Problem Chosen	2020 MCM/ICM Summary Sheet	Team Control Number
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A Fishy Situation: Using Linear Regression and Scoring Model to Predict Fish Migration in the North Atlantic

Summary

Over the past few years, rising temperatures have caused fish populations to migrate further north to more hospitable conditions. This paper takes an microscopic view of this problem to understand how temperature increase propels herrings and mackerels near Scotland to migrate further north in the North Atlantic Ocean and how this imposes consequences on small fishing companies. In order to explain the dynamics of fish movement, and finish all the tasks required of us by our hiring company, we divide the process into 3 co-dependent parts.

First we used a Grid-Based Sea Surface Temperature Predicting Model. To this end, we selected a specific region to concentrate on. This region extends from longitudes 66°N, 20°W to 66°N, 5°E, and from latitudes 51°N, 20°W to 51°N, 5°E. Then this region was divided into 15 square sub-regions. We then used quantitative and qualitative methods to determine the dependence of each of these factors on the temperature of each grid in the next fifty years. For example, increase in temperature correlates to the decrease in the dissolved oxygen level.

Then, we established our Fish-Friendly Scoring Model(FFS Model). We incorporated the relation of the other dependent factors to optimize the most ideal route and direction of the two fish species. This model is a scoring system which weighs the relative importance of different factors of the fish habitats and calculates total score of each possible destination. In the conclusion, this score has been interpreted as the probability of finding fish in the given region.

Finally, we come up with the Cost-Benefit Model in order to come up with suggestions for small fishing companies. Our model for the fishermen incorporates the FFS score developed in the previous part, and considers factors like the selling price of the fish, the cost price of diesel, and the costs of fixed assets. Using this model, we determine the best, worst and average case scenario for the fishing companies. Our research shows that fishermen, depending on their location on the west, east or north side of Scotland should have different responses to tackling the problem at hand. All our suggestions are based on results we get from our model and are backed with scientific reasoning and methodological interpretation of evidence and research.

Keywords: Sea Surface Temperature(SST), Grid-Based SST Prediction, Fish-Friendly Scoring Model(FFS), Cost-Benefit Model, Habitat, Eco-system, Exclusive Economic Zone(EEZ), Small fishing Company

Contents

1 Introduction

1.1 Background

When habitats change due to either a change in the environment, or a change in the food resources, species will often relocate to other regions to ensure their continued mating and thriving. One such example was presented in the 2020-MCM Weekend 1 Problem A:Moving North which mentioned the lobster population of Maine, in the United States who have started to migrate north to Canada, where the lower ocean temperatures provide a more comfortable habitat. In a paper released by Yale Environment 360, similar patterns have been noticed in the sailfish which ideally belong in tropical and sub-tropical regions but was recently found migrating to Cape Cod Canal in Massachusetts.

In lieu of these worrying circumstances in the United States, we were contacted by the Scottish North Atlantic Fishery Management Consortium in the UK in order to analyse the migration patterns of the Scottish herring and the mackerel. On the Scottish Parliament website, mackerel was 43% of the total fish landed by Scottish vessels. The herring, also known as Scotland's "silver darlings" have been a key commodity of trade in Scotland for generations. In 2016 fishing generated £296 million GVA: accounting for 0.2 % of the overall Scottish economy, and eight per cent of the marine economy. Hence the migration of these fishes poses a real threat to small fishermen who depend on fishing as their primary source of livelihood.

1.2 Problem Restatement

In this paper, we are going to propose business solutions to Scottish small fishing companies by decomposing the task into several sub-tasks:

- Determine if and where are herring and mackerel moving in 50 years.
- Determine how the migration of the fish affects fishing business in the course of 50 years.
- Suggest measures that fishermen should take and the timeline they have to follow in the process, such as primary sources of income change, new methods of making profits etc.
- Evaluate and analyze our model from a legal and socio-political angle, to address the problem when fishes move to territories which are outside the Exclusive Economic Zone(EEC) of Scotland.

2 Assumptions and Justifications

In the following section we present the assumptions, and the reasoning and justification behind them.

2.1 Model 1: Grid-Based SST System

In this model, we divided the region to consider into fifteen square grids.

Assumption 1: Any region within a grid behaves identically. This is to say all sea creatures have access to the same oxygen levels and food resources.

Reasoning: Since we are to understand the population dynamics of the entire herring and mackerel population in the whole of North Atlantic, we simplified the process by dividing the region into fifteen grids. Each of the grids are 5°latitude and longitude apart, which approximately corresponds to 250 nautical miles in length, and 300 nautical miles in width. We believe ocean environment characteristics are likely to change at a much lower rate, than the land, both because of higher heat absorption capacity of the ocean, and lower human activities in this region. This assumption also enabled to consider much greater swaths of land.

Assumption 2: Within each grid, the temperature increases as per our line of best-fit.
Reasoning: Since our line of best fit, comes from linear regression calculated using a software, known as LoggerPro, we assume that most data points will lie on or near the line of best fit determined by the software, and not anywhere else.

2.2 Model 2: Fish-Friendly Scoring Model

Assumption 1: There are only two food sources for the fish: phytoplanktons and krills.
Reasoning: Since each of the food sources can be represented as a function of temperature, it is unreasonable to consider all the different sources of food. Hence, we consider only the phytoplankton and the krill and assume that either there are only two species in the ocean, or that every other species' dependence on independent factors can be modelled by the same ones we use for krills or phytoplanktons.

Assumption 2: There is no evolutionary behaviour observed in the fish over the next 50 years.
Reasoning: Our fishes don't develop anatomical capabilities to resist the temperature change.

Assumption 3: Herring and mackerel are identical.
Reasoning: In order to restrict the length of the paper to legible limits, we consider that herring and mackerel behave exactly identically and weigh 1kg each.

Assumption 4: The fish will not come back to their original locations.
Reasoning: Since temperatures are going to rise, the fish won't return to their original locations in the near future even if temperatures go down.

Assumption 5: As per the guidelines given to us by the hiring company, "temperatures are going to change enough to cause populations to move."
Reasoning: This is given in Requirement 1, of he Problem Statement. Fishes won't go deeper, but to a different location.

Assumption 6: All fishes are only in the oceans, none in the rivers.
Reasoning: There are no fishes in the rivers. All fishing is done along the coastline.

Assumption 7: The fish population exists in a dynamic equilibrium with that of its predators. Hence their population is roughly constant.

Assumption 8: The energy consumed by the fish is only expended in swimming.
Reasoning: Due to lack of data, about how exactly metabolism in fish populations is affected by temperature, we assume the farther they travel, the more energy they will consume.

Assumption 9: Temperature, and not ocean currents are the only cause for fish to migrate.
Reasoning: Since the temperature is causing the fish to migrate in the first place, we assume that ocean currents will play no significant role in affecting where he fish will migrate, as the fish can adapt to differing water pressures caused by the ocean current.

2.3 Model 3: Cost-Benefit Analysis Model

Assumption 1: All small companies have the same resources. This means they all use seine fishing, and the same boats for fishing.
Reasoning: This is a simplification. Based on the actual costs of fixed assets, and fuel, the fisherman can use our model explicitly to find out the relative cost.

Assumption 2: The selling price of fish remains constant over the next 50 years. Price of fuel remains constant.
Reasoning: We don't adjust the price values for inflation to avoid complication.

Assumption 3: Just for the purposes of this model, the fisherman has legal rights to venture beyond the EEZ of Scotland.
Reasoning: This is done in order to give quantitative values to the benefit incurred by the fisherman. The political and legal implications of the same are discussed later in the conclusion.

