.up, out hit, Mathf.Infinity, layerMask))
{
    yPos = hit.point.y;
}

allObstacles[i].transform.position = new Vector3(allObstacles[i].transform.position.x, yPos, allObstacles[i].transform.position.z);
```

Fig. 9: Dynamically adjusting the position of the objects to suit the terrain below them.

As seen in Figure 9, all of the objects were spawned up above the terrain, floating. This allowed for a raycast to then be cast down from each object until it impacted the terrain. This impact point became the new y position for each object; dynamically locating them so they are always on top of the terrain below them. Using this technique avoided any strange visuals from obstacles or primary producers clipping through the ground below them.

7.6 User-Controlled Values to Impact the Simulation

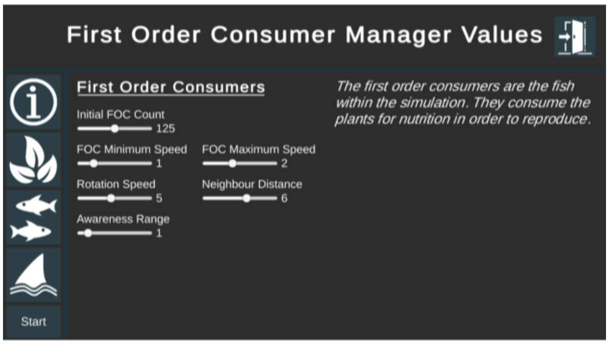


Fig. 10: The value control page for the first order consumer population.

As previously discussed, the user should be able to change the outcome of the simulation by changing a variety of values that impact the populations. To facilitate this, three distinct pages were made in the pre-simulation user interface that contained a variety of fields the user could edit; an example of the first-order consumer page can be seen in Figure 10.

Amongst the values that could be edited were the population sizes on the simulation start, the minimum and maximum speeds of the first-order consumers and the top predators, values to impact the Boids behaviour of the first-order consumers, and the overall size of the simulation space. Each value change would likely edit the outcome of the simulation, for example, if there are very few first-order consumers present when the simulation begins then it is unlikely that their population will grow to a sustainable level before it can be wiped out by the top predators.

7.7 User Testing

Through the period of user testing, discussed in Section 5, the success and effectiveness of the overall implementation was measured by presenting the users with a variety of statements.

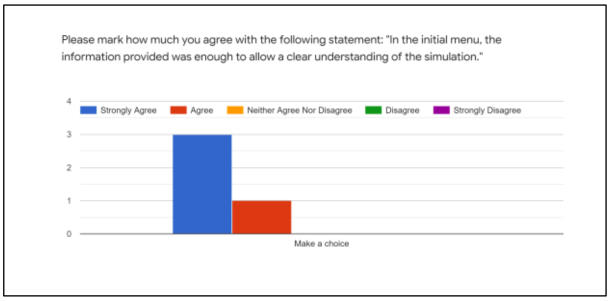


Chart 1: Responses to the statement *'In the initial menu, the information provided was enough to allow a clear understanding of the simulation.'*

To ensure the users were informed of the purpose of the simulation, how it worked, and how to use it, a pre-simulation menu was created that displayed the relevant information to the user. As can be seen in Chart 1, 100% of users agree, with 75% strongly agreeing, that the information provided was enough to allow for a clear understanding.

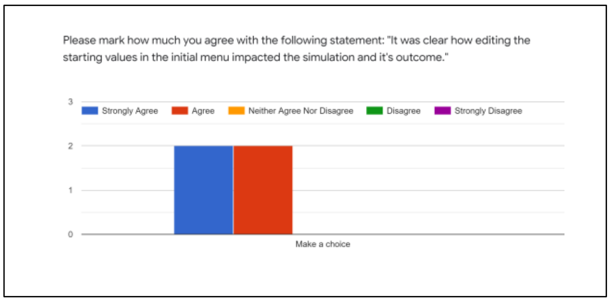


Chart 2: Responses to the statement *'It was clear how editing the starting values in the initial menu impacted the simulation and its outcome.'*

As evident in Chart 2, 100% of users agreed that it was clear how editing the starting values of each population impacted the outcome of the simulation.

