

REPORT 1

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Zooplankton Patterns in Relation to Physical Processes and Behavior

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6. AUTHOR(S)

Loren R. Haury

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Marine Life Research Group
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093DTIC
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13. ABSTRACT (Maximum 200 words)

The report reviews ONR supported studies of zooplankton distributions as affected by oceanic water masses, fronts, current filaments, turbulence, and shear. Model simulations of plankton behavior and patchiness in turbulence were also conducted.

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oceanic biology, zooplankton distributions, patchiness, behavior, physical processes

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ZOOPLANKTON PATTERNS IN RELATION TO
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Agreement Number N00014-89-J-1116
Principal Investigator: Loren R. Haury
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Loren R. Haury
Marine Life Research Group
Scripps Institution of Oceanography
La Jolla, California 92093-0218
Telephone (619) 534-2412
OMNET: L.Haury

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LINKED ONR CONTRACTS

A number of earlier ONR contracts culminating in N00014-89-J-1116 supported this work.

Preparation of a Longhurst-Hardy Plankton Recorder for the 1982 Zooplankton Sampler Intercomparison and Patchiness Study

N00014-80-C-0440	10/01/81-09/30/82	\$25,000
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Continued Improvements to a Longhurst-Hardy Plankton Recorder for 1983-1986 Physical and Biological Studies of the Upper Ocean

N00014-80-C-0440	10/01/82-31/09/83	\$8,232
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Fine-Scale Patterns of Zooplankton in the Upper Ocean in Relation to Physical Features and Processes

N00014-80-C-0440	02/01/83-09/30/84	\$146,925
N00014-85-C-0104	10/01/84-09/30/86	\$157,750
N00014-87-K-0005	10/01/86-09/30/88	\$160,218

LONG-RANGE OBJECTIVE OF SUPPORTED RESEARCH

One of the most challenging problems facing marine ecology today is the proper description of the time and space scales of physical, chemical, and biological variability in the pelagic realm. At the smaller spatial scales (centimeters to kilometers), sampling problems become particularly critical. No single instrument is adequate to sample the multitude of physical and biological parameters needed to gain an integrated picture of the relationships and how they vary over space and time. In most cases, field sampling does not obtain the concomitant organism level information (e.g., behavior, physiological condition, reproductive status) needed to determine the consequences of these interactions. Extrapolation to the field from laboratory data and sparse *in situ* samples, together with theory and models, are now the only way to make the connections. My objective in this research was to participate in interdisciplinary studies using a variety of physical, chemical, and biological instrumentation to describe the physical and biological attributes of marine ecosystems and their temporal evolution at mesoscale and smaller levels. In the latter part of the research period, the focus shifted to field observations at the micro- and fine-scale level and to models of the effects of physical processes on zooplankton distributions.

WORK ACCOMPLISHED

The research conducted under the agreement(s) has been based primarily on the data obtained from the following cruises, source of funding for the ship time is noted (MLRG = Marine Life Research Group, Scripps Institution of Oceanography).

Research Vessel	Dates	Area	Support
NEW HORIZON	30/07/82 30/08/82	Hawaii to San Diego	MLRG
USS DOLPHIN	16/10/84 19/10/84	Monterey Bay, Calif.	ONR to Thomas Osborn
USNS DeSTIEGUER	29/08/84 04/09/84	Southern California Bight	ONR to Paul Greenblatt
NEW HORIZON	01/07/85 23/07/85	Southwest of San Diego	MLRG

These cruises resulted in the papers listed below. The review papers were a product of the integration of the understanding obtained from them with previous research. They also continue to serve as the basis for collaborations with Dr. Hidekatsu Yamazaki (University of Victoria, Victoria, B.C.) involving the study of interactions of zooplankton with turbulence in the field, laboratory and patch simulation models.

PUBLICATIONS

The sequence of ONR contracts has resulted in the following papers:

Haury, L.R., E.L. Venrick, C.L. Fey, P.P. Niiler, and J.A. McGowan In press. The Ensenada Front, July 1985. CalCOFI Reports.

Yamazaki, H. and L.R. Haury In press. A new lagrangian model to study animal aggregation. Ecological Modelling.

Haury, L.R., H. Yamazaki, and C.L. Fey 1992. Simultaneous measurements of small-scale physical dynamics and zooplankton distributions. Journal of Plankton Research 14:513-530.

Haury, L.R., H. Yamazaki, and E.C. Itsweire 1990. Effects of turbulent shear flow on zooplankton distributions. Deep-Sea Research 37:447-461.

Niiler, P.P., P.-M.R.G. Poulain, and L.R. Haury 1989. Synoptic three-dimensional circulation in an onshore-flowing filament of the California Current. Deep-Sea Research 36:385-405.

Haury, L.R. 1988. Vertical distribution of *Pleuromamma* (Copepoda, Metridinidae) across the eastern North Pacific Ocean. Hydrobiologia 167/168:335-342.