Assumption 4: For consistency and simplicity, we assume that all small fishing companies use the same type of boat: RIBTEC740, and same number and types of equipment: 50 35lb test 10ft-deep seines, and these equipment can last for 50 years.
Reasoning: The price and information of the boat: RIBTEC740 and the seines were found on specialized fishing sales websites [9, 10].

3 Model 1: A Grid-Based SST predictor

Figure 1: Map of Scotland

3.1 Choosing the ideal Location

First we chose a location we need to consider in order to predict the most likely location of the two fish. Then, we used monthly Sea Surface Temperature (SST) data (ranging from 2004 to 2019), from the Met Office Hadley Center Observations [1], to predict the trend of the SST in the next five decades. Each data given in the data set corresponded to the temperature at the center of a 1º latitude by 1º longitude grid for each month over a 19 year time span. In order to narrow down this data as well as to cover a large range of area to include the current habitat and possible locations that herring and mackerel might travel to in the future, we selected a box from 51ºN to 66º N, and from 20ºW to 5ºE. This region included mainly Scotland, the North Sea (east of Scotland), and the North Atlantic Ocean (west of Scotland) where most herrings and mackerels are found. A figure has been given below, in order to explain the method more clearly: We further divide the box into 15 5º by 5º sub-grids to distinguish the current habitats from other possible locations. We decided that the current habitat of herring and mackerel is in region VIII, IX, X.

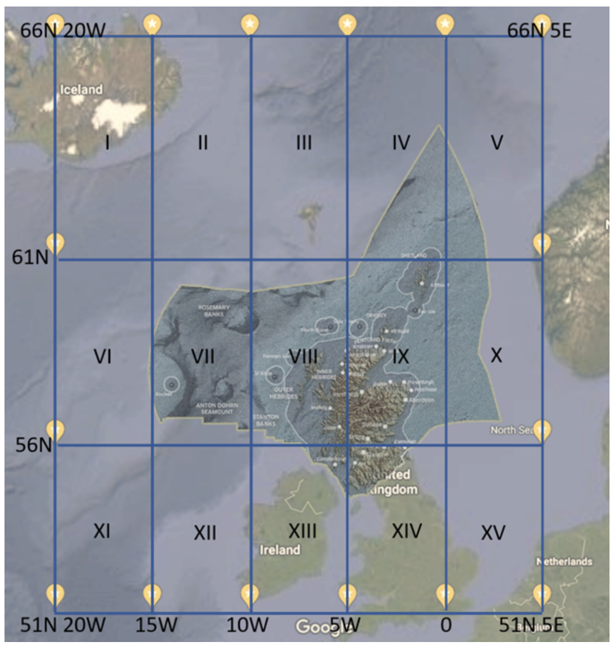

Figure 2: Grid Division

In Figure 2, the strange shape bordered by the yellow line gives us the Exclusive Economic Zone of Scotland.

3.2 Linear Regression for SST Forecast

After this, we calculated the average SST of each of the sub-grids during the summer months(May to October) using the 25 data points within the sub-grid (each data point corresponding to a change in SST by a 1°change in latitude or longitude) and plotted out graphs to see the temperature change over 16 years from 2004 to 2019. One such example has been shown below for Grid 2(G_2).

We then used the software LoggerPro to find out the line of best fit. The line with the lowest RMSE(Root Mean Square Deviation) turned out to be a logarithmic model. y = Aln(Bx), with A

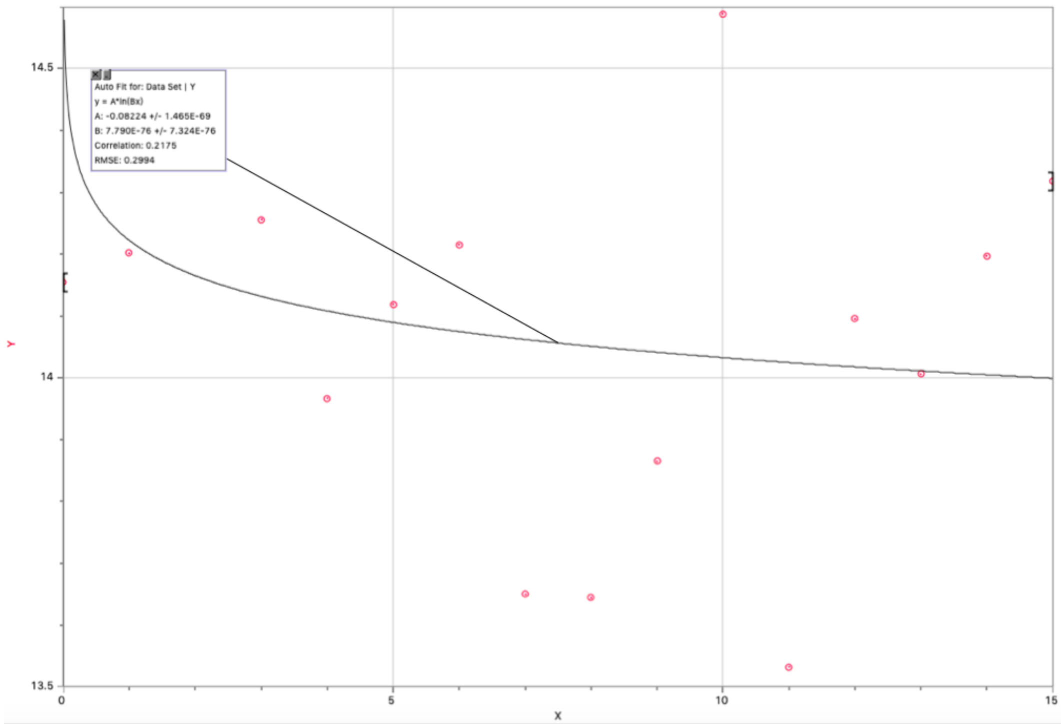

Figure 3: Example: Temperature Model in 61-66N 10-15W

=-0.08224 and B = 7.790*(10^{-76})
We did this for each of the 15 grids. Based on the lines of best fit we got for our model we calculated the average SST during the summer months over the next 50 years. The values are shown below after a five year gap:

	Region I	**Region II**	**Region III**	**Region IV**	**Region V**
Current (2019)	10.87	9.56	9.12	9.94	10.94
In 50 years	11.10	10.10	9.66	10.50	11.40
	Region VI	**Region VII**	**Region VIII**	**Region IX**	**Region X**
Current (2019)	12.28	12.38	12.23	11.97	12.67
In 50 years	11.50	12.10	12.70	12.20	12.50
	Region XI	**Region XII**	**Region XIII**	**Region IXV**	**Regioin XV**
Current (2019)	14.09	14.19	14.32	14.17	15.14
In 50 years	13.20	13.60	13.90	13.80	14.80

Figure 4: Temperature Change Over Time

Based on our research, most herring and mackerels are pelagic fish: they inhabit the upper layers of the ocean surface never going too deep, and their most suitable living temperature is around 7 ºC to 8ºC [5], so looking at the data set we figured that we should only consider the summer months since winter ocean will be a perfectly suitable environment for fishes to survive and it is only in the summer that they may need to move.

4 Model 2: FFS Scoring Model: Predicting Likelihood of Fish Migration to current location

4.1 Factors to be considered

In order to predict the likelihood of fish migration, we considered four factors. Since our model is a scoring model, we assign a relative score to scenario under the different independent variables, and take a weighted average of all these scores. Please bear in mind, that the values we assign to each of the functions below, are **relative** scores out of 5 based on the circumstance.

