Past and future range shifts of Western Baltic fish – how did we get there and where do we go now?

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Introduction

- Baltic Sea is under threat from climate change, pollution, overfishing, and other disturbances [1]
- Climate change drives species distribution shifts which are likely to have impactful ecological and economic consequences and need to be accounted for in fisheries management [2]
- Our research goals are to understand how climate change and eutrophication drive current species distributions and to predict those of the future under four different scenarios that combine model projections of future climate change and eutrophication

Materials and methods

- Catch per unit of effort (CPUE) data for 8 fish species was sourced and calculated from ICES Baltic International Trawl Survey (Q1: February and March) [3] and Baltic International Acoustic Survey (BIAS) [4] data
- Substrate data includes the percentage of rock, mud and sand in each grid cell and was obtained from the results of the BALANCE project [5]
- Depth data was sourced from the topography data set created by the Leibniz Institute for Baltic Sea Research Warnemünde (IOW) [6]
- Environmental data (2001 to 2020) for model training was obtained from Copernicus Marine Data Store (Baltic Sea Biogeochemistry and Physics Reanalysis) [7, 8]
- Future projections of environmental data (2011 to 2098) for species distribution predictions combine RCP 4.5 and 8.5 climate change scenarios with REF and BSAP eutrophication scenarios [9]
- Species distribution models were created with the use of Integrated Nested Laplace Approximation (INLA) approach [10] with sdmTMB R package [11]
- Models were trained using data from 2001 to 2010 and predictive performance was tested on data between 2011 and 2020

Results and discussion

- Table 1. shows the overview of the fitted models for 5 benthic and benthopelagic species with associated predictive performance criteria
- Results below are given for the combination of RCP 8.5 climate change and REF eutrophication scenarios
- European plaice (*Pleuronectes platessa*) is expected to largely increase its range (Fig. 1) and slightly its abundance (Fig. 2), and should, unlike other species, exhibit noticeable range shifts vertically and horizontally, namely northwards and eastwards (Figs. 3 & 4)
- Surprisingly, Atlantic cod (*Gadus morhua*) is expected to slightly increase in both range and abundance, however the models were fit using data from the winter period which likely leads to these conclusions (Figs. 1 & 2)
- European flounder (*Platichthys flesus*) boasts the largest range that should stay rather constant (Fig. 1) and highest abundance that should increase slightly (Fig. 2)
- Whiting (*Merlangius merlangus*) and common dab (*Limanda limanda*) are not expected to demonstrate noticeable changes in range or abundance (Figs 1 & 2)
- Results for 3 pelagic species are not shown here as it was deemed that the associated models require further work in order to produce representable results

Table 1. Overview of fitted models

	Presence – absence part of the model						Density part of the model					
Species	Distribution	Covariates	Spatial fields	Spatiotemporal fields	Train AUC	Test AUC	Distribution	Covariates	Spatial fields	Spatiotemporal fields	Train NRMSE	Test NRMSE
Atlantic cod (*Gadus morhua*)	Bernoulli (link = "logit")	s(depth) + mud* + o2* + s(temp)	ON	AR1	0.9402365	0.8124507	Gaussian (link = "identity")	s(depth) + temp* + sa*l + mud	ON	IID	0.8998883	1.00787
Whiting (*Merlangius merlangus*)	Bernoulli (link = "logit")	sal* + temp*	ON	AR1	0.9897093	0.9470917	Gaussian (link = "identity")	sal* + sand* + temp + o2 + rock	ON	AR1	0.8162995	0.9590308
European flounder (*Platichthys flesus*)	Bernoulli (link = "logit")	s(depth) + temp	ON	IID	0.9998231	0.8311666	Gaussian (link = "identity")	depth* + temp* + o2*	ON	IID	0.8691504	0.9948235
European plaice (*Pleuronectes platessa*)	Bernoulli (link = "logit")	sal + depth	OFF	AR1	0.968359	0.9176089	Gaussian (link = "identity")	sal + depth	ON	IID	0.7340461	1.01839
Common dab (*Limanda limanda*)	Bernoulli (link = "logit")	sal* + mud + depth + o2	OFF	RW	0.9897438	0.978035	Gaussian (link = "identity")	sal + rock + mud + depth + temp	ON	IID	0.7172448	0.717329

