Portfolio Substitution between Coastal Pelagic Species under Shifting Target Species Distributions and Policy Constraints

Felipe Quezada[1,2,*] Desiree Tommasi[1,2] Stephen Stohs[2] Isaac Kaplan[3]
Jonathan Sweeney[4] Barbara Muhling[1,2]

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Abstract

Fishers for forage species typically face a set of possible choices, called fishing portfolios, that allow them to diversify target species and reduce income risk. Switching among species is more feasible for vessels that share similar gear and methods for fishing. More diverse portfolios may increase fisher resilience to climate-driven changes in target species' spatial distributions and availability. However, regulations and other constraints (e.g., port constraints on where landings of a particular species may occur, or permit requirements) may reduce the degree of substitution we observe. In this study, we analyze how historical changes in forage species distribution and the closure of the Pacific sardine fishery affected landing substitution between three coastal pelagic species: Pacific sardine, market squid, and Northern anchovy. Using a discrete choice modeling approach, we also study how spatial distribution and closure affected the coastal pelagic species fisheries' participation decisions over the 2000-2019 period. Our preliminary results show strong substitution between market squid and Pacific sardine when both were available, while the Pacific sardine closure in 2015 was associated with reduced market squid landings suggesting lower fishers' participation in this fishery. We plan to use species distribution model projections to study how landings and participation change under different future climate change scenarios.

[1] Institute of Marine Sciences, University of California Santa Cruz

[2] NOAA Southwest Fisheries Science Center

[3] NOAA Northwest Fisheries Science Center

[4] NOAA Pacific Island Fisheries Science Center

[*] Correspondence: Felipe Quezada <felipe.quezada@noaa.gov>

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 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 the two more important (in terms of landings and revenue) coastal pelagic species (CPS) harvested in U.S. West Coast: Pacific sardine and market squid. Fisheries closures are a interesting policy instrument when fisher target more than one species as give us the opportunity to study how fisher change behavior under the exclusion of one alternative. However, fewer studies have study the effect of one fishery closure in other fishery outcomes. An example is Vermard et al. [2008] that study the effect of an anchovy closure in trip choices conducted by the Bay of Biscai pelagic fleet, . Another example is Richerson and Holland [2017] who study the effect of salmon closures in vessel participation on salmon fishery and other fisheries. In this paper, we study the effect of the 2015 Pacific sardine closure implemented after the over-exploitation of the fishery, as well as the effect of seasonal closures after reaching a catch limit target.

Studying the effect of closures and changes in species distribution is not straightforward as different response can be observed to the same conditions as fishers and vessel are heterogeneous [Zhang and Smith, 2011]. Moreover, vessel heterogeneity and port constraint will dictate the possible set of species that a fisher is able to choose. Species are also interconnected, at least economically if not ecologically. Thus, any regulation or ecological disruption that affect one species would affect fisher's target decision in other species. Therefore, a multiple targeting species framework that considering interrelation between them it is necessary to further undertand the CPS fishery. Our research give a step further and analyze the CPS fishery as one where fisher can target multiple species in line with recent literature that consider this setting in their analysis [Richerson and Holland, 2017]. Our goal is to understand how changing in species distribution, seasonal and total closures 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 the four species analyzed in this study and estimating a multilevel Bayesian model in order to incorporate heterogeneity between fleets and ports areas. 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 incorporating projected substitution between species. 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], expanding their analysis to the CPS fishery . 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 4 we discusses our data set and empirical strategy. Section 5 presents the results of the estimations, and we conclude in Section 7.

2 Coastal Pelagic Species fishery

Before 2000, the only fishery under a Fisheries Management Plan (FMP) was the Northern anchovy. The development of the Northern anchovy FMP started in 1977 and the final draft approved and implemented in 1978 [PFMC, 2021]. During these times, and for many year so on, the Northern anchovy was harvested for reduction. This fleet was called "wetfish" and they also fisher for other CPS species such as Pacific sardine, market squid, Pacific mackerel, Jack mackerel, Pacific bonito and Pacific bluefin tuna [PFMC, 2020]. In March, 1995 the Pacific Fishery Management Council (PFMC) decided to expand the FMP to include the entire CPS species (Pacific sardine, northern anchovy, Pacific (chub) mackerel, jack mackerel, and market squid) along the U.S. west coast. through the Amendment 8. This amendment was partially approved on June 1999, and final regulations were published on December 1999. Finally, the FMP was implemented on January 1st, 2000.

Nowadays, there is no reduction capacity for the Northern anchovy fishery in California and is principally harvest in Monterrey area as substitute of sardine and squid when both are not available [PFMC, 2020]. In Oregon, the Northern anchovy fishery was in a developmental stage between 1995 and 2009. Only 4 of the 15 developmental permits were issued for this fishery. The developmental program was suspended in 2009. The reason it was there were no fundings to support it [PFMC, 2020]. Currently the Oregon Northern anchovy fishery is under open-access, but limited by gear [PFMC, 2020]. A significant fishery start to growth in 2015 and 2016, but there were no landings in Oregon in 2018. In Washington, there are restricting Northern anchovy fishery to develop to a high-volume fishery to protect the traditional bait fishery. Some of these regulations are limiting catch and limiting the percentage of the catch allocated to reduction.

Back in the 60s, the Pacific sardine fishery in California closed due to the collapse of the fishery. The fishery reopened in 1986 with a precautionary quota of 906 metric tons. The Pacific sardine fishery was considered as fully recovered on 1998, and a biomass of over a million metric tons was estimated [PFMC, 2020]. Since 2000, after the implementation of the CPS FMP, the Pacific sardine is managed under a limited entry (LE) permit and quota management system, with a Harvest Guideline (HG) controlling commercial catch of sardine biomass. The CPS LE fleet is composed by 65 permits and 55 vessels. The LE permits program is federal. In the states of Oregon and Washington, the development of the fishery did not happen until the years 2000s. In 1999, a fishery for Pacific sardine started to operate in both states targeting larger sardine to be sold as bait to Asian longline tuna fisheries [PFMC, 2020]. Then, in 2006 the fishery expand on both states to human consumption. In Oregon, the Pacific sardine fishery was categorized as "developmental fishery" until 2005, and the first Limited Entry (LE) permits were issued in this state in 2006 capped at 26 (currently there are 24 LE permits for this fishery in Oregon). In Washington, the Pacific sardine fishery was a "trial fishery" from 2000-2002 with a state HG of 15,000 metric tons (i.e. no limits on the number of participants). Later, from 2003 to 2009, the fishery was under an "experimental fishery" category with experimental permits capped at 25. Finally, in 2009, the Washington's Pacific sardine fishery it was designated as a "commercial fishery" with a Limited Entry (LE) program that allocated 16 permanent permits and 10 temporary ones. In Washington, fishing for sardine is prohibited from January 1st to March 31st, and directed comerciall harvest is prohibited within state waters (0 to 3 miles). The HG for the Pacific sardine follows an allocation framework. There is a geographical boundary at the 39° N latitude that divide the coast in two areas. In 2005, the quota allocation for Pacific sardine was modified from area-based, where 50% of the HG goes to each area, to coast-wide seasonal release that follows an allocation formula: Moreover, the allocation formula for the Pacific sardine HG was defined as follow: 1. 35% of the HG to be allocated coastwide on January 1st. 2. 40|% of the HG, plus any portion not harvested from the initial allocation, to be reallocated coastwide on July 1st. 3. 25% of the HG, plus any portion not harvested from earlier allocations, to be reallocated coastwide on September 15th. Coast-wide, the commercial fishery is currently have been closed since 2015 as the spawning stock biomass (SSB) is estimated as being below the cutoff point of 150,000 metric tons. This total closure came after many years of seasonal closures.