1. Oxygen levels - The fish need oxygen to breathe, however solubility of gases in other fluids varies as a function of temperature. The dependence is given by the equation as follows [3]: $\ln C = -1268.9782 + \frac{36063.19}{T} + 220.1832 \ln \frac{T}{K} - 0.351299\frac{T}{K} + S(6.229 * 10^{-3} - 3.5912/(\frac{T}{K}) + 3.44 * 10^{-6}S^2)$ Here C is the solubility is in $\frac{ml}{l}$ at STP. And S is the salinity of the water which we have assumed to be constant. We calculated the oxygen concentration for each of the grid, and assigned O(t) score on a five-level basis, the 3 grids with the highest oxygen concentration receive the highest score of 5, and the subsequent grids receives decreasing score from 4 to 1. The sample table has been shown below,

	Region I	**Region II**	**Region III**	**Region IV**	**Region V**
O(t)	4	5	5	5	4
	Region VI	**Region VII**	**Region VIII**	**Region IX**	**Region X**
O(t)	4	3	2	3	3
	Region XI	**Region XII**	**Region XIII**	**Region IXV**	**Regioin XV**
O(t)	2	2	2	2	1

Figure 5: Example: Oxygen Score for Each Grid

2. Food sources We have reduced the food sources of the fish to two.

   (a) Phytoplanktons P(T)- According to the research by Bingzhang Chen et al [2], the dependence of the phytoplankton on temperature was calculated by averaging out the maximum and minimum temperature a phytoplankton can survive in.

   $$T_{max(i,j)} = 33.6 + 0.068Lat - 0.005Lat^2 + Phylum_j + \epsilon_{i,sp}$$
   $$T_{min(i,j)} = 9.5 + 0.035Lat + 0.003Lat^2 + Phylum_j + \epsilon_{i,sp}$$

   Here lat is the latitude, and i and j are the i^{th} species of the j^{th} phylum corresponding to particular study this data was extracted from. Because our scores are a **relative** measure, and not an absolute value we we consider the last two terms to be constant. We took the average, T_{ave}, of the T_{max} and T_{min}, and calculated the optimal temperature for phytoplankton by taking the absolute value of the difference between T_{ave} and the predicted temperature, $|T_{ave} - T_{predicted}|$. If T is within T_{max} and T_{min}, and$|T_{ave}$ - T$|<1$, it means that if the predicted temperature differs from the optimal temperature within 1 ºC, we assign P(T) to be 5 and if

|Tave - T| > 1, we assign P(T) to be 3, and if the T falls out of [T_{max} , T_{min}], we assign P(T) to be 0. The scores are shown below:

	Region I	Region II	Region III	Region IV	Region V
P(t)	3	3	5	3	3
	Region VI	Region VII	Region VIII	Region IX	Region X
P(t)	5	3	3	3	3
	Region XI	Region XII	Region XIII	Region IXV	Regioin XV
P(t)	5	5	3	5	3

Figure 6: Example: Phytoplankton Score in Each Grid

(b) Krills K(T) - According to the research by Guoping et al [3]. we take from Figure 6, the mortality rate of krills under different temperatures. The figure has been shown below:

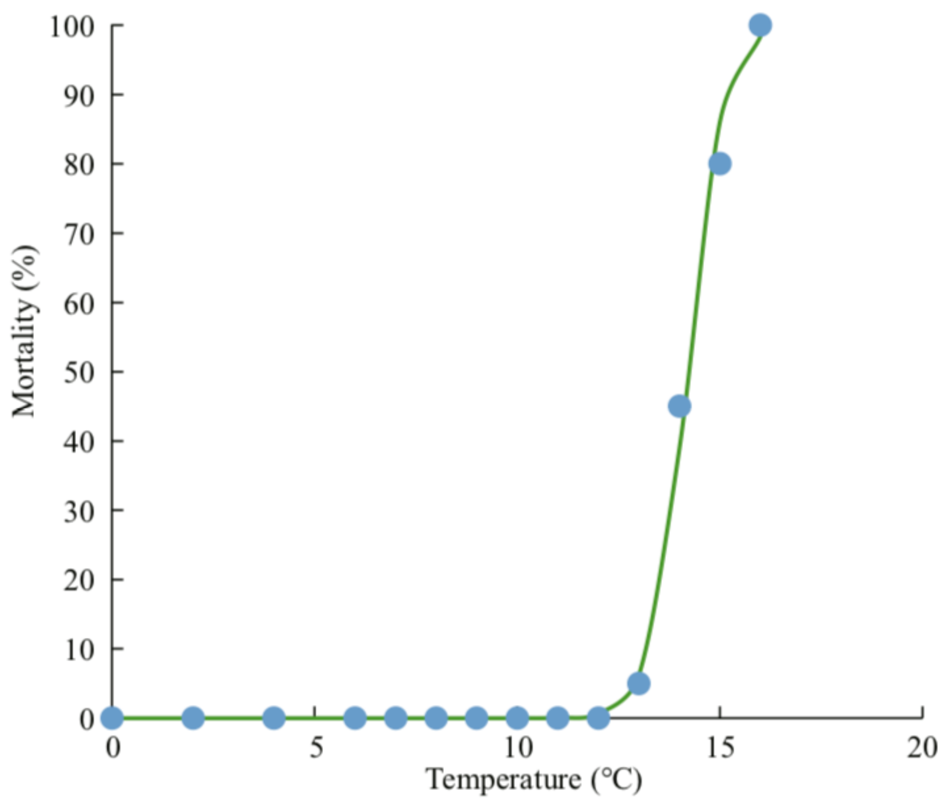

Figure 7: Krill Mortality under Different Temperature

Based on this graph, we came up with two seperate conditions to predict mortality of the krills. K(t) = 5 if T ≤ 13 , 3, when 13 ≤ T ≤ 15 , 0, when T > 15 The sample values for each grid are shown below:

	Region I	Region II	Region III	Region IV	Region V
K(t)	5	5	5	5	5
	Region VI	Region VII	Region VIII	Region IX	Region X
K(t)	5	5	5	5	5
	Region XI	Region XII	Region XIII	Region IXV	Regioin XV
K(t)	3	3	3	3	3

Figure 8: Example: Krill Score in Each Grid

3. Distance to destination, D(T) = We claimed that travelling long distance is not ideal for herring or the mackerel, because their metabolic capacity can only support transportation along a limited distance. Furthermore, since most of these fishes lay eggs in the freshwater or coastal shores [8], we claim that travelling along a further distance is detrimental to them as they cannot find a suitable spot to lay eggs. Since the actual width of our grid (5º longitude) is approximately 200 miles, and as the location moves further away from the fish's current habitat, the fish is less likely to travel there if their current habitat supports enough food and oxygen. Based on our assumption that the fish's current habitat is region VIII, IX, X on the map, we assigned them with the highest score 5. As we move 1º out from the current habitat, we decreased the score by 2, and each region was assigned the sub-score D as the following:

	Region I	Region II	Region III	Region IV	Region V
D	1	3	3	3	3
	Region VI	Region VII	Region VIII	Region IX	Region X
D	1	3	5	5	5
	Region XI	Region XII	Region XIII	Region IXV	Regioin XV
D	1	3	5	5	5

Figure 9: Example: Distance Score in Each Grid

4.2 Scoring the Grid

We calculated the FFS for each grid by taking the weighted average of the above four subscores. In our calculation we tested out different combinations of the weights - putting difference importance on the four factors. So, combined our equation will look like this:

FSS = α(O(T)) + β(K(T)) + γ(P(T)) + λD(T)

The table below shows the result for equal weights on each factor. We can see that the optimal location for the fish to move is Region III (61-66 ºN, 10-5ºW) which receives a score of 4.5. Other regions, such as Region II and Region IV, Region IX exhibit a high score of 4. This is assuming all factors are equally important to the fish.

