Census of Marine Zooplankton (CMarZ)

SCIENCE PLAN

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Prepared by the participants of a Census of Marine Life planning workshop for a CENSUS of the PLANKTON

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Executive Summary

The *Census of Marine Zooplankton* (CMarZ) will work toward a taxonomically comprehensive assessment of biodiversity of animal plankton throughout the world ocean. The project goal is to produce accurate and complete information on zooplankton species diversity, biomass, biogeographical distribution, genetic diversity, and community structure by 2010. Our taxonomic focus is the animals that drift with ocean currents throughout their lives (i.e., the holozooplankton). This assemblage currently includes ~6,800 described species in fifteen phyla; our expectation is that at least that many new species will be discovered as a result of our efforts. The census will encompass unique marine environments and those likely to be inhabited by endemic and undescribed zooplankton species. These include the mesopelagic and abyssopelagic realms, open ocean, benthic boundary layer, and waters around hydrothermal vents, seep and deep-sea coral beds.

Implementation of CMarZ will begin by coordinating with ongoing, planned, and proposed programs, surveys, and initiatives. Such coordination will provide opportunities for sampling zooplankton taxa in many ocean regions during the first years of the project. CMarZ will also make use of existing data and archived zooplankton collections. New field work will involve dedicated cruises, ships of opportunity, and partnerships with national oceanographic and fisheries institutions. Sampling design will be optimized using theoretical and numerical models, in collaboration with the CoML FMAP (Future of Marine Animal Populations) project. Sampling systems will include traditional nets and trawls, remote detection, optical sensors, and integrated sensor systems deployed on towed, remotely-operated, or autonomous vehicles and submersibles. We will require new sampling methodologies to collect and study rare and fragile organisms, which are less well known. New molecular protocols, developed in medical research laboratories in recent decades, will allow analysis of genetic diversity and structure of zooplankton populations and species, identification of cryptic species, and reconstruction of their evolutionary histories. Close coordination between molecular and morphological systematic studies will be essential.

A global census will require international collaboration and coordination, through a distributed network of program centers, field project participants, students and laboratory technical staff, and taxonomic specialists. CMarZ will establish regional centers for scientific leadership, planning and implementation of field activities, and raising funding. Three project offices will be established: in N. America (USA), Europe (Germany), and Asia (Japan). Support for the CMarZ Secretariat and Steering Group will be provided by the USA office. The Steering Group will reflect the project's geographic, taxonomic, and disciplinary diversity; guide scientific and technical development; and ensure close coordination with other CoML field projects.

CMarZ will result in more complete knowledge of biodiversity hotspots and unexplored ocean regions, new understanding of the functional role of biodiversity in ocean ecosystems, and better characterization of global-scale patterns of zooplankton biodiversity in the world ocean. CMarZ will increase our understanding of the pattern, flow, and development (over generational, ecological, and evolutionary time scales) of life in the sea. The knowledge gained will contribute

to our fundamental understanding of biogeochemical transports, fluxes and sinks; productivity of living marine resources; and structure and function of marine ecosystems.

Important outcomes for CMarZ are: new sampling, data gathering, and data visualization technologies. Formal education objectives include training graduate students and professionals, who will enhance capacity for taxonomic identification of species of zooplankton groups. Building new capacity and expertise for taxonomic analysis of zooplankton groups is needed for species-level identification of all zooplankton groups. Informal education outcomes include greater public appreciation for the value of marine biodiversity. Dissemination of information will entail web pages, presentations, and printed materials for students, researchers, and general audiences, as well as peer-reviewed scientific publications. CMarZ will contribute to the CoML Education and Outreach Network, and will identify partners to assist with public education and communications activities. A distributed database for the project will be created, with species-level, specimen-based, geo-referenced entries. The CMarZ database will be fully integrated with and searchable from the Ocean Biogeographical Information System (OBIS) portal.

Using existing technology, as well as accelerating the development of new tools, a global-scale, taxonomically comprehensive census of zooplankton is both feasible and achievable by the CoML target date of 2010.

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Copies of the report are available in downloadable PDF format from the Census of Marine Life program website, http://www.coml.org

I. Introduction

The world ocean fauna is dominated in terms of abundance and biomass by the drifting organisms collectively referred to as plankton. Plankton are exceptional in that they occur in all marine waters, throughout all depths, and – for many species – across widespread biogeographical distributions. Zooplankton (planktonic animals) are critical intermediaries in the flow of energy and matter through marine ecosystems. Zooplankton support many major fisheries and mediate fluxes of nutrients and chemical elements essential to life on earth.

Despite more than a century of sampling the oceans, comprehensive understanding of zooplankton biodiversity has eluded oceanographers because of the fragility, rarity, small size, and/or systematic complexity of many taxa. For many zooplankton groups, there are long-standing and unresolved questions of species identification, systematic relationships, genetic diversity and structure, and biogeography. Molecular systematic analysis has revealed cryptic species within oceanic and coastal species, and has called into question previous interpretations of biogeographical patterns and evolutionary relationships. The global geographic scale of the investigations required to address these issues, as well as the three-dimensional complexity of the world ocean, make complete knowledge of marine zooplankton diversity challenging. The pelagic realm covers 70% of the Earth's surface area and extends more than 10 km below the ocean's surface; complex and variable circulation patterns drive exchange among the ocean basins and continental shelf seas.

Zooplankton are phylogenetically diverse and evolutionarily old, and are sensitive to climate and anthropogenic changes in the sea. Zooplankton species diversity is lower than that of marine benthic and terrestrial environments, because the pelagic realm is thought to have less physical habitat heterogeneity and because of the continual exchange of water and organisms, slowing the evolution of new species. However, recent molecular studies have challenged previous assessments of biodiversity. Zooplankton represent a rich – and accessible – target for species discovery.

There is strong interest and readiness in the zooplankton research community for a global-scale, internationally-coordinated census of the marine metazoan and protozoan zooplankton. There is also a deepening shortage of technical specialists and taxonomic experts in all countries of the world. It is now possible to survey and collect across the full range of marine environments, using traditional net and bottle collection methods, as well as new approaches such as molecular genetic analysis, optical and acoustical imaging, and remote and autonomous detection. The census of marine zooplankton will require a global partnership among ecologists, oceanographers, and taxonomists, and between scientists and technical experts, that can bring to bear the resources of national institutes, contributions from private and commercial organizations, and the interests of teachers and students.

The Census of Marine Life (CoML) program has established an impressive portfolio of projects, which, considered together, focus on many oceanic taxa and regions (Decker and O'Dor, 2003). Several CoML field projects address zooplankton to some extent, and CoML projects in the Mid-Atlantic Ridge, Gulf of Maine, and Arctic Ocean will treat zooplankton as important members of the regional ecosystem. However, no project currently funded by or associated with CoML explicitly addresses global analysis of all major marine zooplankton taxa.

This document summarizes what is known, unknown, and unknowable about zooplankton biodiversity, and explains the need for a new initiative to generate new knowledge and understanding. We outline here a conceptual and logistical plan for a taxonomically comprehensive, global-scale *Census of Marine Zooplankton* (CMarZ). This new project will focus on ~6,800 described species of animals that are planktonic throughout their life (i.e., holozooplankton). These groups share a morphological species concept as a practical approach for delineating species, and taxonomically-useful characters can usually be observed directly. Importantly, it will be possible to carry out faunal inventories for many of these groups and understand processes relating to their biodiversity consistent with the CoML target completion date of 2010.

I.A. Overarching question

The Census of Marine Zooplankton (CMarZ) will address the overarching question: "What are the patterns of zooplankton biodiversity throughout the world ocean, and how are they generated and maintained?"

I.B. Hypotheses

The hypotheses that will guide the design, development, and implementation of CMarZ include:

H1. Zooplankton biodiversity differs among biogeographical regimes and provinces, and is related to ecosystem stability and productivity.
H2. Population genetic continuity among geographic regions is more extensive for deep-sea species than for surface dwelling ones.
H3. Environmental heterogeneity increases the frequency of endemic and cryptic species.
H4. High zooplankton biodiversity results in foodwebs with more complex biotic relationships.
H5. Natural and anthropogenic changes are decreasing endemism and significantly altering biogeographical distributions of marine zooplankton.
H6. Many zooplankton species occur at low abundances over broad geographical distributions, crossing geological and oceanographic dispersal barriers.

I.C. The known, the unknown, and the unknowable

The known: Humans have mapped the oceans, charted the currents and faunal boundaries, and defined biogeographical provinces (e.g., rich fishing grounds) since the earliest sea voyages. The voyage of the HMS Challenger during 1873 – 1876 was one of the earliest attempts to record global patterns of biological, chemical, and physical properties in the oceans. Our current understanding of global patterns of pelagic biodiversity results from decades of work by oceanographers, ecologists, and taxonomists (see McGowan 1974, Longhurst 1998; Fig. 1).

The biogeographical patterns are markedly similar among taxonomic groups of zooplankton, indicating that environmental factors play a major role in structuring biodiversity patterns at large scales. However, all taxa and all regions of the world are not equally well known. In particular, there is a bias toward coastal waters and the Exclusive Economic Zones (EEZ) of developed nations. Our knowledge is most complete for those species inhabiting the upper 100-200 m of the oceans, where most sampling is conducted, and for crustaceans and other groups that generally remain intact through collection by plankton nets and preservation in formaldehyde.

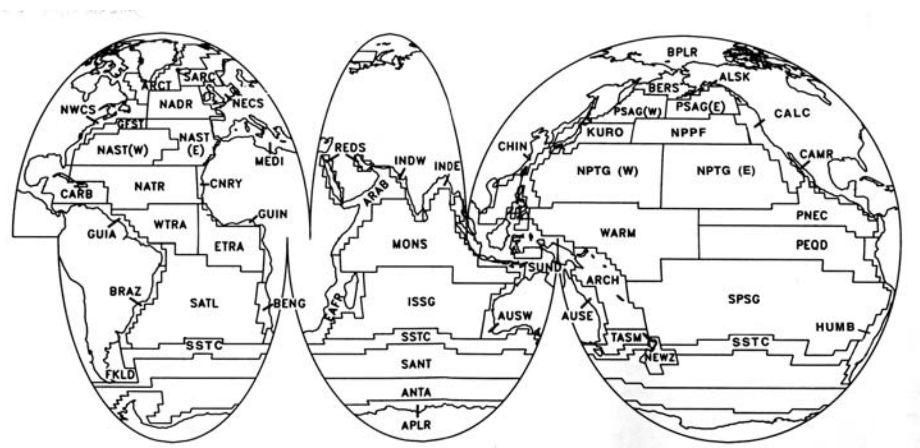

Figure 1. Global biogeographical provinces for oceanic epipelagic zooplankton, based on example euphausiid species. From Longhurst (1998)

We have begun to assemble accurate estimates of the numbers of described species – based primarily on morphological taxonomic analysis – for the major groups represented in the zooplankton using data and information from many sources (see Table 1). Our knowledge base results from many decades of work by taxonomists, who have become expert in the morphological identification of species within one or more taxa. These experts know the numbers of described species and can speculate knowledgably about how many species may truly exist within each taxon. We are thus able to estimate the completeness of our information.

The unknown: There has never been a taxonomically-comprehensive, global-scale summary of the current status of our knowledge of biodiversity of marine zooplankton. Although studies of the taxonomy, distribution, and abundance of zooplankton date back as far as the middle of the 19th century, worldwide distribution patterns have been mapped for fewer than 10% of the species described. The growing number of snapshots from different parts of the world ocean have rarely been merged together, in part because the complicated and time-consuming task of compiling the information from numerous individual publications is undervalued (but see Irigoien et al. 2004).

For most zooplankton groups, significant numbers of species remain to be discovered. This is especially true for fragile (e.g., gelatinous) forms that have never been properly sampled, and for forms living in unique and isolated habitats, such as the water surrounding hydrothermal vents and seeps. All regions of the deep sea are certain to yield many new species in multiple taxonomic groups. The practical difficulties of exploring these regions are gradually being overcome, and they are likely to continue to yield new species discoveries for many years.

Our perception of zooplankton biodiversity has almost certainly been affected by their small size, resulting in a marked under-description of species and morphological types. Until recently, some pelagic taxa (e.g., foraminifers, copepods, euphausiids, and chaetognaths) have been thought to be well known taxonomically, but the advent of molecular genetics has altered this perspective. Morphologically cryptic, but genetically distinctive, species of zooplankton are being found with increasing frequency (e.g., Bucklin et al. 1996, 2003, de Vargas et al. 1999, Dawson and Jacobs 2001, Goetze 2003) and will probably prove to be the norm across a broad range of taxa. Many putative cosmopolitan species may comprise morphologically similar, genetically distinct sibling species, with discrete biogeographical distributions. This issue is especially relevant for widely distributed species and/or for species with disjoint distributional ranges, including those occupying coastal environments (Conway 2003). It is likely that many morphologically-defined zooplankton species will be found to consist of complexes of genetically distinct populations, but how many cryptic species are present is currently unknown, even for well-known zooplankton groups.

Table 1. Major groups of marine zooplankton, with numbers of described species, DNA sequences, and estimated numbers of species to be found. All numbers are approximate.

	Taxa (Class or Order)	**Number described species**	**Number species with DNA sequence data**	**Number new but undescribed species**	**Number new species to be found**
Foraminifera	Foraminifera	49	35 (18S)	~30	100-300
Actinopoda	Acantharea	150	4 (18s)		
	Polycystinea(rads)	350	11 (18S)		
Cercozoa	Phaeodarea (rads)	350	3 (18S)		
Ciliophora	Aloricate Ciliata	150			Many
	Tintinnida	300	6 (ITS)		
Cnidaria	Hydromedusae	842	90 (18S)	many	many
	Siphonophora	160	80 (18S, 16S, COI)	~50	~100
	Cubomedusae	18			
	Scyphomedusae	161	15		
Ctenophora	Ctenophora	90	50	25	50-150
Rotifera	Rotifera	50?			
Platyhelminthes	Platyhelminthes	3?	0	?	
Nematomorpha	Nectonema	5	1	?	?
Nemertea	Nemertinea	99	6 (COI, 28S, H3)	~20	35+
Annelida	Polychaeta	110	?	3	25+
Mollusca	Heteropoda	29	8+		
	Pteropoda	109	12+ (28S, COI)		
	Nudibranchia	6		1	
	Cephalopoda	370	~3		
Arthropoda	Cladocera	8			~5
	Ostracoda	169			200-400
	Isopoda	20			
	Copepoda	2000	300 (COI), 18 (18S)	~67	1000-2000
	Mysidacea	700	1 (28S)		
	Amphipoda	400	1 (28S)		
	Euphausiacea	86	60 (COI)		10-20
	Decapoda	50			
Chaetognatha	Chaetognatha	93	17 (various)	5	25-100
Chordata	Appendicularia	64	5	5	30+
	Pyrosoma	8	1 (18S)		10
	Doliolida	17	1 (18s)	2	10
	Salpidae	45	8 (18S)	1	5-10
	TOTAL	**7,061**	**718**	**209**	**> 1605**

Compared to the dimensions of the known – in terms of numbers of species and regions of the world ocean – the unknown is thought to be many times larger than the known. Introducing his monograph on the biogeography of the Pacific Ocean, McGowan (1971) posed several questions that help frame the unknown territory of zooplankton biodiversity, "What species are present? What are the main patterns of species distribution and abundance? What maintains the shape of these patterns? How and why did the patterns develop?" More than 30 years later, the answers to these questions remain poorly known for many ocean regions and most zooplankton groups.

