Changing fish distributions challenge the effective management of European fisheries

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Area being submitted to (delete as appropriate): *2. Marine Climate Change*

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Changes in fish distribution are being observed across the globe. In Europe's Common Fisheries Policy, the share of the catch of each fish stock is split among management areas using a fixed allocation key known as 'Relative Stability': in each management area, member states get the same proportion of the total catch each year. That proportion is largely based on catches made by those member states in the 1970s. Changes in distribution can, therefore, result in a mismatch between quota shares and regional abundances within management areas, with potential repercussions for the status of fish stocks and the fisheries that depend on them. Assessing distribution changes is crucial to ensure adequate management and sustainable exploitation of our fish resources. We analysed scientific survey data using a three-tiered analytical approach to provide, for the first time, an overview of changes in distribution for 19 northeast Atlantic fish species encompassing 73 commercial stocks over 30 years. All species have experienced changes in distribution, five of which did so across management areas. A cross-species analysis suggested that shifts in areas of suitable thermal habitat, and density-dependent use of these areas, are at least partly responsible for the observed changes. These findings challenge the current use of Relative Stability to allocate quotas.

Acknowledgements

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Tweetable abstract

Changes in northeast Atlantic fish distribution amidst #climatechange and fish stocks recovery challenge the use of relative stability to allocate quotas in #EU #fisheries #MASTSasm2020

@alanbaudron

Experimental investigation of the roles of HCO_3^- and CO_3^{2-} in aragonite precipitation.

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Our experiments study the roles of both HCO3- and CO32- in aragonite precipitation. They provide valuable information on the mechanism responsible for aragonite formation and are key to predicting responses of calcareous organisms to ocean acidification.
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Ocean acidification reduces seawater pH, shifts the dissolved inorganic carbon (DIC) equilibrium (increasing [HCO3-] and decreasing [CO32-]) and reduces the calcification rates of many calcareous marine organisms. Aragonite and calcite precipitation rates are typically surmised to reflect the seawater saturation state, Ω (reflecting the availability of CO32- and Ca2+ for incorporation in the CaCO3 precipitate). However, both aqueous HCO3- and CO32- are inferred to attach to growing calcite crystal surfaces [1] and HCO3- is observed in both coral and synthetic aragonite [2]. Understanding the roles of both HCO3- and CO32- in CaCO3 precipitation is key to predicting the responses of calcareous organisms to ocean acidification.

We are conducting experiments to study aragonite precipitation at a constant saturation state (Ω = 4, 7, 10, 13 or 18) over varying seawater pH levels (pH= 8.337, 8.545 and 8.727). These changes in pH were accompanied by changes in [DIC] (850-7800 µmol kg-1) and, subsequently, [HCO3-] but [CO32-] remains essentially unchanged. All experiments were conducted at T = 25±0.1°C, salinity = 34 and using an aragonite seed. We correlated aragonite precipitation rates with concentrations of CO32- and HCO3- ions. Preliminary results suggest the precipitation rate of aragonite reflects the CO32- ion concentrations while HCO3- ion concentrations had a negligible effect on precipitation rate. This provides valuable information on the mechanism responsible for aragonite formation and has important implications on the interpretation of O isotope proxies.

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Predicting seabird abundance responses to both marine and terrestrial climate change

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Seabirds are exposed to climate change in both the marine and terrestrial environment, but the relative effects of both are rarely compared. Here, we analyse the relationship between marine (SST, stratification) and terrestrial (temperature, precipitation) climate variables and the abundance of 19 seabird species in UK and Ireland using Bayesian spatial models. The effect of terrestrial climate variables on seabird abundance was typically higher in magnitude than that of marine variables, but this varied considerably between species. Having accounted for space, the proportion of variation in abundance explained by climate was typically low but varied between species. Including terrestrial climate in the model often changed the magnitude or even the direction of the projected change in seabird abundance by 2050 from that predicted using marine climate alone. Therefore, to make accurate future projections of seabird abundance and inform management, we must consider climate change in both environments.

