MODELING THE INFLUENCE OF ANTHROPOGENIC PRESSURES ON THE DISTRIBUTION OF THE HUMPBACK WHALE (*MEGAPTERA NOVAEANGLIAE*) IN THE SOUTHERN OCEAN

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JULIA WERDENIG[1], CATARINA FRAZÃO SANTOS[1,2,3], CATARINA PEREIRA SANTOS[1,2], JOSÉ CARLOS XAVIER[4,5,6], FRANCISCO OLIVEIRA BORGES[1,2]

1 MARE — Marine and Environmental Sciences Centre / ARNET — Aquatic Research Network, Faculty of Sciences, University of Lisbon, Lisbon, Portugal; 2 Department of Biology, Faculty of Sciences, University of Lisbon, Lisbon, Portugal; 3 University of Oxford School of Geography and the Environment Oxford United Kingdom; 4 British Antarctic Survey, Natural Environment Research Council, Cambridge, United Kingdom; 5 Natural Environment Research Council British Antarctic Survey Cambridge United Kingdom; 6 University of Coimbra Centre for Functional Ecology Coimbra Portugal.

INTRODUCTION

The **Southern Ocean** is a critical regulator of **global climate** yet faces unprecedented shifts due to anthropogenic pressures. **Humpback whales** (*Megaptera novaeangliae*) are a keystone species in the region, serving as bio-indicators of ecosystem health and ecosystem engineers through significant top-down and bottom-up influences. As a mobile umbrella species, their habitat selection reflects broader environmental shifts within polar food webs. This study utilizes Maximum Entropy (**MaxEnt**) species distribution modelling (**SDM**) to quantify species-specific ecological niches undercurrent and future climate scenarios. Characterizing the spatiotemporal intersection between these ecological responses and intensifying human stressors is fundamental to ensuring long-term **population resilience.** By identifying future **refugia,** these findings offer a vital roadmap for **mitigating spatial conflicts** in an increasingly busy and warming Southern Ocean.

METHODS

1 – Antarctic Krill (*Euphasia superba*) and Humpback whale occurrence records (2000-2009) were retrieved from the Global Biodiversity Information Facility (GBIF).

2 – A set of ecologically relevant environmental predictors were retrieved from BioOracle for the present-day (2000-2009), and into three future timeframes (2030, 2050, and 2090), as well as three IPCC AR6-CMIP6 climate scenarios (SSP2-4.5, SSP3-7.0, SSP5-8.5)

3 – Species Distribution Models were then generated using MaxEnt – within the 'megaSDM' package – to estimate present-day and future habitat suitability for both species in the **Western Antarctic Peninsula (WAP).**

4 – Krill habitat suitability was included as a biotic predictor into the humpback whale SDMs.

5 – Temporal transferability metrics and Multivariate Environmental Similarity Surface (MESS) maps were generated to quantify uncertainty and identify regions of novel future climates. AUC, TSS, and Boyce Index metrics were used to evaluate the models.

6 – Integrating habitat suitability with present-day anthropogenic activities (i.e., fisheries and tourism data from the Global Fisheries Watch and IAATO), as well as marine protected areas, potential climate refugia and areas of human-wildlife overlap (i.e., potential conflicts) were identified.

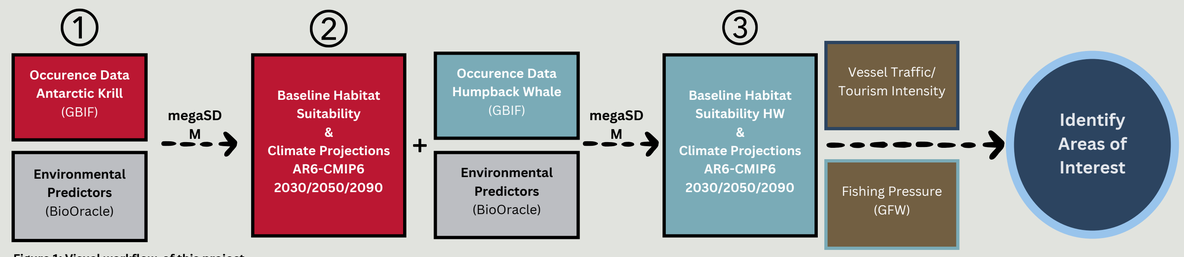

Figure 1: Visual workflow of this project.

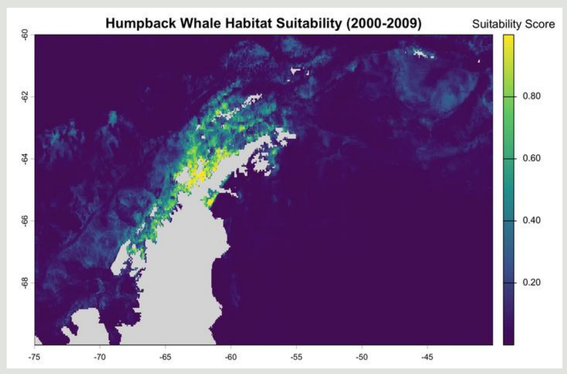

Figure 2: Habitat Suitability humpback whale in the present-day.

