Design of a project using environmental DNA (eDNA) to investigate functional areas of elasmobranch populations in the French Mediterranean Sea

MSc MARRES - Science & Society
Master Thesis
Nice, France

Host institution: Organisation de Producteurs SATHOAN France

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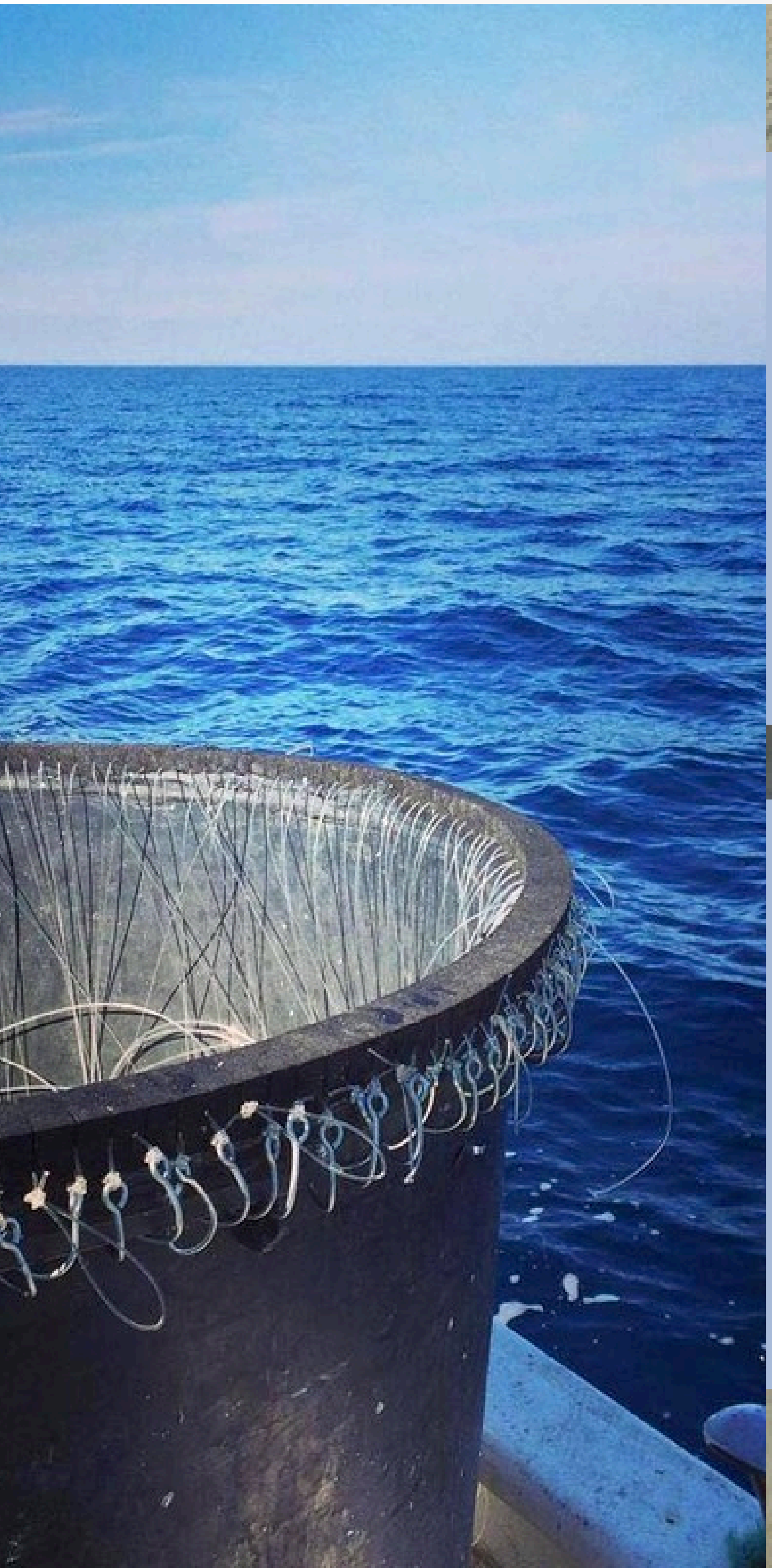
INTRODUCTION - CONTEXT



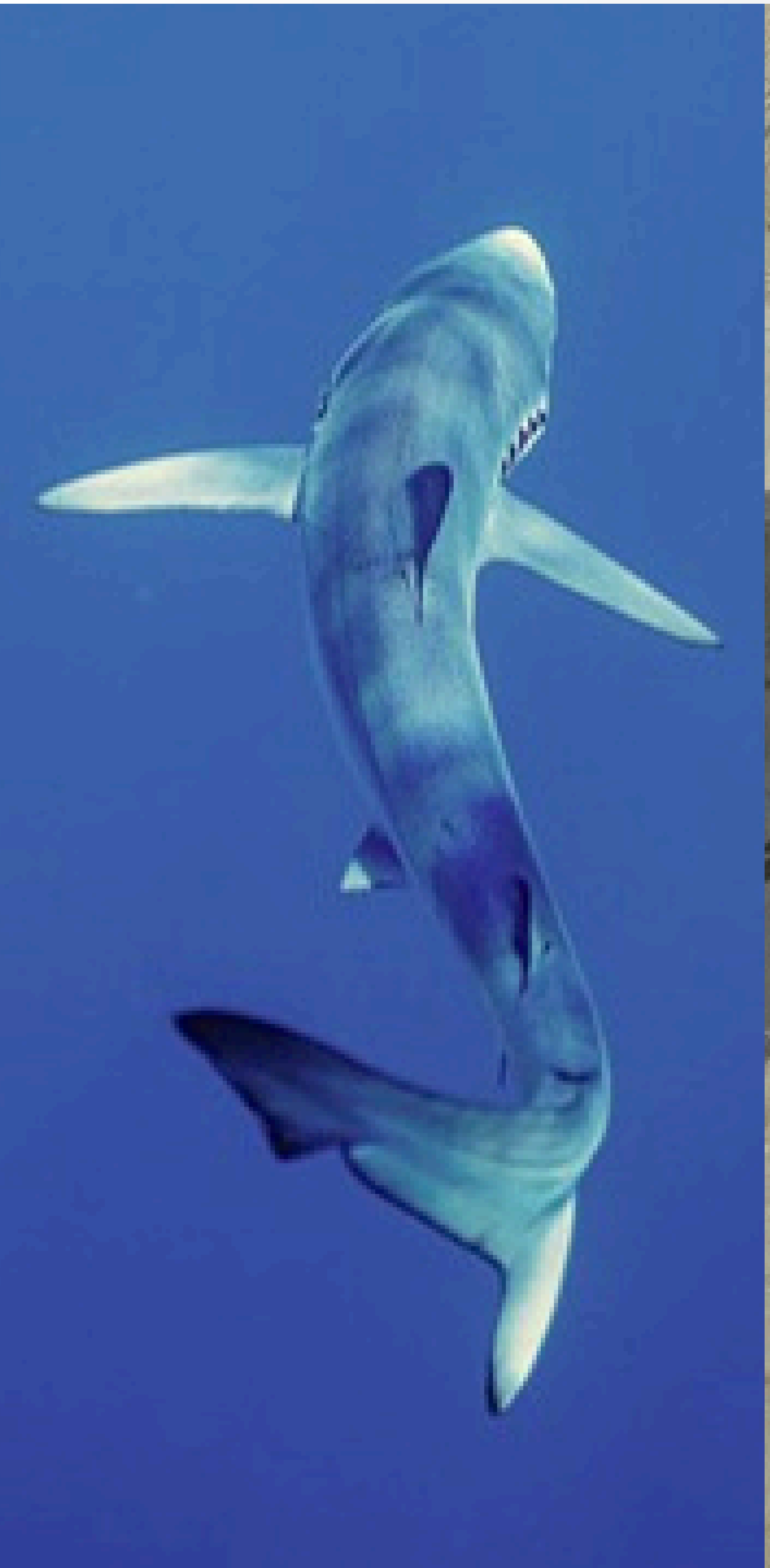
SATHOAN

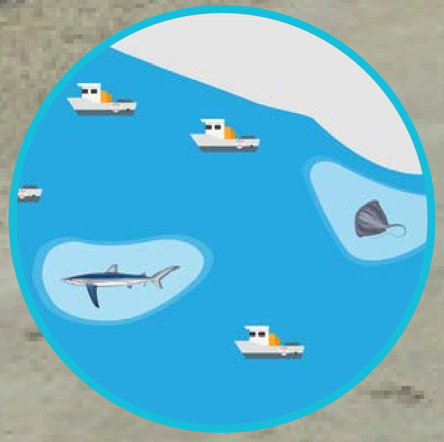
- French Mediterranean producer organization
- 68 Atlantic bluefin tuna authorized small-scale fishing vessels (2025) among 149 in total in the french mediterranean
- Sathoan manages 75% of the fishing quotas (french SSF)
- Sathoan represents over 50% of the total fishing effort
- All analyses presented in this study were restricted to the SATHOAN longline fishing fleet

Why is the implication of SATHOAN important?

✓ Towards a more sustainable fisheries
✓ Better knowledge of the area
✓ Eco-label certification (MSC and "peche durable - EPPM")
✓ Bycatch reduction
✓ Biodiversity monitoring
✓ TUNADNe / ELASMO-DNA projects

INTRODUCTION - CONTEXT



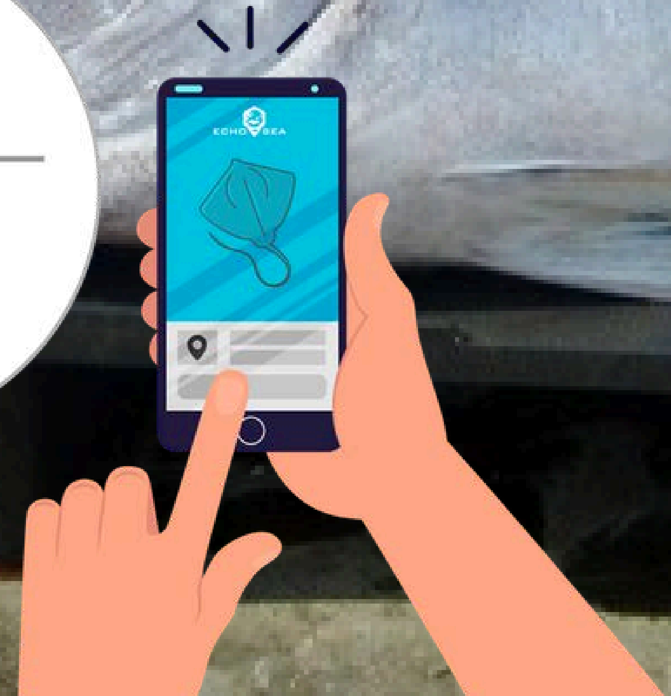


ECHOSEA

- Participatory platform used by:
- professional fishers
- recreational fishers
- sea users (divers, ...)

Reports:

- observations
- bycatch events
- species occurrences



Hind (2015); Mackinson & Nøttestad (1998)

INTRODUCTION - CONTEXT

Pelagic ecosystems → Vulnerable species → Difficult and expensive offshore monitoring → Environmental DNA (eDNA) → Need to identify priority sampling areas

SATHOAN
ELASMODNA

IFREMER
TUNADNE

- Non-invasive biodiversity monitoring
- Detection of rare and elusive species
- Cost-effective large-scale surveys
- Suitable for offshore biodiversity monitoring
- Can be integrated with fisheries-dependent sampling

Valentini et al. (2016); Thomsen & Willerslev (2015).

Where should future eDNA surveys be conducted?

INTRODUCTION - WHY USE FISHERS?

- Broad spatial coverage
- Repeated offshore access
- Long-term observations
- Reduced costs

Lewison et al. (2004) ; Hazin et al. (2008); Hind (2015); Mackinson & Nøttestad (1998).

INTRODUCTION

RESEARCH QUESTION

To what extent can fisheries-dependent participatory datasets identify functional pelagic areas associated with bycatch occurrence in the French Mediterranean, and support the development of an operational eDNA sampling framework?