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Projections of seabird abundance in the UK and Ireland in 2050 differ depending on whether models incorporate terrestrial climate data, or marine climate data alone. To make accurate future projections of seabird abundance and inform management, we must consider climate change in both environments. #MASTSasm2020

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Modelling the impacts of climate change on the abundance of shallow-water marine fish at a global scale

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Area being submitted to: *2. Marine Climate Change*

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A Gaussian temperature-abundance model based on species' thermal affinities and applied to 2,613 shallow-water fish species across the globe highlights possible 'winners' and 'losers' to projected temperature change. #ClimateChange # MASTSasm2020 @edward_lavender

Understanding and predicting the response of marine communities to climate change at large spatial scales, and distilling this information for policymakers, are prerequisites for ecosystem-based management. Changes in abundance are especially concerning because of their implications for species conservation, trophic interactions and fisheries. However, global scale predictions have tended to focus on species range shifts with less attention paid to potential changes in abundance. Here, we report a novel methodology based on Species Thermal Indices that may be applied widely across marine species to predict change in relative abundance. We use this approach to predict change in the relative abundance of 2,613 shallow-water fish species under Representative Concentration Pathways (RCPs) 4.5 and 8.5 by 2050 at a global scale. We find a clear pattern of decline in the tropics versus possible increases in relative abundance at higher latitudes. The Indo-Pacific, the most species-rich study region, emerges as the area of most concern with most species predicted to decline and the magnitude of predicted declines higher and the variation lower than for any other region. These declines reflect small temperature rises but consistently narrow thermal niches, with most species already exposed to temperatures above inferred thermal optima. The western coasts of North and South America, central East Africa and East Asia, where most species live below thermal optima and niches are wider, emerge as the greatest beneficiaries of climate change, despite strong predicted temperature increases. This study contributes towards our understanding of temperature-driven change and ecosystem-based management strategies in a warming world.

Acknowledgements

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Climate change impacts recruitment rates of North Sea and Irish Sea cod by widening the phenological mismatch

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Over the past three decades warming sea temperatures in both the North Sea and Irish Sea have resulted in earlier spawning of Atlantic cod (*Gadus morhua*) (McQueen and Marshall 2017). Temperature-induced shifts in spawning phenology have the potential to impact rates of recruitment via increased mismatch between first-feeding cod larvae and their zooplankton prey (termed phenological mismatch).
To test whether earlier cod spawning has resulted in an increased match-mismatch index (MMI) data from the Continuous Plankton Recorder were used to estimate monthly abundances of zooplankton prey in a size range suitable for the gape width of first-feed cod larvae (ca. 0.5mm). Individual dry weights for prey species was then used to estimate relative biomass of suitable zooplankton prey by month. For each year, the MMI (months) was estimated by subtracting the calendar day of peak abundance of first-feeding cod larvae from the calendar day of peak biomass of zooplankton prey.
Over the 30-year study period a significant increase in MMI was found in all three regions, with MMI increasing between 0.9 and 1.53 weeks per decade. Furthermore, MMI was significantly, negatively correlated to rates of cod recruitment suggesting that increased phenological mismatch has reduced productivity in both cod stocks. The analysis supports Cushing's famous match-mismatch hypothesis and provides a process-based understanding of how future fish yields will be impacted by climatic variability.

McQueen, K., and Marshall, C.T. (2017) Shifts in spawning phenology of cod linked to rising sea temperatures. ICES J. Mar. Sci. 74: 1561-1573.

Tweetable abstract

North Sea cod are spawning earlier due to warming temperatures. This shift in timing has decreased the overlap between production of cod larvae and their zooplankton prey resulting in lower cod survival. Climate impacts on cod recruitment may have led to cuts in North Sea quotas.

Predicting Scottish maerl bed distribution under climate change

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Free-living, calcified red algae (called 'maerl') form complex three-dimensional, reef-like structures on the seafloor that support high biodiversity including many rare, endemic and commercially important species. These bed structures not only provide habitat, shelter and protection for a myriad of species and juveniles they also play an important role in the global biogeochemical cycle and are an important blue carbon source.

