# Oceanography and Cetaceans in the Eastern Tropical Pacific

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Research conducted by NOAA's Southwest Fisheries Science Center on oceanography and cetaceans in the eastern tropical Pacific (ETP) is reviewed and possible implications of climate change are explored. Cetacean distribution in the ETP exhibits spatiotemporal variability due to a number of factors, including the distribution or abundance of prey, and inter- or intra-specific interactions among cetaceans. We assume that oceanographic conditions are the basis of the habitat, or environment, that determines the spatial distribution of cetaceans through bottom-up forcing. Although there are also top-down effects of fisheries, these are not assumed to be of concern today.

Prey availability is the key to understanding cetacean habitat and population dynamics. Cetaceans are large-bodied, warm-blooded, and highly-evolved. They are not directly influenced by temperature or salinity changes. It *is* important to find dense patches of prey (fish, squid or krill) when food is needed. Oceanographic variables have indirect effects on cetacean distribution and dynamics through prey abundance and distribution. Some cetaceans migrate long distances to breeding grounds where they do not feed, but their success on the feeding grounds during the previous season is critical.

Oceanographic habitat variables vary over a range of spatial and temporal scales. Global patterns of the mean and standard deviation of monthly sea surface temperature (SST) encompassing the period from 1982 to 2008 and monthly satellite chlorophyll (1998-2008) show increasing variability toward the poles, primarily due to increasing seasonality. In the equatorial Pacific, interannual variability is relatively high. There are two modes of interannual variability in the Pacific: the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). The ENSO has its greatest amplitude in the central and eastern tropical Pacific and varies on scales of 3-7 years. The PDO has its greatest amplitude in the North Pacific and tends to vary most strongly on scales of 20-30 years.

We built cetacean-habitat models within a generalized additive modeling framework to identify species-specific relationships to a suite of oceanographic variables in the ETP. We focus on the results of these models for three species. Eastern spinner dolphins (*Stenella longirostris orientalis*) tended to be more abundant in warmer Tropical Surface Water where the thermocline is fairly shallow. Common dolphins (*Delphinus delphis*) were more abundant in cooler waters affected by coastal and oceanic upwelling. The model results were less satisfactory for the Bryde's whale (*Balaenoptera edeni*). Bryde's whales have a widespread distribution in tropical and warm temperate waters, and it is likely that all of the ETP could be considered Bryde's whale habitat, given the information content of the available cetacean sighting and oceanographic data used to build the models. Cetacean-habitat models like these can be used to create hypotheses regarding expected changes in cetacean distribution and relative density due to environmental changes, but they cannot predict population size at a future environmental state.

The rapidly warming climate is predicted to affect multiple components of the physical environment in the eastern tropical Pacific. Here we review the global climate projections from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007). The IPCC projections predict the following changes that are relevant to the ETP: 1) the ocean is warming, although interannual variability tends to mask long-term trends in this region; 2) net freshwater flux into the ocean will increase in the tropics, although no changes in salinity of surface waters have yet been detected; 3) vertical structure of the water column is changing in some parts of the Pacific, affecting stratification and nutrient input to surface waters; and 4) $CO_2$ is entering the oceans in increasing concentrations, resulting in acidification and a subsequent shoaling of the calcium compensation depth. A weak shift towards 'El Niño-like' conditions is predicted to occur in the ETP. In addition, weakening trade winds could result in reduced equatorial upwelling and primary production (Vecchi et al., 2006; Vecchi and Soden, 2007). Finally, evidence from remotely sensed chlorophyll data suggests that productivity in the ETP has already declined (Gregg et al, 2003).

To address a climate change scenario specific to the ETP, an Ecopath with Ecosim model of the pelagic ecosystem was presented (Watters et al., 2003). The model was forced with a global-warming projection of SST, bottom-up effects on phytoplankton biomass, and top-down effects on predator recruitment. Although the model predicted that phytoplankton would decline by 50%, animals at higher trophic levels could decline by only 10-20% (spotted dolphins) or even increase (yellowfin tuna).

Effects of ocean warming on marine mammal populations might include changes in distribution, timing and range of migration, abundance of competitors and/or predators, prey availability, timing of breeding, and reproductive success (Learmonth et al., 2006). Cetacean populations in the eastern Pacific Ocean have experienced and survived climate change in the past, along with severe fishery and whaling mortality, although the current rate of change to the physical environment due to climate change is a novel challenge. Ecosystem models will be useful to project effects of future climate change.

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