Sampling position cannot predict how marine tetrapod abundance and distribution changes

1. Introduction

The thermal limit of more species is being reached in certain areas of the world due to global warming [1,2]. Sea surface temperatures around the equator are increasing so many areas are becoming too hot [1]. Hasting *et al.* [1] identified an association between the latitudinal sampling position of a study and the direction of abundance change observed in the study, with declines towards the equator where temperatures were above the thermal tolerance of many species. However, this paper lacked detail on marine tetrapods (mammals, reptiles, and birds), so this study aimed to identify if similar predictions can be applied to this animal group.

2. Methods

Meta-analysis of abundance data that covered at least 19 years, published since 1990, and showed an abundance change for a single species. 1121 records fit these criteria across the marine tetrapods across the world (Fig.1). The sampling position was calculated using the equatorward and poleward extreme latitude for each species and the study latitude. In R 4.0.3, generalized linear mixed-effects models were then used to examine the association between sampling position and the direction of abundance change, which were simplified where possible. Packages used included lme4, piecewiseSEM, effects, and ggplot2 [3-6].

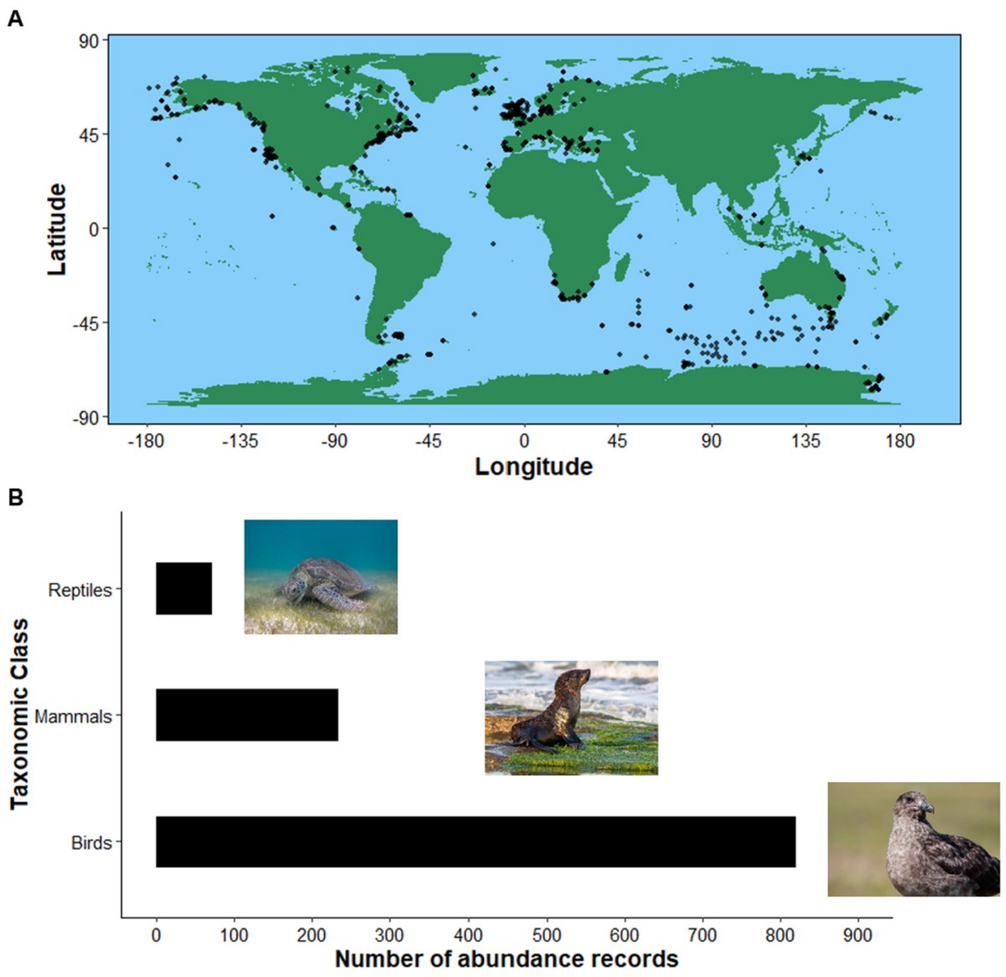


Figure 1 (above). Spatial and taxonomic distribution of records used in this analysis. **(A)** Global distribution of record locations, using the decimal coordinate data. **(B)** Taxonomic spread of records across the three classes of marine tetrapod, n = 1121. Photos represent species within each class: green turtle (*Chelonia mydas*) by P. Lindgren, South American fur seal (*Arctocephalus australis*) by R. M. Teixeira, and great skua (*Stercorarius skua*) by Elrond. Photos from Wikimedia Commons are licensed under the Creative Commons Attribution licenses 3.0 (green turtle), or 4.0 (fur seal and skua).