HYPOTHESIS

Spatially standardized fisheries-dependent data can reveal ecologically relevant pelagic hotspots and provide a valuable framework for optimizing eDNA sampling strategies.

INTRODUCTION – OBJECTIVES

① Standardize fisheries-dependent datasets

② Identify recurrent hotspots and functional areas

③ Investigate environmental drivers

④ Assess temporal robustness

⑤ Propose an operational eDNA sampling strategy

MATERIALS AND METHODS - STUDY AREA AND DATASET

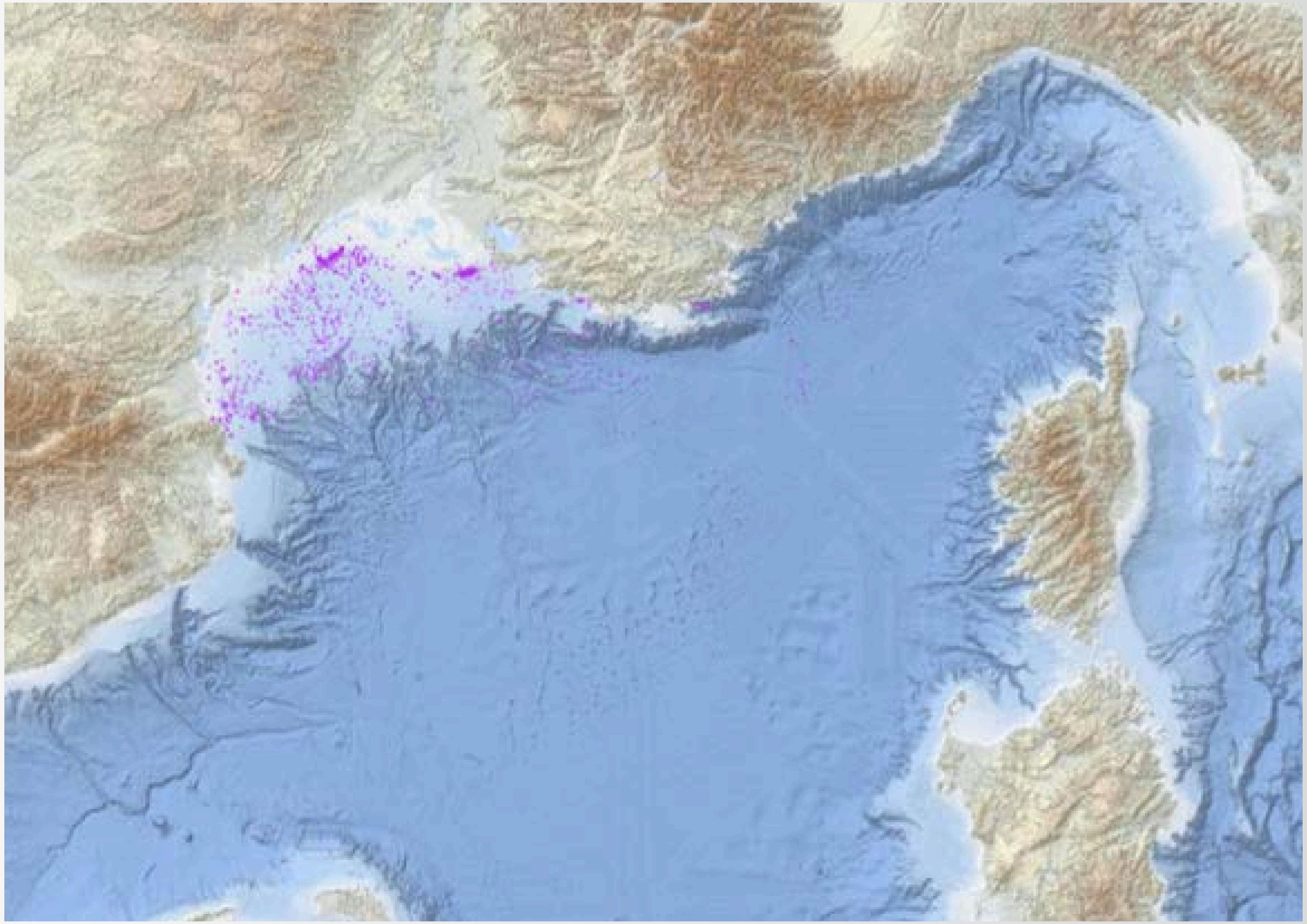


Figure 1. Atlantic bluefin tuna hook-and-line catches from SATHOAN small-scale fishing vessels in 2025. HALIOP® - 2025

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MATERIALS AND METHODS - ANALYTICAL FRAMEWORK

ECHOSEA → BYCATCH DATA
OPQUOTA → FISHING EFFORT
HALIOP → FISHING OPERATION GPS

MATCH
MATCH

FINAL DATASET:

- 2020-2025
- 6545 observations
- 5837 fishing trips
- 439 spatial cells
- 40 reliable vessels
- 18 bycatch species
- 6 × 6 nm grid

ECOLOGICAL ANALYSES

- CPUE
- Species richness
- Shannon diversity
- Temporal variability
- Composite scores

Shannon (1948)

SPATIAL ANALYSES

- Hotspots identification
- Species-specific analyses
- Temporal robustness

ENVIRONMENTAL ANALYSES

- GLMM
    - Depth
    - Distance to coast
    - Season
    - SST

eDNA recommendations

MATERIALS AND METHODS - SPECIES-SPECIFIC ANALYSES

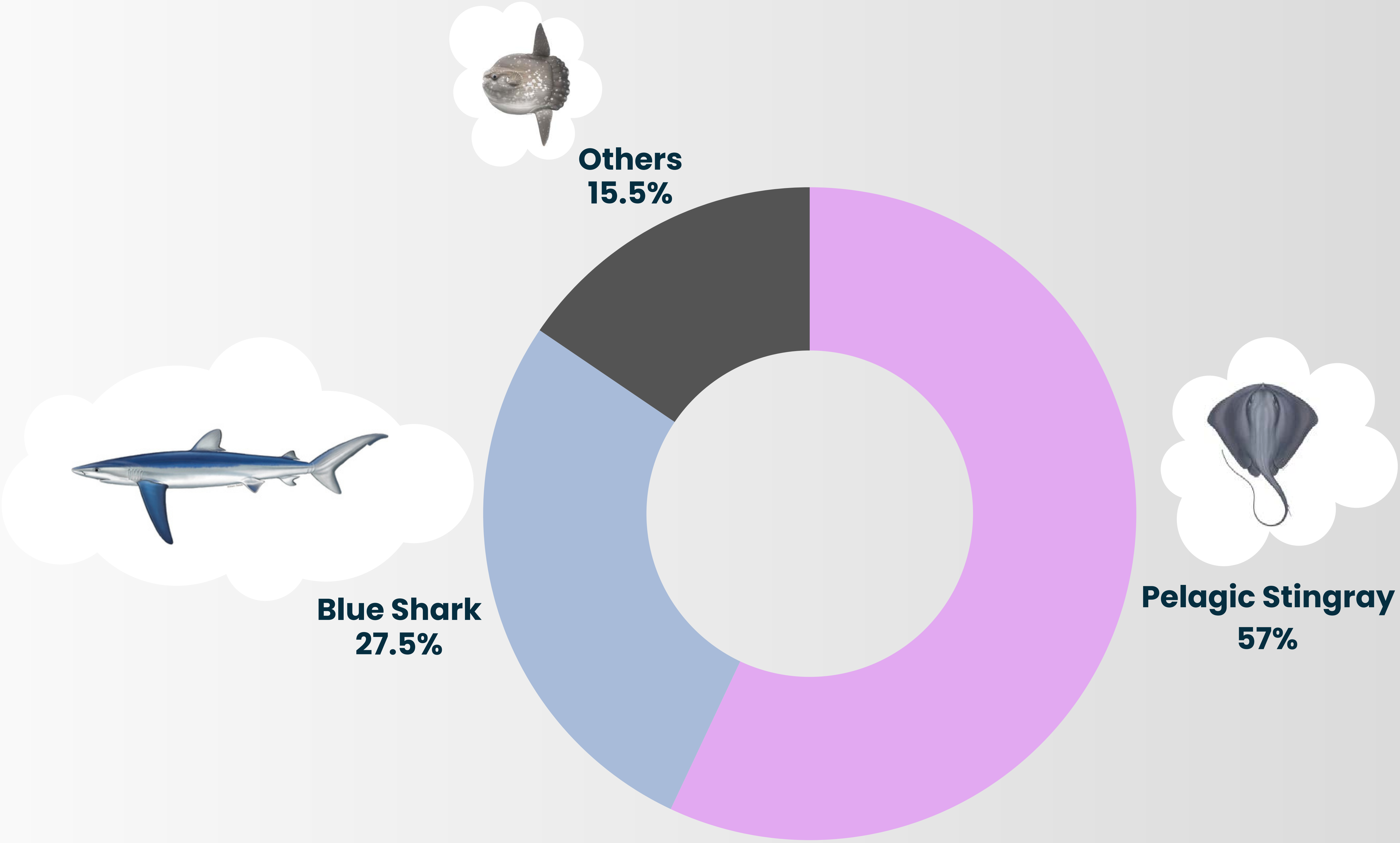


Figure 2: Bycatch species proportions from small-scale longline fishing vessels from SATHOAN , over the period of 2020 to 2025.

