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' and allow them to diversify as a way to reduce income risk. 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 and regulation could reduce substitution between species. In this study we analyze how changing in spatial distribution and the closure of Pacific sardine fishery affects landing subtitution between three coastal pelagic species: Pacific sardine, market squid and Northern anchovy. Moreover, we study how spatial distribution and closure affects vessels participation decisions in the CPS fishery using a discrete choice modelling approach. We use species distribution projection to see how landings and participations change under different future climate change scenarios.

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1 Introduction

Fishing portfolios are an important mechanism to safeguard fishers livelihood. Diversification strategy have been principally associated to reducing income variability [Kasperski and Holland, 2013]. For instance, when a species abundance is reduced due to environmental conditions, fisher can change the targeted species to one that requires similar gears. 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, as well as regulations that limits access to fisheries to avoid collapse of fish stocks from overfishing [Kasperski and

Holland, 2013]. Therefore, it is not clear how change in species distribution and regulation would be reflected in landings compositions and participation.

In this study we analyze how changing in spatial distribution as well as the implementation of a fishery's closure affects landing and fisher participation of three coastal pelagic species (CPS) harvested in U.S. West Coast: Pacific sardine (PSDN), market squid (MSQD) and Northern anchovy (NANC). Fisheries closures are a interesting policy instrument in a multispecies framework as give us the opportunity to study a quasi-experiment. For instance, Vermard et al. [2008] study the effect of an anchovy closure in trip choices conducted by the Bay of Biscai pelagic fleet. Richerson and Holland [2017] study the effect of salmon closures in vessel participation on salmon fishery, but also in other fisheries. In this paper, we study the effect of the 2015 Pacific sardine closure implemented after the overxplotation of the fishery. The answer to this questions is not straightforward as different response can be observed to the same conditions as fishers and vessel are heterogeneous [Zhang and Smith, 2011]. Moreover, we have to consider that species are interconnected, at least economically if not ecologically, so a multispecies framework that considering interrelation between them is necessary. Our research give a step further and analyze the CPS as a multispecies fishery. This is in line with recent literature that start to consider multiple species in their analysis [Richerson and Holland, 2017]. Our goal is to understand how changing in species distribution and closure of Pacific sardine affect vessel responses in landing amount and participation, the substitution between species, and to what extent future projected climate will affect landings, catch composition and participation of fishers.

Our papers builds on the model developed by Smith et al. [2021] for sardine landings. We expand their model including a landing equation for all of the three species analyzed and estimating a multilevel Bayesian model in order to incorporate heterogeneity between fleets and ports. 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. 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. Additionally, we also estimate a multiple species participation model based on Richerson and Holland [2017] who study the effect of salmon closure on annual fishers participation, expanding their analysis to the CPS fishery in monthly basis, allowing to understand seasonality within fishing season. For this, we develop a Random Utility Model (RUM) to model monthly vessel participation in targeting a specific species in the CPS fishery as a function of… **fisher characteristics including revenue level, diversification, dependence on the species and spatial variables of area and range..**

The remainder of the paper is organized as follows: Section 2 provides background on the CPS fishery in the US west coast. In Section 3 we discusses our data set and empirical strategy. Section 4 presents the results of the estimations, and we conclude in Section 6.

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.

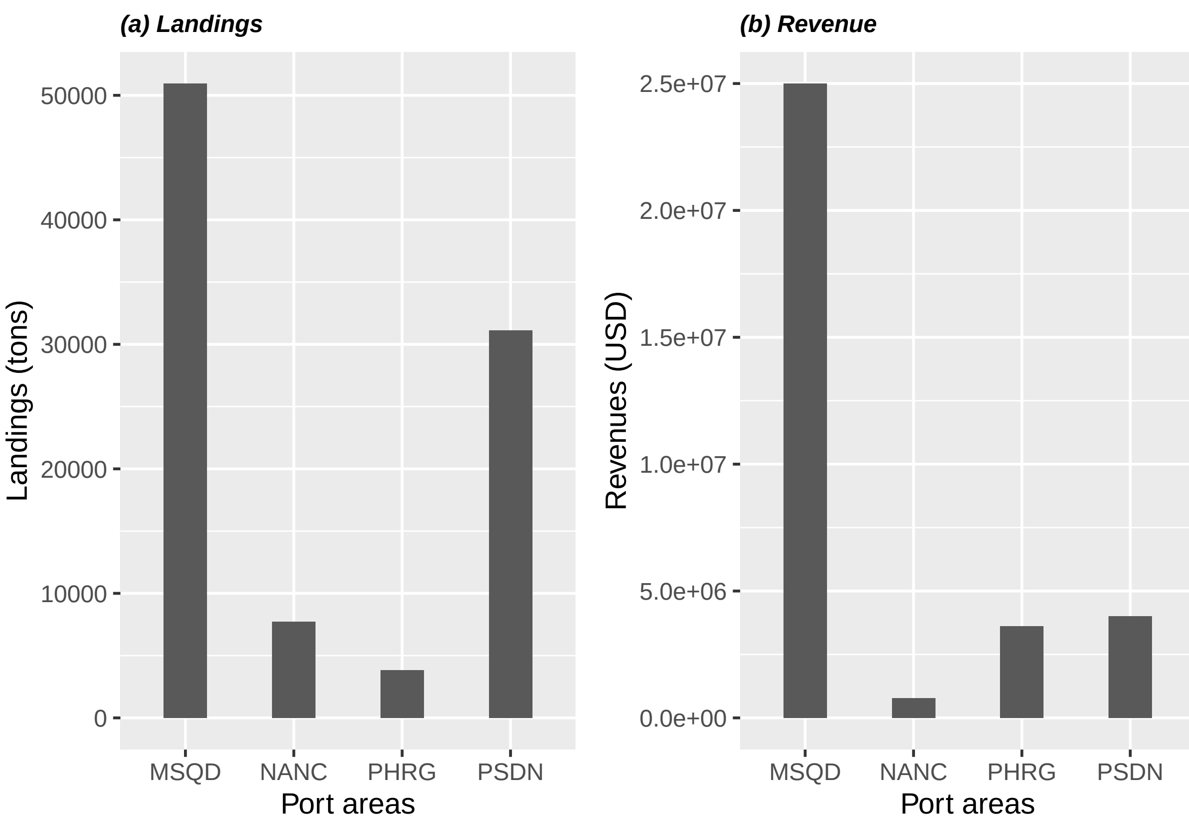

Figure 1: Average annual landing and revenues for the CPS fishery by species.

Landings composition varies geographically. We show in Figure 2 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.

