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The Impact of Environmental Variability on Fishers' Harvest Decisions in Chile

Using a Multi-Species Approach

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Big picture

- Marine resource distribution and abundance is changing due to climate variability, with heterogenous spatial effects (Poloczanska, Brown, Sydeman et al., 2013; Sumaila, Cheung, Lam et al., 2011).
- Harvest levels would be affected (Quezada, Tommasi, Frawley et al., 2023), as well as price and value of catches, fishing costs, fishers' incomes, among others (Sumaila, Cheung, Lam et al., 2011)

Research question

How will fishing decisions, aggregate catch levels, and the price of marine resources be affected under different climatic scenarios in the multispecies small pelagic fishery (SPF) in Chile?

- How do fishers **substitute between species**?
- Contribute to the limited local literature on multi-species economic modeling in Chile
  - Understand fishers' adaptive capacity helps to inform climate-resilient fisheries policies in Chile
  - See Peña-Torres, Dresdner, and Vasquez (2017) for ENSO effects in Jack Mackerel fishery using discrete choice models.
- We will focus in **climate variability** to estimate short-run responses.
  - i.e., climate change effect without adaptation (Auffhammer, 2018)

Why a Multi-Species Model?

- Diversification is a good strategy:
  - Improves income stability and climate resilience (Kasperski and Holland, 2013; Finkbeiner, 2015)
- Fishers respond to environmental variability by:
  - Maintaining the current strategy
  - **Reallocating effort to other species/areas (Gonzalez-Mon, Bodin, Lindkvist et al., 2021)**
  - Exiting the fishery (Powell, Levine, and Ordonez-Gauger, 2022)

Chile's Small Pelagic Fishery

Chile's Small Pelagic Fishery (SPF)

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Some facts

- Mainly composed by anchoveta, Jack mackerel, Sardine
- ~94% of national catch (SUBPESCA, 2020)
- Mostly harvested with purse-seiners
- In the Central-South (CS) region (Valparaiso-Los Lagos) all three species play a major role.
- SPF have been used primarily for fishmeal and fish oil production (Peña-Torres, Dresdner, and Vasquez, 2017) (~85% of jack mackerel for reduction)

Regulations

- Quota (TAC); divided between the small-scale and indutrial sector
- Industrial sector operates under ITQ
- RAE (*Regimen Artesanal de Extracción*) in some areas for small-scale fishery
  - Allocates regional quota to area or fishermen organization (i.e., catch shares)
- Anchoveta and sardine are regulated as a mixed-species fishery

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Status of the stocks (CS)

- Anchoveta:
  - Collapsed until 2018,
  - Overexploited in 2019,
  - Since 2020, within MSY limits.
- Sardine:
  - Within MSY levels, except in 2021 and 2023 (overexploited)
- Jack mackerel:
  - Overexploited until 2018, then within MSY limits.

Methods and data

Methodology Overview

Based on Kasperski (2015):

- Econometrics models
  - Estimate stock dynamics
  - Estimate trip-level costs
  - Estimate annual trips
  - Estimate inverse demand
- Simulations
  - Obtain optimal harvest and quota levels
  - Simulate climate change effects on profits, harvest and prices.

Harvest and biomass data

From IFOP:

- Trip-level data:
  - ID, departure and arrival times, vessel capacity, fleet and gear type, ports of departure and landing, haul timing and location, species, retained catch.
- Annual stock abundance by macro region (e.g. south-central Chile)
- Monthly landings by port/species.
- Prices paid by processing plants (IFOP surveys; month-region)

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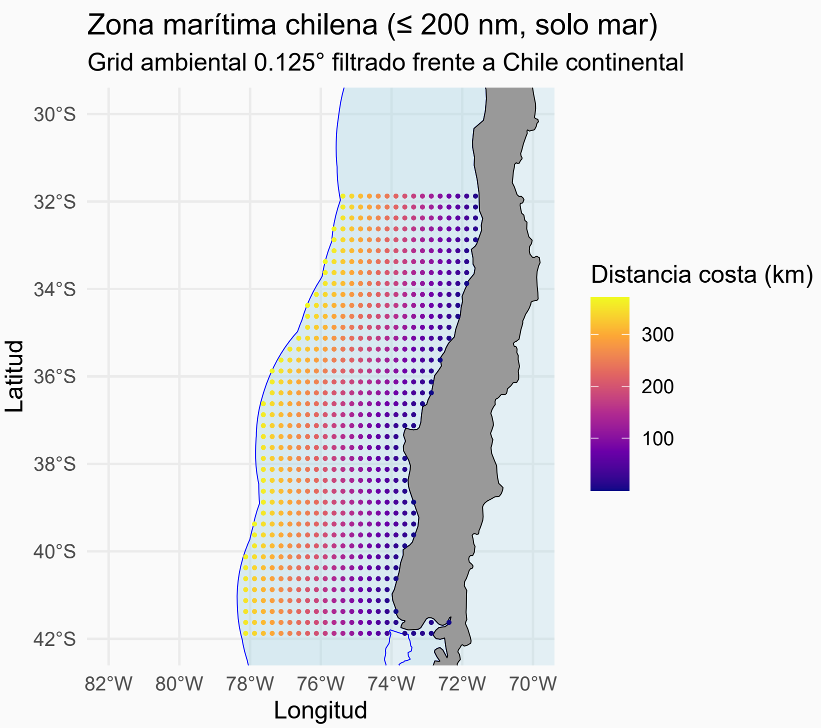
Environmental covariates

