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Organization of marine phenology data in support of planning and conservation in ocean and coastal ecosystems

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ABSTRACT

Among the many effects of climate change is its influence on the phenology of biota. In marine and coastal ecosystems, phenological shifts have been documented for multiple life forms; however, biological data related to marine species' phenology remain difficult to access and is under-used. We conducted an assessment of potential sources of biological data for marine species and their availability for use in phenological analyses and assessments. Our evaluations showed that data potentially related to understanding marine species' phenology are available through online resources of governmental, academic, and non-governmental organizations, but appropriate datasets are often difficult to discover and access, presenting opportunities for scientific infrastructure improvement. The developing Federal Marine Data Architecture when fully implemented will improve data flow and standardization for marine data within major federal repositories and provide an archival repository for collaborating academic and public data contributors. Another opportunity, largely untapped, is the engagement of citizen scientists in standardized collection of marine phenology data and contribution of these data to established data flows. Use of metadata with marine phenology related keywords could improve discovery and access to appropriate datasets. When data originators choose to self-publish, publication of research datasets with a digital object identifier, linked to metadata, will also improve subsequent discovery and access. Phenological changes in the marine environment will affect human economics, food systems, and recreation. No one source of data will be sufficient to understand these changes. The collective attention of marine data collectors is needed—whether with an agency, an educational institution, or a citizen scientist group—toward adopting the data management processes and standards needed to ensure availability of sufficient and useable marine data to understand marine phenology.

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1. Introduction

Information on the life history of a species is an important tool for resource managers and policy-makers as they assess and respond to impacts of climate change on organisms and their physical and biological habitats at local to global scales. Concern for the effects of climate change and the pervasive influence of temperature on a species' life cycle has prompted a number of efforts to collect and analyze phenology data, as summarized for North America by Schwartz et al. (2013). While these efforts have been directed largely toward terrestrial ecosystems, an understanding of phenology is equally important in the marine realm (Richardson et al., 2012).

Lieth (1974), in his classic work, describes phenology as 'the art of observing life cycle phases or activities of plants and animals in their temporal occurrence throughout the year.' Phenology also considers the influence of environmental factors toward the timing of life cycle phases—also referred to as phenophases—and the relationships of a species' phenophases with individuals of the same and other species (Lieth, 1974). Phenology has been described as 'perhaps the simplest process to track changes in the ecology of species in response to climate change' (Parry et al., 2007; Walther et al., 2002) and as a way to 'fingerprint' the response of species to climate change (Parmesan and Yohe, 2003; Root et al., 2003). Phenological shifts—temporal deviations from a species' usual pattern of phenophases—can have consequences for a species' fitness (Thomson, 2010), demography (Miller-Rushing et al., 2010), distribution (Chuine, 2010), and ecological interactions (Singer and Parmesan, 2010), as well as for the human societies managing the species or their habitats (Enquist et al., 2014; Schwartz et al., 2012).

In marine and coastal ecosystems, phenological shifts are documented for multiple life-forms in relation to climatological drivers including

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sea-surface and ocean temperature (Chambers et al., 2013; Kordas et al., 2011; O'Connor et al., 2007; Pachauri and Reisinger, 2007; Roemmich et al., 2012), acidity (Field et al., 2011), and ice environments (Staudinger et al., 2012). Poloczanska et al. (2013) conducted a meta-data analysis of all available studies addressing marine ecology under climate change and found the rate of change for spring and summer phenophases for marine species advanced 4.4 +/− 1.1 days per decade and 4.4 +/− 0.7 days per decade, respectively. These authors concluded that continued response of marine species to climate change, both in phenological shifts and in range shifts, foretells, "future reconfiguration of marine ecosystems, and the services they provide" (Poloczanska et al., 2013). These reconfigurations are predicted to create locally novel environments, isolated environments, and lost environments for marine species (Burrows et al., 2014), often in a complex interaction of increasing temperatures and other chemical, physical, and biological changes (Okey et al., 2014).

Phenological shifts for marine species may manifest as changes in species' recruitment (Asch and Checkley, 2010; O'Connor et al., 2007), timing and abundance of productivity (Batten and Mackas, 2009), migration timing (Cherry et al., 2013; Crozier et al., 2011; Hawkes et al., 2007; Jay et al., 2012), and food web structure and trophic synchrony (Burthe et al., 2012; Costello et al., 2006; Hipfner, 2008; O'Connor et al., 2009; Rockwell et al., 2011; Thackeray, 2012; Thackeray et al., 2010). Ocean acidification, also promoted by global warming, may result in changes in the life history of marine organisms (National Research Council, 2010). Species also respond to climate change through range shifts (Burrows et al., 2011; Chuine, 2010; Hoegh-Guldburg and Bruno, 2010; Nye et al., 2009; Pinsky et al., 2013; Poloczanska et al., 2013) and these distributional changes can interact with phenological shifts in associated species to cause disruptions to local and regional food webs, the trophic mismatch effect (Cushing, 1990; Durant and Hjermann, 2007; Edwards and Richardson, 2004).

