NEP-CCS Progress Report 2004

GLOBEC TARGET SPECIES: INTERACTIONS WITH TOP TROPHIC LEVELS

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PROJECT SUMMARY

This component of GLOBEC NEP addresses the need to integrate top trophic-level predators into GLOBEC interdisciplinary mesoscale and fine-scale process studies of middle trophic levels in the northern California Current system. In collaboration with physical, chemical and biological sampling within the GLOBEC-Northeast Pacific Program, our surveys have provided data to define trophic linkages between middle and upper trophic levels contributing to effects on community structure and function. Results define top-down and bottom-up interactions, especially in regard to GLOBEC target species (juvenile salmon and euphausiids: *Euphausia pacifica* and *Thysanoessa spinifera*) which are important forage for upper trophic level predators. Information on the temporal and spatial distributions of abundant predators, and estimates of feeding rates, relative to seasonal and interannual variability in the productivity and physical forcing in the system, provide estimated rates of energy transfer upward from middle trophic levels. Models of trophic interactions and carbon flow within the system greatly benefit from these data. Predation is likely a factor that explains swarming and schooling of GLOBEC target species, thus, further explaining discontinuities of zooplankton distribution. Finally, our surveys have helped to focus sampling in fine-scale process-oriented studies of zooplankton by identifying foraging aggregations of seabirds and whales, which act as natural integrative plankton recorders.

From the bottom-up perspective, our project was designed to test the hypothesis that variation in prey density does not affect the occurrence patterns of top trophic level predators in the California Current upwelling system; or that there is no threshold of prey density that must be reached before the distribution of predators is affected. Alternately, from the top-down

perspective, we hypothesized that average swarm/school characteristics, as assessed by acoustic and net sampling (i.e. size, depth, density, shape), remain the same regardless of densities and behavior of predators in the vicinity.

1) Key major objectives to our proposed study (from proposal):

1) Determine the correspondence between cross-shelf and along-shelf distributions, community structure, and densities of apex predators and their principal prey as related to the strength, structure and variability of the wind-forced circulation of the northern California Current system.

2) Examine changes in community structure and foraging patterns of apex predators at the meso- and fine-scales.

3) 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 top level predators.In addition, examine whether apex predators seek areas where the concentration of euphausiids and forage fish (including juvenile salmon) surpass a threshold making foraging most efficient.

4) Compare the relationships of apex predators to trophic dynamics in the Cape Blanco jet, and its associated fronts, with the community structure of the northern coastal domain and source regions. Define whether the same species assemblage of apex predators track prey from shelf source regions to offshore filaments and jets, or whether the apex predator community shifts in composition and biomass beyond the continental margin. This addresses one of the GLOBEC goals to determine the factors responsible for variable pressure on juvenile and coho salmon.

5) To conduct mammal and seabird surveys during fine-scale studies in the Heceta Bank region to compare the scale and process-dependent patterns, school structure and species interactions of zooplankton and nekton with the distribution, abundance, and community structure of upper trophic level predators. 'It is likely that local recirculations and upwelling along the bank are responsible for enhanced seasonal productivity in this region.'

6) From the top-down perspective, assess changes in the school/swarm characteristics in the presence/absence of significant numbers of predators.

Field Work (Years 1-3)

During two cruises during the upwelling period of both 2000 and 2002, we conducted strip-transect surveys of seabirds and line-transect surveys of marine mammals in conjunction with other GLOBEC components. These cruises included mesoscale synoptic grids in May-June and July-August between Newport and Crescent City extending 100 km offshore north of Cape Blanco and 150 km offshore south of Cape Blanco; and fine-scale process-oriented cruises on smaller grids (50 X 80 km). These cruises provided the temporal (seasonal) and spatial (mesoscale and fine-scale) variability in euphausiid and forage fish occurrence patterns necessary to identify the important bio-physical linkages between predator distributions and the density and availability of their prey.

During fine-scale process-oriented studies, we collaborated with other GLOBEC researchers to examine the activities of seabirds and whales in conjunction with the horizontal and vertical structure of prey patches. Acoustic and net-tow sampling, when the data are subsequently analyzed, provided the biomass, school characteristics and species composition of juvenile and adult euphausiids (Peterson, Pierce, Batchelder), juvenile salmon (Brodeur), and copepods (Optical Plankton Counter, OSU); apex predators directed sampling toward some of the most dense patches of micronekton. This approach has been shown to obtain the highest zooplankton densities otherwise missed during classical gridded mesoscale surveys (Wishner et al. 1995) and to direct net-sampling, not just of commercial ventures to exploit euphausiids (Ichii 1990), but of scientific investigations on the biology of GLOBEC target species (Smith & Adams 1988).