For the period 2012-2025:

- Daily salinity, sea surface temperature, and current speed and direction (E.U. Copernicus Marine Service Information, 2025a)
- Hourly wind speed and direction at the surface (E.U. Copernicus Marine Service Information, 2025b)
- Chlorophyll-a concentration (E.U. Copernicus Marine Service Information, 2025c)



Data Sources

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To be requested

- Average wage pay to crew member per hour (available?)
- Diesel cost.
- Permits by vessels
- Quota prices (auction or secondary markets, if available)
  - Captures forward-looking behavior and information (Birkenbach, Lee, and Smith, 2024).
  - Simplify the dynamic model to a static one (Reimer, Abbott, and Haynie, 2022).
- Quota by area/fishing organization for small-scale sector, and ITQ for industrial (by vessel?)
  - Information about Reallocations of quotas

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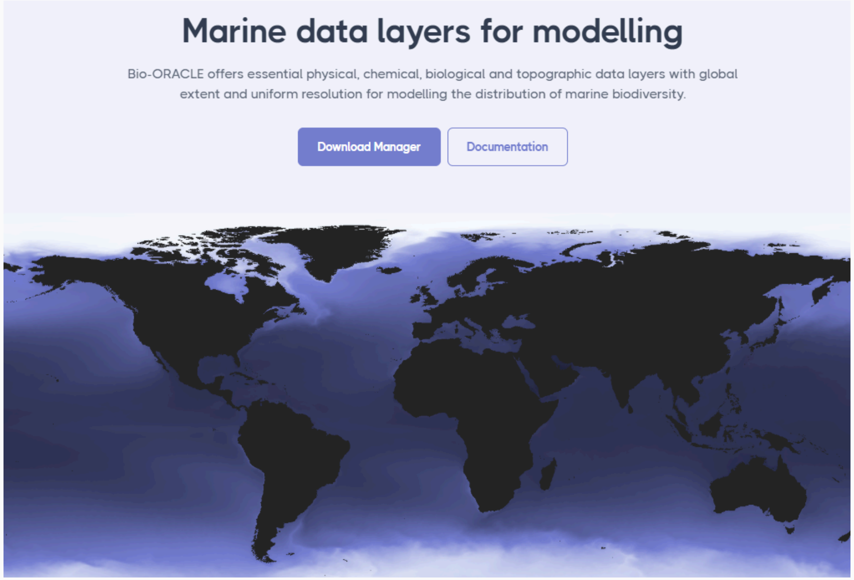
Data for projections

Bio-ORACLE

- Only decadal (e.g., 2040–2050) projections
- Different climate scenarios
- SST, salinity, currents and chlorophyll (4km resolution)
- No winds; CMIP6 for winds? (~100 km).



Econometrics models

Model 1: Stock Dynamics

$$x_{i,y+1} + h_{iy} = \underbrace{(1+r_i)x_{iy} + \eta_i x_{iy}^2}_{R_i(x_{iy})} + \underbrace{\sum_{j \neq i}^{n-1} a_{ij} x_{iy} x_{jy}}_{I_i(x_y)} + \rho_i Env_{iy} + \varepsilon_{iy} \quad i = 1, \ldots, n$$

where:

- x_{iy} is the fish stock by species $i = 1, \ldots, n$ in year y, n is the total number of species,
- h_{iy} is the annual harvest of species i on year y,
- r_i is the intrinsic growth rate of the resource i,
- η_i is a density-dependent factor related to the carrying capacity,
- α_{ij} are the interaction parameters between species.
- Env_{iy} includes **environmental covariates** (SST and chlorophyll)

The system of n growth equations can be estimated simultaneously using SUR

Model 2: Trip-Level Costs

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$$C_{vg} = \sum_{i=1}^{2n+M+k} \alpha_{g,\mathbf{x}_i} \mathbf{X}_{ivg} + \frac{1}{2} \sum_{i=1}^{2n+M+k} \sum_{j=1}^{2n+M+k} \alpha_{g,\mathbf{x}_i \mathbf{x}_j} \mathbf{X}_{ivg} \mathbf{X}_{jvg}$$

where $C_{vg} = wz^*_{vg}$ is the total cost incurred by vessel $v = 1, \ldots, V_g$ conditional on gear used $g = 1, \ldots, G$ -- Mostly purse seiners!

