Proposal for a SCOR Working Group on:

Global Comparisons of Zooplankton Time Series

28 April 2004

1. Background & Rationale

There is an increasing scientific and public focus on how climate variability and climate trends affect marine ecosystems. Important scientific questions include the qualitative character of the ecosystem responses ("what changes"), their amplitudes ("by how much"), and their timing and spatial and temporal scales ("when and where are rates of change strongest"). There is much accumulated evidence that living marine resources in individual ocean regions undergo strong, and sometimes abrupt, changes in stock size and productivity at roughly decadal intervals. This variability is associated with corresponding changes in the atmosphere, and in physical oceanographic, and lower-trophic-level biological processes and state variables. However, in general we do not know the mechanisms by which these changes occur, the relative importance of direct physical forcing vs. biological interactions, and if the dominant mode of biological feedback is "bottom-up", "top-down". or "wasp-waist" (Verheye and Richardson 1998, Cury et al. 2000, Tadokoro et al. in press). Nor do we know how to anticipate the timing and direction of the next major shift.

Perhaps the most provocative and influential example of large-scale, multi-year marine ecosystem variability has been the similarity in duration and phasing of major fluctuations in sardine and anchovy catch in widely-separated boundary current systems (e.g. Kawasaki et al. 1991; SCOR WG98 "Worldwide large scale fluctuations of sardine and anchovy populations" and Schwartzlose et al. 1999; the ongoing SPACC research program).

We are proposing a SCOR Working Group to do a similar global-scale comparison of low frequency variability of marine zooplankton communities. This idea grew out of a workshop convened by Ian Perry and Hal Batchelder during the recent "3rd International Zooplankton Production Symposium" (May 2003 in Gijon, Spain, co-sponsored by GLOBEC, PICES, ICES and the Spanish government). A summary paper from that workshop (Perry et al., in press) includes preliminary but provocative evidence for temporal coherence of zooplankton and climate variability in both the North Atlantic and the North Pacific (Fig. 1). There was a strong consensus at the Gijon workshop that a more detailed and more global comparison of zooplankton time series would be timely, technically feasible, and extremely useful.

Such an analysis must be an international cooperative effort – the relevant data sets are in many places and have been collected by many independent nations and agencies. However, many of the necessary data are available now, and the proposed Working Group could begin immediately. We are confident that we have grass-roots commitment by participating scientists. Endorsement and sponsorship by SCOR will help us attract and retain approvals and financial support from senior national agencies. We also expect to attract co-sponsorship and additional financial support in the form of travel funding for associate WG members (probably 3-5) from PICES, ICES, Census of Marine Life, and the national and international GLOBEC programs. We have been in preliminary contact with most of these organizations and programs (as of April 2004). They agree with the need for such a group, and have confirmed their interest in and support for the activity.

2. The nature of the scientific opportunity

Why zooplankton?

For several reasons, multi-year zooplankton time series provide useful tools for examining climate-ecosystem interactions. First, mesozooplankton (about 0.1-2 cm body length) are a key link between primary producers and larger predators. Second, mesozooplankton are abundant, and can be quantified by relatively simple and intercomparable sampling methods. Third, and perhaps most important, demographic traits of zooplankton make them particularly suitable for analysis of interannual ecosystem changes. Life cycles of most species range from a few months to one year. Recruitment and mortality rates are slow enough that major population fluctuations are not missed by sampling at ~monthly intervals. But (unlike most fish and marine mammals) changes in population size are rapid enough to track seasonal-to-interannual changes in environmental conditions. Fourth, because few zooplankton taxa are fished, most zooplankton population changes can be attributed to environmental causes. Finally, because many fish are dependent on a zooplankton food source during their pre-recruit life history stages, zooplankton anomalies may be a useful leading indicator of what will happen to commercial fish stocks several years later (for two striking examples, see Batchelder et al. 2002 and Beaugrand et al. 2003).