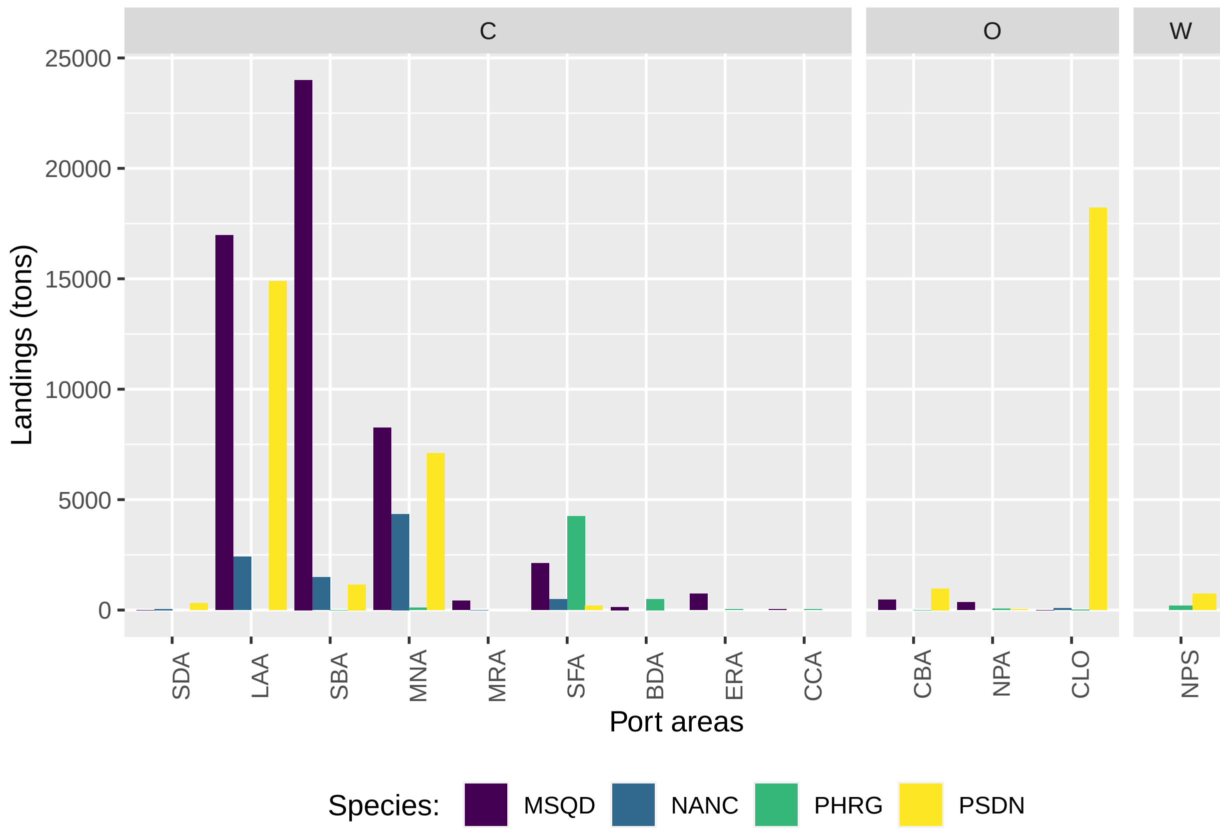

Figure 2: Annual average landings by port area.

To analyze substitution more in detail, we compute total annual landing by port during 1980-2020 period (Figure 3). There is a general conception that vessel that harvest Pacific sardine switch to market squid when the conditions are favorable. However, we can notice from Figure 3 that landings of market squid have been decreasing in the last five years. We would expect that the closure of the Pacific sardine fishery would have switch targeted species, but the graphs show some complementary instead of substitution. Under this scenario is useful to ask to ask whether after the closure, vessel that harvest Market squid left the fishery or stayed, which we can answer from our multispecies participation model. We show the number of vessels by species in Figure 4. This would be suggesting an unintended consequence from a policy that aims to only affect Pacific sardine, but its effect affects indirectly other fisheries [**?**].

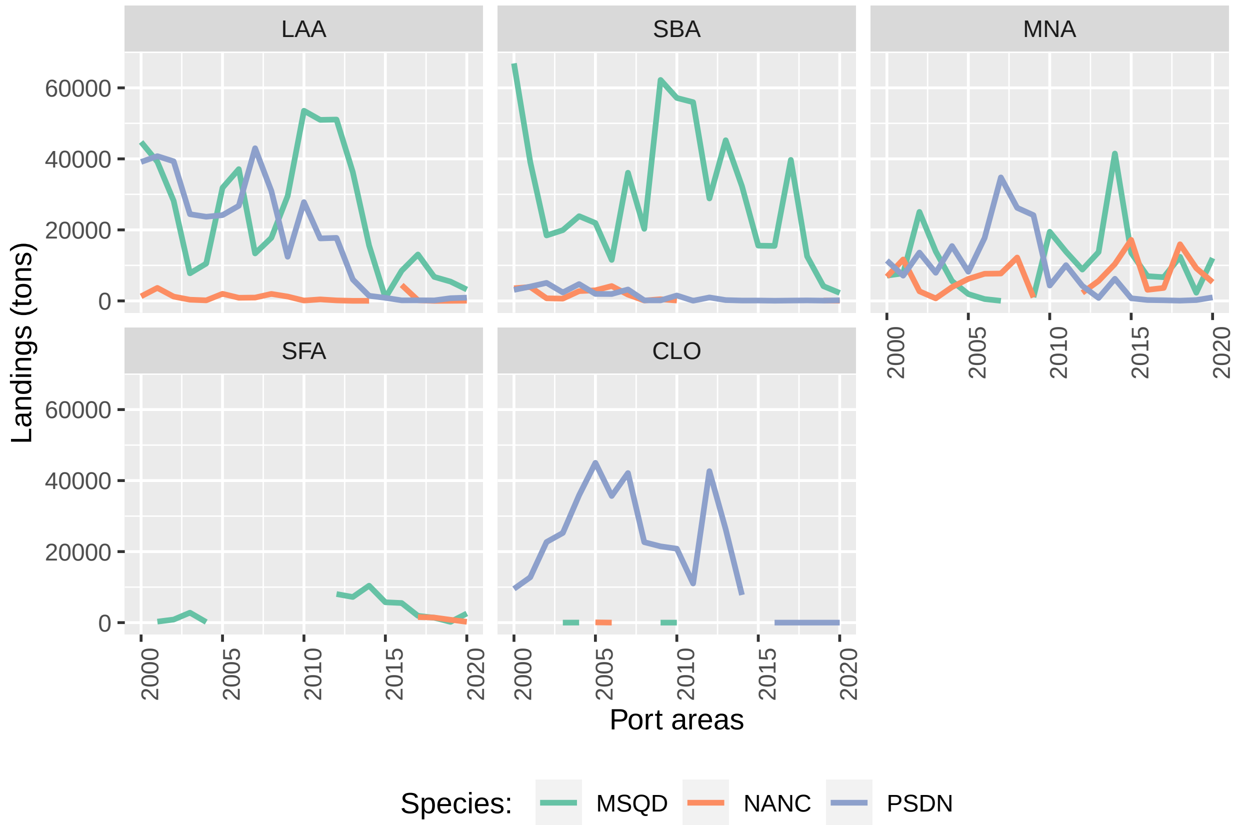

Figure 3: Total annual landing by port area. 2000 - 2020. *Notes:* CLO = Columbia River (OR); LAA = Los Angeles; MNA = Monterey; SBA = Santa Barbara; SFA = San Francisco.