- w is a matrix of variable input prices.
- z^*_{vg} is the optimal quantity of input used
  - Crew members?
  - Time spent at sea?
  - Distance traveled?

Model 2: Trip-Level Costs

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$$C_{vg} = \sum_{i=1}^{2n+M+k} \alpha_{g,\mathbf{X}_i}\mathbf{X}_{ivg} + \frac{1}{2}\sum_{i=1}^{2n+M+k}\sum_{j=1}^{2n+M+k} \alpha_{g,\mathbf{X}_i\mathbf{X}_j}\mathbf{X}_{ivg}\mathbf{X}_{jvg}$$

where $\mathbf{X}_{vg}^{'} = [w; h_{vg}; x; Z_v; Env]$ is a matrix of explanatory variables, and $\mathbf{X}_{ivg}$ represents the ith column of the $\mathbf{X}_{vg}$:

- h_{vg} is a matrix of harvest quantities,
- x is a matrix of given stock levels of the species of interest, and
- Z_v is a matrix of given vessel characteristics.
- Env is a matrix of **environmental covariates**
  - e.g., wind intensity and wave conditions in each trip at the harvest location (or within a port radius?)

Model 3: Total Annual Trips

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The number of trips a vessel will take in a given year is assumed to follow a Poison distribution:

$$Pr\left[T^*_{vgy} = t_v\right] = \frac{exp^{-exp(U'_{vg}\beta_g)} exp(U'_{vg}\beta_g)^{t_v}}{t_v!}$$

where $U_{vg} = [p, w, h_{vg}, \bar{q}, Z_{vg}, Env]$ is a matrix of explanatory variables,

- p is a matrix of species prices,
- $\bar{q}$ is the annual quota level.
- Env include variables that reflect **annual weather conditions**
  - Accumulation of *bad weather days*?
  - *number of storms*?
- Other variables? State dependency?

β_g is a vector of coefficients to be estimated, and t_v is the number of trips taken by vessel v using gear type g in year y.

Model 4: Inverse Demand

The price of each species is modeled using an Inverse Almost Ideal Demand System (IAIDS). The log of the price p_{iy} of a species i in year y is the following:

$$\ln p_{iy} = \sum_{j}^{n} \gamma_j \ln h_{j,y} + \gamma_H \ln H_y + \gamma_{FM} \ln P_y^{\text{FishMeal}} + \epsilon_{iy}$$

where:

- $H_y = \sum h_{j,y}$
- P_y^{FishMeal} is the fish meal world price

Harvest may be endogenous

- Three Stage Least Squares (3SLS) procedure,
- $h_{j,y}$ instrumented by variables that affect supply function such as *SST*, *Chl*, and fuel prices.

Numerical optimization

Numerical optimization

Use models parameters to:

- Obtain the optimal **harvest** and **quota** using historical data
- Conduct numerical optimization to obtain optimal **harvest** and **quota** conditional on climate scenario.
- Evaluate **profits** and **species substitution**

Vessel maximization problem

In each year, a vessel maximizes profits by choosing their optimal number of trips T_g and harvest levels per trip $h_{g\tau}$ given a gear type:

$$\max_{h_{gt},T_g} \quad \pi_{vgt} = \sum_{\tau=t}^{T_g} \rho^{\tau} \left\{ P(h)h_{g\tau} - C_g(h_{g\tau}|w, x, Z, Env) \right\} \quad \tau = t, \ldots, T_g$$

$$\textbf{s.t} \quad q_{g,t+1} = \omega * \bar{q} - \sum_{t=1}^{t} h_{gt} \geq 0, \quad t = 1, \ldots, T-1, \quad g = 1, \ldots, G$$

- where:
  - ρ is the intra-annual discount factor,
  - ω is a vector of shares of $\bar{q}$, and
  - $h_{lt} = 0$ for all $l \neq g$.

Preliminary results

Is there any subtitution?