Measuring the effectiveness of the implementation of each population was achieved by assessing how clear their roles in the simulation were.

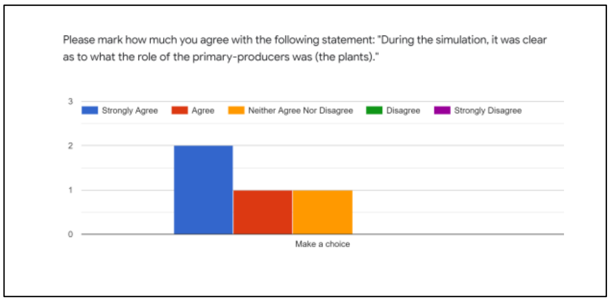


Chart 3: Responses to the statement *'During the simulation, it was clear as to what the role of the primary producers was (the plants).'*

75% of total users agreed that the role of the primary producers was clear, as shown in Chart 3.

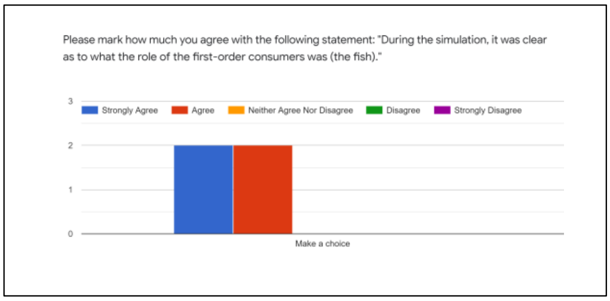


Chart 4: Responses to the statement *'During the simulation, it was clear as to what the role of the first-order consumers was (the fish).'*

100% of users agreed, either strongly or otherwise, that the role of the first-order consumers was clear within the simulation, as shown in Chart 4.

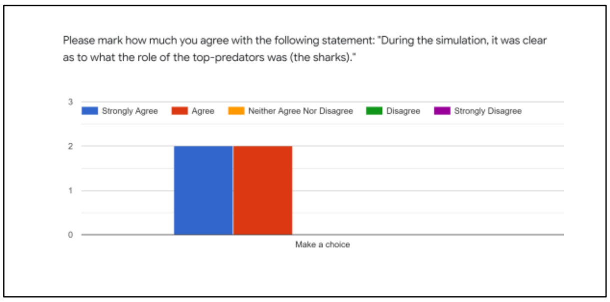


Chart 5: Responses to the statement *'During the simulation, it was clear as to what the role of the top predators was (the sharks).'*

Chart 5 clearly displays that all participants agree that the role of the sharks was clear within the simulation, much like the first-order consumers.

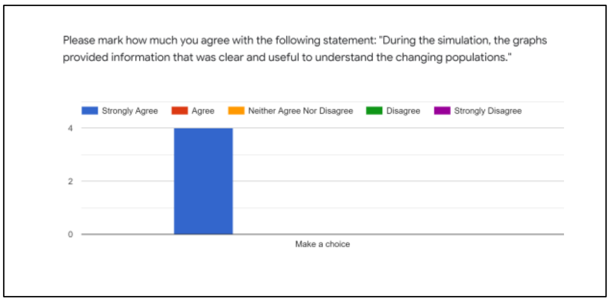


Chart 6: Responses to the statement *'During the simulation, the graphs provided information that was clear and useful to understand the changing populations.'*

To inform users of the current population levels, graphs such as the one in Figure 6 were implemented to record a real-time number of each population. Displaying increases and dips in populations, 100% of users in Chart 6 believed these graphs provided a clear and useful understanding of how each population was changing.

