Catch subtitution between Coastal Pelagic Species under climate change scenarios

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Abstract

Fisher do not only catch one species. They have a set of possible choices, called 'fishing portfolio'. Some species are easier to shift as gear and method used are similar between them. Therefore, the cost of shifting between species is low and fishers could adapt quickly to a shift in fish species spatial distributions in response to climate change. Nevertheless, it is not clear whether actually this substitution happen as other constraint may be in play. Port constraints, as well as market characteristics could reduce substitution between species. In this study we analyze how changing in spatial distribution affects landing subtitution between three coastal pelagic species: Pacific sardine, market squid and Northern anchovy. We primary focus on the substitution that ocur between these species, and we project change on catch composition due to future climate change.

1 Introduction

Fishing portfolios are an important mechanism to safeguard fishers livelihood. Diversification strategy have been principally associated to reducing income variability. For instance, when a species abundance is reduced due to environmental conditions, fisher can change the targeted species. However, there is no always room for diversification. Switching between species can be costly if gears are quite different between species, or a new permit is required for legal fishing. Moreover, even though fisher may have flexibility switching between species, port infrastructure and markets may impose some restrictions on this flexibility. Therefore, it is not clear how change in species distribution would be reflected in landings.

In this study we analyze how changing in spatial distribution affects landing substitutins between three coastal pelagic species (CPS): Pacific sardine (PSDN), market squid (MSQD) and Northern anchovy (NANC). Moreover, using climate projections we can predict how catch composition is affected under climate change. Our analysis is focused on the US west coast CPS fishery.

Our papers builds on the model developed by Smith et al. [2021] for sardine landings. We expand their research Fisheries historically have been analyzed as single species. We expand their model including a landing equation for all of the three species analyzed. Moreover, we use the probability of presence obtained from Species Distribution Models (SDM) as explanatory variable instead of landing by species. This allows us to project landing over time using SDM predictions for different climate scenarios. Additionally, we analyze how species distribution interact between each others. We expect that this additions allows us to characterize better how fishers portfolio is composed, and also to understand better species interactions on catch rates.

The remainder of the paper is organized as follows: Section @ref(coastal-pelagic-species-fishery) provides background on the CPS fishery in the US west coast. In Section @ref(methods) we discusses our data set and empirical strategy. Section @ref(results) presents the results of the estimations, and we conclude in Section @ref(conclusion).

2 Coastal Pelagic Species fishery

Before Pacific sardine closure in 2015, the CPS fishery have been mainly dominated by Pacific sardine and market squid in landings (see Figure 1). In terms of revenue, due to the low prices received for sardine, the revenues in the CPS fishery are the highest for market squid.

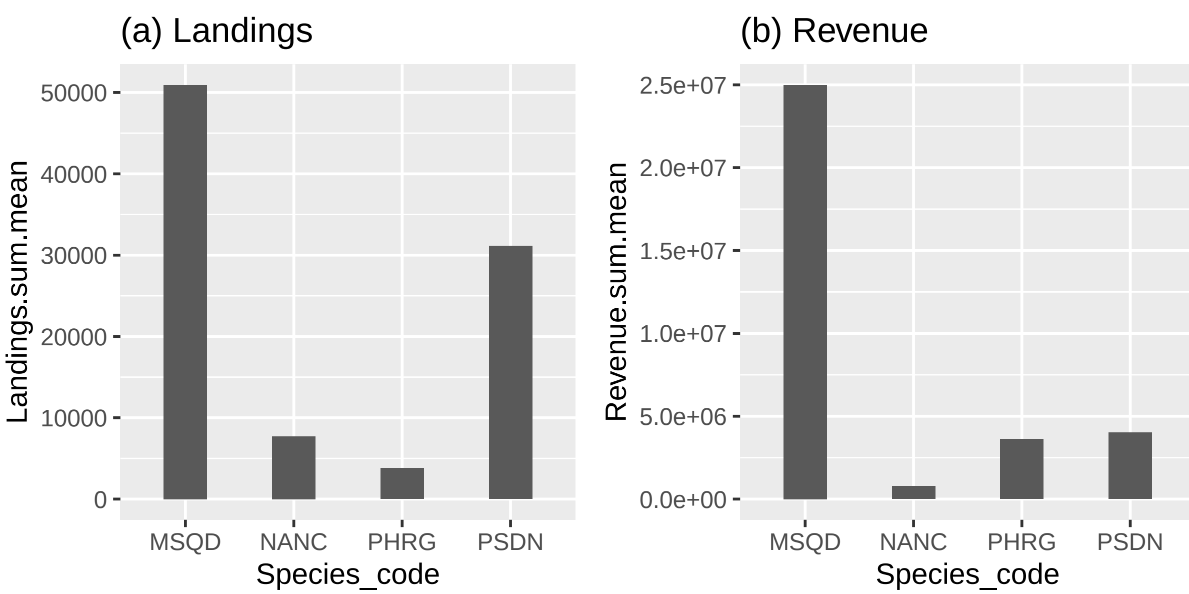
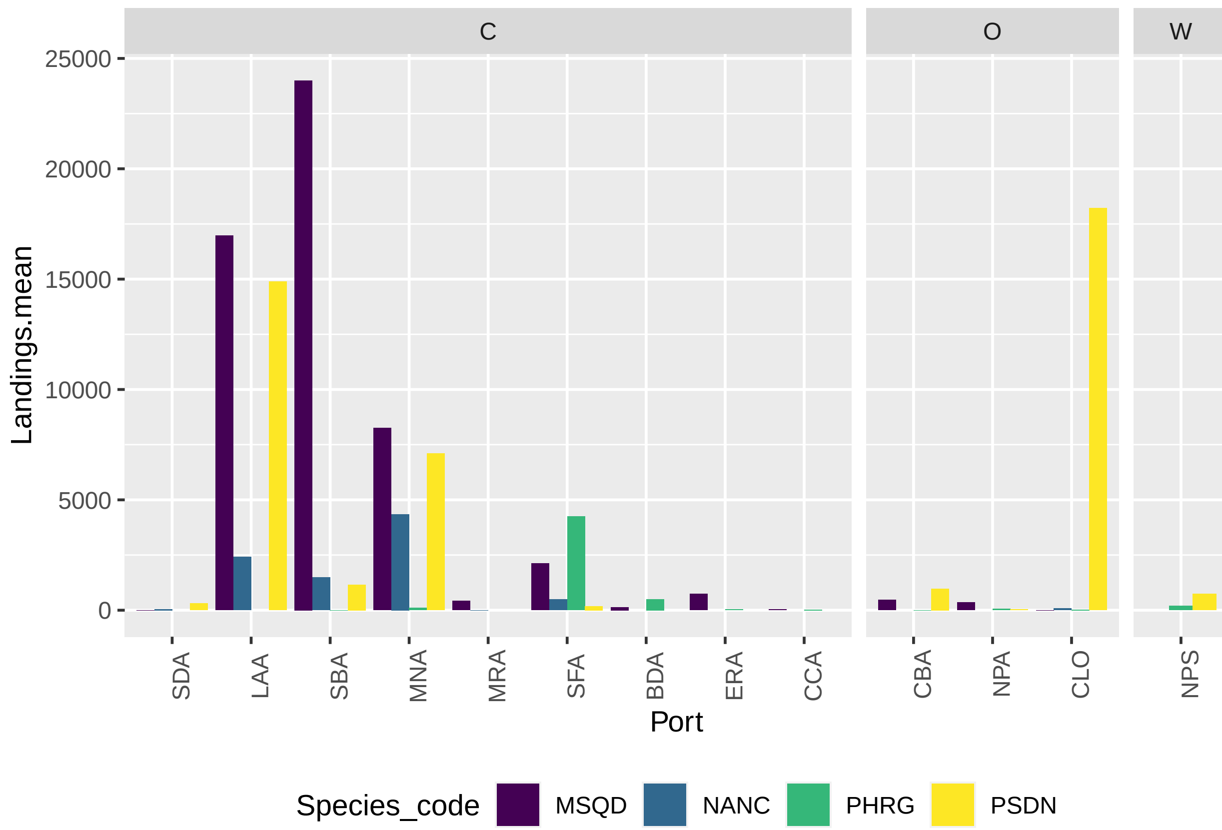
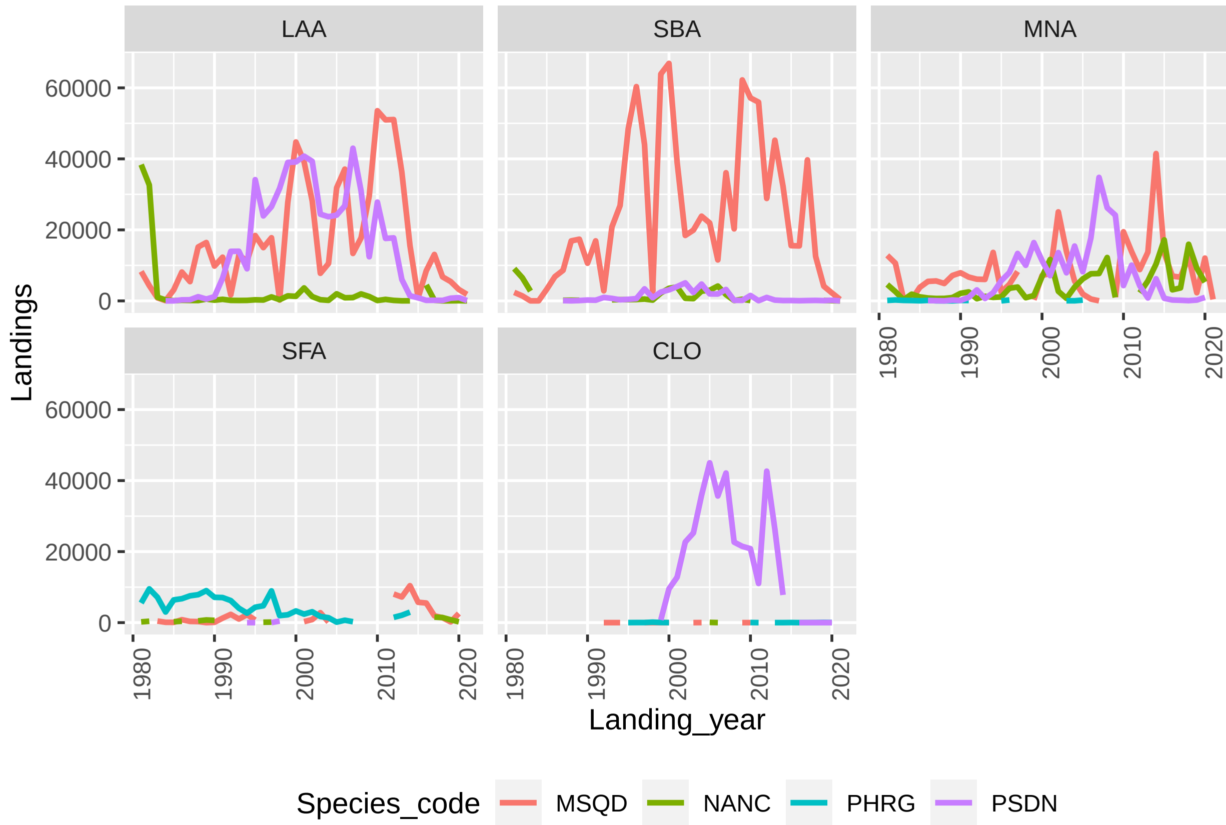


Figure 1: Average annual landing and revenues for the CPS fishery by species.

Landings composition varies geographically. We show in Figure **??** average annual landings by ports areas. We can observe that market squid is mostly landed in the southern ports located in Los Angeles, Santa Barbara and Monterrey areas, while Pacific sardine is mainly landed in Los Angeles and Monterrey areas in California, and also in the Columbia river area in Oregon. Substitution between species seems to be more likely in Los Angeles, Monterrey and Santa Barbara area ports (and in some lower scale at San Francisco area) as positive values for market squid, Pacific sardine and Northern anchovy landings are observed.



To analyze substitution more in detail, we compute total annual landing by port during 1980-2020 period (Figure **??**).



Landings could be reflecting the abundance levels that fishers face in the surroundings areas near to a port. As a first step to test this hypothesis, we plot the annual mean of the probability of presence together with total annual landings, however, a more rigorous approach is required to isolate the effect of abundance on landings, which we develop and present on empirical section. Figure 2 show the relationship between the probability od presence and landings by species in three main port areas: Los Angeles, Monterrey and Santa Barbara areas.

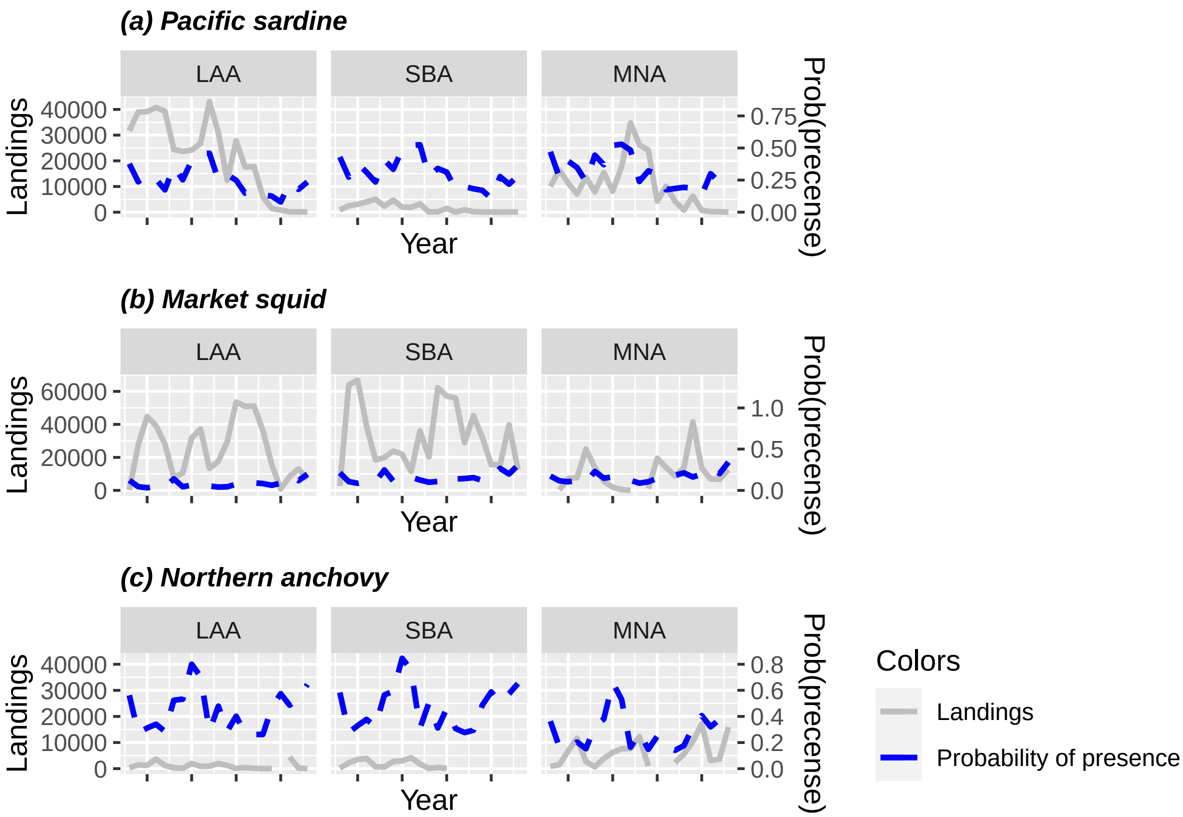


Figure 2: Landings v/s probability of presence by port area. *Notes:* LAA = Los Angeles; MNA = Monterey; SBA = Santa Barbara.

