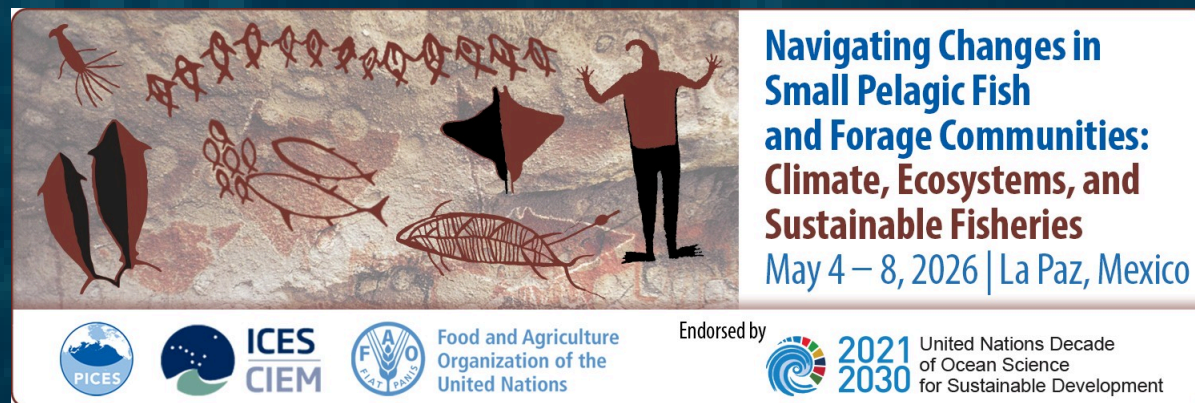


# Linking oceanographic variability and jack mackerel (*Trachurus murphyi*) abundance dynamics off Chile: insights from hydroacoustic observations and data-driven modeling

**Francisco Plaza-Vega**, Montserrat Aránguiz, Víctor Catasti, María Ángela Barbieri, Omar Chocotea & Eleuterio Yáñez  
USACH • IFOP • PUCV





# Roadmap

- **Context.** Jack mackerel in northern Chile: mobile schools, environmental drivers, trophic coupling, and climate variability.
- **Data.** IFOP hydroacoustic surveys aboard the **R/V Abate Molina**, with jack mackerel  $s_A$ , euphausiids, and hydrographic predictors.
- **Approach.** From acoustic observations to **Low / Medium / High aggregation states**, using interpretable machine learning.
- **Message.** Aggregation states reflect **hydrographic structure, oxygen-mediated habitat compression**, and **prey-field variability**.



# Why jack mackerel?

- **Chilean jack mackerel** (*Trachurus murphyi*) is a key pelagic resource in the southeastern Pacific, forming large and mobile schools that respond to environmental forcing and trophic availability (Arcos, Cubillos, and Núñez 2001; A. Bertrand et al. 2004, 2016; Arnaud Bertrand et al. 2006; Lima et al. 2020).
- Its distribution changes with **circulation, productivity fronts, oxygen structure, and ENSO-related variability**.
- This makes it a useful case study for **ecosystem-informed and climate-aware fisheries monitoring** (Lima et al. 2020).

## Central question

*Can hydroacoustic observations and interpretable machine learning help identify the environmental windows associated with jack mackerel aggregation states?*

# Hydroacoustic surveys aboard R/V *Abate Molina*



- IFOP surveys provide **fishery-independent** observations of pelagic aggregations.
- Hydroacoustic surveys provide spatially explicit observations of jack mackerel acoustic density  $s_A$  and euphausiid aggregation states (Foote et al. 1987; MacLennan, Fernandes, and Dalen 2002; Catasti et al. 2025, 2026).
- The cruise platform is part of the story: data come from **field-based acoustic assessment**, not only from fishery-dependent records.

# Aim of this work

- Characterize **aggregation states** of jack mackerel ( $s_A$ ) and euphausiids during the 2023–2025 IFOP hydroacoustic surveys.
- Link those states to **hydrographic, spatial, oxygen-related, and trophic predictors**.
- Evaluate whether interpretable ensemble models can identify **environmental windows** associated with low, medium, and high aggregation states.

The focus is not only predictive performance, but ecological interpretation of aggregation structure in a dynamic upwelling system.