RESULTS – GLOBAL SPATIAL PATTERNS

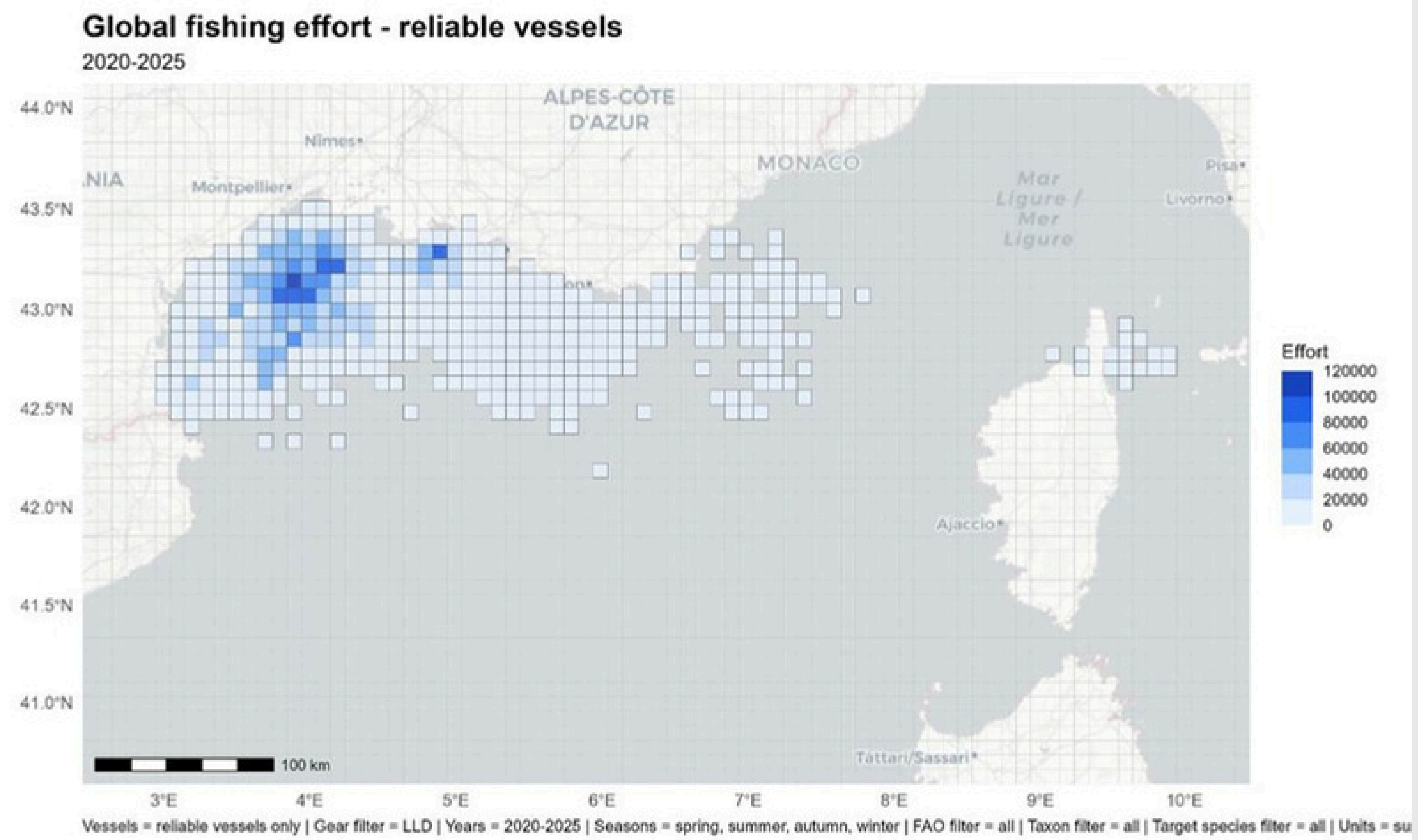
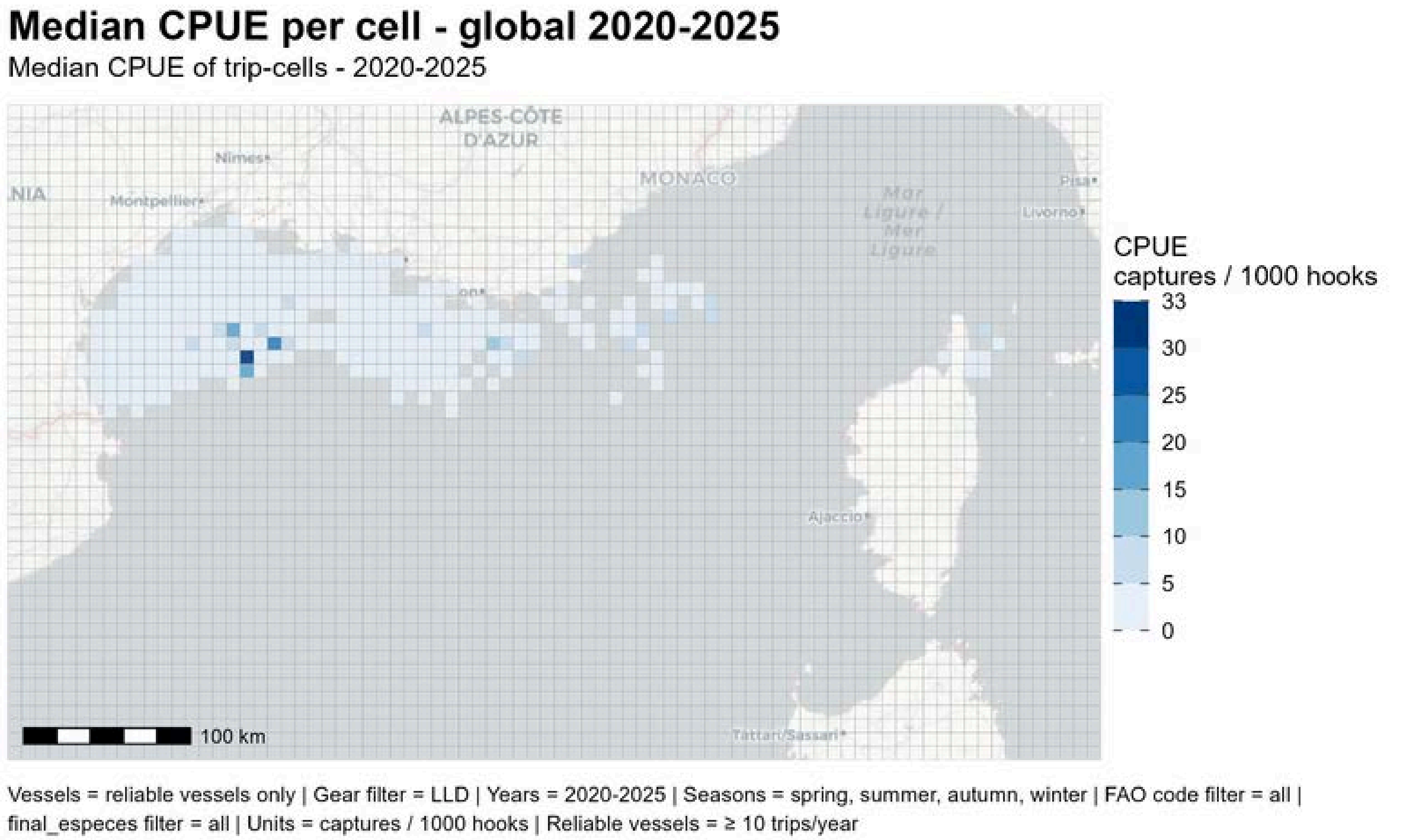


Figure 3. Spatial distribution of standardized fishing effort across the French Mediterranean between 2020 and 2025 after vessel filtering and effort standardization. Fishing effort was concentrated in offshore pelagic fishing grounds of the Gulf of Lion, although broad spatial coverage was maintained throughout the study area. Each cell contains a fishing effort of at least 30 hooks.



Maximum median CPUE = 33
231 cells with CPUE = 0

Figure 4. Median multi-species CPUE. Median CPUE (captures per 1000 hooks) of all bycatch species aggregated at the spatial-cell level. The figure highlights strong spatial heterogeneity in bycatch intensity, with a limited number of offshore cells displaying elevated CPUE values and many cells showing weak or null signal. This spatial concentration partly reflects the geographical distribution of participating vessels and fishing activities within the ECHOSEA dataset.

Strong spatial heterogeneity between fishing effort and bycatch distribution.

RESULTS - ECOLOGICAL HOTSPOTS

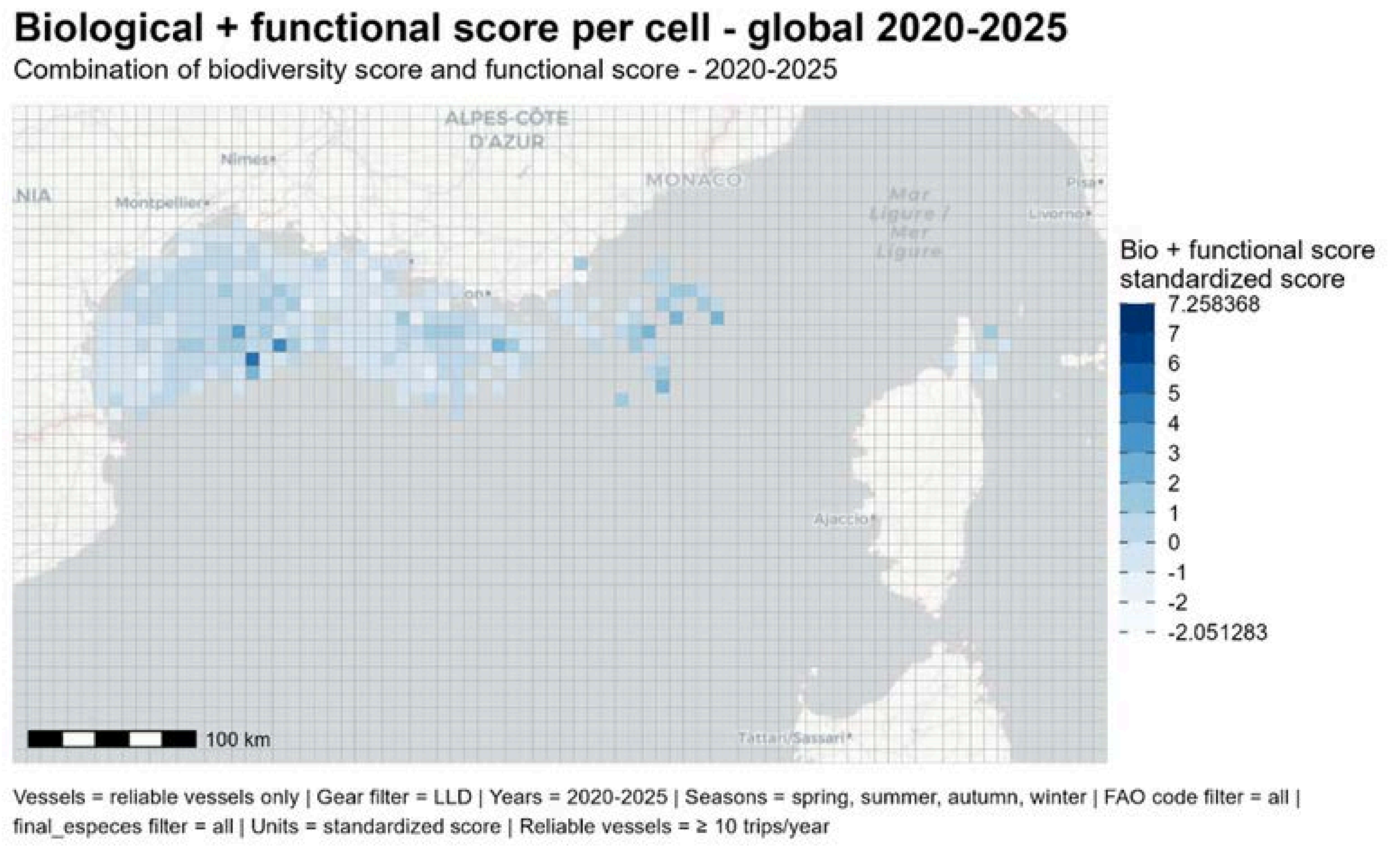


Figure 5. Combined biological-functional score. Combined biological-functional score integrating biodiversity metrics, CPUE and temporal stability across the study area. Higher scores identify cells simultaneously characterized by elevated biodiversity, strong biological signal and greater temporal stability.

Ecologically relevant pelagic areas were identified.

These patterns motivated the cross-classification presented on the next slide.

Shannon (1948)