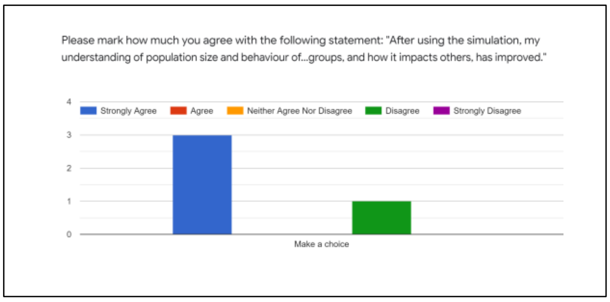


Chart 7: Responses to the statement *'After using the simulation, my understanding of population size and behaviour of certain groups, and how it impacts others, has improved.'*

The results of Chart 7 show that the simulation is informative with 75% of answers strongly agreeing that the simulation improved their understanding of the topic.

8. Discussion of Outcomes

The initial focus of this project was to determine the overall feasibility of a marine-based predator-prey simulation, with the added technicality of user-adjusted values. The vast majority of the goals set out to achieve were met, including but not limited to schooling behaviours of first-order consumers, reproduction of all populations, and effective user input opportunities.

However, there were several features proposed during both the proposal and research stages that were not successfully implemented. For example, it was proposed in Section 6.2 that the creatures within the simulation would have time-sensitive behaviours such as resting at night or only feeding at certain times, and the first-order consumers would avoid the top predators such as in Podila (2019), however these features never saw a full implementation. The primary reason behind this was simply due to a lack of available time where other features took up decidedly more time than was initially allotted to them.

There are several other opportunities for improvements within key areas of this project. As previously mentioned, proper avoidance of predators on the part of the first-order consumers was planned. Several attempts were made throughout development to implement this feature, using a different approach each time, however, none of these attempts proved a success and the feature was not included in the final product.

Increasing the complexity of the first-order consumers beyond the limitation of a single school would have also proved beneficial to the outcome of the project. This would provide the top predators with several different schools of fish to feed on, thus allowing for the outlier behaviour, discussed in section 7.4.1, to be reintroduced, providing the top predators with much more realistic feeding behaviours.

As discussed in Section 7.1, the transfer of energy detailed in Section 6.3 did not result in an effective implementation. However, the information did help to inform the reproductive behaviours of top predators. Each top predator, after this research was complete, required more nutrients to reproduce and produced fewer offspring, in line with their real-life behaviours. Keeping the number of top-predators lower resulted in more diverse outcomes, where before, the majority of the time, the top predators would just consume all first-order consumers, reproduce to massive numers, then starve to death.

At several stages throughout the project, time was managed quite poorly. Several features and implementations took far longer than they ought to. Either due to other commitments or complications in the actual implementation, this aspect of the project could have been improved upon.

Beyond these desired improvements of the project, however, lies a successful implementation of the initially proposed final product. A simulation has been created that allows for several trophic layers of a marine food pyramid to interact with one another; reproducing, eating, and dying completely free of any outside input. The behaviours implemented work exceptionally well in the context they were placed in, providing different outcomes each time the simulation is run. Additionally, the overall system which allows users to impact the outcome of the simulation by changing initial values works as intended and is informative about the potential choices the user can make.

During the period of user testing, the success of various elements of the project was evaluated; including the information supplied, the user input opportunities, and purposes of all three populations.

One of the major elements of this project was the users ability to manipulate the starting values of the simulation. As previously discussed, all users who partook in the test agreed that it was clear what each value change did and its impact on the outcome, as shown by Chart 2. However, several users reported that the functionality could've benefited from a button that reset to the default values. Perhaps if the user testing took place earlier on then this could have been added as an improvement.

Charts 3, 4, and 5 all discussed the implementations of the primary producers, first-order consumers, and top predators respectively. With the majority of responses received being positive, it can be quite resolutely concluded that the implementation of all three was a success. Even with the omission of the previously discussed features such as time-based behaviours and avoidance, the users still believed the purpose behind each population was clear.

