Applications of Dynamic Ocean Management

A Case Study With Blue Whales and the Dungeness Crab Fishery

By Bella Genolio

Introduction

Blue Whales are the largest animal on the planet and often get killed in human related activities. One of these activities is Dungeness crab fishing, a type of fishing that involves catching Dungeness crabs using traps that have ropes from the fishing areas above the water to the sea floor where Dungeness crabs live. While swimming, Blue Whales can become entangled in these traps and become injured or killed. This project focuses on this specific area of ocean management. Our main goal with this project is to visualize the interaction between Blue Whales and Dungeness crab fisheries off of the coast of California. With this, we can attempt to understand the relationship between these giant mammals and our human activity. From this understanding, we can come up with policy related solutions for this entanglement issue, steps to take going forward, and further research that must be done in order to fully understand the complexity of the relationship between Dungeness crab fisheries and Blue Whales in California.

There are many reasons why this issue is important. First of all, Blue Whales are an endangered species and, as many species are, play an important part in the environment they reside in. Because they are so large, these mammals contribute so much to ocean health and climate regulation. If Blue Whales went extinct, the ecology of the ocean would completely change and countless other species would be affected in more ways than we can predict. Secondly, the Dungeness crab fisheries off the coast of California are a very lucrative part of California's economy (Lebon, 2019). Dynamic Ocean Managers have been working to make these fisheries more sustainable so that they can continue running for as long as possible. In order to preserve this valuable part of our economy, making these fisheries have as little impact as possible is crucial. As the ocean temperature rises, domoic acid is produced which can cause harmful algae growth. This algae bioaccumulates in fish, shellfish, and crustaceans including Dungeness Crab. While this has little effect on the species themselves, humans who eat these crabs can get fatally poisoned. This in turn can lead to the closing of the fisheries and a loss of this important part of California's economy.

In order to visualize the relationship between the Blue Whales and the Dungeness crab fisheries, my group utilized multiple graphs and maps of these two entities. First, we created kernel densities of both the Dungeness Crab fisheries and Blue Whales by season and year. Next we plotted the trajectories of each of the whales and then segmented them based on their behaviors.Then we created a hotspot analysis animation that portrayed the overlap between the fisheries and the whales over the years we had in our dataset, as well as histograms and line plots that displayed the overlap of the two species. Finally, we simulated the Blue Whale kernel densities and the Dungeness Crab landings.

Background

Dynamic Ocean Management is an important part of sustainability research happening today. This methodology allows for the continuation of human practices, including fisheries, with the lowest risk of habitat destruction in the ocean. One area that this practice has been trying to fight is the continued endangerment of Blue Whales from human practices. Keeping Blue Whales from extinction is crucial to the health of our ocean and environment. These mammals process multiple tons of krill every day and the resulting waste fertilizes the phytoplankton (Chami, 2019) which in turn produce up to 12% of the oxygen on earth (Hook, 2023). Additionally, after Blue Whales die, their bodies capture "33 tons of CO_2 on average, taking that carbon out of the atmosphere for centuries" (Chami, 2019).

One important study in Dynamic Ocean Management relating to Blue Whales looks at how ship strikes affect these animals and what we can do to prevent unnecessary deaths. This study describes how satellite data of Blue Whales' movements are not used as much as they could be since they only "provide presence-only information rather than abundance information," density for example, and dynamic ocean management studies rely heavily on "spatially and temporally explicit information on their distribution and abundance" (Elliott, 2017). In order to combat this, these scientists used a switching state space model to account for error in the points while providing their positions daily. The result of this produced a "real time tool" that allowed for Ocean Managers to predict the overlap between whales and harmful human activities yearly and seasonally (Elliott, 2017).

According to another study, the uptick in whale entanglements since 2014 could potentially cause a shut down of Dungeness Crab fisheries, one of the West Coast's most important fisheries (Lebon, 2019). The US Endangered species act considers killing of endangered species illegal, so entangling whales in this way could make these fisheries "subject to fines or, if done intentionally, criminal sanctions" (Lebon, 2019, pg 4). Fisheries are working to combat these entanglements with new ways of trapping Dungeness crabs that would limit harm to whales. These new methods include pingers on the lines that alert the whales steering away from harm, weak links in the line or more breakable material, and visible line color (Lebon, 2019, pg 5). A method of forcing fisheries to comply with whale safe standards that the study talked about was putting labels on Dungeness Crab products to tell consumers whether the product is certifiably “whale-safe”(Lebon, 2019, pg 6).

A very relevant study that specifically examines the efficacy of entanglement reduction methods and preventative gear types. What they found was that entanglements reduced a considerable amount without a significant negative effect on fisheries. It highlights the "dynamic nature of species’ spatial distributions and key social and economic impacts that together determine conservation efficacy" (Riekkola, 2022, pg 16). Our project comes out of this study in a way, our goal is to map whale patterns to be able to predict their movements based on the environment area. In order for these fisheries to continue to have sustainable practices.