Regarding market squid, the fishery was unregulated under open access until permits became required in 1998. However, there were no limits to the number of permits issued by the authorities. In 2001 was the first time a Harvest Guideline (HG) was implemented for this fishery to 125,000 U.S. tons. Later, in 2005, the California Fish and Game Commission (CFGC) implemented the Market Squid Fisheries Management Plan (MSFMP), which reduced the fleet to a maximum of 73 vessels, limits the number of light boats to 34, reduced the HG to 118,000 U.S. tons and incorporate a weekend closure to allow for period of uninterrupted spawning [PFMC, 2020][1] Oregon's market squid fishery just started in 2014 with few vessel targeting squid (15 in 2016 ans 11 in 2018), while in Washington there is no directed landings of market squid. In 2019 two permits were issued but with the intention to allow the possibility to deliver Oregon's market squid catch to Washington ports.

The fishing season for Pacific sardine in California have a peak in landings during the early summer to fall in the area of Monterrey, specifically in Moss Landing, while in Southern California, specifically in San Pedro and Terminal Island, occurs during the winter. Fishing seasons for Pacific sardine are shown in Panel (a) of Figure **??**. In Oregon and Washington state, at Astoria and Ilwako/Chinook ports, respectively, the fishing season mostly happen in summer and early fall. Panel (b) shows that market squid fishing season in Southern California, specifically in San Pedro, Terminal Island and Ventura, goes from fall to winter, while in Northern California, specifically in Moss Landing and Monterrey, the season goes from late spring to summer.

[1] Vessel permits allow vessels to attract squid with light and use purse seine for harvest, Brail permits allow to attract squid with light and use brail gear, and light boat permits only allows to attract squid with lights

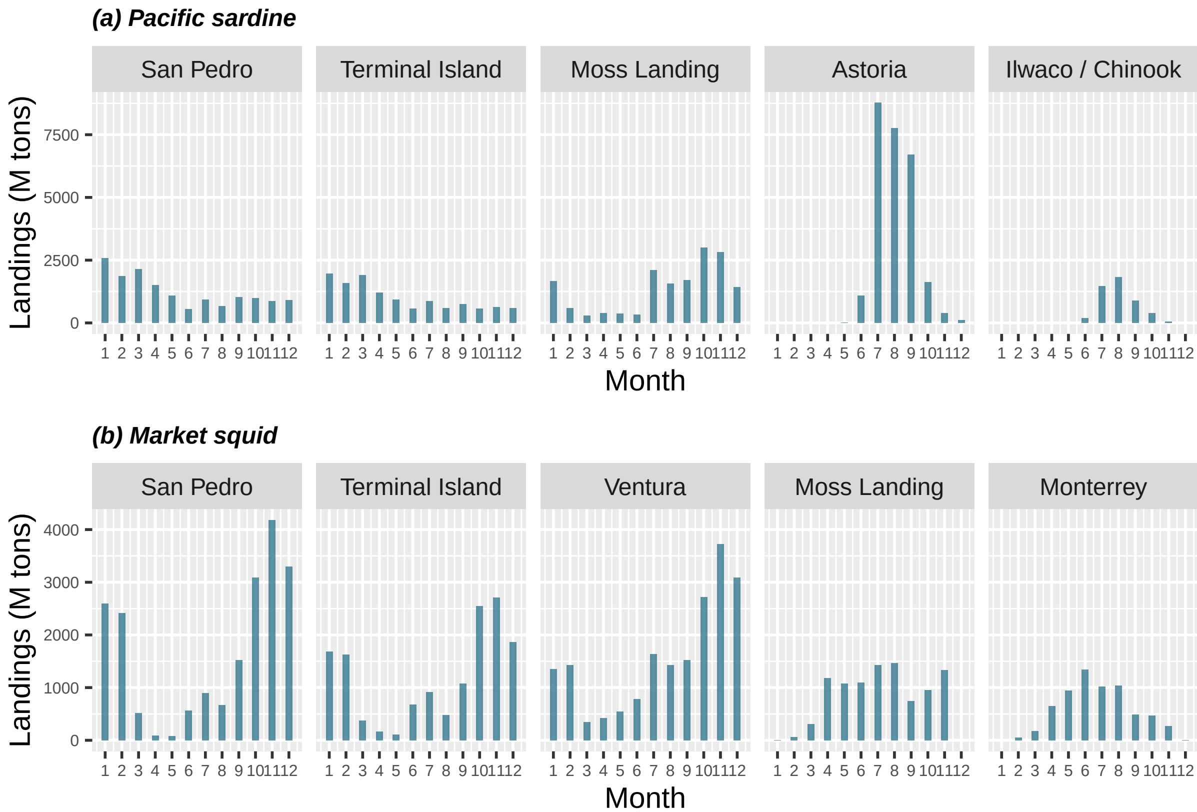

Figure 1: Fishing season for Pacific sardine and Market squid (average monthly total harvest for the period 2000-2014).

3 Data analysis

3.1 Landing, prices and revenue

Landings in the CPS fishery have been mainly dominated by Pacific sardine and market squid during the period 1981-2014 as is shown in Panel (a) in Figure 2. Average annual prices are shown in Panel (b). Average prices are low for all CPS species in comparison to bluefin tuna. Pacific bonito is the only one between CPS species that it prices is above 1.5 USD. This lower price means that revenue are mainly determined by ladings levels. Therefore, similar to what we observe in Panel (a), we can observe in Panel (c) that market squid and Pacific sardine are the principal species in terms of revenue.