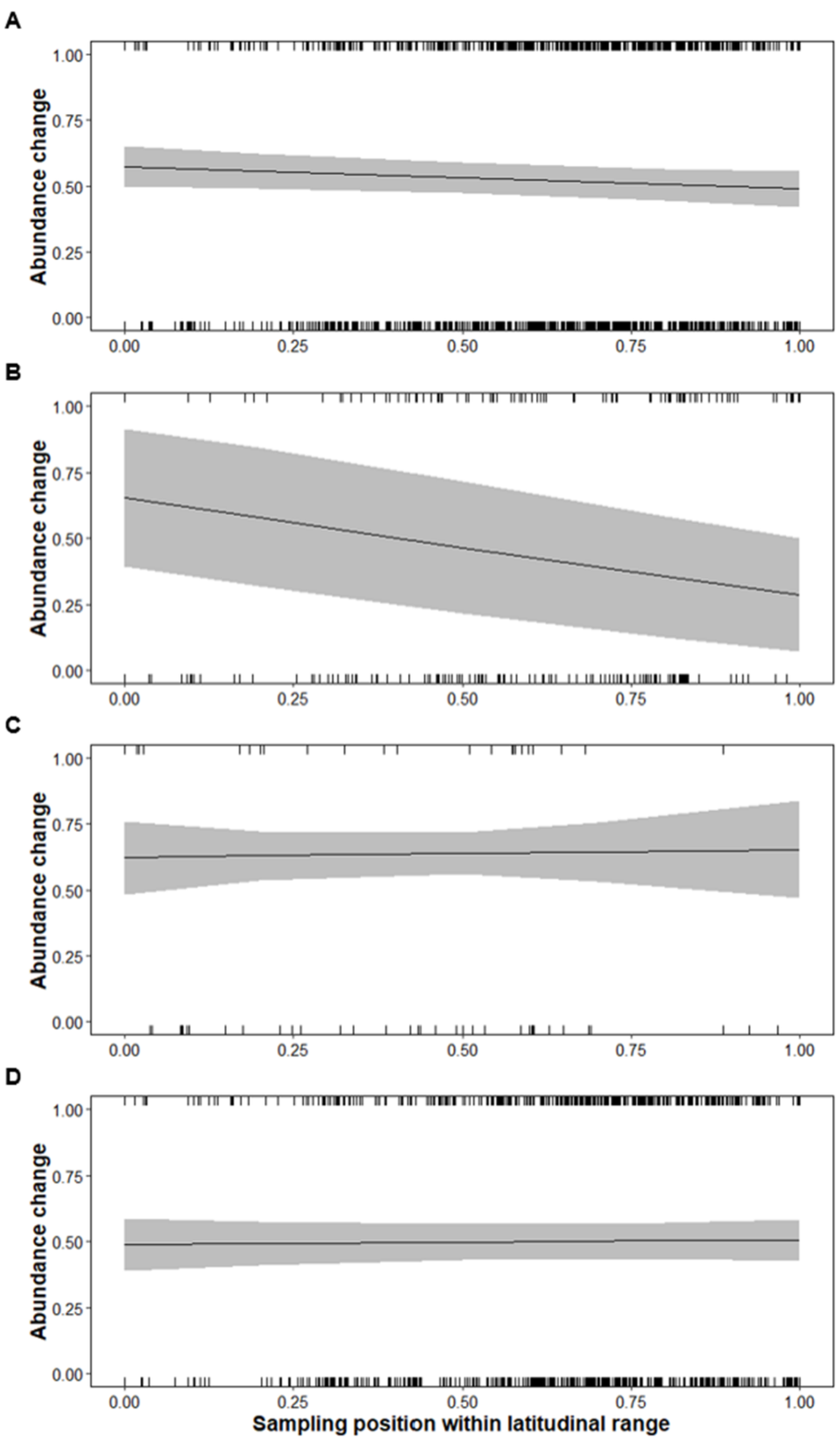


Figure 2 (above). The effect of abundance changes against the sampling position within the latitudinal range of species. **(A)** All records, n = 1121, **(B)** mammal records, n = 233, **(C)** reptile records, n = 70, and **(D)** bird records, n = 818. Sampling position measured as zero at the equatorward extreme value, to one at the poleward extreme value. Direction of abundance change reflects either positive (+1.00 on the axis), or negative (0.00 on the axis) change and the vertical lines represent data points on either axis. The light grey shaded area describes ± 1 s. e.