Case Study and Methodology

Our project focuses on the interactions between Blue Whales and Dungeness Crab fisheries on the seasonal and yearly level. We are looking at this interaction off of the coast of California during the years 1993 to 2008 and 2014 to 2015. With this project, our main goal is to visualize the seasons and years where interaction was higher based on seasonality, movement patterns, or variation in area. From this information, our goal is to try to find solutions in order to reduce entanglement primarily based on movement patterns rather than gear type, which has been studied before.

We are using two main types of data - blocks of Dungeness Crab fisheries and Blue Whale satellite data. The Blue Whale satellite data comes from Movebank, a website that provides free animal tracking data. Though the data is recorded in the same area, it consists of two different sets, one from 1993-2008 and the other from 2014-2015. Both of these tracked sets were led by the same researchers, Barb Lagerquist and Daniel Palacios, and have the same variables, making it easy to apply the same analysis to both datasets and compare. For the earlier dataset, there are 143 Blue Whales being tracked and the later dataset has 8. Each whale has thousands of tracking points and starts and stops being tracked at various times and locations. When mapping these whales' trajectories, I kept these two datasets separate in order to visualize the two different periods as well as compare smaller and larger clusters of whales.

The Dungeness Crab data set comes from the Marine Fisheries Data Explorer from the California Department of Fish and Wildlife. In order to match the Blue Whale data sets, we retrieved data from the years 1993-2008 and 2014-2015. This data was filtered by trap gear type and is measured in block code, pounds, and value for each catch. Blocks in commercial fishing are geographically defined areas designated to define the area in which fisheries are allowed to catch. Though the whales travel well off of the coast and down past the California border, our Dungeness Crab fishery blocks are only the ones in California, so we are looking specifically at the interaction between California fisheries and Blue Whales. In order to visualize and understand the interactions between the tracked Blue Whales and California Dungeness Crab fisheries, we implemented a number of different graphing techniques.

To look specifically at the whales' movements, we utilized multiple mapping techniques. To start, we created a scatter plot on a map of the area with the first location the tracker picked up for each of the whales. This showed us that the whales were seen anywhere from the top of California to South of Mexico. Then we plotted the trajectories of each whale differentiated by color. We then split the whale trajectories into foraging and transiting based on their speeds, we followed the Véronique Lesage paper stating the foraging speed of Blue whales was around ~1 km/hr. From this we plotted a randomly sampled portion of the foraging and transiting trajectories on a map as well as a scatterplot of the points colored by behavior.

For both the whales and the fisheries, we created seasonal and yearly kernel density maps.The map of the whales is based on their latitude and longitude while the map of the fisheries is based on the block code. This allowed us to visualize where the whales traveled most per season and per year as well as the most used areas for commercial Dungeness Crab fishing. For the fisheries, we created a graph that maps the change in center of gravity over time

To begin with a general idea of the interactions between the two entities, we created an interaction hotspot analysis. The hotspots provide a general idea of where the most Dungeness Crab fishing is happening and where the most Blue Whale activity is taking place per year. We differentiated between the two of these with color and a low opacity, this way we could see when and where the hotspots overlapped. With these maps we created an animation that put all of the observed years together, so we could compare the differences in interaction from year to year.

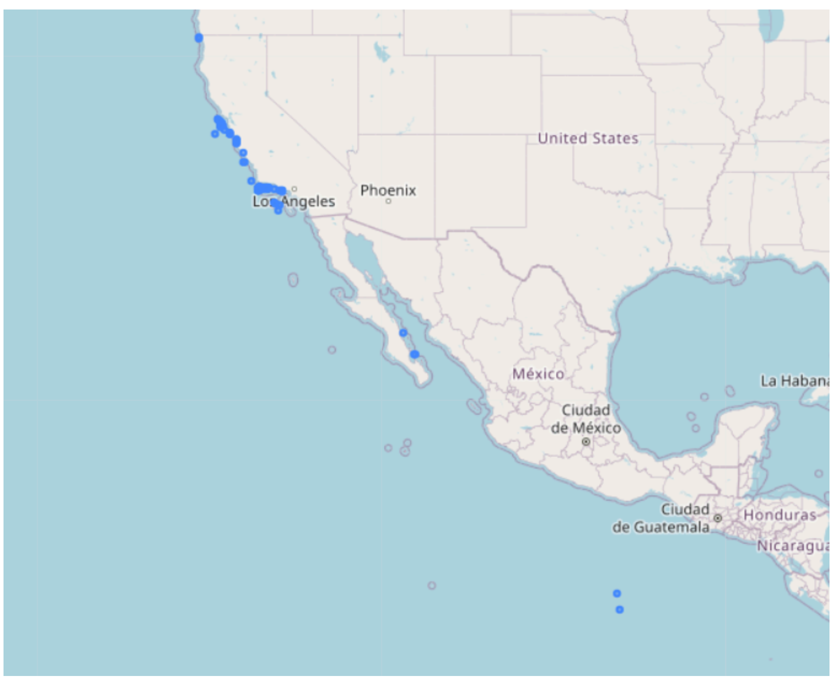
To simplify and summarize the hotspot overlap based on seasonality, we created histograms that quantified the area of overlap per season.