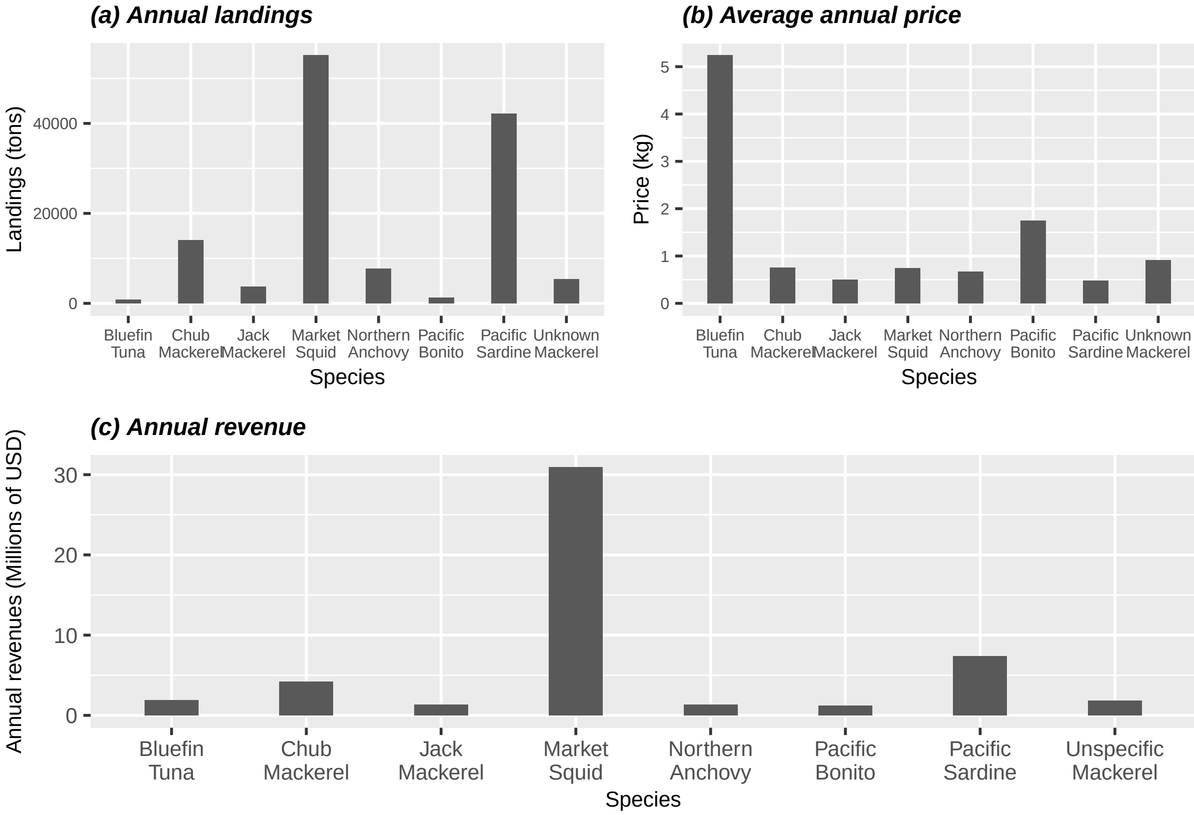

Figure 2: Average annual landings, message=FALSE, warning=FALSE, prices and revenues by species (1981-2020).

Figure 3 shows the evolution of landings and prices and vessel participation by species during the period 1981-2020. We can observe in panel (a) that real prices for market squid have been increasing during the last two decades. Incentives should be high for landing market squid. However, we observe a sharp decline on market squid landings in the last decade.[2]. Regarding Pacific sardine, we observe that the price have been stable after 1990, while landing reached a peak in 2008 and there is a posterior decline in landing until the fishery close in 2015. This trend suggest that Pacific sardibe landing are mostly determine by abundance.

[2]Prices for forage species are likely to be determined in the world market, as the California current landings for forage species correspond to a small share of the total landings in the world

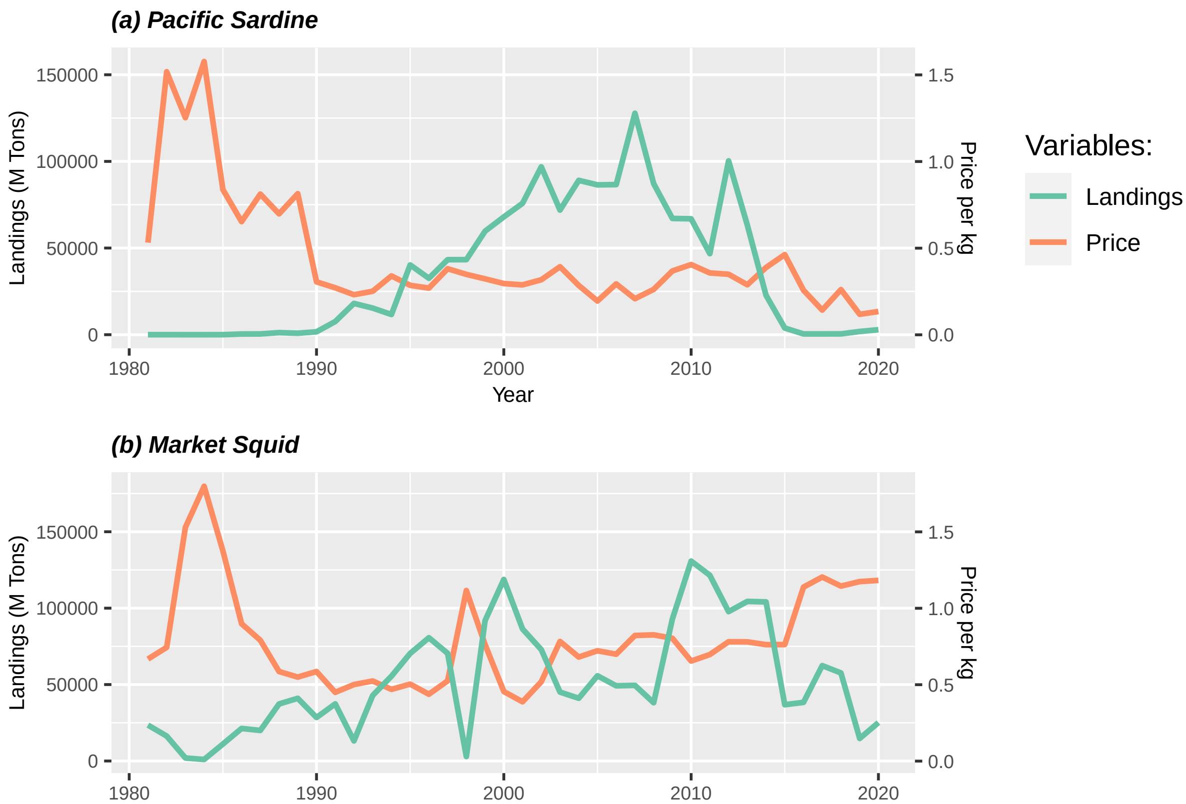

Figure 3: Yearly total landing v/s, warning=FALSE, average price by CPS species (1981 - 2020).

A potential hypothesis for the observed decline in market squid landings could be that the lower abundance and the consequently closure of the Pacific sardine fishery also affect vessels' decision to participate in the market squid fishery. Maybe fishers stop fishing at all as the exclusion of Pacific sardine from their portfolio reduce the ability of fisher to overcome income risk through diversification [Kasperski and Holland, 2013]. We have some suggestive evidence from this in Figure 4, which shows the evolution of Pacific sardine landings and number of vessels landing market squid during the period 1981-2020. In the first year of Pacific sardine closure, we observe that the number of vessel landings Market squid decrease from 99 vessels in 2014 to 74 vessel in 2015. After this abrupt decline, we observe a slightly recovery, reaching 109 vessels in 2020. Nevertheless, this number is below the levels observed in 2012 with 139 vessels landings market squid.

