Evaluation the potential impacts of effort displacement on false killer whale depredation during SEZ closures.

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Motivation

The Southern Exclusion Zone (SEZ; **Figure 1**), a management area created by the False Killer Whale Take Reduction Plan, is closed to deep-set longline (DSLL) fishing if the fishery reaches a certain level of observed false killer whale (FKW) bycatch in a given year. The Southern Exclusion Zone is closed to deep-set longline fishing if, in a given year, the fishery has four observed MSI, false killer whale interactions in U.S. EEZ around Hawai‘i that are mortalities or result in ‘serious injury’ (85 FR 81184, Dec 15, 2020). The SEZ has been closed 7/24/2018 (83 FR 33848) - 12/31/2018 (automatic), 02/22/2019 (84 FR 5356) - 08/25/2020 (85 FR 50959), and an after the fact closure entered into the registry 3/8/2022 (87 FR 12941). There is concern that the effort displacement as a result of the SEZ closure may result in higher-than-expected encounters - in the form of depredation events and interactions with the gear - with FKW due to positive feedback mechanism. There is also concern that effort is displaced into locations where other protected species are present. The Pacific Islands Regional Observer Program data indicate ~6% probability of a depredation event occurring on any DSLL set (Fader and others 2021; Forney and others 2011). Anderson and others (2020) suggest that FKW are attracted by the haul of the gear, potentially from a long distance, and are stimulated to engage in foraging behaviors. This attraction to the haul and the increased effort in areas outside the SEZ may interact synergistically to attract FKW into these regions beyond what is expected by the average per set chance of depredation.

Approach

To explore the potential positive feedback effect of effort displacement a regression analysis was conducted using data from 2013-2021 from the Hawai’i logbook program (Pacific Islands Fisheries Science Center 2022), the Pacific Islands Regional Observer Program (Pacific Islands Regional Office 2021), and high resolution longline fishing hours for non-US flag States from Global Fishing Watch (Global Fishing Watch 2022). Observation south of 9°N were excluded to limit the spatial range and because of very few observations. After initial analyses, the Global Fishing Watch data was excluded as it proved to be very sparse and insignificant in the region of interest. Analyses were conducted in R (R Core Team 2020) using the sdmTMB package (Anderson and others 2022) which is based on VAST (Thorson 2019) and glmmTMB (Brooks and others 2017).

The Pacific Islands Regional Observer Program data was used to explore the potential impact of accumulated effort on depredation during a DSLL set, a binomial spatiotemporal model was employed on depredation presence/absence at the set level. A minimum distance of 100km was used to develop a spatial mesh for the random fields. Annual spatiotemporal latent effects were assumed to be ‘iid’ over a single fixed spatial latent effect over years. To account for the accumulated effect of fishing effort, for each set, the accumulated log effort (measured as hooks) was calculated over the previous 7 days including the hooks set on the current set. This effort effect was included as a smoothed term along with a smother on the time taken to haul the gear. In the few instances where the haul time was reported to be greater than 24 hours, haul time was set to the average haul time. The model also included smooth terms for year and month (these were restricted to have no more that 5 nodes) as well as if a set occurred in the SEZ. A random intercept based on reported permit number was also included.

The Hawai'i logbook program data restricted to 2017-2021 was used to explore the impact of effort distribution during SEZ closures. A gaussian spatiotemporal model was employed on total weekly log effort (measured as hooks) aggregated to 1-degree hexagons. A minimum distance of 100km was used to design a spatial mesh. Annual spatiotemporal latent effects were assumed to be 'iid' over a single fixed spatial latent effect over years. The mode also included smooth terms were also included for year and month along with an integration between sets inside and outside of the SEZ and if the SEZ was closed.

The potential effect on other protected species of effort displacement was not quantified in this study; however, maps of the relative frequency of interaction for giant manta (*Mobula birostris*), oceanic whitetip shark (*Carcharhinus longimanus*), and olive ridley sea turtle (*Lepidochelys olivacea*) were estimated using the Ensemble Random Forest (ERF) approach (Siders and others 2020) on the Pacific Islands Regional Observer Program data from 2005-2021. In this approach, the presence or absence of a particular species on a given set is related to dynamic and static oceanographic and physical features. The 0.25-degree gridded values from the ERF model were averaged over the 1-degree hexagons used in the logbook regression to provide spatial maps for visual comparison.

Findings

On a per set basis, depredations per set have been reasonable similar in recent years following an increase after 2014 (**Figure 2**). An increasing temporal trend in interactions per set is seen over time with a noticeable decrease in observed interactions in 2020 in recent years (**Figure 2**). Marine mammal depredation are shifted west and south of observed and logbook reported sets with observed sets generally slightly west and south of logbook reported sets (**Figure 3**). There is a southerly trend in the median latitude of sets with 2019 standing out as the most southerly median latitude in interactions over the time series with 2018 being the most northerly. From 2013 to 2021, sets outside the SEZ and been getting progressively closer to the SEZ (**Error! Reference source not found.**), a function of the southerly shift in the median latitude of fishing effort, with 2019 having the shorted mean distance. During the closure of the SEZ there is a slight decrease in the distance to the SEZ for sets outside the SEZ (**Figure 5**).