Finally, we visualized interaction by using line plots. One line plot we implemented compared the Northernmost and Southernmost latitudes by species per year. This way we could see how far the Blue Whales and the fisheries went every year and compare them. With the Southernmost and Northernmost plots, we repeated this as a scatterplot but changed the x axis to reflect the seasons rather than the years. We also made a scatterplot of areas where the hotspots overlapped and fit a line to it to see if there was a measured correlation between the areas.

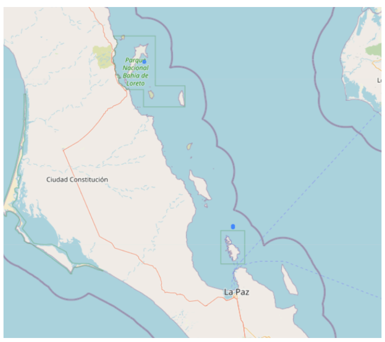
Results and Discussion

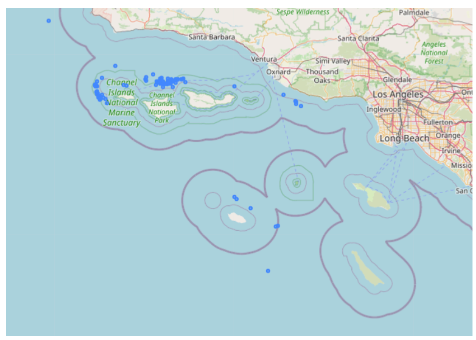
In order to aid with the interpretation, here is the link to the google drive with all of our code, figures, data, and research sources for this project: Final Project

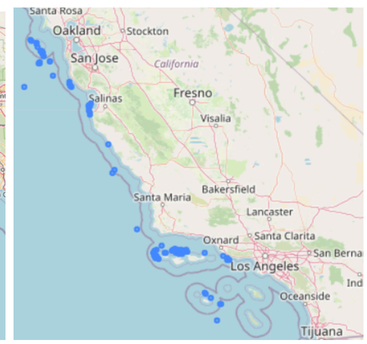
Blue Whales



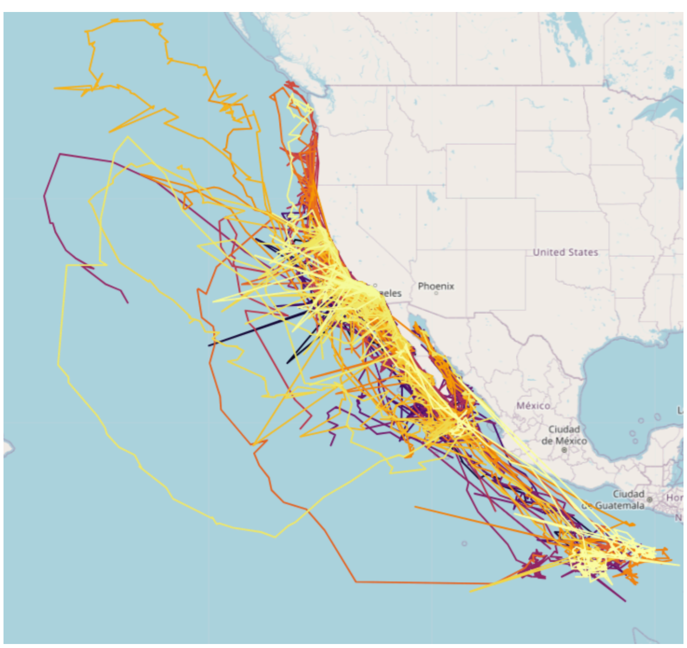
To begin, we can examine the starting points of each of the whales. The figure to the left displays all of the starting points that come from a reference dataset attached to the main dataset. This plot shows us that the furthest North starting point for these Blue Whales was the tip of the border between California and Oregon. Zooming in on the Gulf of California off of Mexico, (in the left figure below) we can see that three whales have starting positions within the Gulf. The furthest south are two Blue Whales that are parallel to the border between Mexico and Guatemala. Looking closer at the area from the San Francisco Bay to Tijuana (in the figure on the right below), we can see that the majority of the Blue Whales begin in this area and are clustered in two main areas: around the mouth of the San Francisco Bay and around the Channel Islands.