** Statistically significant covariates*

Figure 1: Yearly change of species range size; RCP 8.5, REF

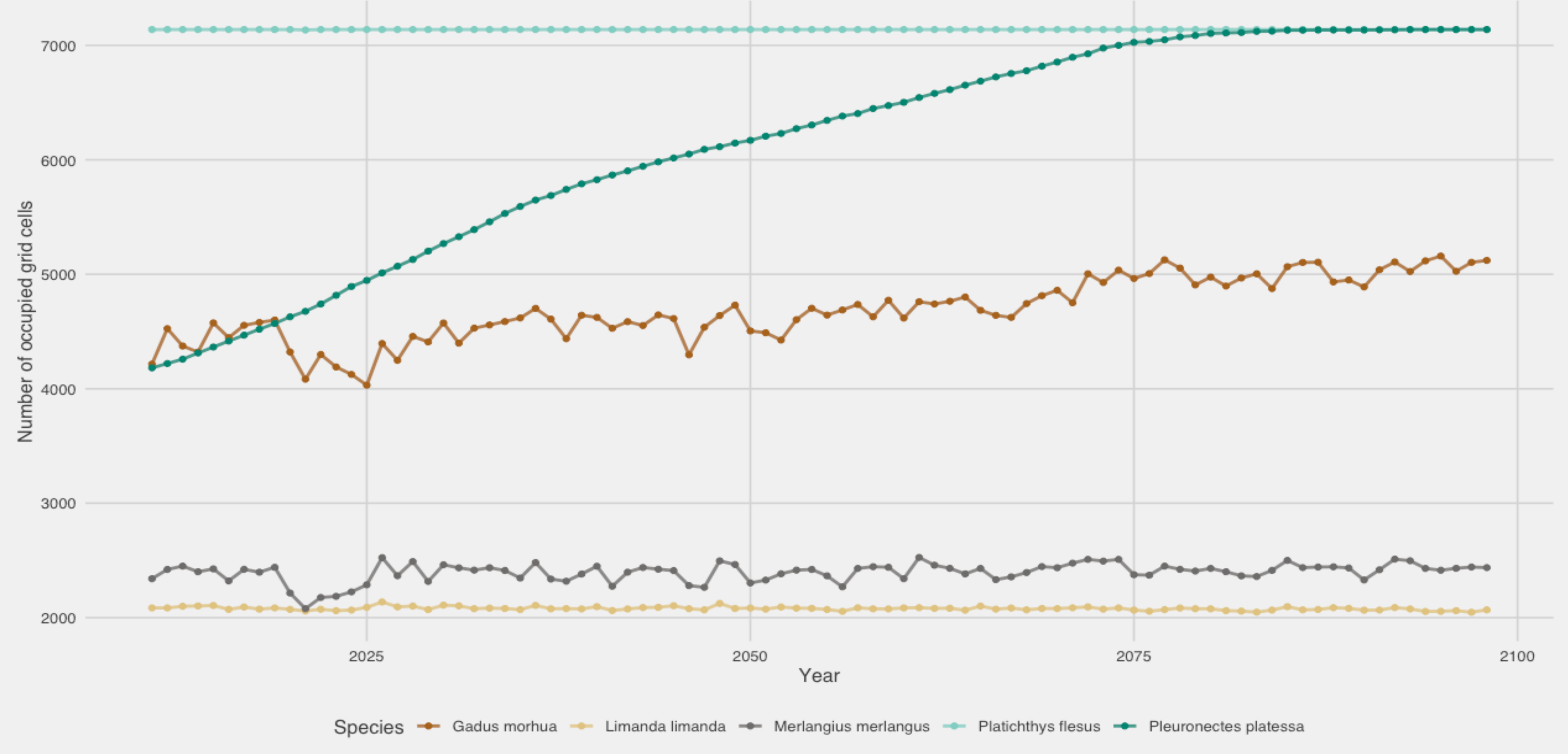