RESULTS – ECOLOGICAL HOTSPOTS

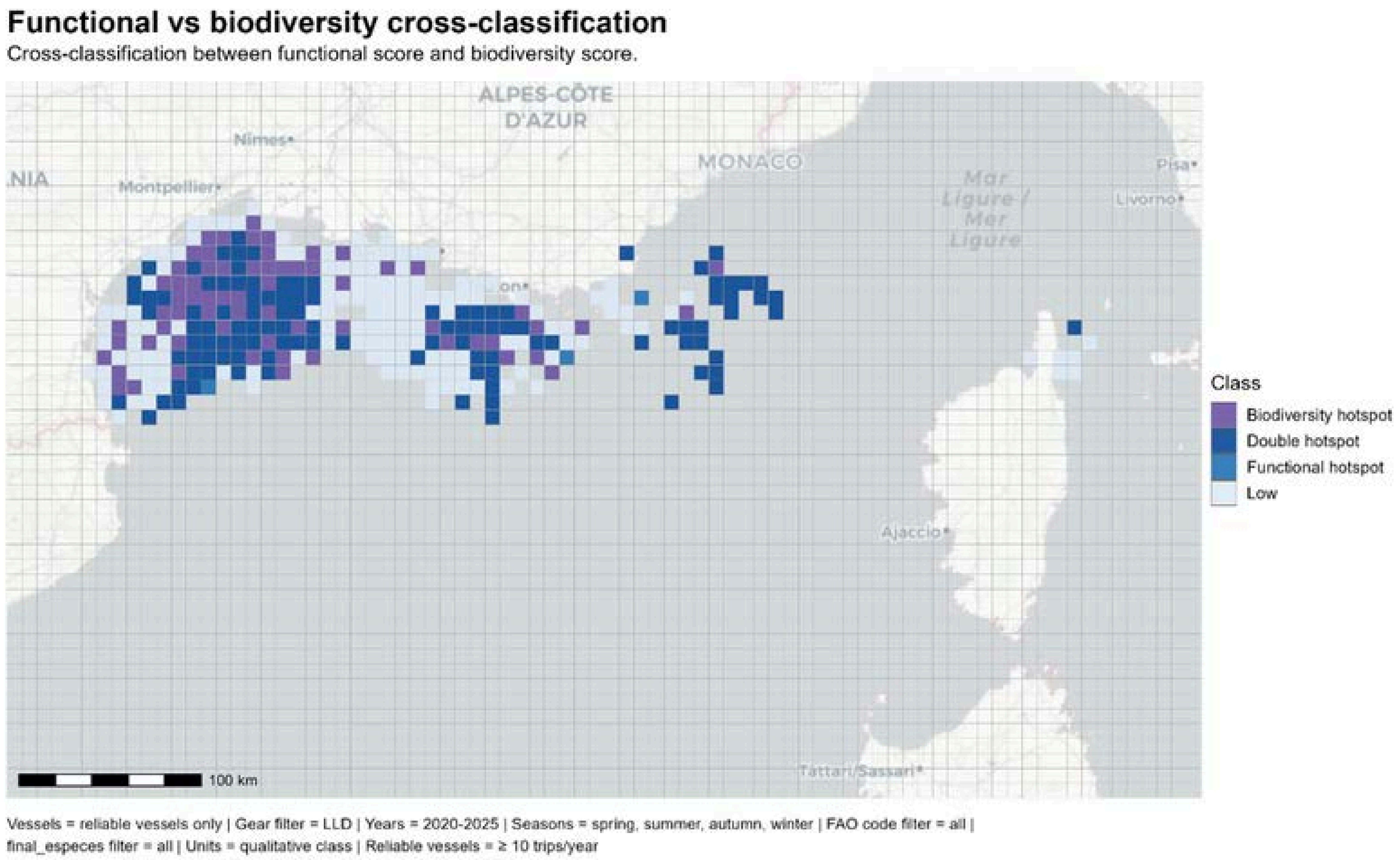


Figure 6. Cross-classification of biodiversity and functional hotspots. Cross-classification of biodiversity and functional hotspot categories highlighting double hotspot cells. Cells classified as double hotspots represent areas of simultaneous biodiversity importance and strong functional ecological signal.

110 double hotspots
65 biodiversity hotspots only
3 functional hotspots only

Biodiversity hotspot

- High species richness
- High Shannon diversity
- Areas where multiple bycatch species are regularly observed

⇨ Reflects biodiversity importance

Functional hotspot

- High median CPUE
- Recurrent bycatch signal
- Low temporal variability

⇨ Reflects the intensity and stability of the ecological signal

Double hotspot

- Biodiversity hotspot + Functional hotspot

⇨ Areas combining biodiversity importance and strong recurrent ecological signal
⇨ Highest-priority areas identified in this study

Shannon (1948); Game et al. (2009).

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RESULTS - SPECIES-SPECIFIC ANALYSES

PELAGIC STINGRAY (*Pteroplatytrygon violacea*)

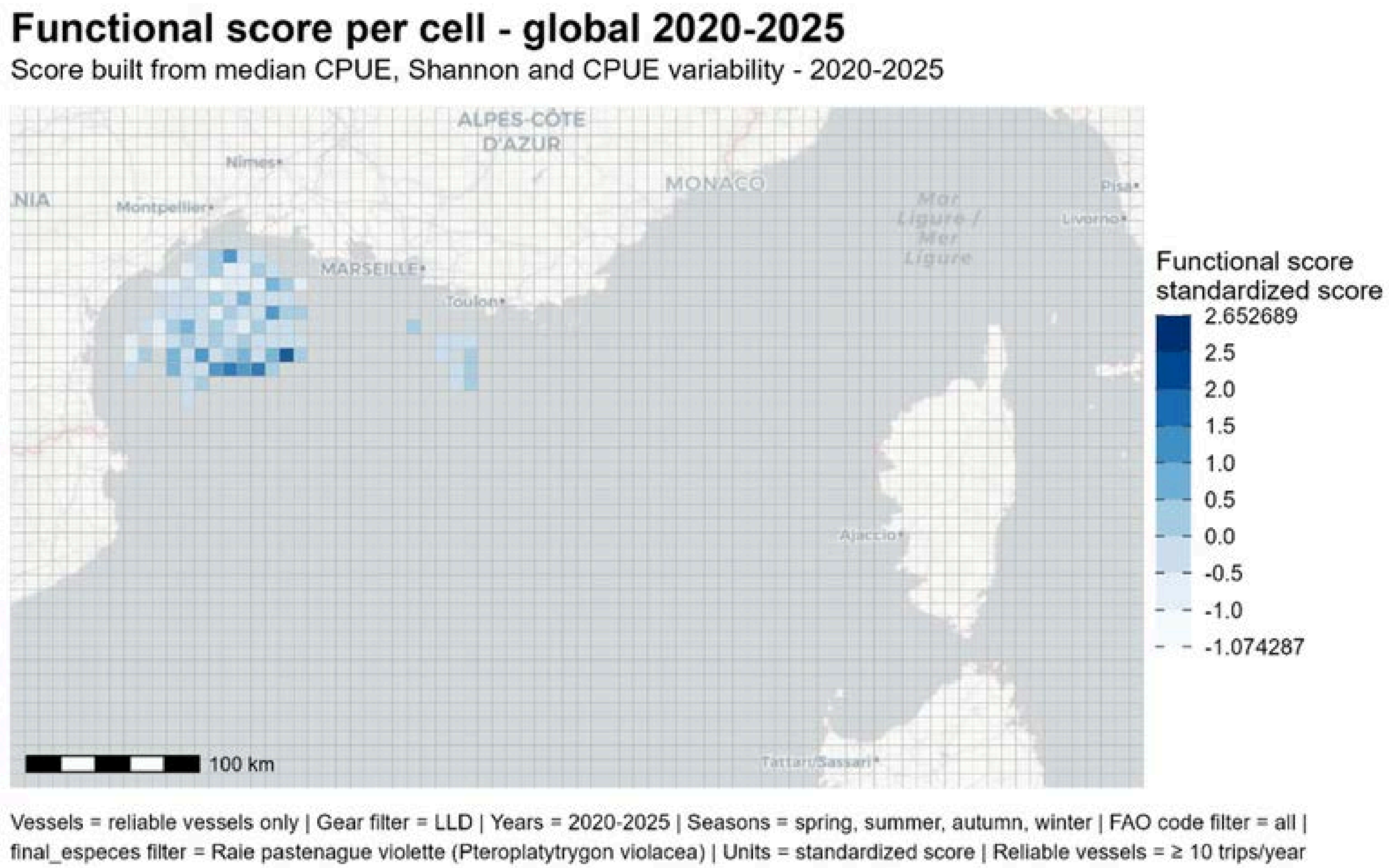


Figure 7. Pelagic stingray functional signal intensity. Spatial distribution of pelagic stingray functional signal intensity based on species-specific CPUE and temporal variability metrics. The figure highlights the spatial extent of pelagic stingray hotspots and the distribution of recurrent species-specific bycatch signal across the study area.

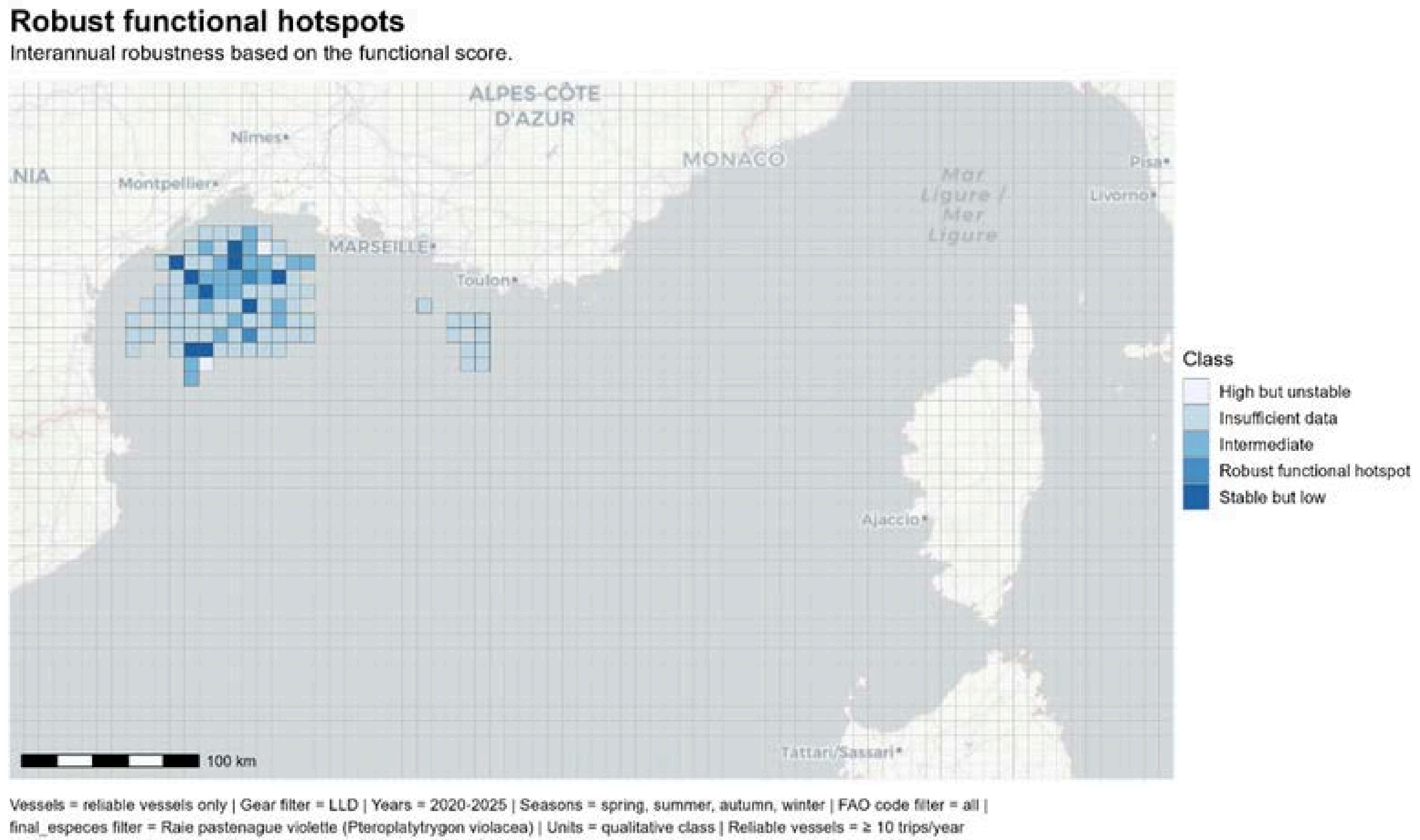


Figure 8. Robust pelagic stingray hotspots. Robust functional hotspots identified for pelagic stingray through temporal robustness analyses. Only a subset of pelagic stingray hotspots met the criteria for temporal robustness, indicating recurrent ecological importance through time.