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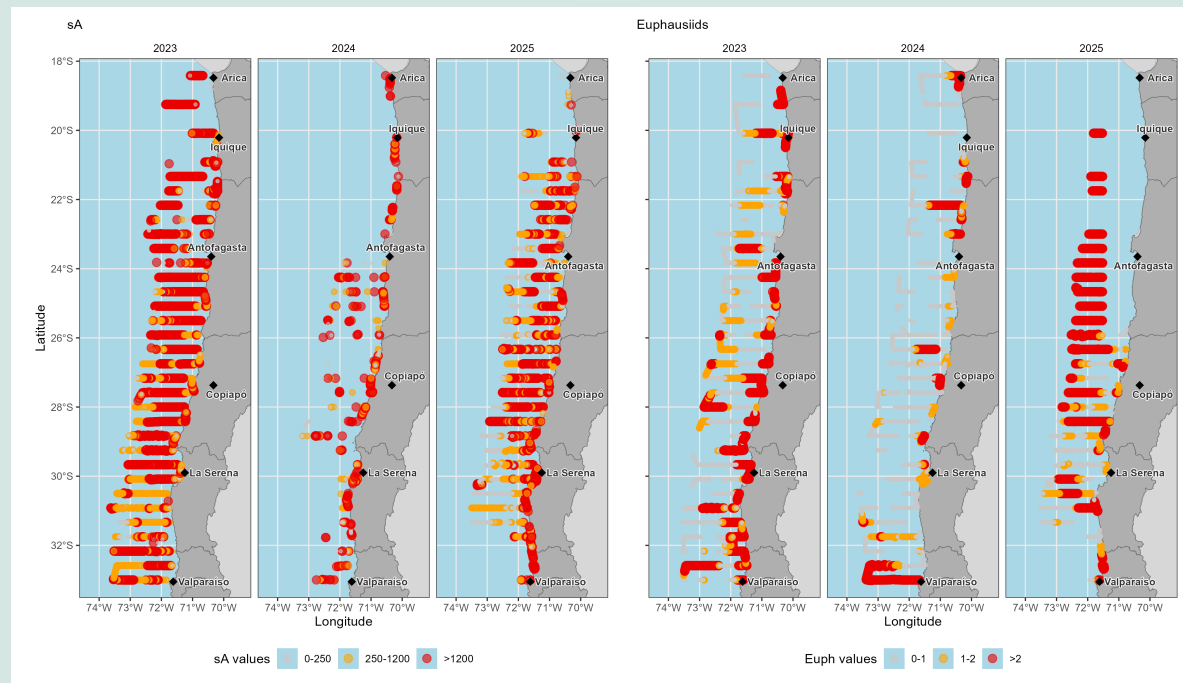


# Data

# Study area and survey data

**Survey:** hydroacoustic campaigns **2023-2025** in Northern Chile (approx. **18–26°S**).

**Observation unit:** Acoustic integration units along standardized transects.



Assessment zone embedded in the Humboldt Current System, where coastal upwelling, mesoscale variability, and oxygen minimum layer structure pelagic habitat conditions (Hormazábal, Yuras, and González 2004; Escribano, Hidalgo, and Krautz 2009; Espinoza-Morriberón et al. 2019).

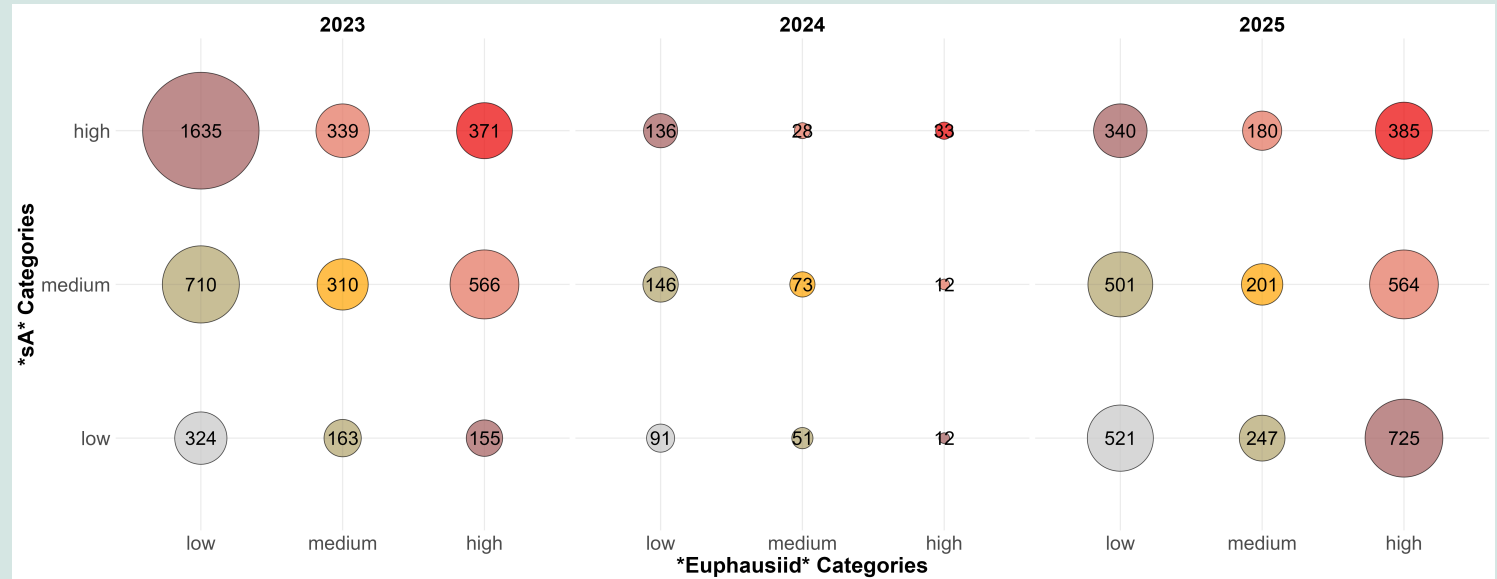
# From acoustic density to aggregation states

These thresholds follow operational criteria used in IFOP hydroacoustic assessments and allow aggregation intensity to be interpreted in a monitoring-oriented framework (Catasti et al. 2025, 2026).