Genin, A., L.R. Haury, and P. Greenblatt 1988. Interactions of migrating zooplankton with shallow topography: predation by rockfish and intensification of patchiness. Deep-Sea Research 35:151-175.

Haury, L.R. and R.E. Pieper 1988. Zooplankton: scales of biological and physical events. In: D.F. Soule & G.S. Kleppel (eds.), *Marine Organisms as Indicators*, Springer-Verlag., pp 35-72.

Haury, L.R. 1986. Patches, niches, and oceanic biogeography. In: A.C. Pierrot-Bults, S. van der Spoel, B.J. Zahuranec, & R.K. Johnson (eds.), *UNESCO Technical Papers in Marine Science 49, Pelagic Biogeography*, pp. 126-131.

In preparation:

L.R. Haury and C.L. Fey Vertical distribution of zooplankton across the Ensenada Front

L.R. Haury and C.L. Fey Vertical distribution of zooplankton across the eastern North Pacific between Hawaii and California, USA

SIGNIFICANCE OF THE RESULTS

Organized by scale of interest, beginning with the smallest (order centimeters).

Dr. Yamazaki and I (Yamazaki and Haury, in press) developed a new one-dimensional, nonlinear Lagrangian model and applied it to the study of animal aggregations in turbulence using zooplankton as representative organisms. This simulation uses two parameters incorporating biology, perception distance and motivation for maintaining a patch. The model realistically mimics animal aggregation with appropriate selection of parameter values for small numbers of organisms (100) and small sizes of patches (100 cm). Behavior such as breakup and coalescence of patches, as well as net drift of patch centers is displayed. We believe this model can be made sophisticated enough to suggest threshold levels of physical disturbance (mixing) at which organisms' (or class of organisms) distributions become determined more by physical forcing than by behavior.

The two papers resulting from the submarine studies done in Monterey Bay, California (Haury et al., 1992, 1990) report the first simultaneous measurements of turbulent dissipation rate, vertical velocity shear, temperature, salinity, and zooplankton distribution and abundance, all made on scales of about 15 m over distances of 10's of kilometers. Our results show that energetic turbulent regimes due to strong winds and high vertical shear can broaden vertical distributions of zooplankton dependent on their swimming ability. Vertical mixing of species normally separated by depth under less energetic conditions can result. Under most conditions, however, the relationship between species distributions and physical structure and dynamics was very complex, probably a consequence of both animal behavior and sampling limitations.

On the scale of hundreds of meters to kilometers, Genin et al. (1988) suggested that shallow seamounts can cause the formation of "holes" in zooplankton distributions and thus intensify regional patchiness of plankton. The holes are apparently caused by physical displacement of diel migrating zooplankton by the seamount and by predation on the zooplankton by seamount-associated predators. This work led to the continuing study of patchiness intensification around both deep and shallow seamounts during the Flow Over Abrupt Topography (TOPO) Accelerated Research Initiative. This TOPO work is again being done in collaboration with Dr. Amatzia Genin (Hebrew University of Jerusalem).

The study of a persistent open ocean front (the Ensenada Front) southwest of San Diego, California has so far resulted in two papers (Niiler et al., 1989 and Haury et al., in press). These papers show that the front is characterized by a complex set of flows, some which feed into eddies, and others that may be subducted under warm waters to the south. Some of the flows are jet-like, with velocities greater than 50 cm s^{-1} and upwelling within the core of the filament. Productivity was not enhanced in the jets, and integrated euphotic zone chlorophyll showed no change across the front. Chlorophyll

concentrations were enhanced, however in the high shear zones between filaments. Zooplankton biomass was higher to the north of the front, but there was a complex relationship of this biomass to integrated chlorophyll. Vertical distributions of zooplankton across the front were varied, with different species responding differently to the contrasting conditions on each side.

The study of vertical distributions of the copepod genus *Pleuromamma* across the north Pacific between Hawaii and California (Haury, 1988) demonstrated vertical differences in distributions on order of a few 10's of meters over horizontal gradients of 100's of kilometers. The most significant finding was that warm water species appear to occur farther into, and are more persistent in, the cold California Current than the cold water California Current species are in the warm central Pacific waters. This is a consequence presumably of adaptive traits of the zooplankton and/or asymmetries in the frequency and depth of penetration of physical exchange mechanisms like eddies, intrusions, and jets. Vertical distributions of both categories of species shoaled towards the coast.

Two papers, Haury (1986) and Haury and Pieper (1988), integrated some of the above results with other literature into reviews of zooplankton distributional patterns at scales from centimeters to 1000's of kilometers. These papers focussed on the use of such patterns to help understand physical and biological oceanographic questions on scales ranging from patchiness at 10 cm to the biogeographic (oceanic) scales. It is clear from these reviews that much work and improvement in instrumentation remains to be done to arrive at a more complete understanding of zooplankton patterns and their interaction with physical dynamics.