On the national level, federal agencies have recently recognized the importance of marine phenology data to inform comprehensive ocean management activities. The National Ocean Policy (NOP; Obama, 2010) and the NOP Implementation Plan (National Ocean Council, 2013) emphasize the necessity of collection, management, and exchange of the best available data of the biological status of marine-dependent plants and animals, including phenology data. In addition, the nation's primary federal ocean agency, the National Ocean and Atmospheric Administration (NOAA), has identified marine phenology as one of the common issues reflecting closely the climate issues addressed in their conservation and management process (Osgood, 2008). In addition, the National Fish Wildlife and Plant Climate Adaptation Strategy recommends increased tracking and assessment of phenological information for marine and other species (NFWPCAS, 2012). The recent call from the U.S. Office of Science and Technology Policy (OSTP) for improved access and reuse of federally generated data (OSTP, 2013, 2014) also emphasizes the need for improved access to disciplinary information.

Phenology and other marine climate change research require improved access to historical and contemporary, agency- and NGO-collected or held, and local to national datasets for assessments at multiple scales. Despite the fact that multiple federal, state and non-government programs are collecting marine biotic, those data and other value-added information on species' phenology are not readily accessible to researchers or decision-makers. Difficult access to—and subsequent underuse of—phenology data for marine and coastal species is hindering vulnerability assessments and adaptation planning for the nation's valuable marine resources. To understand and document barriers to access and use of marine biological data in phenology assessments by researchers, resource managers, and policy-makers, we conducted a broad assessment of potential sources of these data and their availability for potential use in phenology analysis and assessments.

2. Materials and methods

We examined the collection and use of marine phenology data by: 1) surveying the types of online resources for marine biological data, 2) evaluating the use of biological data in select published research on marine phenology, and 3) testing discovery and access of marine biological data for targeted species. In each separate evaluation, we focused on the biological data required to document a species' life cycle and any temporal shifts in that life cycle. We defined the biological data appropriate to phenology to be occurrence records identified to species or lifeform, with corresponding geographic location and date of observation.

2.1. Types of online marine phenology data resources

First, to understand the types of online resources where a researcher may access biological data appropriate for marine phenology analysis, we surveyed agency, academic, and non-governmental web sites potentially representing marine data repositories, metadata registries, or data collection efforts. We started with the NOAA National Oceanographic Data Center (NODC), because it is a primary national repository for marine data. We then evaluated websites identified as contributors to the NODC or that we located through web searches for data holdings of marine data using terms for marine lifeforms (e.g. phytoplankton, seabirds, marine mammals, etc.). For those websites that did support access to marine phenology data, we examined how the online resource addressed the species or lifeforms represented, the geographic area of concern, the mode of data presentation, metadata, controlled vocabulary, and data use policies. Our search was inclusion of multiple marine habitats including deep sea, ice sheet and coastal intertidal.

To understand ongoing web development efforts, we conducted informal telephone interviews with data managers and repository directors for several large marine biological data repositories. These informal interviews were conducted between May 2012 and May 2013 and included representatives of NOAA, Bureau of Ocean Energy Management (BOEM), U.S. Geological Survey (USGS), Integrated Ocean Observing System (IOOS), and National Park Service.

2.2. Marine phenology data use in published literature

Second, we selected ten widely cited scientific studies on marine phenology published since 2006 in high-quality journals. For each, we identified the source of the biological data used, and determined if we could access that data.

2.3. Discovery and access use-case studies

Our third evaluation consisted of two example studies on the ease of marine phenology data discovery and access. We chose a marine mammal, the walrus (*Odobenus rosmarus*), and an anadromous fish, the Chinook salmon (*Oncorhynchus tshawytscha*) on the Columbia River in the Pacific Northwest, as our target species. These species represent well-known marine vertebrates, of contrasting lifeforms, that face deleterious impacts from climate change and have economic and ecological importance. Using the results from the survey of online resources described in Section 2.1 above, we selected websites likely to led to phenology data for these species based on the geographic, thematic, or agency domain of the website. At each site, we applied select search terms to find datasets potentially related to the target species. For the walrus use study, we used the search terms 'marine mammal', 'pinnepedia', and '*Odobenus*' and for the anadromous salmon we used the terms 'salmon', '*Oncorhynhus*' '*O. tshawytscha*', and 'chinook.' Where we identified potentially applicable datasets, we evaluated whether or not we could view the dataset directly to determine if its content was related to the species' phenology.