## Operational categories

Target	Low	Medium	High
J.m. $s_A$	0–250	250–1200	>1200
Euph.	0–1	1–2	>2

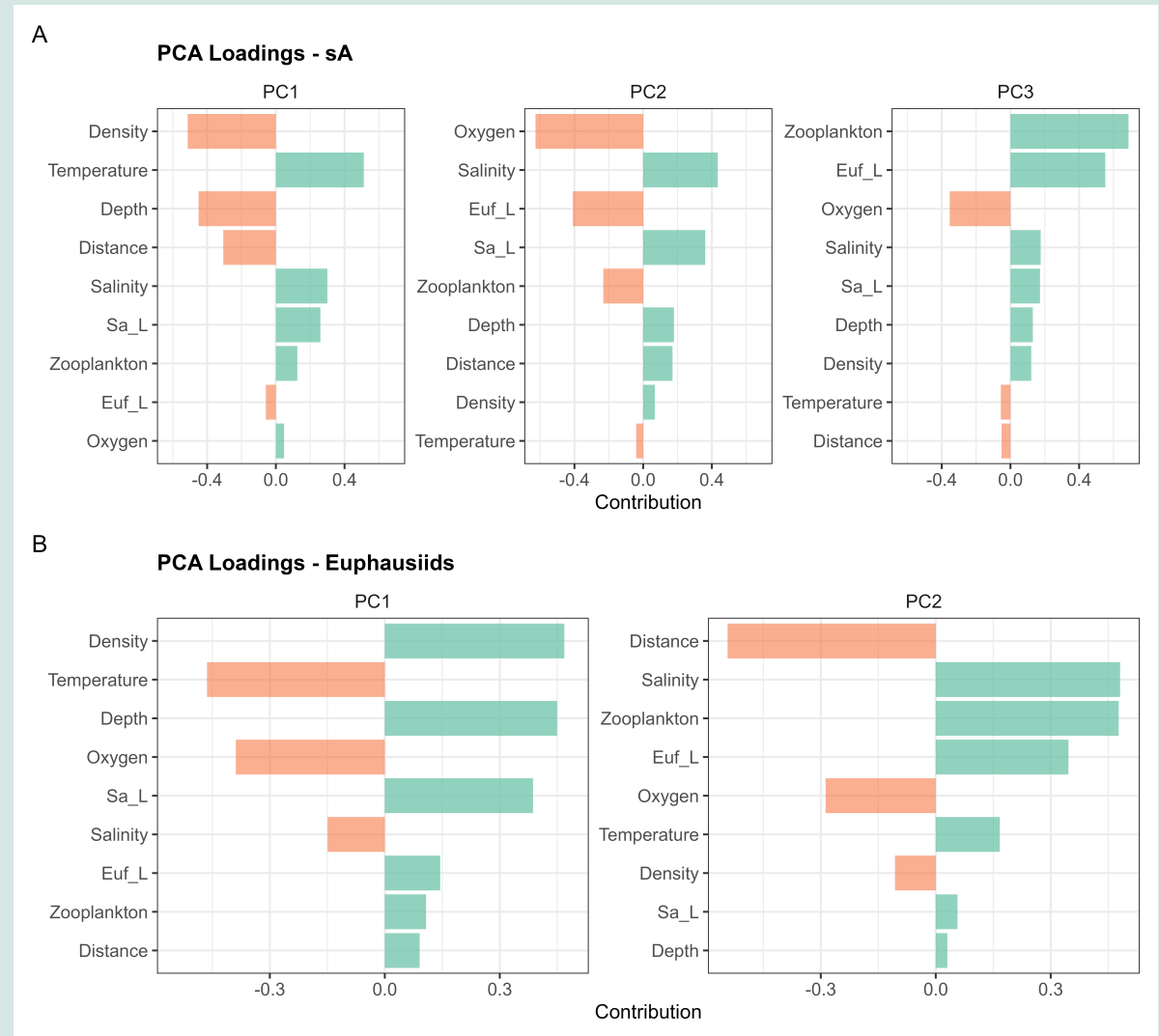
$s_A$ :  $m^2/nmi$ ; euphausiids:  $ind/m^3$ .



The goal is to identify environmental conditions associated with **operational aggregation states**, not to estimate a continuous mechanistic abundance curve.

# Environmental covariates and structure

- Predictors summarize **hydrographic structure, spatial setting, and trophic context**.
- Main variables include depth, distance to coast, temperature, salinity, oxygen, density, euphausiids, and zooplankton.
- PCA helps visualize dominant gradients, but the full predictor space is retained for the main supervised models.