Figure 3: Yearly change in Center of gravity - Longitude; RCP 8.5, REF

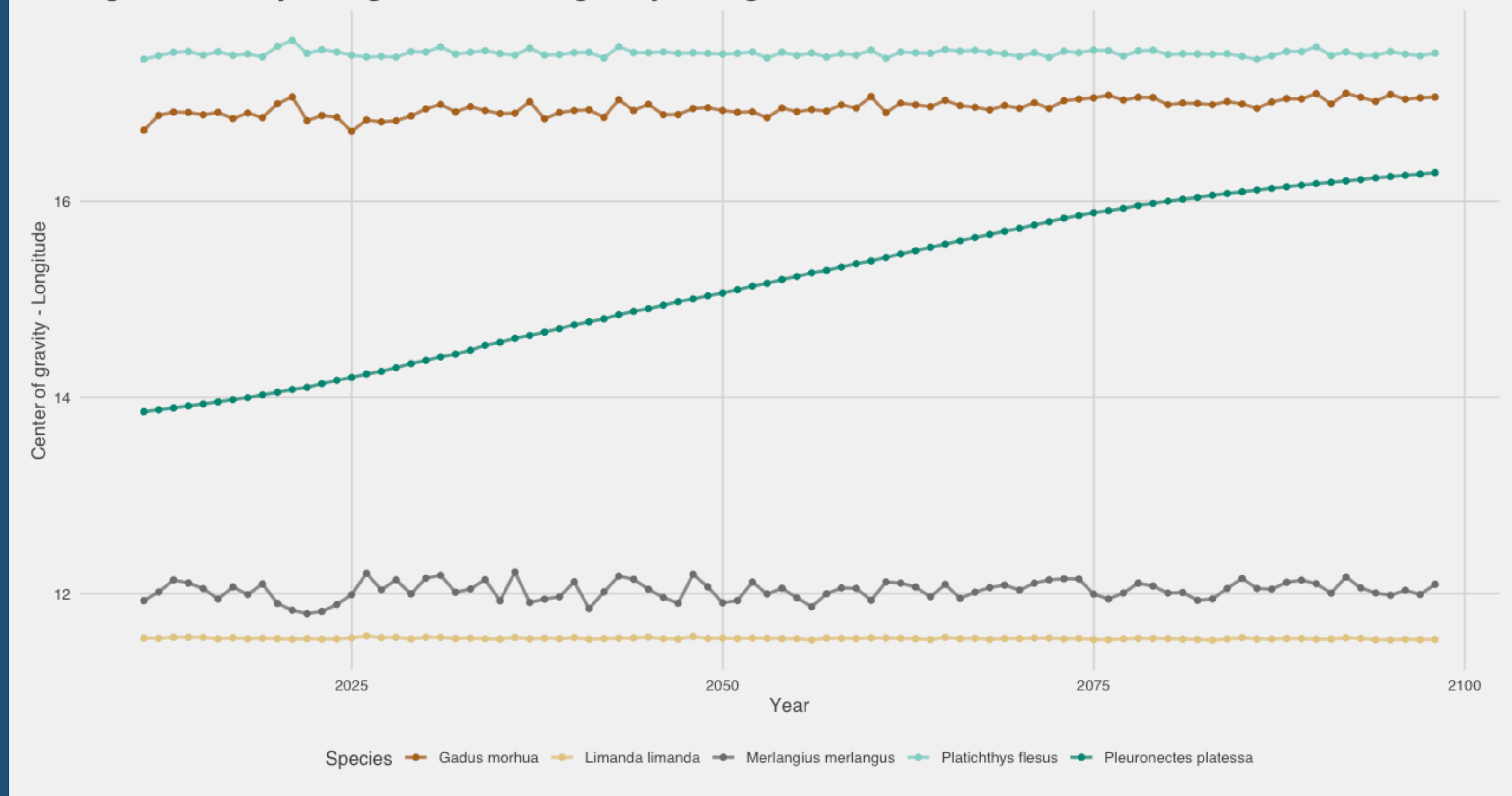