25 functional hotspots cells

2 robust hotspots cells

RESULTS - SPECIES-SPECIFIC ANALYSES

BLUE SHARK (*Prionace glauca*)

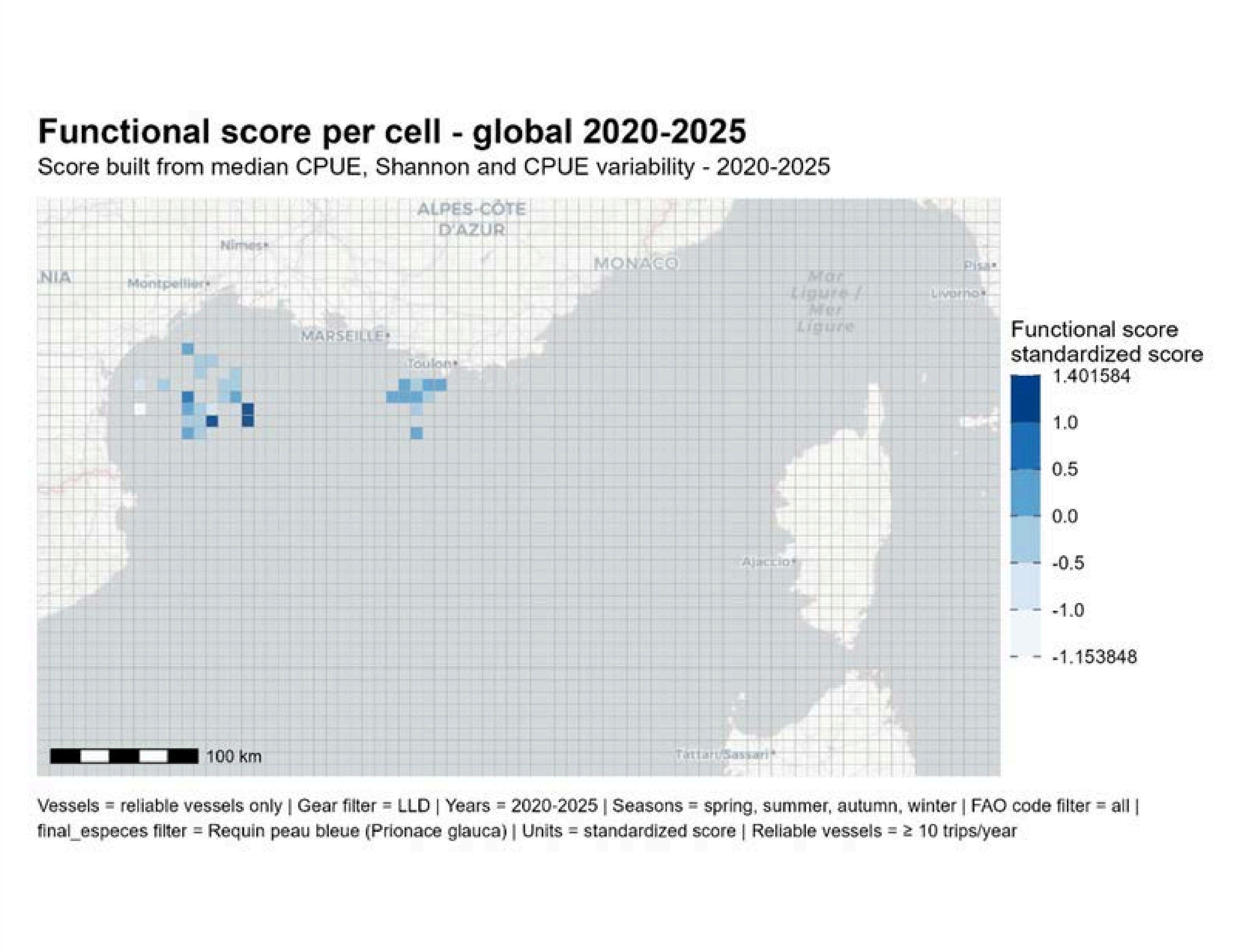
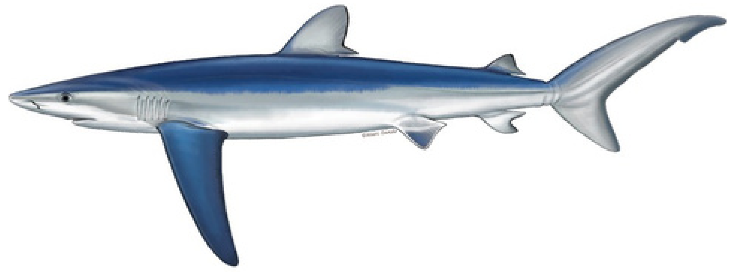


Figure 9. Blue shark functional signal intensity. Spatial distribution of blue shark functional signal intensity based on species-specific CPUE and temporal variability metrics. The figure identifies candidate blue shark hotspot areas requiring further temporal validation.



9 functional hotspots cells

No hotspot remained robust after temporal validation

RESULTS - SPECIES-SPECIFIC ANALYSES

SPECIES COMPARISON

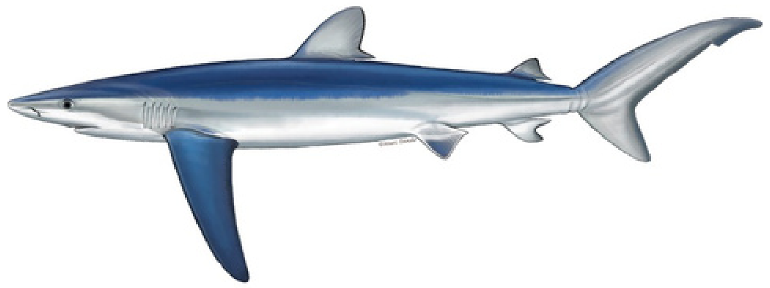


Table 1. Comparison of hotspot characteristics between blue sharks and pelagic stingrays.

	Blue shark	Pelagic stingray
Hotspots	9	25
Robust hotspots	0	2
Spatial extent	Restricted	Broader
Temporal persistence	Low	Higher

Contrasting hotspot dynamics between species.

RESULTS – TEMPORAL ROBUSTNESS

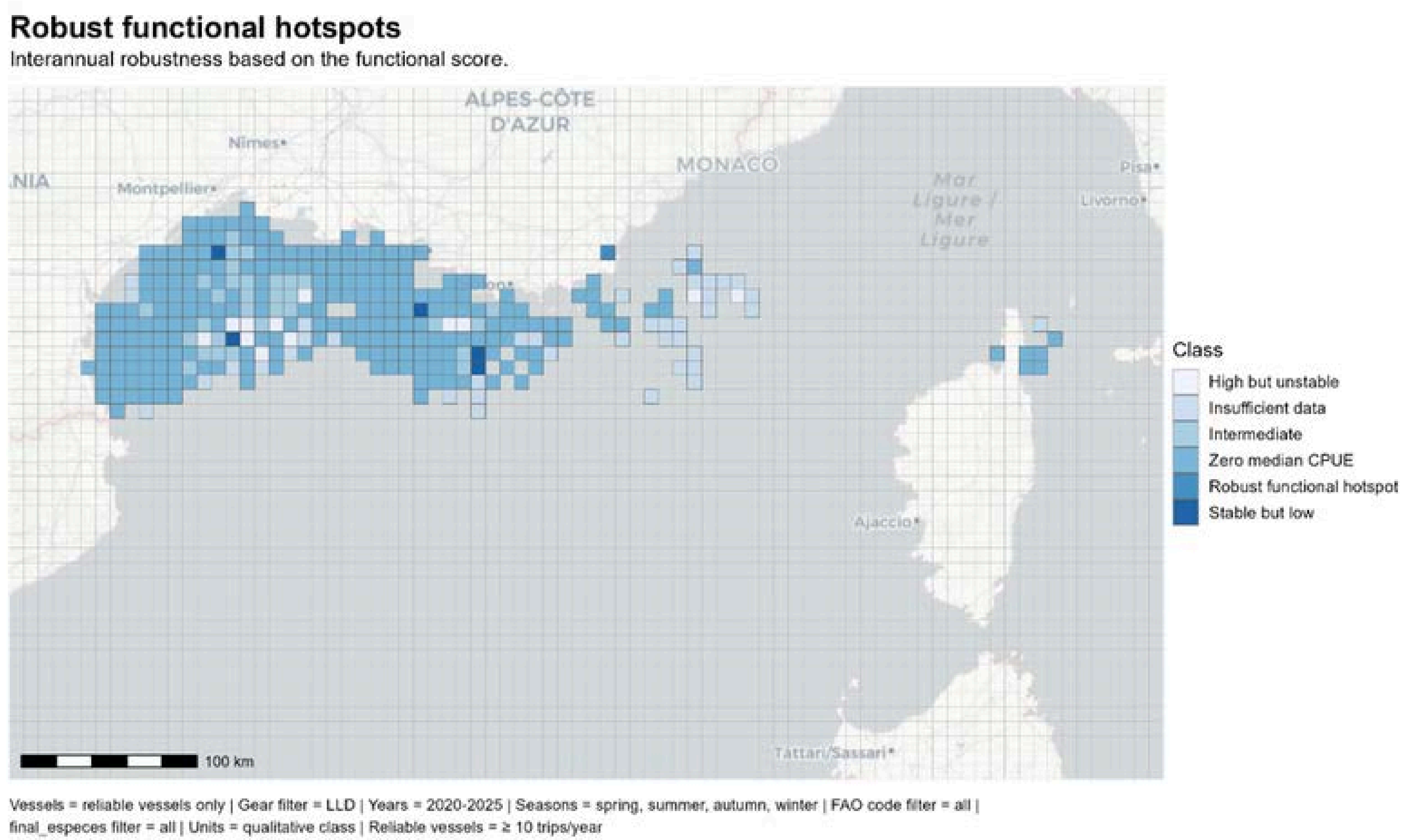


Figure 10. Multi-species robust functional hotspots across the 2020–2025 study period. Classification of multi-species hotspot robustness based on the full study period (2020–2025), integrating annual persistence and temporal consistency criteria. Cells classified as robust hotspots displayed recurrent functional hotspot characteristics across multiple years, whereas other cells were classified as strong but unstable, intermediate, stable but weak, or lacking sufficient temporal information.

Table 2. Comparison of temporally robust hotspots among multi-species and species-specific analyses.

Analysis	Robust hotspots cells
Multi-species	1
Pelagic stingray	2
Blue shark	0

Temporal validation greatly reduced the number of candidate hotspots.

RESULTS – ENVIRONMENTAL DRIVERS

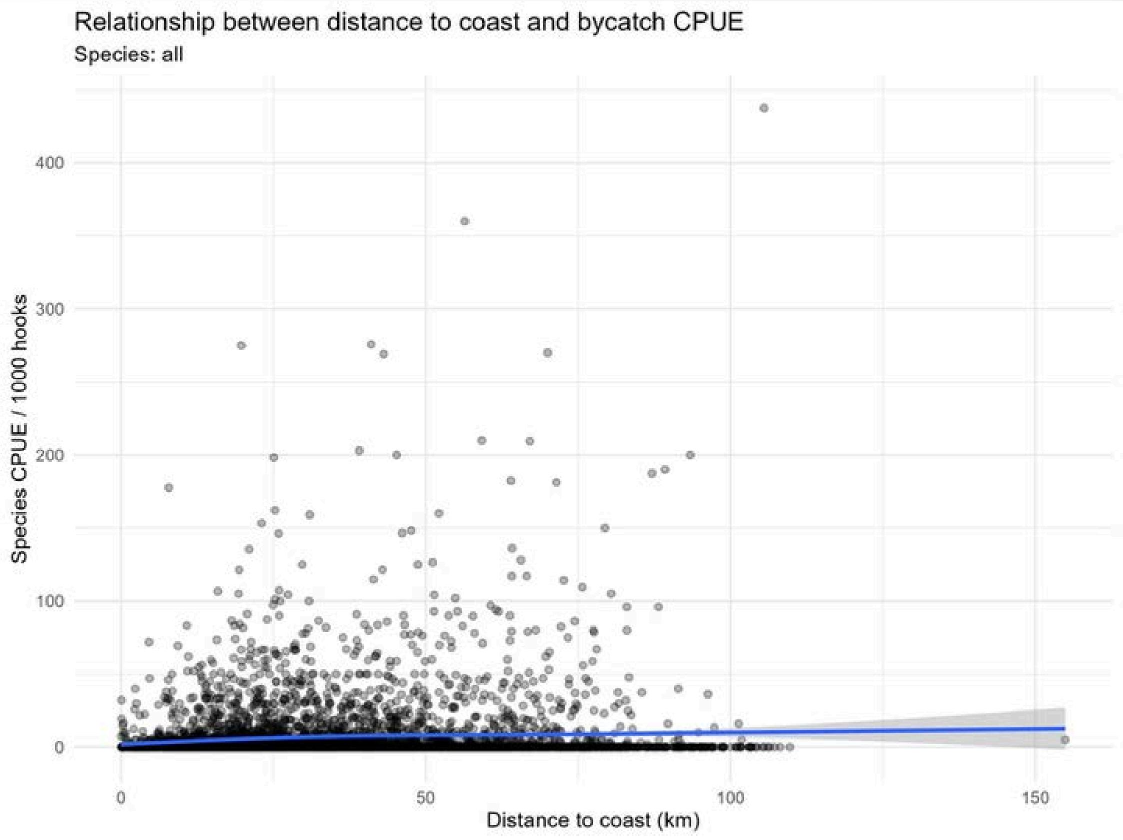


Figure 11. Effect of distance to coast on bycatch occurrence. Predicted bycatch occurrence increased slightly with distance from the coast.