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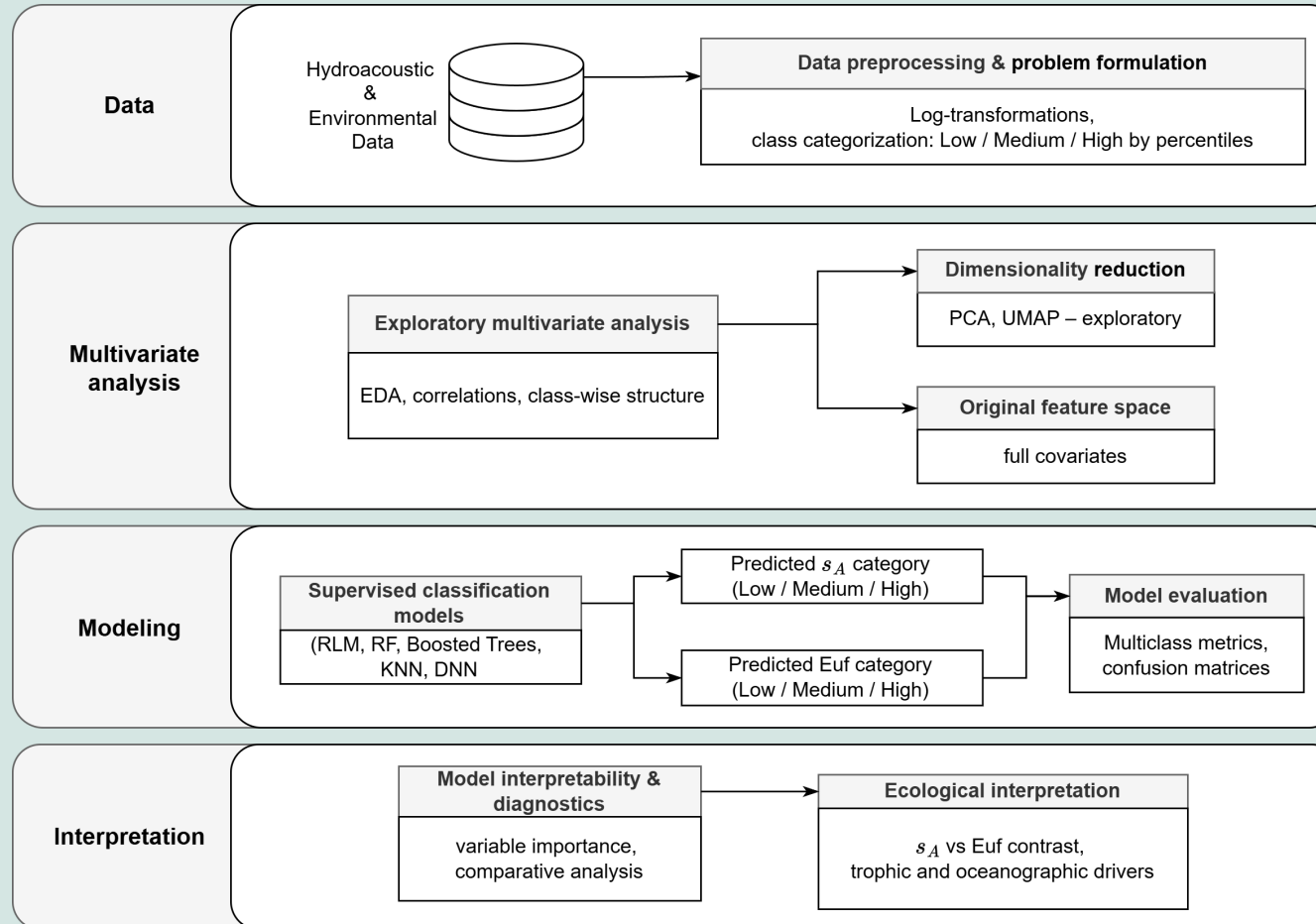
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Item	Value
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# Methods

# Analytical workflow



Data preprocessing → environmental structure → supervised classification → ecological interpretation

# From model comparison to ecological interpretation

## Ecological reason

Pelagic aggregation states are expected to depend on **nonlinear thresholds** and **interactions** among hydrography, oxygen, distance to coast, and prey fields.

## Statistical reason

Several classifiers were compared to evaluate different assumptions about the environment–aggregation relationship.

- We evaluated **multinomial logistic regression**, **Random Forest**, **XGBoost**, **KNN**, and **DNN** models.

## Spoiler alert!

The two models that will reappear in the Results section are **Random Forest** for jack mackerel  $s_A$  and **XGBoost** for euphausiid aggregation states.

- Tree-based ensemble models are well suited to nonlinear and correlated ecological data, while variable importance and SHAP provides a consistent framework for interpreting model predictions (Breiman 2001; Chen and Guestrin 2016; Elith, Leathwick, and Hastie 2008; Lundberg and Lee 2017; Molnar, Casalicchio, and Bischl 2020).