Availability and diversity of zooplankton time series

Zooplankton time series of ten years or more in length are now available for many widely separated ocean regions (Table 1 from Perry et al. in press). The longest are the Continuous Plankton Recorder (CPR) surveys of the eastern North Atlantic (80+ years); the California Cooperative Fisheries Investigations (CalCOFI) surveys of the south-central California Current system (50+ years); Canadian and Japanese sampling in the subarctic NE Pacific (50+ years summer season, continuous 1958-1981); Japanese, Russian and Korean collections from the western margin of the Pacific and the Asian marginal seas (40-50+ years); sampling by IMARPE (Peru), IFOP (Chile) and other agencies in the Peru-Chile upwelling region (~40 years); US and Canadian monitoring programs in the coastal NE Atlantic (~40 years); and several ongoing European sampling programs in the North Sea and Mediterranean (20-30 years). In several additional ocean regions (notably off South Africa and in the Arabian Sea) it may be possible to assemble very long time series by combining information from sequences of shorter observation programs.

Many important within-region analyses of these zooplankton time series have been completed, and are being widely noted by both the scientific community and by decision makers (e.g. Brodeur and Ware 1992; Roemmich and McGowan 1995; Beaugrand et al. 2003). Recurrent themes have been that:

- multi-year variability of zooplankton is large enough to be significant both statistically and ecologically,
- variability at the level of individual species or species guilds (when quantified) is often stronger than the variability of aggregate measures such as total biomass.
- there are many clear correlations of the interannual zooplankton variability with both the physical environment and with the distribution and productivity of harvested fish stocks.

There is growing evidence that zooplankton time series that go beyond biomass to include plankton compositional information are especially useful. In part this is because interannual-decadal changes in community composition, phenology, and physiological ‘condition’ are often very strong. However composition-resolved time series also have greater information content and interpretability because they invite cross-referencing to large scale distributions, physiology, predator-prey associations and behavioral and life history strategies. Many new and ongoing time series are therefore now adding a compositional component (e.g. "zooplankton species" is on the OCEAN.US IOOS list of "core variables"). For the historic biomass time series, this compositional information is often still available in the form of "samples in jars". Re-processing of older archived samples is underway in several regions (e.g. CalCOFI retrospective studies in US GLOBEC; the Odate Project in Japan; and BENEFIT and BCLME programs in the southeast Atlantic, IAI/EPCOR funding for workup of Peru Current samples and data). We will include data from these re-analyses in our Working Groups comparison effort. A showpiece demonstration of value would do much to attract new funding for broader re-processing efforts.

The case for global comparisons

We believe that large-scale (between-region and between-ocean) comparisons of zooplankton time series are the essential next step. The sardine-anchovy story provides one clear example of how such a comparison can stimulate scientific progress. However, both similarities and differences between time series will be informative. If we do find that zooplankton variability has a very large spatial "footprint" (global to basin-scale coherence of type and/or timing, as suggested in Fig. 1), this will be very strong evidence that causal mechanism(s) are also large scale. Conversely, smaller scale forcing mechanisms that are confounded (either temporarily or permanently) within a single region often vary independently or inversely in other regions, allowing statistical discrimination. Third, because individual time series show serial autocorrelation, statistical degrees of freedom accumulate slowly – it takes a very long time to discriminate differences in strength and stability among local correlative associations. Between-region comparisons allow a form of ensemble averaging that is quicker and also very effective at testing the consistency and basis of association.

To date, relatively few between-region comparisons of zooplankton time series have been completed. All have been at much less than global scale (within an individual current system, or at most one ocean basin). Almost all of the basin scale comparisons (with the notable exception of the CPR surveys) have been confined to estimates of total mesozooplankton biomass or biovolume. We now have access to both the data and the tools needed to carry out a global synthesis.

Methodological opportunities and issues

Several methodological issues affect the analysis of zooplankton time series. We have space here for only a brief summary (more detailed discussion is available in Perry et al. in press). However, our overall assessment is that these will complicate our work, but not prevent a useful global comparison.

The first issue is diversity of sampling methodology. No zooplankton sampling method is perfect, and we recognize that there have been differences in sampling methodology both within and between data sets. However, we do not expect these differences to be a serious technical barrier to between-region comparisons. One key reason is that our analysis focuses on comparisons of anomaly time series rather than of the regional climatologies – we are primarily interested in the temporal variability of relative abundance, not the spatial variability of absolute abundance. As practicing zooplankton field ecologists, we are also in a good position to recognize problem situations and taxa. Several of the proposed WG members have expertise in evaluating effects of sampling method changes within individual time series. We will also keep close liaison with SCOR WG 115 on 'Standards for the Survey and Analysis of Plankton'.