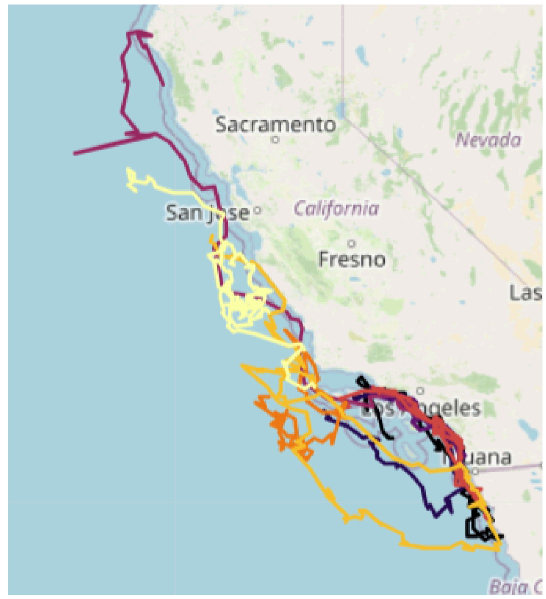




In the center picture above, we can see that there are many whales beginning in the Channel Island area. They get fairly close to the land of the Channel Islands as well as the coast off of Oxnard, but they generally steer clear of the Santa Barbara coast.

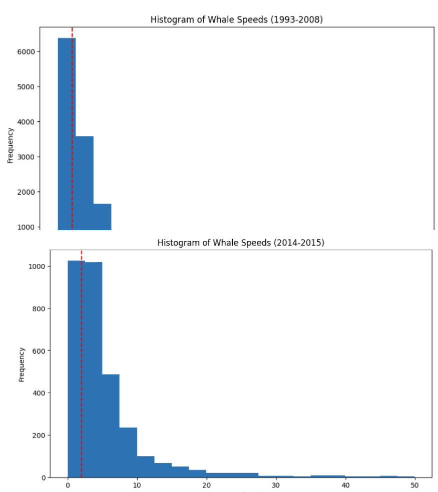


Now that we are able to visualize the areas where the Blue Whales begin their tracking, we can begin to look at their trajectories. The figure on the left displays all of the trajectories of the 143 Blue whales from 1993 to 2008. One thing to note from this figure is that these trajectories connect consecutive tracking points, so some incorrectly map over the land. We tried to minimize this by restricting the maximum distance between the points, though there were a few outliers. Although it can be difficult to visualize each individual whale, some of them are easier to parse than others. All of these trajectories were plotted on top of each other, hence the lighter colors for the closer whales. From this map we can see that a number of the tracked whales travelled further off the coast into deeper waters. Additionally, one of the whales travelled past the Washington border and made it well into Canadian territory. As we found in our initial point map, many of the whales frequented the gulf of California. For the most part, the whales of this data set stayed very close to the coast from the top of Washington down past the end of Mexico. The map

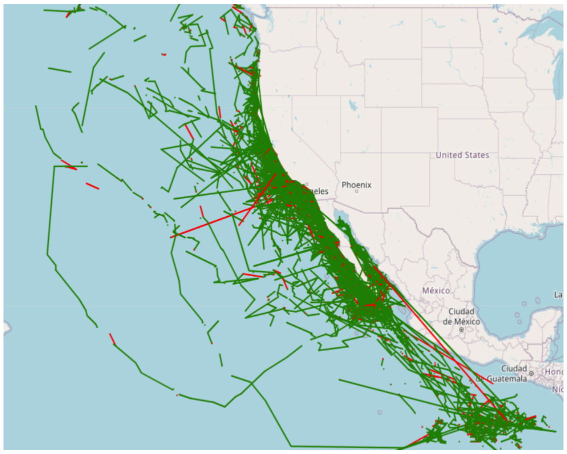


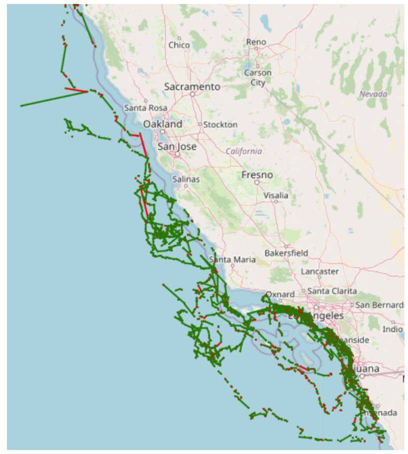
of the eight Blue Whales that were tracked from 2014 to 2015 is easier to see, we can tell almost exactly where each whale traveled during this time. Both of these trajectory maps are important as they show us that Blue Whales are frequently occupying areas off of the coast of California in the same areas where the Dungeness Crab fisheries are.