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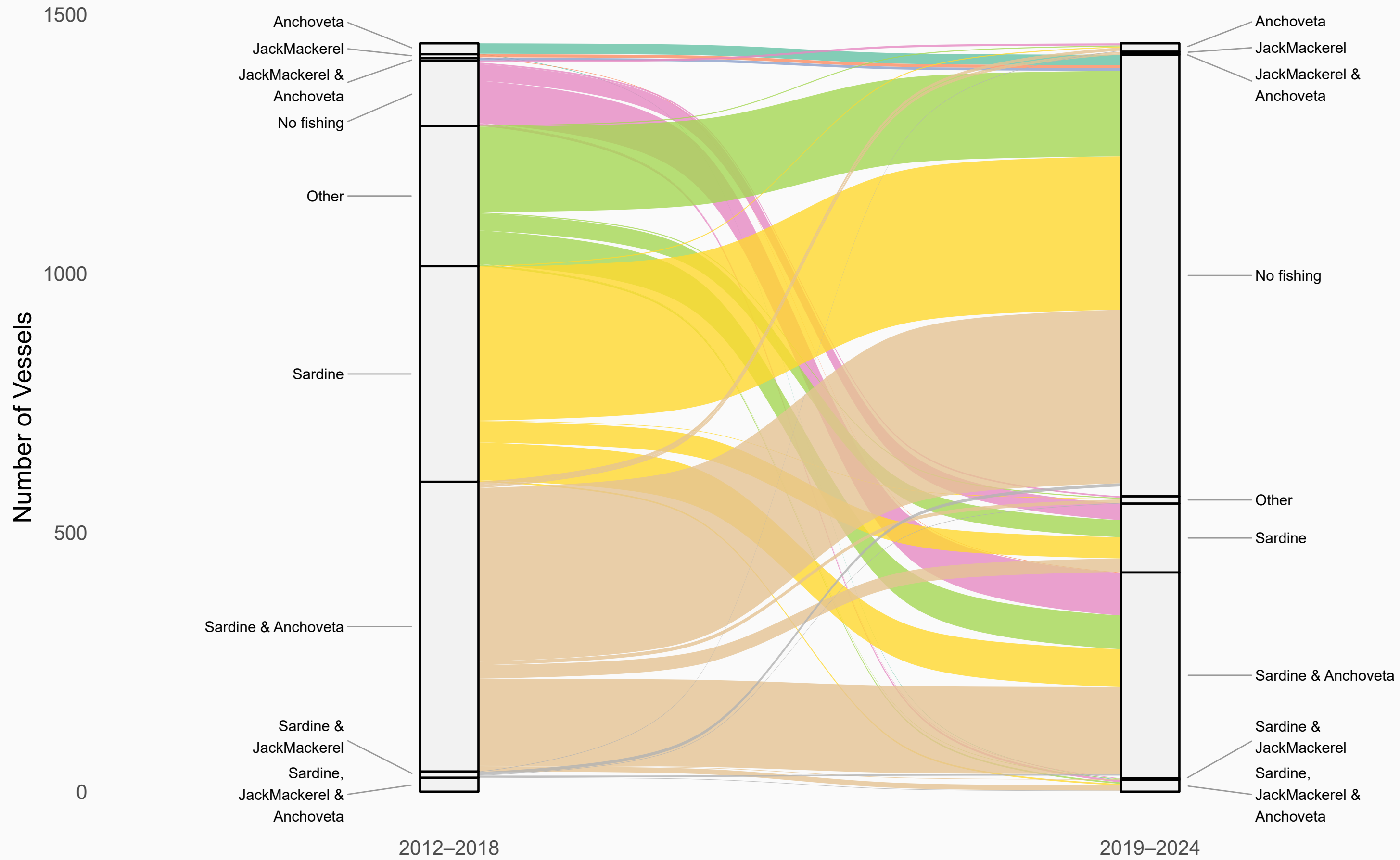
Small-scale vessels



Is there any subtitution?

