Cetacean strandings in the US Pacific Northwest – changes in species and seasonal trends reveal potential linkages to climatic variability.

**Introduction**

Over the past several decades, marine mammal stranding records have been used as an indicator of ocean and cetacean health (Gulland and Hall 2007; Bogomolni et al. 2010; Bossart 2011). Examining where, when, and how often marine mammals strand can provide insight into ecological behaviors, reproductive success, (Norman et al. 2004; Pikesley et al. 2011), the impacts of human activities (Warlick et al. 2018), and species distributions (Evans et al. 2005; MacLeod et al. 2005). Cetaceans are strongly influenced by changes in the marine environment via diverse and dynamic mechanisms, including changes in sea surface temperature, winds, or large-scale oceanographic oscillations that can shift the balance of nutrients and prey species abundance and distribution. These small changes are often amplified up through the food web or exacerbated by increased pollutants or algal blooms, ultimately having noticeable effects on top predators. Monitoring changes in strandings over time provides important information for monitoring cetacean populations, tracking trends, and examining emerging health or disease conditions, particularly in light of recent documented changes in oceanographic conditions on both local and regional scales (Pierce et al 2007; Truchon et al. 2013; Sprogis et al 2017).

Environmental changes are acknowledged to be occurring on a global scale (IPCC 2014), accompanied by degrees of spatial heterogeneity and climate variability depending on the geographic location (Moore 2008; Evans and Bjørge 2013). As top predators of their respective food webs, marine mammals may be especially sensitive to these changes (Moore 2008; Evans et al. 2010). Recent studies have found correlations between long-term stranding trends with various indices of climatic variability, demonstrating how strandings may be used as bio-indicators of prevailing environmental conditions. Evans et al. (2005) found that cetacean strandings in southeast Australia exhibited a periodicity coincident with regional wind patterns. Factors such as sea ice and the North Atlantic Oscillation have been found to correlate with strandings and mortality of certain pinniped and cetacean species in Gulf of St. Lawrence, Canada (Johnston et al. 2012; Soulen et al 2013; Truchon et al. 2013). Keledjian & Mesnick (2013) found that El Niño conditions corresponded with increased California sea lion (*Zalophus californianus*) strandings and fisheries interaction cases along the California coast. Increases in harbor porpoise strandings over the last 12 years in the Pacific Northwest have been posited to be partially due to changes in their prey’s abundance and distribution~~, which can regulate patterns of energy flow in coastal ecosystems, and therefore play critical roles in coastal ecosystems~~ (Greene et al. 2015; Jefferson et al. 2016). Because responses to environmental change are complex, variable, species-dependent, and often poorly understood, oceanographic features should be studied over varying scales (local and continental), ecotypes, and species (Laidre et al. 2008; Evans and Bjørge 2013; Truchon et al. 2013).

The Pacific Northwest, or as it is sometimes referred to as Cascadia, is a loosely defined region in western North America bounded by the Cascade Range and Coast Mountains to the east, the Pacific Ocean to the west and, depending on the definition, can extend as far north as southeast Alaska, and as far south as northern California (Coates 2002). It is an ecosystem that contains important feeding and breeding habitat for numerous marine mammal species in the eastern north Pacific and beyond, including gray (*Eschrichtius robustus*) and humpback (*Megaptera novaeangliae*) whales, endangered southern resident killer whales (*Orcinus orca*), and numerous smaller delphinid and phocoenid species. The Pacific Northwest has experienced increasing sea surface temperatures, ocean acidification, and harmful algal bloom events that can negatively impact marine mammal population dynamics through changes in the abundance and distribution of their prey, among other effects (Mote and Salathé 2010; Mauger et al. 2015).

We aimed to investigate the possible connection between these oceanographic changes and the health and mortality of marine mammals throughout a large ecosystem by evaluating stranding records collected consistently and systematically from 2003-2017. Specifically, the goals of this study were to: compare recent cetacean stranding numbers and patterns in the Pacific Northwest (Washington and Oregon) to those previously reported for 1930-2002 (Norman et al. 2004); detect new mortality trends; and to investigate possible relationships between spatiotemporal variation in cetacean strandings and oceanographic conditions in the Pacific Northwest.

It was expected that strandings of humpback whales and harbor porpoises, for example, might be higher than previously reported for the region (Norman et al. 2004) due to recent anomalous ocean conditions and/or changes in prey availability. We hypothesized that oceanographic variables such as sea surface temperature anomalies, upwelling, large-scale oceanographic processes (e.g., El Niño/Southern Oscillation [ENSO]/Pacific Decadal Oscillation [PDO]), harmful algal blooms, and ocean acidification, as well as changes in prey availability, would be associated with alterations in strandings of specific species depending on how they use the Pacific Northwest marine ecosystem (year-round residents versus migratory and breeding versus feeding habitat) (Truchon et al. 2013). Specifically, we hypothesized that elevated numbers of humpbacks and harbor porpoise strandings would be positively associated with increased biomass of their prey species (e.g., small schooling fish). We further hypothesized that strandings of striped dolphins (*Stenella coeruleoalba*), typically a deep water tropical or warm temperate water inhabitant, were correlated with large positive deviations from mean sea surface temperatures and ENSO events. Lastly, Strandings of gray whales were predicted to be positively influenced by ocean acidification, harmful algal blooms, and large-scale oceanographic events (i.e., ENSO/PDO).

This study allows us to investigate spatiotemporal changes in strandings of key cetacean species in the Pacific Northwest for a relatively long time period, compare to previously reported strandings in this geographic region, and characterize stranding hotspots. This information is useful for both researchers and stranding responders studying the baseline and future health and status of these cetacean populations in a multi-use ecosystem subject to human impacts and exhibiting signs of degradation and environmental change.

**Methods**

**Results**

**Discussion**

**References**

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