To visualize what the whales' behavior was off of the coast of California, we created a map of

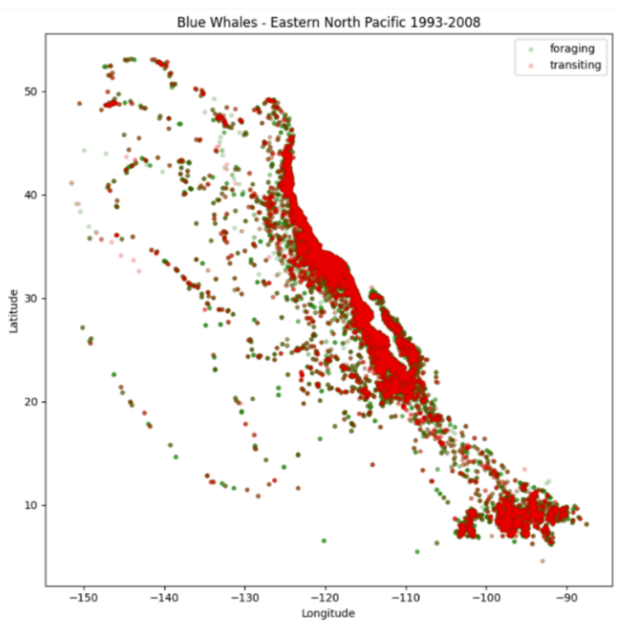


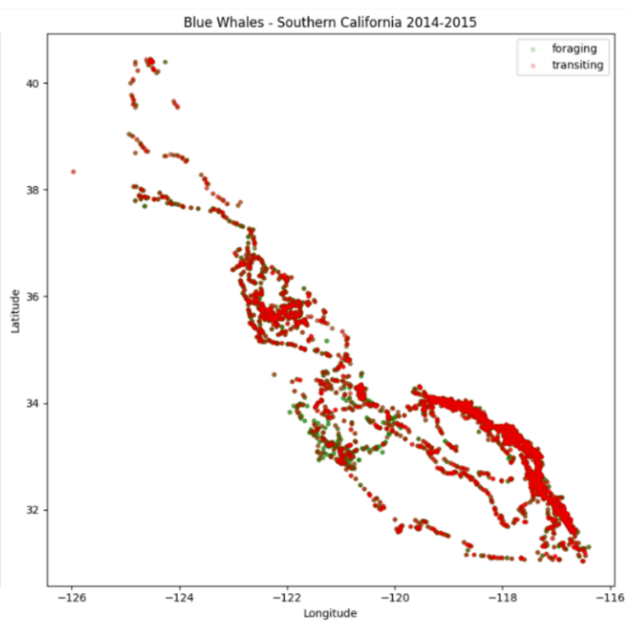
foraging and transiting points. How this works is we calculated the distance and time between two consecutive points, and from that calculated the average speed for each point. To the right is a histogram of the observed speeds for all of the points in km/hr. The red vertical line is at 2 km/hr which is the initial cut off we used for foraging versus transiting, though in the actual plots we ended up cutting off at 5km/her since there were very little foraging points and it was very difficult to visualize. Below are the maps of foraging versus transiting trajectories.





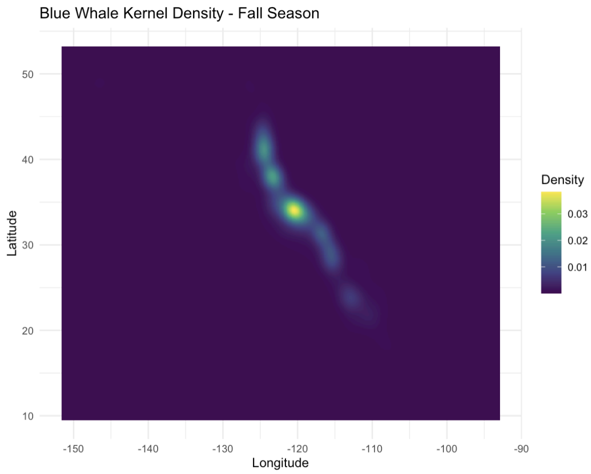
The reason the maps look disjoint is that the we had to sample the data since there were too many data points to be able to run the code. The left plot are the whales tracked from 1993-2008 and the right are the whales mapped from 2014