The unknowable: The huge spatial dimensions of the global ocean make completeness of knowledge an enduring challenge. Efforts using traditional techniques to describe species and map their distributions in space and time – or even modern versions of these nets and other collection devices – can never hope to yield complete knowledge of plankton biodiversity. For a comprehensive view of plankton diversity at a global scale, remote and autonomous methodologies for species capture, identification, and enumeration will be required. Such technological advances are an essential focus of CoML (see Jaffe and Nierenberg 1997, Alldredge 1998, Parrish 1998).

The global ocean may remain unknowable because of its shear size and because of the interplay of time/space scales of variability in this complex environment. Even with anticipated technological advances, it may never be possible to obtain a synoptic top-to-bottom and pole-to-pole view of the world ocean within the time frames of environmental variability, which can be as short as minutes. The accuracy of our global view of zooplankton species diversity will suffer from simple human errors and the inevitable inconsistencies between observations and analyses made by different scientists.

II. Implementation of a global census of the zooplankton

II.A. Use of existing data

The implementation of CMarZ will begin with a comprehensive assessment of our current knowledge of global biodiversity of zooplankton. The compilation of existing data will form the basis for integrating assessments, identifying gaps in our knowledge, and priorities for future advances. The relevant information for each of the identified groups includes: 1) numbers and names of species, 2) biogeographical distributions, 3) biomass and/or abundance (relative and absolute) of species, and 4) estimation of the completeness of our knowledge.

The baseline report will draw upon on all available resources, including people (the taxonomists themselves), published findings, reports, and on-line databases. Among the resources are published monographs and internet databases focused on both regions of the world ocean and taxonomic groups of zooplankton (Appendix 1). Notably, many publications are restricted in scope and extension, hindering the integration of the basic descriptive data needed to develop an accurate global view of patterns of biodiversity. Also, the raw data (i.e., species names with abundances) can only be used when one has confidence in the author's taxonomic skills. The baseline assessment will be structured as follows:

- Identification of the sources of information and selection of data for incorporation;
- Data entry from hardcopy sources and data acquisition from electronic sources;
- Critical evaluation of the records to be incorporated, including identification of dubious records and establishment of synonyms;
- Critical evaluation of the data and cleaning of the database, including identifying taxonomic inconsistencies, assessing synonyms and merging records, or eliminating dubious species or records, as necessary;
- Analysis of patterns using numerical and GIS techniques; integration into the Ocean Biogeographical Information System (OBIS).

CMarZ will generate a detailed database with the distributions of zooplankton species worldwide. The information will be analyzed with the aid of objective numerical and GIS techniques, in order to derive global distributional patterns of species abundance and biomass values. The goals of this task are to build a critically revised listing of valid zooplankton species for the world ocean; standardize the nomenclature and morphological species concept of the forms included in the database; construct a solid taxonomic framework for further morphological and genetic assessment of species boundaries; generate objective models of regional- to global-scale distributions of species, their relative abundances, and their relationships to environmental variables; and compare the species distributional patterns derived and infer causes for the similarities and differences.

II.B. Use of existing zooplankton collections

Archived collections are an invaluable resource for CMarZ. Zooplankton samples are available from some of the great expeditionary cruises of the 20th century, covering extensive geographic regions of the world ocean (Appendix 2). These collections represent excellent sources of specimens for reconstructing patterns of oceanic biodiversity and, in some cases, assessing changes in zooplankton assemblages through time. For some groups, not including fragile and gelatinous taxa, archives contain a record of ocean zooplankton assemblages at known points in time and space (Figs. 2, 3, and 4).

Major existing collections of zooplankton contain exceptional specimens of planktonic organisms for training students, as well as training advanced researchers in specialized taxonomic skills. Collections thus house both physical specimens and scientific expertise in systematics (and increasingly in population genetics), creating opportunities for dissemination of the skills needed for CMarZ. Some collections are also associated with academic centers of molecular systematics and have other analytical capabilities. Institutional archives typically include holotype and other type material that are the foundation of systematics research.

Extensive spatial coverage is required for marine zooplankton biodiversity studies, because of the widespread geographic distributions of many species, the need for comprehensive examination within and between taxonomic groups, and the difficulty of discriminating between temporal and spatial heterogeneity in evaluating changes in more limited datasets. Existing collections, samples, and specimens provide a cost-effective means to obtain wide distributional coverage for some groups of zooplankton.

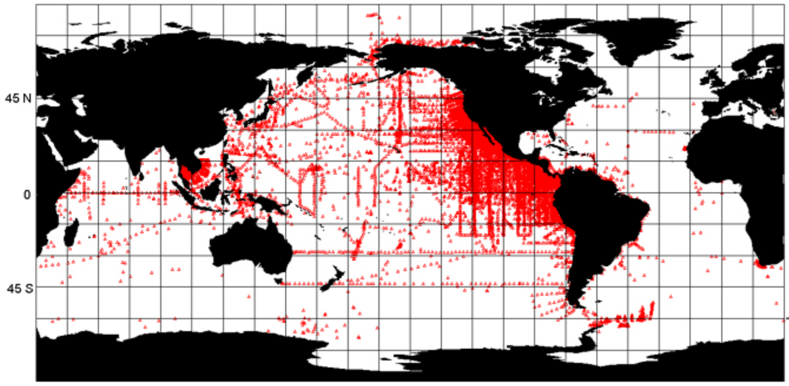

Figure 2. Zooplankton samples archived at the Pelagic Invertebrates Collection of Scripps Institution of Oceanography (USA). The figure shows the collection locations for ~ 118,000 samples.

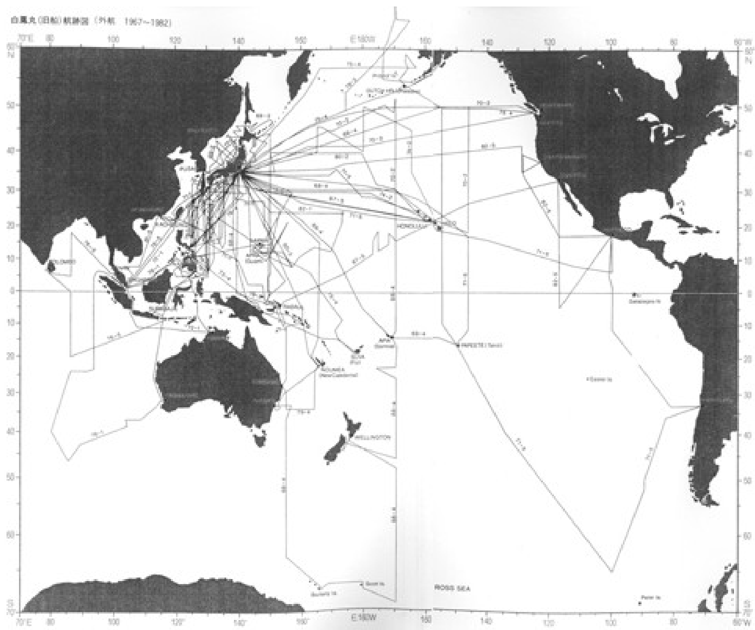

Figure 3. Cruise tracks of the R/V *Hakuho Maru*, 1967-1982, with collection locations for samples archived at the Ocean Research Institute, University of Tokyo, Japan. The collection holds ~ 15,000 samples. (Courtesy S. Nishida, Univ. Tokyo)

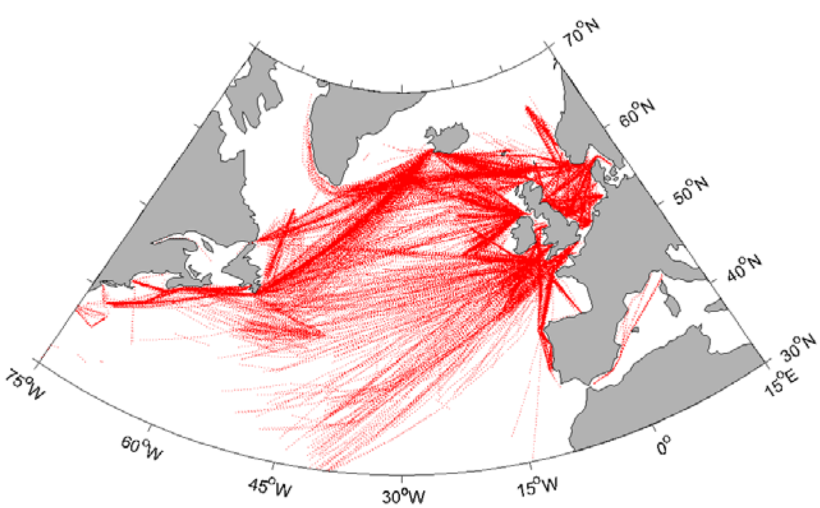

Figure 4. Routes of the Continuous Plankton Recorder (CPR) Survey in the N. Atlantic Ocean (1946-2002). A total of 190,473 samples have been collected and counted, with ~300,000 samples archived.

Collection archives represent an essential resource for reconstructing temporal changes in zooplankton biodiversity. Some plankton collections contain samples extending to the early 1900s, or even earlier, creating opportunities for direct historical reconstructions. On a worldwide basis, there is intense current interest in climate change, concerns about its effects on ocean ecosystems, and a search for means to distinguish natural from anthropogenic sources of variation. Recent results from retrospective analyses of existing plankton collections have begun to reveal low-frequency changes in ocean ecosystems that were not previously suspected. Examples include: use of the California Cooperative Fisheries Investigations (CalCOFI) survey collections to identify regime shifts in zooplankton assemblages related to the Pacific Decadal Oscillation (Brinton and Townsend 2003, Lavaniegos and Ohman 2003, Ohman and Venrick 2003); recognition of long-term shifts in latitudinal distributions of planktonic copepods from the Continuous Plankton Recorder (CPR) collections in the N. Atlantic (Beaugrand et al. 2002); and – also from CPR data – inferences of variation in cod recruitment in relation to long-term change in N. Atlantic zooplankton composition (Beaugrand et al. 2003). These times-series collections and the new Odate project in Japan, extending from 1951 to the present, represent excellent prospects for continuous reconstruction of climate change impacts on plankton communities extending more than 50 years.

Archived collections may also reveal the temporal progression of accumulation of pollutants in marine food webs, such as the accumulation of DDT in marine organisms and the effectiveness of subsequent remediation efforts (e.g., MacGregor 1974). Collections allow analysis of temporal changes in the genetic composition of planktonic populations. Zooplankton microfossils from sedimentary core collections will be critical in resolving temporal changes in ocean biodiversity over geological time scales (Lipps 1970); fossil remains of some taxa (e.g., foraminifers, radiolarians, some ostracods, and pteropods) will allow accurate paleo-oceanographic and stratigraphic reconstructions (e.g., Lange et al. 1987).

Permanent archives of zooplankton collections may ultimately prove informative for research other than their original purpose. Future technological developments are certain to permit unforeseen analyses. For example, stable isotopes of nitrogen can be reliably extracted from preserved zooplankton samples (e.g., Rau et al. 2003). Preliminary experiments with trace metal analyses of mineralized hard parts of some zooplankton suggest that source waters of populations may be characterized (C. Dibacco and D. Mackas, pers. comm.). DNA can be amplified and sequenced from formaldehyde-preserved zooplankton (provided samples are correctly buffered and preserved, France and Kocher 1996, Bucklin and Allen 2004). New developments in automated and computer-aided zooplankton sample analysis make reanalysis and/or more extensive analysis a real possibility.

Voucher specimens from individual research projects must be maintained in permanent repositories for validation by future researchers. Subsequent taxonomic investigation may lead to changes in nomenclature. DNA vouchers may be an invaluable resource for future molecular genetic and genomic analyses. Reliable species identifications are fundamental to research, and voucher specimens maintained in collections provide permanent references for the standards applied.

Despite their recognized value for the scientific community, collections are facing severe financial difficulties in some countries of the world, including the USA. In a comment in the journal *Science* (14 Jan. 2004), S.E. Miller et al. remarked that: "*It is ironic that, just as the U.S. National Science Foundation increases funding for biodiversity research, many states are threatening to discontinue support for their [biodiversity] collections.*" In order to sustain the contributions of such collections to the world scientific community, including CMarZ, financial support for these collections will be essential.

Individual investigators around the world have important collections of zooplankton samples, obtained in the course of myriad research projects. Although it is not feasible to tabulate all of these valuable samples, CMarZ will seek to develop a reference list of these individual collections, using a questionnaire (see Appendix 3). CMarZ will ask all investigators to deposit samples, metadata, and ancillary oceanographic data in a recognized, archival institutional collection, so their utility for present and future generations of scientists can be assured.

II.C. Approaches to global biodiversity assessment

Large-scale studies of zooplankton are needed to evaluate patterns of biodiversity at scales appropriate to dispersal ability in ocean currents. Shifts in geographic ranges may underlie apparent temporal changes observed during spatially-limited studies. In the case of species introductions, clear definition of potential source populations and likely colonization pathways require an understanding of global-scale distributions. For some cosmopolitan species, there may be little genuine endemism, while others may consist of complexes of genetically distinct entities, representing geographically isolated conspecific populations or cryptic species (Pierrot-Bults and Van der Spoel 2003). Cryptic species have been found with cosmopolitan foraminifers (de Vargas et al. 2002), scyphozoans (Dawson and Jacobs 2001), and copepods (Bucklin et al. 1996, 2003, Goetze 2003).

Taxonomically-comprehensive approaches are needed in order to correctly reconstruct phylogenetic relationships across a broad range of levels of organization, from species to phyla. Then, comparative studies of different taxa can be used to infer ecological and evolutionary mechanisms and allow examination of the roles of morphology, behavior, and life history in determining patterns of distribution and diversity.

The urgency and/or vulnerability of regions or taxa to anthropogenic or natural threats will be weighed in determining CMarZ priorities. These include regions where rates and impacts of climate change are most likely to be amplified, and poorly-studied areas threatened by anthropogenic inputs (such as near population centers in emerging nations). The availability of baseline data is a critical issue, since evaluation of biodiversity patterns and hotspots requires improved knowledge of existing data and trends. Sites where time-series collections or long-term monitoring studies have been carried out are of high priority for continued assessment.

An essential feature for a global census of zooplankton biodiversity will be an international partnership, coordinated through a network of regional centers. Each center will be required to identify opportunities for cooperative field work, arrange sampling from ships of opportunity, and lead efforts to secure funding for dedicated cruises in the region. Collaboration among scientists will involve sharing samples, conducting multiple analyses, and using the same platforms. CMarZ will work actively to ensure sharing of material and resources with other CoML field projects, including CeDAMar, ChESS, SeaMounts, and others. All CMarZ observation and collection protocols will be standardized and quality-controlled, in order to ensure comparability of results among different field efforts. Such standards have already been described in organizations such as the International Council for the Exploration of the Sea (ICES, see Harris et al. 2000). Such coordination will provide samples for many zooplankton taxa from many ocean regions, but will not be sufficient for the most problematical or difficult groups, including fragile, cryptic, and systematically complex groups.