Figure 2: Yearly change in catch per unit of effort; RCP 8.5, REF

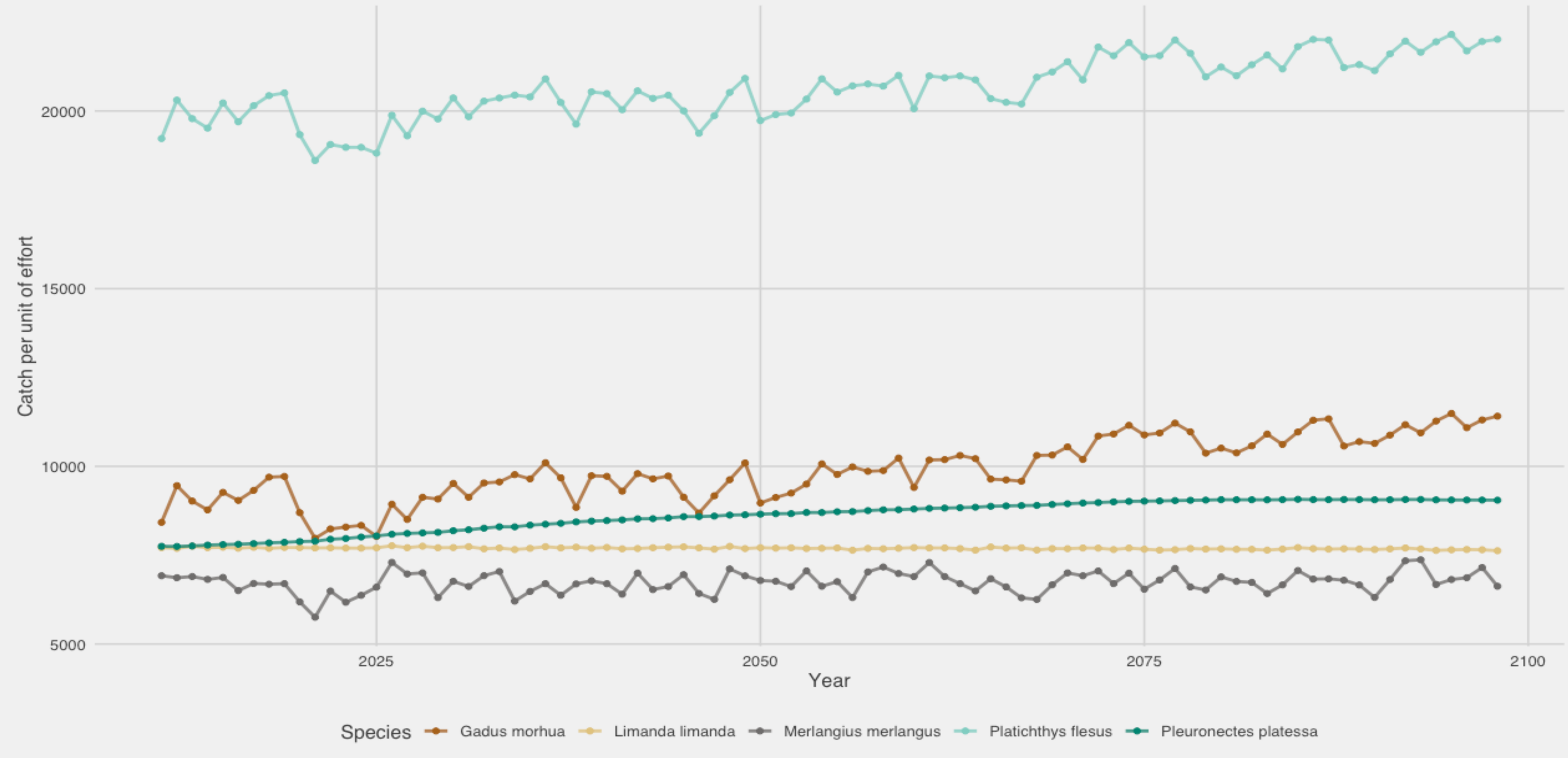
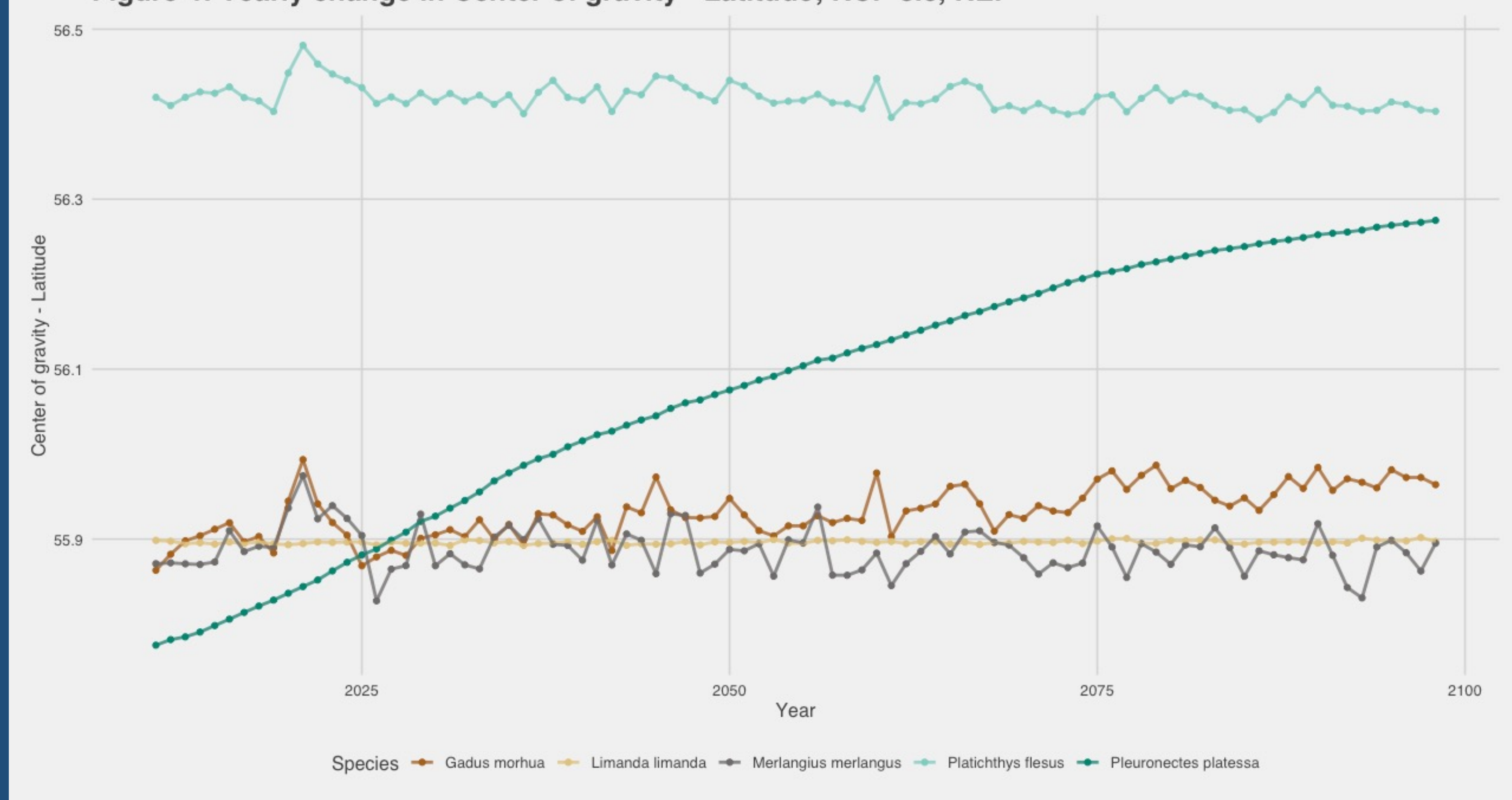