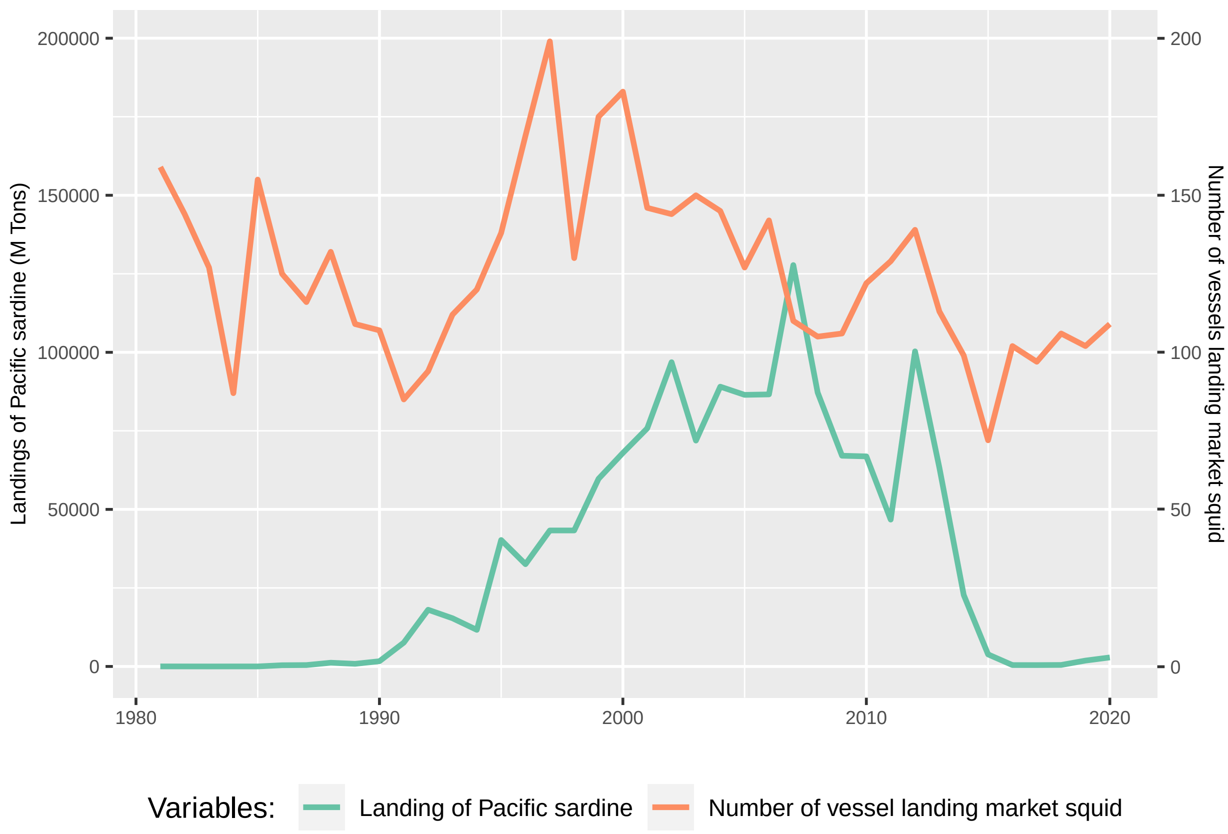

Figure 4: Landing of Pacific sardine v/s Number of vessel landing market squid.

These trends does not coincide with the perception that stalkholders have about switching behavior. They claim that after the Pacific sardine closure many vessels in California switch to market squid.[3] Another hypothesis that could explain the lower landings levels observed for market squid in the last decade could be changing in species availability and substitution to another species more profitable than market squid. According to the stalkholders, substitution of Pacific sardine may occur with other species such as mackerel, tuna, or anchovy. Our empirical strategy is designed to address various concerns about omitted variables to obtain clean causal effect of a set of explanatory variables.

3.2 Switching behavior

3.2.1 Cluster analysis

Before continuing our analysis, we have to verify whether there is actually switching behavior between CPS species. We conduct a cluster analysis to categorize the different portfolio that fisher manage during a year. For this we conduct our cluster analysis using a hierarchical clustering method. This method have been used before in fisheries to define

[3]This was stated by a participant from a workshop that reunite U.S. West Coast fishery stalkholders.

metiers in discrete choice models [Vermard et al., 2008]. This approach do not require to define de number of cluster as is chosen within the algorithm. There are different method to compute the distance between two clusters and conduct the algorithm. We use the Ward's method in our study similar to XXX. The goal of this method is to reduce the within-cluster variance. The algorithm start with all observation in a cluster and then merge in each step the two cluster with the minimum distance between-cluster. The analysis include commercial vessels that have harvest CPS species or have used gear that the CPS generally use at least one during the period 2000-2015.

We start our analysis including Pacific sardine, market squid, Pacific mackerel, Jack mackerel, Pacific bonito and Bluefin tuna as species where substitution is likely [PFMC, 2020]. The results for clustering are presented in Table 1. Many of vessel belong to cluster that can be considered as single-species. For instance vessel belonging to Cluster 1 in average 99.48% of the total landings correspond to market squid. Thus, this vessel only focused on this species. An interesting cluster is Cluster 8. In average, 61.42% of of the total landing registered for vessel associated to this cluster comes from market squid, 26.07% from Pacific sardine, 5.92% from Pacific mackerel, 3.5% from Northern anchovy and the remaining 3% comes from Jack mackerel, Pacific bonito, Bluefin tuna and Unspecified mackerel.

Let us just focus on a subgroup of species identified in Cluster 8: Pacific mackerel, market squid, Northern anchovy and Pacific sardine. The clustering results is presented on Table 2. The first four clusters correspond to vessels that focus their effort on single species. Cluster 5 depict vessel where substitution happen between CPS species, mostly between market squid and Pacific sardine.

Using the cluster analysis we can identify the characteristic of the vessels that are likely to switch and the vessel that are historically single-species focused.

3.3 Fleet characteristics

3.3.1 Gear use

Substitution between species is likely to be related with the gear that a vessel or fisher have already invest for their fishing activities. However, a vessel is not restricted to an specific gear. They can switch between different alternatives. In average a vessel use 1.4 gears for their fishing activities in our sample data, with an standard deviation of 0.72. If we only focus in CPS species, a vessel switch between 1.42 gears in average to harvest market squid, 1.16 gears in average to harvest Northern anchovy, 1.16 gears in average to harvest Pacific herring and 1.28 in average to harvest Pacific sardine. In terms of gears, midwater trawl and seine allow for the highest level of substitution between CPS species. In average, a vessel using midwater trawl harvest 2.36 CPS species, while a vessel using seine harvest in average 1.91 CPS species (see Table **??**)

Seine is the most used gear to harvest Pacific sardine, Northern anchovy and Market squid. From Table 3 we can observe that 41% of vessels have used seine to harvest Market squid since the year 2000, 57% to harvest Pacific sardine and 51% to harvest Northern anchovy. In the case of Pacific herring, half of the vessel observed during the period

2000-2020 use gill net for their harvest instead of seine, where only 7% of vessels have used this gear. A similar pattern is observed when we compute the total landed weight for these four species during the period 2000-2020, presented in Table 4.

