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14. ABSTRACT
Associations between cetacean distributions, oceanographic features and bioacoustic backscatter were examined during two process cruises in the northern California Current System (CCS) during late spring and summer 2000. Line-transect surveys of cetaceans were conducted across the shelf and slope, from Newport, Oregon to Crescent City, California, in conjunction with surveys of ocean and ecosystem structure. Occurrence patterns (presence/absence) of 4 cetacean species were compared with hydrographic and ecological variables (e.g., sea surface salinity, SST, thermocline depth, halocline depth, chlorophyll maximum, distance to the center of the equatorward jet, distance to the upwelling front, and acoustic backscatter at 38, 120, 200 and 420 kHz). Using a multiple logistic regression model, 60.2% and 94.4% of the variation in occurrence patterns of humpback whales during spring and summer, respectively, were explained. For harbor porpoise, the model explained 79.2% and 70.1% of the variation in their occurrence patterns during June and August, respectively. The responses of cetaceans to upwelling processes were seasonally and spatially specific.

15. SUBJECT TERMS
cetacean occurrence patterns, whales, odontocetes, California Current, biophysical models, upwelling

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FINAL REPORT

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PRINCIPAL INVESTIGATOR: Dr. Cynthia T. Tynan

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TITLE: GLOBEC Northeast Pacific Analyses: Linkages Between Cetaceans and Oceanographic Features

AWARD PERIOD: 1 January 2003 - 31 December 2003;
no cost extention 1 January 2004 - 31 December 2004

OBJECTIVES:

The long-term goal is to generate predictive, spatially-explicit models of occurrence patterns of cetaceans based on oceanographic and ecological processes. In this award, analyses focused on cetacean populations in the Northern California Current (NCC) System off Oregon and northern California.

1) Determine the correspondence between cross-shelf and along-shelf distributions, community structure, and densities of cetaceans (and their principal prey) as related to the strength, structure, and variability of the wind-forced circulation of the Northern California Current System. In addition, examine changes in community structure and foraging patterns of cetaceans at the meso- and fine-scales.

2) From the bottom-up perspective, test whether temporal and spatial variation in the density of prey patches does not affect variability in the occurrence patterns of cetaceans. In addition, examine whether cetaceans seek areas where the concentration of euphausiids and forage fish (including juvenile salmon) surpass a threshold making foraging most efficient.

3) Provide necessary information to model the distribution and structure of the cetacean community for the development of predictive models of occurrence patterns of cetaceans in the Northern California Current.

APPROACH: The GLOBEC Northeast Pacific (NEP) program is based on an ecosystem approach to determine how climate change and climate variability affect abundances, distributions and productivity of animals in the coastal ocean. The NEP program included four interdisciplinary mesoscale and process-oriented surveys of the Northern California Current (NCC) system, including hydrography, plankton, fish and top predators, in 2000 and 2002. Cetacean line-transect surveys were conducted continuously during daylight by observers using two pairs of 25 x 150 Fujinon binoculars, equipped with compass and reticle. A third observer surveyed the trackline by eye, aided with 7 x 50 hand-held binoculars. Under ideal viewing conditions, balaenopterids observed up to 8 km from the ship could be identified to species. All sightings were recorded on a laptop computer linked to the ship's GPS.

Occurrence (presence/absence) patterns of cetaceans relative to ocean processes and biological backscatter were examined for four species having a sufficiently large sample size (i.e., number of sightings obtained while on 25 x 150 binocular effort): humpback whale *Megaptera novaeangliae*, harbor porpoise *Phocoena phocoena*, Dall's porpoise *Phocoenoides dalli*, and Pacific white-sided dolphin *Lagenorhynchus obliquidens* (Tynan et al., 2005). The models used cetacean data acquired during line-transect surveys conducted during the periods May 29 - June

13 and July 27 - August 12, 2000. Each sighting for these four species was assigned to the nearest 15-minute segment of track-line (or approximately 4.4 km at average ship speed of 9.5 kts) for which a suite of 16 hydrographic, acoustic and ecological variables were available. Hydrography was obtained from the towed SeaSoar and acoustic volume backscattering data were collected with a Hydroacoustics Technology Incorporated (HTI) model 244 echosounder using 4 frequencies (J. Barth, T. Cowles, and S. Pierce, Oregon State University). The time difference between the collection of hydrographic data and the acquisition of line-transect cetacean survey data was never more than about 12 h, as the two ships were never separated by more than this time lag.

