Zooplankton and Climate: Response Modes and Linkages

by David L. Mackas

The 2008 International Symposium on "*Effects of climate change on the world's oceans*" included a 1-day open workshop, "*Zooplankton and climate: Response modes and linkages among regions, regimes and trophic levels*", which examined zooplankton time series and their links with ocean climate. Demographic characteristics of marine zooplankton make them especially suitable for exploring the mechanisms responsible for ecosystem variability at interannual to decadal time scales. The workshop was held on May 18 and designed as a forum for the viewing and discussion of time series analyses recently carried out by SCOR Working Group (WG 125) on *Global Comparison of Zooplankton Time Series* (http://wg125.net/), which also had a working meeting on May 15–16, at Instituto Español de Oceanografía's Centro Oceanográfico de Gijón. However, the May 18 workshop also included a number of excellent presentations by authors not formally associated with the SCOR Working Group.

The 16 presentations covered a wide but relevant range of topics: data 'tools'; the spatial 'zones of influence' for different modes of physical climate variability; a between-region comparison of trends and amplitudes for anomalies of total zooplankton biomass/biovolume; temperature effects on community size structure and seasonal timing (phenology); 'invasions and outbreaks' by gelatinous zooplankton; spatial and interannual variability of isotopic composition and trophic level; variability of species composition and diversity; and poleward displacements of zoogeographic distributions. In this article, I will give only a few graphical examples and an overall 'highlights and consensus' summary. The full list of presentation titles and abstracts (plus pdf copies of some of the presentations) can be accessed on the symposium website at www.pices.int/meetings/international_symposia/2008_symposia/Climate_change/structure.aspx. Many of these will also be written up for publication in an upcoming special issue of *Progress in Oceanography*.

There has been very good buy-in by the international community of marine zooplanktologists to the WG 125 goal of global comparison. We currently have access to over 100 multi-year zooplankton time series from over 25 countries (and are continuing to gain more). One consequence of this massive response is that WG 125 needed to assemble a suite of 'entry-level' data analysis and visualization tools that could be applied to compare across diverse sampling designs (frequent and regular sampling of a single near-shore station, seasonally-repeated survey grids, and more irregular repeat coverage within defined statistical areas); sampling methods (horizontal, vertical or oblique net tows with different net designs and mesh sizes); and measurement currencies (displacement volume, dry-weight biomass, carbon biomass, numeric abundance at varying levels of taxonomic aggregation). Our step-wise approach (implemented mostly by Todd O'Brien and illustrated in **Fig. 1**) has been to estimate average seasonal cycles from log-transformed raw time

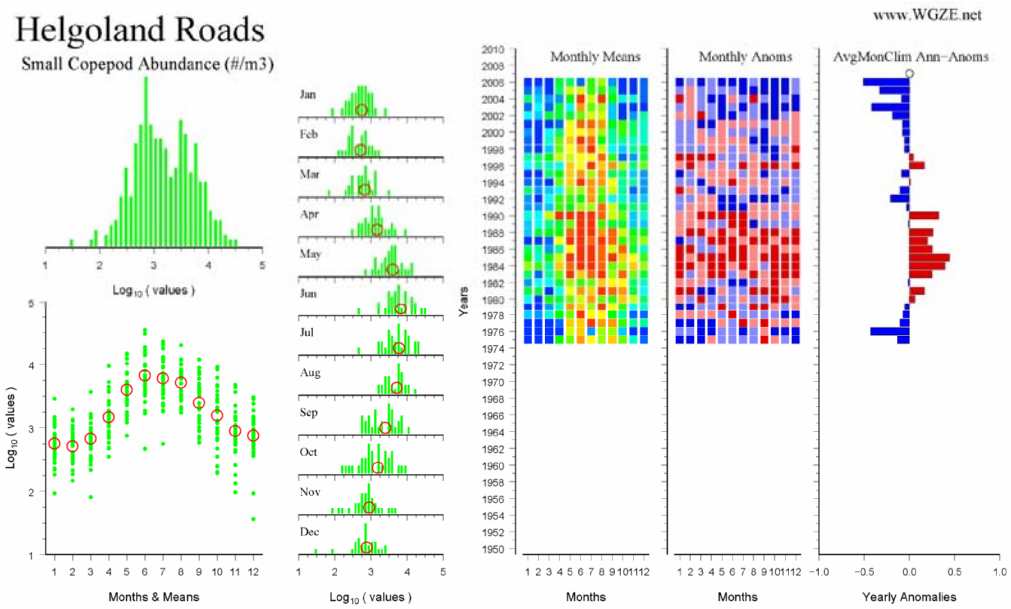

Fig. 1 Graphical output from the WG 125 toolkit, as applied to W. Greve's Helgoland Roads time series. The green dots and bars in the three left-side panels show overall and within-month frequency distributions of individual data points. Red circles overlaid on the bottom-left graph show the average seasonal cycle. Color-coded pixels in the middle panel show ranking of within-month means. The right-side panels show monthly and annual-average anomalies from the seasonal climatology.

series, then use these to calculate anomaly time series (multiplicative deviations from the seasonal climatology), and finally to display both data and anomalies as color-coded month-*versus*-year pixel grids that show which seasons/years have unusually high or low values of the variable being measured. These simple graphical displays have been useful not only for comparison among time series, but also for within-time-series quality control and hypothesis building.