The ability to with suggested by using seine is confirmed when we analyze the gear used by different clusters.

3.3.2 Port landings

It is well known that substitution between Pacific sardine and market squid is more likely in the south of the California Current System as there is a fishery for both species, while in the north there is less target switching (CPS Workshop). Within California boundaries, between Coos Bay and San Francisco, there are ports with little opportunity to handle large volumes of market squid landings due to a lack of infrastructure. It is possible to truck landings to processor from these ports, but due to transport cost this is unlikely to be profitable. Thus, a shifting north of the fishing ground of market squid could imply that market squid is not targeted, independently of its biomass levels (CPS workshop)

In average, a vessel land in 4.8 ports, with an standard deviation of 3.94.

Composition varies geographically. We show in Figure 5 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.

(« From PFMC [2020]: “However, the anchovy fishery is still a very important part of the CPS fishery, as it is the only fishery locally available in Monterey when squid are not available, and the directed sardine fishery is closed”. also: “The Pacific sardine fishery in Oregon operates as a day fishery with vessels based primarily in Astoria where processing plants for sardine operate”. “Weather and tides are major factors in fishing operations and timing of vessels transiting in and out of the Columbia River.”»)

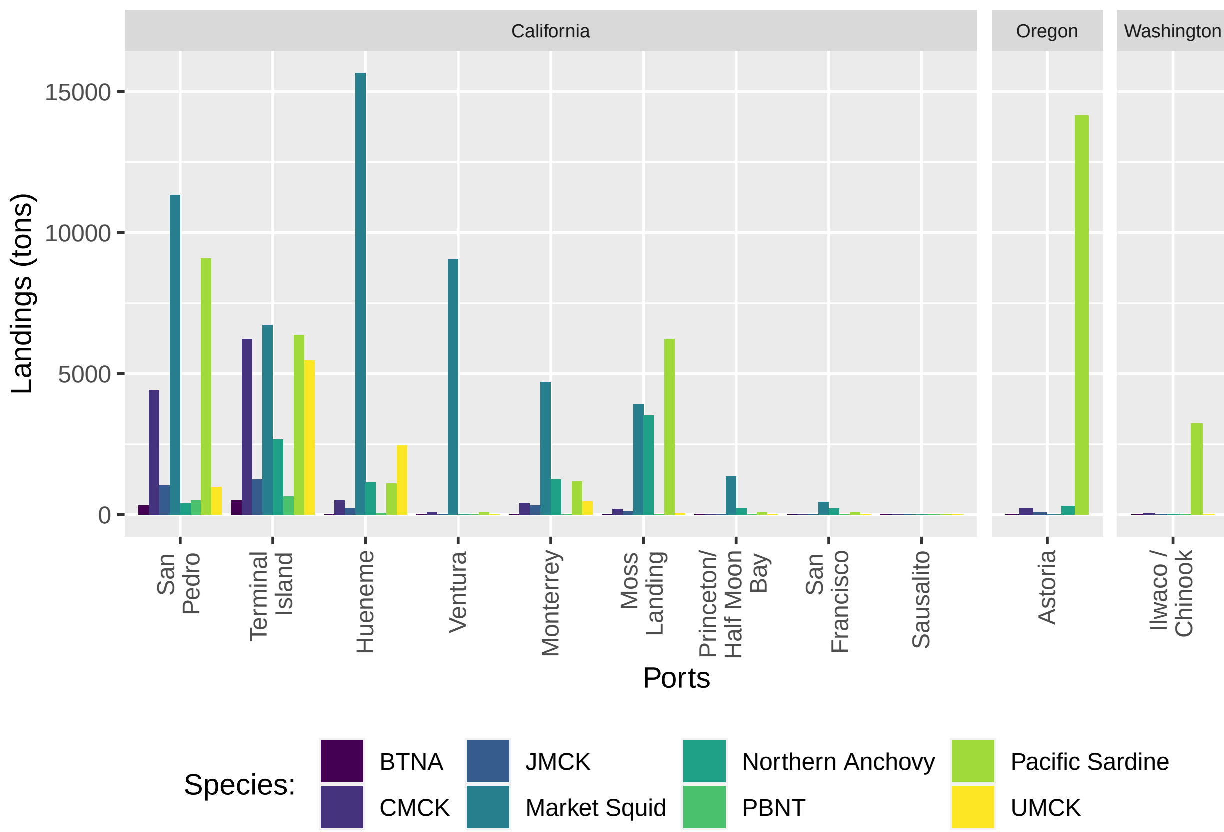

Figure 5: Annual average landings by port area.

To analyze substitution more in detail, we compute total annual landing by port during 1980-2020 period (Figure 6). 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 6 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 **??**. This would be suggesting an unintended consequence from a policy that aims to only affect Pacific sardine, but its effect affects indirectly other fisheries [Richerson and Holland, 2017].