2) Papers or presentations that include data analyses and modeling, to discuss the above hypotheses (Year 3-4)

We have analyzed top predator survey data and have combined it with information from other components, especially the SeaSoar hydrographic data and the acoustic data. The following are abstracts of two summary papers that will appear in publication during 2005; these papers address the first of our two hypotheses, and objectives 1-5 above.

Ainley, D.G., L.B. Spear, C.T. Tynan, J.A. Barth, S.D. Pierce, R.G. Ford, T.J. Cowles. 2005. Physical and biological variables affecting seabird distributions during the upwelling season of the northern California Current. Deep-Sea Res. II (in press, first issue of 2005) (GLOBEC Contribution Number 438).

Abstract: As a part of the GLOBEC-Northeast Pacific project, we investigated variation in the abundance of marine birds in the context of biological and physical habitat conditions in the northern portion of the California Current System (CCS) during cruises during the upwelling season 2000. Continuous surveys of seabirds were conducted simultaneously in June (onset of upwelling) and August (mature phase of upwelling) with ocean properties quantified using a towed, undulating vehicle and a multi-frequency bioacoustic instrument (38–420 kHz). Twelve species of seabirds contributed 99% of the total community density and biomass. Species composition and densities were similar to those recorded elsewhere in the CCS during earlier studies of the upwelling season. At a scale of 2–4 km, physical and biological oceanographic variables explained an average of 25% of the variation in the distributions and abundance of the 12 species. The most important explanatory variables (among 14 initially included in each multiple regression model) were distance to upwelling-derived frontal features (center and edge of coastal jet, and an abrupt, inshore temperature gradient), sea-surface salinity, acoustic backscatter representing various sizes of prey (smaller seabird species were associated with smaller prey and the reverse for larger seabird species), and chlorophyll concentration. We discuss the importance of these variables in the context of what factors seabirds may use to find food. The high seabird density in the Heceta Bank and Cape Blanco areas indicates them to be refuges contrasting the low seabird densities currently found in most other parts of the CCS, following decline during the recent warm regime of the Pacific Decadal Oscillation.

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) (GLOBEC Contribution Number 483).

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. Thus, the responses of cetaceans to biophysical features and upwelling processes in the northern CCS were both seasonally and spatially specific. Heceta Bank and associated flow-topography interactions were very important to a cascade of trophic dynamics that ultimately influenced the distribution of foraging cetaceans. The higher productivity associated with upwelling near Cape Blanco also had a strong influence on the distribution of cetaceans.

In addition to these two papers, we have also published the following using, in part, GLOBEC-derived data:

Ainley, D.G., D.N. Nettleship, H.C. Carter & A. Storey. 2002. Common Murre (*Uria aalge*). *In* The Birds of North America (A. Poole & F. Gill, Eds.). The American Ornithologists' Union, Washington, D.C. 54 pp.

Batchelder, H.P., J.A. Barth, P.M. Kosro, P.T. Strub, R.D. Brodeur, W.T. Peterson, C.T. Tynan, M.D. Ohman, L.W. Botsford, T.M. Powell, F.B. Schwing, D.G. Ainley, D.L. Mackas, B.M. Hickey & S.R. Ramp. 2002. The GLOBEC Northeast Pacific California Current System Program. Oceanography 15: 36-47.

Spear, L.B., D.G. Ainley, H.R. Carter, K.D. Amey, L.T. Ballance, K.T. Briggs, R.G. Ford, G.L. Hunt, N.J. Karnovsky, C. Keiper, J.W. Mason, K.H. Morgan, R.L. Pitman, C.T. Tynan. 2004. At-sea distribution, abundance and behavior of Xantus's Murrelet. Auk (accepted with revision).

Presentations:

We have given more than 25 presentations of our research at universities, national and international conferences, and GLOBEC meetings.

Tynan, C.T., D.G. Ainley, J.A. Barth, 'Cetacean distributions and oceanographic features of the Northern California Current: GLOBEC Northeast Pacific process studies during 2000', Eastern Pacific Ocean Conference (EPOC), Fallen Leaf Lake, California, 23-26 September, 2001, poster.

Ainley, D.G., L. Spear, C. Tynan, J. Barth, 'Seabirds and ocean fronts in the California Current: A GLOBEC study', EPOC, Fallen Leaf Lake, California, 23-26 September, 2001, poster.

Tynan, C.T., D.G. Ainley, J.A. Barth, 'Cetacean distributions and oceanographic features of the Northern California Current: GLOBEC Northeast Pacific process studies during 2000', North Pacific Marine Science Organization (PICES) conference, held in Victoria Canada, 7-12 October; poster.