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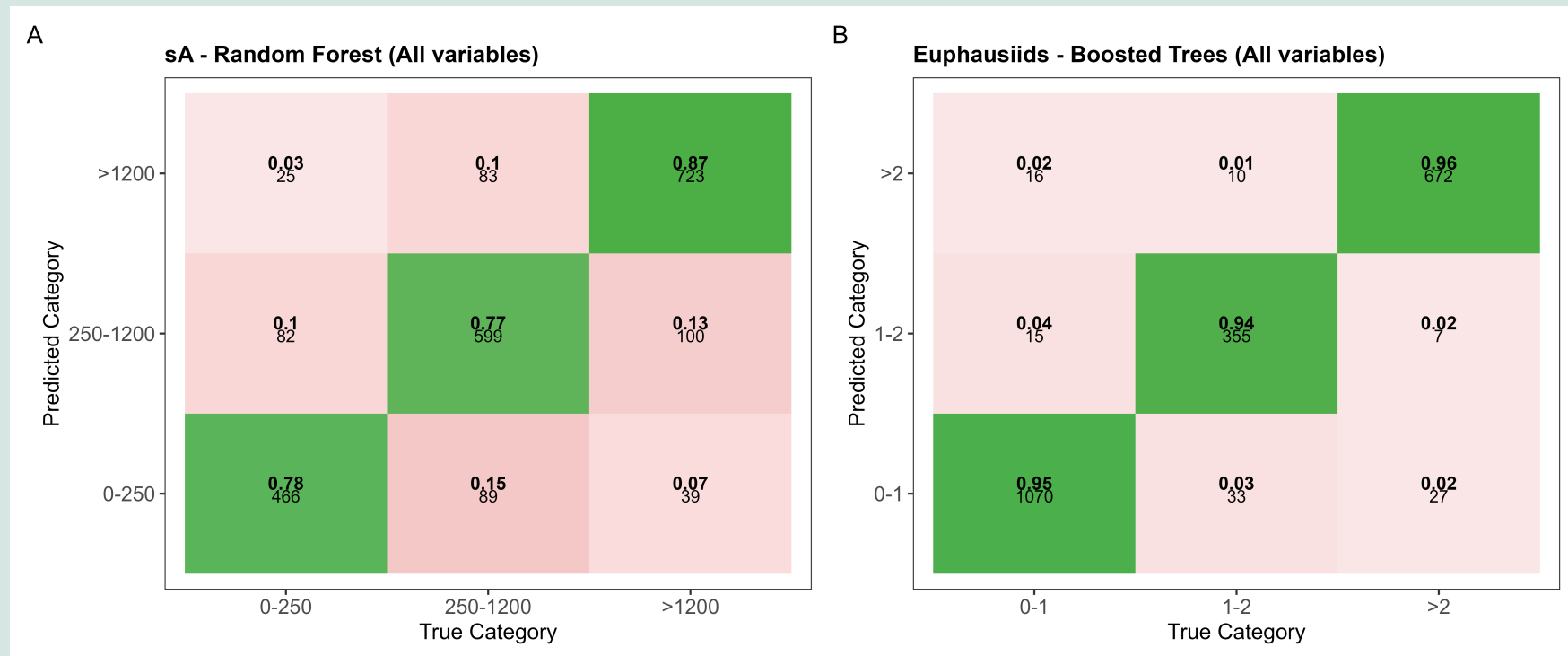
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# Results