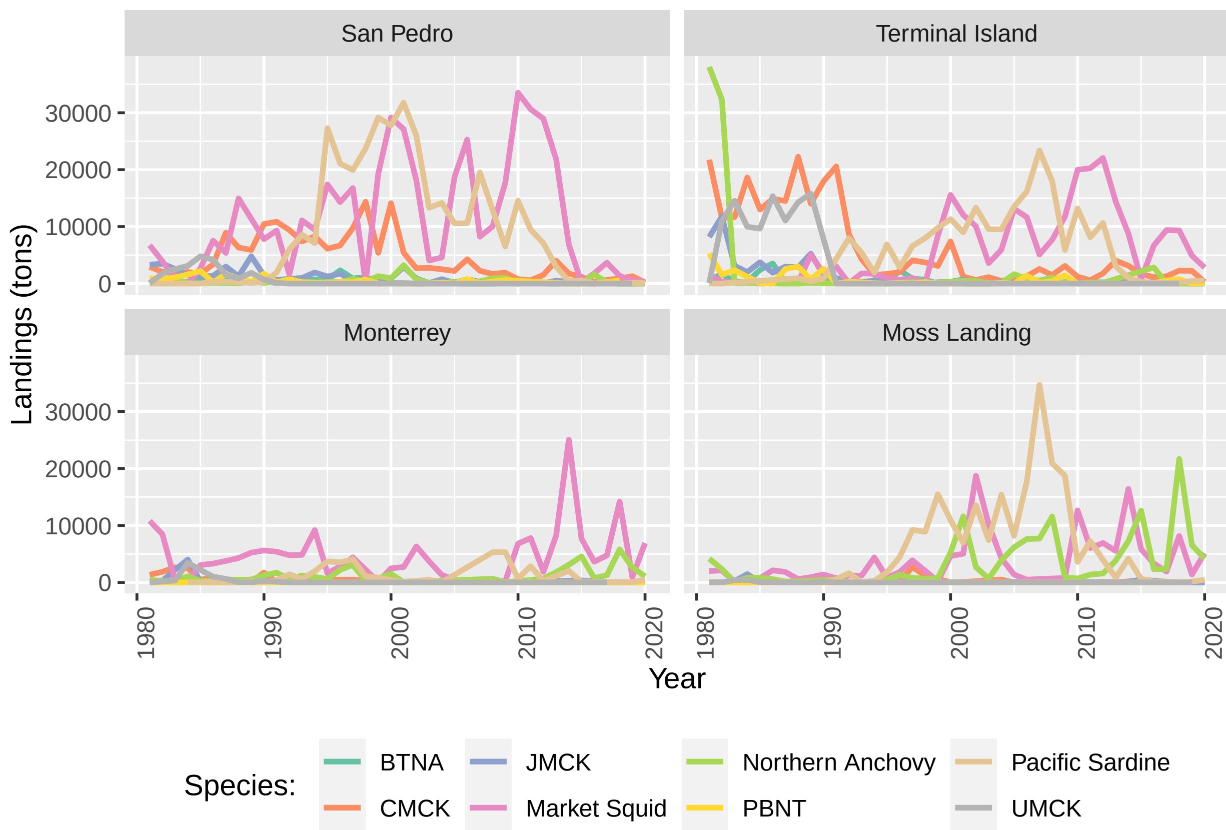

Figure 6: Total annual landing by port area. 2000 - 2020. *Notes:* CLO = Columbia River (OR); LAA = Los Angeles; MNA = Monterey; SBA = Santa Barbara; SFA = San Francisco.

« 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? »

3.3.3 Vessel lenght

There is heterogeneity on vessel characteristics depending on the gear and target species. In general, vessel harvesting Pacific herring tends to be smaller in length (see Table **??**), except for vessels using pole. Vessels using seine and harvesting Market squid, Pacific sardine and Northern anchovy have similar length, suggesting easier substitution between these species. About fishing days…

3.3.4 Fishing days

3.4 Other determinants of behavior

4 Methods

4.1 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.[4] 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. Distribution of species have change relative to ports in the last decades [Selden et al., 2020]. Thus, it have been used to explain variability in fish landings [Selden et al., 2020, Smith et al. [2021]]. 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.[5] 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.[6]

Figure 8 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

[4]N/A were converted to zero.

[5]Selden et al. [2020] use the 75th quantile of the travel distances made by vessels to define the availability of an species associated to a port for multiple species, and weight this distances by the catch of those species.

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

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.

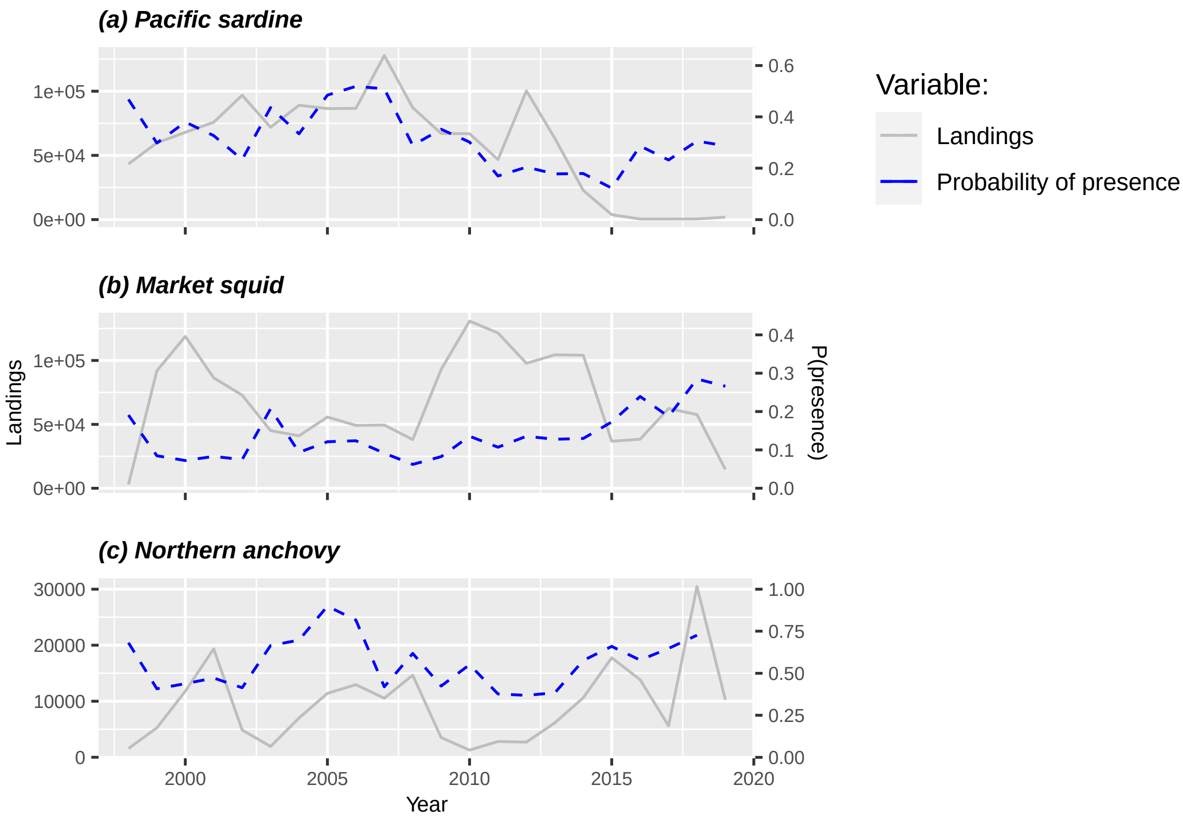

Figure 7: Landings v/s probability of presence by port area. *Notes:* LAA = Los Angeles; MNA = Monterey; SBA = Santa Barbara.

