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Introduction

Impacts of climate change on marine top predators: Advances and future challenges

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ABSTRACT

Oceanic top predators are the subject of studies by researchers under the international Climate Impacts on Oceanic Top Predators (CLIOTOP) program. A wide range of data sets have shown that environmental conditions, such as temperature and marine productivity, affect the distribution and biological processes of these species, and thus the activities of the humans that depend on them. In this special issue, 25 papers arising from the 2nd CLIOTOP symposium, held in Noumea, New Caledonia in February 2013 report the importance of realistic physical descriptions of oceanic processes for climate change projections, demonstrate a wide range of predator responses to historical climate variability, describe new analytical approaches for understanding the physiology, behaviour and trophodynamics, and project future distributions for a range of species. Several contributions discuss the implications for conservation and fisheries and show that resolving ecosystem management challenges and conflicts in the face of climate change is possible, but will require attention by decision-makers to issues that are broader than their traditional mandate. In the coming years, an increased focus on the development of management options to reduce the impacts of climate change on top predators and their dependent industries is needed.

1. Introduction

Oceanic top predators include pinnipeds, cetaceans, tunas, seabirds, sharks and, due to their large size, other species such as turtles and some cephalopods. They are ecologically important in some regions due to their top-down influence on ecosystem structure (e.g. Cox et al., 2002; Myers et al., 2007; Hunsicker et al., 2012), and a number are of high economic importance (FAO, 2011; Dyck and Sumaila, 2010). From historical harvests of whales, seals and seabirds to the industrial fishing of tuna, billfish and sharks, top predators have represented lucrative resources for many nations (Rounsevell and Copson, 1982; Hindell and Burton, 1987; Branch et al., 2007; Gillett, 2009; Bell et al. 2011a). Ecotourism benefits in regions that are accessible and have reliable top predator presence are also increasing (e.g. Bradford, 2013; Hearn et al., 2014).

Despite their remoteness, pelagic ecosystems face a number of threats, including pollution effects such as ingestion of plastics (Vegter et al., 2014), and contamination by a range of chemical and radioactive materials (Madigan et al., 2012), expanding marine dead zones (Diaz and Rosenberg, 2008), direct and indirect fishing interactions (Croxall et al., 2012), and climate change (Sydeman et al., 2012; Hoegh-Guldberg et al., 2014). Those species that have land or coastal life cycle phases (e.g. turtle, seabird, pinniped species) can be subject to multiple threats across both coastal and pelagic regions (Fuentes et al., 2010). Because many top predators spend most of their life far from land, understanding of the life history, ecology and physiology of these species is often derived from indirect sources such as fisheries catch data (e.g. Nicol et al., 2013; Hobday and Evans, 2013). More recently, understanding of these aspects of the lives of oceanic species has been enhanced by a range of data collection technologies including ocean sensors, electronic tags, and satellite data (e.g. Block et al., 2003; Nielsen et al., 2009), comprehensive observer programs (e.g. Nicol et al., 2013), and data assimilating ocean models (Oke et al., 2008; Brasseur et al., 2009).

Substantive collection and analysis of data sets from top predators have shown that environmental conditions, such as temperature and marine productivity, affect the distribution and biological processes (e.g. growth and survival) of most species in the open ocean. Given the importance of top predator species, understanding, predicting and minimising the impacts of anthropogenic climate change has become an important focus for several national and international research efforts for oceanic predators (e.g. GLOBEC, 2003; Ottersen et al., 2010; Lehodey and Maury, 2010; Block et al., 2011). In particular, in 2003 under the umbrella of the Global Ocean Ecosystem Dynamics (GLOBEC) program, and now as one of five programs within the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) program, the Climate Impacts on Oceanic Top Predators (CLIOTOP) program was organised to facilitate a large-scale worldwide comparative effort on top predators. The program goal is to identify the impact of both climate variability