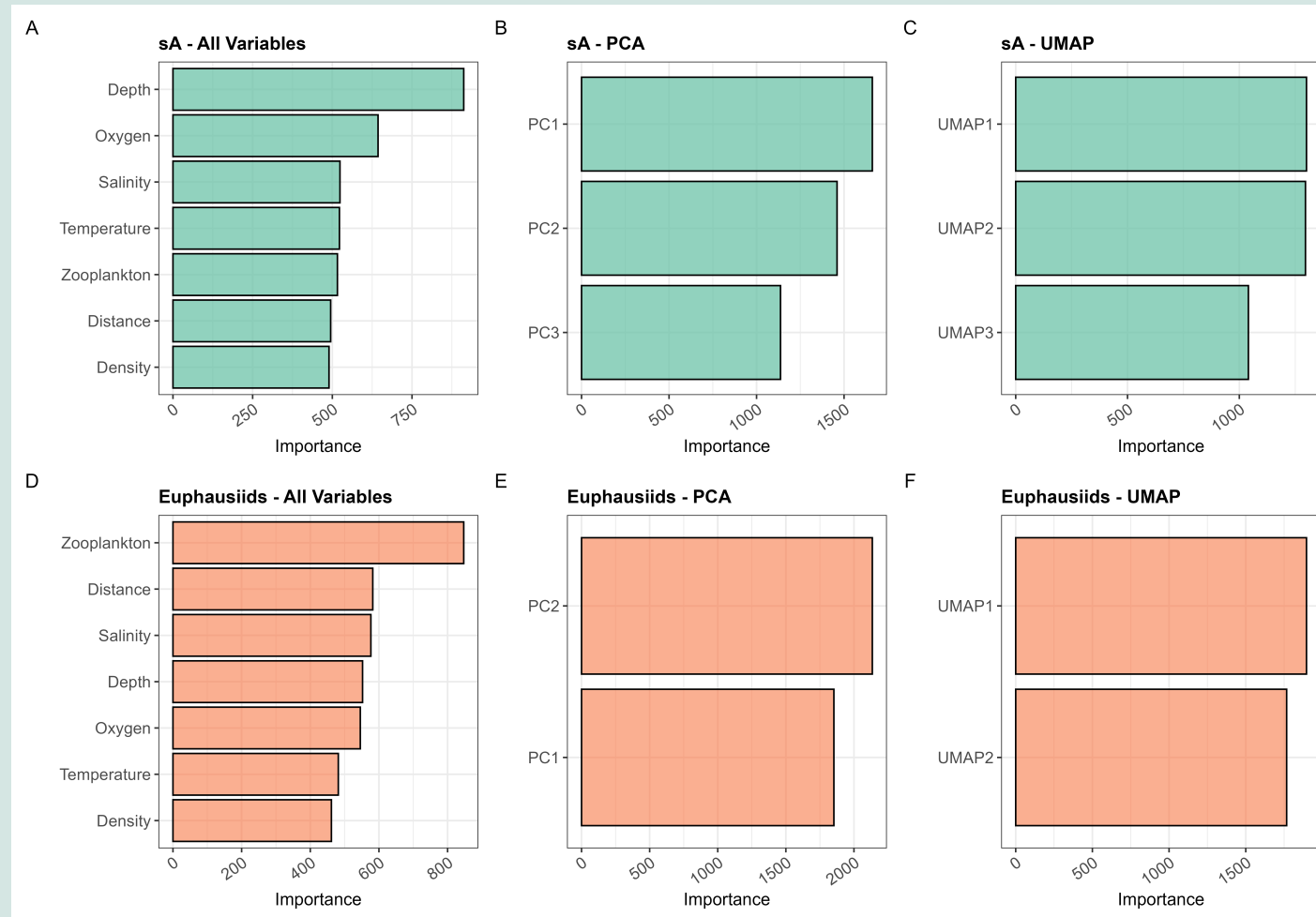
# Predictive performance

Ensemble models showed strong out-of-sample discrimination under the full environmental predictor set.



- Jack mackerel  $s_A$ : **Random Forest** accuracy  $\approx 0.81$ , macro-F1  $\approx 0.81$ .
- Euphausiids: **XGBoost** accuracy  $\approx 0.95$ , macro-F1  $\approx 0.94$ .
- Most errors occur between **adjacent categories**, not between extreme low and high states.

# Environmental drivers: global rankings

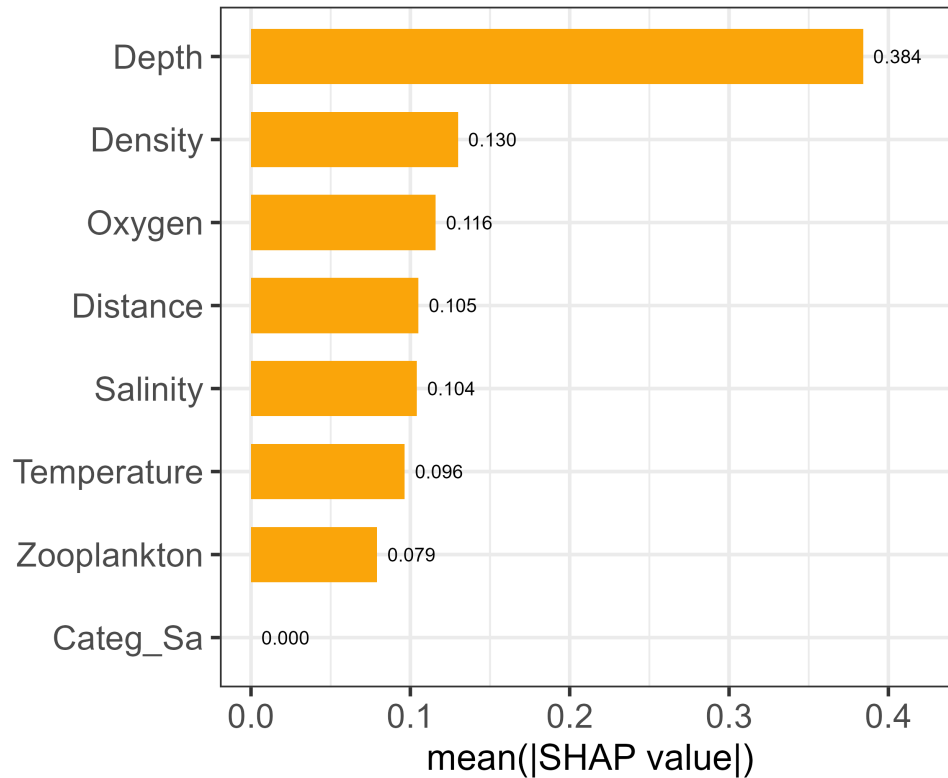


- For jack mackerel, importance is distributed across **hydrographic and spatial gradients**.
- For euphausiids, the signal is more concentrated in **zooplankton, oxygen, salinity, depth, and distance**.
- Rankings should be read as **hydrographic windows**, not isolated causal effects.