Nearly all of our available zooplankton time series provide one or more indices of 'total amount': biovolume, biomass, or total abundance. How do the amplitudes of fluctuations and trends differ among regions? One approach is to classify and map time series based on the max-to-min or RMS 'span' of their anomaly time series (**Fig. 2** from O'Brien *et al.*). The strongest interannual variability was in the time series from sub-polar regions, from the eastern boundary current upwelling systems, and from the ocean margins off Korea and Japan. The weakest range of variation has been on mid-latitude continental shelf regions and marginal seas.

Another important question is which time series are most 'synchronous', and how their temporal correlations vary with spatial separation. Hal Batchelder presented a preliminary but interesting spatial auto-correlation analysis (**Fig. 3**) of the 'biomass' time series. He found that these time series tend to be positively but relatively weakly correlated across separations smaller than a few thousand kilometers, and that the spatial autocorrelation is stronger in the Pacific than in the Atlantic. However, there is no evidence supporting a 'global synchrony' similar to that suggested by catch time series of anchovy and sardines. Does this mean that fish 'regimes' are more teleconnected than zooplankton 'regimes'? Perhaps, but not necessarily – the zooplankton analysis is of a highly aggregated currency (total biomass), while the fish analyses are at species level. We are still working on the corresponding global species-level analysis for zooplankton, but comparisons within the California Current system show that the short-range spatial auto-correlation of zooplankton community variability is considerably stronger than the spatial autocorrelation of total zooplankton amount (**Fig. 3**). We need data to extend the species-level analysis to larger separations. Stay tuned,

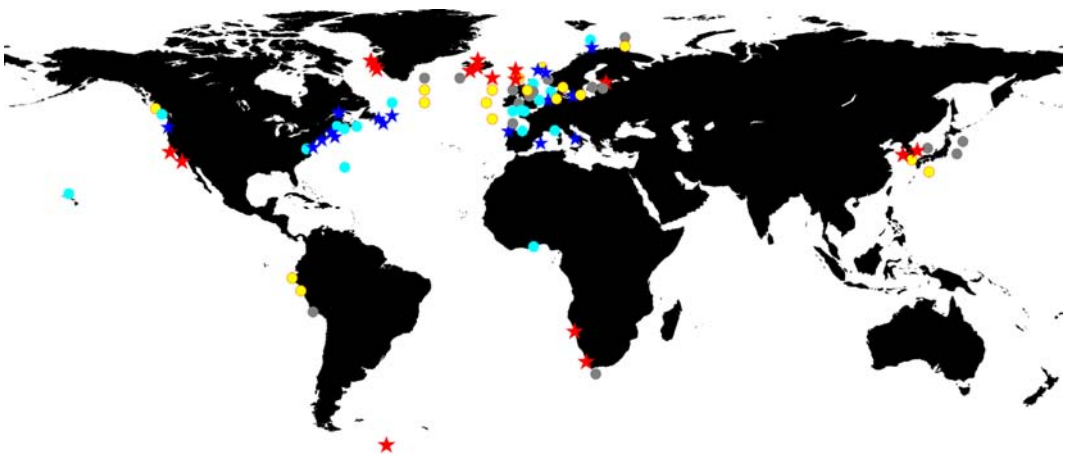

Fig. 2 Map of 'anomaly span'. Red and yellow symbols show locations of time series with a large interannual range; blue symbols have a much smaller range (some because they are brief). Grey symbols are intermediate.