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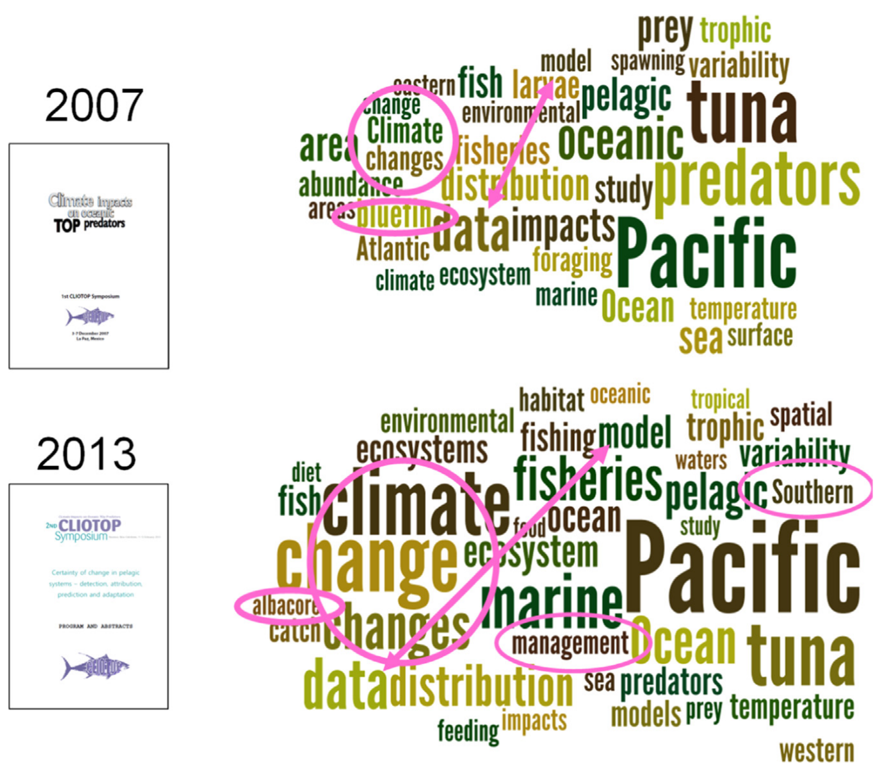

Fig. 1. A Wordle comparison of words in the titles and abstracts of the presentations delivered at the 1st and 2nd CLIOTOP symposia. The size of each word indicates the relative frequency of word use. The circles and lines indicate some differences between the word frequencies that indicate a change in emphasis between the symposia.

and fishing on the structure and function of open ocean pelagic ecosystems and their top predator species by elucidating the key processes involved in open ocean ecosystem functioning. The ultimate objective of this international program is the development of a reliable predictive capability for the dynamics of top predator populations and oceanic ecosystems that combines both fishing and climate (i.e. environmental) effects (Lehodey and Maury, 2010; http://www.imber.info/index.php/Science/Regional-Programmes/CLIOTOP). Research is fostered and presented at a range of working group meetings, collaborative projects and international symposia.

Scientists involved in research aligned with the CLIOTOP objectives addressed a range of issues at the 2nd CLIOTOP Symposium held in Noumea, New Caledonia, February 11–15, 2013. As documented in this special issue, there has been significant progress in overall understanding of oceanic predators and the impacts of climate change on ocean ecosystems since the 1st CLIOTOP Symposium in 2007 (Lehodey and Maury, 2010). This includes an expansion in the range of species and geographic areas covered (Fig. 1), although there is still a strong focus on the Pacific Ocean, and increasingly sophisticated approaches to data collection, management and analysis. The initial focus of CLIOTOP towards tropical pelagic fish and fisheries has expanded to temperate and polar regions where marine mammals, birds and groundfish, such as cod, are important top predators. Many researchers are now using and incorporating climate models into analyses focused on investigating biological patterns in future marine ecosystems. Comparative approaches in CLIOTOP are advancing global early life history analyses and developing prey and biochemical databases on global scales. Tool development to support comparative analyses has advanced to include new approaches to statistical analyses, and the continued development and formulation of habitat and ecosystem models. Research on the socioeconomic implications of top predator changes has emphasised the importance of strategic actions to enable adaptation to changes in key natural resources and sources of employment and revenue.

2. Recent advances in the study of oceanic top predators

In this special issue, 25 papers representing contributions from many authors and countries, demonstrate progress in understanding the impacts of climate change on oceanic top predators, their ecosystems and dependent human systems, as described in the following sections.

2.1. Physical change in oceanic systems

Understanding historical and projected changes in ocean conditions underpins much of the research and management on top predators. It is now well known that the climate phenomenon El Niño Southern Oscillation (ENSO) has profound impacts on the physical state of oceans which has flow-on impacts on marine ecosystems (e.g. Lehodey et al., 1997; GLOBEC, 2003) and the economies that rely on them. Projections of ENSO under future changing environmental conditions are highly uncertain (Collins et al., 2010; Cai et al., 2014; Risbey et al., 2014) and it is therefore unclear how changes to the frequency or intensity of ENSO events may impact oceanic ecosystems. Based on the 137-year record of sea level pressure recorded at Darwin, Australia, Harrison and Chiodi (this issue) showed that ENSO dynamics have not changed over this timescale, nor does there appear to be a trend in dynamics over the long-term. They caution that use of shorter time series may be misleading in terms of understanding oceanic responses to CO_2 input to the atmosphere and ocean, and projecting future change in ENSO impacts on marine ecosystems.

Projecting potential changes to oceanographic processes and habitats in response to atmospheric warming has direct relevance to the development of natural resource management and policy.