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Letter to the editor

Recent global model underestimates the true extent of Arctic kelp habitat

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Quantifying and predicting the abundance and extent of marine habitat-forming species in the face of anthropogenically-driven global change is a key goal in marine conservation. Our ability to do so depends on a reliable understanding of the factors that predict and/or influence habitat suitability and how the spatial variation of these factors might change in the future (Bonebrake et al., 2018). In recent years, scientists have used species distribution modelling approaches to identify the extent of suitable habitat for species of interest for conservation. This approach can help managers infer baselines, forecast changes, and ultimately identify candidate regions for conservation and/or restoration initiatives (Rodríguez et al., 2007).

Recently published in *Biological Conservation*, Jayathilake and Costello (2020) make a first attempt to formally predict suitable habitat globally for an important group of marine foundation species, the kelps (order Laminariales). Using presence-only occurrence data and maximum entropy modelling, the authors identify nearly 1.5 million km^2 of coastline predicted as suitable kelp habitat (hereafter JC model). Although we commend the objective of predicting kelp biome distributions with an impressively curated dataset at a global scale, we are concerned that several understudied and low diversity regions are excluded by their modelling due to limited occurrence data from these regions. While their model undoubtedly captures habitat that is optimal for most kelp taxa (i.e. cool-temperate coastlines), marginal, yet expansive habitat in the Arctic was largely excluded from the final predictions. In this case, the prediction of poor habitat at high latitudes is an artifact of the occurrence dataset, which -at no fault of the authors- reflects sampling bias towards temperate regions and difficulties incorporating historical surveys from the Arctic that are not easily obtained from public databases. While we recognize the considerable value of the authors' work (and their curated occurrence dataset), this important caveat should be considered when using and interpreting their predictions.

To reassess the predicted extent of high latitude kelp habitat, we collated a more geographically comprehensive set of occurrence records for three common species of Arctic-dwelling kelp, *Agarum clathratum*, *Alaria esculenta* and *Laminaria solidungula*, in particular drawing on historical ranges depicted by Lüning (1990) and references therein, occurrence records derived from the Macroalgal Herbarium Portal (https://macroalgae.org/portal/index.php) and recent genetic survey records available through the Barcode of Life Data Systems (see supplemental for methods). Altogether, our occurrence dataset for these species included 3134 observations but we note that there is some degree of overlap in the occurrence records presented here (Figshare: doi: https://doi.org/10.6084/m9.figshare.13302116) and used by Jayathilake and Costello (2020); a conservative approach for future analysis (to avoid duplicate records) would be to pool the georeferenced records of Lüning (1990) and the dataset of Jayathilake and Costello (2020).

Our stacked distribution model of Arctic kelps revealed large stretches of high latitude coastlines predicted to be suitable kelp habitat, including the northern half of Greenland, the Canadian Archipelago, and the Siberian coastline (Fig. 1), areas not predicted as kelp habitat by the JC model. Our model also identified kelp habitat in cold temperate areas not predicted by the JC model, including much of Atlantic Canada, and far Eastern Russia (Fig. 1). Importantly, these regions are clearly represented in our occurrence dataset (Fig. S1). We note that neither model likely captures the full extent of suitable habitat in the Sea of Okhotsk, a hotspot for endemic kelp diversity (Bolton, 2010) that remains poorly characterized. We also note that our model is likely conservative with regards to the true extent of Arctic kelp habitat due to the exclusion of non-rocky substrate. For instance, northern Alaska was masked from our analysis given the presence of depositional (i.e. unsuitable) substrate, however, it is well documented that kelp communities occur on patches of boulders throughout this area (Wilce and Dunton, 2014). Future work could incorporate finer resolution habitat modelling that captures the patchy nature and types of suitable kelp substrate in the Arctic.

Kelps (Laminariales, Phaeophyceae) are highly productive ecosystem engineers, creating habitat for a wide range of other organisms and structuring the ecosystems in which they live (Teagle et al., 2017). Kelp forests are threatened in many parts of the ocean from a wide variety of stressors, including climate change, and kelp forest losses can have substantial impacts on ecosystem productivity, functioning and the provisioning of services to humankind (Wernberg et al., 2019). Kelps also play a key role in the global carbon cycle and could help mitigate climate change through carbon capture and sequestration