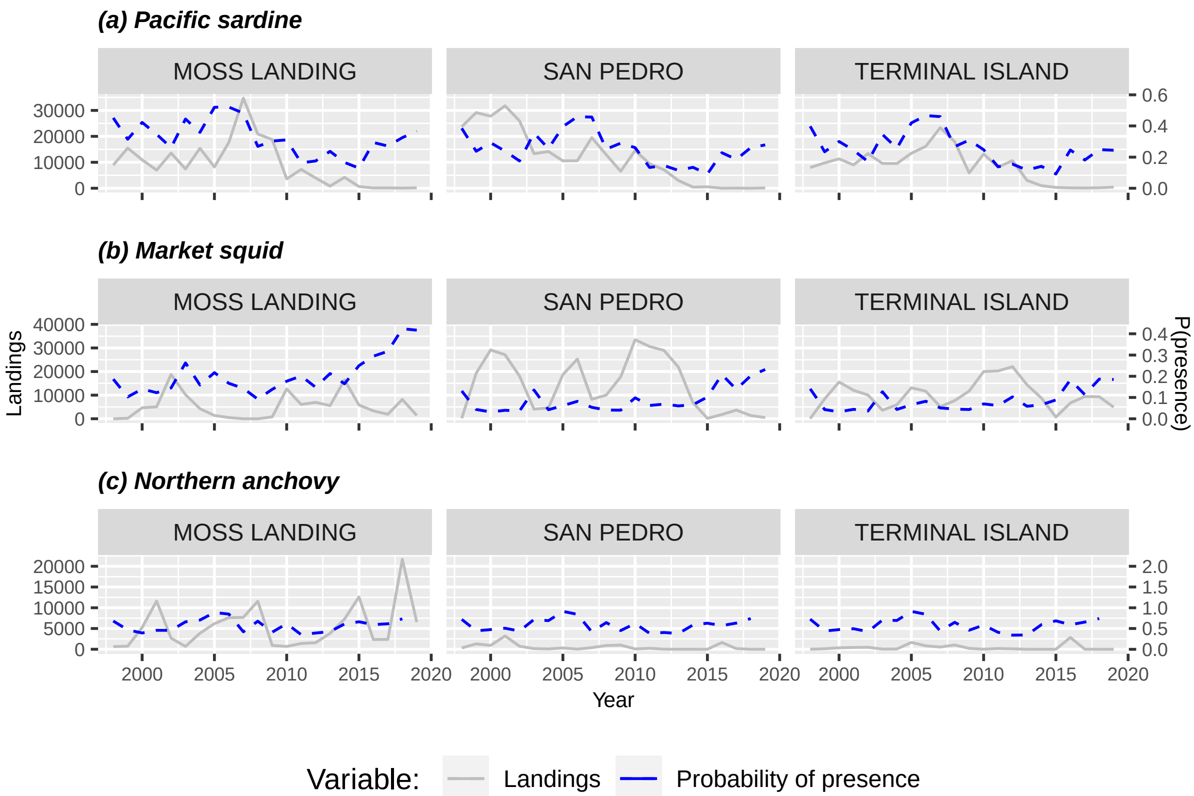

Figure 8: Landings v/s probability of presence by port area. *Notes:* LAA = Los Angeles; MNA = Monterey; SBA = Santa Barbara.

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:

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

where q_{it} 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.[7] The distribution $f\left(q_{it}|\theta_i\right)$ can be rewritten as:

$$f\left(q_{it}|\theta_i\right) = \begin{cases} p_{it} & \text{if} \quad q_{it} = 0 \\ [1 - p_{it}]\,\text{gamma}\left(q_{it}|\frac{\mu_{it}^2}{\sigma^2}, \frac{\mu_{it}}{\sigma^2}\right) & \text{if} \quad q_{it} > 0. \end{cases}$$

where $\text{logit}(p_{it}) = \mathbf{X}\gamma_\mathbf{i}$ and $\mu_{it} = \mathbf{X}\beta_\mathbf{i}$. Specifically μ_{it} is defined as the following:

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

$\text{logit}(p_{it})$ follows the same structure, but coefficient β_i are replaced by γ_i.

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.

WEATHER ALSO. BAD WEATHER REDUCE FISHING DECISION, Become risky, but also this is compare to revenue and how risk averse is a fishermenr (see Lisa's work)

We include the Annual Catch Limit (ACL) for the Pacific sardine model as an additional explanatory variable in both μ_i and $\text{logit}(p_i)$ equations. ACL variable is the total quota allocated each year for this fishery and was 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.

- NOTE: We have to think about some arbitrary decision with the database:
  - If we don't observe price, how we fill the NA. I calculate the year/month mean by port, then by port code, then by port area, then by state.
  - Same for SDMs. I first I get an average month/year by port code and then by port area.

Note: We have to think about: + Which port to exclude/include. I'm including port where substitution may happen (there is landing of sardine and squid) + At which level should I conduct the analysis? Port code or port area? I start with port area.

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

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

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 9.

4.2 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?» « We can use the approach of metier, where a choice is created from data (see Andersen, 2012, ICES). Here would be a combination of target species» <>** 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 [Richerson and Holland, 2017] (MORE REF), 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]
- Years in the sample that the vessel have participate in the fishery.

We model the probability p_{ijm} that vessel i fishes species j in month y as:

$$\begin{aligned}\text{logit}(p_{ijy}) =& \beta_1 + \beta_2 Closure + \beta_3 Mean.revenue_j + \beta_4 ExpectedCatch_j \\ &+ \beta_5 HHI_i + \beta_6 Percent.revenue_j + \beta_7 LCG_i + \beta_8 LI_i + \beta_9 Year.fished.\end{aligned}$$

Note that we are not able to observe if a vessel leave the CPS fishery for another resource or actually exit fishing entirely. Therefore, the outside option include is interpreted as "No fishing in any of the CPS fishery".

Should we study also the desicion to leave or stay the CPS fishery? I think in implicit in the participation model. Can we test this using the prediction from that model?

First, we observe how many vessel participate in both the Pacific sardine and market squid fishery. To do this, we first have to define what we understand as participation. Following Richerson and Holland [2017], we consider a vessel participate in a specific fishery if they met the following criteria:

1. Harvest the species during the period 2000-2014 (before the Pacific sardine closure)
2. Total annual revenue from the species averaged at least 1000 USD per year over 2000–2014. This calculation exclude years where the vessel did not fish.
3. Revenue from the species at least 5% of total vessel revenue per year over 2000–2014.
4. The vessel fished at least 3 of 15 years in 2000–2014.

From 2000 to 2014, there are 74 vessels that participate in both Pacific sardine and market squid fisheries, while 26 vessel participate in the Pacific sardine but not in the market squid fishery, and 82 vessels participate in the market squid fishery but not in the Pacific sardine fishery. From this calculation, we can infer that it is more likely that a vessel that harvest Pacific sardine will also harvest market squid, instead of the opposite. This is also reflected in Figure **??**, which shows the number of vessel that harvest squid in a year conditional they also harvest sardine, and the number of vessel that harvest sardine in a year conditional that they also harvest squid.

4.3 Effort susbsitution

- Time series of number of trips (as a proxy for effort) for all the species

- Richerson and Holland [2017] use a method identify the nature of the outliers in an ARMA time series model (read more if interested)
  - I propose to estimate a system of simultaneous equations (VECM model) to study equilibrium of effort and short-run and long-run effects of the closure (structural breaks)
  - Have a long-run equation for each species (simultaneously estimated) and test for structural break in this long-run relationship.

4.4 Seasonality changes

- Seasonality can be studied calculating monthly share of total trips by species, regress it using month dummiues and see any is there any structural change after the closure [Richerson and Holland, 2017].