Using a spatiotemporal binomial model for the occurrence of depredation on a set, a base probability of set depredation of 5.4% per set was found (**Table 1**). Month showed a clear seasonal pattern with a depression of interaction rates in the summer months (**Figure 7**). As shown previously, there is an increase in the probability of depredation over the early years of the time series. Haul time was estimated to increase depredation over the sparser lower haul times but the trend declined over the more common haul times in the data. Although cumulative effort over the previous 7 days as estimated to have an increasing trend this only occurred at sparse low effort values. Over the more common effort values the trends was weekly positive and declined at higher effort levels. Sets is the SEZ were estimated to have a higher probability of interaction (~1%). The estimated random effect of permit number indicated some permits had a statistically higher probability of interaction (**Figure 8**).

The static spatial and spatiotemporal latent effects produced by the model showed interesting patterns. The spatiotemporal residual pattern did not indicate any strong patterning (**Figure 9**). The static spatial effects show a clear northeast to southwest gradient in values suggesting a higher probability depredation in the southwest. A noticeable area of increased probability of depredation is seen north of the SEZ at the more northerly edge of the effort distribution (**Figure 10**). Spatiotemporal 'iid' effects indicate a more complex shifting mosaic pattern over time. Most notable are positive values to the east of the SEZ in 2018, a broad patch of positive values to the east and south of the SEZ in 2019, and positive values to the north in 2021 (**Figure 11**).

The gaussian spatiotemporal model used to explore the effect of the SEZ closure on the distribution of fishing effort estimated an increasing trend in effort over years a seasonal increase in effort in the later part of a year (**Figure 12**). The SEZ effect was estimated to be positive and the closure effect negative with the sez/closure interaction having a negative effect (**Table 1**). To illustrate the effect of effort displacement as a result of the SEZ closure, the difference between the average annual 'iid' spatiotemporal effects by 1 degree hexagon for times when the closure is and is not in operation was calculated for areas outside the SEZ (**Figure 13**). This map indicated that for times when the SEZ was closed net positive effects are seen to the east and to the south of the SEZ as well as further to the north west and the north. This suggests that when the SEZ is closed effort was displaced into these areas. For effort displaced to the south and east there is the potential to increase interactions with giant manta rays, oceanic whitetip sharks, and olive ridley sea turtles (**Figure 14**). Such a displacement may also increase interaction with other fishing nations (**Figure 15**).

Highlights

- Closing the SEZ appears to displace effort south and east.
- Fishing in the SEZ has a positive effect on depredation rate.
- Haul time has a weak effect on depredation that increase at low haul times and decrease slowly over the range of most haul times.
- Cumulative longline effort over the previous 7 days has a very weak positive effect on depredation rate.
- Season play a role in interactions rates with winter month increasing depredation rates.
- There is an increasing year effect on depredation early in the time period used
- There is an indication that some permits have statistically higher depredation rates
- Effort displaced to the south and east there is the potential to increase interactions with giant manta rays, oceanic whitetip sharks, and olive ridley sea turtles.
- Effort displaced to the south and east may also increase interactions with other fishing nations

Table 1. *Summary statistics for spatiotemporal models. DEP_PA in the set level occurrence of depredation. L_Hooks is the 7 day cumulative fishing effort prior to a set in the first model and the weekly total effort at a 1 degree hexagon in the second model.*

DEP_PA ~ s(L_HOOKS) + s(HAUL_TIME) + s(YEAR) + s(MONTH, k = 5) + SEZ + (1 | PERMIT_NUM) Family: binomial(link = 'logit')

Fixed effects				
	estimate	SE	CI low	CI high
Intercept	-2.86	0.08	-3.008	-2.703
SEZ	0.18	0.14	-0.094	0.452
sL_Hooks	-0.62	1.9		
sHaul time	5.66	2.49		
sYear	0.97	0.76		
sMonth	2.92	0.68		
Random intercept				
	sd			
Permit #	0.24		0.181	0.307
Error				
range	470.404		291.623	758.787
Spatial	0.298		0.211	0.423
S/T	0.446		0.342	0.582

L_HOOKS ~ s(YEAR) + s(MONTH, k = 5) + SEZ * CLOSURE Family: gaussian

Fixed effects				
	estimate	SE	CI low	CI high
(Intercept)	8.298	0.063	8.175	8.422
SEZ	0.049	0.038	-0.026	0.123
CLOSURE	-0.014	0.014	-0.041	0.013
SEZ:CLOSURE	-0.847	0.232	-1.302	-0.393
sYear	0.31	0.00		
sMonth	0.68	0.26		
Error				
range	796.2		673.6	941.2
Dispersion	0.79		0.78	0.80
Spatial	0.27		0.22	0.31
S/T	0.22		0.19	0.25