II.D. Design of a global census

From a theoretical perspective, there are many approaches to designing a synoptic study of the global ocean. CMarZ will seek assistance from a partner CoML project, the Future of Marine Animal Populations (FMAP), which will provide a source of numerical modeling capacity to explore approaches to synoptic, global-scale sampling that can capture the desired time/space scales of variability.

A global-scale survey of the world ocean will be designed using existing descriptions of pelagic biogeography, of which there are a number (Beklemishev 1969, Van der Spoel and Heyden 1983, Briggs 1995, Longhurst 1998, Sherman 2001). The general approach will entail a nested sampling approach, with carefully-designed field sampling programs in each region. Additional studies will be needed to evaluate the extent of spatial isolation and connectivity among populations, measure heterogeneity within each region (and thus the validity of the regional characterization), and examine and confirm the reliability of the boundaries of each region.

One possible global biogeographical context is that of Longhurst (1998), who described 12 biomes and 51 provinces in the epipelagic realm based on observed biological productivity regimes (see Fig. 1). These biogeographical entities can be used to structure field collection efforts in the epipelagic, and to examine the validity of these provinces with regard to species assemblages. Alternative biogeographical approaches, such as the Pacific provinces recognized by Reid et al. (1978) or the Large Marine Ecosystems (LME) of Sherman (2001), will be considered for comparative purposes. Focused studies in each biome or ecosystem will seek to characterize patterns of zooplankton biodiversity, and allow examination of whether such studies accurately reflect larger-scale patterns. An interesting avenue of research will be to ascertain how well these epipelagic biogeographical provinces describe plankton biodiversity deeper in the water column.

Each focused regional field study will require coordinated, international or multinational efforts. Examples of successful ventures are numerous and other international programs may serve as templates or models for CMarZ. A model for how regionally-led field programs can be integrated to achieve global understanding is the Global Ecosystem Dynamics (GLOBEC) Program, with regional studies underway or completed in many coastal regions of the world ocean. Another is the Cooperative Marine Science Program for the Black Sea (CoMSBlack), which involved zooplankton sampling in the Black Sea by scientists from five countries, with careful quality control and inter-calibration of sample processing.

Dedicated ship-time for CmarZ: Global surveys of exploration and discovery for marine zooplankton will necessarily require dedicated ship-time for cruises in targeted regions of the world oceans. Although both existing data and archived samples are critical components of CMarZ, they have significant limitations in terms of collection and preservation biases, as well as geographic and bathymetric extent. In particular, limited molecular analysis of archived samples will prohibit comprehensive genetic analysis of species and species boundaries. Surveys should be conducted in a quasi-synoptic manner, with top-to-bottom (epi-meso-bathy-abyssopelagic) sampling. Long transects across ocean basins will require multiple sampling techniques to collect from all depths. We envision one or more trans-ocean cruises involving multidisciplinary teams of scientists and students, representing the full range of taxonomic, disciplinary, and methodological spectra needed for CMarZ.

Transit legs of oceanographic research vessels may provide the most cost-effective platforms for such sampling design. It may be possible to secure several days of ship-time, to be added to such trans-ocean transits, in order to allow occasional sampling at pre-arranged locations. CMarZ would provide appropriate collection gear (e.g., Multiple Opening-Closing Net and Environmental Sensing System, MOCNESS, Wiebe et al. 1985) to allow depth-stratified sampling and physical ocean data collection. Ship time will be sought for concentrated field work in biodiversity hotspots, and to allow careful collection of fragile or rare taxa.

The Continuous Plankton Recorder: The pre-eminent example of the power of ship-of-opportunity sampling is the Continuous Plankton Recorder (CPR) survey, the longest-running, basin-scale plankton monitoring survey in the world. The CPR itself is a ~1 m long, robust near-surface plankton sampler that is towed behind commercial ships of opportunity. Such programs are recognized as cost-effective means for sampling regional and global patterns of zooplankton biodiversity, and is one way that CMarZ can meet its aim of performing a truly global survey. The CPR survey is the only biological monitoring program that is currently incorporated into the Global Ocean Observing System (GOOS). The CPR has proven itself to be a versatile and robust zooplankton sampler, which has conducted regular programs in the Atlantic (Fig. 4), Pacific, Indian and Southern Oceans. The CPR is a valuable tool for providing information on large-scale, near-surface zooplankton distribution and relative abundance.

Commercial fishing vessels: Cooperative research by teams of scientists and fishermen is gaining in visibility, funding, and participation in many countries. Fishing vessels may be available because of over-capacity, curtailed effort, or other regulatory impediment. Fishermen are increasingly interested in participating in both oceanographic and fisheries research. Commercial fishing vessels may provide cost-effective means to sample zooplankton, especially in coastal regions in association with particular fisheries.

Partnership with national fisheries institutions: Most nations with commercial fisheries conduct regular surveys of those resources and associated physical and biological variables. We anticipate that arrangements for ancillary collection of plankton samples during these surveys will be possible in a number of countries and regions. CMarZ scientists may be able to obtain zooplankton samples, and in return provide data useful for fisheries management. Because nations typically undertake regular sampling only in their EEZ, opportunities for sampling may be restricted to more coastal environments. Such collaborative partnerships currently exist in:

- *USA:* CMarZ has received positive response to our request to arrange for zooplankton collections during resource and environmental surveys by the National Marine Fisheries Service (NMFS). Sampling will be done on a not-to-interfere basis, requiring flexibility in exact collections locations. NMFS' regular, geographically extensive, and spatially intensive surveys assess fisheries resources and monitor environmental conditions in US waters and the Antarctic. The surveys are organized by the five NMFS science centers, requiring 500+ ship days each year from each center.

- *Norway*: The Institute of Marine Research (IMR) surveys the Nordic and Barents Seas annually, and cooperation with CMarZ will be a great opportunity for IMR to advance research related to the diversity of zooplankton in support of ecosystem-based fisheries management. The exact terms of the cooperation will be discussed with IMR administrators, and will likely be similar to those described for the US NMFS.

- *South Africa:* Coordination of oceanographic and fisheries field efforts has allowed extensive field sampling of the Benguela Current, off the west coast of Namibia and South Africa, and the southern Angola Current since the mid-1900s. Biological oceanography and fisheries research in South Africa became tightly interconnected through the Benguela Ecology Programme (Hutchings and Field 1997). In Namibia, the SWAPELS (South West Africa Pelagic Eggs and Larvae Surveys) program sampled along almost the entire Namibian coast during the 1970s and 1980s (Shannon and Pillar 1986).

- *Argentina:* The Instituto Nacional de Investigación y Desarrolo Pesquero (INIDEP) carries out regular seasonal cruises in the Argentine EEZ and neighboring areas. Also, the Instituto Antártico Argentino (IAA) conducts at least one or two cruises a year between Buenos Aires and Antarctica, sampling the Weddell Sea and Bellingshausen Sea. Limited numbers of berths on these cruises can be arranged, and cooperative sampling with CMarZ should be possible.

- *Other nations*: It is likely that links to a range of countries through the International Council for the Exploration of the Sea (ICES) will provide for such opportunistic sampling on regular cruises throughout many regions of the N. Atlantic basin and continental shelf seas. CMarZ will also seek to establish partnerships with national fisheries organizations in Australia, Brazil, Chile, China, Cuba, India, Japan, Mexico, New Zealand, Peru, Russia, and Thailand.

II.E. Opportunities for species discovery: biodiversity hotspots

Biodiversity hotspots are geographic or taxonomic domains for which there is greatest scope for improved knowledge of species richness. These could be regions or taxa where the ratio of unknown to known species is greatest, where there is insufficient current knowledge to speculate about diversity, where environmental gradients will most strongly affect biological communities, or where threats of habitat loss and extinction are most immediate. Marine ecologists and oceanographers will need to identify and prioritize such regions, similar to terrestrial ecologists, who have identified 18 biodiversity hotspots based primarily on degree of endemism and impacts of human activities (Wilson 1999).

Specific areas of the world ocean are dramatic biodiversity hotspots. One such area is the Indo-Malaysian Archipelago. For instance, 25% of all species of pelagic copepods are found in this region. The reasons may include, stable climatic conditions through the ice-ages, uninterrupted opportunities for radiation, topographical variability allowing opportunities for reproductive isolation and speciation, and convergence of different water masses with distinct faunal compositions (see Santini and Winterbottom 2002).

Sampling within regions and/or for taxa that have historically been ignored or understudied will be a key objective of CMarZ. However, even in areas that are considered to be well sampled, new sampling and analysis (e.g., DNA sequencing) techniques are certain to uncover new species. In regions where zooplankton species are well known, sampling will be targeted toward accurate description of biogeographical distributions and evaluation of population genetic diversity. In areas that are less well known, baseline sampling for species – with parallel molecular studies – will occur across the sampling spectrum. The following areas and taxa will be considered.

- *Southern hemisphere*: Oceans of the southern hemisphere are poorly studied relative to the Northern Hemisphere in both coastal and oceanic regions.

- *Open ocean waters*: Oceanic waters are generally under-sampled relative to coastal regions.

- *Deep sea*: Deeper waters are usually under-explored. Well-known deep-sea areas include Monterey Bay, Sagami Bay, Villefranche-sur-Mer Bay, Porcupine Banks, and Bermuda waters, yet these areas continue to yield a multitude of new species, emphasizing the need for continued intensive study.

- *Unique environments*: Water surrounding hydrothermal vents, seeps, seamounts, canyons, and deep coral reefs may be biodiversity hotspots.

- *Benthic boundary layer*: Benthopelagic faunas are poorly known and need further study; recent investigations in this habitat have revealed many new species.

- *Oxygen minimum layers*: Areas immediately above and below oxygen minimum layers accumulate organisms in the deep-sea, and will be targeted for mesopelagic sampling. As the vertical extent of oxygen minima changes, biodiversity patterns will be impacted.

- *Zooplankton taxa*: Some groups, by virtue of their size, morphology, or preferred habitat are more likely to yield new species discovery. These include soft-bodied organisms, such as ctenophores, medusae, physonect siphonophores, nemerteans, pelagic tunicates, protists. Cosmopolitan species, whether oceanic or coastal, may be found to comprise suites of geographically-distinct cryptic species.

II.F. Trends in marine zooplankton biodiversity

Zooplankton species diversity can be correlated with patterns and processes across a wide range of temporal and spatial scales in the ocean. Global patterns are related to large-scale ocean circulation: zooplankton species richness is highest in large, climatically-stable subtropical open ocean gyres (Angel 1997, Brinton et al. 1999, Rutherford et al. 1999, Fig. 5). Biodiversity also tracks biological phenomena in the ocean, including productivity and biomass (Bé et al. 1971, Boltovskoy 1979).

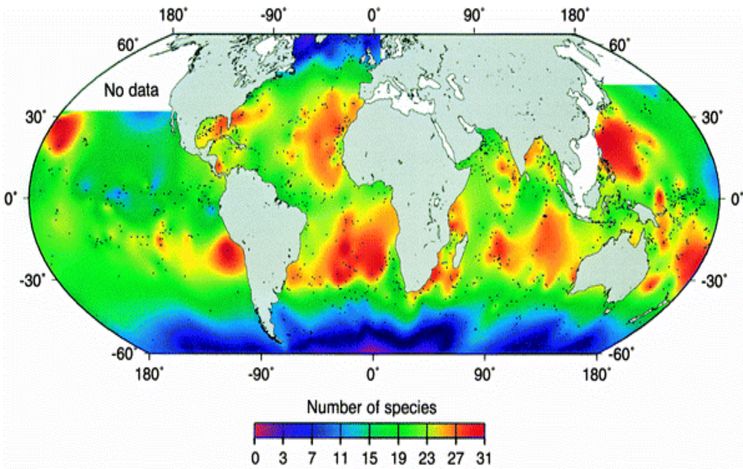

Figure 5. Species richness of planktonic foraminifers, illustrating maximal species richness in subtropical latitudes, with lower levels in equatorial regions. From Rutherford et al. 1999

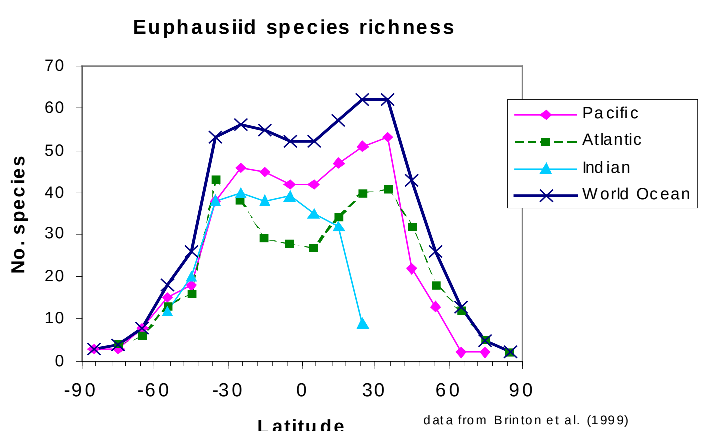

Figure 6. Euphausiid species richness as a function of latitude, illustrating maximal species richness in subtropical latitudes. From Brinton et al. 1999

There are distinctive latitudinal gradients in marine zooplankton species richness (Boltovskoy, 1982, Brinton et al. 1999, Figs. 6 and 7). These trends depart markedly from usual patterns for terrestrial and marine benthic ecosystems. On land, the classical latitudinal pattern is a monotonic increase in species richness from the poles to the tropics, with a maximum richness of trees, birds, mammals, insects and other organisms in tropical rain forests (see e.g., Rosenzweig 1995). An equatorial maximum in species richness is also typical for marine benthic taxa (e.g., Rex et al. 1997). In contrast, zooplankton exhibit a local minimum in species richness along the equator, likely related to enhanced physical disturbance associated with equatorial upwelling and/or elevated primary production rates. Such exceptional patterns of diversity indicate that focused study is needed to elucidate the underlying mechanisms driving zooplankton diversity.

There are marked trends in zooplankton diversity with depth in the water column, which differ among taxa (Longhurst 1985). Foraminifers may show highest diversity in the upper strata, around the thermocline, or near the deep chlorophyll layer (Boltovskoy and Wright 1976, Hemleben et al. 1989); polycystine radiolarians and acantharians are more speciose in the surface layers; and phaeodarian radiolarian species richness is highest around 500 m (Kling and Boltvskoy 1999). Copepods display a mesopelagic maximum in species richness (Vinogradov 1970), as do planktonic ostracods (Angel 1997). Euphausiid species richness declines with depth (Vinogradov 1967, Boltovskoy 1999). Species richness of chaetognaths declines with depth, until increasing in the benthopelagic (Casanova 1999). Diversity of pelagic nemerteans increases with depth to a maximum in the bathypelagic, declining in the benthic boundary layer (Gibson 1999, Roe and Norenburg 1999). Appendicularian diversity appears to peak in the mesopelagic realm (Fenaux et al. 1998). We do not yet have a good understanding of the processes that lead to such differing vertical patterns among taxa. It is noteworthy that productive epipelagic waters rarely have the highest zooplankton species richness, even though steep vertical gradients in biological and physical properties might be expected to foster niche differentiation. The finding of subsurface maxima requires further examination. Also, the observed decrease in species richness at depth may be an artifact of scant sampling effort and limited taxonomic knowledge of deep sea zooplankton (see e.g., Hopcroft 2004).