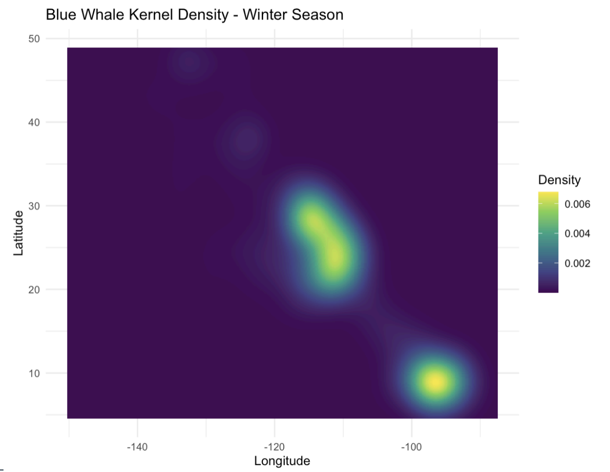


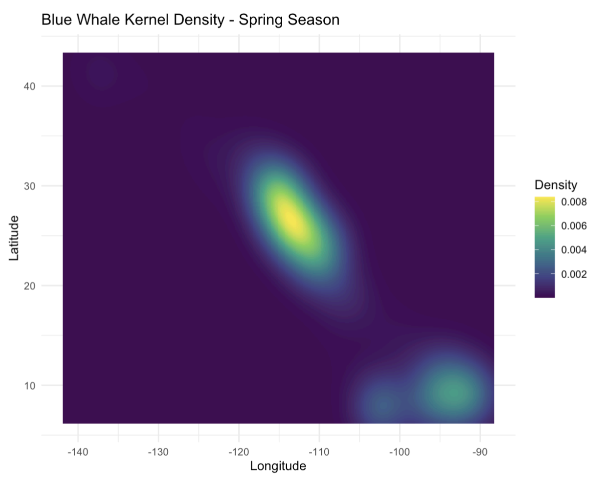


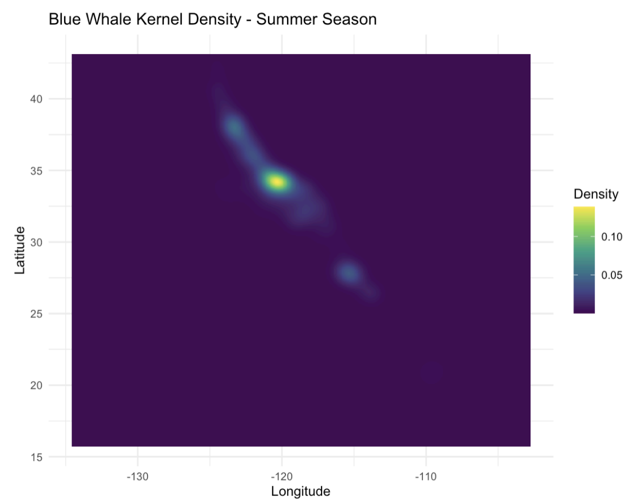
to 2015, green is foraging and red is transiting. Above are the individual points and the correlated behavior colored in the same way.

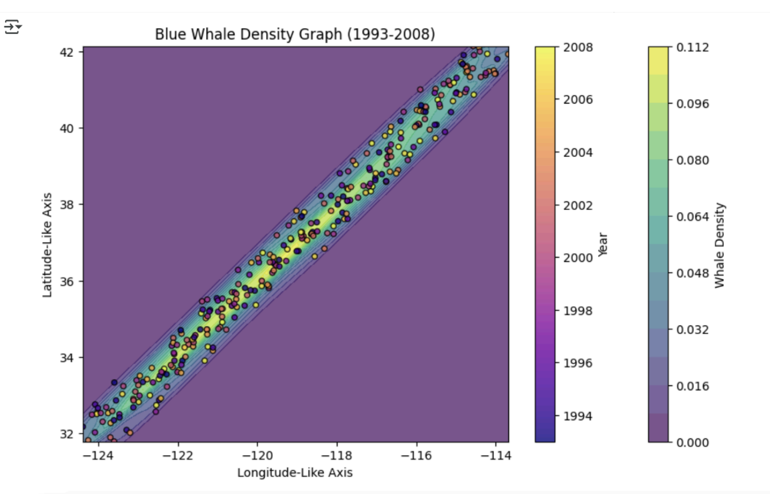
We then mapped the whale's kernel densities per season, as you can see Winter and Spring have higher densities than the other two seasons. The Whale Density Graph below maps the densities per longitude and latitude while plotting individual points for each year observed. This way we can see a linear representation of how the plots changed over the years.