A second issue is consistency of taxonomic identification within and among data sets. Again, we are helped by the fact that we are primarily comparing anomalies relative to local norms, and looking for when, where, and how long the community changes. We also expect that all or most of our analyses will be weighted on the better-known taxa that dominate the community in each region.

A third issue is the volume, accessibility, and diversity of data. The situation here is much better than it was even a few years ago. Several key data sets have already been put in readily-accessible form. Good computer tools for dealing with diverse-origin and moderately large data sets are now more available, cheaper, and more flexible and user-friendly. We anticipate that this trend will continue. Although data management work will be necessary, we do not expect that electronic assembly and consolidation of the zooplankton data sets will be a major technical problem.

The final issue is the diversity of visualization and statistical tools that have been applied in previous regional zooplankton analyses. Our intent is to use this diversity rather than try to eliminate it. We will apply a range of analytical tools and evaluate the degree to which they are effective, redundant, or complementary. As with data archival and formatting, many of the necessary tools are becoming much more available and user friendly. Other important practices and concepts, such as how to deal with temporal and spatial autocorrelation, and with data gaps, are not yet familiar to many zooplankton ecologists. Demonstration, evaluation, and perhaps packaging of these tools will be another important WG product.

3. Proposed terms of reference

- Identify and consolidate a globally representative set of "long zooplankton time series" (selected from the data sets listed in Table 1, plus perhaps from additional regions for which time series can be composited from a sequence of shorter programs). Where appropriate, facilitate migration of individual data sets to a permanent and secure electronic archive.
- Develop and share protocols for within-region and within-time-period data summarization (e.g. spatial, seasonal and annual averaging, summation within taxonomic and age categories). The goal is to learn what level of detail provides the optimal tradeoff or information gain vs. processing effort
- Based on the above, develop priorities and recommendations for future monitoring efforts and for more detailed re-analysis of existing sample archives.
- Once regional data sets are compiled and collated, carry out a global comparison of zooplankton time series using (in parallel) a diverse suite of numerical methods. We will examine:
    - Synchronies in timing of major fluctuations, of whatever form.
    - Correlation structure (scale and spatial pattern) for particular modes of zooplankton variability (e.g. changes in total biomass, replacement of crustacean by gelatinous taxa, alongshore or cross-shore displacements of zoogeographic distribution boundaries).
    - Likely causal mechanisms and consequences, based on spatial and temporal coherence with environmental and fishery time series.
    - Sensitivity and specificity of data-analysis tools.

4. Time frame and expected products

If this proposal is successful, we could begin work in early 2005 and would continue for three years. We would convene annual WG meetings (each of about one-week duration), and a larger open-attendance symposium in the final year. An ideal venue for the final session would be the next International Zooplankton Symposium, scheduled for 2007 in Japan. This would also include a collective scientific publication (either a special issue of an international journal, or a book). For each year, expected activities and products include:

- *Year 1*: Summarize and evaluate methods, results, and questions arising from the zooplankton time series analyses that have been completed to date. For the proposed new comparative analyses, select and prioritize the set of regional time series, and the suite of variables from each time series that will be compared (e.g. total zooplankton biomass, major-group and/or species -level zooplankton taxonomic composition, phenology, and physical and biological environmental indices). Identify obstacles to pooled analyses (e.g. incomplete processing, differences in formatting, differences in resolution). Develop recommendations for data-exchange, and feasible enhancements of sample processing.
- *Year 2*: Begin comparative analyses. Evaluate sensitivity and specificity of data analysis (statistical) tools, and improve their availability and "user-friendliness". Identify time scales and date intervals of particular interest. Post selected tools and data on a web or ftp site (initially closed, eventually public?).
- *Year 3*: Complete comparative analyses of zooplankton and environmental time series, incorporating any new data that have become available during years 1-3. Identify synchronies (if any) in timing of fluctuations, and quantify correlation time and space scales. Prepare interpretive paper(s) for symposium presentation and publication. Prepare recommendations for "best practice" sampling and analysis methodologies

5. Proposed Working Group membership

Our primary goal is broad experience on zooplankton time series, combined with local knowledge of the contents and quality issues for each regional data set. However, we suggest that one member of the core working group should be a statistical specialist and another should strong data management expertise. Our suggested list (#11-15 could be Associate Members funded by other agencies):