Ainley, D.G., L. Spear, C. Tynan, J. Barth, 'Seabirds and ocean fronts in the California Current: A GLOBEC study', North Pacific Marine Science Organization (PICES) conference, held in Victoria Canada, 7-12 October; 2001, poster.

Tynan et al. and Ainley et al. presentations, GLOBEC PI meeting, held in Seattle, 13-16 November, 2001.

Tynan, C.T., D.G. Ainley, L.B. Spear, J.A. Barth, S.D. Pierce, W.T. Peterson, R.D. Brodeur, 'Top-trophic response to ocean structure during upwelling and downwelling events off the Oregon-California coast: A GLOBEC study. 14th Biennial World Conference on the Biology of Marine Mammals, held in Vancouver Canada, November 28 – December 3, 2001.

Ainley, D.G., L.B. Spear, C.T. Tynan, J.A. Barth, R.G. Ford, 'Occurrence patterns of seabirds in the California Current GLOBEC study area: indicators of top-down influences on food-web structure', Pacific Seabird Group Annual Meeting, Santa Barbara, Feb 2002.

Tynan, C.T., D.G. Ainley, L.B. Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., Peterson, W.T., Brodeur, R., Batchelder, H., Strub, T., Thomas, A. 'Distributions of upper-trophics in 2002 compared to 2000', GLOBEC NEP CCS PI/SI Meeting, Corvallis, Nov. 19-21, 2002.

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

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.

Ainley, D.G., Spear, L.B., Tynan, C.T., Barth, J.A., Cowles, T.J., Pierce, S.D., 'Factors affecting the spatial patterns of occurrence of seabirds in the northern California Current waters, spring and summer, 2000'. Eastern Pacific Ocean Conference (EPOC), Sept. 24-27, 2003, poster

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

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

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

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

Ainley, D.G., L.B. Spear, C.T. Tynan. 'Occurrence patterns of seabirds in the California Current'. Pacific Seabird Group, Cabo San Jose, Mexico, January 2004.

Tynan, C.T. and R. D. Brodeur, Session Chairs for OS21J, 'Understanding the Physical and Biological Coupling of Marine Population Dynamics: Higher Trophic Levels in the Northeastern Pacific, January 26-30, 2004 AGU Ocean Sciences, Portland, Oregon.

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', January 26-30, 2004 AGU Ocean Sciences, Portland, Oregon; participation in GLOBEC SI meeting and synthesis planning workshop following AGU.

Ainley, D.G., L.B. Spear, C.T. Tynan. 'Occurrence patterns of seabirds in the California Current'. ASLO, Honolulu HI, February 16-20, 2004.

Tynan, C.T. 'Toward predictive biophysical models of cetacean occurrence patterns in the California Current System, an upwelling boundary current system'. Requested 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.

Tynan, C.T., Ainley, D.G., Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., 'Biotic and abiotic cross-shelf transport: comparing carbon transport by humpback whales with carbon transport in offshore jets of the California Current System', Eastern Pacific Ocean Conference (EPOC), Sept. 22-26, 2004, poster.

Ainley, D., C. Keiper, G. Ford, 'Response of top-trophic species in the California Current to the recent shift of the Pacific Decadal Oscillation', EPOC, Sept. 22-26, 2004, poster.

Tynan, C.T., Ainley, D.G., Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., 'Biotic and abiotic cross-shelf transport: comparing carbon transport by humpback whales with carbon transport in offshore jets of the California Current System', GLOBEC SI Meeting, Corvallis, Oregon, November 15-16, 2004, poster (Batchelder presenting).

Ainley, D., C. Keiper, G. Ford, 'Response of top-trophic species in the California Current to the recent shift of the Pacific Decadal Oscillation', GLOBEC SI Meeting, Corvallis, Oregon, November 15-16, 2004, poster (Batchelder presenting).

Ainley, D.G., G. Ford, C. Keiper. 'Long-term trends in seabirds of the northern California Current'. Annual Meeting, Pacific Seabird Group, Portland, Oregon. January 2005.

3) Online status of data.

Bird and cetacean data from the two GLOBEC NEP NCC cruises of 2000 have been posted on the U.S. GLOBEC website http://globec.whoi.edu/jg/dir/globec/nep. Data for 2002 will be posted soon. Robert Groman (Woods Hole Oceanographic Institution) manages the data pages for U.S. GLOBEC. Initial processing of the bioacoustics backscattering data is publicly available online (http://damp.coas.oregonstate.edu/globec/nep).

4) Papers and products to emerge by the Fall of 2005.