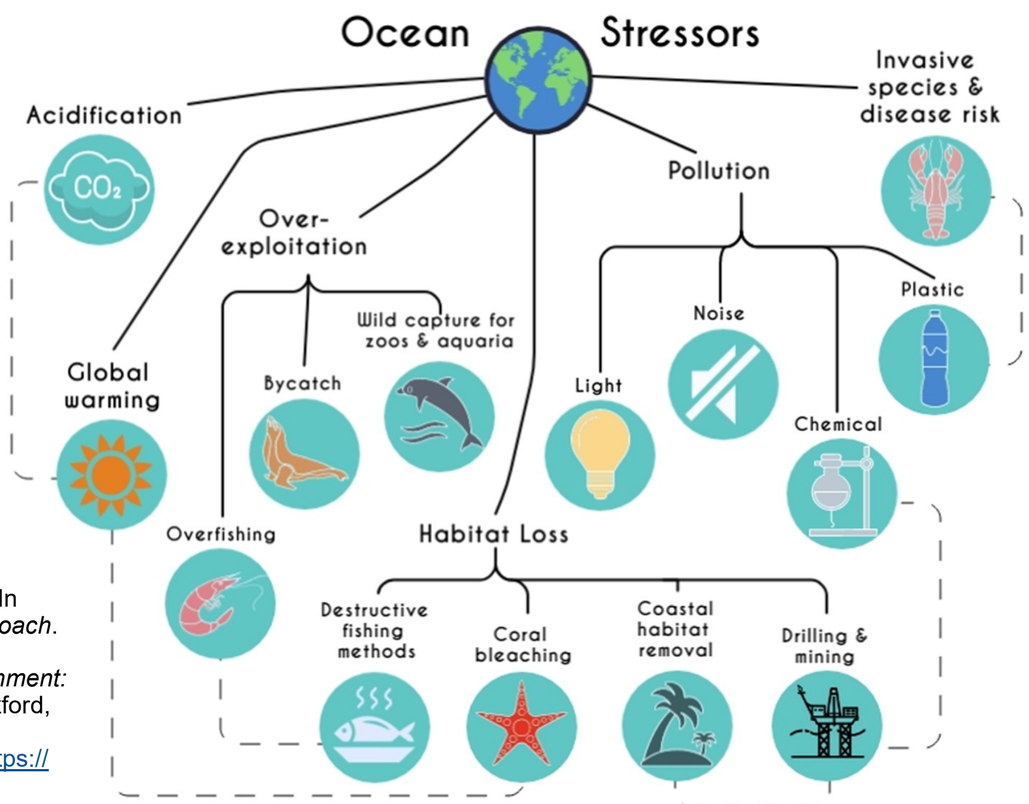
3. Results

When the models were applied to the dataset as well as taxonomic subsets, non-significant associations were found between sampling position and the direction of abundance change (Fig. 2; $p > 0.05$). The full dataset describes abundance increases towards the equator, with abundance decreases towards the poles (Fig. 2A). However, when split into the subsets, each class shows a different pattern, varying from negative (Fig. 2A; mammals), positive (Fig. 2B; reptiles), and flat (Fig. 2D; birds).

4. Discussion

This study shows that sampling position of a study cannot effectively predict the direction of abundance change for marine tetrapods, unlike as suggested by Hastings et al. [1]. This could be due to differences in the stress experienced by marine tetrapods such as pollution or over-exploitation [7], which has impacted large marine tetrapods greatly (Fig. 3). Their life histories could also influence how species abundance are changing, as k-select species often do not experience fast population growth, but can experience dramatic declines [8]. There are many complexities associated with marine tetrapods that could influence their abundance, not just temperature, described via sampling position in this study. Therefore, future meta-analyses need to take into account other factors that could influence where a species inhabits, not just the temperature of the water.

Figure 3 (right). Infographic describing many key stresses marine animals are facing, based on information from Chapman [7] and the book 'Stressors in the marine environment' edited by Solan and Whiteley [9]. Solid black lines represent direct connections whereas dashed grey lines represent indirect connections, for example between global warming and coral bleaching as rising temperatures may be linked to increased frequency of bleaching events. Cartoon images sourced from visme.co [10].



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