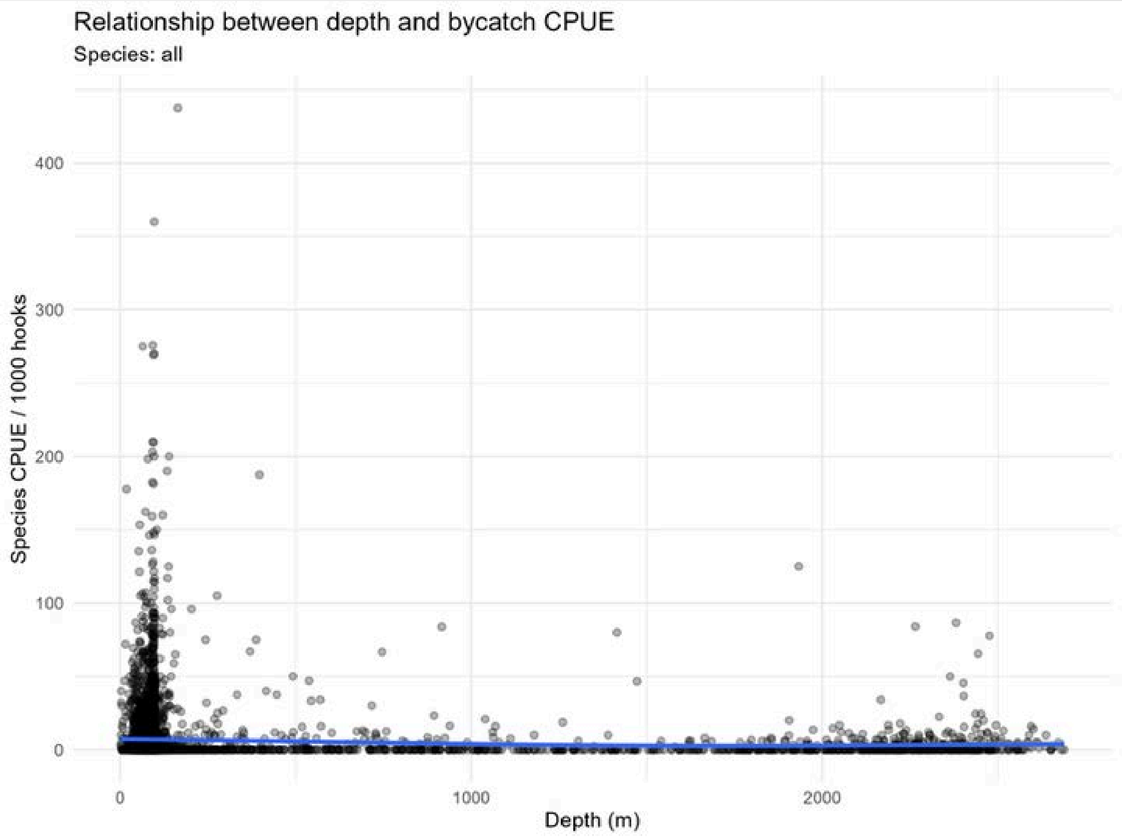


Figure 12. Effect of bathymetry on bycatch occurrence. Predicted bycatch occurrence decreased with increasing depth.

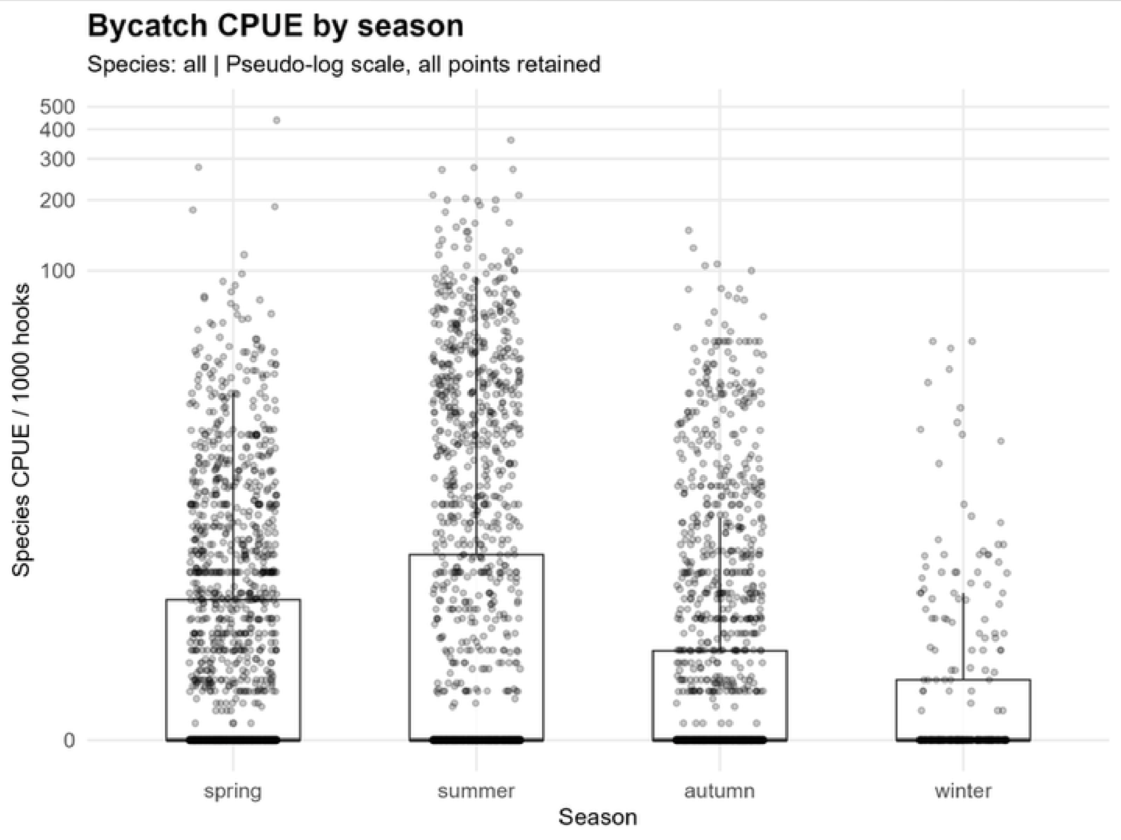


Figure 13. Seasonal variation in bycatch CPUE. Bycatch CPUE was highest during summer and autumn and lowest during winter.

Variable	Effect	p-value
Bathymetry	–	<0.001
Distance to coast	+	0.042
Summer	++	<0.001
Autumn	+	0.013
Winter	–	0.002
SST	n.s.	0.525

Table 3. Effects of environmental variables on bycatch occurrence based on the global negative binomial GLMM.

Depth, distance to coast and seasonality significantly influenced bycatch patterns.

Zuur et al. (2009)

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DISCUSSION – MAIN FINDINGS

Temporal robustness matters

Only a few hotspots remained recurrent through time

Species-specific responses differ

Pelagic stingrays exhibited greater hotspot persistence than blue sharks

Offshore conditions shape bycatch

Depth, distance to coast and season significantly influenced bycatch patterns

Only a few pelagic areas exhibited recurrent ecological importance.

Valentini et al. (2016) ; Andruszkiewicz et al. (2019)

DISCUSSION - FROM HOTSPOTS TO EDNA

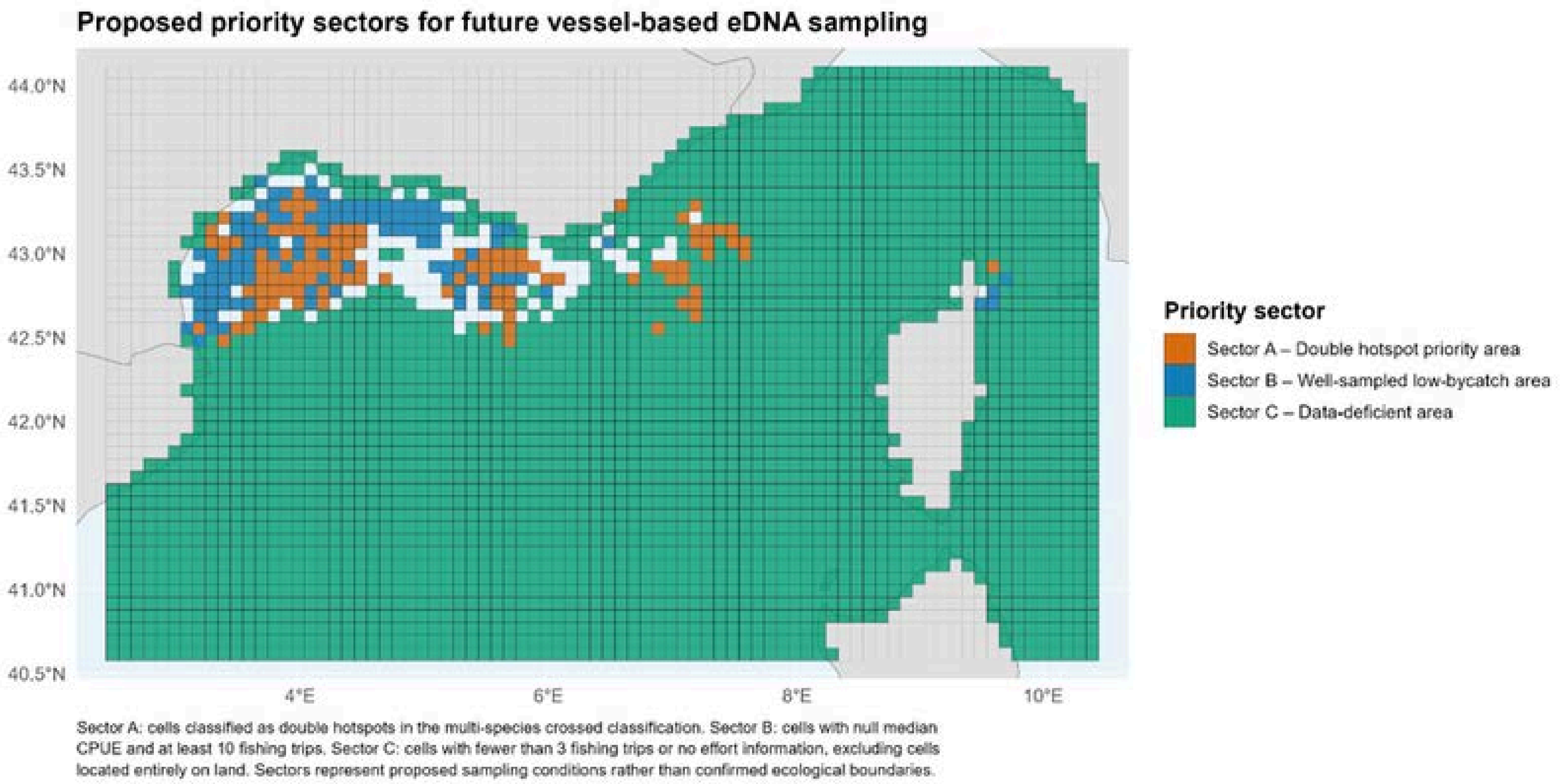


Figure 14. Proposed priority sectors for future vessel-based eDNA sampling.