3 Methods

3.1 Data

Our data set contain a number of variables measured at the port and *vessel levels*. We only include ports areas where substitution could happen as they have landed all of the CPS species at least once.

3.1.1 Outome variable

Our outcome variable is landings by port areas. Data on landing by port areas is publicly available from PacFIN. It is a yearly panel data for the period 1980 - 2020 that contains landings of commercial species by ports located in the west coast of the United States (i.e. Washington, Oregon and California).

3.1.2 Treatment variables

Our main treatment variables are species presence. This variables were obtained from Species Distributiuon Models (SDM). Future forecast on this variable allows us to simulate a fishery in the future.

3.1.3 Explanatory variables

Additional explanatory variables are the annual catch limit (ACL) for the species in consideration.

3.2 Data processing and summary statistics

Summary statistics for the whole data set is shown in Table 1.

Table 1: Descriptive statistics.

	Mean	Std.Dev	Min	Max
ACL_MSQD.mean	108213.70	2459.39	107047.00	113398.00
ACL_PSDN.sum	42014.25	55826.16	0.00	186791.00
ACT_PSDN.sum	42503.50	55335.76	0.00	186791.00
Landing_year	2001.89	11.65	1981.00	2021.00
Landings	293.31	2172.46	0.00	66890.30
MSQD_SDM_120	0.14	0.06	0.02	0.37
MSQD_SDM_60	0.22	0.11	0.03	0.56
MSQD_SDM_90	0.18	0.08	0.02	0.47
N_dealers	20.38	13.01	0.75	68.00
N_vessels	42.10	31.42	0.75	182.00
NANC_SDM_60	0.37	0.17	0.11	0.89
NANC_SDM_90	0.30	0.15	0.08	0.85
Price	1.37	1.79	0.00	28.53
PSDN_SDM_60	0.27	0.11	0.08	0.57
Revenue	347993.43	1835052.50	0.00	49987499.00

3.3 Model

In general, landings are conditional to biological stocks (affected by climate change), harvest cost, prices and regulations.

- Outcome variable:
  - Pacific sardine landings by vessel, port and year. In this case we would predict landing by vessel i that land in port j
- Treatment variable:
  - Change spatial distribution of species due to climate.

        * Smith et al. [2021] relate port-level landings to the probaility of presence from a sardine species distribution model (SDM), and then makes projection to quantify future changes in landings.
        * Specifically, Smith et al. [2021] use mean monthly probability of presence of sardine within 60 km of port.

- Explanatory variables
    - Harvest costs (e.g., distances and fuel cost)
    - Own price and substitutes
    - Effort
        * Fishing effort from matching PacFIN data to Global Fishing Watch
        * "VESSEL_NUM" in PacFIN data: "It can be a USCG VID (ex: 1234567 or AK1234nn) or MISSING or UNKNOWN if vessel ID not provided or invalid. It is also "Null" if no vessel was used."
    - Regulations.
        * Incorporate ACL in the model (Smith et al. [2021] obtained this information from CPS Fisheries Management Plan, and Federal Register), maybe with a function that have a ceiling limit, or as **censored data** (Stan code).
        * Port capacity.
        * Closures.
- Random-coefficients?
    - By port: Different intercept / coefficient by vessel port.
- Some considerations:
    - Vessels likely to have contract with ports. Less flexibility where they land.
    - Harvest happen near-shore, less probability of longer trips if species move further.
    - Multivariate framework allows us to consider interrelation between species and CPS fleet.
        * Sardine harvest affect squid harvest?
        * If Sardine opens... Sardine more preferred? Sequentially or simultaneous harvest?

3.3.1 Empirical strategy

- Statistical model:
    - Bayesian hierarchical model
        * Hierarchical effects by port.
        * Uncertainty from modeling the process (as well as from the imperfect observation of the process).
        * Model the zeros in data

· Included in the estimation.
· N/A landings were converted to zero.
· Closures.
· Port restrictions (i.e. no infrastructure)

– Smith et al. [2021] estimate with GAM framework (allows for non-linear relationships)
– Some details:
  * Spatial autocorrelation between ports through species abundance? Between areas where vessel harvest?
    · Morris et al. [2019] include spatial errors in a bayesian framework.
    · How to deal with non-linearities
    · How far vessel travel for each species? (See animation here)

3.3.2 Bayesian model

We estimate a Hierarchial Bayesian Hurdel model for each species. The model have the following structure:

$$[\alpha_i, \beta_i, \sigma^2_\alpha, \sigma^2_\beta, \Sigma | q_{i,t}] \propto \text{multivariate normal}(q_{i,t} | \alpha_i + \beta_i SDM_{i,t}, \Sigma) \times \text{normal}(\alpha_i | \mu_\alpha, \sigma^2_\alpha)$$
$$\times \text{normal}(\beta_i | \mu_\beta, \sigma^2_\beta) \times [\mu_\alpha][\mu_\beta][\sigma^2_\alpha][\sigma^2_\beta][\Sigma],$$

where $q_{i,t}$ is the observed landings in port $i \in (1, \ldots, L)$ at year t, L is the total number of ports, $SDM_{i,t}$ is the SDM output for sardine observed at port i during the landing year t, α_i is the coefficient estimate by port, β_i is the effect of SDM on landing by port, and Σ is a matrix covariances.

- Changes on estimations:
  – SDM outputs of Market Squid included (using first 60km within coast)
  – Separate equation depending on species
  – Time fixed effects included.
  – Separate correlation matrix (0.37 positive correlation between sardine and squid)

4 Results

4.1 Pacific Sardine model

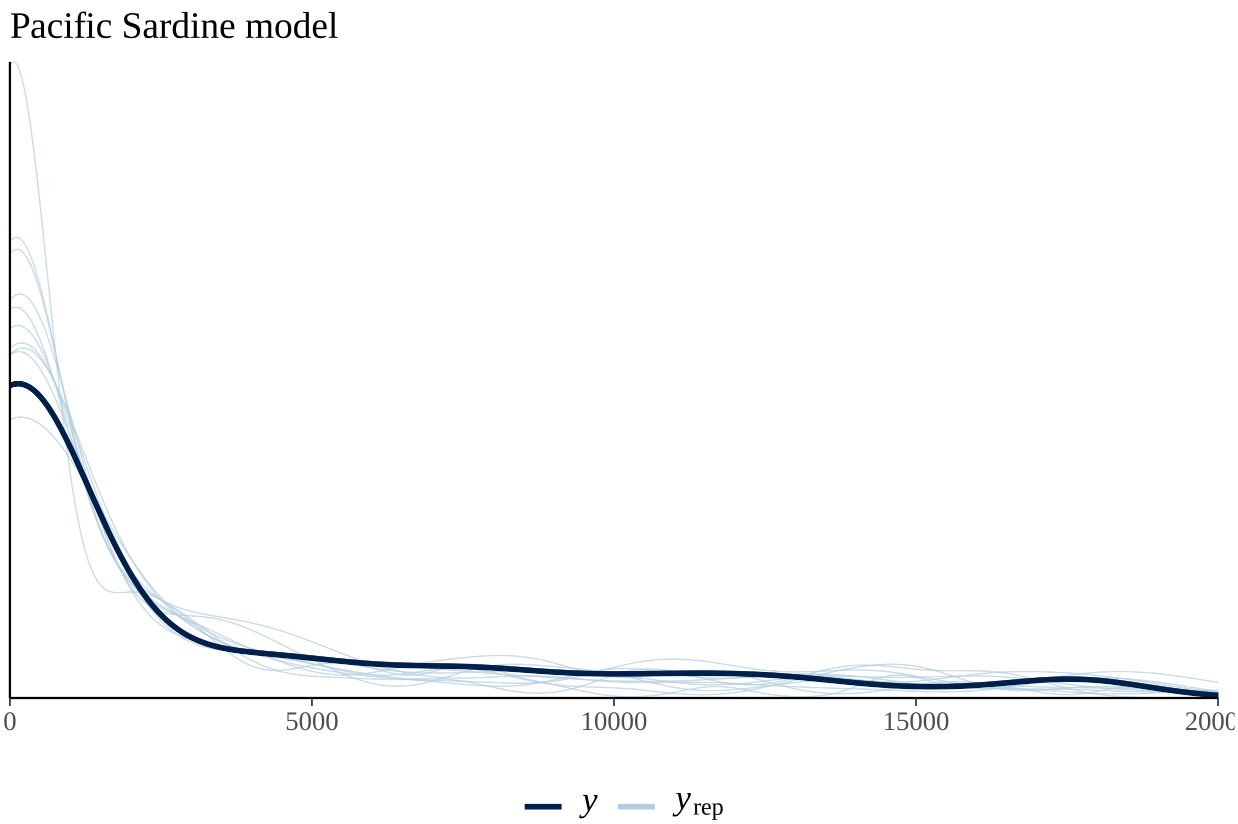
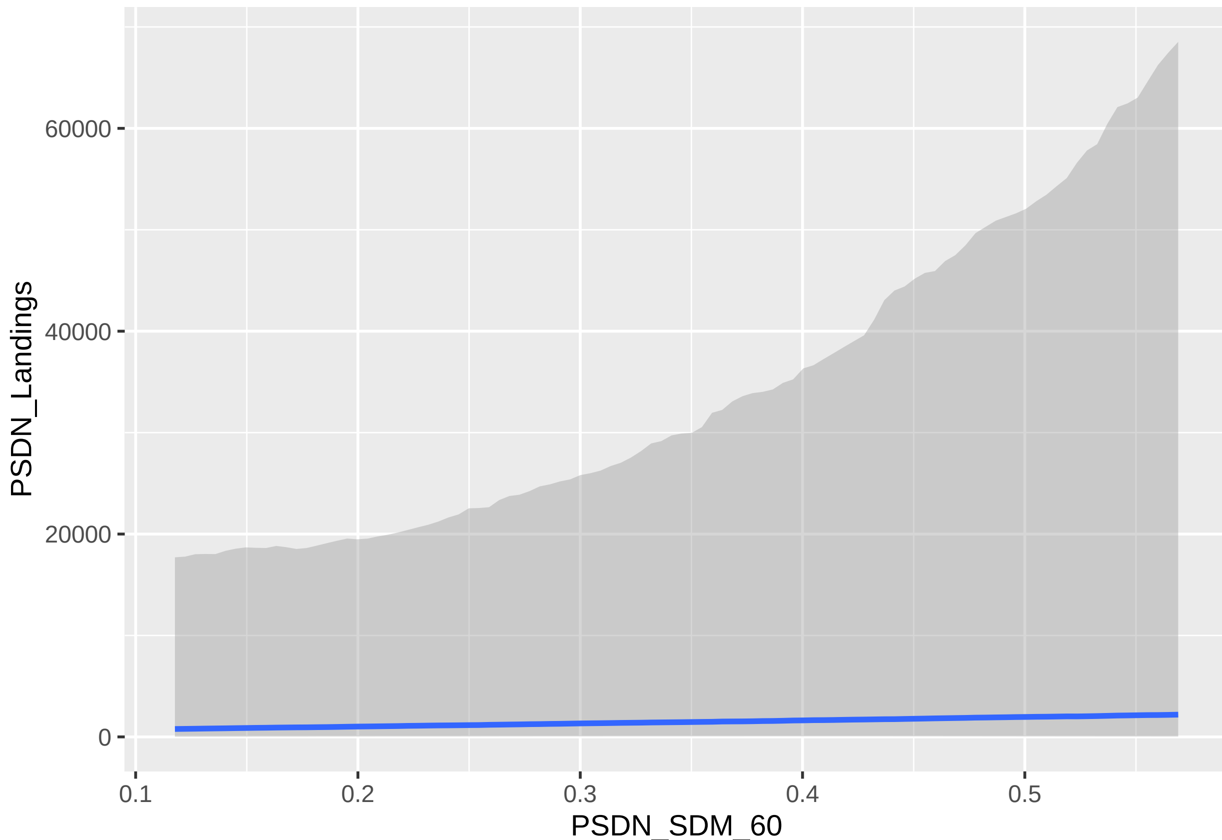
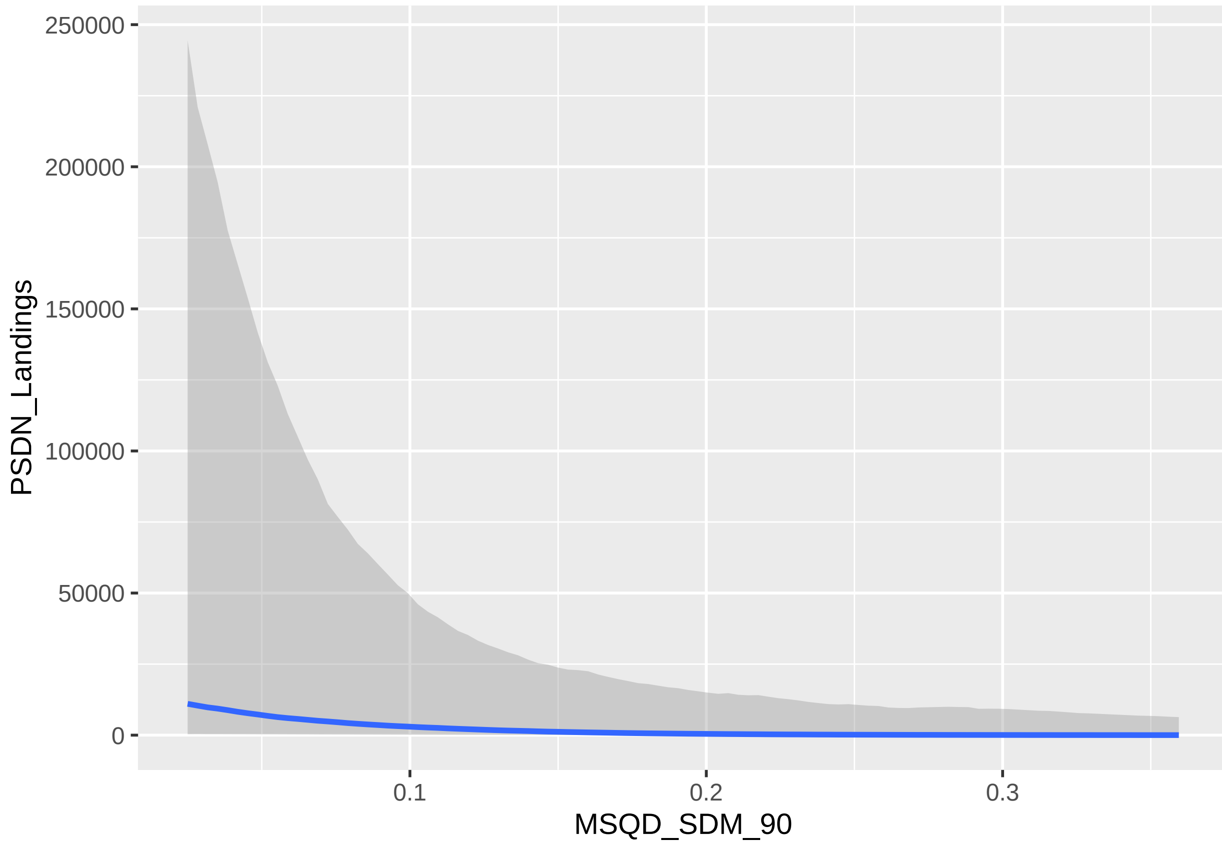