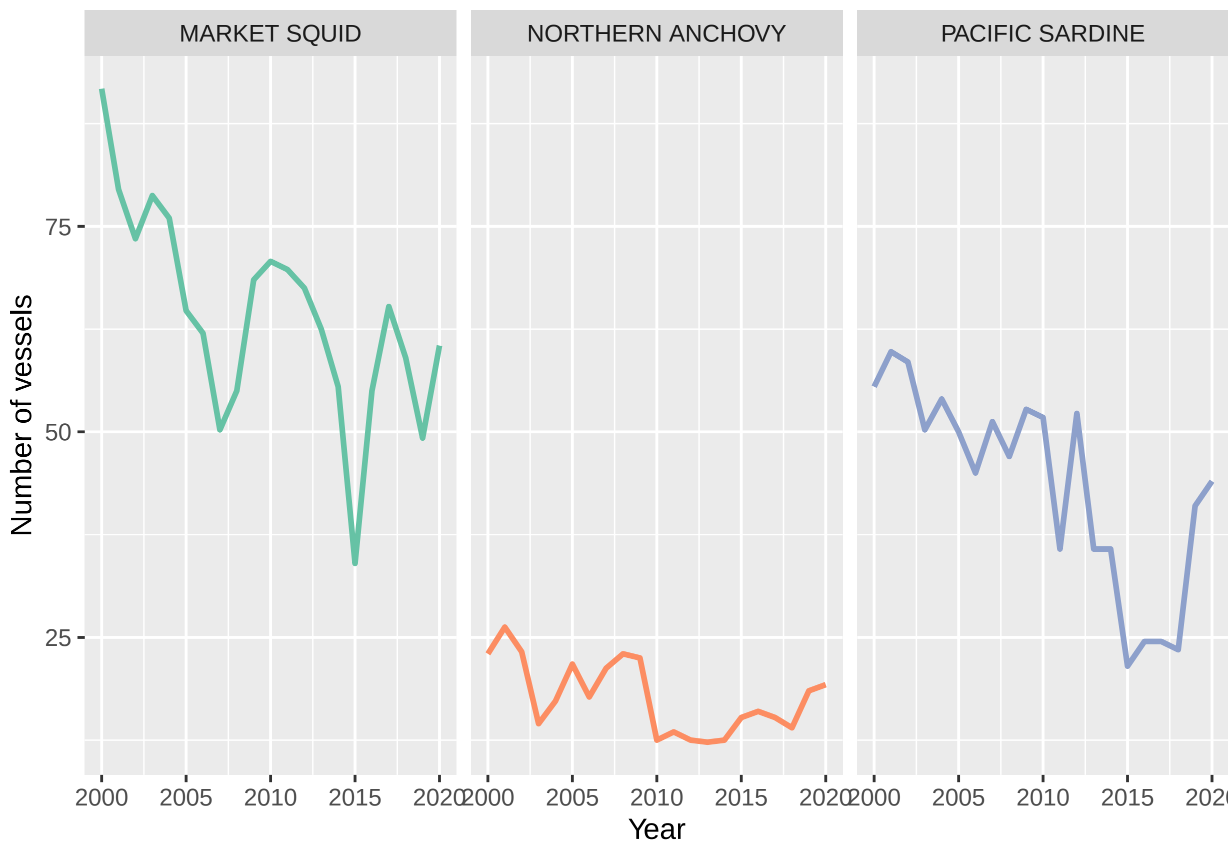

Figure 4: Total number of vessel by species. 2000 - 2020.

« SHOULD WE STUDY HOW FISHING GROUNDS CHANGE FROM PORTS (THUS DISTANCE TO FISHING GROUNDS AND WEATHER VARIABLES AFFECTED), LIKE SELDEN (2020) AND PAPAIOANNOU (2021)??? IN BOTH MODELS? »

3 Methods

3.1 Multispecies Landing Model

Our data set contain a number of variables measured at the port and *vessel levels* for CPS the fishery located in the U.S. West Coast. In regard to landings, our outcome variables are landings by port areas in a year, landing by vessel in a month. These two different outcome variables would allows us to study the degree of flexibility that vessel have in comparison to ports in regard to species substitution and catch composition. If vessels have strong contracts with processor associated with a port, then we should observe that substitution of vessels and port is similar. Yearly panel data data on landing by port areas during the the period 1980 - 2020 is publicly available from PacFIN. **Vessel level**

data was obtained upon request from… We only include ports areas where substitution could happen. In practical terms, we drop port that have never landed either Pacific sardine, market squid or Northern anchovy during our period of analysis.[1] We assume that this criteria would allows to identify ports that have the infrastructure to land all of the species in consideration.

Our main treatment variables are species probability of presence and Pacific sardine closure. Probability of presence were obtained from Species Distribution Models (SDM), and future forecast of these variables allows us to simulate the CPS fishery in the future. Prior landings models have shown that the probability of presence have a large contribution on explaining landings. For instance, Smith et al. [2021] use mean monthly probability of presence of sardine within 60 km of the port as explanatory variable. They found a positive effect of probability of presence on Pacific sardine landings. Moreover, landings where mostly explained by this variable. We follow their same procedure to associate SDM's outputs with ports. For Pacific sardine, we compute the average probability of presence within the same radius of 60 kilometers around the port. This radius also coincide with the average distance with two standard deviation traveled by vessels based on logbooks available for these fisheries. For market squid and Northern anchovy, we set this radius to 90 and 20 kilometers, respectively, also based in the average distance to fishing ground obtained from logbooks.[2]

Figure 5 show the relationship between the probability of presence and landings by species in three main port areas: Los Angeles, Monterrey and Santa Barbara areas. The graph suggest that Pacific sardine landings are positive correlated with the probability of presence of this species, similar to Smith et al. [2021]. This is also true in Monterrey area for the Northern anchovy, In the case of market squid, we cannot distinguish correlation between landings and probability of presence. Note, however, that the evidence shown in this figure may not capturing the actual effect of the probability of presence as other effect may be in play. Our empirical strategy is designed to isolate the effect of the probability on landing in a multivariate model framework.

[1]N/A were converted to zero.

[2]To see an animation of how far vessel travel please visit this link.