Chart 7 addresses the question of whether the simulation was informative to users. With 75% of users agreeing that the simulation improved their knowledge and understanding of population size and behaviour of certain groups, and how they impacts others. These results potentially open the door to an educational application for this simulation such as in CLE (2012) or Darkow (2019). With the added aspect of detailed 3D visuals improving upon CLE (2012) and Darkow (2019), it could be argued that this would make the simulation more engaging for a classroom environment.

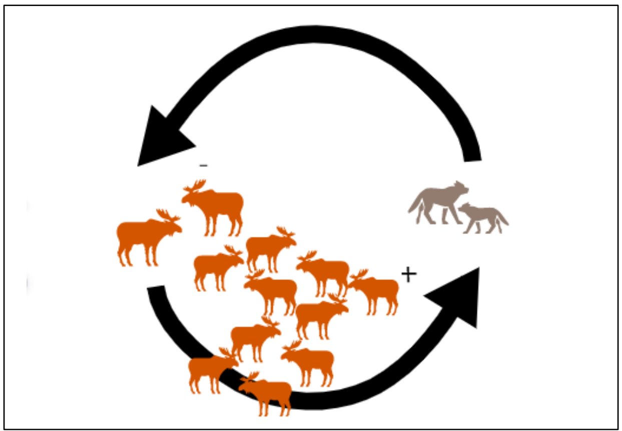


Fig. 11: The visuals provided in the simulation by Darkow (2019).

Concerning professional context, the simulation both emulates and builds upon previous simulations of this type. The simulation by Darkow (2019), for example, displays the relationship between two populations, however, it is shown in a purely informative manner with very few visuals, as can be seen in Figure 11. The simulation detailed in this report provides a much-improved visual experience whilst retaining the informational aspect, such as through the in-simulation graphs shown in Figure 6.

Moving the concept of a predator-prey simulation to a 3D model allowed for the implementation of more realistic behaviours than the ones seen in simulations such as Shodor (1997) and CLE (2012). This allowed for those complex behaviours to contribute an additional factor to the final outcome of the simulation. Schooling, vicinity-based feeding and more all played a unique part in providing a more involved final result than the ones found in simulations of the like of Darkow (2019).

This project proves that it is possible to have complex systems constituting a predator-prey simulation within a 3D, interactive environment.

9. Conclusion and Recommendations

This report discussed the systems implemented to achieve the final goal of a predator-prey simulation within a marine environment, and the process undertaken to develop said systems.

To take this project further, it would be beneficial to consider the implementation of the omitted trophic layer *'intermediate predators'* in Figure 1. Successful implementation of this population would serve a great deal to enhance the realism and potential outcomes of the predator-prey simulation. Alongside this, implementation of the aforementioned avoidance behaviours between first-order consumers and top predators would be a key focus. To make the project more accessible for users, a great deal of optimisations would need to be carried out primarily to the first-order consumers, but also all other elements of the simulation.

Taking this project beyond the bounds of a university assignment, it is possible to see it as an educational tool to assist in teaching students about a variety of topics, such as discussed in Section 8, from the unique predator-prey relationships to the impact of overpopulation on various species. Additionally, this implementation could also form the basis for a wider video-game implementation, either as an environmental asset or with the systems tied directly into the core gameplay loop; forming a potential commercial avenue for the project to take.

Although, as previously discussed, several features were omitted from the final implementation, the finished product resolutely fulfilled all of the initially proposed project, research, and learning objectives. The final simulation was a success, containing all of the core functionality that was intended and providing unique and customisable outcomes to the user.