Figure 3: Graphical posterior predictive checks. (Gamma distribution)

4.1.1 Effect of SDM's on Sardine landings





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50000
0
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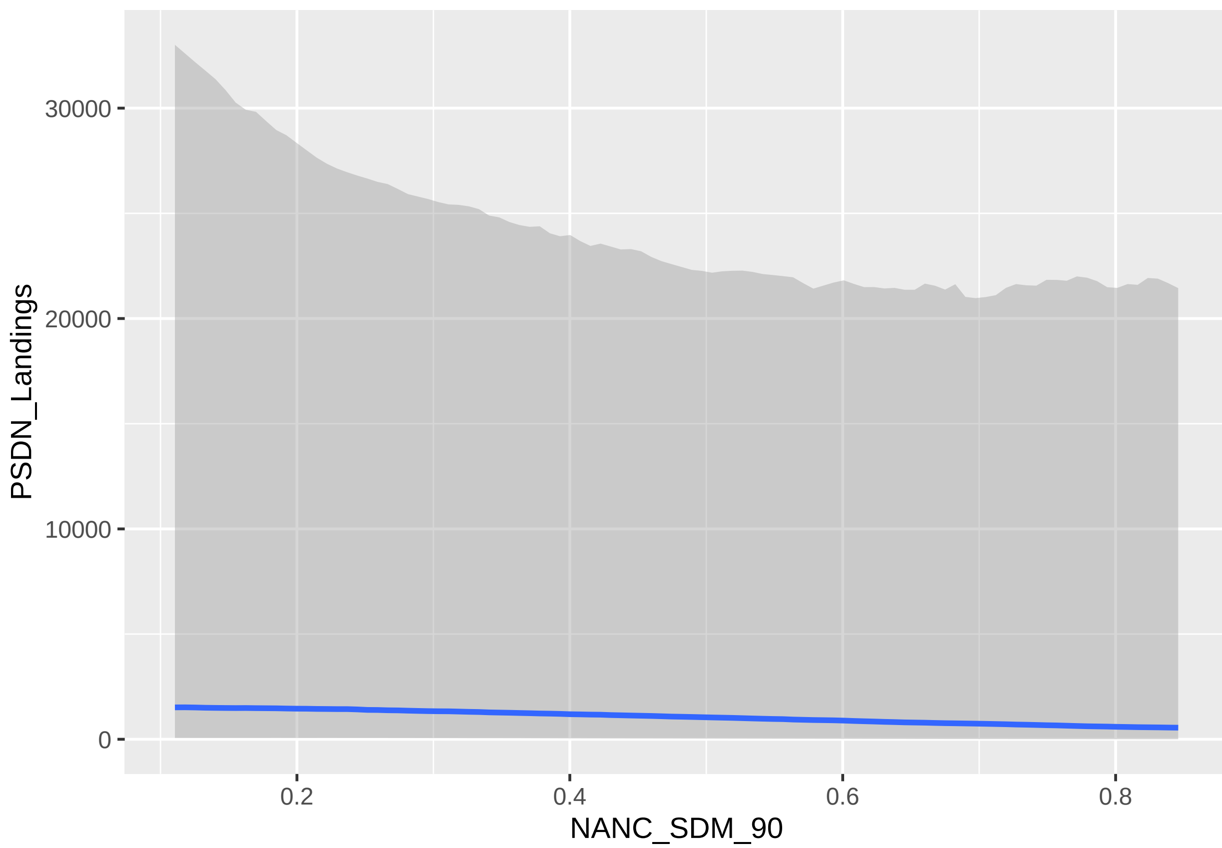
0.2
0.3
MSQD_SDM_90



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20000
10000
0
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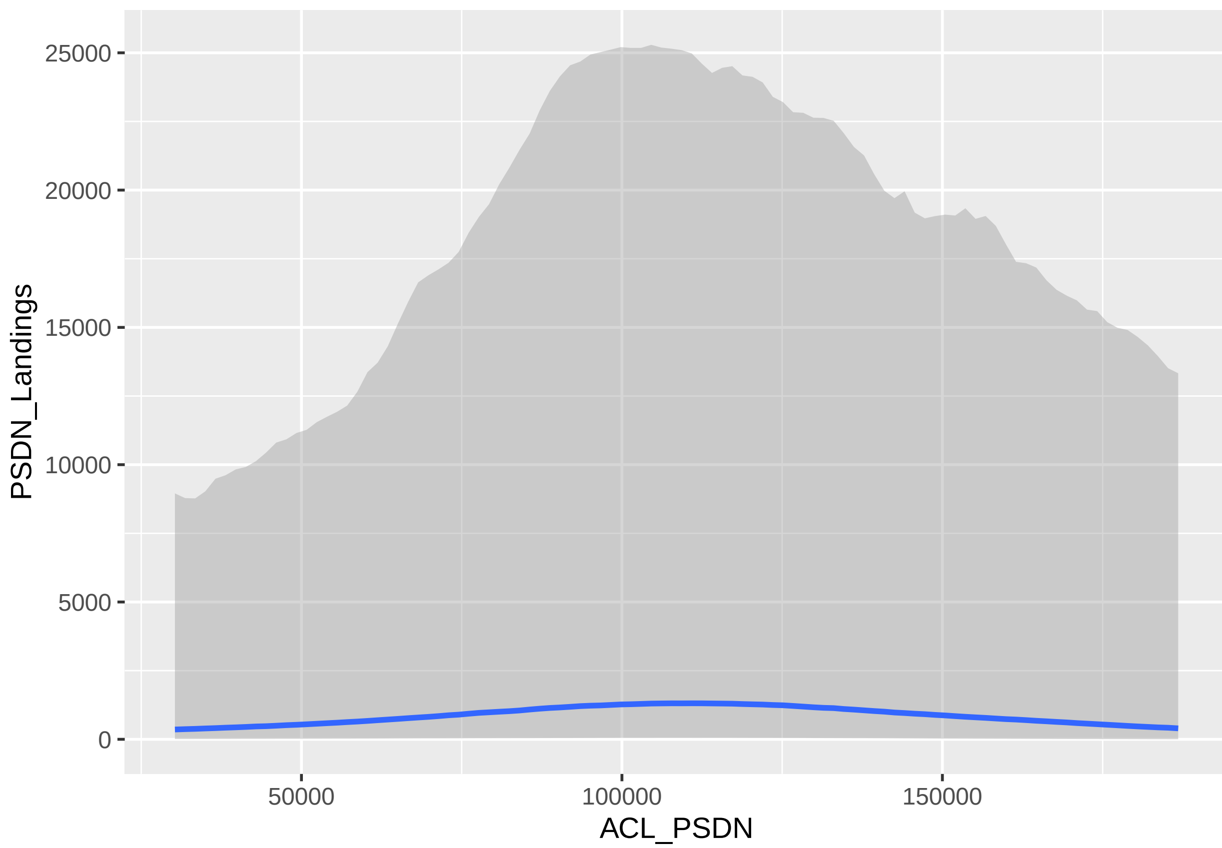
0.4
0.6
0.8
NANC_SDM_90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20000
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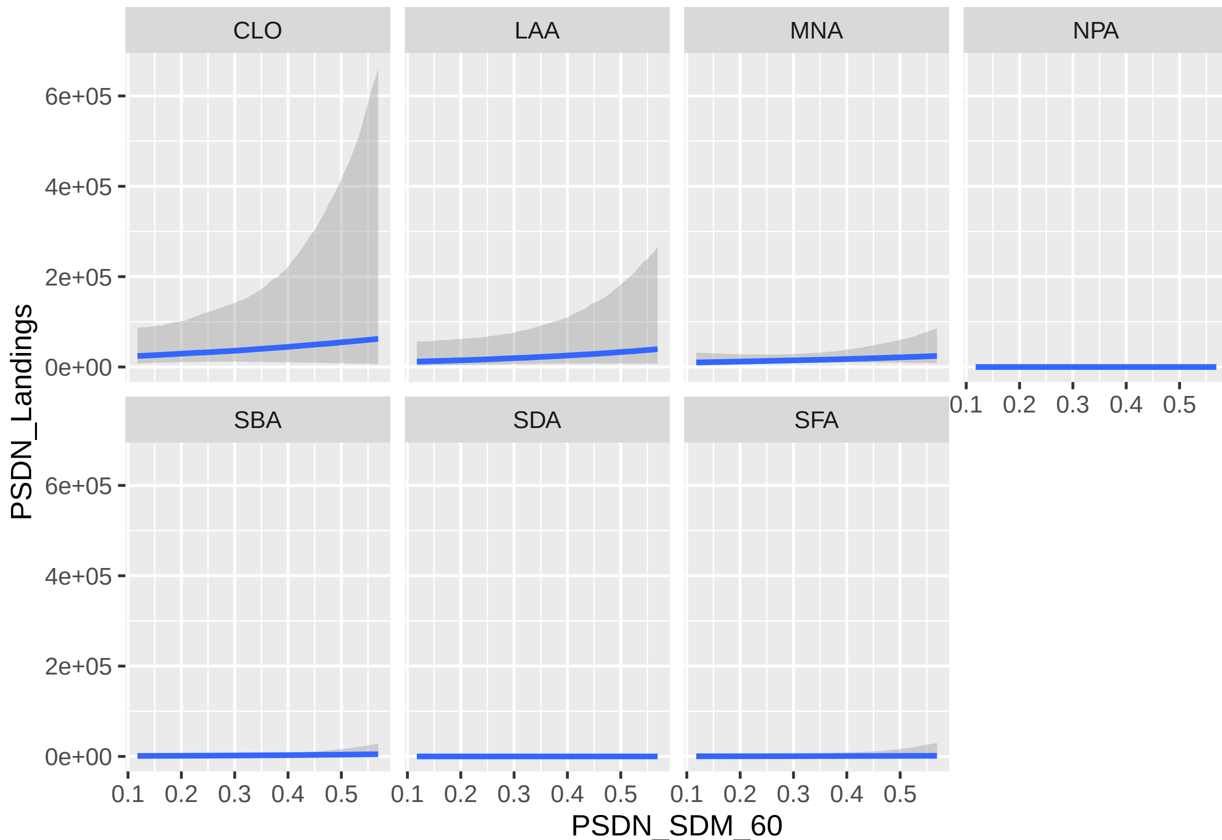
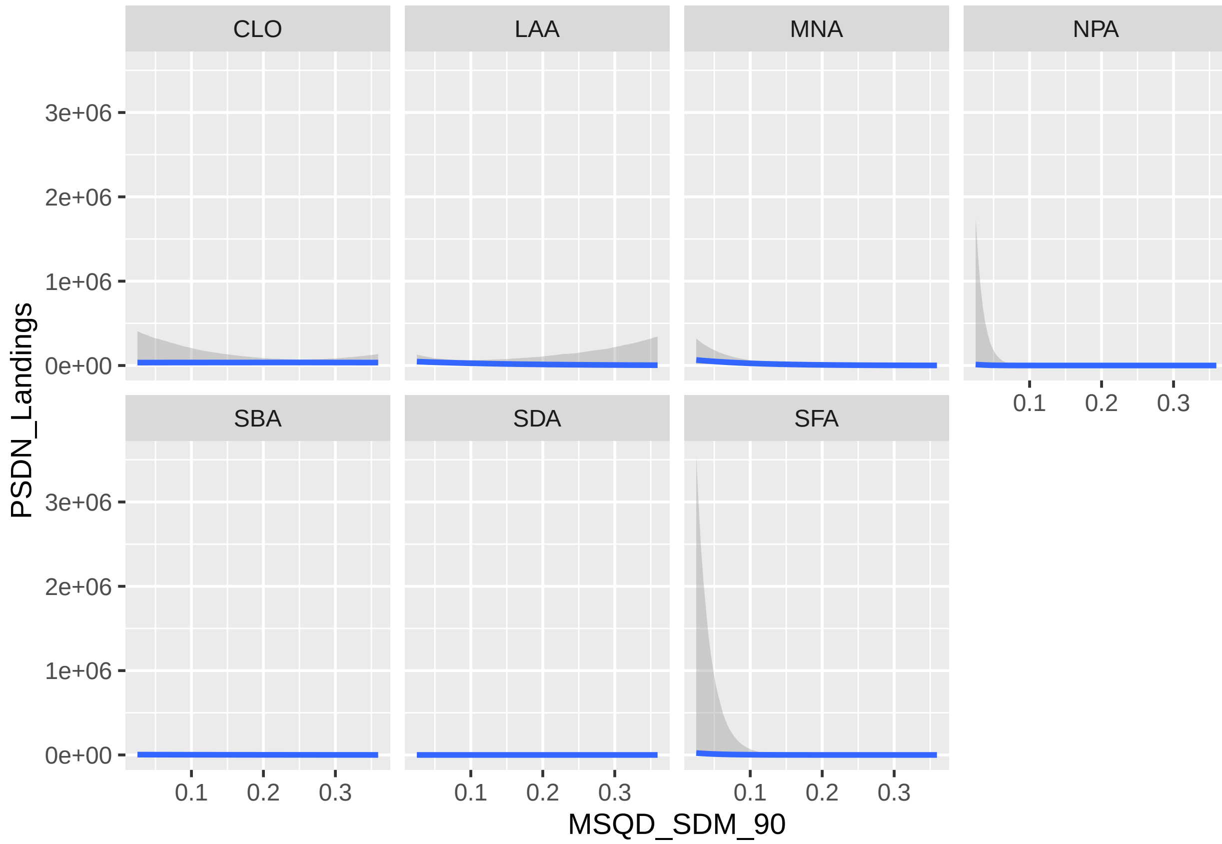
50000
100000
150000
ACL_PSDN