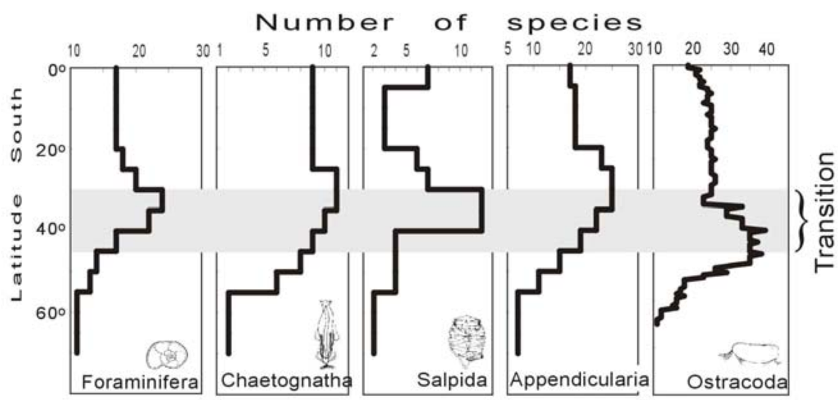

Figure 7. Approximate numbers of zooplankton species of each taxon that can be recorded throughout the year in pelagic waters of the South Atlantic. Ostracod data are from a single cruise (Deevey, 1974). From Boltovskoy 1982

III. Scientific rationale

The need for a taxonomically comprehensive, global scale census of marine zooplankton biodiversity has it origins in some of the most critically important and interesting questions that drive ecology, oceanography, and evolutionary biology today. The intellectual and conceptual basis and need for CMarZ are outlined here:

- *Functional consequences for marine ecosystems:* Changes in zooplankton diversity can have significant consequences for the functioning of marine ecosystems. Shifts in the relative abundances of important species can be propagated throughout the food web. For example, short-term shifts in zooplankton species compostion and biomass have been associated with El Niño or La Nina (see Hopcroft et al. 2002, Mackas and Galbraith 2002, Marinovic et al 2002, Peterson et al 2002) and can impact the distribution of cetaceans (Benson et al. 2002). In the NE Pacific, zooplankton species have shown shifts in abundance which may persist over 20-25 years (Lavaniegos and Ohman 2003, Ohman and Venrick 2003). Such shifts apparently result from cyclical processes in ocean-atmosphere circulation, and are associated with altered fluxes of organic matter into the deep sea (Smith et al. 2001). Altered copepod species composition can dramatically alter the biological pump, or export of carbon from surface waters into the ocean's interior (Svensen and Nejstgaard 2003). In the Antarctic, polar warming and a decrease in sea-ice cover have been associated with changes in the relative importance of Antarctic krill and salps (Loeb et al. 1997), species that play central roles in the Antarctic food web.

- *Marine bioinvasions*: Species invasions are occurring with ever-increasing frequency, particularly in coastal waters (Grosholz 2002). Non-indigenous gelatinous species have negatively affected ecosystems throughout the world. A spectacular example of this phenomenon is the inadvertent introduction of the ctenophore *Mnemiopsis leidyi* into the Black Sea – and now the Caspian Sea – presumably by transport in ballast water. The resultant perturbation of the food web included devastation of Black Sea and Caspian Sea fisheries (Kideys 1994, 2002, Kideys et al. 2004). The subsequent introduction of the ctenophore, *Beroe ovata*, which preys on *Mnemiopsis*, has permitted some components of the ecosystem to recover in the Black Sea. In 1977, *Rhopilema nomadica* invaded and established a population in the Mediterranean Sea, causing both environmental and economical consequences (Lotan et al. 1992). In the Bering Sea, enormous increase in jellyfish biomass, dominated by the scyphozoan *Chrysaora melanaster*, will have likely consequences for groundfish fisheries (Brodeur et al. 2002). In 2000, the Gulf of Mexico was invaded by the Australian spotted jelly *Phyllorhiza punctata*, which negatively affected local fishing by consuming fish eggs and zooplankton and clogging fishing nets (Graham et al. 2003). Gelatinous zooplankton blooms reported in Japanese waters, eastern Mediteranean Sea (Goy 1989, Kideys and Gucu 1995), North Sea (Hay et al. 1990, Lynam et al. 2004), estuaries in Argentina (Hoffmeyer 2004), and elsewhere have had deleterious effects on ecosystems and fisheries.

- *Global elemental cycles:* Marine zooplankton are significant mediators of fluxes of carbon, nitrogen, and other critical elements in ocean biogeochemical cycles (see Berger et al. 1989). It has been recognized for many years that changes in the species composition of zooplankton assemblages have strong impacts on rates of recycling and vertical export (e.g., Frost 1984, Gorsky and Fenaux 1998). Long-term changes in fluxes into the deep sea (Smith et al. 2001) may be related to zooplankton species composition in overlying waters (Roemmich and McGowan 1995, Lavaniegos and Ohman 2003). Recent changes in ctenophores in the Black and Caspian Seas have led to ecosystem effects that have cascaded to the level of primary producers (Yunev et al. 1998). CMarZ can also build upon a new IGBP/SCOR program on this topic, Integrated Marine Biogeochemistry and Ecosystem Research (IMBER).

- *Food web stability:* The majority of pelagic species may be consistently rare (McGowan 1990). We cannot assume that these species play a negligible role in community dynamics, although theories from terrestrial studies argue for this view. In recent years, theoretical ecologists have found that food webs containing many species with weak trophic interactions exhibit greater ecological stability than those having few species with strong interactions (McCann et al. 1998). This result and ongoing research suggest that rare species may play an important role in stabilizing communities over time. Species dominance patterns may also change through time: previously rare species may become predominant, and vice versa. The ecology of rare species needs to be better understood, in order to work toward genuine understanding of community and ecosystem dynamics, and especially the effect of rare species on foodweb stability. Rare species can also serve as indicators of changes in ecosystem function.

- *Pelagic speciation models:* Classical models of speciation focus on allopatric mechanisms (i.e., spatial isolation of populations leading to genetic divergence over time). The allopatric model remains the predominant view of terrestrial biologists. However, it is not clear that this model is appropriate in pelagic systems,where extensive gene flow may occur over large geographic distances as a consequence of circulation throughout the world ocean. Sympatric, parapatric, or other models may be important and relevant for marine zooplankton (see e.g., Knowlton 1993). We should now use combinations of molecular and morphological approaches to examine the processes that generate and maintain the patterns of zooplankton diversity.

- *Phylogenetic relationships:* Molecular characters and methods are used increasingly to describe the genetic diversity and structure of populations, discriminate and identify species, reveal cryptic species, and reconstruct the evolutionary history of zooplankton. Phylogenetic studies for zooplankton with fossil records, including foraminifers and radiolarians (e.g., Riedel and Sanfilippo 1982; Buzas and Culver 1991), are particularly useful. Molecular and morphological phylogenies have been compared for taxa lacking fossil records (e.g., Podar et al. 2001). These studies have brought to our attention deficiencies and ambiguities in our current understanding at all levels of systematic relationships of marine zooplankton. However, accurate phylogenies are a necessary basis for evolutionary and ecological studies. Comparative studies must consider evolutionary relationships among taxa, because many aspects of morphology, behavior, and life history can result from constraints of phylogenetic heritage rather than ecological adaptation. Accurate phylogenies for diverse groups of marine zooplankton are needed to understand and interpret mechanisms causing present-day patterns of biodiversity, and to suggest likely patterns and processes in the past and future.

- *Patterns of endemism:* Patterns of endemism are not well known in the pelagic ocean, but are fundamental to understanding how geographic ranges may change over time, how new species may arise, and what may cause extinction of species in the perpetually changing ocean environment. Comparative studies of endemic versus cosmopolitan distributions among diverse zooplankton taxa will permit assessment of the roles of life history and evolutionary ancestry in determining species distributions and diversity.

- *Molecular clocks:* The pelagic environment can be rapidly transformed by environmental change, which drives alterations in circulation patterns, water mass structure, ice cover, etc. Molecular clocks (i.e., DNA sequences for which rates of change over time can be calibrated by a geological record) are needed to measure rates of adaptation and evolution over geological time scales for populations and species of zooplankton, most of which lack fossil records. Some geological events provide benchmarks for calibration of rates of change in genes and species, including the salinization of the Black Sea, filling of the Mediterranean Basin, closure of the Isthmus of Panama, and sea level and circulation changes in the Indo-West Pacific (see e.g., Fleminger 1986). Zooplankton taxa with mineralized skeletal elements (e.g., foraminifers, radiolarians, tintinnids, and pteropods) have fossil records, so molecular clocks can be directly calibrated with the stratigraphic record. For these taxa, molecular genetic examination will provide documentation of their biogeography and biodiversity through geological time.

- *Management of marine ecosystems:* Knowledge of prior and existing patterns of zooplankton distribution and diversity is useful for management of coastal marine ecosystems. For example, knowledge of the geographic distributions of zooplankton can be used to evaluate risks of marine bioinvasions, to regulate ballast water discharge, minimize exchange of invasive zooplankton species among coastal ecosystems (e.g., Gollasch and Leppakoski 1999). Zooplankton diversity impacts biological production of marine ecosystems: changes in zooplankton diversity in the North Sea have been related to the gadoid outburst and subsequent recruitment failure in cod. Long-term shifts in relative importance and seasonal abundance of the copepods *Calanus finmarchicus* and *C. helgolandicus* in the North Sea and NE Atlantic Ocean have been associated with variation in the successful recruitment of cod (Beaugrand et al. 2003). Almost all commercial fish species rely on zooplankton prey during some portions of their lifecycle – whether as larvae, juveniles or adults. Species diversity of zooplankton can be useful in predicting recruitment and survivorship of commercially fished species, and are a critical element in ecosystem-based fisheries management (Link et al. 2002).

- *Indicators of ecosystem health:* When properly characterized and understood, the biodiversity of zooplankton can be used as a measure of the status and health of marine ecosystems. For example, in the Caspian Sea, changes in zooplankton species richness (i.e., declines from 22 to 7 cladoceran species and from 7 to one or two copepods) were associated with deterioration of water quality and ctenophore invasions (Roohi et al., unpublished data). In the Black Sea, neustonic pontellid copepods disappeared in the 1980s, serving as indicators of near-surface hydrocarbon pollution (Kideys 1994). Changes in the North Sea zooplankton community have been linked to climatic change and fish harvesting (Reid et al. 2003). Long-term monitoring of the planktonic assemblage, including retrospective analysis to establish baseline conditions, is needed in ecosystems throughout the world ocean.

- *Baseline biodiversity assessment:* There is an urgent need for a global baseline assessment of marine zooplankton biodiversity. Changes in the ocean environment and the availability of new methods to observe, analyze, and monitor zooplankton species make such a global census both feasible and necessary. A baseline assessment will provide a contemporary benchmark against which future changes can be measured. The census should encompass entire biogeographical ranges of species and meet the need for complete phylogenetic analysis of zooplankton groups.

IV. Approaches to sampling and sample analysis

Zooplankton sampling approaches will be designed to obtain specimens and data from a variety of taxa using protocols that will yield specimens suitable for morphological and molecular analysis, as well as samples that are suitable for quantitative analysis. Biological sampling will provide specimens for morphological and molecular processing, and will retain appearance, morphology, and molecular and biochemical properties of the specimens. Technological advances in sampling will lead to better information on abundance, specimens in better condition, and lowered cost per specimen for collection and subsequent processing.

IV.A. Optical sampling

Creative approaches have led to the development of a variety of remote plankton-sensing platforms – those deployed from ships which return data on plankton distribution, but not actual material. These methods include digital still images, video sequences, holographic imagery, and direct observation. Each method has advantages and disadvantages in terms of the signals, scales, or coverage obtained (Table 3). In general, these systems provide higher spatial resolution than nets and more accurate depiction of the animal in its environment. Numerical data on relatively well-known species will be valuable in addressing geographic and temporal changes in zooplankton populations in relation to their environment and behavior.

Table 3. Examples of contemporary zooplankton sampling methods and platforms. Meanings of abbreviations are given in the footnote below.

Name	Principle/Measurements	Advantages	Disadvantages
ESP	Presence of genetic tag		
ZooVis	Optical		
ZooScan	Optical		
VPR	Optical		Sample volume
UVP	Optical		
MVP	Optical	Multisensor	2-D only
OPC/LOPC	Optical		No image
CPR	Material	Robust, inexpensive	Only near-surface, damages specimens
Holocam	Optical		
AUVs	various instr	Sample remote areas	Power and range limitations
Towfish			
Nets and Trawls	Sample		Damages specimens
ROVs	Optical and sample	Can be manipulated	Limited range
Submersibles	Optical and sample	Collect fragile organisms	Expensive, labor intensive
SCUBA	Optical and sample		Labor intensive
Whole water	Sample		

Footnote: Video Plankton Recorder (VPR), UVP (Underwater Video Profiler), MVP (Moving Vessel Profiler), Optical Plankton Counter (OPC), Continuous Plankton Recorder (CPR), Autononous Underwater Vehicles (AUV), Remotely Operated Vehicles (ROV), Self-Contained Underwater Breathing Apparatus (SCUBA).

IV.B. Sample collection and processing

Zooplankton samples will be collected by nets, water bottles, sediment traps, light traps, ROVs, submersibles, or divers. Materials collected will either be processed as bulk unsorted samples in the case of cruises of opportunity, or as individual hand-picked specimens. As with remote sampling, there are many trade-offs for each type of sampling gear. Some may obtain numerous specimens, but under-sample fragile taxa. Others may be suited for collecting fragile organisms, but may be unable to sample across spatial scales appropriate for biogeographical analysis.

Biological samples obtained will be processed in order to preserve their appearance as well as their morphological, molecular, and biochemical properties. It is desirable to process some samples as bulk unsorted samples, and others as individual selected organisms. A simple and standardized method will insure that the specimens are used to their full potential (Fig. 8). To preserve the appearance of organisms, photographs and micrographs of live organisms are important, despite being labor-intensive. Improvements in 3-D reconstruction software may add another dimension to 2-D images without additional effort. Methods that preserve morphology are critical for archiving type specimens and vouchers. In the case of taxonomically valuable specimens, it is essential to have one-to-one correspondence between the specimen and a DNA sequence. Of the several available options (formaldehyde, ethanol, acetone, glutaraldehyde, Bouin's fluid, Lugol's solution, and potentially RNALater), those that preserve DNA, at least for a limited period of time, will be preferred.

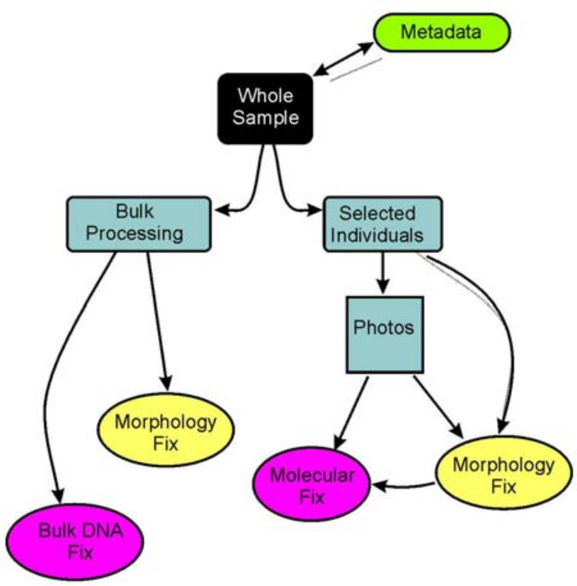

Figure 8. Flowchart for the processing of CMarZ zooplankton samples.