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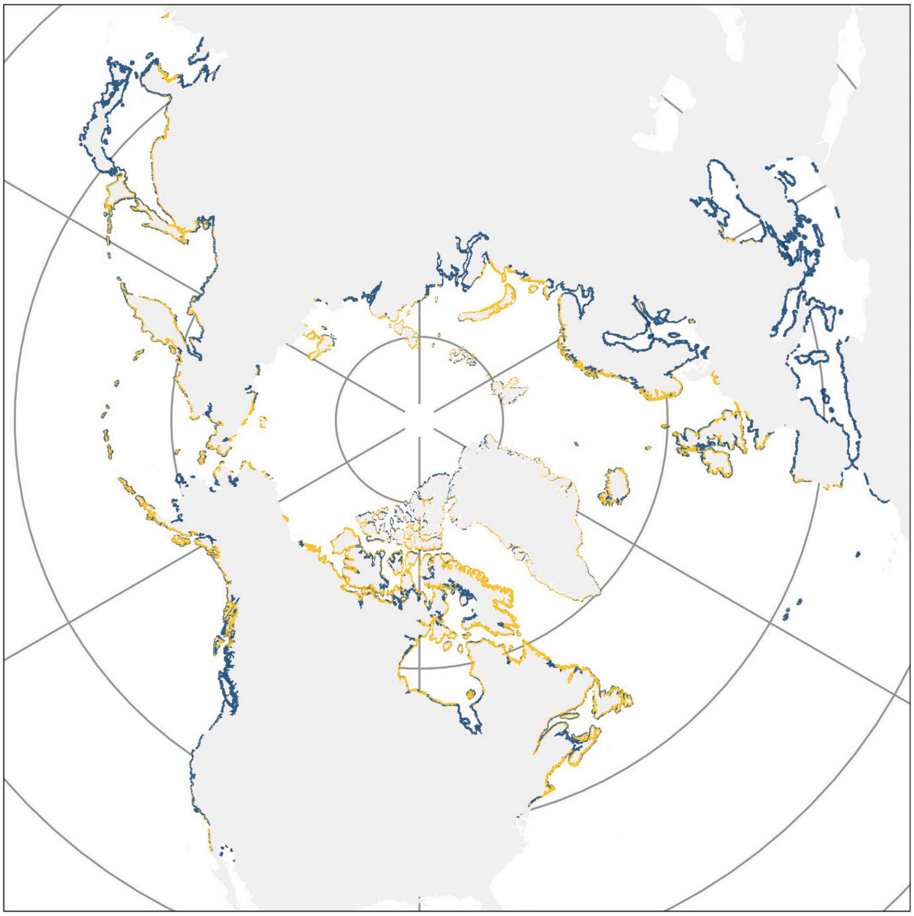

Fig. 1. Predicted distributions (stacked) for three kelp species with Arctic distributions (*Agarum clathratum*, *Alaria esculenta*, and *Laminaria solidungula*) based on MaxEnt species distribution model. A binary prediction is presented, with the predicted presence of any species shown in yellow, and absence of all species shown in blue. Shorelines without colour were not included in the analyses. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(Krause-Jensen and Duarte, 2016). Thus, a global estimate of total kelp habitat would be highly informative. Although often overlooked, high latitude kelp forests play key ecological roles in the Arctic and are likely to become increasingly abundant and productive into the future (Filbee-Dexter et al., 2019), a trend already reported for some pan-Arctic areas (Krause-Jensen et al., 2020). We predict that these three Arctic kelps alone have suitable habitat across 12.1% of the world's coastlines, with the Arctic endemic *L. solidungula* accounting for ~6.2% of this global estimate (see Figs. S2–4 for individual species predictions). Importantly, the habitat of *L. solidungula* is almost entirely absent from the JC model. Jayathilake and Costello (2020) calculated the kelp biome occupies 22% of the world's coastlines; given our conservative analysis, we suggest this figure is at least 28%, with the caveat that it is problematic to compare across analyses given differences in methodological choices (e.g., map projections or threshold values for presence vs. absence). Nonetheless, Arctic-dwelling kelps clearly make up a significant percentage of the global kelp biome and should not be overlooked. We note that gross habitat predictions should be considered coarse estimates, as the suitability of kelp habitat may vary at fine scales due to microhabitats and biotic interactions not captured in present models. Further global scale modelling will be needed to refine these estimates, work we eagerly anticipate under further impending changes to the global kelp biome.

Declaration of competing interest

The authors have no competing interests to declare.

Appendix A. Supplementary Material

Supplementary materials associated with this article (including methods and supplementary figures) mater can be found online at https://doi.org/10.1016/j.biocon.2021.109082.

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