4.1.2 Results by port

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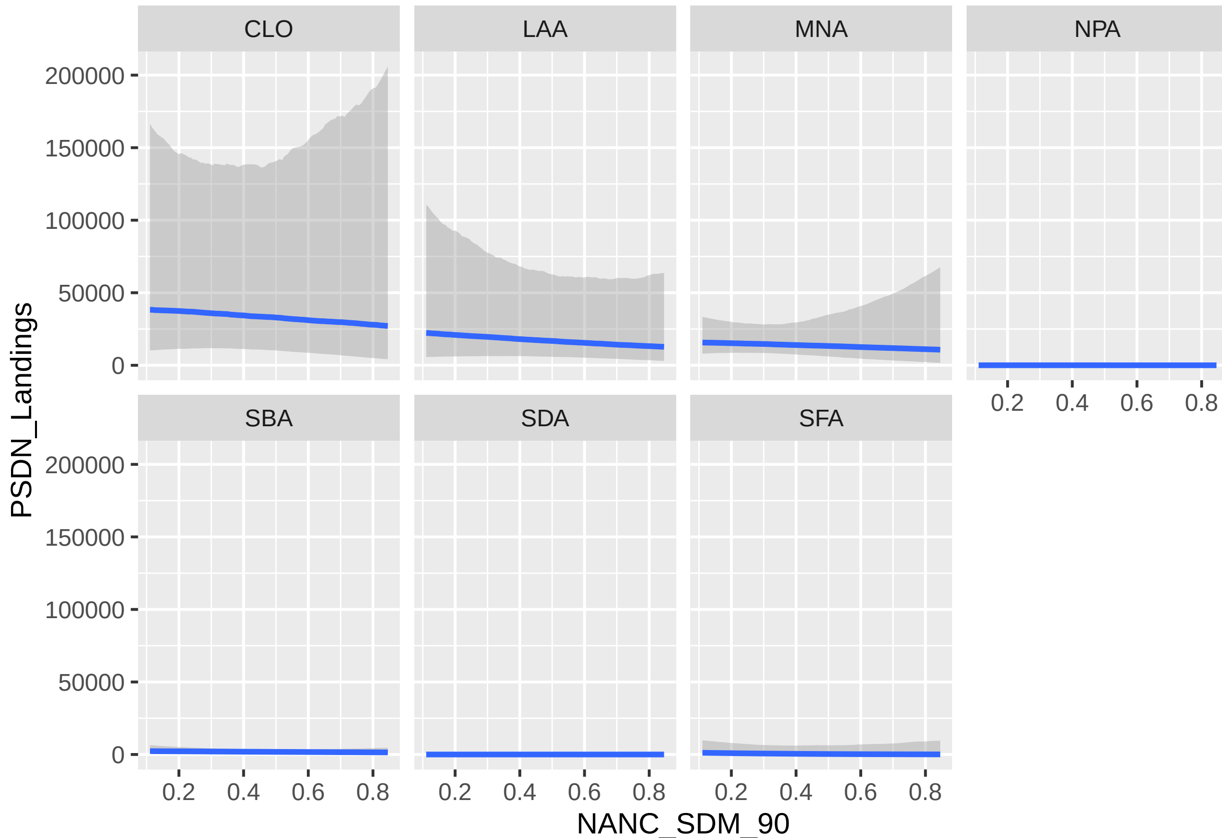
PSDN_Landings
MSQD_SDM_90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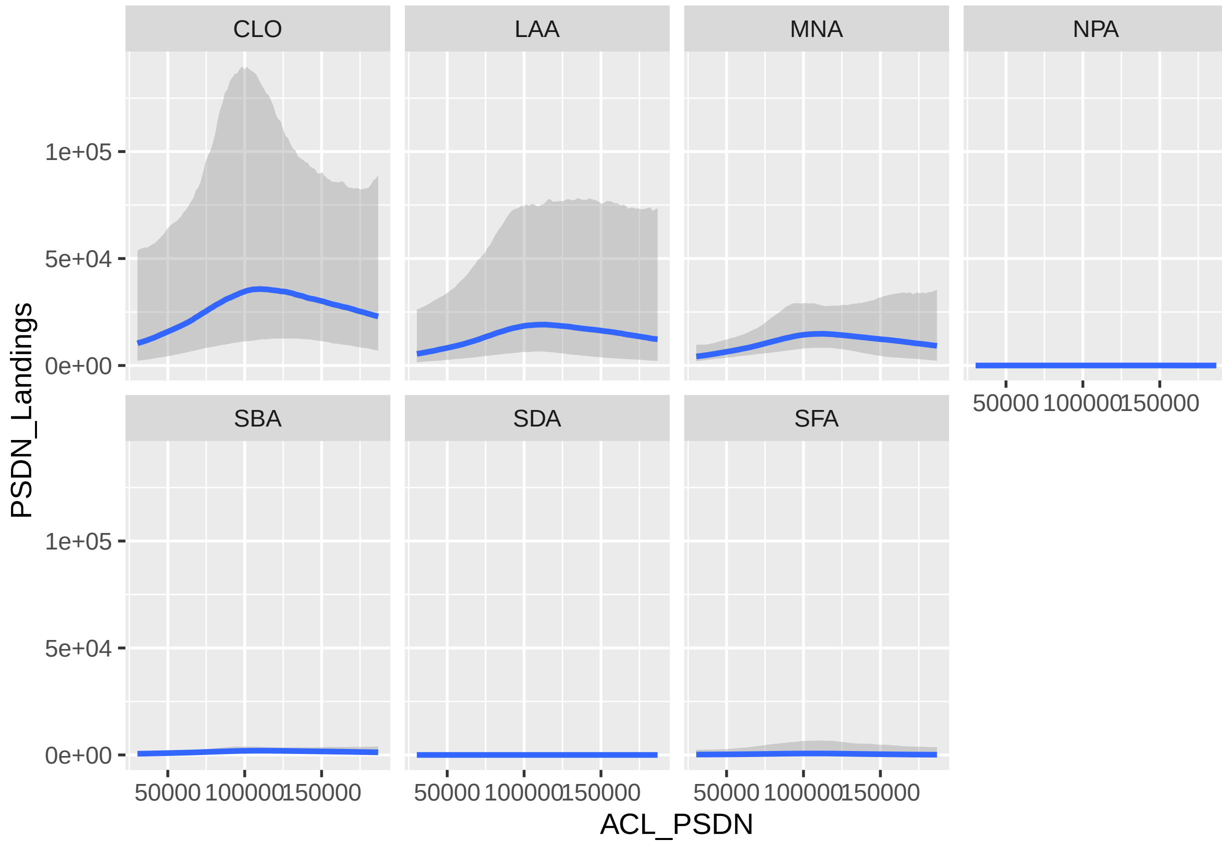
PSDN_Landings
NANC_SDM_90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SBA
SDA
SFA
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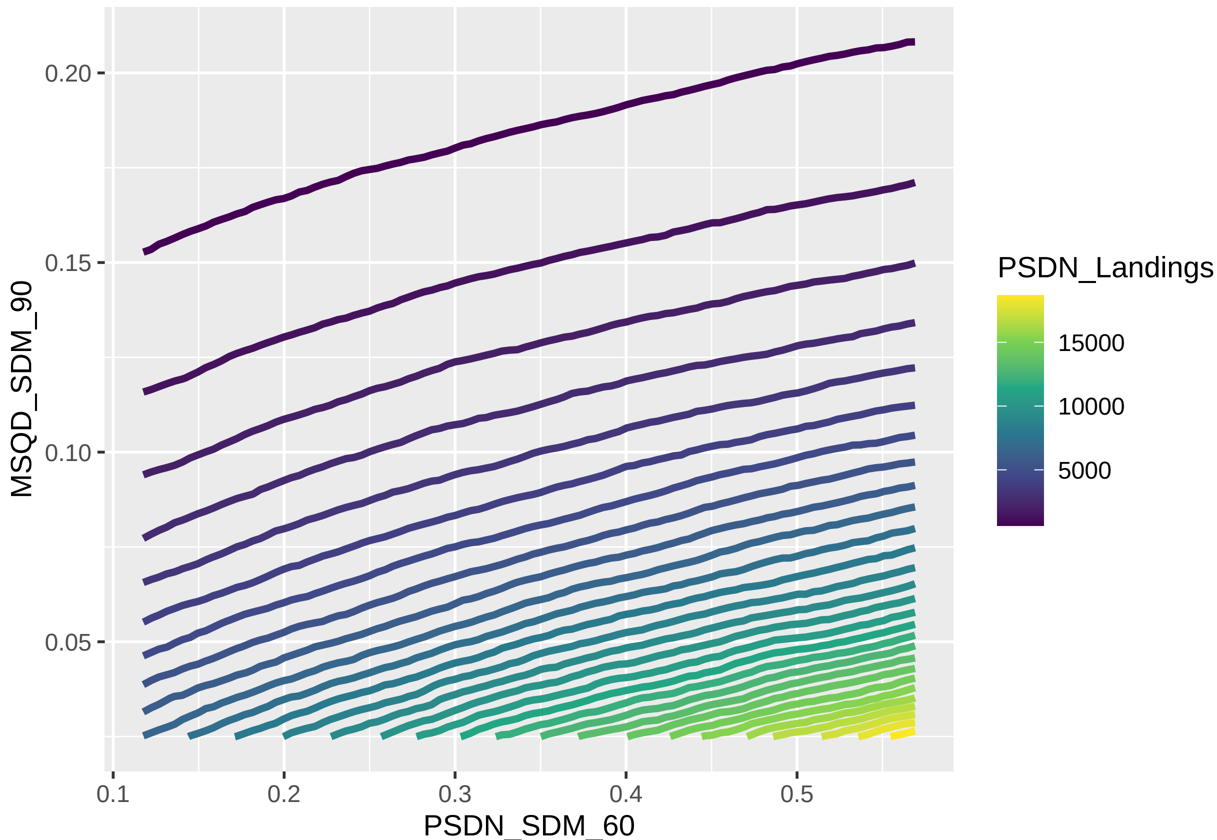
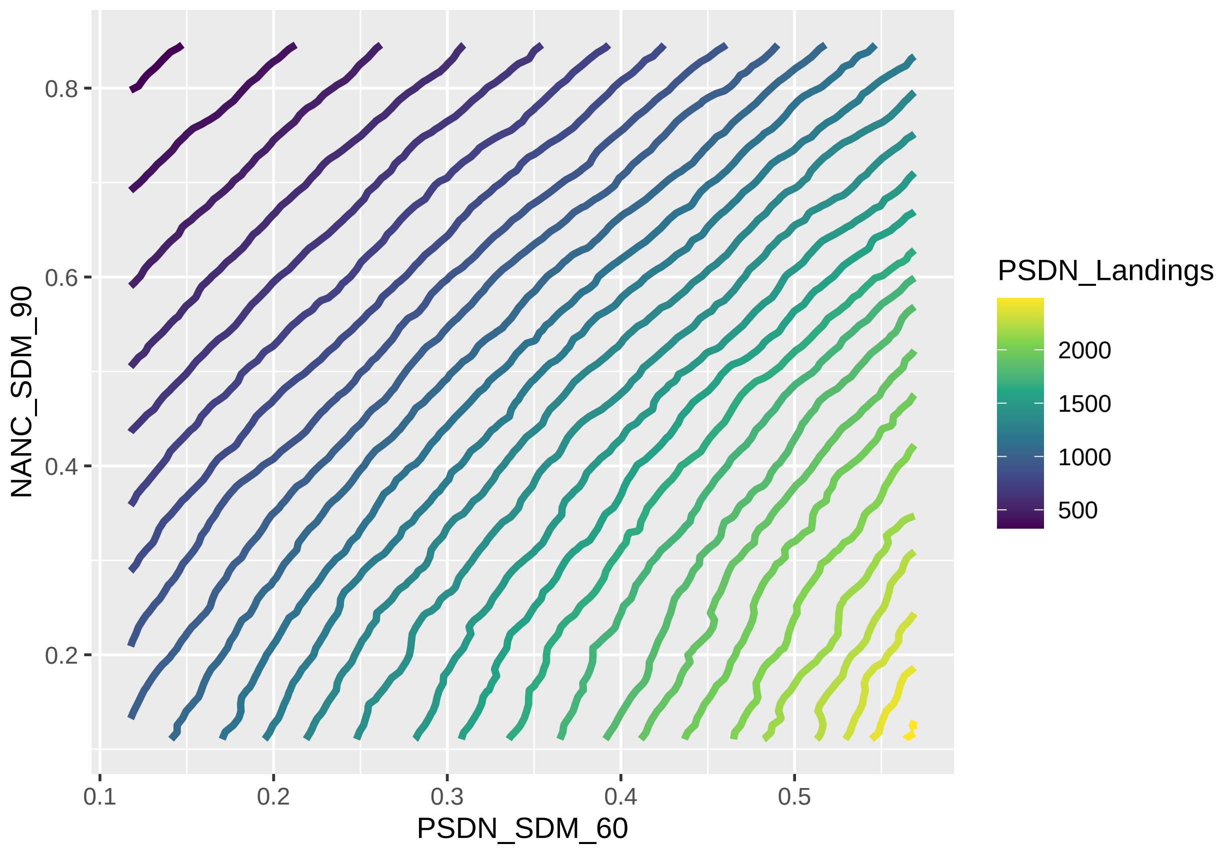
PSDN_Landings
ACL_PSDN