Temporal priorities

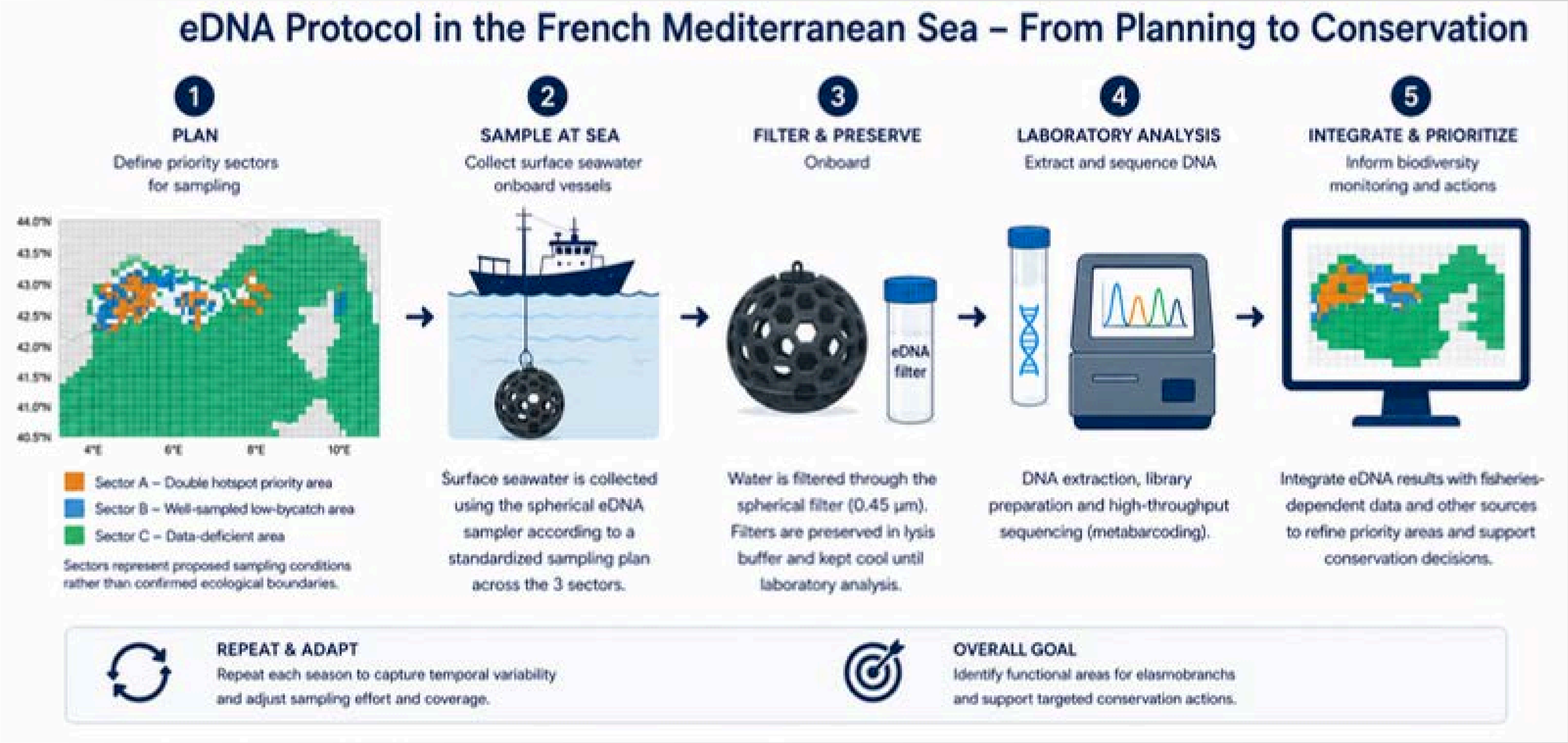
- Prioritize summer and autumn sampling campaigns to maximize detection probability
- Repeat sampling across seasons to account for temporal variability

Operational considerations

- Use fishing vessels as offshore sampling platforms
- Target recurrent hotspot areas identified by ECHOSEA
- Include data-deficient sectors to validate model predictions

Valentini et al. (2016); Andruszkiewicz et al. (2019); Mariani et al., 2021; Albonetti et al. (2023).

DISCUSSION – FROM HOTSPOTS TO EDNA



DISCUSSION - LIMITATIONS AND FUTURE PERSPECTIVES

LIMITATIONS

Limited fleet representation
Only SATHOAN small-scale vessels were included

Uneven sampling effort
Spatial and temporal heterogeneity and potential observer effect

Data integration uncertainties
Matching among independent databases and missing information

Limited temporal replication
Few recurrent hotspots identified

Simplified environmental model
Limited set of oceanographic variables

FUTURE PERSPECTIVES

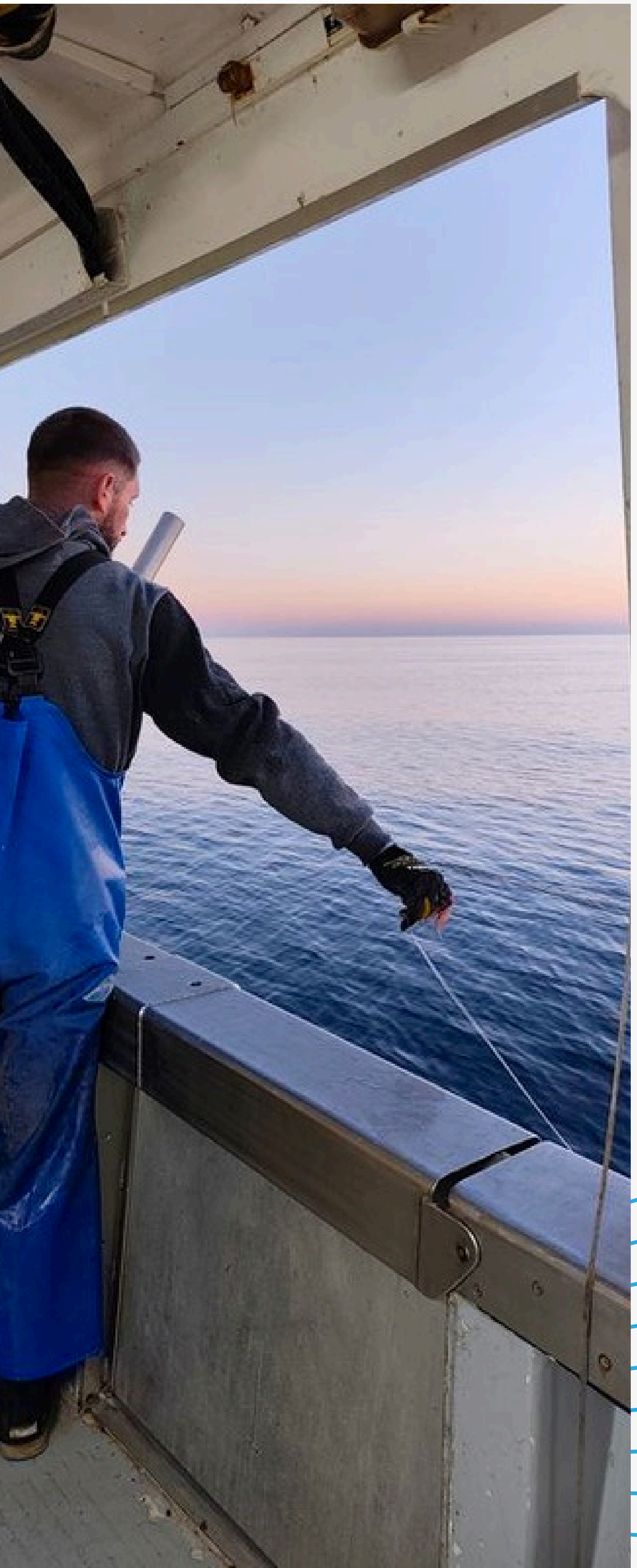
Vessel-based eDNA surveys
Validation of priority sectors

Species-specific environmental models
Dedicated approaches for different species

Increased temporal replication
Assessment of long-term hotspot persistence

Standardized fisheries-dependent data collection
Improved spatial and temporal coverage

DISCUSSION - LIMITATIONS AND FUTURE PERSPECTIVES



Vessel-based eDNA surveys

Validation of priority sectors

DISCUSSION – TOWARDS A STANDARDIZED MONITORING DATASET

CURRENT DATA

- Current ECHOSEA
- Species
- Abundance
- GPS
- Fishing effort

DISCUSSION - TOWARDS A STANDARDIZED MONITORING DATASET

CURRENT DATA

- Current ECHOSEA
- Species
- Abundance
- GPS
- Fishing effort

IDEAL DATA

- Sex
- Size
- Maturity
- Soak time
- Bait type
- Environmental variables
- Future integrated dataset
- eDNA metadata
- Tagging
- Oceanographic variables
- Biological traits
- Temporal information

DISCUSSION - TOWARDS A STANDARDIZED MONITORING DATASET

CURRENT DATA

- Current ECHOSEA
- Species
- Abundance
- GPS
- Fishing effort

IDEAL DATA

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- Soak time
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- Future integrated dataset
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- Oceanographic variables
- Biological traits
- Temporal information

Better data → Better ecological models

CONCLUSIONS

- Fisheries-dependent data revealed clear spatial patterns
- Only a few hotspots showed temporal persistence
- These results provide a practical basis for future eDNA monitoring

Hind (2015); Mackinson & Nøttestad (1998)

Broader implications

- Continuous improvement of sustainable fisheries
- Strengthened collaboration between scientists and fishers
- Enhanced recognition of professional fishers in biodiversity monitoring

Bridging fisheries and science for future biodiversity monitoring.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to SATHOAN for providing me with the opportunity to conduct this research project, and to my supervisor for his guidance and support throughout the entire process.
I would also like to thank my colleagues for their constant encouragement, their kindness, and the many interesting conversations we shared on almost every imaginable topic, which made this experience particularly enjoyable.

My sincere thanks also go to the IFREMER team for taking the time to exchange ideas with me and for helping me navigate the complexity of this project.

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APPENDIX A. EQUATIONS AND METHODOLOGY

Z-score :
$Z = (x-\mu) / \sigma$
Where:
- x = observed value
- μ = mean of the variable
- σ = standard deviation

Purpose:
- Standardize variables measured on different scales
- Ensure equal contribution of each metric to the composite scores

Coefficient of Variation :
CV = SD / Mean
Where:
- SD = standard deviation of CPUE values
- Mean = mean CPUE

Interpretation:
- Low CV = stable ecological signal through time
- High CV = highly variable or opportunistic observations

Catch Per Unit Effort :
CPUE = captures / hook × 1000

Shannon Diversity Index :
Shannon = H′=-∑S(i=1)piln(pi)
Where:
- p_i = relative abundance of species i
- S = total number of species

Interpretation:
- Higher values indicate greater biodiversity
- Integrates both species richness and evenness

APPENDIX A. EQUATIONS AND METHODOLOGY

Functional score

Score_functional = 0.5 × CPUE_median + 0.3 × Shannon - 0.2 × CV

Objective:

- Emphasize biological productivity
- Favor recurrent ecological signals
- Penalize high temporal variability

Biodiversity score

Score_biological = 0.4 × Shannon + 0.3 × Richness + 0.2 × CPUE_median - 0.1 × CV

Weighting scheme:

- Shannon diversity: 40%
- Species richness: 30%
- Median CPUE: 20%
- Temporal stability (CV): 10%