In the Figure 10below, each box is colour-coded in relative order of performance.

	Wk = 0.25, Wp = 0.25, Wo = 0.25, Wd = 0.25				
	Region I	**Region II**	**Region III**	**Region IV**	**Region V**
FSS	3.25	4	4.5	4	3.75
	Region VI	**Region VII**	**Region VIII**	**Region IX**	**Region X**
FSS	3.75	3.5	3.75	4	4
	Region XI	**Region XII**	**Region XIII**	**Region IXV**	**Regioin XV**
FSS	2.75	3.25	3.25	3.75	3

Figure 10: Example: Calculated Fish Living-Friendly Score in Each Grid

5 Model 3: Cost and Benefit Analysis

In this model, we are going to evaluate the profit that small fishing companies can make within a particular grid by evaluating their selling price and cost price. The cost price is divided into two parts: fixed cost and variable cost. Each type of cost is divided into the following sub-costs:

- Variable cost:
    - Price of ice needed for freezing the fish on each trip
    - Price of fuel the boat needs for one trip
- Fixed cost:
    - Price of the boat
    - Price of the equipment
    - Salary of the fishermen

5.1 Cost price factor calculation

5.1.1 Variable cost (VC):

The price of the ice is calculated using the following factors:

Variable	Explanation	Value
A_I	Amount of ice per kg of fish	1.2kg/10kg fish
P_I	Price of ice per kg	£0.17/kg
P_f	Probability of finding fish in a grid	FFS / 5(full score)
$A_{f,\ annual}$	Total amount of fish caught annually (herring/mackerel)	103819 kg
k	Proportion of the fish caught by small company	0.3
$A_{f,\ weekly}$	Total amount of fish caught by small company in a week	$A_{f,\ annual}$ k/12/4

Figure 11: Factors of ice cost

The cost of ice is determined by the following formula():

$$\text{Price of Ice} = A_I \times P_I \times P_f \times A_{f,weekly} = \frac{1.2\text{kg ice}}{10\text{kg fish}} \times \frac{0.17}{1\text{kg}} \times \frac{FFS}{5} \times \frac{0.3 \times 103819\text{kg}}{50 \cdot 12 \cdot 4}$$

The price of the diesel is calculated using the following factors[12]:

Variable	Explanation	Value
P_d	Price per liter of diesel	£1.3/L
d	Distance in miles	variable
v	Velocity of the boat in mph	15.7 mph
A_d	Liter of diesel needed per hour	75L/h

Figure 12: Factors of diesel cost

The cost of diesel is determined by the following formula:

$$\text{Price of diesel} = P_d \times \frac{d}{v} \times A_d = \frac{£1.3}{1\text{L}} \times \frac{d}{15.7\text{mph}} \times \frac{75\text{L}}{1\text{h}}$$

5.1.2 Fixed cost (FC):

The fixed cost is calculated using the following factors:

Variable	Explanation	Value
P_b	Price of the boat (i.e. RIBTEC740)over the 50 years	£14995/50/12/4
P_s	Price of 50 seines with 35lb test, 10 ft deep	£6,74*50/50/12/4
S_f	Salary of the 5 fisherman in the company	5*£10,000

Figure 13: Factors of fixed cost

The fixed cost can be calculated by summing up all the factors:

$$FC = P_b + P_s + S_f = \frac{£14995 + £6.74 \cdot 50 + £5 \cdot 10000}{50 \cdot 12 \cdot 4}$$

5.2 Sell price of fish (SP):

The average market price is £13 for mackerel, and £8 for herring, we took the average to represent the price for both of the fish, and calculated the annual sell price by multiplying the unit price by the total amount of fish caught annually. The weekly sell price of the fish is calculated through this formula([11]):

$$\text{SP} = \frac{13 + 8}{2} \times A_f, weekly$$

5.3 Cost Benefit Analysis model

The weekly profit for the small fishing company can be calculated in the following formula:

$$\text{Profit} = SP - VC - FC$$

6 Results and Sensitivity Analysis

This paper uses the Fish Friendly Model to manipulate and predict the future migration of herrings and mackerels as well as the future strategy small fishing company could choose in terms of the migration. So below, we present the sensitivity analysis of our model.

6.1 Impact of different Linear Regression Model on The Predicted Temperature

In order to establish the Grid-Based SST system to predict the temperature change in the sea surface over the next 50 years, we ran linear, logarithmic, exponential and polynomial models on Logger Pro and chose the model with the least RMSE (Figure 14). The predicted temperature in each models differs greatly but we chose the logarithmic model which gave the least RMSE and also the most reasonable temperature in the future.

	61-66\`N, 20-15'W	61-66\`N, 15-10'W	61-66\`N, 10-5'W	61-66\`N, 5-0'W	61-66\`N, 0-5'E	56-61\`N, 20-15'W	56-61\`N, 15-10'W	56-61\`N, 10-5'W	56-61\`N, 5-0'W	56-61\`N, 0-5'E	51-56\`N, 20-15'W	51-56\`N, 15-10'W	51-56\`N, 10-5'W	51-56\`N, 5-0'W	51-56\`N, 0-5'E
a	0.1659	0.2091	0.1609	0.1491	0.1027	-0.1686	-0.0777	0.189	0.05433	-0.1474	-0.2534	-0.179	-0.08224	-0.04694	0.04103
b	1.32E+27	1.21E+19	1.63E+24	5.72E+28	2.93E+46	2.64E-32	4.37E-70	1.84E+27	3.94E+95	2.39E-39	3.34E-25	1.14E-35	7.79E-76	3.1E-130	1.4E+155
R^2	0.38	0.29	0.32	0.34	0.36	0.44	0.32	0.29	0.27	0.42	0.39	0.35	0.3	0.3	0.51

Figure 14: The Least R Squared Data

6.2 Impact of Higher Temperature in 50 Year on the Fish Living-Friendly Model

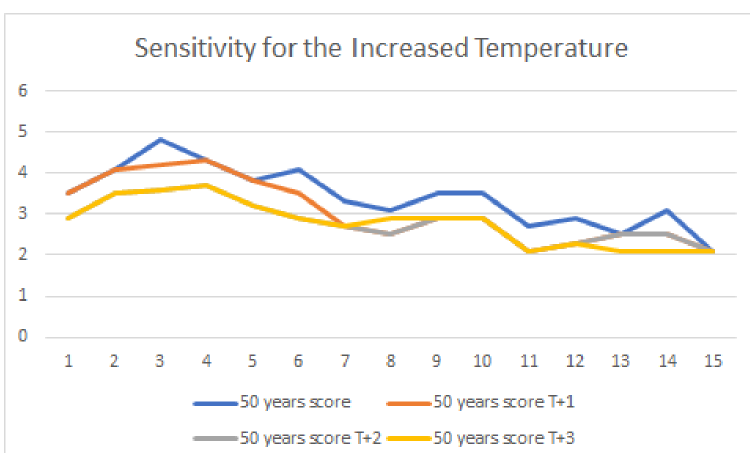

Figure 15: Sensitivity Analysis for Increased Temperature

In order to test how sensitive the FFS is to the future temperature, we add 1°C, 2°C, 3°C to the original temperature we got from the predicting model. Through Figure 15, we can tell that with the increase of temperature, the score of each grid drops. But the grids with the highest score still have the highest, and vice versa.