4.1.3 Interactive effects between Pacific Sardine and Market Squid SDMs




0.8
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0.2
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PSDN_Landings
2000
1500
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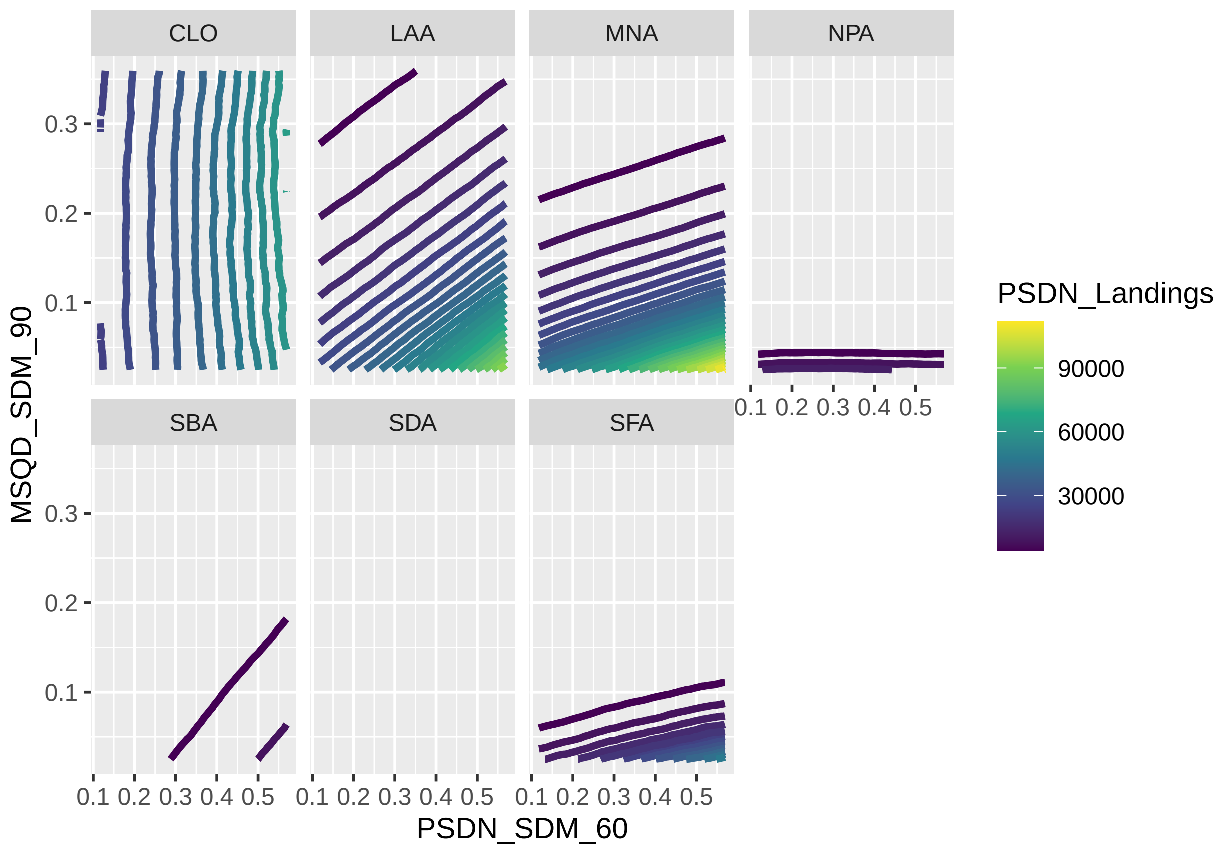
500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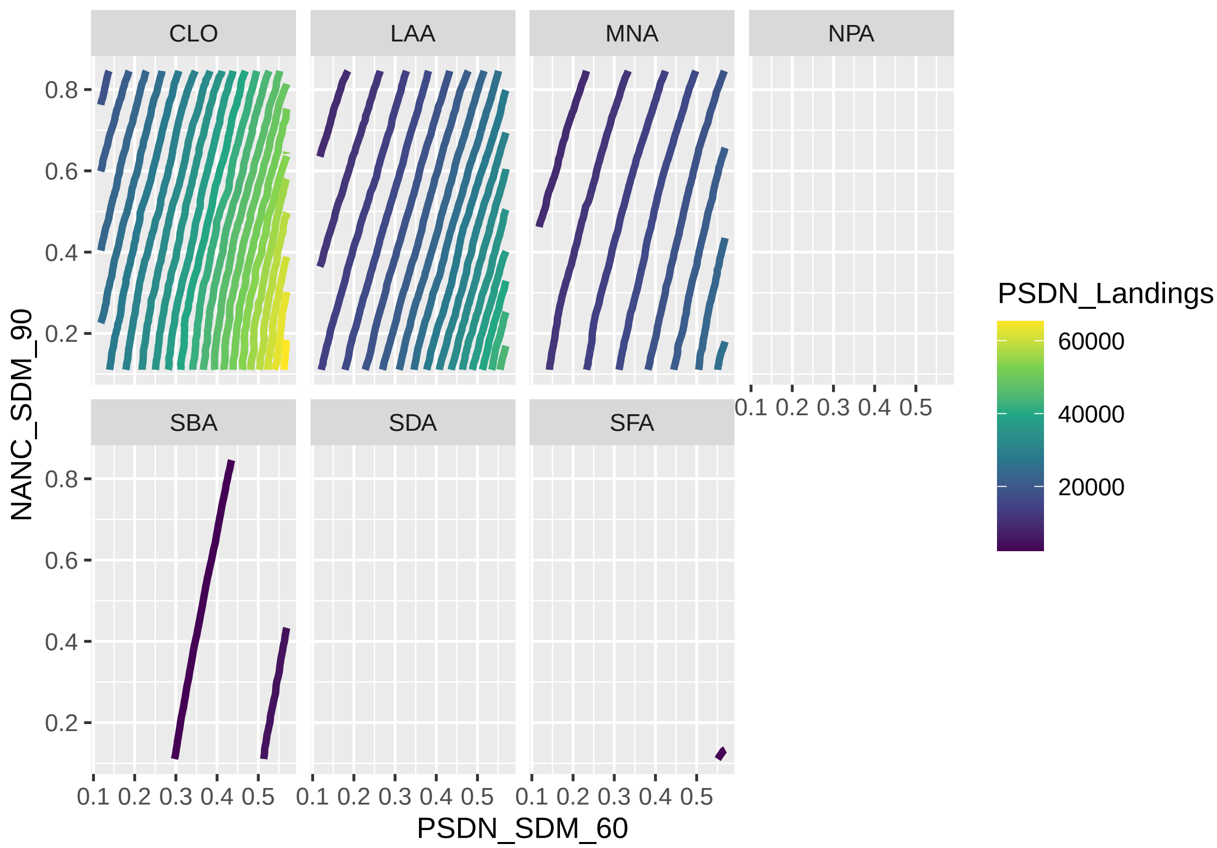
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PSDN_SDM_60
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0.4
0.6
0.8
0.1 0.2 0.3 0.4 0.5
PSDN_Landings
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40000
20000

4.2 Market Squid model

4.2.1 Compare models

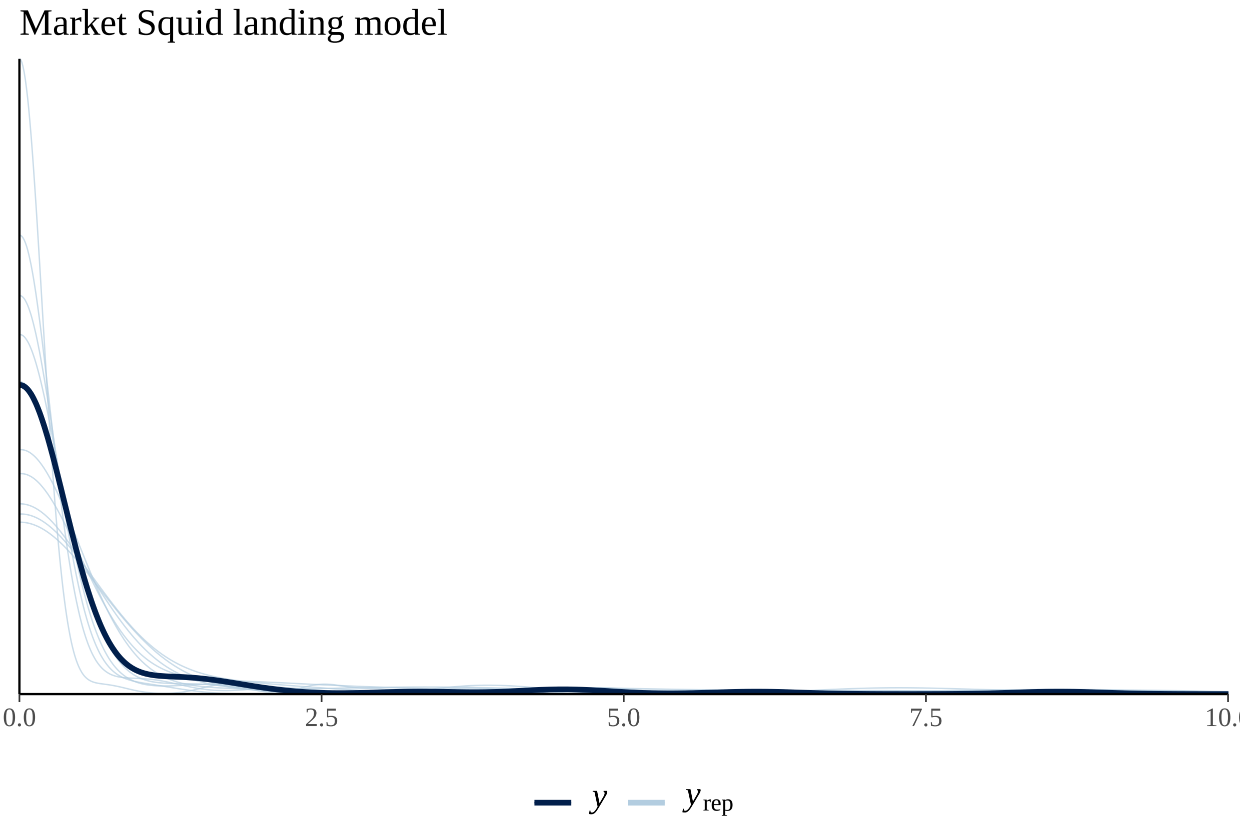


Figure 4: Graphical posterior predictive checks for Market Squid landings model.

4.2.2 Effect of SDM's on Market SquidSardine landings

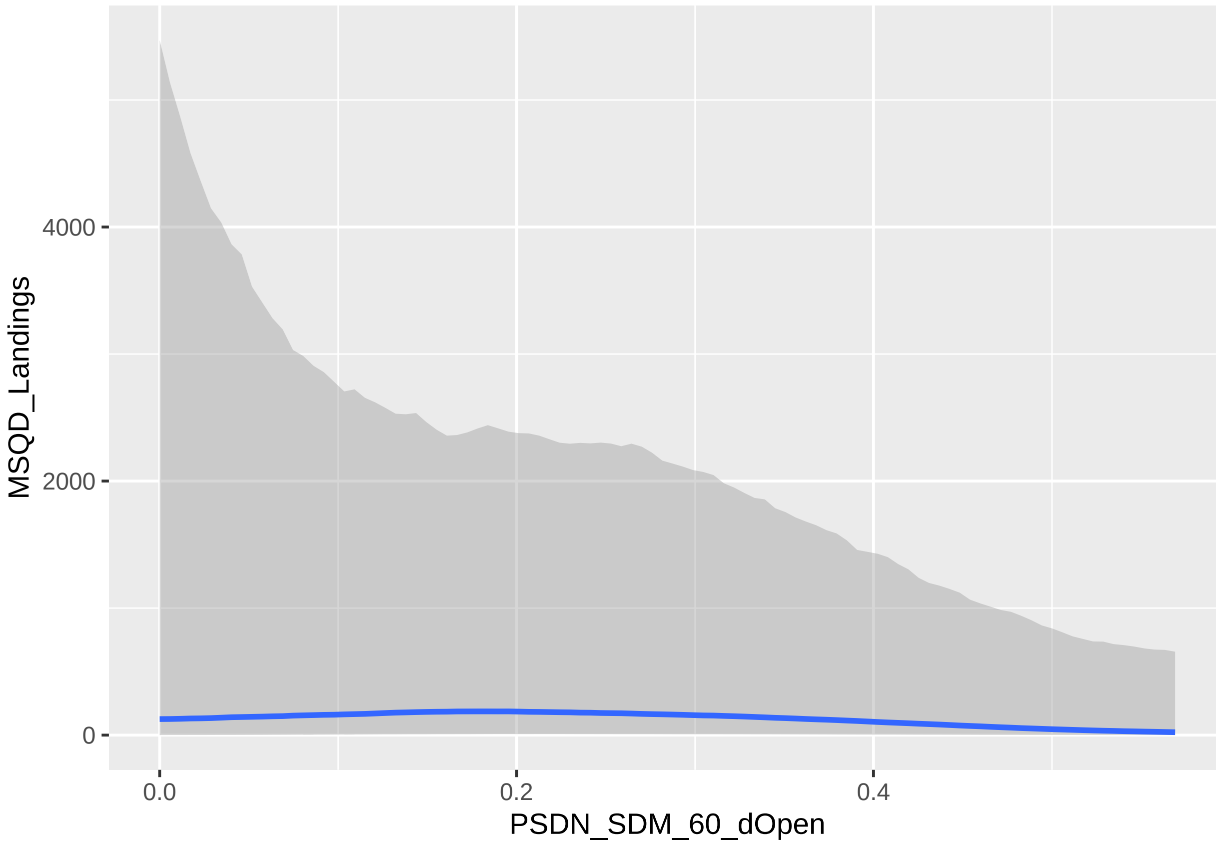


Figure 5: Conditional effect of probability of occurrence of Pacific Sardine on Squid landings.