Multiple logistic regression was used to model cetacean occurrence, because outcomes were treated as binary (a cetacean species was either present or absent within a 15-min segment of transect). An important assumption of logistic regression is that outcomes are binomially distributed; therefore, we confirmed that occurrence of each species did not deviate from binomial distribution. We also tested for autocorrelation of cetacean occurrence among the 15-min transect segments for each species. Occurrence patterns were not autocorrelated among transects for any of the species.

Maximum-likelihood logistic regression was used to examine the occurrence of each species by season (i.e., May-June and July-August) relative to two spatially-fixed variables (latitude, depth) and the following 14 spatially-varying variables: SST, SSS, depth of the thermocline, thermocline gradient, depth of the halocline, halocline gradient, distance to the jet 'center' (geopotential anomaly of 2.35 m^2 s^{-2}), distance to the inshore edge of the jet (geopotential anomaly of 2.0 m^2 s^{-2}), distance to the inshore edge of the surface front (11.5 ºC SST isotherm during spring and 12.0 ºC SST isotherm during summer), value of chlorophyll maximum, and integrated acoustic backscatter at 4 frequencies (38, 120, 200, and 420 kHz). A total of 420 grid-segments, for which cetacean effort (while on 25 x 150 binoculars) and the full suite of SeaSoar-derived and bioacoustic data were available, were used in the multiple logistic regression models: 226 segments in May-June and 194 segments in July-August. Occurrence patterns for each species were modeled by season, except for Pacific white-sided dolphin. The number of sightings (3) of Pacific white-sided dolphins during August 2000 was insufficient for meaningful analysis; therefore, we modeled occurrence pattern for this species after combining spring and summer data.

The multiple logistic regression analyses were conducted by initially entering all 16 independent variables together in each model. Using a step-wise procedure, insignificant terms were dropped, one at a time, in order of increasing P-values. Because many terms were correlated, the importance of some variables was likely masked by others in the initial model. Therefore, we tested for effects of eliminated terms by putting them, one at a time, back in the model. The model was complete when no terms could be added or dropped.

ACCOMPLISHMENTS: Our first manuscript, summarizing models of the occurrence patterns of cetaceans in the northern California Current System during 2000, has been accepted in *Deep-Sea Research II*, and will appear early in 2005:

Tynan, C.T., D.G. Ainley, J.A. Barth, T. J. Cowles, S.D. Pierce, L.B. Spear. 2005. Cetacean distributions relative to ocean processes in the northern California Current System. *Deep-Sea Res. II* (in press; first issue of 2005).

Abstract: Associations between cetacean distributions, oceanographic features and bioacoustic backscatter were examined during two process cruises in the northern California Current System (CCS) during late

spring and summer 2000. Line-transect surveys of cetaceans were conducted across the shelf and slope, out to 150 km offshore from Newport, Oregon (44.6º N) to Crescent City, California (41.9º N), in conjunction with multidisciplinary mesoscale and fine-scale surveys of ocean and ecosystem structure. Occurrence patterns (presence/absence) of cetaceans were compared with hydrographic and ecological variables (e.g., sea surface salinity, sea surface temperature, thermocline depth, halocline depth, chlorophyll maximum, distance to the center of the equatorward jet, distance to the shoreward edge of the upwelling front, and acoustic backscatter at 38, 120, 200 and 420 kHz) derived from a towed, undulating array and a bioacoustic system. Using a multiple logistic regression model, 60.2% and 94.4% of the variation in occurrence patterns of humpback whales *Megaptera novaeangliae* during late spring and summer, respectively, were explained. Sea surface temperature, depth, and distance to the alongshore upwelling front were the most important environmental variables during June, when humpbacks occurred over the slope (200 - 2000 m). During August, when humpbacks concentrated over a submarine bank (Heceta Bank) and off Cape Blanco, sea surface salinity was the most important variable, followed by latitude and depth. Humpbacks did not occur in the lowest salinity water of the Columbia River plume. For harbor porpoise *Phocoena phocoena*, the model explained 79.2% and 70.1% of the variation in their occurrence patterns during June and August, respectively. During spring, latitude, sea surface salinity, and thermocline gradient were the most important predictors. During summer, latitude and distance to the inshore edge of the upwelling front were the most important variables. Typically a coastal species, harbor porpoises extended their distribution farther offshore at Heceta Bank and at Cape Blanco, where they were associated with the higher chlorophyll concentrations in these regions. Pacific white-sided dolphin *Lagenorhynchus obliquidens* was the most numerous small cetacean in early June, but was rare during August. The model explained 44.5% of the variation in their occurrence pattern, which was best described by distance to the upwelling front and acoustic backscatter at 38 kHz. The model of the occurrence pattern of Dall's porpoise *Phocoenoides dalli* was more successful when mesoscale variability in the CCS was higher during summer.