6.3 Impact of Weights α, β, γ and λ of Each Element on the Fish Friendly Model

In our Fish Living-Friendly Model, we derived a function which depends on the temperature to calculate the livability of each subgrid in our grid system. The scoring function has been presented below:

$$\text{FFS} = \alpha \times O(Temperature) + \beta \times K(Temperature) + \gamma \times P(Latitude) + \lambda \times S(Distance)$$

This score is out of 5. First, we tried adjusting every coefficient in our function to first confine the fish in their current habitat (i.e. to make the score of current habitats as high as possible using the temperature from 2019). Since the Fish Living-Friendly Model is directly depend on the temperature and latitude, we fixed each of these sub scores (i.e. O(Temperature), K(Temperature), P(Latitude) and S(Distance)) for each grid in 50 years and only test how the score affected by the α, β, γ and λ.

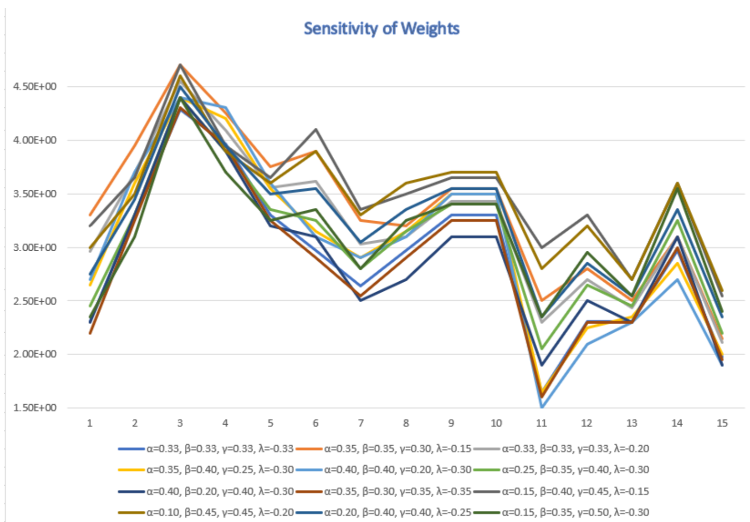

Figure 16: Sensitivity of the different coefficients α, β, γ and λ

From Figure 16 we can see that the current habitats for herrings and mackerels is inside region G4, G5, G7, G8 and G9 and from Figure 16, scores from different grids does not change dramatically with the variation of the weights. G3, G4, G5 and G6 always have the relative highest scores among all the grids no matter how the coefficient changes. Hence, we can claim that our model is relatively sturdy.

6.4 Sensitivity of the Cost Analysis Model : Impact of FFS and Distance on the Cost-Benefit Analysis Model

In our cost-benefit analysis model, we calculated the profit of every single fish for the fishing company to harvest. According to this model, the independent variables are only P(score) (i.e. FFS) and the

Distance.

$$FC = P_b + P_s + S_f = \frac{£14995 + £6.74 \cdot 50 + £5 \cdot 10000}{50 \cdot 12 \cdot 4}$$

We directed this test using the FFS data we got from the sensitivity assessment for different weights. We fixed all the price for a single fish, for all the equipment and facilities related to fishing and only tested the outcome correspondent to different FFS and Distance.

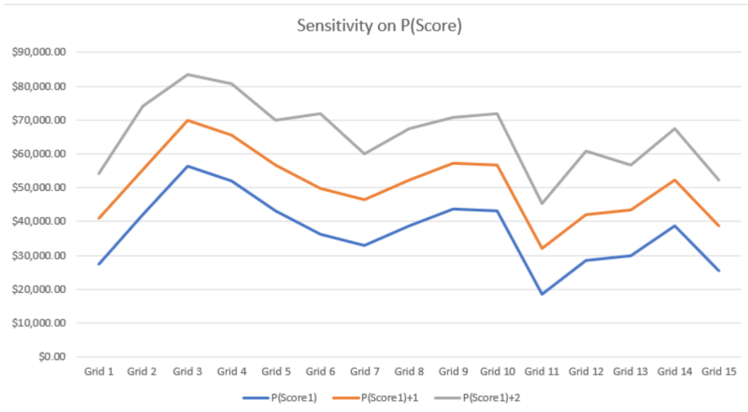

Figure 17: Sensitivity analysis on increasing the P(Score)

As we can see in figure 17 in sensitivity of P(score), the profit will only increase with the rising of P(Score).

From figure 19, it can be intuitively found that the cost benefit model is relatively stable. Since with the different score jiggling, the overall profit for each grid approximately stays the same and the ratio of profit between grids is roughly equal. So our model doesn't vary much unless the score drastically drops to 0 or so.

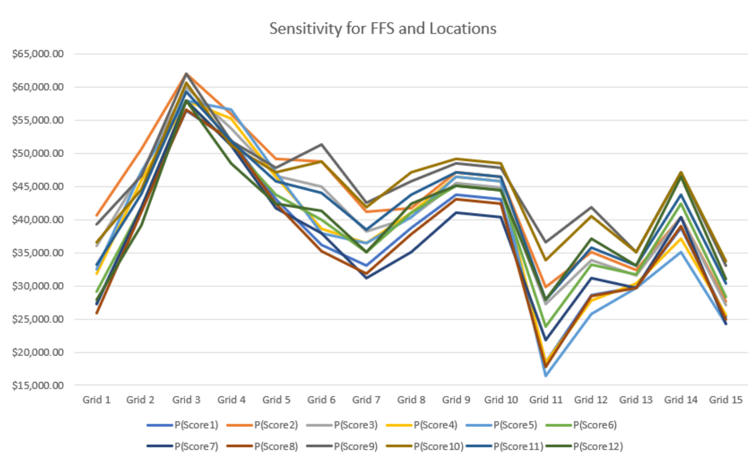

Figure 18: Sensitivity Analysis on FFS and Locations

7 Conclusions

From our models, we predict that the temperature in 50 years would possibly increase by 0.5 degree Celsius on average which is cause enough for herrings and mackerels to migrate towards the cooler ocean temperatures in the north. Further, in incorporating these temperature differences we developed the FFS model in order to predict which grid regions are the best areas for the fish to migrate to. It turns out to be Grid 3, Grid 4, Grid 8, Grid 9 and Grid 10 (Figure 2). Also, in our Cost-Benefit Model, we considered the profit per week for small fishing companies which harvest herrings and mackerels. From this model, we have the conclusion that the fishing companies would have higher profit in Grid 3, Grid 4, Grid 8, Grid 9 and Grid 10 which exactly matches the conclusion we get from the Fish Living-Friendly Model.

7.1 Suggestion to Fishermen

In conclusion, the fish would very likely move north in Grid 3 ad Grid 4, (61.0N – 66.0N, 10.0W – 0). And in order for the small fishing companies to make higher profit, they should also go to this region. However, since we see from the (Figure 2) that this region lies beyond the EEZ for the country, the further implications of this might explained below in the next section. Furthermore, if it is possible we highly advise all fishermen to move to Grids 4, 8 and 9, as this is where we predict most fishes to be. So if it is possible for fishermen to keep the fixed costs constant, they can consider moving to these regions. Furthermore we advise fisherman to not go near Grid 7, because even though this falls within the EEZ of the country it has a very low score. Region 10 also has a score of 4, which is a relatively high score. However, since its much farther our in the ocean, our intuition says that the large fishing companies might monopolise the catch of fish in this region, and hence they should try and steer clear of that region.

