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Filling historical data gaps to foster solutions in marine conservation

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ABSTRACT

Ecological data sets rarely extend back more than a few decades, limiting our understanding of environmental change and its drivers. Marine historical ecology has played a critical role in filling these data gaps by illuminating the magnitude and rate of ongoing changes in marine ecosystems. Yet despite a growing body of knowledge, historical insights are rarely explicitly incorporated in mainstream conservation and management efforts. Failing to consider historical change can have major implications for conservation, such as the ratcheting down of expectations of ecosystem quality over time, leading to less ambitious targets for recovery or restoration. We discuss several unconventional sources used by historical ecologists to fill data gaps – including menus, newspaper articles, cookbooks, museum collections, artwork, benthic sediment cores – and novel techniques for their analysis. We specify opportunities for the integration of historical data into conservation and management, and highlight the important role that these data can play in filling conservation data gaps and motivating conservation actions. As historical marine ecology research continues to grow as a multidisciplinary enterprise, great opportunities remain to foster direct linkages to conservation and improve the outlook for marine ecosystems.

1. Introduction

Our oceans have undergone extensive changes as a result of human influence, and consequently we are forced to manage marine ecosystems relative to shifted environmental baselines (Dayton, 1998; Jackson et al., 2001; Pauly, 1995; Roberts, 2012). In many regions human interaction with the marine environment originated hundreds, thousands or even tens of thousands of years before record keeping began (Pandolfi et al., 2003; Rick and Erlandson, 2008; Roberts, 2003). Whilst access to the marine environment and our ability to monitor the oceans has been spurred by technological innovations, such as SCUBA and remotely operated video technology, by the time these advances occurred many ecosystems had already been altered by human activities (Thrush and Dayton, 2002; Thurstan et al., 2014). These temporal gaps in our knowledge are significant and create uncertainties about the extent to which humans have influenced changes in marine ecosystems, particularly as our activities have expanded and intensified.

Where long-term data describing ecological change have been limited or absent, researchers have utilised alternative approaches to fill gaps in our understanding of past change. For example, hindcasting estimates are usually extrapolated from existing time series data, together with contemporary production estimates or life-history parameters, and can provide insights such as the theoretical number of individuals a system can support (Jennings and Blanchard, 2004; Marsh et al., 2005). Patterns of genetic variation

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have been used to infer past effective population sizes for some marine species (e.g., Alter et al., 2007), although these can only provide a single past value, rather than information on population trajectories over time. Space for time approaches have also been used to provide insights into past ecosystems (Hawkins and Roberts, 2004; Pickett, 1989). In these cases remote areas are viewed as a virtual 'time machine' and give us glimpses as to how the seas looked before extensive anthropogenic changes. Useful information on past trophic structuring of communities can be gained from the space for time approach (Barott et al., 2010; Sandin and Sala, 2012). However, the use of reference ecosystems overlooks changes that may have happened in any one place or to wide-ranging species, and even 'so-called' pristine reference marine systems will be impacted by global issues such as climate change and ocean acidification. Furthermore, the only available reference systems (i.e., those least impacted by human activities) are usually remote oceanic systems that are dissimilar to continental coasts and shelf systems, and hence are not suitable controls for the locations that have been the most altered by humans (Sandin et al., 2008). Importantly, few of these approaches are detailed enough to provide an understanding of the trajectories and drivers of past change, and often start with the assumption that contemporary and historical ecosystems are comparable (Lotze and Worm, 2009).

In recent years a multidisciplinary enterprise – marine historical ecology – has developed to produce data to fill gaps in our knowledge of the levels of change and long-term dynamics exhibited by marine ecosystems. It can be described as "the study of past human–environmental interactions in coastal and marine ecosystems and the ecological and social outcomes associated with these interactions" (Kittinger et al., 2015). This field of research spans multiple disciplines, including historical, social, ecological, archaeological and palaeontological disciplines, to unravel temporal changes in marine ecosystems ranging from decades to tens of thousands of years (Coll et al., 2014; Erlandson et al., 2008; Lotze et al., 2006; Pandolfi and Jackson, 2006). Historical data sources have a number of unique features that are of value to contemporary conservation and management. Historical data can improve our understanding of past system dynamics, enabling us to determine whether contemporary systems are acting within the historical range of variability exhibited prior to large-scale human impacts (Morgan et al., 1994). Historical data, if detailed enough, may also provide information on the rate and trajectory (i.e., linear, non-linear) of temporal change. Long-term data can also assist in unravelling the mechanisms driving these changes, and whether the major driving forces have altered over time (Pickett, 1989). Such data may also allow us to identify if contemporary communities are 'novel', that is, they have not previously occurred in the historical record.