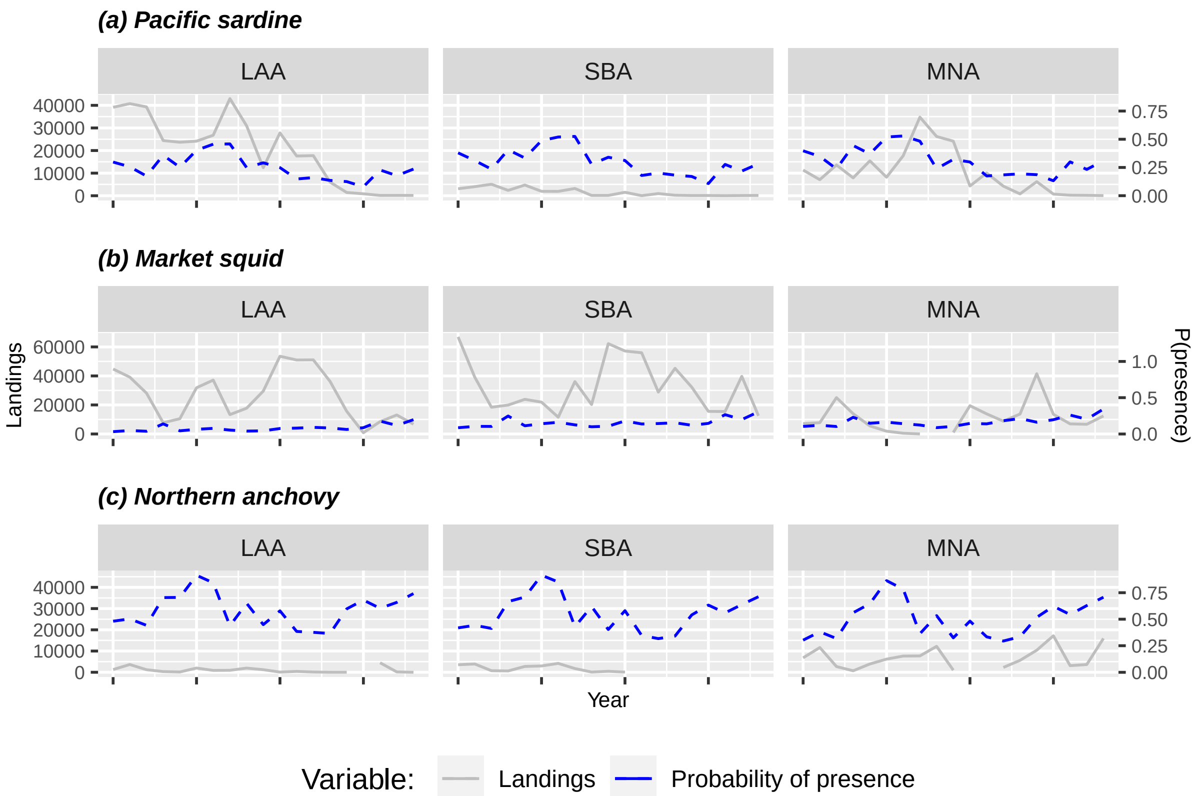

Figure 5: Landings v/s probability of presence by port area. *Notes:* LAA = Los Angeles; MNA = Monterey; SBA = Santa Barbara.

We use a Hierarchical Bayesian Hurdle model to estimate the effect of species distribution on fish landings. We estimate a separate model for the three species in consideration. We use a Bayesian framework for several reasons. First, it allows us to consider uncertainty from modeling the process as well as from the imperfect observation of the process, assuming that all parameters are random variables. Second, it allows us to incorporate multilevel effects (i.e. hierarchical effects). Finally, it allow us to incorporate previous knowledge as a prior. For instance, we can include a prior the results obtained in Smith et al. [2021] for the Pacific sardine landing equation.

Specifically, we fit a hierarchical Bayesian hurdle model to model the zeros included in our landing data. We observe a zero when no landings occur in a specific time period (landings observations with "NA" were transformed to zero). This zero could mean that there was no incentives for the fleet/vessel to harvest the species in consideration. In general, our Bayesian models have the following structure:

$$[\theta_i | q_{i,t}] \propto f\left(q_{i,t} | \theta_i\right) \times [\theta_i]$$

where $q_{i,t}$ is the observed landings of the corresponding species in port $i \in (1, \ldots, L)$ at year t, L is the total number of port, and θ_i are the parameters (i.e. random-coefficients) to be estimated at the port level. The latter give the name of hierarchical to our model.[3] The distribution $f(q_{i,t}|\theta_j)$ can be rewritten as:

$$f(q_{i,t}|\theta_j) = \begin{cases} p_i & \text{if} \quad q_{it} = 0 \\ [1-p_i]\,\text{gamma}\left(q_{i,t}|\frac{\mu^2}{\sigma^2}, \frac{\mu}{\sigma^2}\right) & \text{if} \quad q_{it} > 0. \end{cases} \tag{1}$$

where logit$(p_{i,j}) = \mathbf{X}\gamma$ and $\mu = \mathbf{X}\beta$. Specifically μ is defined as the following:

$$\mu_{i,j} = \beta_{0,i} + \beta_{1,j}P(Precense)_{PSDN} + \beta_{2,j} + P(Precense)_{MSQD} + \beta_{3,j}P(Precense)_{NANC}. \tag{2}$$

where j indicate the species in consideration. logit$(p_{i,j})$ follows the same structure, but coefficient are replaced by γ.

Beside the biological stock, landings are affected by socio-economics conditions. Some of them are harvest cost, prices received by species and their substitutes, and regulations imposed by the authorities. In our data we include as a proxy of harvest cost average distances traveled by vessel from the port of origin *(TO BE INCLUDED USING GLOBAL FISHING WATCH. . .)* and fuel cost *(TO BE INCLUDED. . .)*. Own price was included and it was obtained from PacFIN landings dataset. When price was missing, we replace this value for the average price of the species in all ports for the corresponding year.

We include the Annual Catch Limit (ACL) for the Pacific sardine model as an additional explanatory variable in both μ_i and logit(p_i) equations. The ACL for Pacific sardine were obtained from the CPS Fisheries Management Plan???. For this species, we restrict our data set to the period when the fishery was open (2000-2015). We only consider ports where landing have occur at least once in our sample period. Thus, we avoid to deal with ports where infrastructure to land Pacific sardine is nonexistent.

