Bycatch Hotspot Prediction in Baffin Bay, Canadian Arctic

Final Project Report

Spatial Statistics

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Date:	December 6, 2022

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1 Introduction

Bycatch refers to the discarded unintentionally caught marine animals, especially of the protected species such as dolphins, whales, protected fish, sea turtles, sharks, etc, and the unobserved mortality due to the direct encounter with fishing vessels and gear [1]. The Greenland sharks are regularly caught bycatch in Baffin Bay 1, a large basin and major large-scale commercial fisheries between Baffin Island and Greenland in the Canadian Arctic [2].
Bycatch is a common problem in many fisheries worldwide as discarded animals often die, impacting marine ecosystems [1]. More so, high levels of bycatch contribute greatly to broader concern about overfishing, which can shut down significant fisheries and inadvertently impact the seafood markets [3]. The effects of these bycatch could be mitigated by limiting access to spatiotemporal hotspots [2]. Investigating bycatch data can provide insights into bycatch hotspots, particularly for vulnerable species such as sharks, and assist in establishing effective management measures.

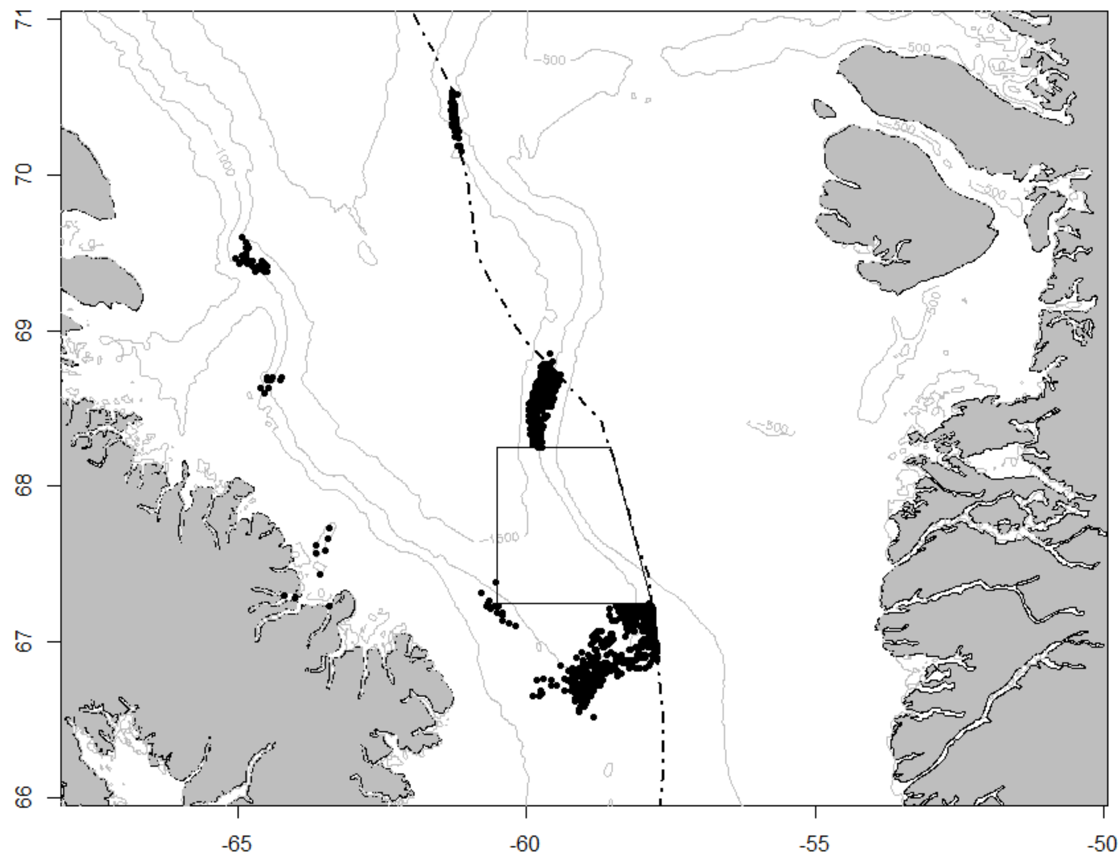

Figure 1: Baffin Bay with Isobaths. Bounded box: marine protected area. Black dots: fishing locations

2 Data

Greenland shark data was collected over a 4-year period (2008-2011) between July to November.