Figure 4: Yearly change in Center of gravity - Latitude; RCP 8.5, REF



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References

[1] Reusch T. B. H., et al. 2018. The Baltic Sea as a time machine for the future coastal ocean. Science Advances 4.5: eaar8195.
[2] Ojea E., Lester S.E., and Salgueiro-Otero D. 2020. Adaptation of fishing communities to climate-driven shifts in target species. One Earth 2.6: 544-556.
[3] ICES BITS (Baltic International Trawl Survey) dataset 2022. ICES, Copenhagen.
[4] ICES Acoustic data portal, 2022 ICES, Copenhagen.
[5] Al-Hamdani Z. and Reker J. (eds.). 2007. Towards marine landscapes in the Baltic Sea. BALANCE interim report #10. Available at http://balance-eu.org/.
[6] Seifert T., Tauber F., and Kayser B. 2001: "A high resolution spherical grid topography of the Baltic Sea - 2nd edition", Proceedings of the Baltic Sea Science Congress, Stockholm 25-29. November 2001, Poster #147.
[7] Baltic Sea Biogeochemistry Reanalysis, E.U. Copernicus Marine Service (CMEMS), https://doi.org/10.48670/moi-00012
[8] Baltic Sea Physics Reanalysis, E.U. Copernicus Marine Service (CMEMS), https://doi.org/10.48670/moi-00013
[9] Markus Meier H.E., Dieterich C., and Gröger M. 2021. Natural variability is a large source of uncertainty in future projections of hypoxia in the Baltic Sea. Commun Earth Environ 2, 50. https://doi.org/10.1038/s43247-021-00115-9
[10] Rue H., Martino S., and Chopin N. 2009. Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations. Journal of the royal statistical society: Series b (statistical methodology) 71.2: 319-392.
[11] Anderson S. C., Ward E. J., English P. A., and Barnett L. A. K. 2022. sdmTMB: an R package for fast, flexible, and user-friendly generalized linear mixed effects models with spatial and spatiotemporal random fields. bioRxiv 2022.03.24.485545; doi: https://doi.org/10.1101/2022.03.24.485545