5 Results

5.1 Landing model

5.1.1 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 **??** 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.

In addition to a posterior predictive check, we also check divergence and treedepth.[8] 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.

5.1.2 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 **??** 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

[8] Explain what are these concepts. . .

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.

5.1.3 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 **??**. 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 **??**, 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.

We found some similar findings for market squid in Figure **??**. 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.

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.

5.1.4 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.

5.2 Multispecies participation model

6 Predictions

...

7 Conclusions

A possible extension of our research is to consider spatial autocorrelations between ports.[9] 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.

References

N. Thompson Hobbs and Mevin B. Hooten. *Bayesian models*. Princeton University Press, 2015.

Stephen Kasperski and Daniel S Holland. Income diversification and risk for fishermen. *Proceedings of the National Academy of Sciences*, 110(6):2076–2081, 2013.

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.

PFMC. Status of the pacific coast coastal pelagic species fishery and recommended acceptable biological catches: Stock assessment and fishery evaluation for 2019. Technical report, 2020.

PFMC. Coastal pelagic species fishery management plan. Technical report, 2021.

Kate Richerson and Daniel S Holland. Quantifying and predicting responses to a us west coast salmon fishery closure. *ICES Journal of Marine Science*, 74(9):2364–2378, 2017.

Rebecca L Selden, James T Thorson, Jameal F Samhouri, Steven J Bograd, Stephanie Brodie, Gemma Carroll, Melissa A Haltuch, Elliott L Hazen, Kirstin K Holsman, Malin L Pinsky, et al. Coupled changes in biomass and distribution drive trends in availability of fish stocks to us west coast ports. *ICES Journal of Marine Science*, 77(1):188–199, 2020.

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

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.

Youen Vermard, Paul Marchal, Stéphanie Mahévas, and Olivier Thébaud. A dynamic model of the bay of biscay pelagic fleet simulating fishing trip choice: the response to the closure of the european anchovy (engraulis encrasicolus) fishery in 2005. *Canadian Journal of Fisheries and Aquatic Sciences*, 65(11):2444–2453, 2008.

Junjie Zhang and Martin D Smith. Heterogeneous response to marine reserve formation: a sorting model approach. *Environmental and Resource Economics*, 49(3):311–325, 2011.

Table 1: Cluster by percentage of landings by species.

	Pacific mackerel	Market squid	Northern anchovy	Jack makerel	Pacific bonito	Pacific sardine	Bluefin tuna	Unspecified mackerel	Obs.
1	0.12	99.48	0.05	0.03	0.04	0.23	0.02	0.02	271
2	0.45	1.70	0.01	0.52	95.50	0.00	1.14	0.67	81
3	1.04	2.27	0.00	0.56	3.13	0.00	92.37	0.62	107
4	1.32	3.16	0.79	0.36	0.00	93.97	0.17	0.23	109
5	44.55	6.36	1.13	11.78	16.57	4.10	9.59	5.92	70
6	96.92	0.22	0.00	0.78	0.93	0.44	0.21	0.50	162
7	0.39	0.35	87.42	0.81	1.36	6.07	3.61	0.00	52
8	5.92	61.41	3.50	0.85	0.97	26.07	0.41	0.87	103
9	5.59	0.24	0.31	0.96	1.87	0.16	0.56	90.31	27
10	6.82	1.20	0.00	85.90	0.00	1.13	0.19	4.77	101

Table 2: Cluster by percentage of landings by species (main species).

	Pacific mackerel	Market squid	Northern anchovy	Pacific sardine	Obs.
1	0.43	99.05	0.06	0.47	309
2	95.35	2.05	0.36	2.24	278
3	1.64	3.07	0.76	94.53	114
4	0.63	0.34	93.14	5.88	54
5	9.89	55.41	4.12	30.57	87

Table 3: Percentage of vessels using a gear to harvest CPS species.

	Market squid	Northern anchovy	Pacific sardine
Dip Net	0.26	0.03	0.06
Gill Net	0.02	0.00	0.04
Midwater Trawl	0.07	0.07	0.12
Other Net Gear	0.09	0.27	0.21
Pole	0.16	0.06	0.08
Seine	0.41	0.57	0.51

Table 4: Landings of CPS species by gear used.

	Market squid	Northern Anchovy	Pacific Sardine
Dip Net	18418.00	13.00	47.00
Gill Net	1.00	0.00	1.00
Midwater Trawl	8.00	0.00	14.00
Other Net Gear	14702.00	6202.00	110740.00
Pole	37.00	0.00	0.00
Seine	760105.00	100843.00	199050.00

Table 5: Average number of CPS species landed by a vessel by gear used.

	1	2	3	4	5
Midwater Trawl	0.03	0.92	0.29	0.00	0.03
Other Net Gear	0.00	0.00	0.28	0.02	0.07
Roller Trawl	0.14	0.03	0.00	0.00	0.00
Seine	0.49	0.00	0.36	0.12	0.88
Troll	0.01	0.00	0.00	0.60	0.00

Table 6: Average number of ports where a vessel landed their CPS species catch.

	Species
Market squid	2.58
Northern Anchovy	1.61
Pacific sardine	2.25

Table 7: Vessel lenght used in the CPS fishery by gear used.

	Market squid	Northern Anchovy	Pacific Herring	Pacific Sardine
Dip Net	43.16	34.83	14.76	41.12
Gill Net	37.50	0.00	34.26	34.07
Midwater Trawl	80.21	92.00	84.88	85.94
Other Net Gear	61.34	60.30	48.88	72.47
Pole	23.01	25.00	33.57	22.35
Seine	61.47	61.01	47.30	63.07

Table 8: Number of days fishing by species and gear used

	Northern Anchovy	Pacific Herring	Pacific Sardine
Dip Net	0.00	2.97	0.00
Midwater Trawl	1.25	1.39	1.37
Other Net Gear	8.19	2.56	0.00
Seine	1.37	1.76	1.03

Table 9: Summary Statistics

Variable	N	Mean	Std. Dev.	Min	Pctl. 25	Pctl. 75	Max
Prob(presence): PSDN	16960	0.301	0.137	0.014	0.193	0.394	0.687
Prob(presence): MSQD	16960	0.132	0.104	0.011	0.054	0.183	0.672
Prob(presence): NANC	16951	0.547	0.177	0.092	0.411	0.674	0.955
Landings: PSDN	6382	181.483	288.67	0	2.858	236.327	2672.929
Landings: MSQD	11979	114.288	166.493	0	9.544	151.005	2197.037
Landings: NANC	2314	75.331	164.62	0	1.461	61.546	1633.578
Price: PSDN	16929	0.379	0.876	0.002	0.115	0.253	12.849
Price: MSQD	16907	0.781	0.515	0.019	0.622	0.886	18.558
Price: NANC	16756	0.539	0.877	0.003	0.124	0.647	7.91
Annual Catch Limit: PSDN	16982	88321.42	55062.73	0	50526	122747	186791