Table 1: Dataset Description of Variables of Interest

Variable	Description
y	count of shark bycatch
duration	soak time in hours and decimal minute
Ngillnets	number of gillnet panels
TC.tspp	total catch of Greenland halibut (in metric tonnes, t = 1000kg)
bathymetry	measure of the depth of water (metres, m)

2.1 Data Exploratory Analysis

The Greenland shark data shows some nonlinearity and spatial correlation. This dataset is also characterized by excess zeros in the response variable 3. Except for some indication of a nonlinear relationship between the count of shark bycatch and bathymetry, the exploratory analysis failed to find any conclusive relationships between Greenland shark bycatch with other covariates 2.

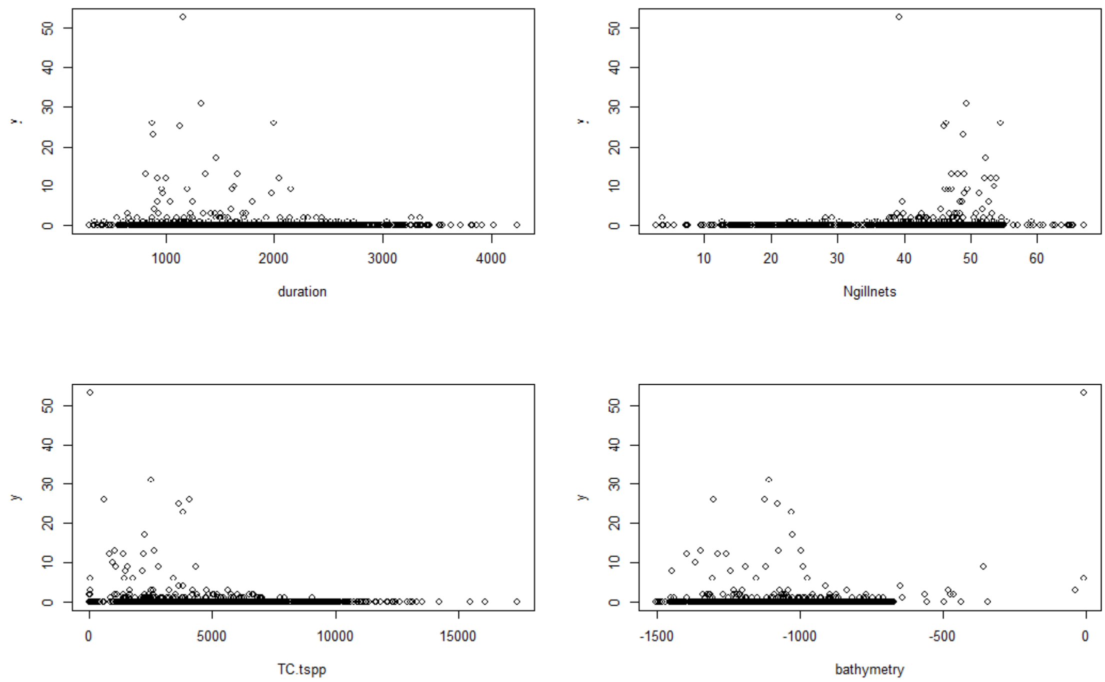

Figure 2: Relationship between bycatch and covariates of interest

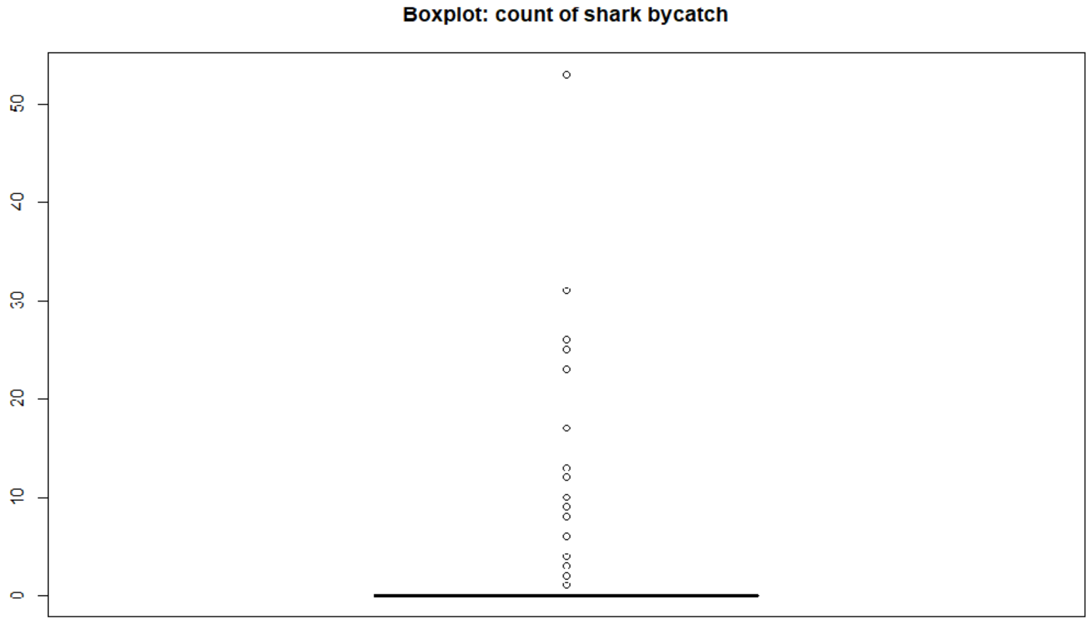

Figure 3: Response variable: count of shark bycatch showing excess zeros

2.2 Map

We obtain the map of Baffin Bay using the R library mapdata. We include the Canadian Exclusive Economic boundary zone and the ocean depths from the data zip folder. The marine protected area bounding box and fishing locations are also plotted, see 1.

3 Modeling

The steps needed to fit a Spatio-temporal model suitable for predicting Greenland shark bycatch using R-INLA are demonstrated in this section. First, project the geostatistical data from a latitude-longitude point unto locations on a plane using the coordinate reference system NAD83 (CSRS) - UTM zone 19N (suitable for use in Canada between 66°W and 72°W).
To model the spatial correlation, we assume a spatial Matérn correlation using the SPDE approach [2, 4]. Next, construct a triangulated mesh to approximate the gaussian field of the study area. A fine mesh will result in a higher resolution output, with cluster zones of greater precision. To improve this precision, I constructed the mesh using the fishing locations. The SPDE model is then built with default prior settings. An index set for the latent spatio-temporal Gaussian model is then constructed with a projection matrix that projects the spatio-temporal continuous Gaussian random field from the observations to the mesh nodes.