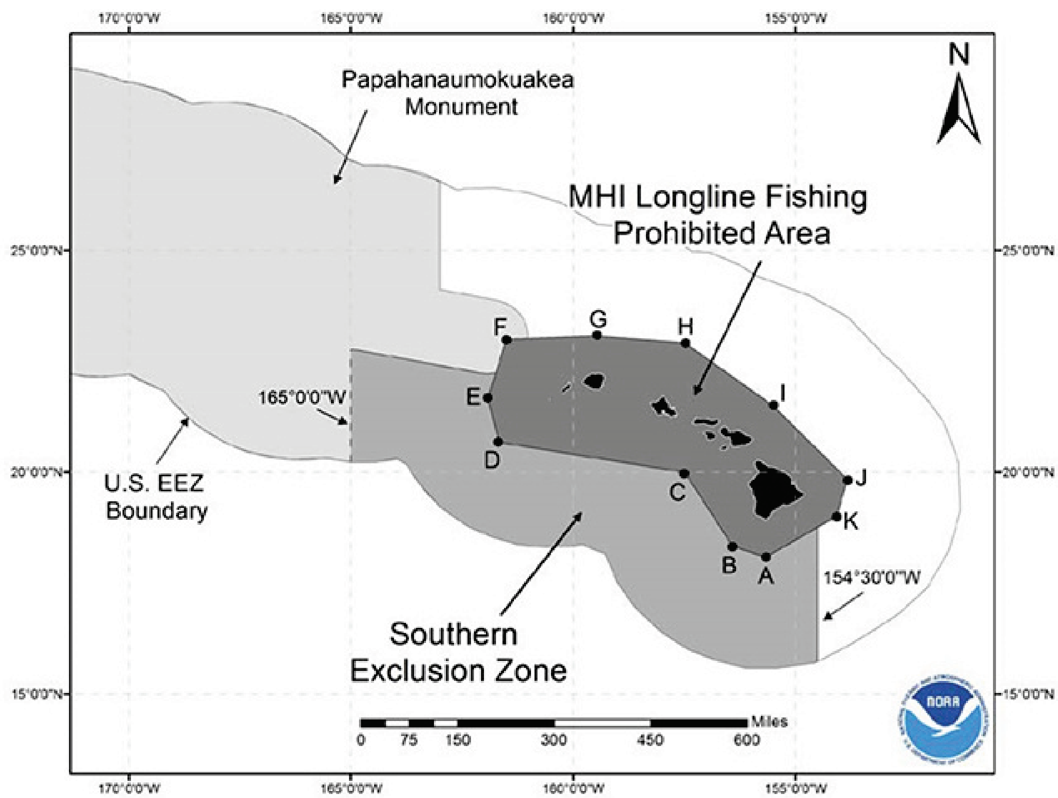

Figure 1. *Map showing the boundaries of the Main Hawaiian Islands Longline Fishing Prohibited Area, the Southern Exclusion Zone, the Papahanaumokuakea Monument and the U.S. EEZ boundary. Taken from https://www.fisheries.noaa.gov/pacific-islands/marine-mammal-protection/frequently-asked-questions-about-2019-southern-exclusion.*

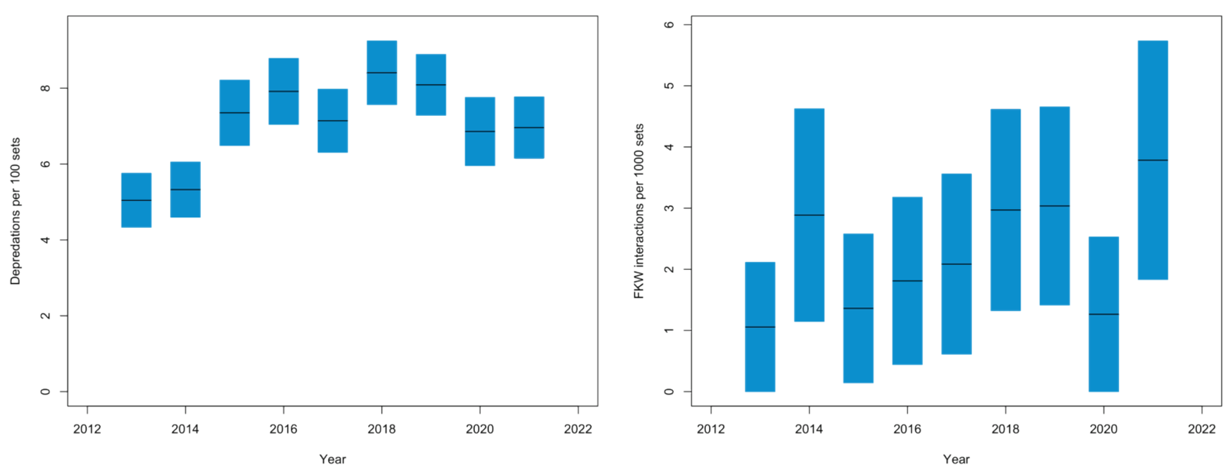

Figure 2. *Marine mammal depredations and false killer whale interactions per set in the Hawai'i deepset longline 2013-2021.*