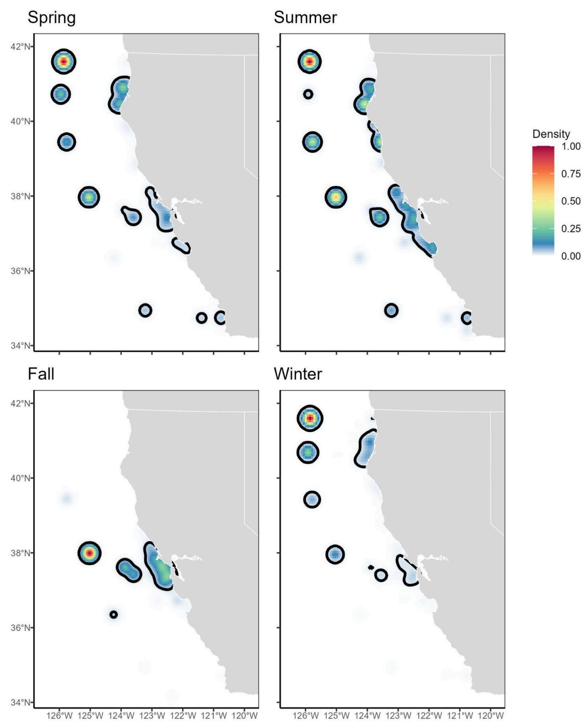


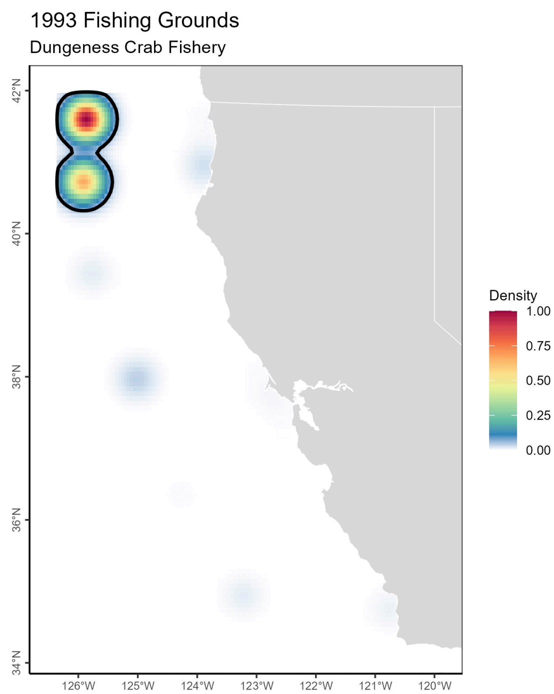




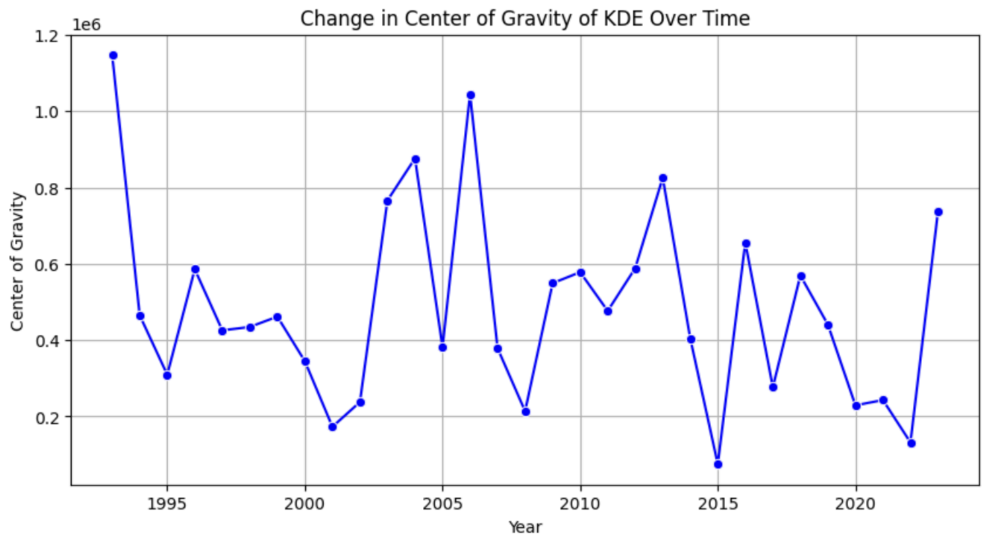
Crabs

The primary way we visualized the Dungeness Crab fisheries usage was using kernel density plots. As you can see below, we plotted the kernel densities based on year and season.