Table 1: Summary Statistics

Variable	N	Mean	Std. Dev.	Min	Pctl. 25	Pctl. 75	Max
Landings: PSDN	92	10828.886	13499.627	0.1	156.025	20991.3	45016.5
Landings: MSQD	103	13383.623	17166.411	0.1	222.2	19693.75	66890.3
Landings: NANC	59	2769.698	3928.055	0	149.55	3651.65	17180.2
Prob(presence): PSDN	322	0.261	0.104	0.08	0.177	0.341	0.569
Prob(presence): MSQD	280	0.17	0.078	0.025	0.12	0.217	0.467
Prob(presence): NANC	308	0.499	0.175	0.176	0.349	0.623	0.914
Price: PSDN	437	0.079	0.039	0	0.05	0.108	0.37
Price: MSQD	437	0.266	0.121	0	0.185	0.32	0.5
Price: NANC	437	0.091	0.054	0	0.06	0.114	0.35
Revenue: PSDN	92	1497414	1920819.177	0	31471	2646660.75	8979099
Revenue: MSQD	103	7734746.485	9938728.985	0	97348	11193641.5	43742173
Revenue: NANC	59	311373.814	427339.961	17	42203	437046.5	1930490
Annual Catch Limit: PSDN	436	82613.151	55614.651	0	30259	122747	186791

[3]For more details about Hierarchichal models, see Hobbs and Hooten [2015].

In the case of market squid, our database comprise the time period between 2000 and 2018. We do not include ACL as an explanatory variable as there is no variation between years. To capture any change on fishers behavior when Pacific sardine fishery closed, we include a binary variable called **dClose** that takes the value "1" when the Pacific sardine fishery is close, and the value "0" when its close. Pacific sardine probability takes the value of zero when the fishery is closed. Thus, the effect of this variable is only relevant when it PAcific sardine fishery is open in order to capture potential substitution between targets. Finally, a similar structure than Market squid models is followed for our estimation of Northern anchovy landing by ports. A summary statistics of our data set is shown in Table 1.

3.2 Multispecies participation model

For the multispecies participation model, we follow a similar methodology than Richerson and Holland [2017]. We estimate a discrete choice model for probability that a vessel participate in a particular species fishery during a specific month. This approach allows us to further understand how a closure or abrupt weather/abundance changes restructure fisher's portfolios.

In the participation model, our outcome variable is a categorical variable that indicate whether a vessel participate in a specific fishery. It ranges from 0 to 4 where: 0 = "No fishing during the month", 1 = "Pacific sardine", 2 = "Market Squid", 3 = "Northern Anchovy", and 4 = "Other". **«Can I combine Anchovy + sardine in category 5? What if in the same month a vessel harvest two different species. Should we maybe assume 1 for the principal species, zero to the second one?»** To select vessels in or database, they should met the following criteria:

1. Vessel active at least **XX%** of the sample.
2. Total revenue at least **XX%** of CPS fishery.
3. Total annual revenue average for two or more species listed of at least **XXX**.

We expect that using monthly **«Should I use Yearly data???»** data allows us to observe seasonality in fishers´ behavior and to reduce the risk to not loosing general behavior when we dissagregate data in a finer scale.

According Richerson and Holland [2017], fishers participation decision should depend, in general terms, on profitability, species distribution and regulations. Specifically, based on different studies (**REF here**), variables that can explain fishery participation on a particular fishery in a month are:

- Previous revenues
- Expected catch:
  - We calculate expected revenue as a function of average outputs of the SDMs. Using SDM outputs instead of catch to compute expected revenues allow us to project fishers decision on time using SDM's projections. Moreover, using catch to compute expected revenue as a regress in a discrete choice model could incorporate endogeneity as it can be correlated with unobservables not captured by the choice constant.

- Closure: Whether or not the Pacific sardine fishery was closed.
- Diversification using HHI (measurement of diversification, from Richerson and Holland [2017])
- Dependence on the species in consideration (historical % of the revenue from the species considered)
- Typical landings location: Latitudinal center of gravity (LCG) index from [Richerson and Holland, 2017]
- Dispersion around centre of gravity: Latitude inertia (LI) index from [Richerson and Holland, 2017]

4 Results

4.1 Landing model

4.1.1 Graphical posterior predictive

Before presenting the results for the three species in consideration, we check graphically whether the posterior distribution is able to predict the actual distribution. We exclude zero in our graph to avoid plotting different data generation processes. In Figure 6 we show a posterior sample compare with the true sample distribution for the three species in analysis. Some deviation from the true sample distribution is observed in the three models, but still the posterior sample follow a similar shape than the actual curve. Moreover, our pacific sardine sample do well in predicting probabilities at lower landing levels.

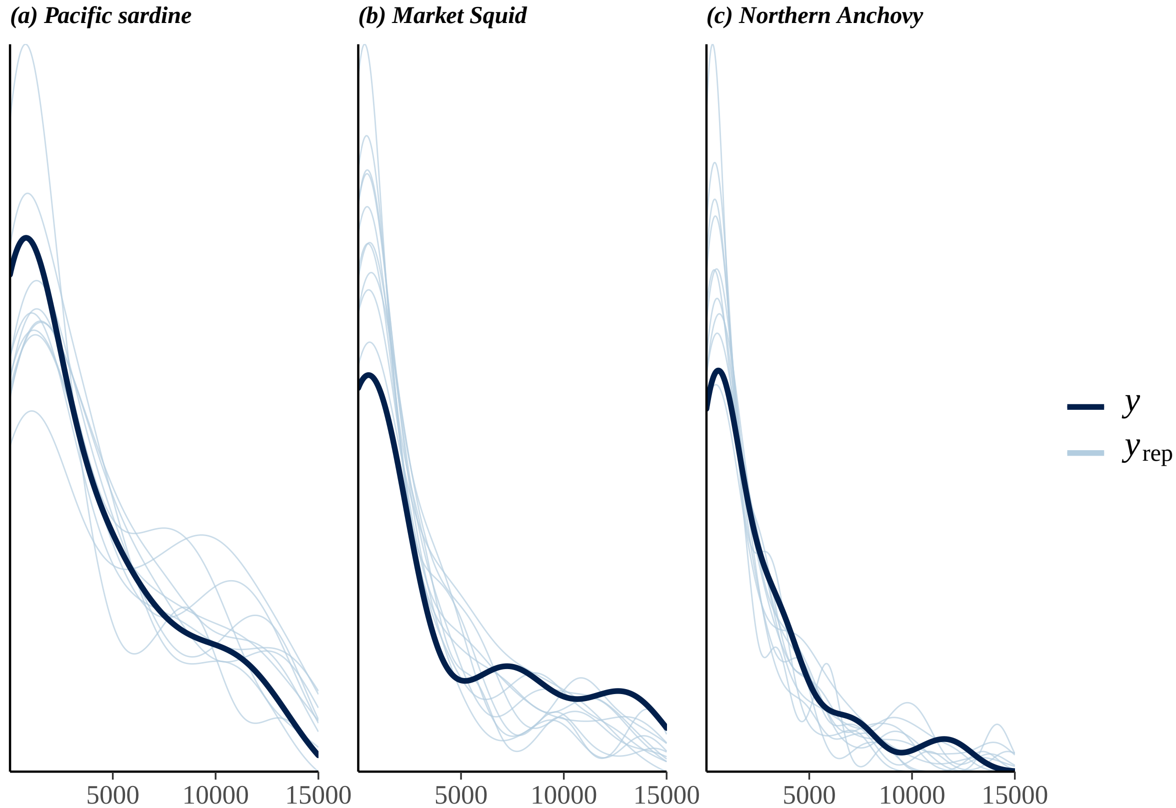

Figure 6: Graphical posterior predictive checks

In addition to a posterior predictive check, we also check divergence and treedepth.[4] In all three models, we did not have any divergent step in our estimation. The maximum treedepth was 11 for the Pacific sardine model, while in the others it was 10.