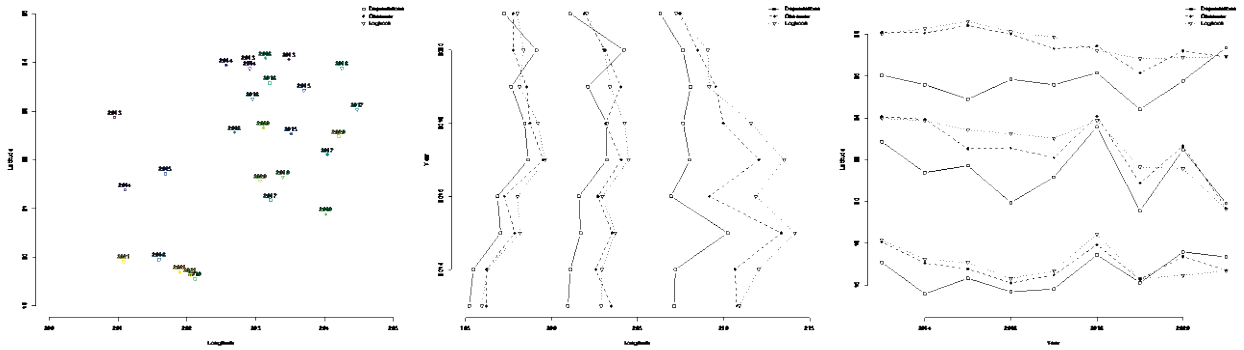

Figure 3*.* Spatial distribution of depredations, observed sets, and the logbook reported sets for the Hawai'i deepset longline 2013-2021. Left panel shows the position of the median longitude and latitude for each year and data type. Center panel shows the temporal change in the 20th, 50th, and 80th quantile of the longitude for each data set. The right panel shows the temporal change in the 20th, 50th, and 80th quantile of the latitude for each data set.

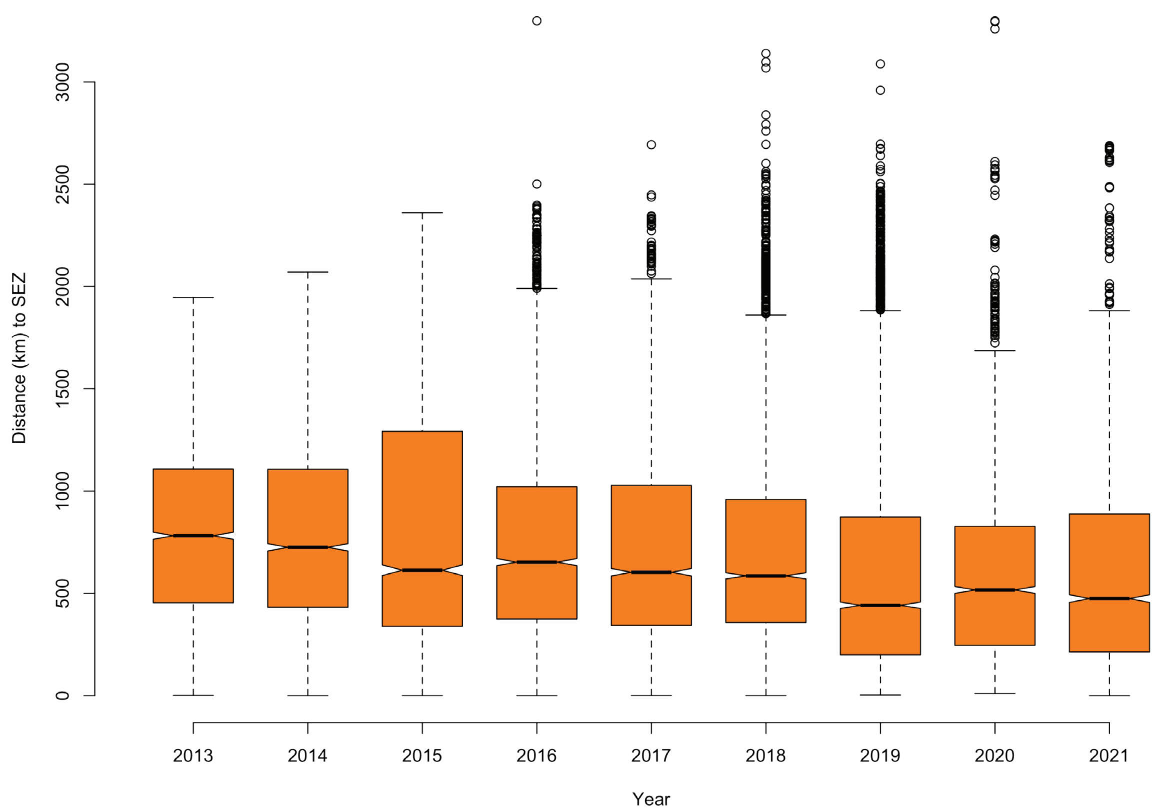

Figure 4*. Standard b*oxplots of the distance to the Southern Exclusion Zone (SEZ) for sets outside the SEZ.

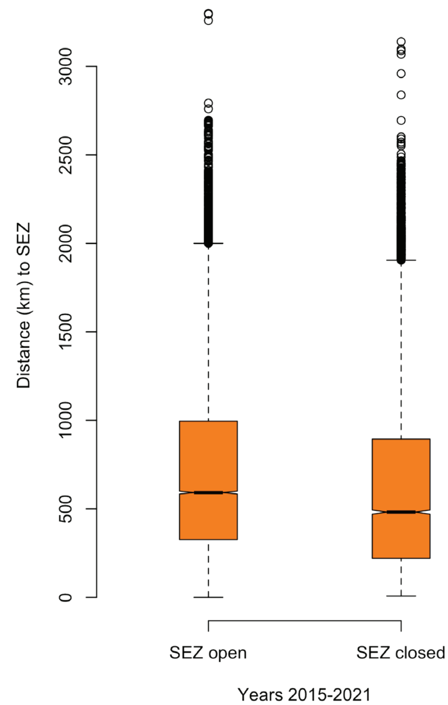

Figure 5*. Standard b*oxplots of the distance to the Southern Exclusion Zone (SEZ) for sets outside the SEZ when the SEZ is open and closed.