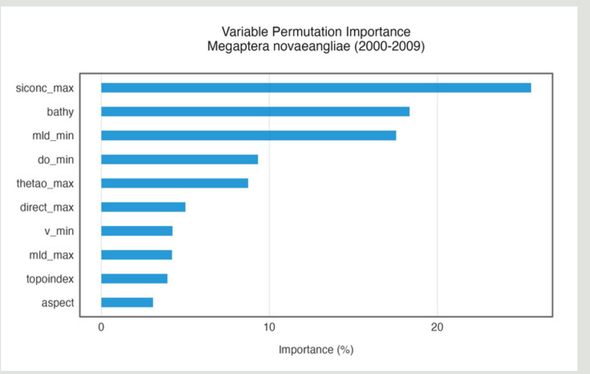

Figure 3: Variable importance for the baseline model for humpback whales. High importance of sea ice concentration, bathymetry and mixed layer depth.

RESULTS

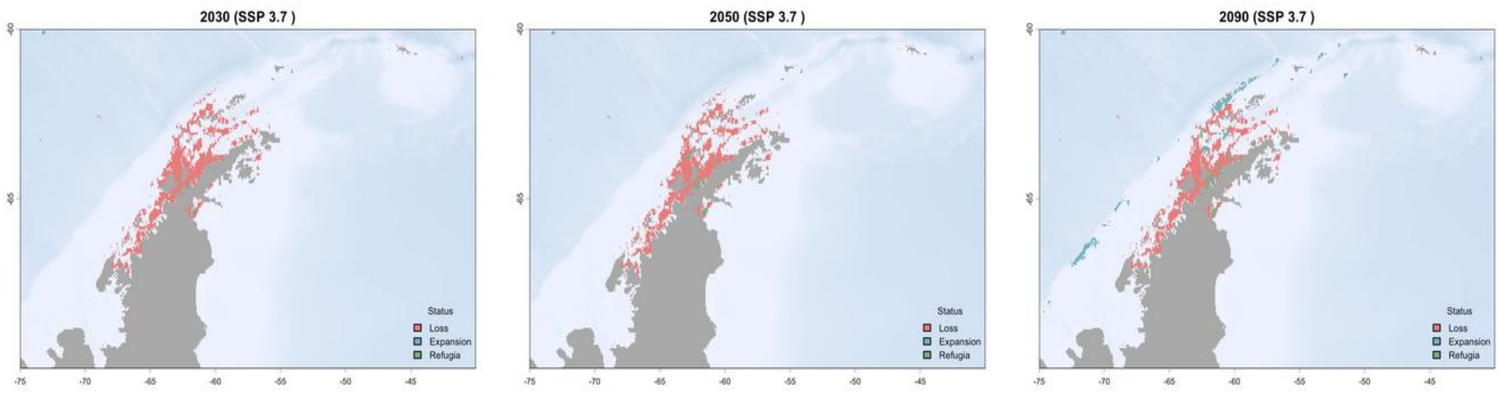

Figure 4: Habitat Shifts between Baseline (2000-2009) and 2030s, 2050s and 2090 for the IPCC AR6-CMIP6 climate scenarios 2.45, 3.7 and 5.85. While habitat loss is evident in a large area, areas of refugia (areas where the habitat stayed equally suitable) and of expansion (areas that have formerly not been suitable) are becoming visible as well.

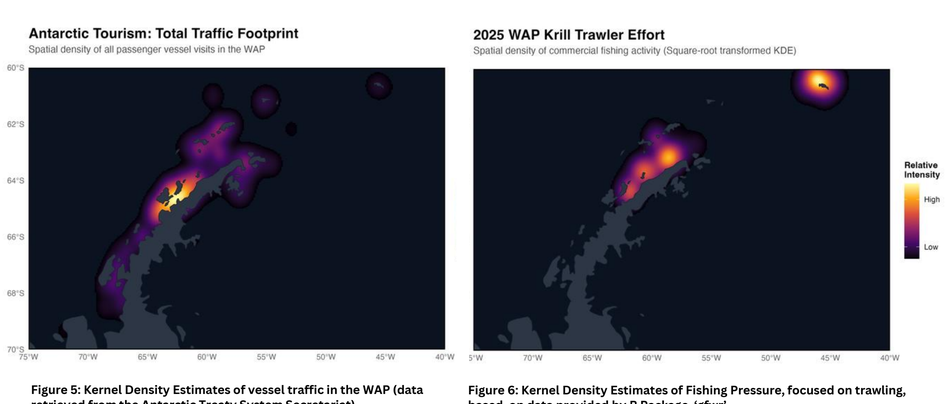

Figure 5: Kernel Density Estimates of vessel traffic in the WAP (data retrieved from the Antarctic Treaty System Secretariat)

Figure 6: Kernel Density Estimates of Fishing Pressure, focused on trawling, based on data provided by R Package 'gfwr'.