4.1.2 Own species distribution effect

The inclusion of hierarchical effects by port allows us to analyze the effects of the probability of presence on landings disaggregated by ports. We only focus our analysis in owns probability of presence effects, as other probability are analyzed as interaction (see next subsection). We can observe in Figure 11 that the effects of the own probability of presence on landings are not strong (maybe I should use logs…). However, it is clear that it have a positive effect on landings, specially on port areas such as Columbia River at Oregon for Pacific sardine, and Monterrey for Northern anchovy, while a more moderate effect is observed at Santa Barbara Area for Northern anchovy.

[4]Explain what are these concepts…

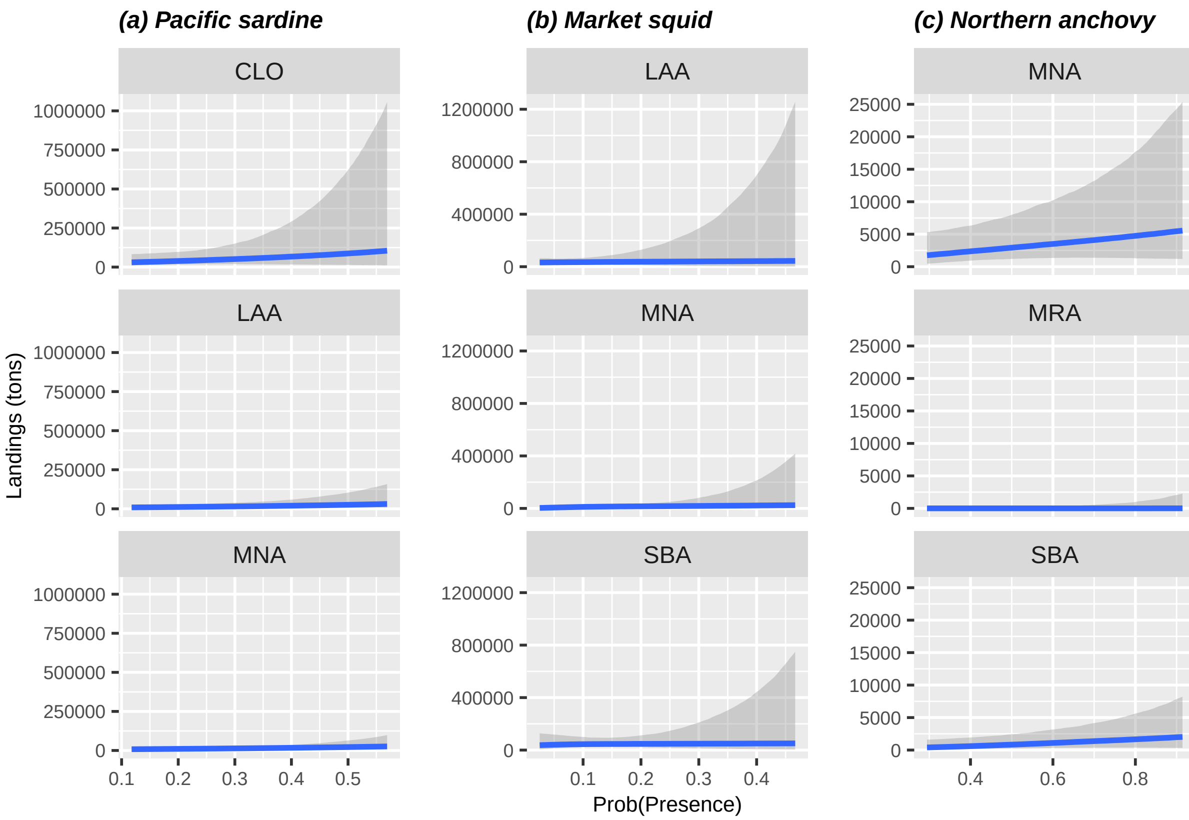

Figure 7: Effect of probability of presence on landings by species and port

4.1.3 Interaction effects

To study the effect of other species distribution on landings, we compute the conditional effects of the interaction between probabilities of presence. Let denote species A the species which we are analysing its landings, and species B and C the other species included in the model for species A landings. For each species, we compute the effect on landing of the interaction between the probability of presences of: + Species A and species B, + Species A versus species C, + Species B versus species C. For example, for the Pacific sardine equation, we compute these results for the probability of presence effect between Pacific sardine and market squid, Pacific sardine and Northern anchovy, and market squid and Northern anchovy.

Let first analyze the interaction effect of the probability of presences on Pacific sardine landings, presented in Figure 8. We only shows results for the main three port where Pacific sardine is landed (Columbia River at Oregon, Los Angeles Area and Monterrey Area). As we already commented in Figure 11, the effects the Pacific sardine's own probability of presence is positive, changing color from left to right in panels (a) and (b). Market squid seems to be an stronger substitute for Pacific sardine than Northern anchovy. This is suggested by the different slopes between panel (a) and panel (b). For instane, in Columbia River, an increase in the probability of presence for anchovy does decrease Pacific sardine landings as much as an increase in the probability of presece of market squid.

