EFFECTS OF OCEAN ACIDIFICATION ON MARINE ORGANISMS

TYPE III INDICATOR

Ocean chemistry is changing at an unprecedented rate due to anthropogenic carbon dioxide (CO_2) emissions to the atmosphere. When CO_2 is absorbed by seawater, chemical reactions occur that reduce seawater pH in a process known as “ocean acidification” (see *Acidification of coastal waters* indicator).

Several biological processes in marine organisms are sensitive to changes in seawater chemistry. The best-documented and mostly widely observed biological effects are due to a reduction in carbonate ion — a building block for shell forming organisms — under reduced pH conditions. Decreased calcification rates and/or shell dissolution has been observed in a wide range of shell-forming organisms, including plankton, mollusks, and corals. These processes have been elucidated in controlled laboratory experiments, including documentation of decreased shell size/thickness in shellfish. Through modeling, researchers have estimated that pteropod shell dissolution in response to increasingly acidic conditions experienced during seasonal upwelling events has increased ~19-26 percent along the US West Coast, including California, since the Industrial Revolution (Feely et al., 2016).

Impacts on the physiology and behavior of marine species can accrue as organisms face greater challenges in maintaining internal acid-base balance in ocean waters of lower pH (e.g., Munday et al., 2009; Somero et al., 2016; Jellison et al., 2016). Broader ecological consequences are additionally possible (Gaylord et al., 2015), including altered predator-prey relationships (e.g. Ferrari et al., 2011; Kroeker et al., 2014; Sanford et al. 2014), and degradation of habitat provisioning by structure-forming taxa like corals and mussels (e.g., Sunday et al., 2016). Current knowledge regarding changes to ocean chemistry and impacts on California species has been summarized by the West Coast Ocean Acidification & Hypoxia Panel (Chan et al., 2016). However, there is still much to learn about biological consequences of ocean acidification using ‘indicator species’ in the field.

The California Current Large Marine Ecosystem (CCLME) is the environment that spans from southern British Columbia to Baja California and includes US-controlled waters, the land-sea interface and adjacent wetlands. This ecosystem may provide early indication of the impacts of ocean acidification and decreasing dissolved oxygen due to its unique oceanography (Feely et al., 2008; Hauri et al., 2009). In particular, the wind-driven process of seasonal coastal upwelling brings deeper, high-CO_2 water to the surface where it bathes shoreline communities. In upwelled waters, elevated CO_2 conditions co-occur with low dissolved oxygen concentrations (hypoxia). As a result, California’s coastal waters may reach acidic and low oxygen conditions well before this is observed on a global scale (Feely et al., 2008). As such, California is positioned to provide for early examination of effects of ocean acidification and hypoxia.

Regional biological indicators can help improve the understanding of these impacts on California’s varied smaller-scale ocean ecosystems. A first step towards this goal was accomplished by the Greater Farallones National Marine Sanctuary Advisory Council in the publication of *Ocean Climate Indicators: A Monitoring Inventory and Plan for Tracking Climate Change in the North-Central California Coast and Ocean Region* (Duncan et al., 2013). This plan recommends indicator species for processes such as climate change, ocean acidification, and hypoxia that include: primary producers, mid-trophic level species, habitat forming species, and seabirds. A comprehensive review and analysis of biological responses to ocean acidification provides additional possible indicator species and other guidance for indicators of ocean acidification (Kroeker et al., 2013). Results suggest that variables such as calcification and growth in key marine calcifiers are important to consider.

Other potential effects of ocean acidification on marine organisms that might be tracked include:

- Changes in ionic form of marine nutrients and potentially harmful substances (e.g., metals)
- Increased photosynthetic rates in carbon-fixing organisms
- Altered reproduction and survival in organisms
- Reduced olfaction (sensory function) in fish
- Changes in the strength or outcome of species interactions (including predation, herbivory, and competition)