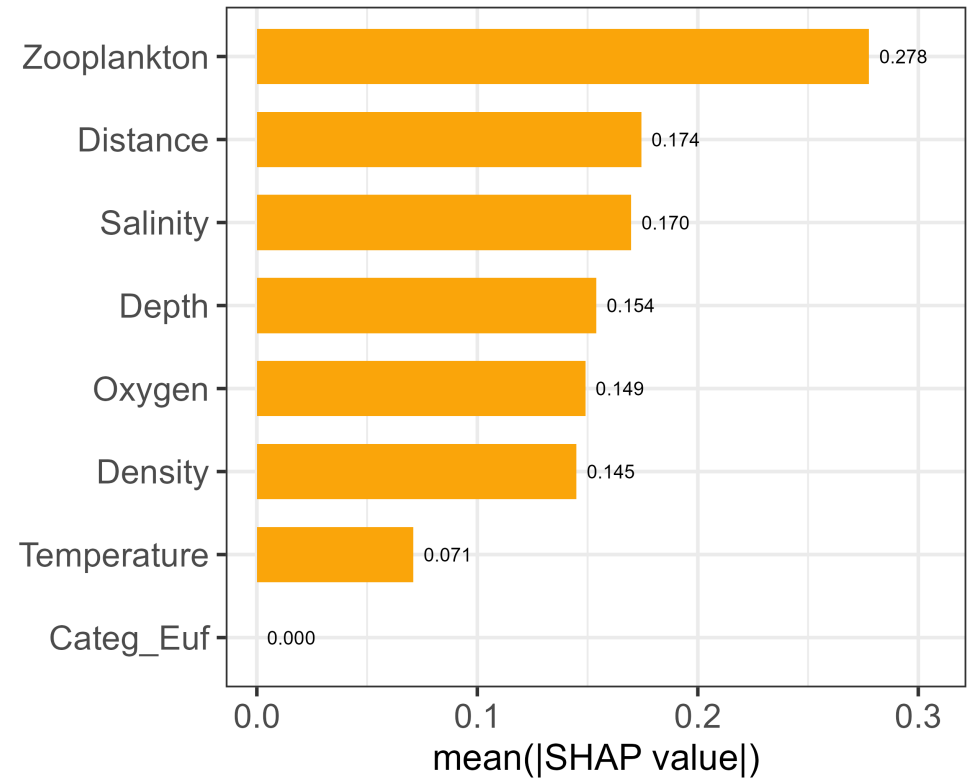
# SHAP: global attribution

SHAP importance - Best model per target (sA: RF, Euphausiids: Boosted Trees)

sA - Random Forest (SHAP importance)

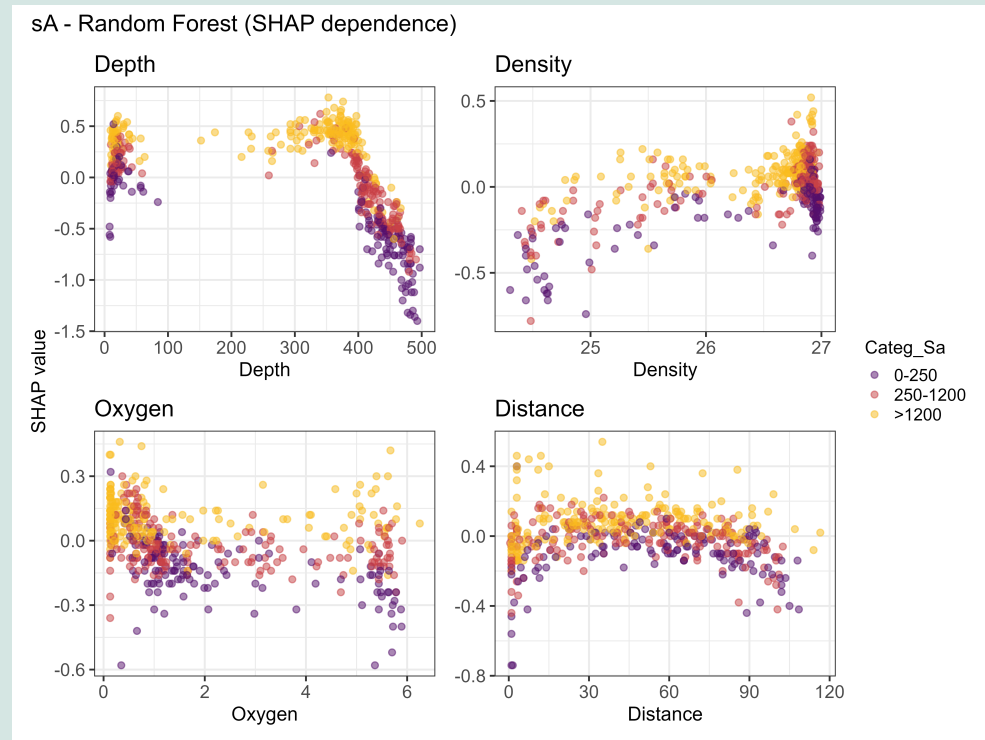


Euphausiids - Boosted Trees (SHAP importance)