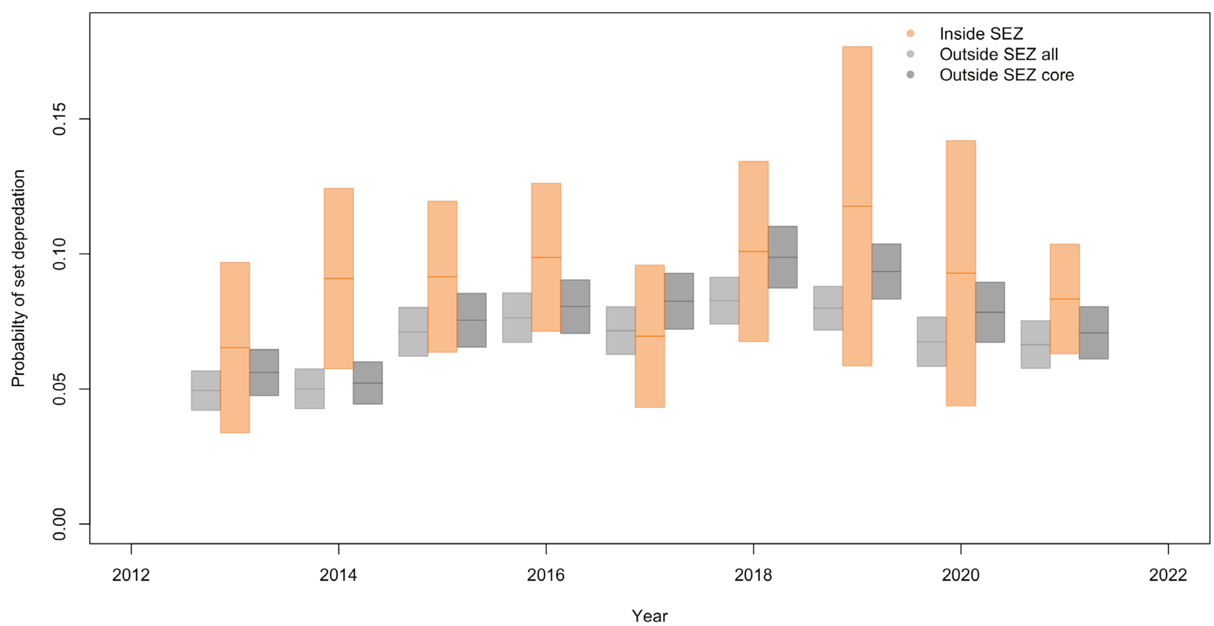

Figure 6*. Rectangles covering the 95% confidence Interval of the probability of depredation on a set for sets Inside and outside the SEZ as well as sets within the core of the fishing effort (80% quantile from a 2D kernel density estimator). Line indicates the mean.*

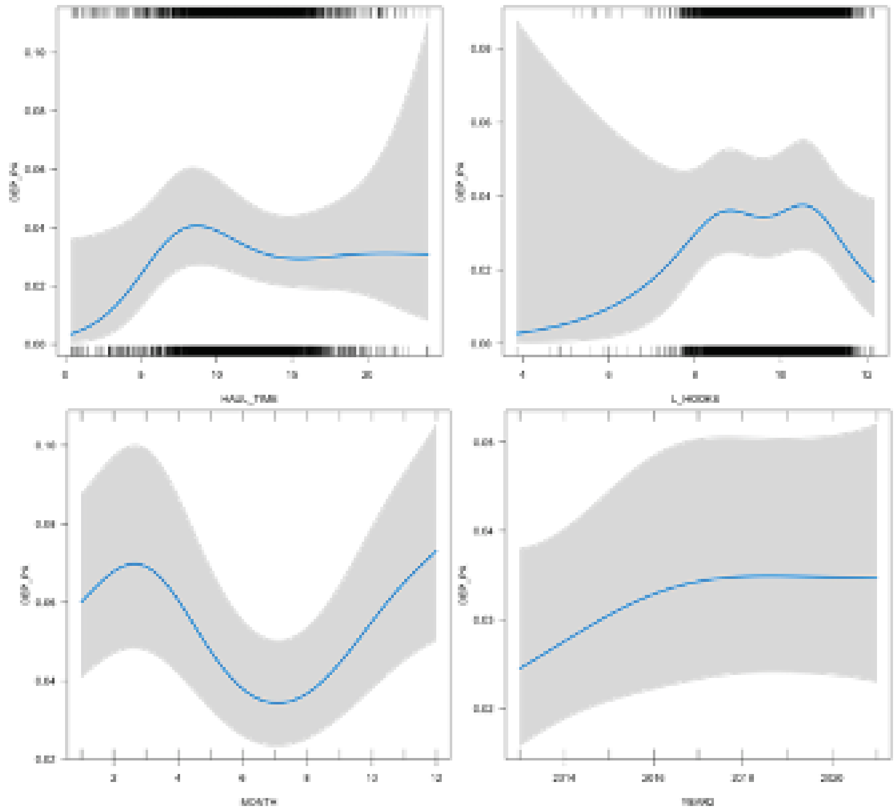

Figure 7. *Smoothing patterns and uncertainty for year, month, haul time and the cumulative effort over the previous 7 days in an area where a set occurred.*