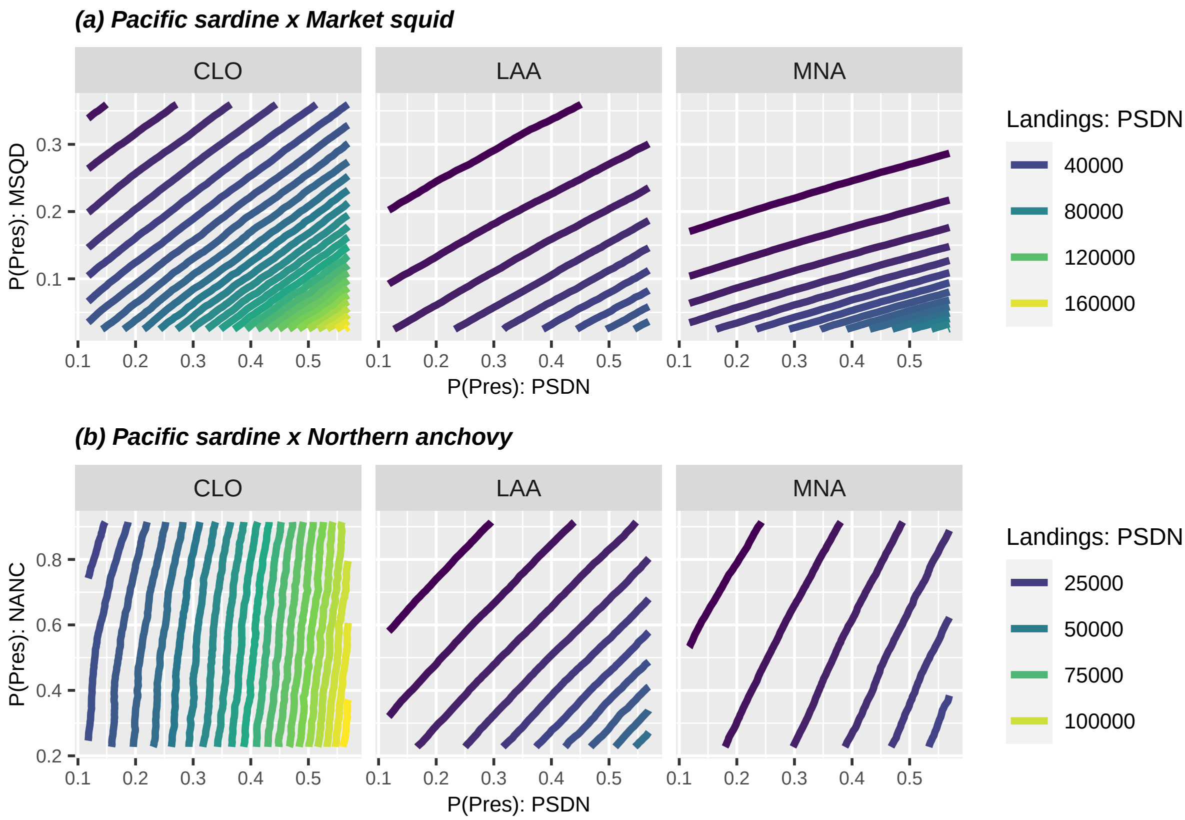

Figure 8: Interaction effects between species distribution on Pacific sardine landings by port

We found some similar findings for market squid in Figure 9. Pacific sardine it is a strong substitute of market squid. In regard to Norther anchovy, there is some complementarity with market squid. We observe that when Northern anchovy presence increase, there is also an increase in market squid landings.

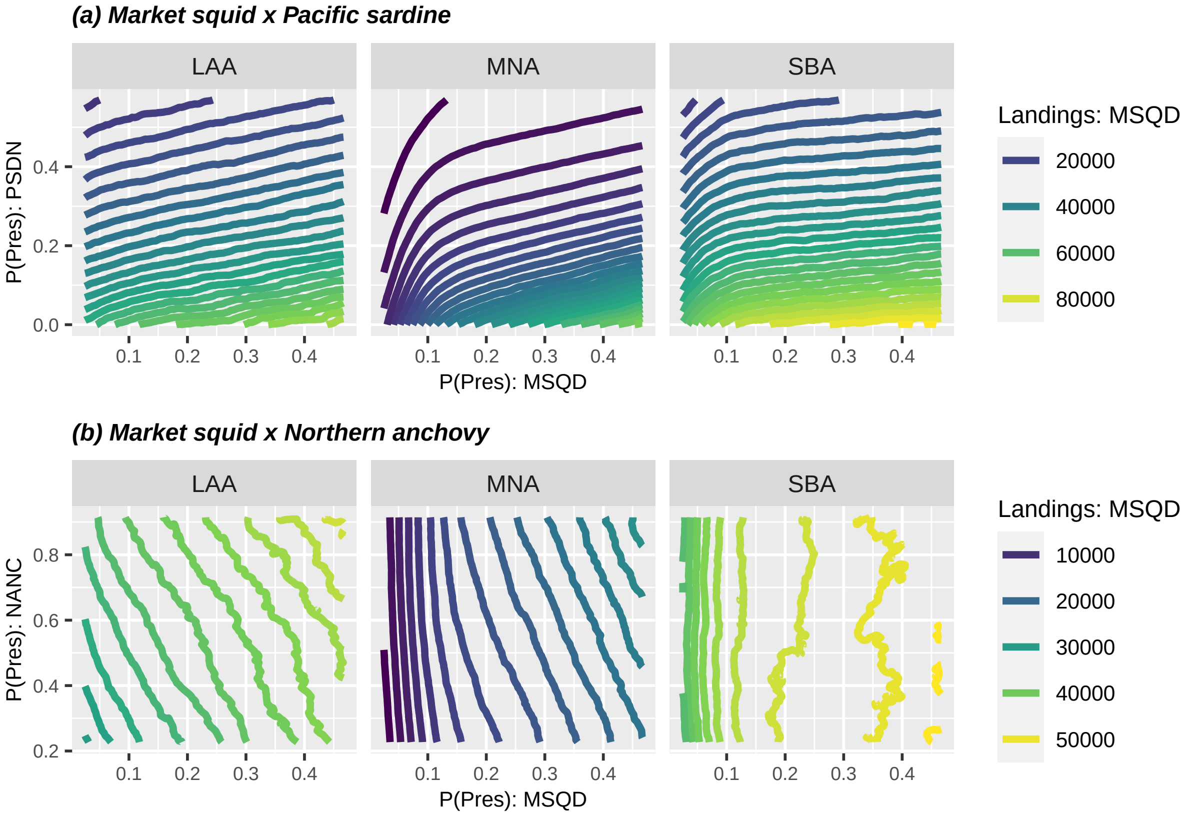

Figure 9: Interaction effects between species distribution on market squid landings by port

However, this complementary is not observed for Northern anchovy landings. When market squid presence increase, we observe a decrease in Northern anchovy landings. An interesting case is observed for Pacific sardine and Northern anchovy, in particular at Monterrey area. For small levels of Pacific sardine presence, Pacific sardine is a complement with Northern anchovy. However, after certain threshold, Pacific sardine is no longer complement and Pacific sardine become a substitute, reducing Northern anchovy landings when the probability of presence for Pacific sardine increase.