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Appendix A: Project Log

18022610 **Harry Newton**	**Simulation of Predator-Prey Relationships in a Marine Environment**	
Date:	**Progress made:**	**To do for next week:**
20/10/2020 - Week 1	• First meeting with my supervisor (Simon Emberton) • Discussed my initial proposal and what would be beneficial to add for next week's meeting	• Add references to my initial proposal • Flesh out the already completed research • Consider what relationships should be emulated between the creatures (predator-prey simulations)
27/10/2020 - Week 2	• Decided on the primary focus of my project as the simulation of a predator-prey style relationship in the ocean • Significant research into the topic	• Add more references • Rewrite using the new template • Extend methods section

03/11/2020 - Week 3	• Discussed with Simon the references I'd used, decided more academic references were required. • Significant work on the Methods section to properly articulate the visuals and implementations.	• Talk with Simon about the use of older simulations in my proposal to allow for discussion of a modern interpretation of the simulation. • Finalise proposal for next Thursday.
10/11/2020 - Week 4	• Included more academic references to flesh out the detail. • Added a draft version of the timetable.	• Finalise the proposal using Simon's feedback which includes the addition of the ethics checklist.
17/11/2020 - Week 5	• Finalised proposal including finishing methods section, additional research and fleshing out the project timetable.	• Begin the implementation by producing basic fish behaviour using Boids.
24/11/2020 - Week 6	• Basic implementation of fish behaviour achieved using a Boids system. These fish will swim together in a school and avoid obstacles. • Instantiation of various objects in the scene which will later be used as food and cover.	• Implement the basic shark behaviour, including patrolling and feeding on fish. • Flesh out the fish behaviour by adding the ability for them to feed on kelp.
01/12/2020 - Week 7	• Basic shark implementation achieved, they will currently only feed on fish they deem to be outliers to the rest of the school.	• Flesh out shark behaviour with patrolling. • Implement basic avoidance of sharks on the fish's part. • Add a movement controller for the user to move around the scene.
08/12/2020 - Week 8	• Improved fish avoidance behaviour.	• Further improve collision detection. • Add user movement controller. • Research shark behaviours based on time of day.
15/12/2020 - Week 9	• Improved collision detection for sharks and fish. • Added user movement controller.	• Add a basic day/night cycle ready for time-based behaviours. • Add the basics of kelp consumption and the natural death of fish.
12/01/2021 - Week 13 (Post-Christmas break)	• Added a 24-hour clock within simulation ready for the time-based behaviours (sleeping, patrolling, eating etc). • Added the ability for fish to eat kelp and die if they are starving.	• Complete research documentation for 21/01. • Further work on the collision issues and try to resolve the bugs currently occurring.

19/01/2021 - Week 14	• The research document is almost completed, it will be done by tomorrow. • Collision is almost fixed, just a few more bugs to work out.	• Submit research document on the 21st. • Create a draft for the demo video to show off next week.
26/01/2021 - Week 15	• Research document submitted. • Video demo draft created.	• Follow up on Simon's feedback and reduce the length of the video demo down to around 2 minutes.
02/02/2021 - Week 16	• Further work on the demo video.	• Finish the video for the demo, trim out the unimportant bits.
09/02/2021 - Week 17	• Demo completed. • Worked on improving shark behaviour.	• Continue improving the sharks.
16/02/2021 - Week 18	• Optimised the code to allow for better performance. • Improved shark collision behaviour.	• Improve the way sharks decide which target to chase. • Improve shark roaming behaviour
23/02/2021 - Week 19	• Sharks now roam the scene more naturally. • Worked on rewriting the shark target acquisition system.	• Continue working on the target system for sharks. • Add the ability for users to change simulation space size.
02/03/2021 - Week 20	• Finalised the new targeting system for sharks. • Users can now change the size of the simulation space before simulations begin.	• Change the models in the simulation so it is more clear. • Add basic terrain generation to give the floor some more depth.
09/03/2021 - Week 21	• Added a system to randomly spawn obstacles on the ocean floor. • Added more obstacles than just coral.	• Add growth of the fish and sharks so they do not spawn at full size. • Add basic terrain generation to give the floor some more depth.