CONCLUSIONS: The models were able to explain a high percentage (up to 94% for humpback whales) of the variance in the cetacean distribution using measured oceanographic data. Having fine-scale ocean and cetacean data on comparable space and time scales was important. The responses of cetaceans to biophysical features and upwelling processes in the northern CCS were both seasonally and spatially specific. Cetacean community structure varied across-shelf and along-shelf and was influenced by several ocean features and processes. The higher productivity associated with upwelling near Cape Blanco had a strong influence on the distribution of cetaceans. Heceta Bank (ca. 44.0 - 44.5 N) and associated flow-topography interactions were also very important to a cascade of trophic dynamics that ultimately influenced the distribution of foraging cetaceans. It is likely that local recirculations and upwelling along the bank are responsible for enhanced seasonal productivity in this region. Humpback whales occurred on the bank, late in the upwelling season (August), when their distribution was significantly correlated with high chlorophyll concentration and higher backscatter at 38 kHz (i.e. larger prey such as fish). Harbor porpoises also respond to the broad upwelling signature over the bank. The occurrence pattern of Dall's porpoise on the slope was influenced by the presence of a warm mesoscale eddy or meander during August; porpoise avoided the warm, low-chlorophyll feature. During August, four species of deep-diving odontocetes (i.e. sperm whale, Baird's beaked whale, Cuvier's beaked whale and *Mesoplodon* sp.) occurred in the slope region southwest of the submarine bank, in a band of surface convergence between the equatorward flowing jet and the northward flow along the edge of an anticyclonic mesoscale eddy or meander.

SIGNIFICANCE: The models of cetacean occurrence patterns in an upwelling boundary current system are a significant step toward development of longer-term predictive biophysical models of occurrence patterns of cetaceans (many of which are endangered species) in shelf systems. The analyses also provide a valuable baseline of cetacean response to several scales and sources of variability in the northern California Current System. Evolution of such models will assist resource management and planning of human activities (e.g. fisheries, marine sanctuaries, transportation and commerce) in the northern California Current ecosystem off the west coast of the U.S.

PUBLICATIONS AND ABSTRACTS: (including presentations)

1. Tynan, C.T., D.G. Ainley, J.A. Barth, T. J. Cowles, S.D. Pierce, L.B. Spear. 2005. Cetacean distributions relative to ocean processes in the northern California Current System. *Deep-Sea Res. II* (in press; first issue of 2005).

2. Tynan, C.T., Ainley, D.G., Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., Peterson, W.T., Brodeur, R., Batchelder, H., Strub, T., Thomas, A., 2003. 'Mesoscale distributions of cetaceans and seabirds relative to oceanographic processes in the northern California Current: A GLOBEC study, 2000 and 2002.' ONR International Field Office, Joint Planning Meeting US, UK, NATO, London, January 21, 2003

3. Tynan, C.T., Ainley, D.G., Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., 'Cetacean distributions relative to ocean processes in the northern California Current System: A GLOBEC study.' Eastern Pacific Ocean Conference (EPOC), Sept. 24-27, 2003.

4. Tynan, C.T., Ainley, D.G., Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., 'Cetacean distributions relative to ocean processes in the northern California Current System: A GLOBEC study.' Invited seminar: WHOI Biology Department Seminar, October 2, 2003

5. Tynan, C.T., Ainley, D.G., Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., 'Toward predictive biophysical models of cetacean occurrence patterns in the California Current System, an upwelling boundary current system.' Invited seminar: ONR - Effects of Sound on the Marine Environment (ESME), Woods Hole, October 21, 2003

6. Tynan, C.T., 'Developing predictive biophysical models of cetacean distribution in the California Current System.' Invited seminar: Old Dominion University, Center for Coastal Physical Oceanography, November 3, 2003

7. Tynan, C.T., Ainley, D.G., Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., 'Toward predictive biophysical models of cetacean occurrence patterns in the California Current System.' Invited Science Talk, US GLOBEC SSC, National Academy of Sciences, Woods Hole, November 6, 2003

8. Tynan, C.T., D.G. Ainley, L.B. Spear, J.A. Barth, T.J. Cowles, S.D. Pierce, 'Toward predictive biophysical models of cetacean occurrence patterns in the California Current System', Abstract, presented January 26-30, 2004 AGU Ocean Sciences, Portland, Oregon,

9. Tynan, C.T. 'Toward predictive biophysical models of cetacean occurrence patterns in the California Current System, an upwelling boundary current system'. Presentation for Mr. Donald Schregardus, Deputy Assistant of the Navy (Environment) (DASNE) and CDR Karen Kohanowich, Ocean Resources Advisor, during visit to WHOI, March 9, 2004.