Preservation of material for molecular analysis is essential for many different types of studies, including: population genetic diversity and structure; phylogeography (i.e., geographic distribution of genetic lineages); recognition of species boundaries using molecular phylogenetics; specimen identification by barcoding; phylogenetic reconstruction using DNA sequences; structural and functional genomics through expressed sequence tag (EST) libraries; microarray development; quantitative PCR to measure protein-coding gene expression; and stable isotopes. The most robust method of molecular fixation is the freezing of the specimen in liquid nitrogen, but this method is not always feasible. Liquid nitrogen may be hard to obtain and maintain on long cruises, and transport of specimens back to a laboratory may place them at risk. Storing the samples in -80^{o} C freezers is an acceptable alternative, with the exception of material for examination of RNA (e.g., gene expression, RNA/DNA ratios, etc). For most molecular analyses, specimens must be identified and placed in individual containers prior to freezing.

Alcohol (i.e., 95% non-denatured ethanol) is also widely used to preserve specimens for DNA analysis, although it is not appropriate for preservation of RNA. However, long-term storage in alcohol will eventually result in degradation of the DNA; specimens may become useless for molecular analysis over the course of 2 to 5 years. Storing ethanol-fixed material at low temperatures (-20º C) appears to slow degradation. One approach to preserving specimens is to excise a portion for molecular study, leaving the remainder for morphological analysis. This approach is frequently used for larger gelatinous organisms and others that require special handling, but is not applicable to very small organisms.

There have been many recent developments in the preservation of DNA from diverse tissue preparations. Alternate approaches to preservation, including RNALater (Ambion, Inc., USA) and FTA paper (Whatman Co., UK), may be practical in some circumstances. Evaluation of the efficacy of these new and emerging protocols for both molecular and morphological preservation of specimens (especially those containing chitin) will be re-examined during CMarZ.

As technology advances, all collection, fixation, and preservation techniques will become increasingly amenable to automated or *in-situ* techniques. Although we can only speculate about the time-line of future advances, in the near future we expect that routine and detailed re-analysis of archived plankton samples will be possible using expert artificial intelligence systems and combined morphological and molecular techniques. This prospect, and others as yet unconsidered, emphasize the need for long term physical archiving of zooplankton collections.

IV.C. Sample analysis

Traditional morphological analysis of zooplankton samples will remain a central component in the processing of new and existing collections of zooplankton. Such analysis continues to provide an ecological context for most groups. Methods of analysis have been reviewed and recommended recently (see e.g., Harris et al. 2000). CMarZ will ensure that additional efforts will be applied to sample analysis to improve the quality of data, especially for rare species, which are typically under-represented in zooplankton studies.

Reference specimen collections: As sample collections are made and analyzed, a reference specimen collection must be assembled for all the species or groups identified. These reference collections can be used for quality control of the analysis, and can serve as resource data for expert confirmation of problem species. Collections must be archived in association with metadata descriptions, including: originators, collection time and place, georeference coordinates, allied photographs, references to keys used, further analyses, contact information people responsible for specimen or sample exchange, and links to ancillary information, such as environmental measurements etc. All of these should be held in an appropriate, internet-accessible database.

Improving access to taxonomic information: It is essential to put existing bodies of taxonomic information into an accessible form. Increasingly, this will mean creating electronic versions (i.e., CD-ROMs and web-based sites) of printed monographs. CMarZ will place a high priority on the conversion of print materials to electronic versions for greater accessibility and more rapid distribution. We will also improve the presentation of taxonomic identification manuals and keys, by making use of pictorial representations and drawings to illustrate the appearance and key features of both live and preserved specimens, and to reference and relate to appropriate keys. A number of taxonomic manuals and guides have been published for coastal seas that describe zooplankton, albeit at differing taxonomic levels. Such efforts will be encouraged, updated, and expanded to include additional regions and greater taxonomic detail. We now have many new and exciting tools for imaging, image analysis, and information technology, many of which were developed within the past decade. It will be a priority to use these tools to preserve the knowledge and skills of taxonomic specialists, and to provide them with every opportunity to teach students and pass on their skills, collaborate with other experts, and make available their bibliographic and type specimen resources.

Digital Expert Systems: Digital Expert Systems have been developed in recent years for taxonomic work, and greatly facilitate the training of students and professionals in practical aspects of identification of marine plankton. Some of these digital tools include pictorially-oriented keys and efficient pattern-matching algorithms to aid identification, complete morphological descriptions, depiction of known biogeographical distributions, digital video of aspects of animal behavior, and comprehensive glossaries and bibliographies. These are extremely useful because they provide access to historical and current literature for those working at sea, in remote locations, or without access to libraries. The digital environment readily permits updates and refinements as knowledge advances, as well as incorporation of new types of information. Digital expert systems currently exist for selected zooplankton taxa (e.g., euphausiids, pelagic mollusks, ostracods, aetideid copepods), but they are not available for some of the most speciose groups, including most copepods, hydromedusae, amphipods, and mysids. It would be useful to have such resources for many common taxa, including pelagic tunicates and chaetognaths. Development of digital taxonomic tools for training and research is a high priority for CMarZ.

DNA analysis of zooplankton: Laboratories associated with CMarZ and equipped for molecular analyses (including DNA sequencing) will coordinate to ensure storage, archiving, and molecular systematic analysis of specimens sent by CMarZ researchers, who may be focused on taxonomic, morphological, or ecological studies. A DNA sequence appropriate for species identification and discovery (i.e., a DNA barcode, Hebert et al. 2003, Stoeckle 2003) will be selected for each zooplankton taxon. Specimens should be sequenced within a reasonable time frame, and the DNA sequences submitted to the GenBank molecular database (http://www.ncbi.nlm.nih.gov). Voucher specimens and voucher DNA will be permanently maintained by the molecular laboratory, and will be accessible for scientific study.

IV.D. Engaging and enhancing taxonomic expertise

Engaging taxonomic experts will be essential to achieving the aims and objectives of CMarZ. Such skills are the domain of a very few specialists worldwide, and are a diminishing resource. The lack of manpower – both expert and technical – is a bottleneck for CMarZ. Integration and coordination among taxonomic experts (and students and technicians) is needed, because: 1) taxonomic analysis of samples will be the most labor-intensive part of CMarZ; 2) identification of all taxa must be standardized and quality-controlled; 3) taxonomic expertise is in very limited and ever-worsening supply; and 4) this will create new opportunities for teaching and knowledge dissemination.

CMarZ will identify specialists in taxonomic groups and geographic areas, and encourage them to collaborate on CMarZ efforts. CMarZ will establish a virtual network of taxonomic experts on marine zooplankton and provide a portal for taxonomic expertise to reach the larger community. A virtual resource center will provide public access to taxonomic information, and link to existing centers and web-based resources, such as ETI, Integrated Taxonomic Information System (ITIS), and the National Ocean Data Center (NODC). It will also be beneficial to assemble and provide image collections of zooplankton for teaching and demonstration.

Specialists will be enabled to produce global syntheses of particular groups, which can be partitioned into regional compilations or manuals, suitable for students and field workers. A workshop approach will be used to connect taxonomic specialists and para-taxonomists working on particular collections, since taxonomic specialists will not have time or resources to sort samples or deal with all specimens others cannot identify.

Taxonomic experts will be engaged as consultants for seagoing collection and analysis projects; their participation and assistance will be appropriately supported. The goal is to involve taxonomic specialists in projects of ecological and oceanographic scope, and to give the marine science community greater access to taxonomic expertise. Routine checking of species identifications will not require an expert. Validation of species identifications, especially for uncertain identifications and possible new species, is the task of an expert. Taxonomic description of new species is a very specialized and time consuming activity, and thus must be explicitly funded by CMarZ as part of the field projects.

CMarZ will encourage and facilitate coordination among scientists and technical experts, to ensure the cooperative analysis of zooplankton samples from both existing collections and new field activities. Such cooperation will be critically needed to complete a global, taxonomically-comprehensive biodiversity census, since the number of specialists and their available time are very limited. The general approach will include the following elements:

- Participants in any field survey will be primarily responsible for analysis of higher taxonomic groups in all samples they collect during CMarZ activities.
- Prior to each cruise, specialists will be identified for each taxon. They will agree to identify and describe difficult, rare, or new species collected throughout the project.
- Participants will receive training in taxonomic identification to allow them to identify major taxa to the species level.
- Special collections will be selected for analysis by Ph.D. students as a part of their dissertation research, working in association with specialists whose effort is paid for by the project.

For local- to regional-scale projects, such coordination works well, especially since the specialists have direct knowledge of the regional fauna. For the global assessment to be completed by CMarZ, some changes from this approach will be required: 1) specialists will be identified using directories, such as those in the ETI and WAC registries, and will include retired experts (who may volunteer) and organizational scientists (who may be able to work unpaid); 2) travel costs will be included to allow specialists and CMarZ participants to meet together to work on particular sets of samples; 3) flexibility will be built into the schedule to allow for different pacing and completion dates in different countries. Precedents for such coordination exist. In an ongoing project using the Odate zooplankton collection (held at the Tohoku National Fisheries Research Institute, Japan), 50-year-old samples collected off NE Japan are being analyzed by specialists in a private company, with funding from the Ministry of Environment. Such a collaborative approach may work well in other instances as well.

V. Data management and analysis

User-driven distributed database: Dissemination of data and information resulting from CMarZ will require internet-accessible web pages and databases. The CMarZ data management system will constitute a distributed network of databases, which will be independently served, managed, quality controlled, and updated. All component databases will share common formats for data entry and display, and will be searchable using standardized protocols.

Zooplankton metadata guidelines: The ICES Working Group on Zooplankton Ecology (WGZE), with guidance from the ICES Working Group on Marine Data Management (WGMDM), has provided general metadata guidelines for zooplankton data. The existence of such guidelines are intended to ensure that quality and usable plankton data sets will be preserved and available to investigators in the present and future. Metadata fields in this document do not cover every possible metadata type, nor will every plankton data type include all of these metadata fields. Instead these fields are intended to serve as an example of the types of information important for preserving the highest level of quality and understanding within the zooplankton data. It should also be noted that while these guidelines were written for zooplankton data, they are also appropriate for other groups, including phytoplankton and bacteria.

The fields below represent many of the most common metadata fields important to preserving high quality plankton data. Many of these data-fields may be better stored along with each station or tow within the plankton data sheet itself. The intent is to describe the general types of information that should be preserved either within the data or as a separate metadata or cruise summary.

- Metadata fields relating to the entire cruise: This is general information relating to the sampling cruise. This information links these data to physical and chemical measurements taken on the same cruise (but stored in a separate data file or location), and also credits the investigators participating in the cruise.
- Metadata fields relating to a specific station: This is specific information relating to the position and time of the sampling station, along with the weather conditions and other details observed during the sampling.
- Metadata fields relating to the net tow or bottle cast: This information describes the towing (or bottle deployment) methods and procedures.
- Metadata fields relating to the sampling gear: This information describes the sampling gear employed, with key metadata fields such as the effective mesh size of the sampler.

- Metadata fields relating to sample processing: This information describes the sample processing methods and protocols.

Integration with OBIS: The capacities to manage, analyze, distribute, integrate, and visualize data and information have increased enormously in recent years, with new tools and approaches under continuous development and improvement. A leading example of this growing capacity is the Ocean Biogeographical Information System (OBIS), a globally-distributed network of databases (Zhang and Grassle 2003). OBIS features an internet portal (http://www.iobis.org) which provides data searching, taxonomy name service, integration with environmental data, and analysis and visualization tools. OBIS in particular – and internet-based data and information management systems in general – will provide invaluable resources for the proposed new effort.

CMarZ will ensure compliance with the requirement for all CoML field projects to provide data, metadata, and information via OBIS. A CMarZ portal and web-site will be established to integrate all project data and information, and/or to serve project data, as required. Participants will be responsible for quality control, updating, and correcting their own project data. All data formats will be integratable directly with OBIS or via the CMarZ portal.

CMarZ will build upon an existing databases, which include specimen, taxonomic, and molecular data on zooplankton. One such is the CoML-affiliated ZooGene database (http://www.ZooGene.org), a member of the OBIS federation of databases. ZooGene includes DNA sequence data for all specimens. Integration via the OBIS internet portal ensures that ZooGene data can be analyzed, distributed, integrated, and visualized similarly to other CoML project data. ZooGene also provides data searching and integration with environmental data.

Data analysis: The data produced by CMarZ will require adequate databasing and statistical analysis techniques, which can synthesize results from different studies across vast regions and among various taxa. Much of the CMarZ data will be field collected, as opposed to laboratory generated. Thus, a comparative approach will be best suited for analyses designed to reveal underlying relationships. We will use a comparative approach across regions and among taxa to statistically evaluate the central hypotheses. This will allow us to evaluate the degree to which the hypotheses are universally versus specifically applicable.

One formalized method to apply the comparative approach is meta-analysis. This is a statistically robust method of synthesizing findings from a suite of independent studies (see Hedges and Olkin 1985). Many recent global reviews of possible climate change impacts on a variety of animal and plants are based on synthesizing results from a large number of studies using meta-analysis (see e.g., Root et al. 2003). Meta-analytic approaches will draw the results from CMarZ together, and highlight factors underlying zooplankton biodiversity.

VI. Education and outreach activities

Electronic public access to CMarZ will be via an internet portal, integrated with and linked to the CoML and OBIS portal. The site will provide a background information on zooplankton ecology and biology written for students and general readers, as well as more technical material on marine biodiversity. The site will be user-friendly, with graphical user interfaces suitable for use by a diversity of audience types and educational levels. We anticipate serving as a resource for K-12 educators, as well as zooplankton specialists. We expect it to provide vivid imagery of zooplankton and species home pages for many species. Links will assist users to find a variety of zooplankton resources on the web.

CMarZ will encourage participating researchers and educators to provide regular updates, with links and descriptions of research activities and discoveries. We will provide at-sea coverage of major expeditions, as has been done very successfully by NOAA's Office of Ocean Exploration (http://www.oceanexplorer.noaa.gov/); Harbor Branch Oceanographic Institution's program; @Sea (http://www.at-sea.org); and the US GLOBEC Southern Ocean project coverage by the National Geographic television channel (see http://globec.whoi.edu). We will explore other communications tools, including public forums, call-in and email-in radio programs, and video-cam coverage.

VI.A. Graduate and professional training

A multitude of opportunities for graduate training are envisioned under the umbrella of the CMarZ project. The international nature of this undertaking virtually guarantees the exchange of samples and students at a global scale. Similarly, the increased breadth of knowledge of both professionals and their support staff will be unprecedented. Workshops to be sponsored by this program will not only serve to disseminate knowledge and skills, but foster collaborative international interactions. Once rolling, we foresee the engagement of a wide variety of individuals and the production of a new generation of taxonomists and parataxonomists.