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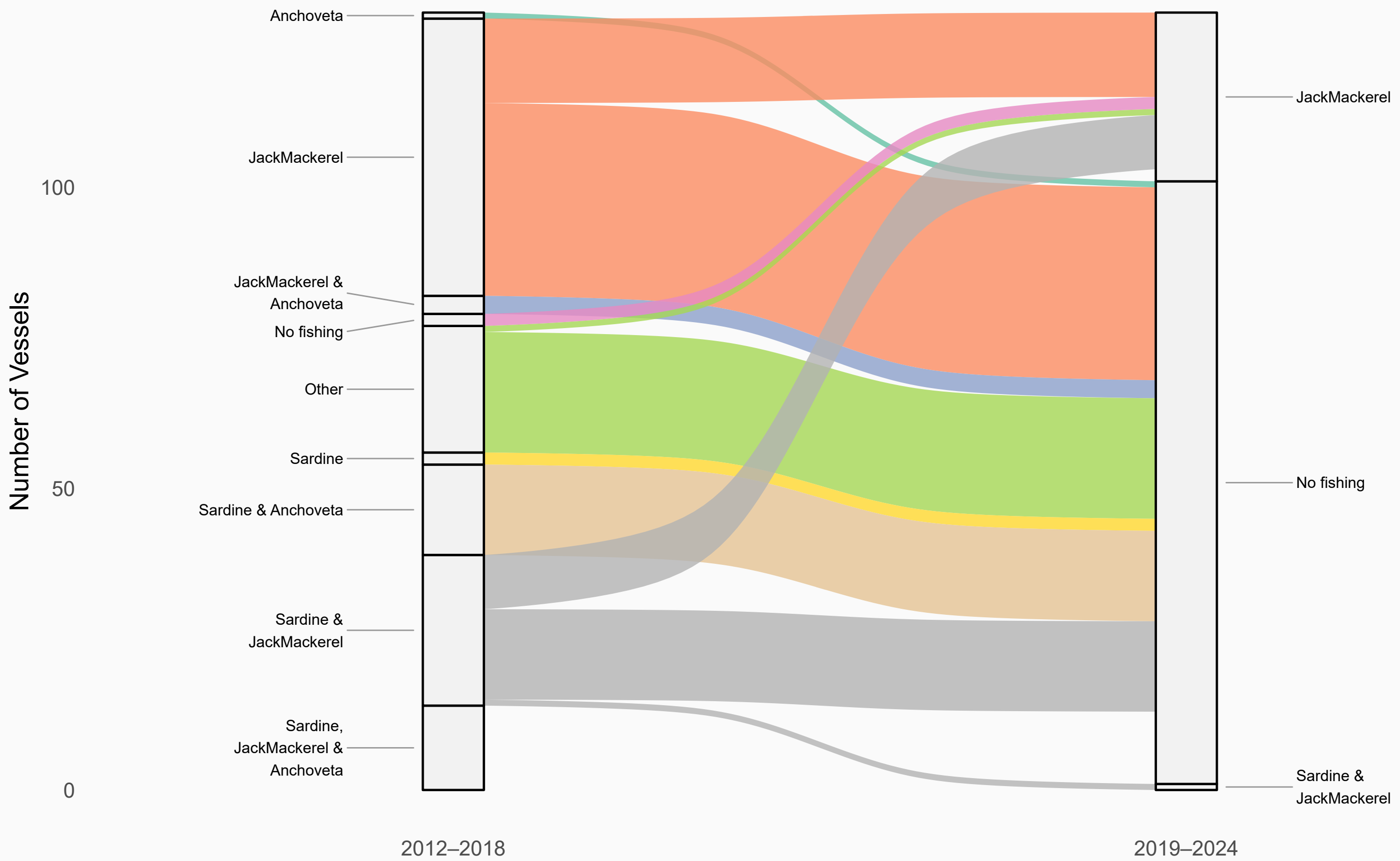
Industrial vessels



Stock dynamics

Seemingly Unrelated Regression (SUR) estimates of biomass dynamics for small pelagic species in Central–Southern Chile.

	Species		
	Sardine	*Anchoveta*	*Jack mackerel*
Biomass dynamics			
Constant	23.781***	10.355***	25.891***
Biomass (t)	0.353*	1.260***	1.035***
Biomass sq (t)	-0.011	-0.209***	-0.022**
Environmental effects			
SST	-12.377	-4.985	5.168
(SST) sq	52.233*	-2.526	-46.039
Chlorophyll-a	70.441**	-6.189	-15.631
Chlorophyll-a sq	155.277	59.220	438.550
Cross-species interactions			
Sardine × Jack mackerel	0.012	-	-0.008
Sardine × Anchoveta	0.017	-0.010	-
Anchoveta × Jack mackerel	-	0.011	0.045
Model fit			
R-squared (Adj.)	0.516	0.279	0.732

Entries are coefficients; significance: * p<0.10, ** p<0.05, *** p<0.01. Quadratic terms shown with “sq”; interactions use ×.

- SST and CHL improves model performance (F = 1.908; p-value = 0.07).

What’s Next?

- Finish biomass estimations
- Start soon with total annual trips
  - Hopefully, a short paper can come out of that work
- Two undergraduate students are working on the inverse demand (i.e., price) module for their theses
  - Results expected by July 2026
  - If time allows, they will also analyze long-run and short-run dynamics using a VEC model
  - Plan to write a paper based on their dissertations

¡Muchas gracias!

¿Preguntas?

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