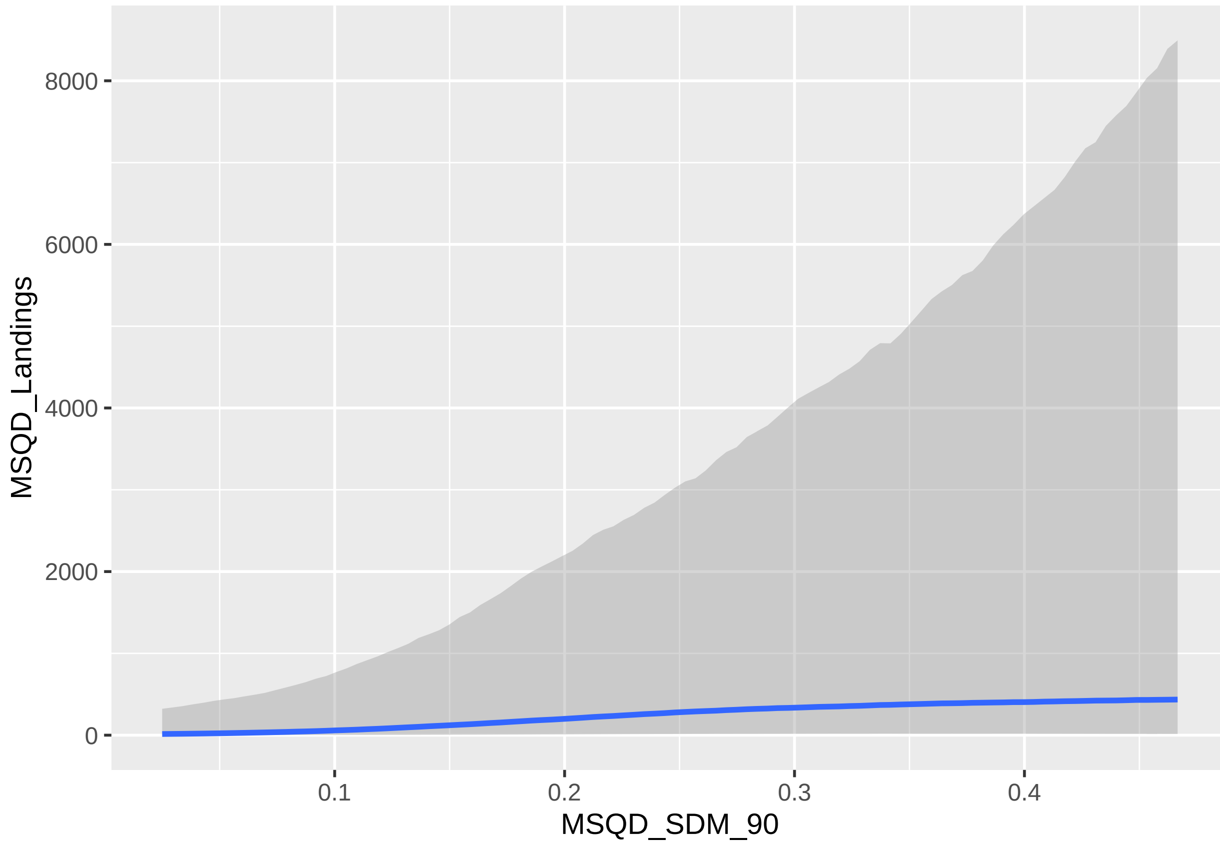


Figure 6: Conditional effect of probability of occurrence of Market Squid on Squid landings.

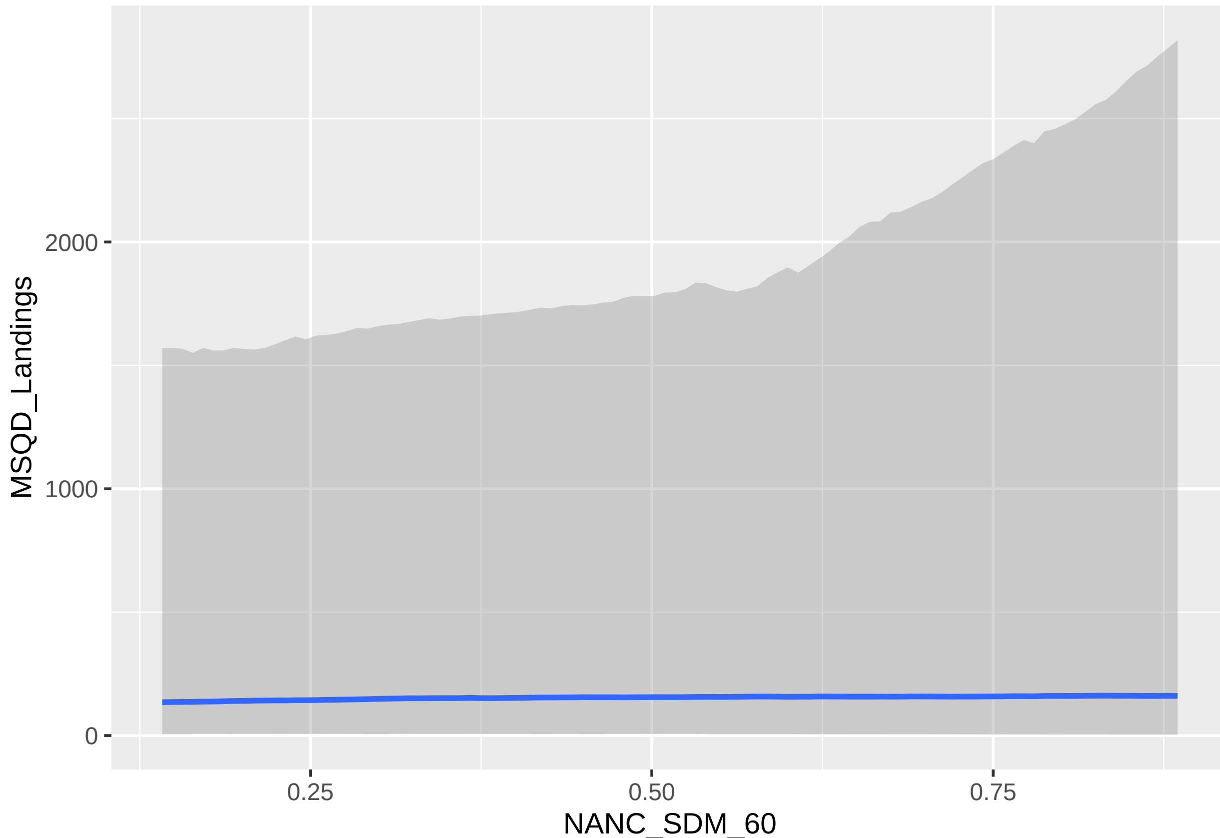


Figure 7: Conditional effect of probability of occurrence of Northern Anchovy on Squid landings.

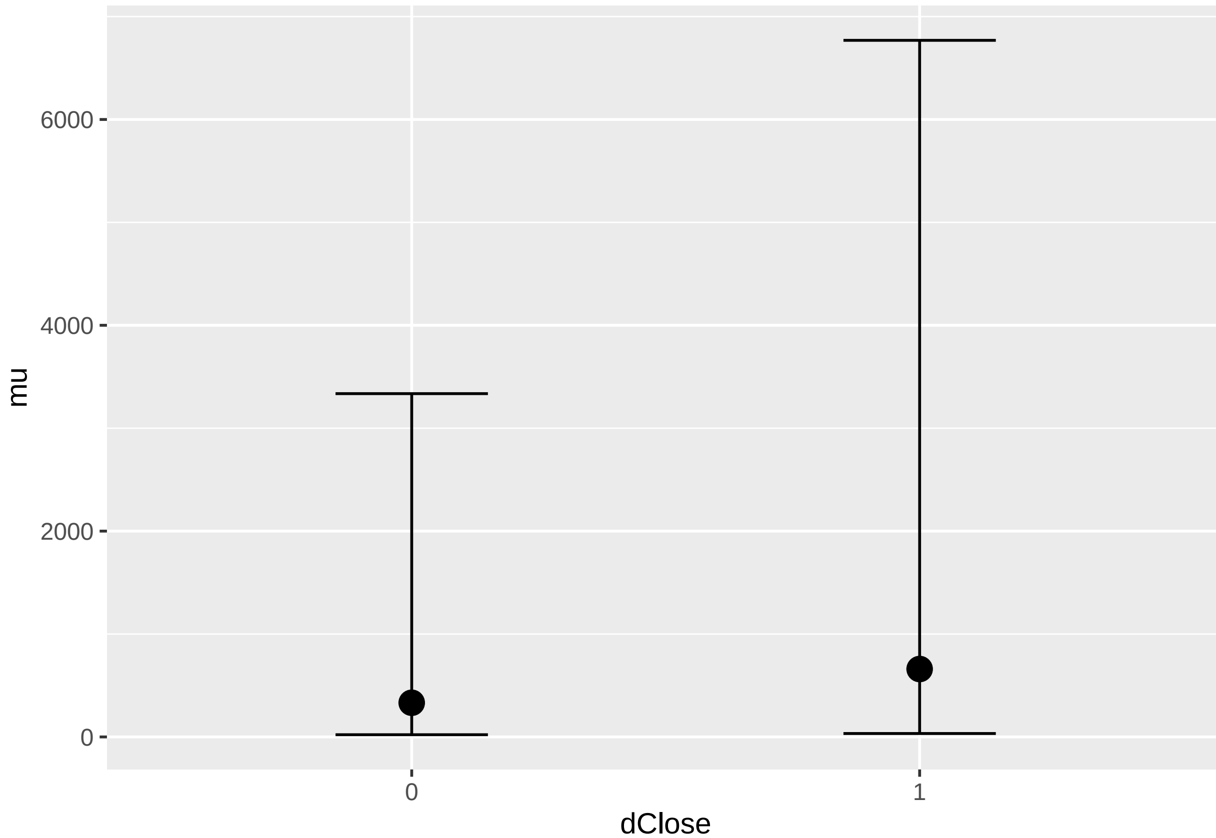
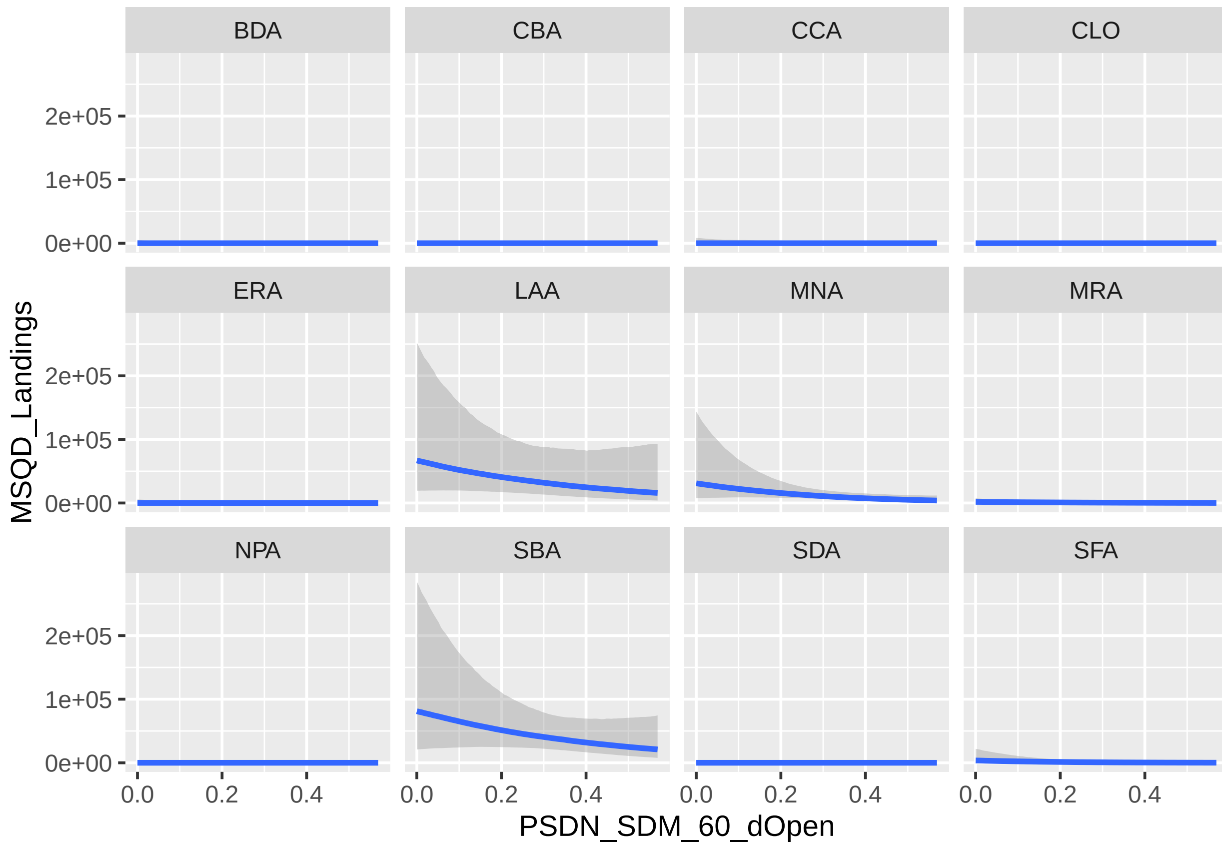
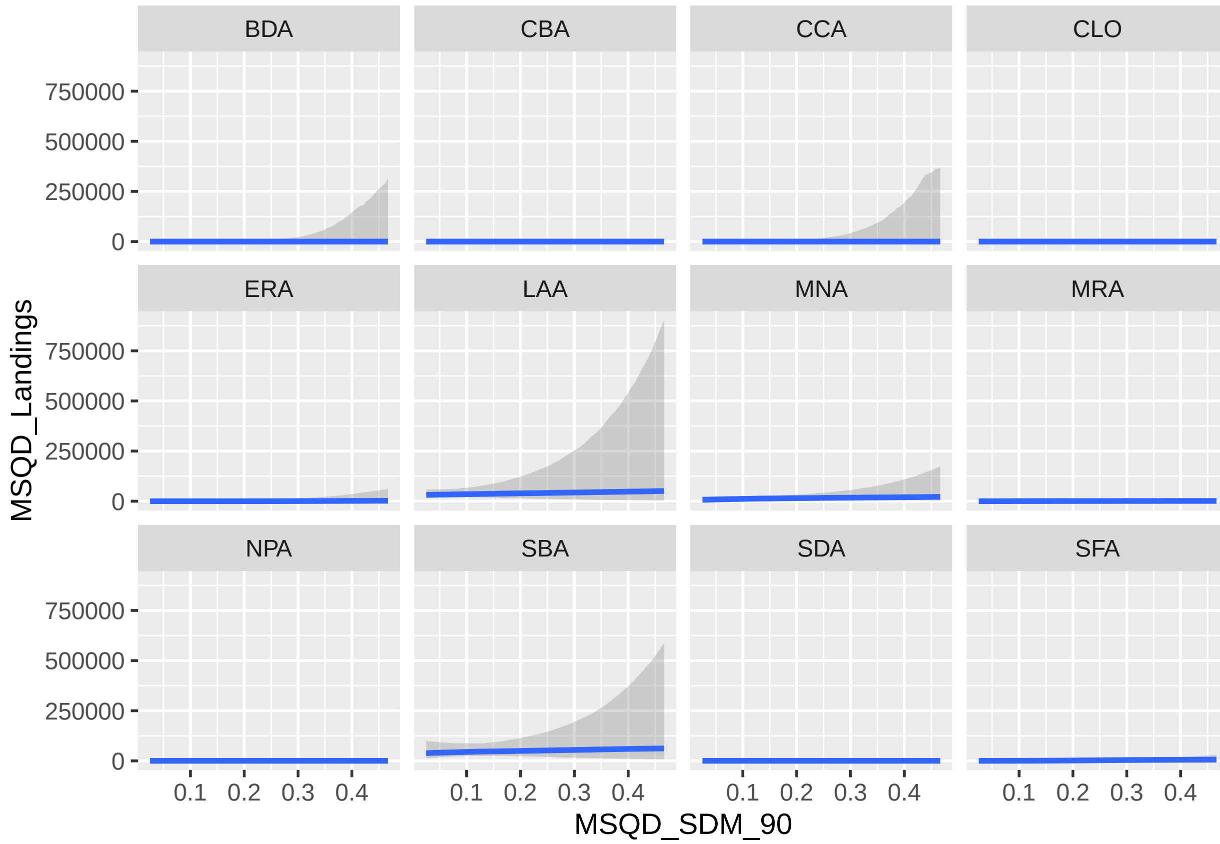