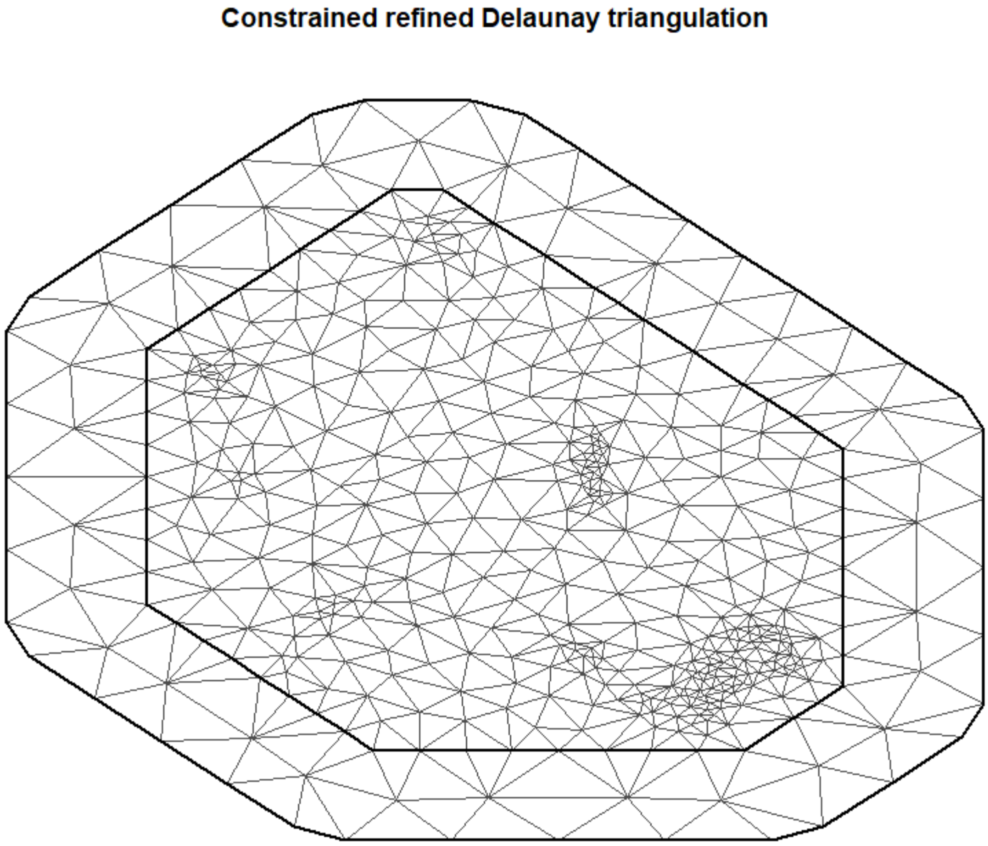

Figure 4: Triangulated mesh used to build the SPDE model

3.0.1 Prediction

To make predictions for each fishing location and year between 2008-2011, construct the matrix that projects the spatially continuous Gaussian Markov random field from the prediction locations to the mesh nodes. inla.stack() is used to construct the stacks for estimation (stke) and prediction (stk.p).

3.0.2 Model Formula

The formula that we apply to fit the model is defined thus: The intercept is subtracted from the formula (by adding 0) and added as a covariate factor (adding b0). The SPDE model is specified with f() adding the name s, the model spde, the group given by the indices s.group of indexes, and the control group with bathymetry and model = 'rw1'. By using group = s.group we specify that in each of the years, the spatial locations are linked by the SPDE model. inla.group(bathymetry) reduces the model to unique values based on ocean depths; model = 'rw1' [5] specifies that across time, the process evolves according to a random walk process.
Finally, we call inla() providing the formula, data, and options. Based on the family parameter, we have proposed two models which incorporate a new realization of spatial correlation each year: (1) using the traditional Poisson distribution to predict bycatch, (2) using zero-inflated

Poisson of type 2 [2, 6] to account for the excess zeros in the distribution of the response variable (see 3). By assuming a zero-inflated Poisson distribution rather than the standard Poisson distribution, we are allowing for the additional probability of 0. In control.predictor, we specify the projection matrix and compute = TRUE to obtain the predictions. We set control.compute=list(dic=TRUE) so as to enable us to select the best model of (1) and (2) based on their respective DICs. We also set control.inla=list(strategy='laplace') for faster computing.

3.0.3 Model Selection

DIC results of the two likelihood families tested are shown in 2 with their respective inference time. This result shows that the zero-inflated Type 2 Poisson has the least DIC and therefore performs better than the standard Poisson likelihood.

Table 2: Table showing DIC of proposed model formula

	Poisson	**Zero-inflated Poisson**
DIC	1023.15	943.368
Approx Inference Time	7 minutes	30 minutes

4 Results and Discussion

On inspecting the parameter estimates of the fixed and random effects seen in 3, we observe that the duration (of the hauls) and TC.tspp(total catch of greenland halibut) had no significant effect. Ngillnets (number of gillnet panels) was positively correlated with the amount of bycatch such that for every panel, the expected bycatch increased by 1.9%.

Table 3: Estimates of model parameters with zero-inflated Type 2 Poisson

Parameters	**Mean**	**sd**	**0.025quant**	**0.5quant**	**0.975quant**
duration	0.000	0.000	0.000	0.000	0.000
Ngillnets	0.019	0.007	0.006	0.019	0.033
TC.tspp	0.000	0.000	0.000	0.000	0.000

The posterior means of the Relative Risk of Greenland shark bycatch for each year are shown in 5. This map highlights the estimates of the Relative Risks of the Greenland shark bycatch and their uncertainties for each location. Locations with Relative Risks > 1 indicate a higher amount of bycatch. Shallower fishing locations closer to the coasts are associated with higher bycatch than deeper waters. We also see that spatial effects differ each year with increasing levels of bycatch along the protection fishing region.