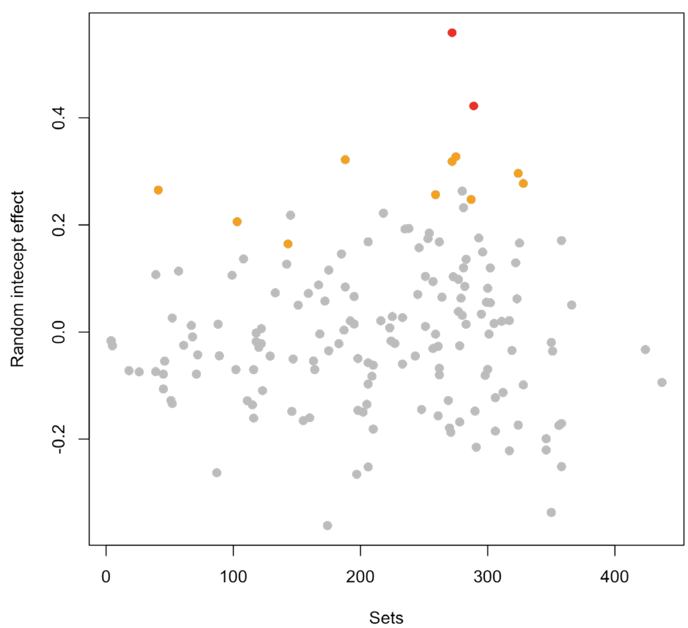

Figure 8. *Permit number random effect plotted with the number of observed sets for a given permit. Colored dots suggest a significantly higher effect.*