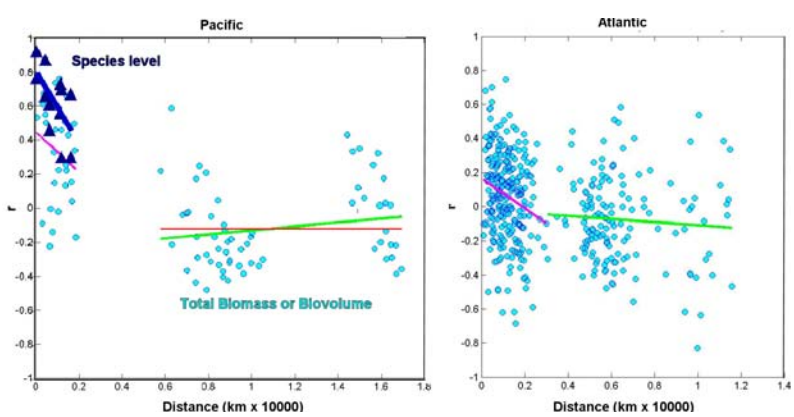

Fig. 3 Spatial correlograms for zooplankton anomaly time series from the Pacific (left, total biomass and community composition) and Atlantic (right, total biomass only). Data points are similarity (y-axis) vs. *separation (x-axis) of annual anomaly sequence for all pairs of time series with more than 12 years of overlap. Light blue circles are 'biomas/biovolume', dark blue triangles are species groups defined by zoogeographic zonation. In both oceans, correlation decays to zero at separations greater than a few thousand kilometers (*i.e.*, there is little or no global synchrony). However, 'local' correlation is stronger in the Pacific than in the Atlantic, and is much stronger at species level than for total biomass.*

we will be extending this analysis (and please join us if you have any suitable time series data).

What else stood out as strong climate linkages? As noted above, several papers (Conversi *et al*., Mackas *et al*., Schlueter *et al*.) examined changes in zooplankton seasonal timing. All found that zooplankton phenology is very sensitive to ocean climate as indexed by water temperature during the growing season for a given species. But a very interesting composite result was that the temperature dependence is not uniform across species and regions. High latitude and 'spring' species show earlier seasonal maxima in years when temperatures are higher. Subtropical 'fall bloom' species show the opposite pattern – later maxima when temperatures are higher, suggesting that their population responses track autumn cooling and de-stratification, rather than spring warming and stratification. Species richness, average body size, and success of 'invading' (or merely 'expanding') species also show strong relationships to ocean warming. Again, stay tuned.

Post-workshop tapas and time series (what could be better?) The Pacific-resident author (David Mackas, blue-shirted male, a.k.a 'Canadian frog') compares data and wine preferences with Euro-princess colleagues (clockwise from left) Lydia Yebra-Mora, Delphine Bonnet, Maité Alvarez-Ossorio, and Maria-Luz Fernandez de Puelles. Photo courtesy Maite (camera and email) and Antonio Bode (shutterbug). Commentary from Maité: "[Frog is obvious but] I don't see any crowns [on the princesses]".

Dr. David Mackas (Dave.Mackas@dfo-mpo.gc.ca) is a Research Scientist with Fisheries and Oceans Canada at the Institute of Ocean Sciences and Co-Chairman of SCOR WG 125. He is also a member of several PICES Committees and expert groups, including WG on Comparative Ecology of Krill in Coastal and Oceanic Waters around the Pacific Rim.

(*continued from page 7*)

Day 3 allowed the group to refocus on the outstanding issues that had been identified during the previous two days of database beta-testing, discussions, and problem solving. Representatives from each country had an opportunity to provide input on their expectations of the final version of the database that WG 21 expects to have fully operational (if not fully populated) in time for the rapid assessment surveys to be conducted at two locations in China, prior to PICES XVII in Dalian. With an identified path forward that all attendees were comfortable with, including specific interim deliverables and associated timelines, the field trip portion of the meeting began. First, it was a boat tour of the port of Busan, arranged by Dr. Yoon Lee in conjunction with the local port authority. The group then proceeded on to Busan New Port which is currently under development and will greatly increase the shipping traffic in this part of the world once the expansion is complete. The day ended with the last group dinner associated with this inter-sessional meeting that allowed the participants to continue developing research collaborations and a better understanding of how non-indigenous species are impact-ting various PICES member countries.

Our meeting was a tremendous success thanks to Dr. Lee and his staff. Not only were meeting facilities extremely comfortable, the group meals every evening allowed participants to mingle in a less formal setting. In addition, we were able to sample a number of local delicacies (food and drink) and take in some of the sights this region has to offer. WG 21 continues to make significant advances towards better understanding non-indigenous marine species in the North Pacific and the dedication of its members will ensure that we are successful in all our endeavors, including completion of the database we beta-tested at our recent meeting in Busan.

Dr. Thomas Therriault (Thomas.Therriault@dfo-mpo.gc.ca) is a Research Scientist with Fisheries and Oceans Canada (DFO) at the Pacific Biological Station in Nanaimo, BC. Tom is working on aquatic invasive species (research, monitoring, risk assessment, and rapid response planning) both within DFO and through the Canadian Aquatic Invasive Species Network (CAISN). He also conducts research on forage fishes, notably eulachon and Pacific herring, from conservation and ecosystem perspectives. Tom is a Principal Investigator on the Taxonomy Initiative of PICES WG 21 that will include rapid assessment surveys for non-indigenous species in PICES member countries.