VI.B. Taxonomic and special-focus workshops

CMarZ has begun to identify needs and interested experts, using on-line information and databases, as well as personal contacts among Steering Group members. Existing resources for information about active taxonomic specialists include ETI, the World Association of Copepodologists (WAC), and others. CMarZ will hold a series of international training workshops, to be conducted prior to the start of the active field years. These taxonomically-focused meetings will address the need for additional technical expertise in the identification of selected zooplankton groups. Each workshop organizer will seek shared funding from another agency or program. Some of the workshops to be organized and funded by CMarZ are listed here. Additional workshops will be organized has need and opportunity arise.

- *Design of globally synoptic biodiversity surveys:* This workshop will team FMAP (Future of Marine Animal Populations) and CMarZ investigators in a wide-ranging discussion of theoretical, modeling, and practical approaches to the design of ship-board surveys to assess global patterns of zooplankton biodiversity. Among the topics: use of trans-oceanic surveys and transit legs of oceanographic research vessels in global surveys; need for depth-stratified sampling and associated physical ocean data collection; identification and sampling of biodiversity hotspots; and appropriate collection of rare or fragile taxa.

Scheduled for September 16, 2004 in Woods Hole, MA (USA). Workshop organizers: Ransom A. Myers (Canada) and Ann Bucklin (USA)

- *Zooplankton taxonomy in southern Africa*: In the Benguela Current region off southern Africa, which includes the neighbouring coastal states Angola, Namibia and South Africa, zooplankton has been collected routinely, usually in support of fisheries research, since the development of the pelagic fishing industry in South Africa in the early 1950s. Although this zooplankton monitoring is still continuing, this coastal upwelling region has suffered an enormous loss of expertise in zooplankton taxonomy at an exponential rate over the past 2 decades, to the extent that the very few experts remaining are on the list of Endangered Species, if not already extinct. Initial steps have already been taken to redress this situation, by setting aside some funding to invite experts to the region and organize one or a series of local zooplankton taxonomic identification workshops through ongoing projects under the umbrella of two regional collaborative programs, BENEFIT (Benguela Environment Fisheries Interaction and Training) and BCLME (Benguela Current Large Marine Ecosystem). Workshop organizers: Hans Verheye and Larry Hutchings (South Africa)

- *Methods of zooplankton ecology and identification:* Educating students and active scientists of Southeast Asia with the methods on zooplankton ecology and identification, and examining plankton samples from local waters to establish regional faunal list of zooplankton. Workshops will be held in the Philippines (2004), Indonesia (2005), Vietnam (2006), and Malaysia (2007). Workshop organizer: Shuhei Nishida (Ocean Research Institute, University of Tokyo, Japan).

- *Identification of macrozooplankton*: Identification of major zooplankton groups will be taught to 15 participants involved in CoML projects. Invited experts will reveal their "kitchen secrets" and use interactive tools. It will be a hands-on workshop with short presentations and long microscope sessions. Location to be determined based on interest, need, and matching funds availability. Workshop organizer: Annelies Pierrot-Bults (University of Amsterdam, Netherlands).

VI.C. Public education

Professional communications staff members will be needed for CMarZ. High quality communications materials – including brochures, posters, and books – will be essential to draw public interest for this new global activity, and to ensure that the new knowledge is introduced rapidly into programs and curricula for classrooms from kindergarten to college. Live plankton are exquisite when viewed in high quality color still photos and/or video. Zooplankton are appropriate mascots for any marine biodiversity initiative. Professional communications staff will be engaged in association with the project office and cooperating projects to ensure that this new CoML project has public appeal and visibility.

VII. CMarZ cooperating projects

VII.A. Funded cooperating projects

A1. Banda Sea (Indonesia) water column inventory (Larry Madin): Zooplankton samples will be collected during an expedition to the Banda Sea, Indonesia in the spring of 2005. Funded by NOAA Ocean Exploration and the National Geographic Society, this project, titled "A Vertical Inventory of Marine Life in the Banda Sea", will include sampling throughout the water column for zooplankton and nekton, using nets, trawls, ROV with suction sampler, baited cameras and SCUBA diving. The Indonesian archipelago is considered a center of marine biodiversity, but relatively little work has been done on the fauna of the water column. Support from CMarZ will be used for distribution of specimens to appropriate experts (sample containers, shipping, communications) and payment for their services (outside services). These are expenses not covered by existing expedition funding.

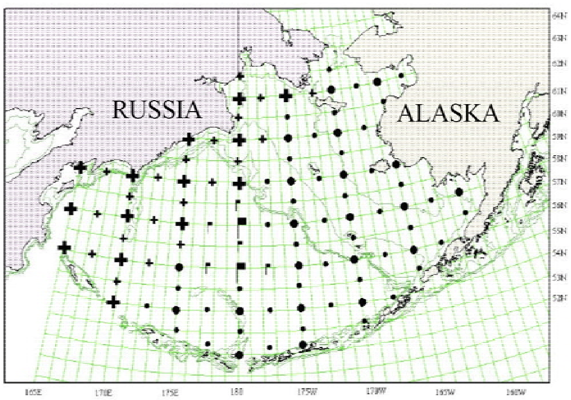

Figure 9. Station locations for BASIS surveys during 2002-2006.

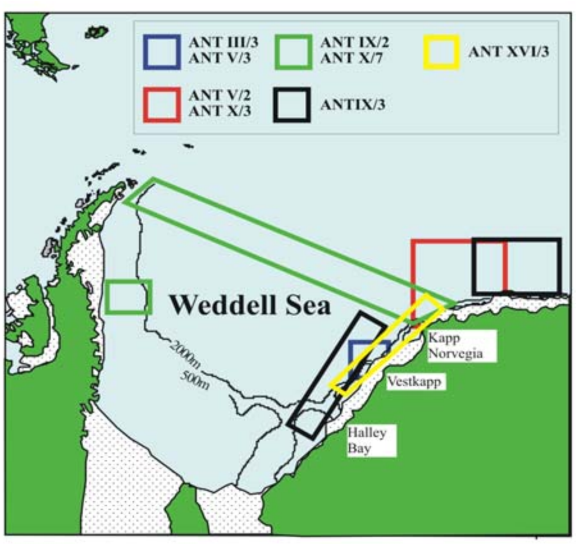

Figure 10. ISPOL Weddell Sea cruise areas.

A2. Coastal biodiversity in Southeast Asia - plankton (Shuhei Nishida): This international collaboration will include Japan, Thailand, Malaysia, Indonesia, Philippines, and Vietnam. The field studies will focus on zooplankton diversity, abundance, and community structure, as well as biodiversity and biogeochemical cycling in coastal waters of Southeast Asia, and marginal basins such as the Sulu Sea and Celebes Sea. Cruises will use the RV Hakuho-maru (requested for 2007) among others. The project will host a training course and workshop, and produce a practical manual, illustrated keys, and species lists.

A3. Science for the Protection of Indonesian Coastal marine Ecosystems (SPICE) (Sigrid Schiel): This cooperation project between Indonesia and Germany has support from the German Federal Ministry of Education and Research for 2004-2007. The study site is Spermonde Archipelago, Strait of Makassar, SW Sulawesi. In association with the Hasanuddin University (Makassar, Sulawesi), research topics include zooplankton diversity, distribution, abundance, community structure, and benthic-pelagic coupling. Sampling will be done with small plankton nets (Apstein, Nansen), with phytoplankton collection and hydrographic analysis.

A4. BASIS zooplankton sample analysis (Russ Hopcroft): The Bering-Aleutian Salmon International Survey (BASIS) (http://www.afsc.noaa.gov/abl/occ/basis.htm) is an ongoing program developed by the North Pacific Anadromous Fish Commission (NPAFC), whereby Canada, Japan, Russia, and the US conduct long-term, large-scale ecosystem research on salmon in the Bering Sea. There are four cruises each year during 2002-2006 covering much of the Bering Sea region (Fig. 9). Samples could be collected for CMarZ, although funding is needed for more detailed taxonomic analysis. This project is expected to be followed by the Bering Sea Ecosystem Study (BEST) (http://www.arcus.org/bering/), which will also examine the ecology of the Bering Sea with zooplankton, including gelatinous forms.

A5. Ice Station Polarstern (ISPOL) (Sigrid Schiel): This international, multidisciplinary Antarctic expedition is taking place in the Weddell Sea from the *Polarstern* during November 2004 - January 2005 (Fig. 10). Zooplankton development in and under ice will be studied, with vertically-stratified sampling to 1000 m, and deeper where possible.

A6. Eastern Atlantic meso-zooplankton diversity in the euphotic zone (Steve Hay): This survey will cover the European continental shelf edge, from northern Bay of Biscay along the west coast of Ireland to northeast of Shetland. To be carried out during Scottish ICES mackerel egg surveys in 2004, these surveys will allow study of zooplankton biodiversity in the northeast Atlantic and European shelf seas. There will be opportunities for concurrent sampling for CMarZ.

A7. Long term investigations on zooplankton biomass and distribution in Icelandic waters in relation to marine climate (Astthor Gislason, with Olafur S Astthorsson and Hildur Petursdottir, Marine Research Institute, Reykjavik, Iceland): The geographical coverage of the Icelandic Marine Research Institute (MRI) zooplankton monitoring, including both Atlantic and Arctic water masses, provides important opportunities to examine species distributions and species composition in relation to the environment and biodiversity. Begun in 1960, the MRI spring survey samples 100-120 fixed stations along 10-12 transects each year. Samples are routinely preserved in formalin, but can be otherwise preserved by special arrangement.

A8. IMR (Norway) research cruises (Webjørn Melle): The Institute of Marine Research (Norway) conducts research and survey cruises throughout the Nordic and Barents Seas each year. Collection and preservation of zooplankton samples for CMarZ scientists will be possible, subject to restrictions on time required for any special protocols. Vertically-stratified sampling for major zooplankton groups is routinely carried out. Sample preservation in formaldehyde and alcohol, and possibly liquid nitrogen, is possible.

A9. Ecosystem monitoring by the US National Marine Fisheries Service (David Mountain, NOAA, NMFS, NEFSC): The US NMFS conducts environmental monitoring surveys on the northeast US continental shelf, in the Gulf of Mexico, on the California continental shelf, and off coastal Alaska. The surveys document the distribution, abundance and species composition of the zooplankton community in US coastal waters. The four regional programs have been conducted for a least a decade; two – on the northeast shelf and off California – for multiple decades. Subject to other constraints and by prior arrangement, NMFS will cooperate with CMarZ by providing access to existing databases, by collecting samples on surveys cruises (preserved in formalin, alcohol or liquid nitrogen), and by providing bunk space for CMarZ participants on some cruises.

A10. Zooplankton sampling during SEA cruises (Peter Wiebe): Zooplankton samples will be collected in nets during teaching cruises of the Sea Education Association (SEA, Woods Hole, MA). SEA will arrange for collections during three or four cruises each year from NW Atlantic, Caribbean, and NE Pacific regions. Of particular interest are long transects crossing diverse ocean regions, e.g., between ports in Alaska, Baja California, Tahiti, and Hawaii.

A11: Seasonal oceanography and fisheries in the Benguela Current region (Larry Hutchings and Hans Verheye): A BENEFIT-funded, dedicated environmental monitoring program for key areas along the Angolan, Namibian and South African west coasts. Five monitoring transects with comparable sampling and analysis methodologies are in place (Fig. 11).

A12. Environmental monitoring and pelagic fish stock assessment surveys in South Africa (Hans Verheye, with Jenny Huggett and Larry Hutchings): Annual zooplankton collections have been made along nearly the entire coast of South Africa since 1983, yielding information for management of marine ecosystems, indicators of ecosystem health, and baseline biodiversity assessment. Area of sampling is the continental shelf between ~29º S on the west coast and 28º E on the east coast of South Africa. Samples are routinely taxonomically analyzed, local taxonomic expertise needs to be uplifted.

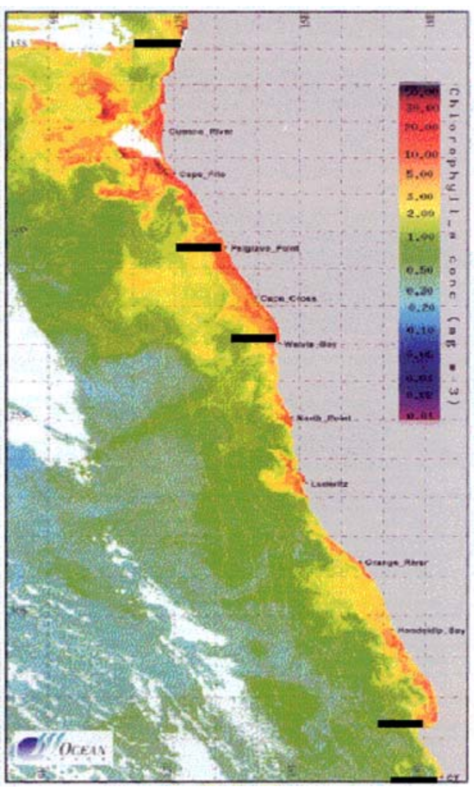

Figure 11. Ocean color satellite image of Benguela Current region (S. Atlantic Ocean), with monitoring lines off Angola, Namibia, and South Africa.

A13. African coelacanth ecosystem program (Hans Verheye). Coelacanths generally reside in caves (for predator avoidance and habitat preference). Zooplankton studies could help determine the food web associated with coelacanths and their unique environment, which in a CoML-CmarZ context is likely to be inhabited by endemic and hitherto undescribed zooplankton species. ACEP regions of study are Sodwana Bay, near the border between South Africa and Mozambique, and the Mozambique Channel. Zooplankton studies would be best added in Delagoa Bight, the Tanzanian coast, and Madagascar.

A14. US GLOBEC Gulf of Alaska field sampling (Russ Hopcroft). This project will contribute a more detailed taxonomic analysis of areas not extensively sampled during other field efforts associated with the LTOP surveys, including offshore sites and a site deep inside Prince William Sound fjord. Depth-stratified samples (to 600m) will be collected during seven cruises each year from 2004 – 2008. Samples will be preserved in ethanol for taxonomic analysis, and specimens of all species identified by taxonomic experts.

VII.B. Proposed cooperating projects

B1. World Radiolarian Distributional Database (WoRaDD) (Demetrio Boltovskoy): The objective of this project is to generate a detailed database using all available published and unpublished data on the distribution of polycystine radiolarian species worldwide, from both planktonic and sedimentary (surface) materials. The information thus summarized will be analyzed with the aid of objective numerical and GIS techniques in order to derive global distributional patterns of both species and cell numbers. A proposal has been submitted to the Antorchas, a Latin American private funding agency. It will involve personnel from Argentina (D. Boltovskoy), Norway (K. Bjorklund), Japan (K. Takahashi), and the US (S. Kling).

B2. Digital expert system for pelagic copepods (Mark Ohman): This project will fill a critical need for modern, digital taxonomic tools to permit accurate species identifications of the most abundant and diverse multicellular plankton, the copepods. It will focus on the pelagic copepods in the upper 500 m of the Northeast Pacific, from the equator to the Bering Sea, and include pictorially-oriented keys and innovative pattern-matching algorithms for identifications, as well as complete morphological descriptions, depictions of known biogeographical distributions, digital video illustrating aspects of animal behavior, and hot-linked digital glossaries and bibliographies. It will build upon our successful *Euphausiids of the World Ocean* CD-ROM, in partnership with ETI at the University of Amsterdam.