Under the framework of marine historical ecology, researchers from across the world have amalgamated data on different geographical and oceanic regions, from temperate to tropical climates (Pandolfi et al., 2003; Reise et al., 1989), and benthic to pelagic systems (Baum and Worm, 2009; Edgar and Samson, 2004). Over the last 15 years, several synthetic papers (e.g., Jackson et al., 2001; Pandolfi et al., 2003), popular and academic books (e.g., Jackson et al., 2011; Kittinger et al., 2015; Roberts, 2007) and a global research initiative, the History of Marine Animal Populations (Holm et al., 2010; Schwerdtner Máñez et al., 2014), have initiated a surge of interest in the collation and analysis of historical data on marine ecosystems, aiding our understanding of long-term changes in the oceans and the roles that humans have played in driving these changes. In many cases researchers have found that degradation, or even fundamental alterations of marine ecosystems, have occurred as a result of human activities such as fishing, pollution or the introduction of non-native species (Bax et al., 2003; Bowen and Valiela, 2001; Roberts, 2007). Historical ecology has also been an important component in shaping debate about the changing role of conservation in an increasingly human-dominated world (Kueffer and Kaiser-Bunbury, 2014; The Breakthrough Institute, 2012).

Although there is much potential for historical data to contribute to conservation data gaps, these data are not without their challenges. These include disparate sources or incomplete data, historical data collection methodologies that may be of questionable reliability or where analytical robustness is uncertain, or where data reporting is subject to unknown biases (issues that are not just confined to historical data sets). Yet if these challenges are addressed, the insights afforded by a greater understanding of historical conditions can alter how scientists and the public perceive the condition of our natural environment today, with implications for how conservation goals are set and prioritised (Caro et al., 2012; Kueffer and Kaiser-Bunbury, 2014).

In this paper we discuss the implications of historical data gaps for conservation and management. We demonstrate that even in situations where historical data are limited, information on past trends can be uncovered when alternative, perhaps unconventional, data sources are considered. We highlight innovative approaches or techniques that have provided novel insights into past ecosystem dynamics. We then provide examples of how historical data can be used to help address a range of conservation challenges.

2. Implications of historical data gaps for conservation

Historical data gaps contribute to shifting environmental baselines or cultural amnesia, described as social or institutional losses in memory (Papworth et al., 2009). These shifted baselines can ultimately lower ambitions for conservation if degraded states are accepted as natural (Pauly, 1995). Targets to rebuild or restore ecosystems or communities can only reflect what is known about previous ecosystems and/or species abundance. Thus, a lack of appreciation for how an ecosystem has changed can have major implications for conservation and management.

Historical data have been used to illustrate changes in species abundance, and commonly show that the magnitude of change over long time scales is greater than contemporary data sets suggest. One of the better-known examples of how historical data can readjust our perspective of the productivity of past environments is in the comparison of historical and contemporary cod (*Gadus morhua*) biomass on Canada's Scotian Shelf (Rosenberg et al., 2005). Contemporary analyses of cod biomass showed an increase from 1970 – the beginning of recent records – then a decrease from 1980 onwards. Alone, these data would suggest that targets for the rebuilding of cod stocks be set to the 1980s level, for which indeed, people have argued (Rosenberg et al., 2005). However, historical data on individual vessel catch and effort during the mid-19th century, when combined with population modelling, suggest that total cod biomass during the 1980s – its contemporary peak – was just 4% of the historical levels of cod on the Scotian Shelf alone (Rosenberg et al., 2005). Similar examples where historical data have uncovered past productivity that was much higher than contemporary systems include the Adriatic Sea, where multidisciplinary investigations suggested that 98% of traditional marine resources had been depleted to under half their previous abundance (Lotze et al., 2011). In the Wadden Sea, historical sources showed that many targeted species were severely reduced by the early 20th century (Lotze, 2005), when fishery records began to be kept.

Historical data have also been used to illustrate local extirpation of a species or habitat. An example of how having a complete historical record could lead to different conservation regimes can be found when profound changes to the faunal composition of an area