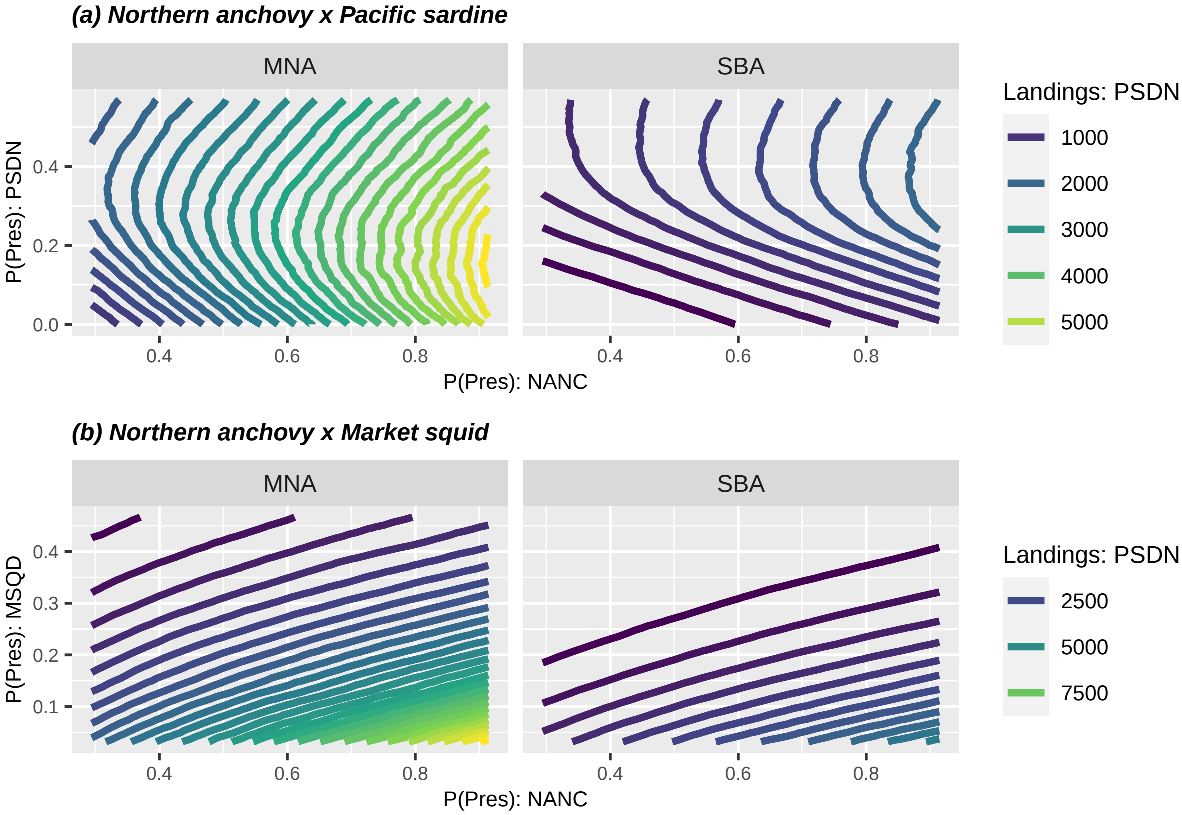

Figure 10: Interaction effects between species distribution on Northern anchovy landings by port

4.1.4 Pacific sardine closure

Finally, lets analyze the effect of the Pacific sardine closure on market squid and Northern anchovy landings. We do not find significant results in the case of Northern anchovy. In the case of market squid, we found a decrease in the level of landing after the closure was implemented. It seems that some fisher exit the CPS fishery after the closure of Pacific sardine, reducing their participation in the market squid fishery. Our participation model results give us more details about what happen after the Pacific sardine closure.

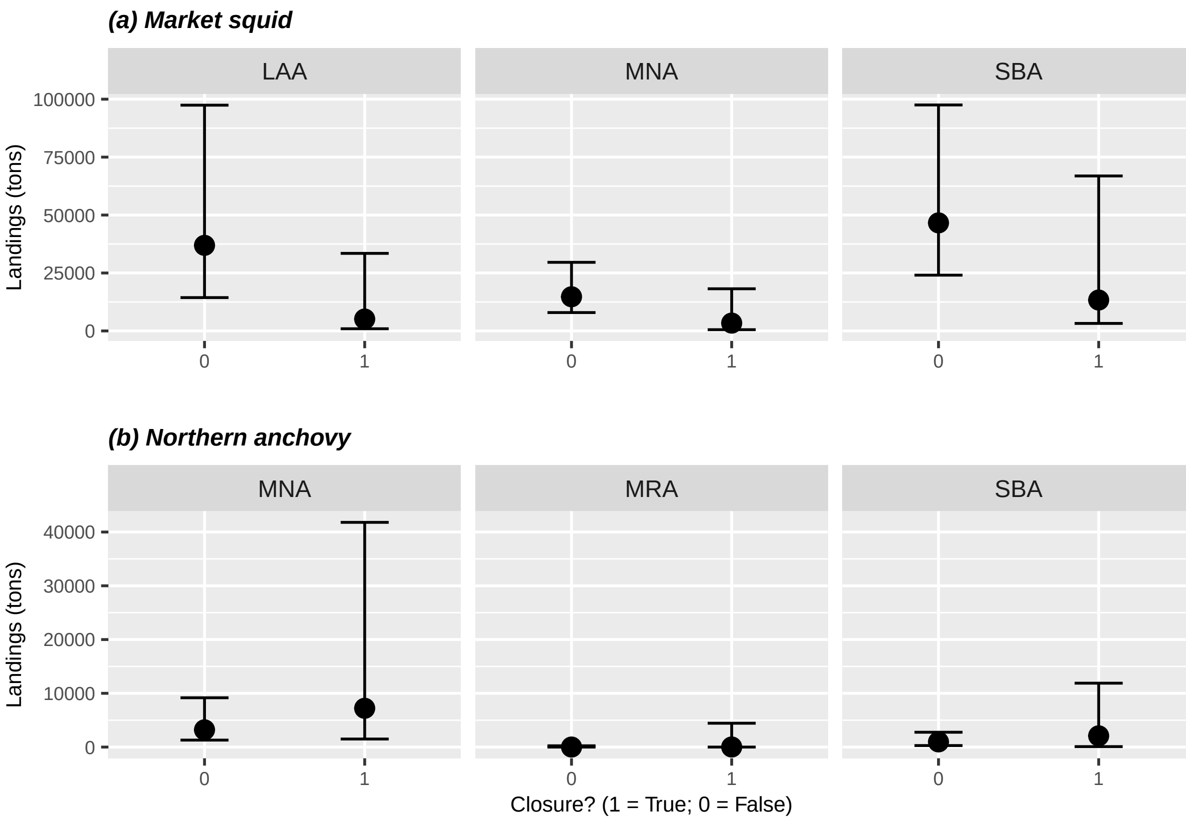

Figure 11: Effect of Pacific sardine fishery closure on markt squid landings by species and port

4.2 Multispecies participation model

5 Predictions

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6 Conclusions

A possible extension of our research is to consider spatial autocorrelations between ports.[5] Ports landing maybe correlated as vessel have the incentives to choose the port of landing, conditional on whether the port have the infrastructure for this. It is likely that they just land wherever is closer to the area they are fishing. Nevertheless, differential in prices could encourage them to travel a little further for higher prices.

[5] See Morris et al. [2019] for an application of a spatial model in a Bayesian framework.

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