16/03/2021 - Week 22	• Added basic terrain generation.	• Add in the graph to display shark populations.
23/03/2021 - Week 23	• Added in the shark graph. • Made male and female fish look different so users can tell the difference. • Further optimisations.	• Redo the in-game UI to be more user friendly. • Add information for the user to read regarding the information. • Finalise questions for the user testing.

13/04/2021 - Week 26 (Post-Easter break)	• Created the Google Form for user feedback. • Finalised version for user testing. • Sent off to testers. • Created bullet point list of topics for practice and discussion of outcomes section for the final report.	• Begin final write up. • Email a draft to Simon for review by 18/04/2021.
20/04/2021 - Week 27	• Began work writing the final report. The practice section has seen a considerable amount of work completed.	• Continue working on the final report, completing at minimum the practice and introduction sections. • Email a second draft to Simon for review by 25/04/2021.
27/04/2021 – Week 28	• Introduction and practice sections are completed. • Added relevant information under the biography section. • Added information on how to access the project. • Began work on the discussion of outcomes section.	• Finalise discussion of outcomes section and complete the conclusion. • Add the relevant information regarding the research section. • Email final draft to Simon for review by 02/05/2021.
04/05/2021 – Week 29	• All sections of the report have been filled out.	• Make the relevant changes suggested by Simon to ensure the document is to the highest possible quality. • Submit the Artefact and Report by 06/05/2021.

Appendix B: Project Timeline

Month	Tasks Planned	Allotted Days per Task
October	Work on project proposal document.	7
November	Finalise proposal document.	5
	Hand-in proposal document	1
	Find appropriate models on Google Poly	1
	Implement basic fish movement behaviour in the form of boids.	7
	Implement the underwater terrain for simulation environment.	3
	Implement shark movement behaviour	7
December	Implement a movement controller to allow free movement within the simulation	2
	Generate plants on the ocean floor for the fish to consume based on an editable value.	7

	Implement the fundamentals of consumption (plants for fish, fish for sharks)	7
	Implement reproduction and natural death system for plants and creatures.	7
January	Implement user controls control over populations of plants and creatures at the simulation's start	7
	Ensure the simulation is running efficiently and not causing any performance loss.	(Continuous)
February	Hand in and demo currently completed work which should involve a basic, functional version of the simulation.	7
	Improve visuals within the simulation with post processing effects.	2
	Conduct user test to determine any changes that need to be made.	5
March	Fix any remaining bugs and make improvements discovered in user testing.	7
	Finalise the visuals; including animations, models and environment details.	7
April	Build the final project with a functional scene for the user to explore and edit the simulation within.	1
	Write final report for the project.	14
May	Hand in the final project and completed report.	1

Appendix C: Assets Used in the Project

The model for the primary producers was sourced under a CC-BY license from:
https://poly.google.com/view/4cFllH6Iazk

Models for the first order consumers and top predators were sourced under a CC0 license from:
https://quaternius.com/packs/animatedfish.html

The models for the rocks placed on the terrain were sourced under a CC0 license from:
https://quaternius.com/packs/ultimatenature.html

The model for the coral placed on the terrain was sourced under a CC-BY license from:
https://poly.google.com/view/4KUXdtDdgHR

The UI Icons used were sourced under a CC-BY from:
https://game-icons.net/

Appendix D: User-Testing Documents

User-Testing Questions: https://forms.gle/u5q5cjLZwGKsUdnj6

Information Sheet: https://docs.google.com/document/d/1xFh6uDsdkEE6Df3p7GgMMmlG-AO9Ee9e/edit

Consent Form: https://docs.google.com/document/d/1zDfxJJoC2TrqxdegqlnMdjV8DxwcUGjy/edit

Research Privacy Notice:
https://docs.google.com/document/d/1d3spL6hjNayUsAxwnq3VsuuQMOPoSqwy/edit