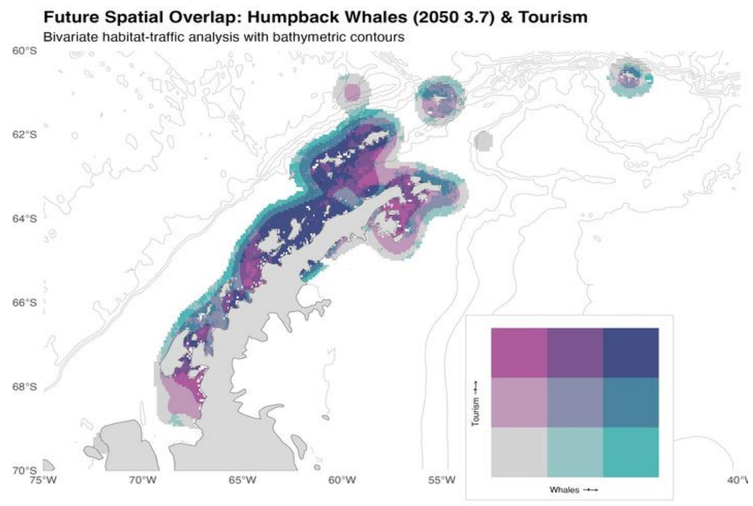

Figure 8: Overlap of Habitat Suitability 2050, SSP 3.7 and Vessel Traffic.

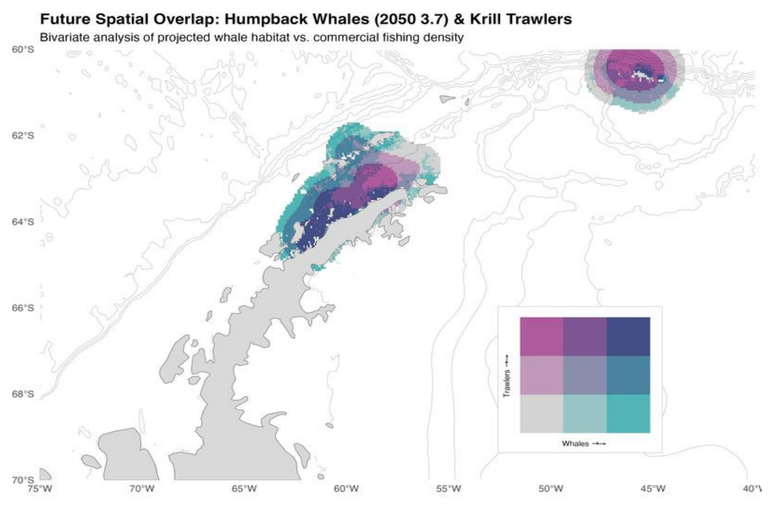

Figure 7: Overlap of Habitat Suitability 2050 and Fishing Pressure.

- **SDM**: Initial spatial modelling successfully characterises baseline habitat suitability for humpback whales in the WAP and establishes a foundation for anticipating climate-driven vulnerabilities.
- **Projected Dynamics**: Projections under AR6-CMIP6 scenarios indicate localized habitat contraction and shift as optimal conditions progressively track retreating environmental margins.
- **Spatiotemporal Conflict Zones***: Spatial overlays identify the WAP as an escalating conflict zone where predicted climate refugia increasingly intersect with active corridors of high-intensity tourism and commercial krill fishing.

*worth noting that present-day pressures were used with future habitat suitability, due to the absence of future projections of fisheries and tourism data.

CONCLUSION

1. This study integrates multi-scenario climate projections with footprints of commercial fishing and tourism.
2. By evaluating these anthropogenic pressures against predicted species distributions, the framework offers a critical lens for assessing potential future human-wildlife conflicts in the WAP.
3. Crossing this data with current and proposed Marine Protected Area (MPA) will help to inform the adequate management of these areas and spatially safeguard humpback whale habitats now and in the ocean of tomorrow, providing an essential foundation for adaptive conservation planning in the Western Antarctic Peninsula.
4. The development of 'climate-informed' SDMs which incorporate human pressures into generating management-ready outputs is paramount for the sustainable management of the Southern Ocean.

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MARE ARNET AQUATIC RESEARCH NETwork Ciências ULisboa

1290 UNIVERSIDADE D COIMBRA British Antarctic Survey NATURAL ENVIRONMENT RESEARCH COUNCIL UNIVERSITY OF OXFORD

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LinkedIN

Julia.werdenig@gmx.net

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