Tynan, C. T., D.G. Ainley, J.A. Barth, and T. J. Cowles. In prep. Biological and physical cross-shelf transport: Carbon flow through whales equates with that of an upwelling jet. *Nature.*

Tynan, C. T., D.C. Ainley, J.A. Barth, T.J. Cowles. In prep. Ecological importance of offshore filaments of the California Current to fin whales. *Marine Ecology Progress Series.*

Tynan, C. T., D.G. Ainley, J.A. Barth, T.J. Cowles. In prep. From physics to *Physeter*:

associations of deep-divers with complex topography in a boundary current system. *Science*.

Tynan, C. T. et al. Biophysical coupling at a submarine bank; enhanced multi-trophic response to recirculation mechanisms. *Deep-Sea Res.*

PLANS FOR THE FUTURE (YEARS 5-7)

We have submitted a proposal for funding during the 'synthesis phase' of GLOBEC NEP, with the title, "**Collaborative: US-GLOBEC NEP Phase IIIa-CCS: Scale-Dependent Dynamics of Top-Trophic Predators and Prey - Toward Predicting Predator Response to Climate Change." Co-PIs are Tynan and Ainley.**

As of December 2004, this proposal, for an effort that will be the core of what we can say toward testing GLOBEC hypotheses, has been recommended for funding.

PROJECT SUMMARY. We propose a collaborative synthesis to investigate the mesoscale and finer-scale spatial and temporal relationships between top predators (marine mammals, seabirds), their prey and physical-biological processes in the northern California Current System (CCS). We will use data sets collected during the multi-ship GLOBEC NEP effort that surveyed waters off Oregon and northern California in 2000 and 2002, including estimates of marine bird and mammal densities (continuous surveys) and coincident acoustic estimates of prey biomass using a multi-frequency array (backscatter subsequently validated by net sampling) and underway sampling of water-column structure and chlorophyll concentration using SeaSoar technology. Analyses of the 2000 data indicated that >40% of variation in the more abundant mammal and bird densities was explained by distance to upwelling-generated features (e.g., alongshore front, center of upwelling jet), acoustic backscatter at various frequencies (high frequencies explaining planktivore distribution; low frequencies the piscivore distribution), and chlorophyll maximum.

Variability in the productivity of the CCS is notably large owing to climate variability on time scales ranging from days (upwelling) to interannual (ENSO) to decadal (Pacific Decadal Oscillation, PDO). For example, in response to the warm phase of the PDO 1976-1998, it is well known that zooplankton declined with a major reduction in its predators. In addition, major components of the food web have been removed by commercial fishing or whaling, with some species in a slow process of recovery (whales). While these trends can be best seen from a large-scale view, it is at the mesoscale or finer-scale perspective that predators are exploiting the patches of prey that become available. We will synthesize the above data to understand the scale-related dynamics between predators and prey in the CCS. Two major null hypotheses will be tested: 1) mesoscale forcing, that alters the alongshore upwelling front and equatorward jet, does not affect the cross-shelf and along-shelf density and community structure of top predators; and 2) the spatial scale of plankton and nekton distribution, measured by spatial autocorrelation, is everywhere comparable to that of physical parameters; in turn, the spatial scale of planktivore or piscivore distributions is comparable to the scale of plankton and fish distributions, respectively.

We will construct a predictive model of factors affecting top-predator distribution based on 2000 data and will test it using 2002 data. We will also estimate predator abundance and distribution using general additive models (GAMs), from which we will construct a carbon flow model to estimate carbon egested, respired and sequestered by upper trophic levels (as well as carbon removed by migrants). It may be greater than the amount of carbon advected offshore by meandering jets. We will use several modeling approaches to determine the magnitude and significance of prey correspondence or depletion at a range of scales. We will examine spatial heterogeneity at two levels of the ecosystem: the density or patch size

of prey relative to physical oceanographic features; and the density of predators relative to their prey.

Intellectual merit. The ecological roles of top predators in structuring communities and affecting the flow of carbon in shelf systems are known to be significant. What is less well understood is how the spatial and temporal variability in mesoscale forcing influences cross-shelf and along-shelf structure of mid-trophic communities and the transfer of carbon from zooplankton and fish to top predators. Therefore, in order to understand how climate variability affects populations of top-trophic species through changes in marine production and prey availability, a study such as ours is necessary to examine how predators interact with biophysical structure of their habitat at the spatio-temporal scales in which they forage on daily basis.

Broader impacts. The syntheses proposed herein provide a valuable baseline, for the early part of this century, on top predator response to several scales and sources of variability in the northern CCS. In addition, the synthesis forwards the longer-term development of predictive biophysical models of occurrence patterns of top-predators (many of which are endangered species) in the CCS. Evolution of such models will assist with resource management and planning of human activities (e.g., major fisheries, 5 marine sanctuaries, transportation and commerce) in the northern California Current ecosystem off the west coast of the U.S.