Figure 8: Conditional effect of Pacific Sardin Closure on Market Squid Landings

4.2.3 Results by port





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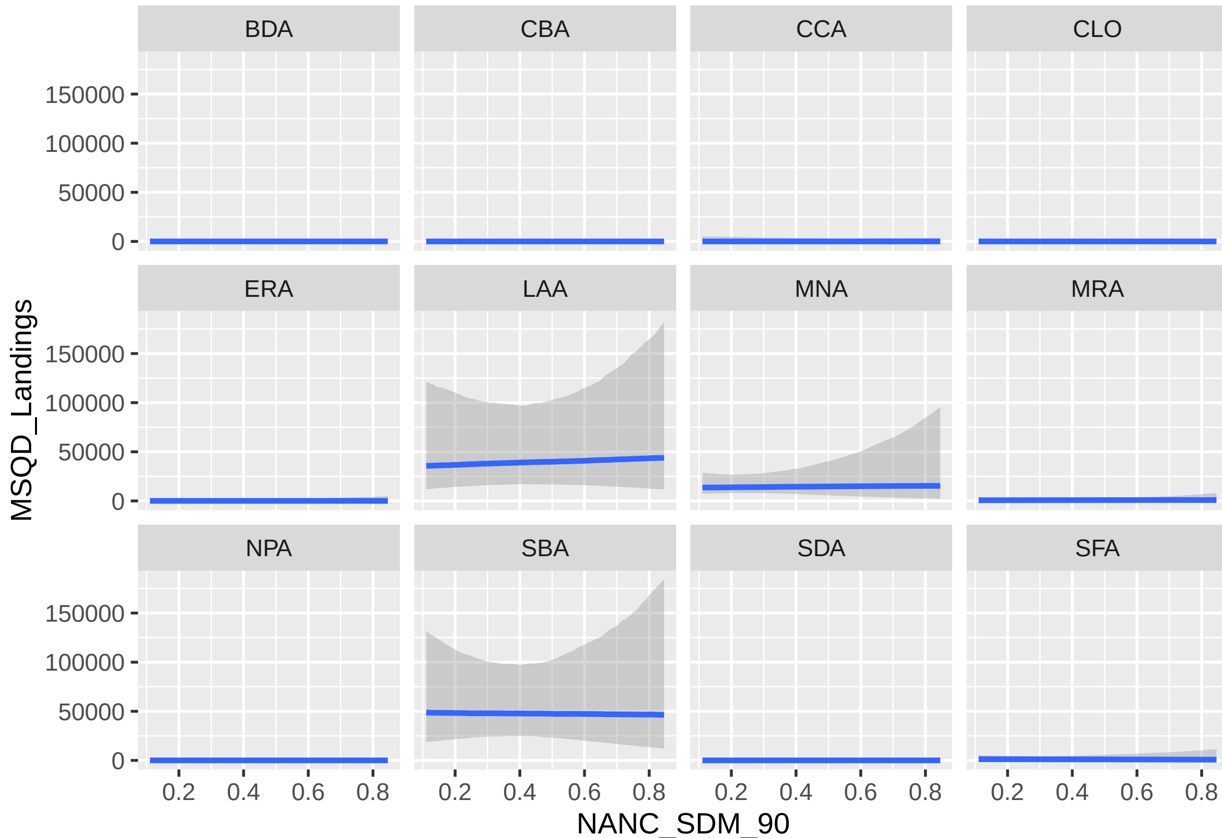
MSQD_SDM_90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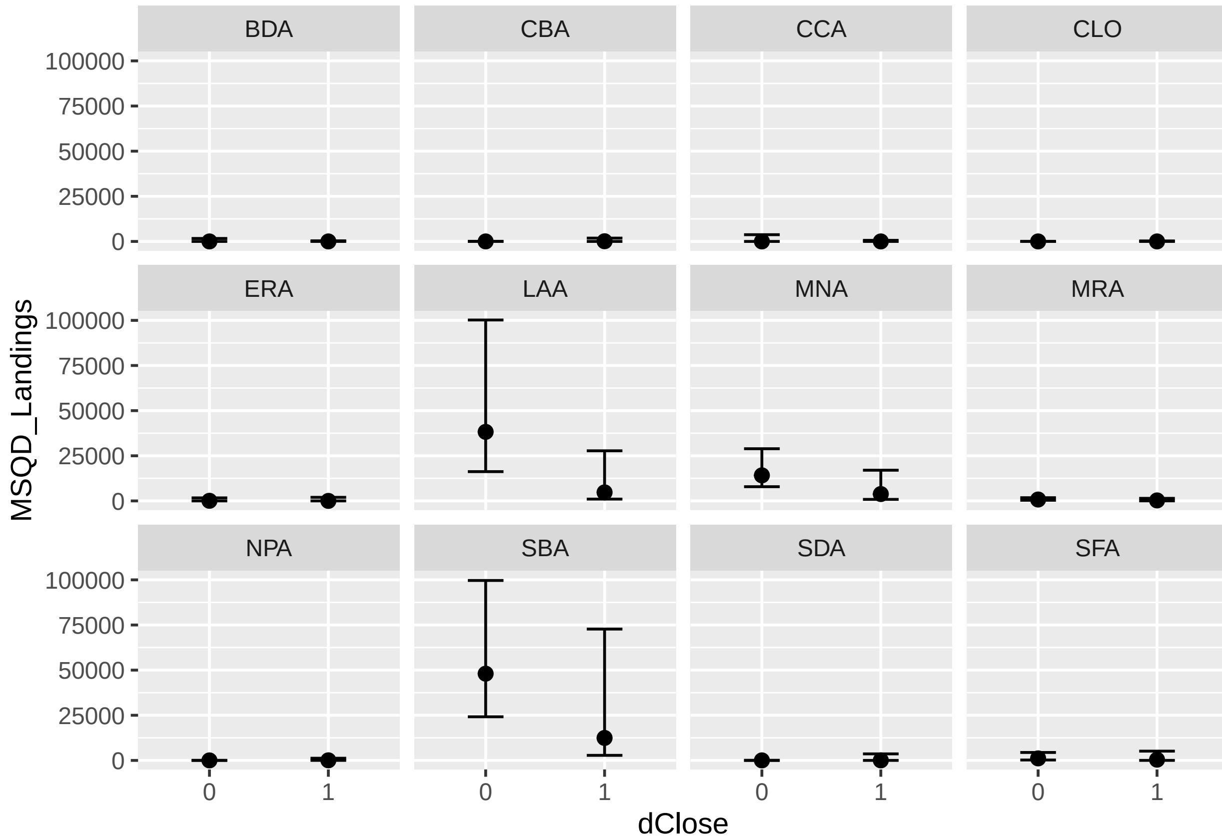
NANC_SDM_90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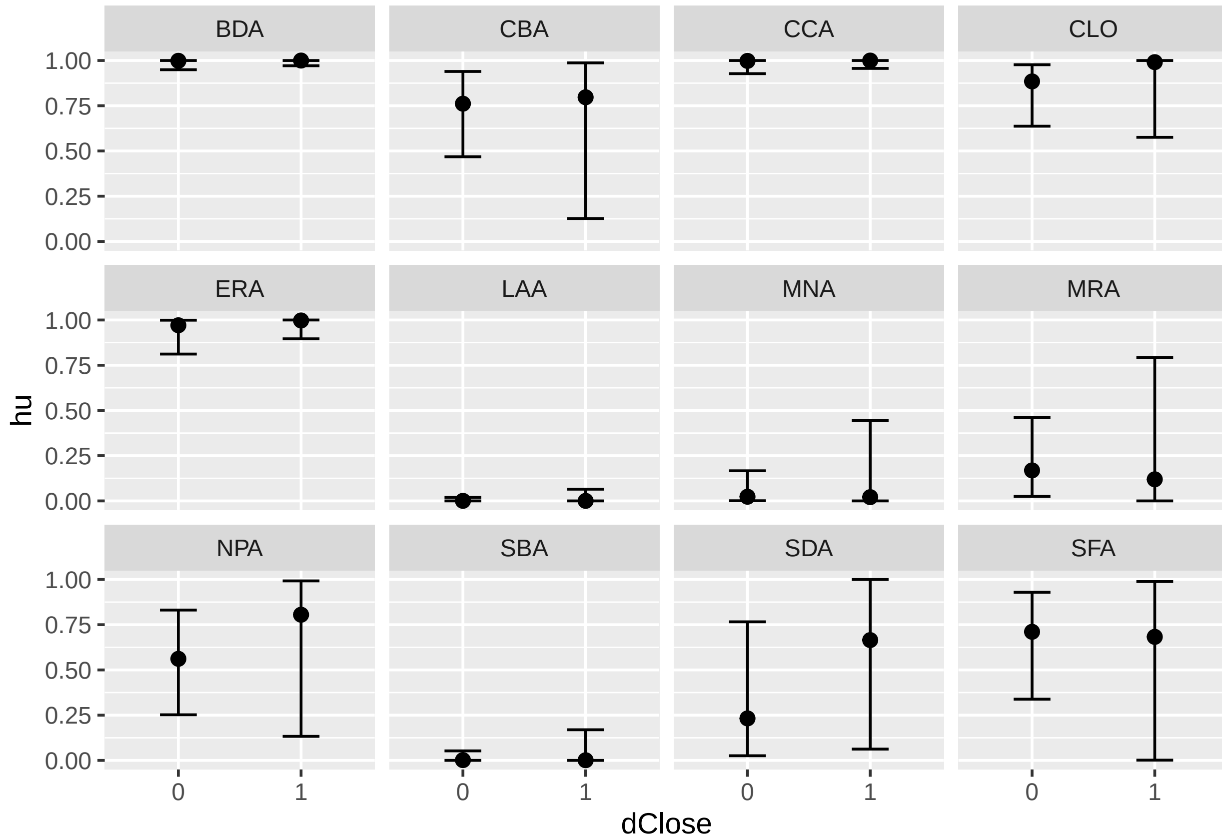
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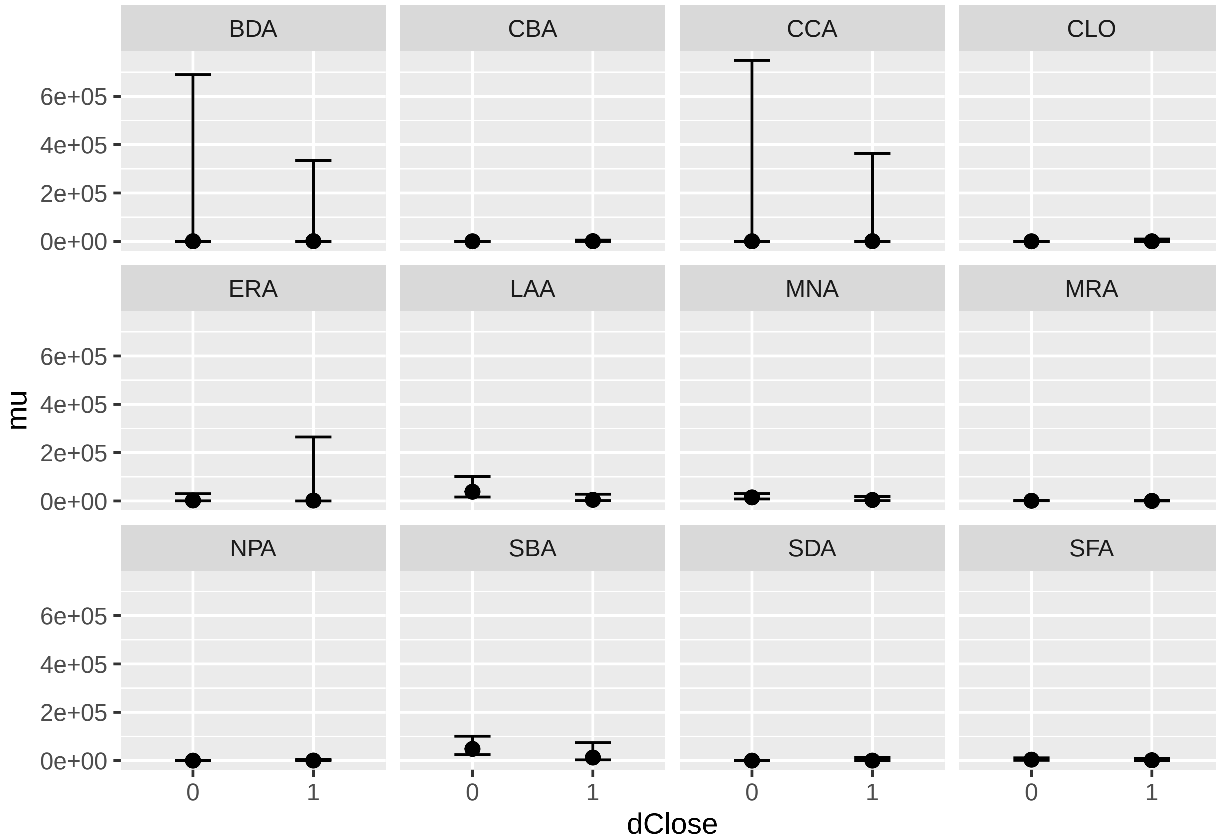