7.2 Legal and Social Implications

If we were to consider that some proportion of the fish would move into the territorial waters of another country, which we have labeled in the map (Figure 2), Grid 3 and most of Grid 4 are out of the boundary. However, these regions have some of the highest scores in the regions. Some countries have been known to venture out beyond the Exclusive Economic Zone, however this is illegal. So in order to make the most of it, UK might have to petition in the United Nations to be allowed exclusive rights in Grid 3 and 4. This might be necessary as a large portion of UK's GVA comes from the fishing industry. And if some fish species are already beginning to move north, it might be the case that more fish species also consider migrating. So, we suggest that Scotland looks to alternative sources of income instead of the fishing industry exports, and that fishermen also start to look for other opportunities over the course of the next fifty years in order to prevent possible structural unemployment. Or the Scotland government might just come under larger and larger amounts of pressure to petition for rights to access the waters beyond just the Exclusive Economic Zone of the country.

8 Strength and Weaknesses of model

8.1 Strengths

Here we assess the various strengths of our model.

1. **Our model is region independent** This means that our model is relatively independent specific other locations in Northern Europe and our grid-based modelling system can be replicated in other oceanic regions. This can help us model the movement of other species.

2. **Our model is relatively simple to understand but can be complicated based on needs and requirements, by adding more independent factors** This means that our model is not that hard for the fisherman to understand, should they choose to go beyond the article in the Hook Line Sinker Article. Furthermore, since our model is customisable most fishermen can add more factors both to the FFS model, and Cost-Benefit model pertaining to their own specific needs.

3. **Our model gives us some clear answers** Our model gives us clear indications about the strategies that can be adopted by fishermen in order to ensure they continue reaping benefits from their trade, and it also gives us clues about whether and when they might start incurring losses.

8.2 Weaknesses

Some of the weaknesses of our model are listed below:

1. We have little information about the costs incurred by small fishing companies. We were forced to make some assumptions about how these small companies work, biases which may not have been reflected in the assumptions part of our report. But since our model is customisable, we hope the fishermen can tweak the values as per their need.

2. We did not specifically consider the effect of temperature on fish metabolism.

3. Finally, we applied the same logarithmic model to each of the 15 grids, because **most** of the grids had the lowest RMSE values for the logarithmic model, but not all of them.

4. Finally, all our scores are relative to one region or another, which means in the sentences below, Sentence 1 doesn't make sense, but Sentence 2 does:
   Sentence 1 : G_1 has a score of 4.2. Hence it is a good place to fish.
   Sentence 2: G_1 is a better place to fish than G_5 because G_1 has a higher score than G_5.
   Because of this region, we cannot give absolute scores to any region.

9 Additional Questions to consider

Based on the strengths and weaknesses of our model, we consider what factors might matter in the scenario that our model is in not as simple an ecosystem as we thought it would be.

9.1 Presence of a Predator: A Shark

For instance we consider the case that, there is a shark(which is a predator in the ocean. In order to predict how the population of the fish might be affected in such a situation, the additional factors we might need to consider are:

1. Dependence of shark on the temperature:
   We might need to consider another model which incorporates the dependence of sharks on temperature. In this case, a scoring model may still be the most ideal case. This is so because we interpret the score as a probability of finding the shark in a particular region. And this score too, could have a weight in our FFS model. For instance, consider the score we give to the shark be called the SFS model(Shark Friendly Score) model.

2. Does the shark population also consider migration?
   Things are rendered more complicated if the sharks also consider migration due to rising temperatures, in which case we will have to account for that in our model. One way to do that we assume, is by multiplying the score of the shark by another co-efficient. This co-efficient can map the possibility of finding the shark in the particular region based on its migratory preferences. Based on data we receive from the SFS model, we can then multiplied it another co-efficient, for instance χ subtract it from our FFS score.

3. Lotka-Volterra(A predator-prey model) Finally, since in this case the model is more complicated we might need to consider using the Lotka-Volterra equations, as given below, in order to predict the long-term growth rate of the sharks and the fishes in the particular regions, to predict if one of the species will even survive.

   $\frac{dx}{dt} = \alpha$ x-β xy
   $\frac{}{dydt=}\delta$ xy-γ y

Here, x is the number of fishes and y is the number of predators. We can use the scoring model as a value for probability and multiply it by the total number of fish or shark. In this way, we can then use Matlab to predict the values for different values of the co-efficients till the two reach a dynamic equilibrium or if our model predicts: one of the fishes becomes extinct.

10 Article for Hook Line and Sinker

10.1 "A Red Herring?"

In recent times, the United States has witnessed the migration of large-scale migration of some of its fish species. For instance, the Maine lobster has been migrating up north to regions in Canada due to the lower temperatures there which is more suitable for its habitat. This is also true of the sailfish, a recent one was caught in New England, Massachusetts. Anyone who knows about fishing in Massachusetts realizes how rare the sailfish there is in Cape Cod because most sailfish are usually found in the tropical and subtropical regions. In fact, they are so rare in this region, that their government didn't even have an official record for these species of fish in their directory. In light of these worrying circumstances, we

Figure 19: Commercial Fishery

were hired as analysts by the Scotish North Atlantic Fishing Consortium in order to analyse migration patterns of the Scottish herring and mackerel.

Considering our love of mathematics, but even more so that of fish(we all come from coastal regions), we decided to combine all our love for these issues to find a solution to this problem. If there was one. Yes, you read that right. When we were initially contacted by the Consortium we were a little skeptical. Coming across the temperature data about the sea surface temperatures of areas corresponding to certain latitudes and longitudes within the EEZ of Scotland, we started wondering if this call for action was a red herring. Absolutely no pun intended.

When we tried to draw conclusions from our data and we realised that temperature increased very slowly in the parts of the water body surrounding Scotland. Hence fish migration was not a very real threat in Scotland. This fit perfectly with the biases and assumptions in our head that since per capita emission of greenhouse gases is much much more in the United States than in Celtic countries, fishes were much more likely to migrate in and around these regions than in the North Atlantic sea, which are very cold already.

However, whether these trends will likely continue over the next fifty years is something worth looking into and informing the Scottish fishermen about.

When we managed to parse out years and years of data, we saw that herring and mackerel were susceptible o temperature change over time. However, it was highly unlikely for them to migrate to a different area all at once, or even so in the next ten years. However, our model can and does give some predictions about where the most likely locations of these fish are and will be. We can use this data to advise fishermen to move to the most likely locations, where there is a higher probability of finding these kinds of fish, should their resources permit them to do so.

So if you are a fisherman whose livelihood mostly depends on catching mackerel and herring, we advise you to move to the Highlands, as this lies in one of the most highly-likely zones for finding herring and mackerel in the near future. If Highland is not your preferred choice of a future home, maybe you might like to consider Aberdeenshire or Angus. These locations had the next highest scores as per our team's analysis. Otherwise, the Orkney Islands may also be a great location to come across more sightings of the mackerel and herring. Please also bear in mind, that this region has the highest possibility of finding herrings and mackerels in the scores that we assigned. However, we caution you to not consider the data values we calculate in out technical reports in absolute terms since these are only the relative prices we assign to each of the specific region.

Furthermore, if you are nearer to the Ayrshires or the Galloways awe are afraid that the likelihood of finding herrings in mackerels in this region is very very less, and you might either have to give up on the "silver of the sea". You would have a much higher chance of harvesting salmon in this region than you would of herring and mackerel.

