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Original research article

Identifying potential marine climate change refugia: A case study in Canada's Pacific marine ecosystems

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HIGHLIGHTS

- Combining historical data, climate models, and expert opinion could identify refugia.
- We found limited evidence for potential climate refugia in the northeastern Pacific.
- Certain oceanographic features may be more stable as the climate changes.
- Areas of stability and overlap with features identified by experts may be refugia.

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ABSTRACT

The effects of climate change on marine ecosystems are accelerating. Identifying and protecting areas of the ocean where conditions are most stable may provide another tool for adaptation to climate change. To date, research on potential marine climate refugia has focused on tropical systems, particularly coral reefs. We examined a northeast Pacific temperate region – Canada's Pacific – to identify areas where physical conditions are stable or changing slowly. We analyzed the rate and consistency of change for climatic variables where recent historical data were available for the whole region, which included sea surface temperature, sea surface height, and chlorophyll *a*. We found that some regions have been relatively stable with respect to these variables. In discussions with experts in the oceanography of this region, we identified general characteristics that may limit exposure to climate change. We used climate models for sea surface temperature and sea surface height to assess projected future changes. Climate projections indicate that large or moderate changes will occur throughout virtually the entire area and that small changes will occur in only limited portions of the coast. Combining past and future areas of stability in all three examined variables to identify potential climate refugia indicates that only 0.27% of the study region may be insulated from current and projected future change. A greater proportion of the study region (11%) was stable in two of the three variables. Some of these areas overlap with oceanographic features that are thought to limit climate change exposure. This approach allowed for an assessment of potential climate refugia that could also have applications in other regions and systems, but revealed that there are unlikely to be many areas unaffected by climate change.

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1. Introduction

Despite rapid increases in understanding of climate change effects in the world's oceans, there is limited practical guidance on how to incorporate and address these challenges in spatial planning, management, and conservation strategies (Groves et al., 2012; Watson et al., 2012). Effects of climate change include increasing ocean temperatures, ocean acidification, changing patterns of ocean currents and productivity, sea level rise, and decreasing dissolved oxygen (IPCC, 2013). Conceptual responses to these changes to facilitate ecosystem adaptation include bolstering resilience through reducing non-climate stressors, protecting sufficient space, and fostering connectivity among habitats (Magris et al., 2014). Identifying areas of the ocean where some or all variables affected by climate change are stable or changing the least – which some have called "climate refugia" – may be one way to assist marine conservation efforts and planning in a changing climate.

The concept of climate refugia is not new and is fairly well-established in terrestrial ecosystems (Keppel et al., 2012; Noss, 2001; Taberlet and Cheddadi, 2002), even if its integration and implementation in conservation has been slow (Heller and Zavaleta, 2009). A contemporary definition offered by Keppel et al. (2012) is "habitats that components of biodiversity retreat to, persist in and can potentially expand from under changing environmental conditions". Its original application was (and often continues to be) in reference to areas where some taxa were able to survive glacial periods (Bennett and Provan, 2008), and more recently, has been used in conservation planning to indicate places that may be less susceptible to expected future climate change impacts, including extreme or anomalous conditions (Barnosky, 2008; West and Salm, 2003). Macrorefugia (also called classical refugia) occur at regional scales, while microrefugia are smaller areas where the microclimate remains suitable within a region where conditions are generally becoming unsuitable (Ashcroft, 2010). In this paper, we will be considering regional-scale (i.e., macro) refugia. Hereafter, we use the term refugia to refer to areas in the ocean with relatively stable (e.g., the middle quintile in a normal distribution, where the mean is the historical average or standardized anomalies) physical and oceanographic properties that can continue to provide a suitable range of physical conditions for species to persist where surrounding or adjacent areas may be changing.

Conservation research to date has primarily focused on identifying marine climate refugia by assuming that historical patterns of change will continue into the future, and have focused on tropical ecosystems, particularly coral reefs (e.g., Ban et al., 2012; Chollett and Mumby, 2013) —but also see Magris et al. (2015) and Van Hooidonk et al. (2013) for examples of longer-term analyses on coral reefs. For coral reefs, potential refugia from thermal bleaching have been identified from satellite data including sea surface temperature (SST) (Ban et al., 2012; Gove et al., 2013), wave height and period (Gove et al., 2013), chlorophyll *a* (Gove et al., 2013), and irradiance (Gove et al., 2013), and by using outputs from oceanographic models of current speeds and upwelling (Chollett and Mumby, 2013). Outside of coral reefs, there has been some exploration of cold, deep-water refugia for kelp in tropical waters (Graham et al., 2007), and of possible refugia in the Arctic for retained sea ice (Moore and Huntington, 2008). In temperate systems, seamounts have been proposed as potential refugia from acidification for stony corals (Tittensor et al., 2010), but little systematic evaluation of potential refugia exists as yet.

The purpose of the present paper was to use satellite data and model projections to identify potential marine climate refugia at a macro scale, and to evaluate the process and results using expert input. We used the northeast (NE) Pacific Ocean as a temperate case study region, focusing on British Columbia (BC), Canada. Canada's Pacific waters have been identified as a key area of observed climate change and associated ecosystem vulnerabilities (Ban et al., 2010; Jessen and Patton, 2008; Okey et al., 2015, 2014, 2012). For example, NE Pacific Ocean waters are the most acidic in the global ocean (DFO, 2008; Ianson, 2008), and changes in the depth of the oxygen minimum zone and overall oxygen concentrations have been particularly evident (Chan et al., 2008; DFO, 2013; Feely et al., 2008; Koslow et al., 2011; McClatchie et al., 2010; Whitney et al., 2007). Additionally, the high temporal and spatial heterogeneity of the oceanographic transition zone in this region may make the biota generally more responsive to oceanographic changes related to climate change (Okey et al., 2014, 2012).

Our objectives were to (1) analyze retrospective satellite data to identify trends to date, (2) examine and identify future trends from model projections, (3) identify areas of recent and future oceanographic change and stability from the historical analysis and expert input, (4) gather expert knowledge about the physical and oceanographic properties that might constitute potential refugia, and (5) identify whether candidate climate refugia exist for the region.

2. Methods

We identified potential climate refugia using the following steps: First, we identified datasets for the study region of features potentially affected by climate change and with sufficient temporal coverage, and analyzed climate trends to date to identify areas of stability and change (Table 1). We considered a spatial resolution of at least 4 km^2 to be sufficient because this is fine enough to capture most of the complexity of the coastline and associated differences in oceanographic patterns, although higher resolution data are preferred. Although a temporal resolution of 30 years is ideal to capture decadal trends (Cummins and Masson, 2014), we considered any time series with at least 10 years of uninterrupted data. Second, we identified downscaled climate model projections for some of those variables, and compared trends in the projections to those in recent historical records to assess present and future areas of stability. Third, we elicited feedback from experts on preliminary results and data used. Finally, we also solicited expert input on the physical and oceanographic characteristics in the region that may confer the ability of places to act as refugia and limit climate change exposure, and to identify whether such places exist on the BC coast.