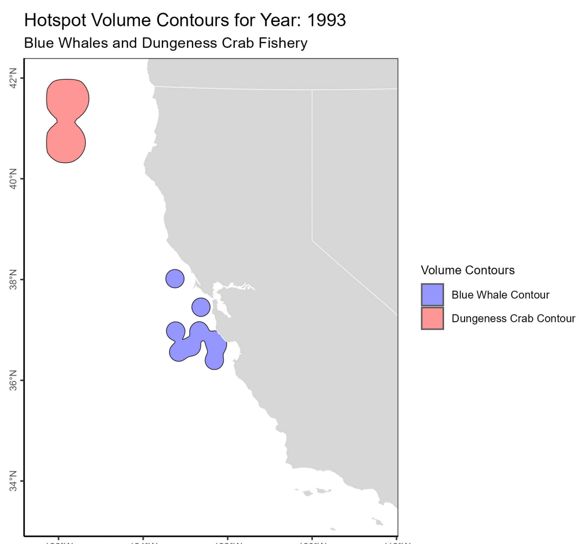


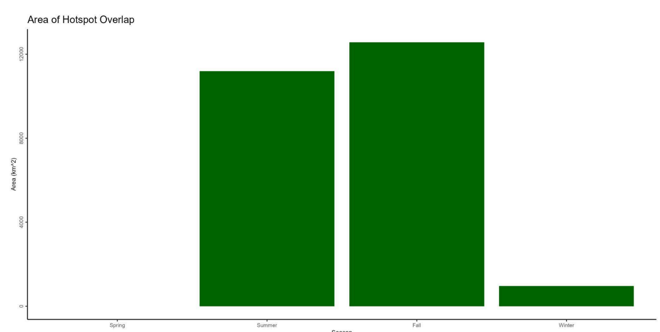
From these plots we can see that over the years, the fishing grounds area stayed in generally the same areas with a subtle increase in coverage. As for seasons we can see that Summer and Spring are the most popular seasons for the fisheries while Fall is the least. Below we have a graph that displays the change in center of gravity of these kernel densities over time. We can see that the general trend stays under 1 and occasionally dips down to zero. This makes sense in 2015, as there was an algae bloom that prevented fishery operation due to the harmful effect that eating this crab would have on humans.



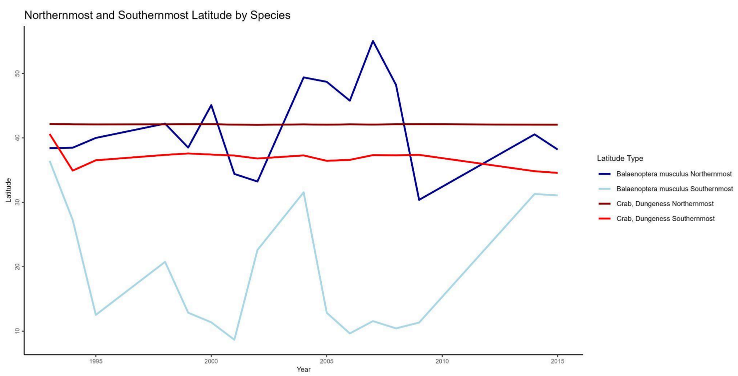
Interaction

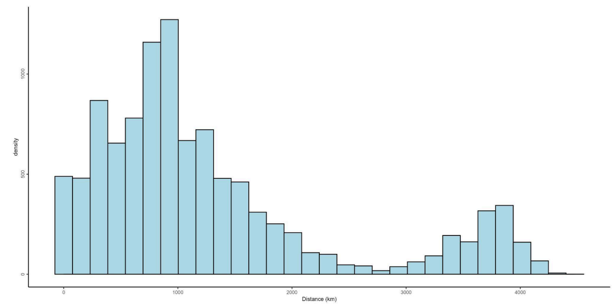
Now that we have visualized the areas that both the whales and the fisheries occupy, we can combine these visualizations to depict the interactions between these two entities.





On the left is a figure that shows the movement of the hotspots for the Blue Whales and the fisheries per year. The fisheries are mainly consistent except for 1993 and 2014/2015. During the latter, as stated earlier there was an algal bloom due to increased temperatures, so fisheries were trying other areas. Above and to the left is a histogram of the areas of hotspot overlap based on season. On this plot, Winter is very low and Spring has no overlap, while Summer and Fall have a lot of overlap. This is interesting since in the figure above we observed that the kernel density for the fisheries in the Fall is the smallest, it must mean that whales are in that specific area a lot in the Fall.





These final two plots show the Northernmost and Southernmost latitudes by species per year and the nearest distance from the blue whales to the closest block organized by month and year. We can see in the first graph that the fishing areas occupied remain mainly the same while the whale distances vary more drastically. On the histogram, we can see that the majority of the whales are under 1,500 km from the nearest fishing block. Clearly these two entities occupy much of the same space and have frequent overlap

Conclusion

From these visualizations we can see that the Blue Whales in this dataset occupy much of the same space as the Dungeness Crab Fisheries, they stay near the coast and their trajectories run through much of the fishing block areas. More specifically, we found that much of the overlap happens during the Fall, which is when the fisheries are fishing less. Another thing we found is that from year to year the fisheries generally trap crabs within the same areas, but the whales' areas that they occupy vary more sporadically.

These findings are important because they allow us to envision a couple of new methods for Dynamic Ocean Management. First, we could restrict the Fall months of fishing to lower entanglement risks. Since the Dungeness crab fisheries that we have mapped exhibit less activity during this season but have more overlap with the Blue Whales, it likely means that these whales are closer to the coast in these specific block areas, likely due to breeding or foraging patterns with changing environmental factors. Another thing we can do is move the available blocks for fishing with the seasonal kernel densities of the whales. We know which areas off of the coast of California are most populated by Blue Whales and so we can develop strategies to move the allowed blocks seasonally. Since Blue Whales are an endangered species and putting them in danger of entanglement could risk a shut down for Dungeness Crab fisheries, these commercial fisheries would be incentivised to move their seasonal fishing along with the Blue Whale's movement patterns.

Appendix

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Riekkola, Leena, et al. "Retrospective Analysis of Measures to Reduce Large Whale Entanglements in a Lucrative Commercial Fishery." *Biological Conservation*, vol. 278, 2022, 109880. https://doi.org/10.1016/j.biocon.2022.109880.