We argue that if you choose to relocate your business to some other regions, over the long period of time it might be beneficial for you because it is likely to be the case that herrings and mackerel might become rarer. For that to happen, you would still have to be in the fishing business over the next 50 or so years. And we are not sure what life goals you plan to have that long ahead. So if you want some serious suggestions that you might want to consider at this present moment, we advise you to do one of the following:

1. Become more entrepreneurial! Maybe consider not moving all your resources at the present moment, but instead fishing for many different kinds of fish in order to increase the revenue generated. Then use this revenue generated to build a larger fleet of fishing vessels which are larger in size. This way if someone decides to inherit your company, they can use this larger fleet to go deep-sea fishing to look for rarer fishes(which by that time in the future, will be the herring and the mackerel)

2. Try fishing for other fishes! This might be useful especially if you are not willing to relocate your resources or are not looking to start a business!

3. Try some other occupation altogether! Maybe over the long run, fishing might not be as beneficial you thought it would be, in which case we advise you to look other sources of income which you might enjoy more!

11 References

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12 Appendices

12.1 Appendix A: Plots

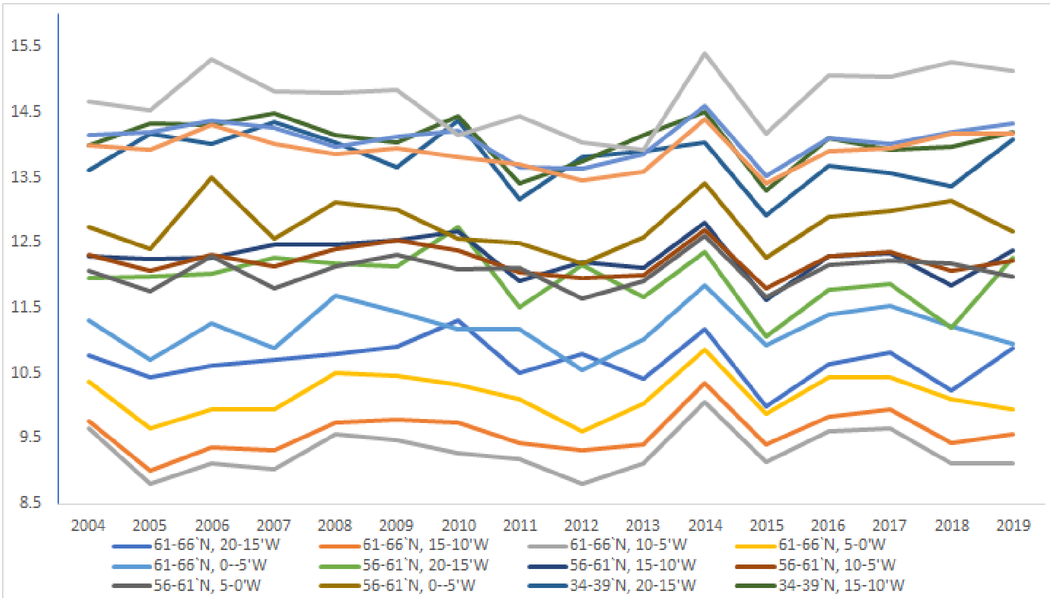

Figure 20: Average Temperature from 2004-2019 in Each Grid

Scoring Section	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
α=0.33, β=0.33, γ=0.33, λ=-0.33	2.31E+00	3.30E+00	4.29E+00	3.96E+00	3.30E+00	2.97E+00	2.64E+00	2.97E+00	3.30E+00	3.30E+00	1.65E+00	2.31E+00	2.31E+00	2.97E+00	1.98E+00
α=0.35, β=0.35, γ=0.30, λ=-0.15	3.30E+00	3.95E+00	4.70E+00	4.25E+00	3.75E+00	3.90E+00	3.25E+00	3.20E+00	3.55E+00	3.55E+00	2.50E+00	2.80E+00	2.50E+00	3.10E+00	2.15E+00
α=0.33, β=0.33, γ=0.33, λ=-0.20	2.96E+00	3.69E+00	4.55E+00	4.09E+00	3.56E+00	3.62E+00	3.03E+00	3.10E+00	3.43E+00	3.43E+00	2.30E+00	2.70E+00	2.44E+00	3.10E+00	2.11E+00
α=0.35, β=0.40, γ=0.25, λ=-0.30	2.65E+00	3.60E+00	4.40E+00	4.20E+00	3.55E+00	3.15E+00	2.90E+00	3.15E+00	3.50E+00	3.50E+00	1.65E+00	2.25E+00	2.35E+00	2.85E+00	2.00E+00
α=0.40, β=0.40, γ=0.20, λ=-0.30	2.70E+00	3.70E+00	4.40E+00	4.30E+00	3.60E+00	3.10E+00	2.90E+00	3.10E+00	3.50E+00	3.50E+00	1.50E+00	2.10E+00	2.30E+00	2.70E+00	1.90E+00
α=0.25, β=0.35, γ=0.40, λ=-0.30	2.45E+00	3.30E+00	4.40E+00	3.90E+00	3.35E+00	3.25E+00	2.80E+00	3.15E+00	3.40E+00	3.40E+00	2.05E+00	2.65E+00	2.45E+00	3.25E+00	2.20E+00
α=0.40, β=0.20, γ=0.40, λ=-0.30	2.30E+00	3.30E+00	4.40E+00	3.90E+00	3.20E+00	3.10E+00	2.50E+00	2.70E+00	3.10E+00	3.10E+00	1.90E+00	2.50E+00	2.30E+00	3.10E+00	1.90E+00
α=0.35, β=0.30, γ=0.35, λ=-0.35	2.20E+00	3.25E+00	4.30E+00	3.95E+00	3.25E+00	2.90E+00	2.55E+00	2.90E+00	3.25E+00	3.25E+00	1.60E+00	2.30E+00	2.30E+00	3.00E+00	1.95E+00
α=0.15, β=0.40, γ=0.45, λ=-0.15	3.20E+00	3.65E+00	4.70E+00	3.95E+00	3.65E+00	4.10E+00	3.35E+00	3.50E+00	3.65E+00	3.65E+00	3.00E+00	3.30E+00	2.70E+00	3.60E+00	2.55E+00
α=0.10, β=0.45, γ=0.45, λ=-0.20	3.00E+00	3.50E+00	4.60E+00	3.90E+00	3.60E+00	3.90E+00	3.30E+00	3.60E+00	3.70E+00	3.70E+00	2.80E+00	3.20E+00	2.70E+00	3.60E+00	2.60E+00
α=0.20, β=0.40, γ=0.40, λ=-0.25	2.75E+00	3.45E+00	4.50E+00	3.95E+00	3.50E+00	3.55E+00	3.05E+00	3.35E+00	3.55E+00	3.55E+00	2.35E+00	2.85E+00	2.55E+00	3.35E+00	2.35E+00
α=0.15, β=0.35, γ=0.50, λ=-0.30	2.35E+00	3.10E+00	4.40E+00	3.70E+00	3.25E+00	3.35E+00	2.80E+00	3.25E+00	3.40E+00	3.40E+00	2.35E+00	2.95E+00	2.55E+00	3.55E+00	2.40E+00

Figure 21: Sensitivity Analysis on FFS Model

12.2 Code to Parse Data from Met Office

12.3 Enjoy some delicious herring!

Or at least a picture of it!