1. David Mackas [cochair](Canada, northern California Current & subarctic NE Pacific)
2. Hans Verheye [cochair] (S. Africa, Benguela)
3. Andy Solow (primarily as statistics expert on spatially and temporally autocorrelated time series, but also familiar with NW Atlantic data sets)
4. Sanae Chiba (Japan, Kuroshio/Oyashio and oceanic NW Pacific) or other rep from Project ODATE
5. Mark Ohman (USA, CalCOFI region) or other CalCOFI rep
6. Gregory Beaugrand (CPR, NE Atlantic) or other SAHFOS associate
7. Young-Shil Kang (Korea, NE Asian marginal seas)
8. Sergei Piontkowski (USA but familiar with USSR and tropical oceanic data sets)
9. Patricia Ayon (Peru, IMARPE data set plus general Humboldt Current region)

10. Technical advisor on data management and formatting issues (e.g. someone from the US National Oceanographic Data Center)
11. (SPACC liaison e.g. David Checkley, USA or Claude Roy, France. Both would also provide expertise on oceanography of key Eastern Boundary Current ecosystems)
12. (additional N Atlantic, not CPR data)
13. (Bering Sea)
14. (Southern Ocean)
15. (Indian Ocean/Arabian Sea)

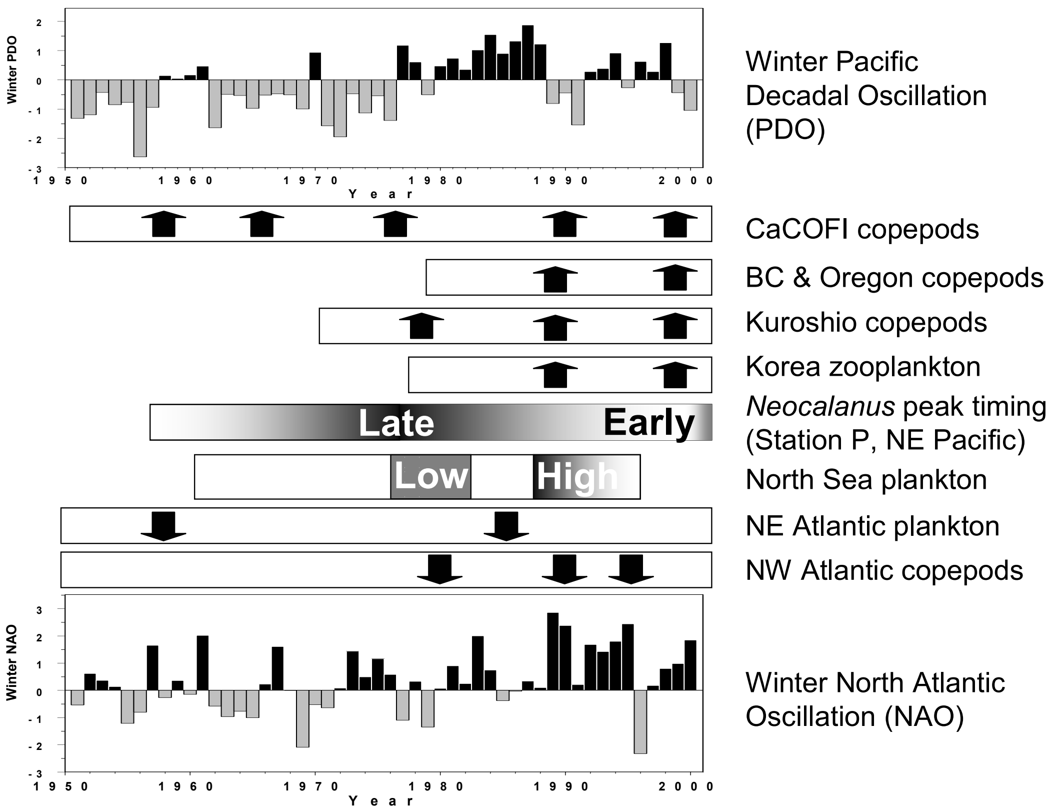

Fig 1. (from Perry et al., in press) Schematic showing timing of identified shifts in North Pacific and North Atlantic zooplankton abundance, community composition and/or life cycle timing, matched with time series for Pacific (PDO) and Atlantic (NAO) climate indices. Arrows indicate timing of zooplankton change, not direction. Source data are from: CalCOFI (Rebstock, 2002; McGowan 2003; Lavaniegos and Ohman 2003); British Columbia and Oregon (Mackas et al., in press); winter season Kuroshio region (Nakata and Hidaka 2003); Korean coastal waters (Kang et al., 2002; Rebstock and Kang 2003); Neocalanus life cycle timing (Mackas et al. 1998); North Sea (Edwards et al., 2002; Beugrand et al. 2003); NE Atlantic (Beaugrand and Reid 2003); NW Atlantic (Jossi et al. 2003)