B3. CalcOBIS (Colomban de Vargas): The aim of this project is to implement the Calcareous Plankton Ocean Biogeographical Information System, or *CalcOBIS* database. *CalcOBIS* is an interactive biogeographical system that will provide global taxonomic and phylogenetic information at the morphological and genetic species levels for all calcareous skeleton-bearing taxa in the marine zooplankton (foraminifers, tintinnids, pteropods, ostracods, heteropods). These groups have built a km-thick fossil archive at the ocean bottom that allows unique analyses of global distribution patterns of living plankton. Comprehensive gathering of fossil, plankton-tow, sediment trap, and genetic data from the target groups will establish global biogeographical maps for living organisms (Fig. 12); allow comparison of morphological and molecular biogeographies for each taxon; calibrate molecular clocks for diverse taxa; and provide valuable ecological and genetic data for accurate inferences about impacts of climatic variation.

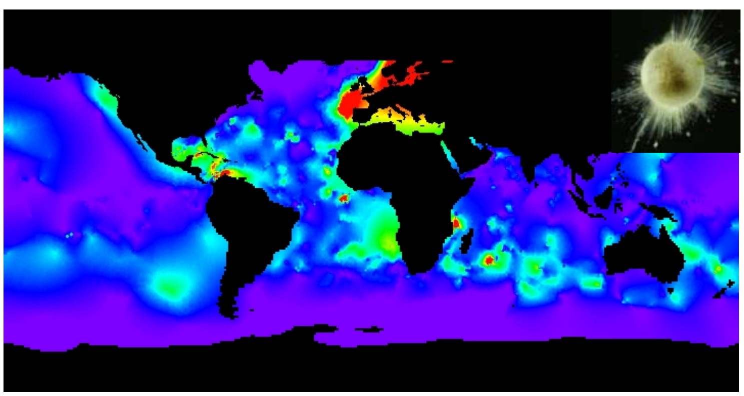

Figure 12. Map typical of CalcOBIS, this one for the planktonic foraminifer (*O. universa*) in modern deep-sea sediments of ocean basins.

B4. Potential plankton pilot project (Steve Haddock and Erik Thuessen): This project will implement a prototype sampling strategy in the Monterey Bay, NE Pacific coastal waters. The project will cross-calibrate collection methods, develop methods for sample processing and species identification, and train plankton parataxonomists. The goal is to compare abundance, biomass, and diversity among zooplankton taxa based on the sampling gear used (nets, divers, ROV, submersibles). Preliminary data (Thuesen and Childress, in prep.) have shown that the taxonomic composition of samples varies widely with type of net or trawl. This effort will use simultaneous data collection from multiple sampling platforms, with near-immediate sample quantification. Funding is requested to add on to planned monthly cruises and/or to conduct a one-week midwater trawling cruise during December 2004.

B5. Biocontrol of an invasive specıes causing immense ecosystem damage and social problems in the Caspian Sea (Ahmet Kideys): A major objective of this project is a careful scientific study of the introduction of the invasive ctenophore, *Mnemiopsis leidyi*, to the Caspian Sea. Zooplankton monitoring and assessment will continue for 2004-2008 in different coastal regions of the Caspian, with participation by scientists from nine riparian and European countries. Zooplankton samples can be made available for other purposes, including molecular genetic analysis. The riparian countries propose to use a specific predator against *M. leidyi*. Proposed for EU funding.

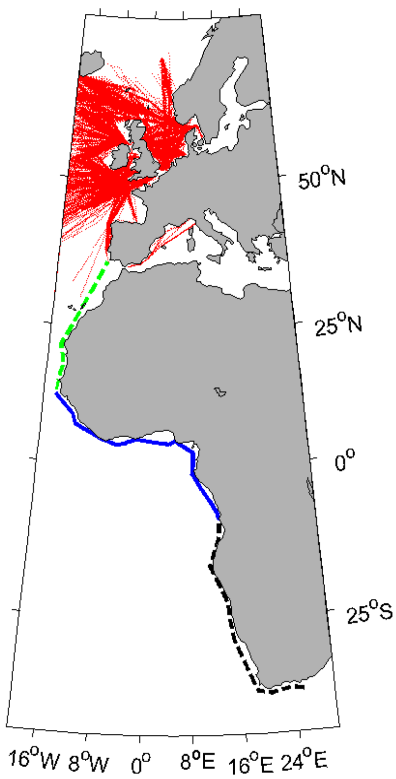

Figure 13. Routes of the Atlantic Eastern Margin Transect (AEMT), with proposed section from Portugal to Guinea Bisseau (in green).

B6. Plankton diversity of Andaman Sea (Russell Hopcroft): This proposed international collaboration (Denmark, Thailand, and US) will begin a sampling program in conjunction with Phuket Marine Biology Center (PMBC), where CoML NaGISA is already involved, using the PMBC research vessel, Chakratong Tongyai. The Andaman Sea is a deep-water basin separated from the remainder of the Indian Ocean by an archipelago along its western border. Plankton diversity is high, onshore-offshore gradients can be strong, and gelatinous zooplankton form a significant proportion of the zooplankton community. Funding has been requested from the NSF (US) and the Carlsberg Foundation (Denmark).

B7. Pelagic Ecophysiology and Lifecycles: African German Oxygen Studies (PELAGOS) (Hans Verheye): An integrated multilateral collaborative program to examine the effects of low oxygen levels on the physiology of zooplankton and other taxa. This multi-year program, now in final planning stages, will offer good opportunities to make collections of species specially adapted to hypoxic/anoxic conditions. PELAGOS will continue an ongoing focus on the ecology of zooplankton in the region of the Angola-Benguela Front (ABF) and the northern Namibian shelf, which is characterized by extensive and persistent epipelagic oxygen minimum layers in the vicinity of the ABF and hypoxic conditions with hydrogen sulphide further south.

B8A. The Atlantic Eastern Margin Transect (AEMT) (Anthony Richardson): This pilot project by SAHFOS will provide a synoptic, frequent (six-weekly) view of plankton biodiversity along the eastern continental margin of the Atlantic Ocean, in order to resolve seasonal variability at large spatial scales. The transect will be sampled by towing the Continuous Plankton Recorder (CPR) behind Ships of Opportunity. Many of the CPR routes required for AEMT already exist or are likely to be funded. Funding from CMarZ will be used for proof-of-concept tows from southern Portugal to Guinea Bisseau (Fig. 13, shown in green) in order to complete the AEMT. A regional center for each section of the AEMT will be set up to ensure training of local parataxonomists.

B8B. Plankton biodiversity in the Guinea Current (Anthony Richardson): As part of the Guinea Current Large Marine Ecosystem program, six-weekly CPR tows are planned over five years, beginning in 2005 (Fig. 13, see blue line). Samples will be counted for phyto- and zooplankton. Topics for research include zooplankton biodiversity, distribution and relative abundance.

B8C. Southern African CPR route (Hans Verheye): This effort will add another new CPR route between Port Elizabeth, South Africa and Luanda, Angola (Fig. 13, see dotted black line). This route will extend the proposed AEMT and link up five monitoring transects of the BENEFIT program.

VIII. Programmatic integration and coordination

VIII.A. Coordination with other CoML projects

In order to share resources and cross-fertilize among CoML field projects, CMarZ will ensure coordination in planning and implementation, especially for any field work and sample collections, with other ongoing projects. There are particular opportunities for collaboration with several projects:

- MAR-ECO (*Patterns and processes of the ecosystems of the northern Mid-Atlantic*) will collect zooplankton samples over the mid-Atlantic ridge. CMarZ coordination is in place, with Webjørn Melle serving in leadership positions in both projects. Also, Ann Bucklin is a participant in both CMarZ and MAR-ECO.

- CeDAMar (*Census of the Diversity of Abyssal Marine Life*) coordination will be done with the assistance of Victor Gallardo. We anticipate that CeDAMar will sample in deep-sea areas where there is high likelihood for zooplankton species discovery. We will seek opportunities for added sampling on CeDAMar cruises, to allow collection of zooplankton in these seldom-explored regions.

- ArcCoML (*Arctic Census of Marine Life*) project will yield much new information on zooplankton biodiversity. Coordination with this study will be done with the assistance of Russ Hopcroft, who leads that effort and is also serving on the Steering Group for CMarZ.

- GoMA (*Gulf of Maine Census of Marine Life)* will provide opportunities for understanding the ecosystem role of zooplankton, and will provide a useful coordination for CMarZ. Ann Bucklin, Larry Madin, and Peter Wiebe are participants and

Zooplankton Working Group members for the Gulf of Maine project, and can ensure close coordination with CMarZ.

- CoML Microbes will overlap with CMarZ in our shared focus on protists. A Joint Working Group (JWG) will be created, composed of members from both projects, that will design and lead efforts to share resources, coordinate sampling and analysis, and integrate results. Demetrio Boltovskoy (radiolarians and acantharians) and Colomban de Vargas (foraminifers) have agreed to represent CMarZ on the JWG.

VIII.B. Other programs and organizations

Early planning for CMarZ has stimulated discussion among zooplankton investigators in Europe and Scandinavia. Discussions are underway to consider approaches for allying with and exploiting existing programs to support the CMarZ objectives. Such ad hoc groups are also beginning to plan future projects and seeking funding opportunities for advancing the aims of CMarZ.

- *GLOBEC*: As part of the US GLOBEC Northeast Pacific program, field sampling in the Gulf of Alaska will continue through 2004, and will provide opportunities for sample coordination. Archived zooplankton samples collected during all GLOBEC programs will serve as an invaluable resource for CMarZ scientists; the GLOBEC databases will provide information for the baseline summary. Peter Wiebe will coordinate between US GLOBEC and CMarZ. European GLOBEC also has ongoing field collection programs; projects leaders will be contacted by Ann Bucklin, Peter Wiebe, and other Steering Group members to request samples and/or data for integrated and coordinated analysis.

- *Integrated Marine Biogeochemistry and Ecosystem Research*: The new IGBP/SCOR Global Change program, IMBER, is moving into implementation phase, with field work beginning in 2004. The comprehensive IMBER science plan will allow many opportunities for joint planning and coordination of field efforts with CMarZ. Ann Bucklin was a Transition Team member and one (of many) authors of the Science Plan; she will continue as a Scientific Steering Committee member for IMBER and can ensure full coordination with CMarZ.

- *BarCode of Life Initiative*: BOLI was recently launched with funding from the Sloan Foundation (Stoeckle 2003). DNA barcodes (i.e., DNA sequences to identify species, see Hebert et al. 2003) will be determined for all zooplankton species, using appropriate genes selected in consultation with BOLI and other CoML projects. DNA sequences are useful for species discovery among zooplankton, and can be used to reveal cryptic species and classify newly-discovered taxa (e.g., Bucklin et al. 2003). Ann Bucklin is an individual member of the Consortium for the Barcode of Life.

- *SCOR Working Groups*: There are several SCOR working groups that can directly inform CMArZ activities, including: *New Technologies for Observing Marine Life* (WG 118); *Standards for the Survey and Analysis of Plankton* (WG115); and a proposed working group on Global Comparisons of Zooplankton Time Series.

- *ICES and PICES Working Groups*: The International Council for Exploration of the Sea (ICES) is an effective international organization for coordinating field and planning activities around the North Atlantic basin. The ICES Working Group on Zooplankton Ecology (WGZE) has led efforts to standardize collection and analysis protocols (Harris et al. 2000), which will be adopted by CMarZ. Coordination will be achieved by CMarZ Steering Group members: Ann Bucklin is the USA academic delegate to ICES; ICES WGZE members include Steve Hay (chair) and Peter Wiebe. An additional group is the ICES Study Group on Management of Integrated Data (SGMID), co-chaired by Peter Wiebe. The Pacific International Council for Exploration of the Sea (PICES) provides coordination among Pacific rim nations. Analogous approaches to cooperation with PICES will be sought.

VIII.C. Oceanographic cruises of opportunity

CMarZ scientists have been asked to gather and share any information regarding planned cruises for the 2004 – 2010 field years. On the project website, CMarZ will maintain a list of research cruises, fisheries resource and environmental surveys, ships of opportunity, and commercial fishing or shipping vessel tracks. The web-site will also indicate possibilities for direct participation by CMarZ scientists and students, possibilities for special sample collection and preservation, data collection, etc. We will coordinate with the CoML Secretariat, who will also be assisting in gathering this information for CoML-related cruises.

IX. Project organization and governance

The CMarZ project will be constructed according to a consortium model of distributed authority and responsibility. The Science Plan will provide a statement of project priorities and goals, which will serve as a programmatic umbrella for use by interested scientists and others.

IX.A. CMarZ steering group

The CMarZ Steering Group will include all planning workshop participants, plus additional people who can represent particular geographic areas and/or taxonomic groups (as needed). The Steering Group currently includes:

- Demetrio Boltovskoy (Universidad de Buenos Aires, Argentina)
- Ann Bucklin (University of New Hampshire, USA)
- Colomban de Vargas (Rutgers University, USA)
- Ruben Escribano (Universidad de Concepcio, Chile)
- Steven H.D. Haddock (Monterey Bay Aquarium Research Institute, USA)
- Steve Hay (FRS Marine Laboratory, Scotland)
- Russell R. Hopcroft (University of Alaska, USA)
- Ahmet Kideys (Institute of Marine Sciences, Turkey)
- Larry Madin (Woods Hole Oceanographic Institution, USA)
- Webjørn Melle (Institute of Marine Research, Norway)
- Shuhei Nishida (University of Tokyo, Japan)

- Mark D. Ohman (Scripps Institution of Oceanography, USA)
- Francesc Pagés (Institut de Ciències del Mar, Spain)
- Annelies C. Pierrot-Bults (University of Amsterdam, The Netherlands)
- Anthony Richardson (Sir Alister Hardy Foundation for Ocean Science, UK)
- Sigrid Schiel (Alfred Wegener Institute for Polar & Ocean Research, Germany)
- Erik V. Thuesen (Evergreen State College, USA)
- Hans Verheye (Dept. of Environmental Affairs &Tourism, South Africa)
- Peter H. Wiebe (Woods Hole Oceanographic Institution, USA)

The CMarZ Steering Group will remain balanced in terms of representation, considering geographic, taxonomic, and technical (i.e., molecular vs. morphological) expertise and interests. In order to ensure this, we will add more people to the above group. A member of the CMarZ Steering Group will be nominated to serve on the CoML Scientific Steering Committee.

The CMarZ Steering Group will elect a Chair and Vice-Chair, and may choose to select an Executive Group for efficient operation and oversight of program activities. Responsibilities of the Steering Group as a whole include: evaluation of application for CMarZ endorsement; distribution of discretionary funds; coordination and oversight for taxonomic expert groups, special focus and ad hoc groups, and outreach groups; coordination of outreach activities; oversight of database management activities; interfacing with national funding agencies and programs; and coordination and collaboration with other CoML projects.

IX.B. CMarZ program office and secretariat

The CMarZ program office will be established at an appropriate academic or national research institution. The program office will host the Secretariat (i.e., an organization centered around the program office) that assists the investigators and Steering Committee members, and coordinates and sponsors program workshops and meetings. Additional satellite program offices will be established as needed, to provide regional leadership, to ensure coordination among project scientists, and to secure funding from national and regional programs and agencies.