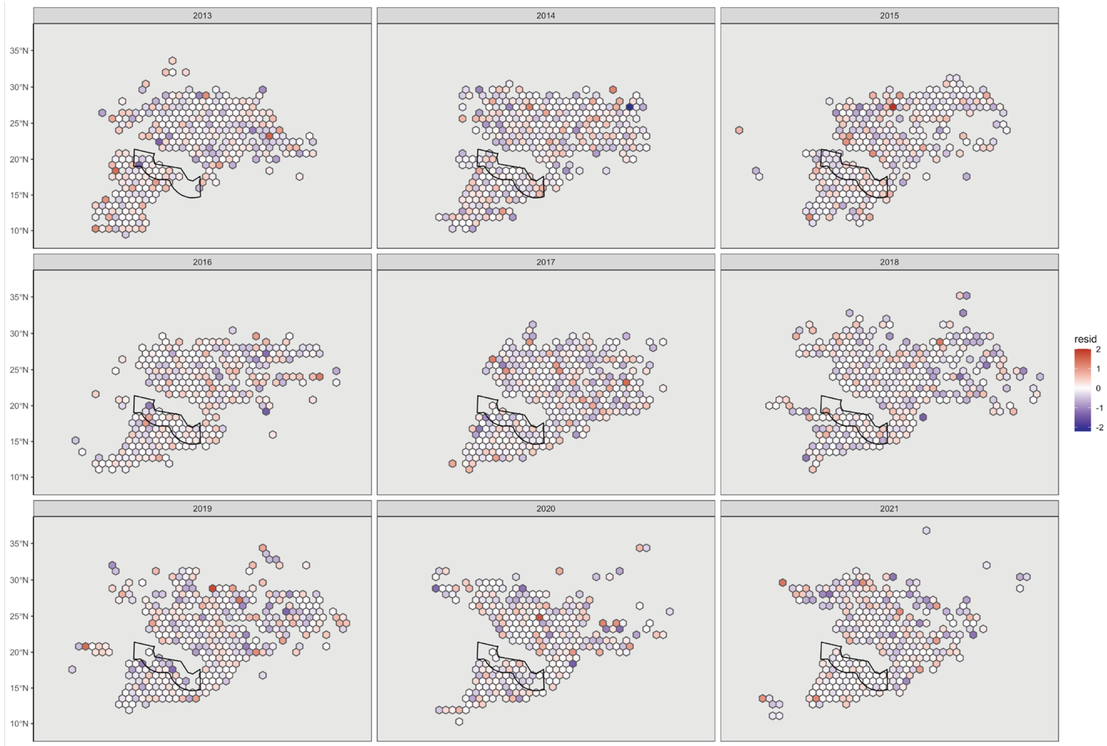

Figure 9. *Spatial residuals averaged by year.*

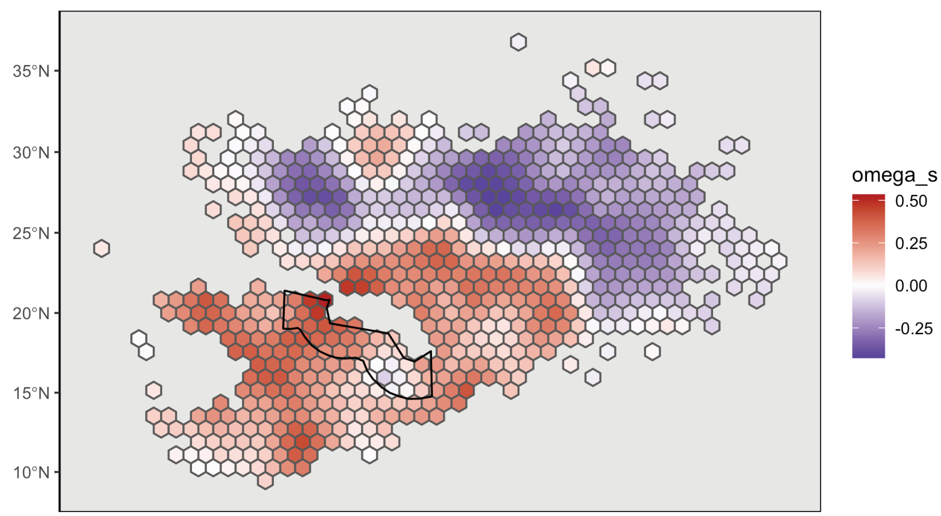

Figure 10. *Static spatial latent effects.*

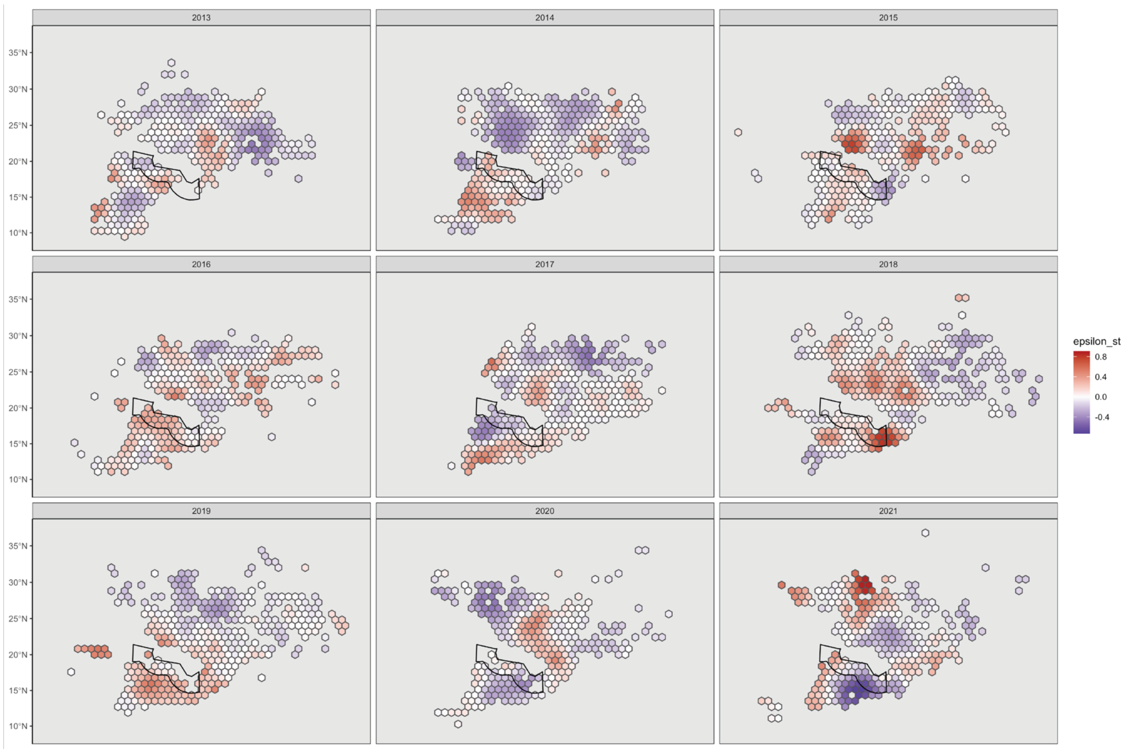

Figure 11. *Annual spatiotemporal latent effects.*

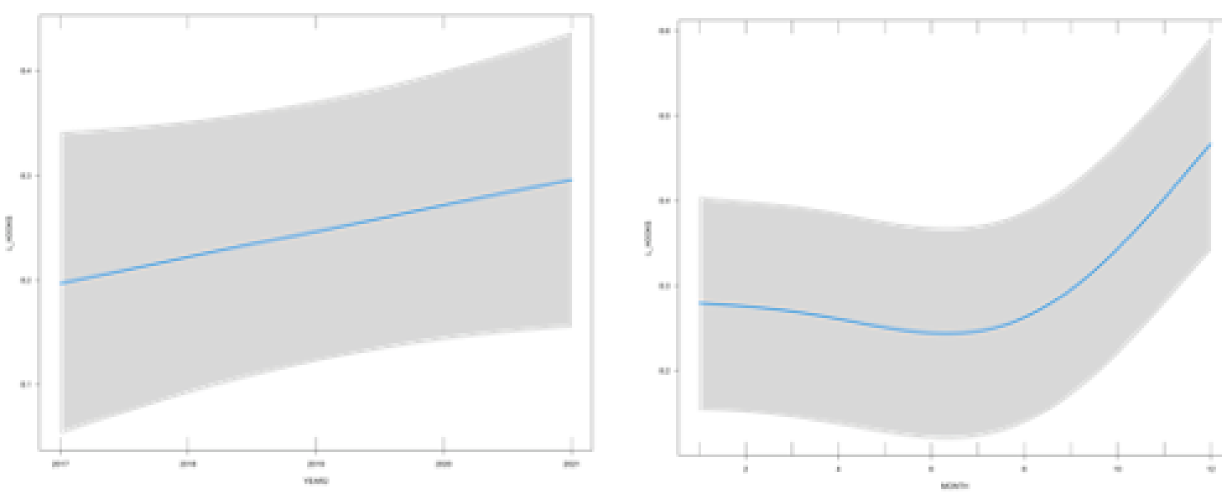

Figure 12. *Smoothing patterns and uncertainty for year and month.*

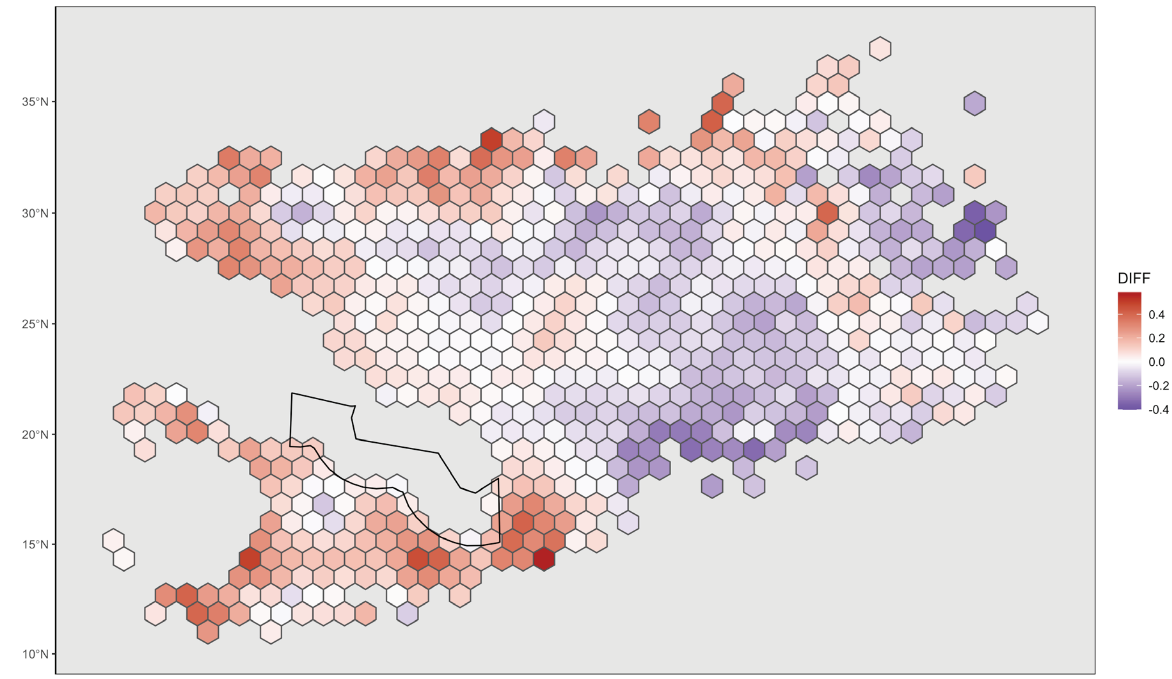

***Figure 13**. The net difference between spatiotemporal latent effects when the SEZ is open and closed. Effects are averaged between the two conditions.