Although maerl beds occur globally they are particularly abundant in the North-East Atlantic and Scotland is a particular stronghold. Despite their ecological, economic and biogeochemical importance, maerl beds are threatened and declining. The IUCN Red List categorizes all maerl beds as 'Vulnerable' or 'Endangered' and in the North-East Atlantic maerl beds are protected under the OSPAR convention and EU Habitats Directives (and the legislation that implements it nationally). One of the biggest threats facing maerl beds in the coming century is climate change and ocean warming as they are sensitive to both temperature and pH. Maerl beds are vital ecosystem engineers and it is important to understand exactly how their distribution will be impacted by projected climate change. To this end, we constructed the first species distribution model for maerl-forming species and modelled their distribution under the IPCC Representative Carbon Pathways (RCPs) for 2050 and 2100. We have shown that large-scale declines in habitat suitable for maerl beds are likely to occur under all RCPs. This even applies to the least severe pathway, RCP 2.6, which represents a significant reduction in fossil fuel emissions, resulting in a predicted 38% decline in maerl bed habitat around Scotland by 2100. In Contrast, RCP 8.5 (which represents a 'business as usual' model) is predicted to result in an 84% decline in suitable habitat for maerl beds by 2100.

We have also shown that the fastest rate of decline in habitat suitable for maerl beds is likely to occur between now and 2050.

Despite the wide scale declines predicted, this modelling technique has identified refuge populations that may be able to persist under predicted climate change – we suggest that these should be the focus of conservation management in order to best ensure the long-term survival of this ecosystem.

References

Simon-Nutbrown, C., *et al.* (2020). Species distribution modelling predictions significant declines in coralline algae populations under projected climate change with implications for conservation policy. *Frontiers in Marine Science*, in review.

Please provide an additional tweetable abstract first (max. 280 characters) to assist online promotion. #MASTSasm2020.
Species distribution #modelling predicts between 38% (RCP2.6) and 84% (RCP8.5) declines in habitat suitable for #maerlbeds by 2100 and fastest rate of loss by 2050. This method also identifies refuge populations that should be protected #IPCC #climatechange #conservation #sdm #maerl

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The full abstract should be submitted to masts@st-andrews.ac.uk, in an editable format, by 16:00 Friday 14th August 2020.

Interactions between ice shelves and phytoplankton blooms in the Amundsen Sea, West Antarctica

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Area being submitted to *2. Marine Climate Change*

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Ice shelves and phytoplankton blooms are crucial components of our changing climate and ecosystems. In the Southern Ocean large quantities of anthropogenic carbon are taken up by phytoplankton (Arrigo & van Dijken, 2003), often close to ice shelves in waters free of sea ice – coastal polynyas. Many ice shelves, particularly in the Amundsen Sea sector of West Antarctica, are undergoing rapid basal melting (Gourmelen et al. 2017), with implications for ice sheet stability as well as regional oceanography. In this study we use coupled physical-biogeochemical modelling to investigate the interactions between a fast-melting ice shelf and a highly productive but iron-limited polynya.

We find that the surface distribution of phytoplankton in the polynya is primarily a function not of surface conditions (cloud cover, sea surface temperature), but instead of the ocean temperature at depth (below 250m). More precisely, interannual variability in the thickness of the warm and saline Circumpolar Deep Water (CDW) layer leads to interannual variability in melting from the deeper portions of the ice shelf. In years with higher melt rates there is a stronger overturning circulation beneath the ice shelf and thus more glacial and benthic iron supplied to the surface ocean. However different melt rates also lead to different pathways for meltwater, such that the location of the modelled phytoplankton bloom depends on the quantity of CDW on the continental shelf.

We go on to investigate the impact of chlorophyll on the upper ocean heat budget. We find that the presence of a phytoplankton bloom in the top 50m of the ocean increases radiative heating of surface waters, which by conservation of energy implies a decrease in radiative heating below. Hence in the summertime there is a biologically forced cooling of the water column at depths between 50m and 250m. This leads to a reduction in seasonal melting from the shallowest portions of the ice shelf, but leaves the more rapid (CDW-driven) melting at depth unaffected.

Acknowledgements

This work was supported by a UK Natural Environment Research Council (NERC) doctoral training partnership grant (NE/L002558/1) as part of the E3 DTP at the University of Edinburgh.

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