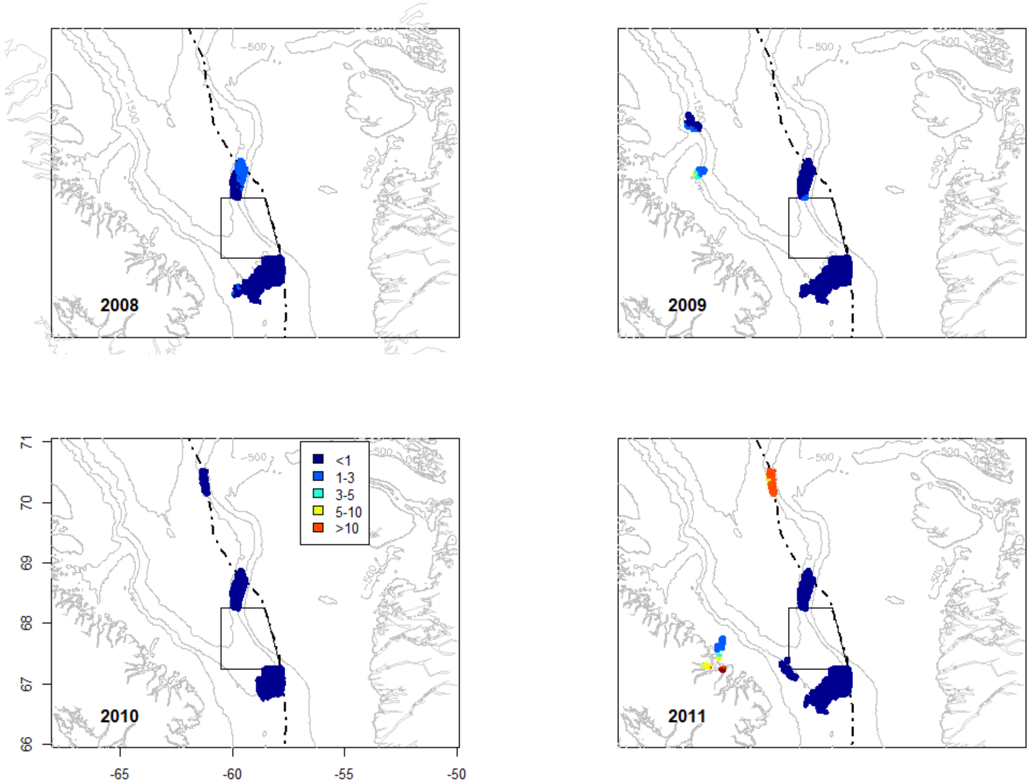

Figure 5: Posterior means of the Relative Risk of Greenland shark bycatch

Discussion:

1. Shallower waters (<1000m) show Relative Risks > 3 and in extreme cases as seen in the Northernmost locations, Relative Risks > 10. I recommend that fishing be limited to deeper waters (>1000m).

2. 2011 shows high levels of RR in the Northernmost fishing locations: recommend putting up restriction measures to limit fishing in hotspots. Examples of such management measures could range from setting a limit to the number of gillnet panels (Ngillnets).

3. South-Western fishing locations show promise of a higher Relative Risk: future bycatch monitoring and tracking studies are required here.

5 Conclusion

- Zeroinflated distribution is best for frequent zero-valued observations
- Fishing locations near the coast are positively correlated with bycatch
- The northernmost fishing locations in 2011 showed higher bycatch risk.
- There is no obvious bycatch pattern based on location, however, we observed a lot of fishing activities closer to the protected boundaries.

- There is a considerable increase in bycatch each year. The next year should be monitored closely after recommendations have been implemented to note changes and patterns.

References

[1] K. Brogan, "Noaa partnerships highlight technical solutions to bycatch reduction," August 31, 2016. [Online]. Available: https://www.noaa.gov/media-release/noaa-partnerships-highlight-technical-solutions-to-bycatch-reduction

[2] A. Cosandey-Godin, E. T. Krainski, B. Worm, and J. M. Flemming, "Applying bayesian spatiotemporal models to fisheries bycatch in the canadian arctic," *Canadian Journal of Fisheries and Aquatic Sciences*, vol. 72, no. 2, pp. 186–197, 2015.

[3] D. S. Kirby and P. Ward, "Standards for the effective management of fisheries bycatch," *Marine Policy*, vol. 44, pp. 419–426, 2014.

[4] P. Moraga, *Geospatial health data: Modeling and visualization with R-INLA and shiny*. CRC Press, 2019.

[5] M. Speekenbrink, *An R companion to Statistics: data analysis and modelling*, 2022-12-06.

[6] J. Bruin. (2011, Feb.) newtest: command to compute new test @ONLINE. [Online]. Available: https://stats.oarc.ucla.edu/stata/ado/analysis/