Oceanography and Cetaceans in the Eastern Pacific

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Research at NOAA's Southwest Fisheries Science Center on oceanography and cetaceans in the eastern tropical Pacific and California Current is reviewed and possible implications of climate change for cetaceans are explored. Oceanographic conditions are the basis of the habitat or environment that determines the spatial distribution and population success of cetaceans. Although there are also top-down effects of fisheries, these are not of concern today; oceanographic variables are bottom-up cetacean habitat variables.

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

These habitat variables vary spatially over a range of spatial and temporal scales. Global patterns of the mean and standard deviation of monthly SST (1982-2008) and monthly satellite chlorophyll (1998-2008) are reviewed. Variability increases toward the poles, primarily due to increasing seasonality. In the equatorial Pacific, inter-annual variability is relatively high. There are two modes of inter-annual 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 30-40 years.

We have developed cetacean habitat models of the eastern tropical Pacific (ETP) and California Current regions to predict local cetacean densities as a function of oceanographic habitat variables. Results for a few selected species in each region are presented. In the eastern tropical Pacific, eastern spinner dolphins tend to be more abundant in warmer Tropical Surface Water where the thermocline is fairly shallow. Common dolphins are more abundant in cooler waters affected by coastal and oceanic upwelling. The model results are less satisfactory for the Bryde's whale, which has a widespread distribution in tropical and warm temperate waters, because our surveys cover only a small part of its range and cannot define habitat limits. For common dolphins in the California Current, the model results were different than in the ETP; surface salinity and surface chlorophyll were relatively important predictor variables, as well as depth. For Dall's porpoise, a cold-water North Pacific species, the model explained a high proportion of deviance; SST and mixed layer depth were important predictor variables, as well as depth and surface chlorophyll. Blue whales feed along the California coast during the summer; yearly observations and predictions show inter-annual variability of habitat conditions and habitat use.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) states that there are three basic responses to climate change: 1) move to track environmental changes, 2) adapt to changes, or 3) go extinct. Cetaceans are mobile, social and behaviorally adaptive; and long-lived or k-selected; and have been dealing with habitat variability for millions of years. IPCC global climate projections are briefly reviewed: the ocean is warming, although not uniformly; net freshwater flux into the ocean is increasing at higher latitudes and decreasing at lower latitudes, with concomitant changes in salinity of surface waters; vertical structure of the water column is changing, affecting stratification and nutrient input to surface waters. The dramatic retreat of sea ice in the Arctic Ocean, and around Antarctica, will have major consequences for ice-associated marine mammals.

For the eastern tropical Pacific, a weak shift towards 'El Niño-like' conditions is predicted. Weakening trade winds could result in reduced equatorial upwelling and primary production. There is evidence that productivity in the ETP has already declined, based on an analysis of satellite chlorophyll data (Gregg at al. 2003). We are working on modeling the effects of such a change on top predators in the ETP. An Ecopath with Ecosim model of the pelagic ecosystem was forced with a global warming projection of SST, with bottom-up effects on phytoplankton biomass and top-down effects on predator recruitment (Watters *et al.* 2003). Although phytoplankton decline by 50%, animals at higher trophic levels, such as spotted dolphins, decline by only 10-20%, or even increase (yellowfin tuna).

Direct effects of ocean warming are unlikely for most marine mammals, because of their mobility and thermoregulatory ability. Indirect effects 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. Ecosystem models will be useful to project effects of future climate change.

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