Table 1. Representative long time series (with ≥10 years of consecutive sampling) zooplankton observation programs (summarized from Perry et al., in press)

Program	**Start & end years**	**Location**
North Pacific		
CalCOFI	1949 – continuing (quarterly)	California
Station PAPA	1956 – continuing (3 times per year)	North Pacific, 50°N, 145°W
Newport, OR, USA	Intermittent since 1969, continuous since 1996 (5 times per year)	Offshore transect at 44º39.1'N (Oregon)
Vancouver Island Shelf	1985 – continuing (3-5 times per year)	Southwest shelf of Vancouver Island
Odate plankton time series	1951 – continuing (monthly)	Western North Pacific (Kuroshio, Oyashio and transition region east of Japan)
Hokkaido University, Oshoro-Maru time-series	1953 – 2001 (annual)	western and central subarctic North Pacific, and Bering Sea (mostly along 180°E)
Japan meteorological Agency (JMA)	1967, 1972 – continuing (seasonal)	Several transects in western North Pacific (all around Japanese waters)
National Research Institute of Fisheries Science (Japan), fish egg and larvae survey.	1971 – continuing (annual)	western subtropical North Pacific (including Kuroshio region)
Hokkaido National Institute of Fisheries, A line monitoring	1987 – continuing (5-8 times per year)	western subarctic North Pacific (Oyashio region)
National Fisheries Research and Development Institute (Korea), oceanographic survey	1965 – continuing (6 times per year)	Korean waters
North Atlantic		
Continuous Plankton Recorder (CPR)	1931 – continuing (monthly)	North Atlantic
Helgoland Roads	1974 – continuing (daily to weekly)	Southern North Sea (54.19ºN 7.9ºE)
Dove Marine Laboratory	1968 – continuing	Central-west North Sea
Stazione Zoologica Anton Dohrn; Station MC	1984 – continuing (weekly to bi-weekly sampling)	Gulf of Naples (40°48.5'N, 14°15'E)
Station 'C', western Mediterranean	1985 – 1995 (weekly)	Gulf of Tigullio, Ligurian Sea, western Mediterranean
Plymouth Marine Lab, Station L4	1988 – continuing (weekly)	Western English Channel
Central Baltic (various agencies)	1976-continuing (seasonal)	Central Baltic deep basins
Icelandic Monitoring Programme	1961 – continuing (annual)	transects radiating from Iceland
Emerald Basin	1984 – continuing (twice per year)	Scotian Shelf, NW Atlantic
MARMAP and follow up program	1977 - continuing (quarterly)	NE United States continental shelf
Station "2"	1972-1997; 2002 – continuing (weekly)	Lower Narragansett Bay, RI, USA

Table 1 continued

South Atlantic		
Cape Routine Area monitoring programme, expanded in 1961 to Southern Routine Area monitoring programme	1951 – 1961 (monthly) 1961 – 1967 (monthly)	Western Cape coast of South Africa (32-34°S; 16°30’-18°15’ E) Southwestern Cape coast of South Africa (32-38° S; 15°30’-22° E)
Pelagic Fish Stock Assessment surveys	1983 – continuing (3 times per year)	Most of South Africa’s west and south coasts (28°30’ S - 27° E)
Walvis Bay Routine Area monitoring programme SWAPELS Programme	1957 – 1965 (monthly) 1972 – 1989 (monthly)	Namibian coast, vicinity of Walvis Bay (21-24° S; 12°30’-14°30’ E) Namibian coast (17°30’-27° S; 10°30’-15° E)
South Pacific		
IMARPE zooplankton sampling	1964 – continuing (seasonal)	Peru coast and continental shelf
IFOP zooplankton and icthyoplankton surveys	Dates to be confirmed	Northern Chilean coast
Southern Ocean		
Elephant Island	1977 – continuing	Elephant Island region of the Antarctic Peninsula

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