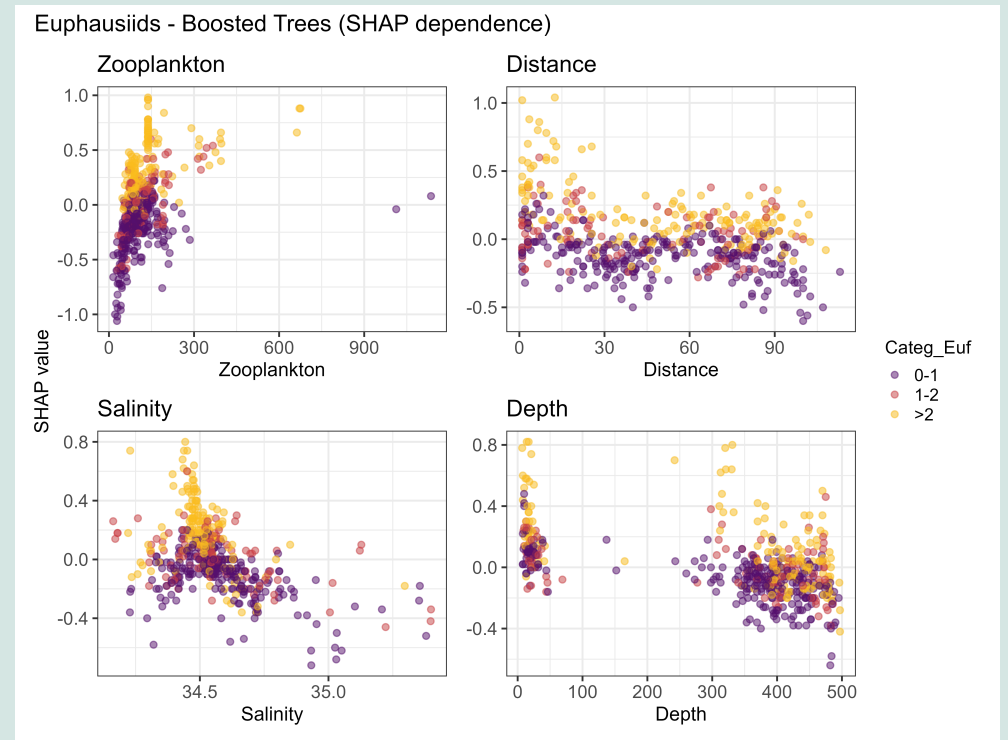


- SHAP confirms the main predictors identified by ensemble importance.
- For **sA**: depth, oxygen, density, distance, salinity, and temperature define aggregation windows.
- For euphausiids: zooplankton and hydrographic variables suggest stronger bottom-up and biogeochemical control.

# Nonlinear environmental responses



**Jack mackerel  $s_A$**   
Random Forest



**Euphausiids**  
XGBoost

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# Ecological synthesis

# Ecological interpretation

## **Hydrographic structure**

Salinity, density, and temperature represent coherent water-mass conditions rather than independent scalar drivers.

## **Oxygen-mediated compression**

Oxygen and depth help define the vertical and horizontal habitat envelope available to predator and prey.

## **Trophic coupling**

Jack mackerel and euphausiids share environmental structure, but their overlap changes across years.

Aggregation states are interpreted as emergent outcomes of hydrographic structure, oxygen-mediated habitat compression, and prey-field variability in the Humboldt Current System (Antezana 2009; Arancibia et al. 2019; Escribano, Hidalgo, and Krautz 2009; Espinoza-Morriberón et al. 2019).

# Why the 2023–2025 contrast matters

- The three cruises should not be interpreted as repeated samples of the same environmental state.
- **2023** showed stronger predator–prey coincidence under warm El Niño-influenced conditions.
- **2024** showed reduced medium/high euphausiid availability, consistent with weaker bottom-up support.
- **2025** suggested a transition toward cooler conditions with more heterogeneous predator–prey overlap.

The ecological signal is therefore not only “model accuracy”, but the interannual reorganization of aggregation states under contrasting oceanographic conditions.

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# Implications

# Take-home messages

- Hydroacoustic  $s_A$  provides a field-based view of **jack mackerel aggregation intensity**.
- Interpretable ensemble models identify **hydrographic windows** associated with low, medium, and high aggregation states.
- Jack mackerel aggregation states should be read as signals of **habitat structure, oxygen constraints**, and **trophic variability**, not as simple abundance changes alone.
- This framework can support **climate-aware monitoring** and future spatially explicit habitat assessment.
- Future work should explicitly account for spatial dependence using block cross-validation, transect-level resampling, or spatially structured models (**Roberts et al. 2017; Valavi et al. 2019**).

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# Thank you

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