	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6	Grid 7	Grid 8	Grid 9	Grid 10	Grid 11	Grid 12	Grid 13	Grid 14	Grid 15
P(Score1)	2.73E+04	4.19E+04	5.65E+04	5.20E+04	4.32E+04	3.62E+04	3.30E+04	3.87E+04	4.38E+04	4.32E+04	1.85E+04	2.86E+04	2.98E+04	3.87E+04	2.54E+04
P(Score2)	4.07E+04	5.07E+04	6.20E+04	5.59E+04	4.92E+04	4.87E+04	4.12E+04	4.18E+04	4.71E+04	4.65E+04	2.99E+04	3.52E+04	3.24E+04	4.05E+04	2.77E+04
P(Score3)	3.61E+04	4.72E+04	6.00E+04	5.38E+04	4.66E+04	4.50E+04	3.83E+04	4.05E+04	4.55E+04	4.49E+04	2.72E+04	3.38E+04	3.16E+04	4.05E+04	2.71E+04
P(Score4)	3.19E+04	4.59E+04	5.79E+04	5.53E+04	4.65E+04	3.86E+04	3.65E+04	4.11E+04	4.65E+04	4.58E+04	1.85E+04	2.78E+04	3.04E+04	3.71E+04	2.57E+04
P(Score5)	3.26E+04	4.73E+04	5.79E+04	5.66E+04	4.72E+04	3.80E+04	3.65E+04	4.05E+04	4.65E+04	4.58E+04	1.65E+04	2.58E+04	2.97E+04	3.51E+04	2.43E+04
P(Score6)	2.92E+04	4.19E+04	5.79E+04	5.12E+04	4.38E+04	4.00E+04	3.52E+04	4.11E+04	4.51E+04	4.45E+04	2.39E+04	3.32E+04	3.17E+04	4.25E+04	2.84E+04
P(Score7)	2.72E+04	4.19E+04	5.79E+04	5.12E+04	4.18E+04	3.80E+04	3.11E+04	3.51E+04	4.11E+04	4.05E+04	2.18E+04	3.11E+04	2.97E+04	4.05E+04	2.43E+04
P(Score8)	2.59E+04	4.12E+04	5.66E+04	5.19E+04	4.25E+04	3.53E+04	3.18E+04	3.78E+04	4.31E+04	4.25E+04	1.78E+04	2.85E+04	2.97E+04	3.91E+04	2.50E+04
P(Score9)	3.93E+04	4.66E+04	6.20E+04	5.19E+04	4.79E+04	5.14E+04	4.26E+04	4.58E+04	4.85E+04	4.79E+04	3.66E+04	4.19E+04	3.51E+04	4.72E+04	3.31E+04
P(Score10)	3.66E+04	4.46E+04	6.06E+04	5.12E+04	4.72E+04	4.87E+04	4.19E+04	4.72E+04	4.92E+04	4.85E+04	3.39E+04	4.06E+04	3.51E+04	4.72E+04	3.37E+04
P(Score11)	3.33E+04	4.39E+04	5.93E+04	5.19E+04	4.58E+04	4.40E+04	3.85E+04	4.38E+04	4.71E+04	4.65E+04	2.79E+04	3.59E+04	3.31E+04	4.38E+04	3.04E+04
P(Score12)	2.79E+04	3.92E+04	5.79E+04	4.85E+04	4.25E+04	4.13E+04	3.52E+04	4.25E+04	4.51E+04	4.45E+04	2.79E+04	3.72E+04	3.31E+04	4.65E+04	3.10E+04

	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6	Grid 7	Grid 8	Grid 9	Grid 10	Grid 11	Grid 12	Grid 13	Grid 14	Grid 15
P(Score1)	2.73E+04	4.19E+04	5.65E+04	5.20E+04	4.32E+04	3.62E+04	3.30E+04	3.87E+04	4.38E+04	4.32E+04	1.85E+04	2.86E+04	2.98E+04	3.87E+04	2.54E+04
P(Score1)+1	4.08E+04	5.54E+04	6.99E+04	6.55E+04	5.66E+04	4.97E+04	4.65E+04	5.22E+04	5.72E+04	5.66E+04	3.19E+04	4.20E+04	4.33E+04	5.22E+04	3.88E+04
P(Score1)+2	5.43E+04	7.41E+04	8.34E+04	8.07E+04	7.01E+04	7.19E+04	5.99E+04	6.74E+04	7.07E+04	7.18E+04	4.54E+04	6.07E+04	5.67E+04	6.74E+04	5.23E+04

Figure 22: Sensitivity Analysis for Cost-Benefit Model on P(Score)

```python
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt

df_total = pd.DataFrame()
df_summer_total = pd.DataFrame()

# parse data into a list of lists
for file in range(2004, 2020):
    filename = str(file)+".txt"
        # print(os.path.join(directory, filename))
    file_obj_read = open(filename, 'r')
    list1 = []
    i = 0;
    for line in file_obj_read:
        line.strip()
        innerList = [];
        line2 = line.split()
        for word in line2:
            firstPosition = word.find("-32768")
            lastPosition = word.rfind("-32768")
            #in the case that in that specific line we have no instance of the repititi
            if (firstPosition == -1):
                innerList.append(int(word))
            else:
                #find out the number up and until the -32768 comes up
                num1 =   word[0:firstPosition]
                innerList.append(num1)
                forLoopIterations = int((lastPosition - firstPosition)/6)
                for i in range(0, forLoopIterations):
                    innerList.append(-32768)
                innerList.append(-32768)
        list1.append(innerList)


    for list2 in list1:
        if list2[0] == "":
            list2.pop(0)


    file_obj_read.close()

```

```python

    # yearly temperature data of the 15 grid
    df_yearly = pd.DataFrame()
    summer_list = []
    for i in range(12):
        print("********** Month: "+ str(i+1) + "***********")
        j = 24 + i*180
        k = 39 + i*180
        target = ori_array[j:k, 160:185]
        average_list = []
        df_monthly = pd.DataFrame()
        index = ["51-56`N, 20-15'W", "51-56`N, 15-10'W","51-56`N, 10-5'W","51-56`N, 5-0'W","51-56`N, 0--5'W",
        "56-61`N, 20-15'W", "56-61`N, 15-10'W","56-61`N, 10-5'W","56-61`N, 5-0'W","56-61`N, 0--5'W",
        "61-66`N, 20-15'W", "61-66`N, 15-10'W","61-66`N, 10-5'W","61-66`N, 5-0'W","61-66`N, 0--5'W"]

        columns = [str(file)+"/"+str(i) for i in range(1, 13)]

        # calculating average temperature of the 15 grids
        for x in range(3):
            for y in range(5):
                print("-------" +str(51+x*5)+"-"+str(51+(x+1)*5)+"`N, "+ str(20-y*5)+"-"+str(20-(y+1)*5)+"`W ----------")
                grid = target[(x*5):(5+x*5), (y*5):(5+y*5)]
                grid_water_only = []
                for g in grid:
                    grid_water_only.extend([e for e in g if e != -32768])

                average = sum(grid_water_only)/(100*len(grid_water_only))

                print(average)
                average_list.append(average)

        df = pd.DataFrame(average_list)
        # monthly data of the 15 grids
        df_monthly = pd.concat([df_monthly, df], axis = 1)

        df_yearly = pd.concat([df_yearly, df_monthly], axis = 1)

    df_yearly.columns = columns
    df_yearly.index = index

    # yearly data for all of the grids
    df_total = pd.concat([df_total, df_yearly], axis = 1)
    df_total.to_excel("temperature_time.xlsx")

# plot the temperature over 15 years for each of the grid
for i in range(15):

    plt.plot(label, temp_list[i])
    plt.title(list(df_summer_total.index)[i])
    plt.show()

```