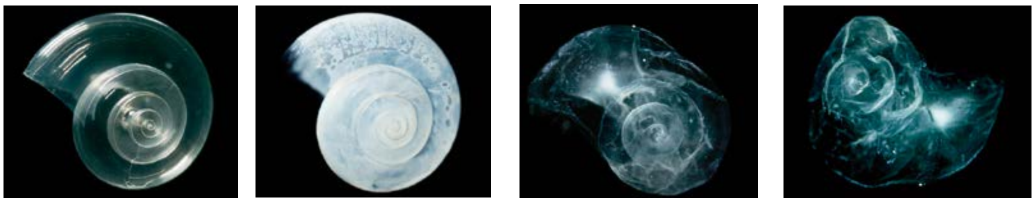
In considering potential indicator species, the most successful target organisms are often those that are important community members and are present over a wide geographic extent, enabling their performance to operate as a metric of broader ecosystem function. Some potential species for tracking the biological impacts of ocean acidification in California waters are:

- The California mussel (*Mytilus californianus)* - a classic ‘foundation species’ that dramatically influences community structure both through its dominant status and because mussel beds provide habitat for hundreds of other species that reside within them (Suchanek, 1992). The distribution of *M. californianus* spans the entire west coast of the US (Morris et al., 1980), and the species is found in most of the state’s shoreline Marine Protected Areas (MPAs). *M. californianus* has already been identified as an indicator species by two National Marine Sanctuaries in California. Research is ongoing to determine whether *M. californianus* can be utilized as an ‘early warning’ indicator of biological change due to ocean acidification and other stressors (Gaylord et al., 2011; California’s Fourth Climate Change Assessment).

- Krill, a fundamental and important component of the marine food web. Krill have recently been shown to be sensitive to ocean acidification, with responses that include reductions in growth rates and increased mortality (e.g., Cooper et al., 2016; McLaskey et al., 2016). Krill therefore may provide an early indication of food web impacts from ocean acidification.

- Pelagic snails (pteropods) (see Figure 1), species which have delicate shells that are subject to severe dissolution when exposed to low pH seawater. Recent studies of the pteropod *Limacina helicina* within the California Current Large Marine Ecosystem indicate that 24 percent of offshore individuals and 53 percent of nearshore individuals exhibited signs of severe shell dissolution (Bednaršek et al., 2014). Continued acidification is expected to place these nearshore populations of pteropods at particular risk (Bednaršek et al., 2014; Feely et al., 2016; Bednaršek et al., 2017).

Figure 1. Dissolution of pelagic snail shells exposed to corrosive seawater



0 days 15 days 30 days 45 days

Photo credit: National Geographic Images

At the statewide level, excellent progress (albeit yet incomplete) has been made in identifying indicator species that can be monitored at local and regional scales to identify and track ocean acidification and other components of global environmental change. Specifically, for marine biological indicators for the state of California, there are over 490 publicly available data sets of observations or measurements of relevant parameters collected successively over a period of time (these data sets are referred to as "time series"). The majority of the longest running biological datasets in California are less than 10 years in length; however, a few extend beyond 20 years.

Broad-scale impacts of ocean acidification and climate change may be elucidated by integrated biological, chemical and physical oceanographic monitoring. Long-term ecological monitoring programs for intertidal and subtidal ecosystems (e.g., LiMPETS, MARINe, and PISCO), others associated with the Marine Protected Area Monitoring efforts (e.g., Ocean Science Trust), and oceanographic monitoring conducted by the Applied California Current Ecosystem Studies (ACCESS) (http://www.accessoceans.org/) provide essential data to better understand and interpret the impact of ocean acidification for California. Such data could be used by the scientific community to identify potential indicator species. For example, the longest biological dataset (64 years) for California quantifies zooplankton volume and diversity from quarterly cruises conducted by the California Cooperative Oceanic Fisheries Investigations (e.g., Bograd et al., 2003). To date, these biological data are paired with measurements of dissolved oxygen, but not other aspects of seawater chemistry (see *Dissolved oxygen in coastal waters* indicator). Another available dataset is based on surveys of *Macrocystis pyrifera* (giant kelp) and several fish species, which have been conducted by the Santa Barbara Coastal Long-Term Ecological Research program in the Santa Barbara Channel. However, these data are more limited in duration (12 years) and geographic extent (southern California only). Finally, the Partnership for

Interdisciplinary Studies of Coastal Oceans (PISCO) has generated a 12-year dataset on abundance, growth, and fecundity of several intertidal invertebrate and algal species. If these time series can be continued and extended, they may provide greater ability to detect the biological impacts of ocean acidification.

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