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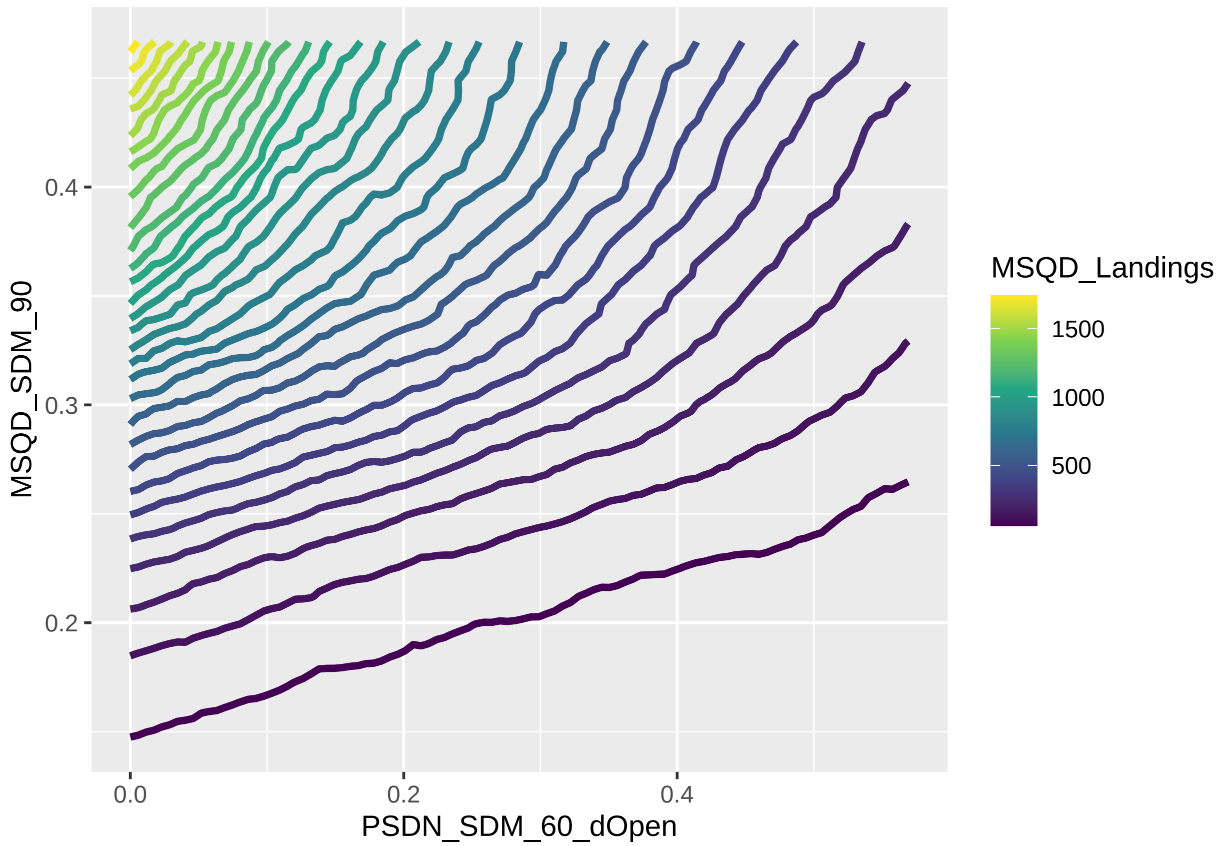
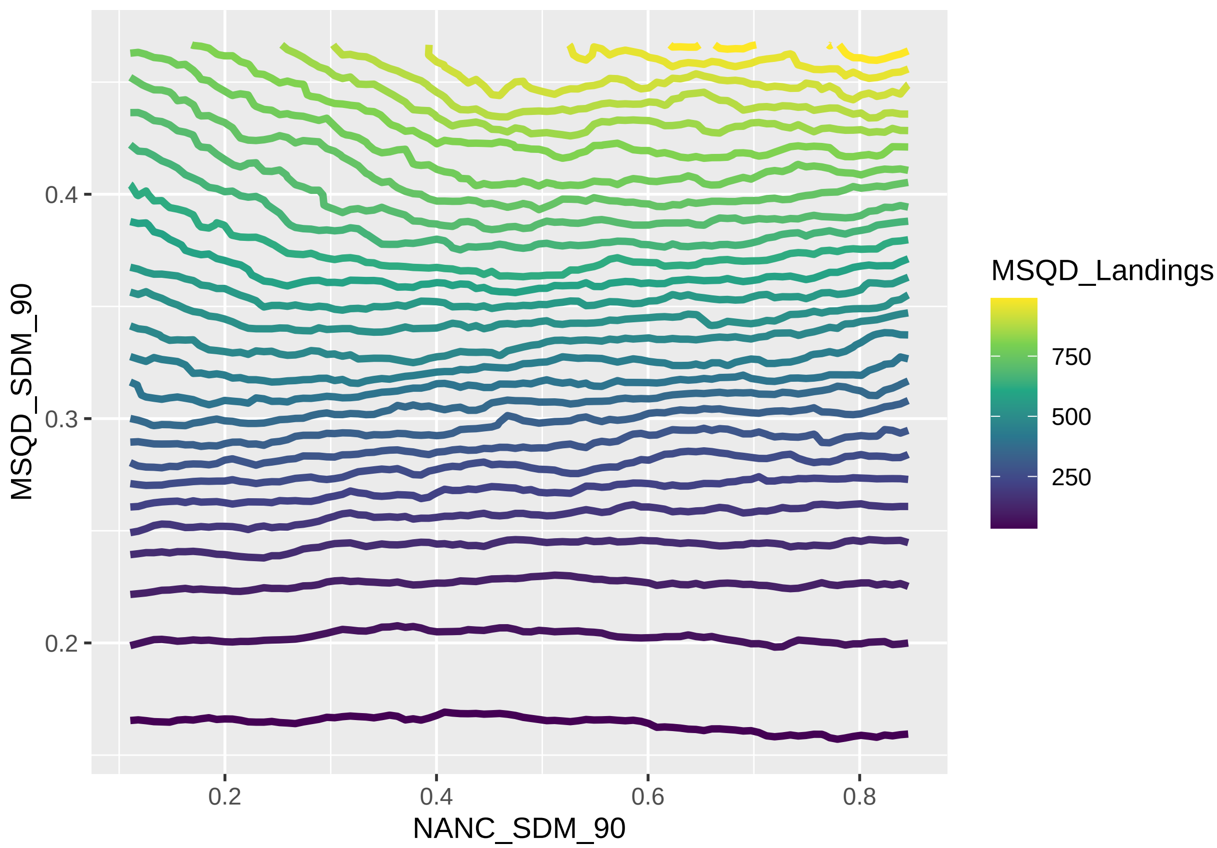
1
dClose

4.2.4 Interactive effects between Pacific Sardine and Market Squid SDMs

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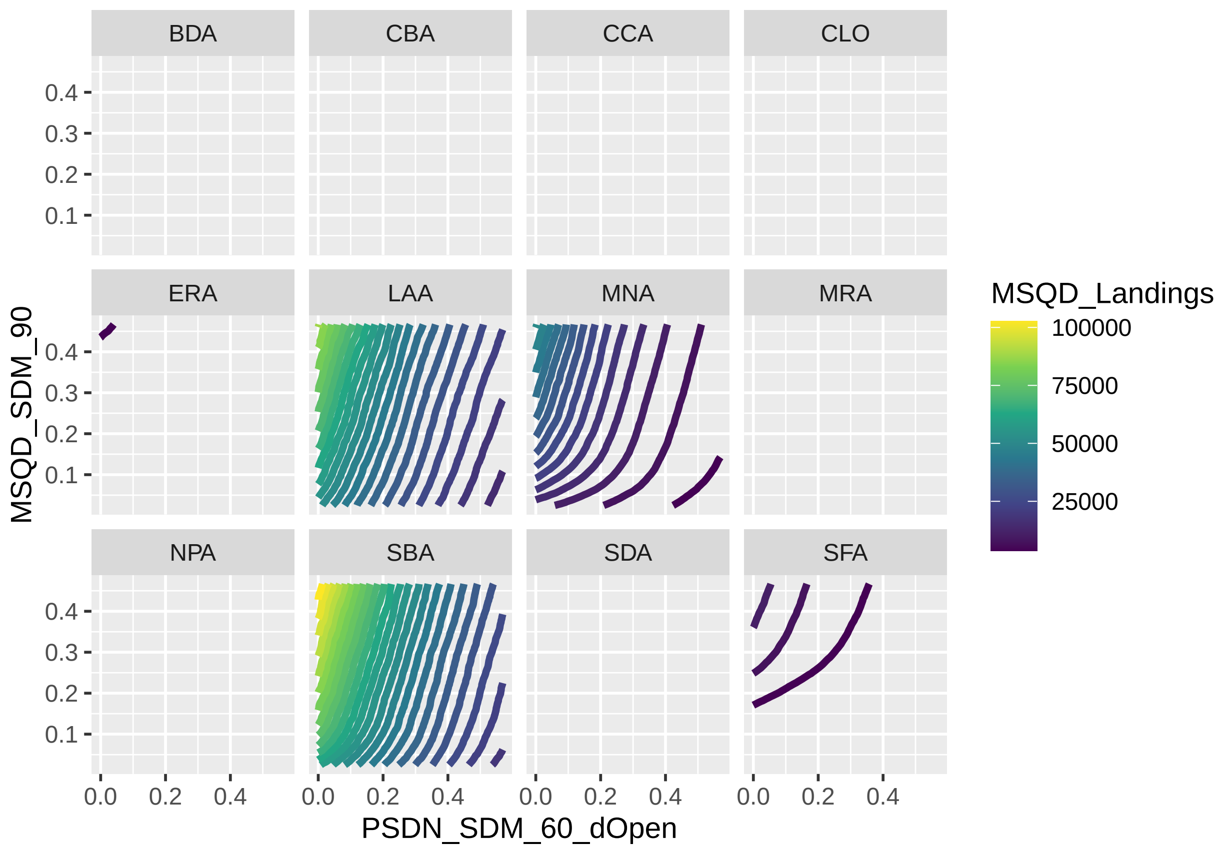
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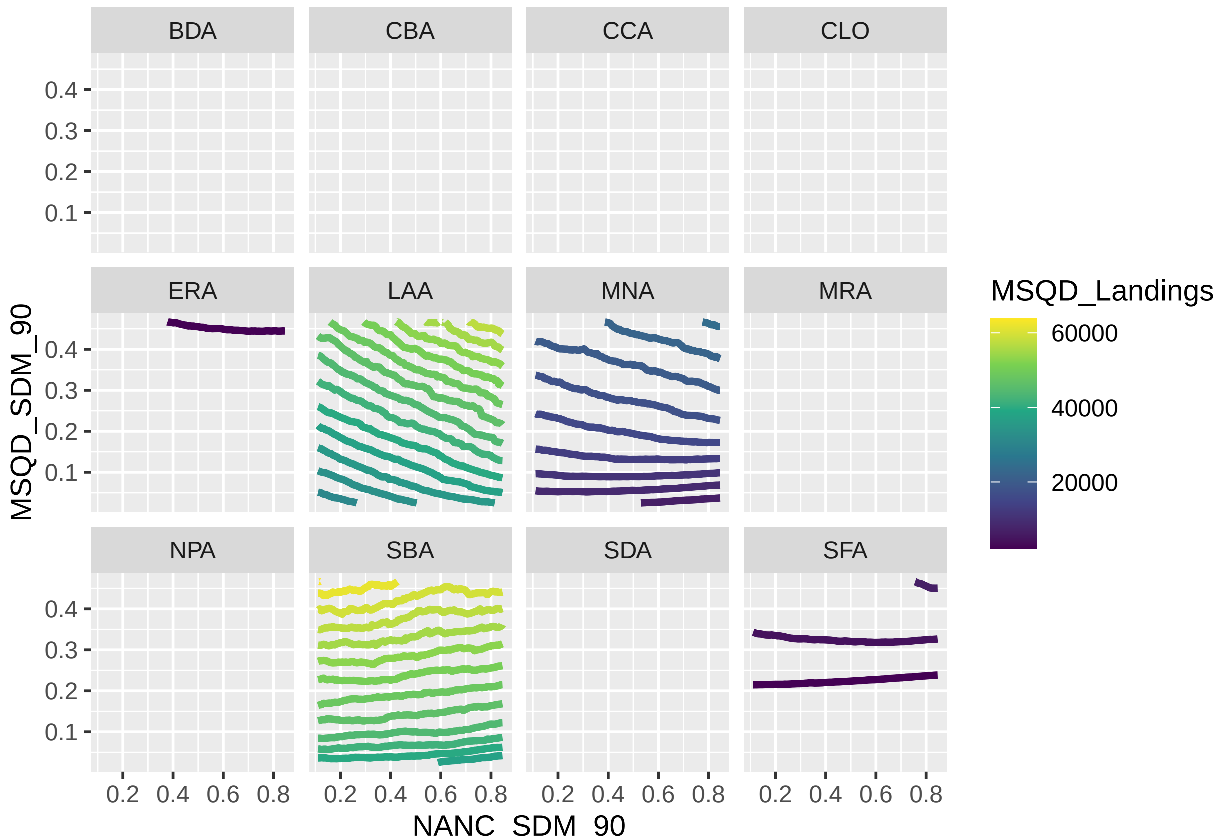

5 Conclusions

Appendix

Mitzi Morris, Katherine Wheeler-Martin, Dan Simpson, Stephen J Mooney, Andrew Gelman, and Charles DiMaggio. Bayesian hierarchical spatial models: Implementing the besag york mollié model in stan. *Spatial and spatio-temporal epidemiology*, 31:100301, 2019.

James A Smith, Barbara Muhling, Jonathan Sweeney, Desiree Tommasi, Mercedes Pozo Buil, Jerome Fiechter, and Michael G Jacox. The potential impact of a shifting pacific sardine distribution on us west coast landings. *Fisheries Oceanography*, 2021.