*

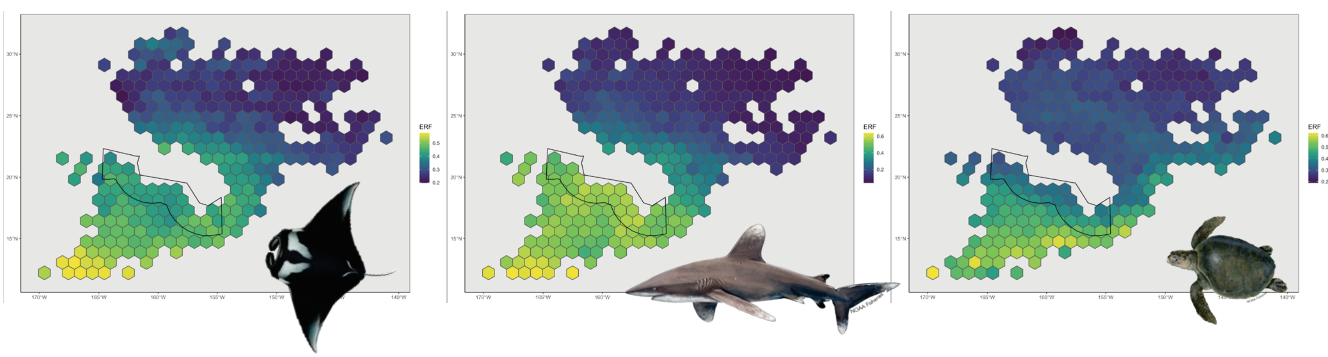

***Figure 14**. Spatially averaged values of the ensemble random forest for giant manta ray, oceanic whitetip shark, and olive ridley sea turtle.*

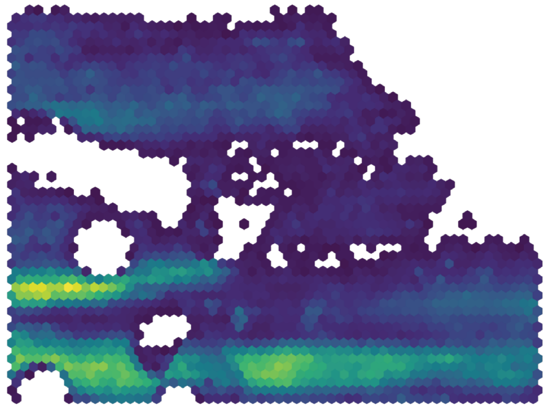

Figure 15. *Total Global Fishing Watch estimated effort over time by non-US flagged vessels setting longlines. Areas of green and yellow indicate higher effort hours.*

Citations

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