IX.C. Coordination with CoML national and regional committees

The growing CoML global infrastructure will be beneficial to CMarZ's goal of a genuinely global-scale biodiversity survey. The National and Regional Implementation Committees (NRICs) can help provide local contacts, identify interested participants, and help seek appropriate funding sources for the local and regional field projects. CMarZ will identify a member of the Steering Group to serve as liason to each NRIC.

X. Progress to date

A CoML *Census of the Plankton* Planning Workshop was convened in Portsmouth, NH USA during March 17-22, 2004 (Fig. 14). This workshop was not intended as a scoping exercise to discuss possible topic areas, but as a working meeting for a small group of experts, who focused on designing the program and are producing the current Science Plan to guide its implementation. The workshop agenda and participant list (Appendix 4 and 5) are included here.

Invitees were experts in one or more groups of marine plankton, with expertise across the taxonomic spectrum and throughout the world oceans (see attached participant list). Importantly, the workshop participants were all active researchers, with recent publications and records of success in securing funding for their research programs. In some cases, they were also associated with government research institutions and/or have direct access to sources of logistical and/or research funding.

The workshop participants shared a commitment to the implementation of a Census of Marine Zooplankton that is global-scale in design and implemented using all available and appropriate methodologies and technologies. They also decided upon the appropriate scope – both taxonomic and geographic – for the census of zooplankton. This program will encourage and facilitate the establishment and integration of partner programs, including census activities for allied groups, and seek to lay the groundwork for their independent but coordinated analysis. These groups are the ichthyoplankton (i.e., early life stages of fish), meroplankton (i.e., organisms with non-planktonic adult life stages), as well as phytoplankton. Although these groups are functionally or systematically related, their inclusion would bring the number of species to be studied to over 25,000 (Lenz 2000). This comprehensive effort to carefully describe the current status of our knowledge of marine plankton biodiversity will result in a publication in the peer reviewed literature, and will serve also serve as a baseline for the proposed census.

Figure 14. Participants and guests for the CoML *Census of the Plankton* Workshop, March 17-22, 2004, in Portsmouth, New Hampshire (USA).

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Appendix 1. Reference materials for zooplankton identification

Partial list of reference materials arranged by year for marine zooplankton identification and analysis focused on geographical regions (A) and taxonomic groups (B).

A. Geographically-based reference materials:

- *Introducción al estudio del plancton marino* (Masutí and Margalef, 1950)
- *Manuel de planctonologie Méditerranée* (Trégouboff and Rose, 1957)
- *Illustrated Atlas of the Marine Plankton of Japanese Waters* (Yamaji, 1962)
- *Copepods of the Florida Current* (Owre and Foyo, 1967)
- *An Illustrated Guide to Marine Plankton in Japan* (M. Chihara & M. Murano)
- *Polevoi Opredelitel Planktona* (Zooplankton identification cards) (Zool. Inst. Akad. Nauk SSSR, 1971-1984)
- *Atlas del Zooplancton del Atlántico Sudoccidental y métodos de trabajo con el zooplancton marino* (Boltovskoy, ed., 1981)
- *Plankton of the North Sea* (M. van Couwelaar)
- *Antarctic Research Series*
- *Marine fauna of New Zealand* (J. Bradford-Grieve)
- *South Atlantic Zooplankton* (D. Boltovskoy (ed.) 1999)
- *Intkey, A Program for Interactive Identification and Information Retrieval* (M.J. Dallwitz et al., 2000)
- *Guide to the Coastal and Surface Zooplankton of the South-western Indian Ocean* (D. Conway et al., 2003)
- *The Continuous Plankton Recorder Atlas* (Beaugrand, 2003)
- *Coastal and Oceanic Plankton Ecology, Production and Observation Database* (COPEPOD, T. O'Brien, 2004)
- *European Registry of Marine Animals* (M.J. Costello, 2004)
- *Fiches d'Identification de Zooplancton* (ICES, 2004)

B. Taxonomically-defined reference materials:

- *Copepods (Calanoida) of the far-eastern seas of the USSR and the polar basin*. (K.A. Brodsky, 1950)
- *The copepod fauna (Calanoida) and zoogeographic zonation of the North Pacific and adjacent waters*. (K.A. Brodsky, 1957)
- *British Columbia pelagic marine Copepoda: an identification manual and annotated bibliography* (Gardner G.A. and I. Szabo, 1982)
- *Checklist of the marine planktonic copepods Africa and their worldwide distribution* (Carola, 1994)
- ETI World Biodiversity Database on CD ROM
    - *Pelagic Molluscs of the World* (S. van der Spoel, et al., 1997)
    - *Euphausiids of the World Ocean* (E. Brinton, M.D. Ohman, et al., 1999/2003)
    - *Copepods: Aetideidae of the World Ocean* (E. Markhaseva)
    - *Marine Planktonic Ostracods* (M. Angel)
- *The Planktonic Ciliate Project* (Dave Montagnes, 2004, http://www.liv.ac.uk/ciliate/)

Appendix 2. Institutional zooplankton collections

Partial list of zooplankton collections housed in and supported by recognized museums or other institutions; maintained as permanent archives; and accessible to the scientific community.

World Collections

Natural History Museum (London, UK)
Ocean Research Institute, University of Tokyo (Japan)
Sir Alister Hardy Foundation for Ocean Science (SAHFOS, Plymouth, UK)
Scripps Institution of Oceanography (La Jolla, USA)
Shirshov Institute of Oceanology (Moscow, Russia)
Smithsonian Natural History Museum (Washington DC, USA)
Zoological Institute (St. Petersburg, Russia)

Regional Collections

Alfred Wegener Institute (Germany)
British Antarctic Survey (London, UK)
Canadian National Museum (Canada)
Commonwealth Scientific and Industrial Research Organization (CSIRO, Australia)
Fisheries Research Agency (FRA, Japan)
Fisheries Research Services (Scotland UK)
Hokkaido University, Subarctic Pacific collection (Japan)
IFM-GEOMAR, Arabian Sea MOCNESS Collections (Germany)
Instituto Nacional de Investigación y Desarrolo Pesquero (INIDEP, Argentina)
Institute for the Biology of the Southern Seas (Ukraine)
Institute of Marine Research (Norway)
Institute of Marine Science (Spain)
Institute of Ocean Sciences (Canada)
Instituto del Mar del Perú (IMARPE, Peru)
Instituto de Investigacao Marinha (IIM, Luanda & Namibe, Angola)
Fisheries Research Centre (TINRO, Russia)
Marine and Coastal Management (South Africa)
Marine Research Institute (Iceland)
Museum Tenerife (Canary Islands, Spain)
National Institute of Oceanography (India)
National Institute of Water and Atmospheric Resources (NIWA, New Zealand)
National Marine Information and Research Centre (NatMIRC, Swakopmund, Namibia)
Observatoire Océanologique de Villefranche (France)
Scottish National Museum (UK)
South African Museum (South Africa)
Spanish Institute of Oceanography (Spain)
Tokai University, Cooperative Study of the Kuroshio and Adjacent Regions (CSK, Japan)
University of Izmir (Turkey)
Zoological Museum, University of Amsterdam (Netherlands)
Zoological Museum, Copenhagen (Denmark)
Zoological Museum, University of Tromsø (Norway)

Appendix 3. CMarZ zooplankton collections questionnaire

Name of Collection :

Institution housing the Collection:

Responsible person:
Contact address, email:

Digital database available?:

On-line search engine available? (please indicate URL):

Are plankton samples available for loans?:

Approximate number of whole plankton samples currently in collection:

Geographic coverage (please attach map, if available):

Particularly well sampled geographic regions?:

Depth strata covered:

Sampling devices used:

Year collection was founded:

Unique or unusual features:

Approximate percentage of samples in:
Formadehyde:______Ethanol:
Isopropyl alcohol:________Other preservatives:________

Frozen samples available?:

Samples sorted for specific taxa?

Accompanying physical/chemical data?

Bibliography of publications from collections available?

Other comments:

Email, fax, or send this questionnaire to:
Mark D. Ohman [Email: mohman@ucsd.edu, Fax 619-534-6500]
Scripps Institution of Oceanography, UCSD
9500 Gilman Drive, Mail Code: 0218, La Jolla CA, 92093 USA

Appendix 4. CoML *Census of the Plankton* Workshop Agenda

Census of Marine Life *Census of the Plankton*
Sheraton Harborside Portsmouth Hotel
Portsmouth, New Hampshire
17 – 22 March 2004

Workshop AGENDA
(Dated March 11th, 2004)

March 16 (Tuesday) – Arrivals

March 17 (Wednesday)

8:00 am	Breakfast buffet (available until 9:00 am)
9:00 am	Welcome and Introductions Purpose and goals of the Workshop
10:00 am	Guest Presentation: Ron O'Dor (Census of Marine Life) *Overview of the Census of Marine Life*
11:00 am	Background on CoML *Census of the Plankton* (Ann Bucklin)
11:30 am	Discussion: - Scope (taxonomic / geographic) and name of the *Census of the Plankton* - Plan of work for meeting participants - Approach to Working and Writing Groups
12:30 noon	LUNCH (Buffet on site)
2:00 pm	Working Groups I, II, and III meet (see list below)
4:00 pm	Presentations: Focus on geographic regions (15 min each) - Southeast Asia: a hotspot in plankton diversity (Shuhei Nishida) - Zooplankton studies in the Gulf of Aqaba / Red Sea (Sigi Schiel) - Eastern Mediterranean, Black and Caspian Seas zooplankton studies, with special reference to invasive ctenophores (Ahmet Kideys) - New information on gelatinous zooplankton fauna of the Gulf of Maine (Francèsc Pages) - Arctic zooplankton (Russ Hopcroft)
5:30 pm	Adjourn
7:00 pm	DINNER at local restaurant

March 18 (Thursday)

8:00 am	Breakfast buffet (available until 9:00 am)
9:00 am	Working Groups I, II, and III report
10:00 am	Working Groups IV, V, VI, and VII meet
12:30 pm	LUNCH (Buffet on site)
2:00 pm	Working Groups IV, V, VI, and VII report
3:00 pm	Writing Groups meet (see list below)
4:00 pm	Presentations: Issues, approaches, and tools for global surveys (15 min each) - Role of natural history collections in ocean biodiversity research (Mark Ohman) - Monitoring zooplankton diversity using ships of opportunity (Anthony Richardson) - Species-level evolution in oceanic microplankton (Colomban de Vargas) - The gelata gap: causes and cures (Steven Haddock) - Remote detection of zooplankton (Peter Wiebe) - Integrating morphology and DNA to identify zooplankton species (Ann Bucklin)
5:30 pm	Adjourn
7:00 pm	DINNER at local restaurant

March 19 (Friday)

8:00 am	Breakfast buffet (available until 9:00 am)
9:00 am	Writing Groups progress reports
10:00 am	Writing Groups meet
12:30 am	LUNCH (Buffet on site)
2:00 pm	Guest Presentation: Jesse Ausubel (Alfred P. Sloan Foundation) *The Known, Unknown, and Unknowable*
2:30 pm	Guest Presentation: Fred Grassle (Rutgers University) *Ocean Biogeographical Information System (OBIS)*
3:00 pm	Guest Presentation: Jim Hanken (Harvard University) *DNA barcoding: a new diagnostic tool for rapid species recognition, identification, and discovery"*

March 19 (Friday) – continued

3:30 pm	Guest Presentation: Lew Incze (University of New England) *CoML pilot project in the Gulf of Maine*
4:00 pm	Guest Presentation: David Mountain (NMFS/NEFSC) *Coordination with NOAA Fisheries Ecosystem Surveys*
7:00 pm	Dinner at local restaurant

March 20 (Saturday)

8:00 am	Breakfast buffet (available until 9:00 am)
10:00 am	Depart for field trip to Boston (optional)
12:30 pm	LUNCH at Boston restaurant
6:00 pm	Return to Portsmouth DINNER (on own)

March 21 (Sunday)

8:00 am	Breakfast buffet (available until 9:00 am)
9:00 am	Writing Groups meet
12:30 pm	LUNCH (Buffet on site)
2:00 pm	Writing Group progress reports and discussion
3:00 pm	Writing Groups meet
5:30 pm	Adjourn
7:00 pm	Dinner (on own)

March 22 (Monday)

8:00 am	Breakfast buffet (available until 9:00 am)
9:00 am	Writing Group reports
10:00 am	Discussion

March 22 (Monday) – continued

12:30 pm	LUNCH (Buffet on site)
2:00 pm	Discussion: Next Steps and Action Items - CoML Sloan Foundation Proposal - Funding strategies and proposal group identification - BioScience article and other peer-reviewed journal articles - Program brochure
5:30 pm	Adjourn
6:00 pm	Reception at Portsmouth Athenaeum
7:30 pm	Dinner at local restaurant

March 23 (Tuesday) – Departure

8:00 am	Breakfast buffet (available until 9:00 am)

Working Groups

Set 1 (WG I – III)

I. Approaches to global / taxonomically comprehensive surveys
II. Biodiversity hotspots: targeting regions for species discovery
III. New technologies

Set 2 (WG IV – VII)

IV. Summary of existing zooplankton samples
V. Data management, integration, visualization
VI. Using ships of opportunity
VII. Education and outreach

Writing Groups

1. Baseline Report
2. Implementation Plan

Appendix 5. CoML *Census of the Plankton* workshop participant list

Organizing Committee

Ann Bucklin, Professor (Local Host), University of New Hampshire, Durham, NH USA
Colomban de Vargas, Rutgers University, New Brunswick NJ, USA
Russell R. Hopcroft, University of Alaska Fairbanks, Fairbanks, AK USA
Larry Madin, Woods Hole Oceanographic Institution, Woods Hole, MA USA
Erik V. Thuesen, Evergreen State College, Olympia, WA USA
Peter H. Wiebe, Woods Hole Oceanographic Institution, Woods Hole, MA USA

Workshop Participants

Demetrio Boltovskoy, Universidad de Buenos Aires, Buenos Aires, Argentina
Steven H.D. Haddock, Monterey Bay Aquarium Research Institute, Moss Landing, CA, USA
Steven J. Hay, FRS Marine Laboratory, Aberdeen, Scotland
Ahmet Kideys, Institute of Marine Sciences, Erdemli, Mersin, Turkey
Webjørn Melle, Institute of Marine Research, Bergen, Norway
Shuhei Nishida, Ocean Research Institute, University of Tokyo, Tokyo, Japan
Mark Ohman, Scripps Institution of Oceanography, UCSD, La Jolla CA, USA
Francesc Pagés, Institut de Ciències del Mar (CSIC), Barcelona, Spain
Annelies C. Pierrot-Bults, University of Amsterdam, Amsterdam, The Netherlands
Anthony Richardson, Sir Alister Hardy Foundation for Ocean Science, Plymouth, UK
Sigrid Schiel, Alfred Wegener Institute for Polar and Ocean Research, Bremerhaven, Germany

Invited Guests

Jesse H. Ausubel, Alfred P. Sloan Foundation, New York, NY USA
Victor A. Gallardo, Universidad de Concepcion, Concepcion, Chile
J. Frederick Grassle, Rutgers University, New Brunswick NJ, USA
James Hanken, Harvard University, Cambridge, MA, USA
Lewis S. Incze, University of Southern Maine, Portland, ME, USA
David Mountain, NMFS Northeast Fisheries Science Center, Woods Hole, MA, USA
Ron O’Dor, Consortium for Oceanographic Research and Education, Washington, DC, USA