Combined score

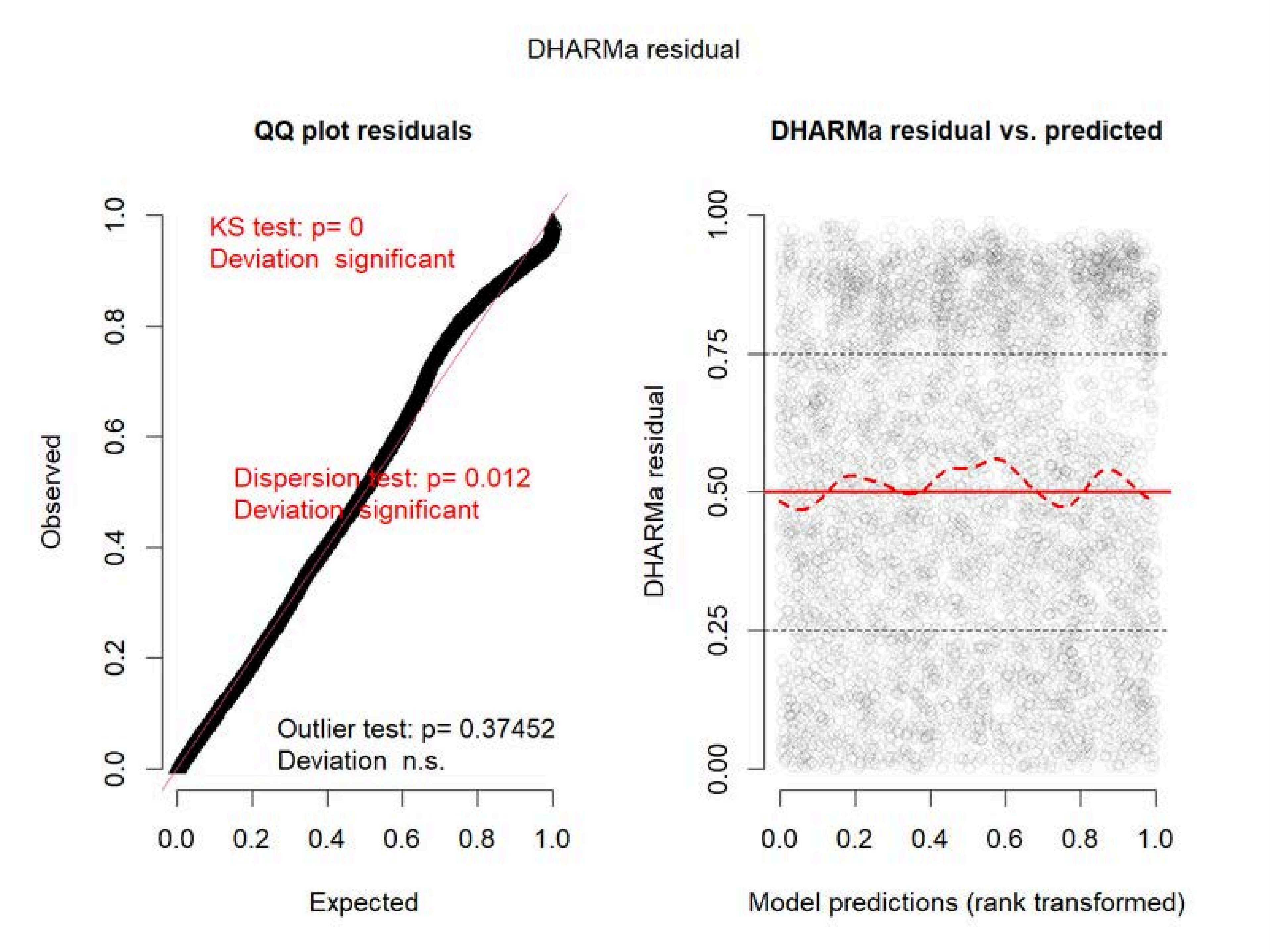
Score_combined = 0.5 × Score_functional + 0.5 × Score_biological

Objective:

- Give equal importance to biodiversity and functional relevance
- Identify areas combining high ecological value and strong recurrent biological signals
- Prioritize the most ecologically important pelagic sectors identified in this study.

APPENDIX B. GLMM

Bycatch ~ depth + distance_to_coast + SST + season + offset(log(hooks)) + (1 | vessel)



Fixed effects
Bathymetry
Distance to coast
SST
Season

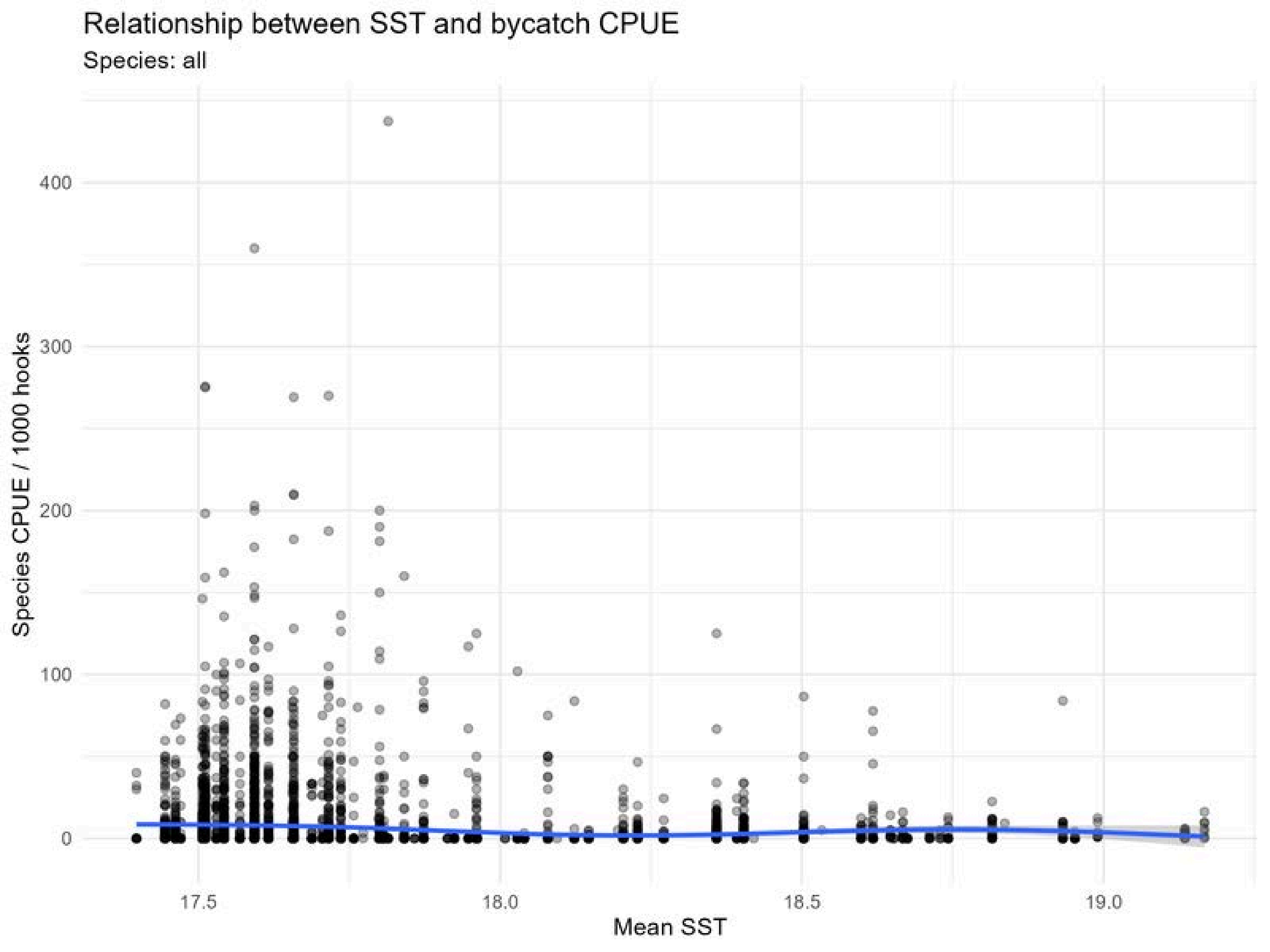
Random effect
Vessel identity

Offset
log(number of hooks)

Why this model?

- Negative binomial distribution to account for overdispersion
- Vessel identity included as a random effect
- Fishing effort standardized using an offset

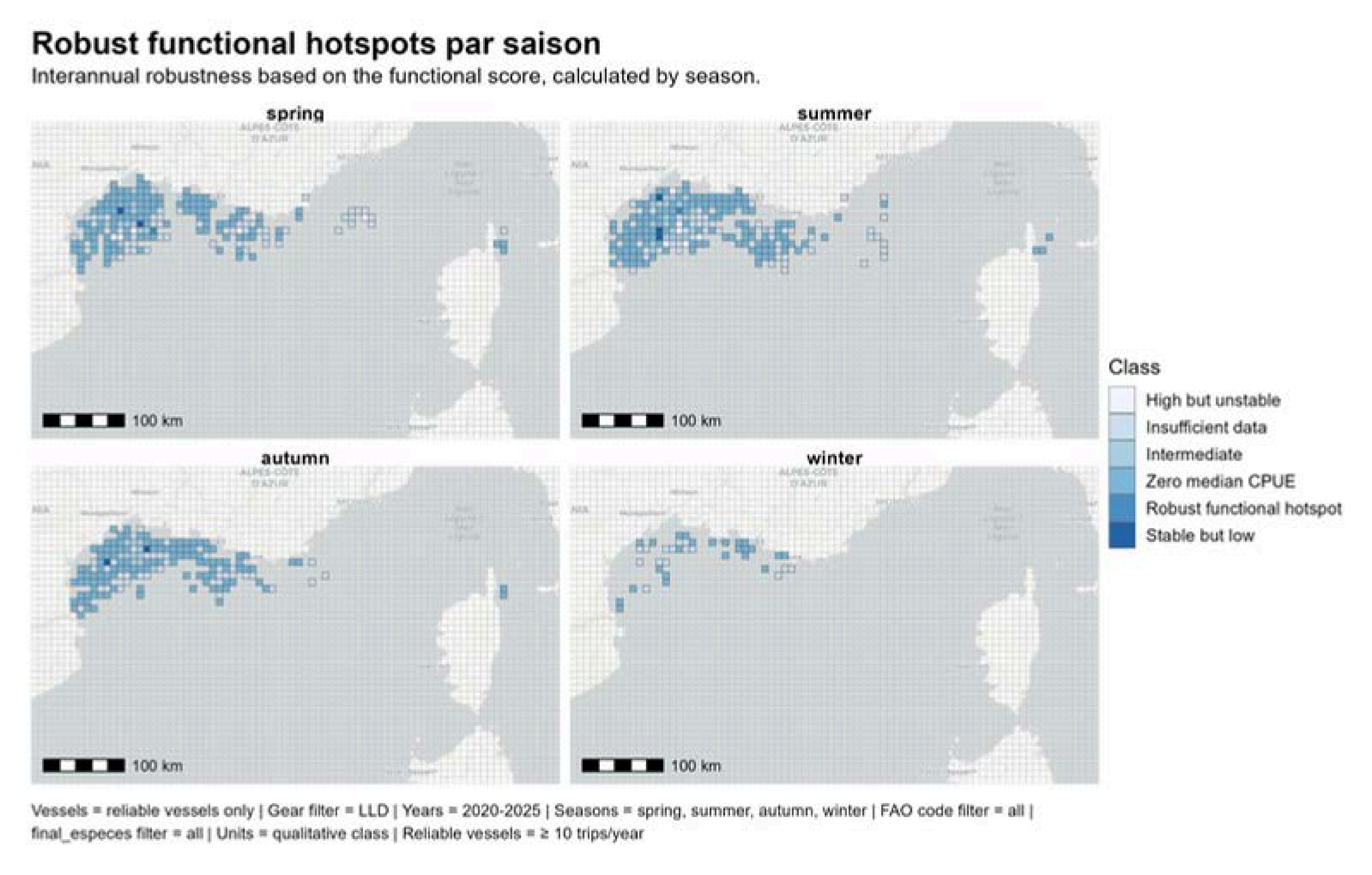
APPENDIX B. GLMM



SST effect (non-significant)

- No clear relationship with bycatch CPUE
- High variability among observations
- Other oceanographic variables may better explain offshore bycatch patterns
- Species-specific models could reveal hidden ecological responses

APPENDIX C. SEASONAL PATTERNS



APPENDIX C. SEASONAL PATTERNS

Table A1. Criteria used to classify temporal robustness categories.

Category	Definition	Interpretation
Robust functional hotspot	Functional score in the top 25% and low interannual variability	Highest-priority recurrent hotspot
High but unstable	Functional score in the top 25%, but not temporally stable	Candidate hotspot requiring validation
Stable but low	Low interannual variability, but not high functional score	Stable low-signal area
Intermediate	Neither high enough nor stable enough to meet other classes	Moderate or unclear ecological signal
Insufficient data	Not enough interannual information to estimate temporal variability	Cannot assess robustness
Zero median CPUE	Median CPUE equal to zero	No recurrent bycatch signal detected