Diel, Seasonal and Interannual Patterns in Zooplankton and Micronekton Species Composition in the Subtropical Atlantic

2. Abstract

Planktonic communities comprise an incredibly wide diversity of organisms that form the basis of marine food webs. We propose a multi-species inventory of zooplankton and micronekton at the Bermuda Atlantic Time-series Study (BATS) station, an 11-year, ongoing oceanographic time series situated in the western North Atlantic subtropical gyre or Sargasso Sea. The program will provide high-resolution species data that covers diel, seasonal, interannual, and decadal time scales. Detailed accompanying environmental data already available from BATS cruises (e.g., water column temperature, oxygen, nutrients, and plant pigment concentration) add additional value to the data set. Both species and environmental "metadata" will be formatted using techniques already well developed and in use at BATS for compilation and provision of data of interest into OBIS. Our proposed project will involve participation from both academia (Bermuda Biological Station for Research, Woods Hole Oceanographic Institution, Russian Academy of Sciences' Zoological Institute) and government (the Smithsonian Institution's National Museum of Natural History). We have developed a partnership with significant collective experience in the study of the subtropical North Atlantic system and expertise in the identification (and ecology of) all major taxa of zooplankton and micronekton. This project will provide a high quality time series of zooplankton and micronekton species composition enabling us to dissect the difference between natural variability and real 'change' in the diversity of plankton communities. This will be critical for testing and validation of ecosystem models, and for understanding the effects of long term climate change on ecosystems.

3. Relevance of proposed research to NOPP Objectives

3.1 Support of Critical Research Objectives and Operational Goals

The critical research objective of OBIS is to provide data on species distribution and abundance and to serve as a starting place in which data collected in the future can be placed. The proposed multi-species inventory of zooplankton and micronekton at the Bermuda Atlantic Time-series Study (BATS) station in the subtropical Atlantic ocean will provide high resolution data that covers diel, seasonal, interannual, and decadal time scales. Detailed accompanying environmental data already available from BATS cruises and trawl collections (e.g., water column temperature, oxygen, nutrients, and plant pigment concentration) add additional value to the data set. Both species and environmental "metadata" can be easily formatted using techniques already well developed and in use at BATS for compilation and provision of data of interest into OBIS.

<u>Data accessibility and distribution</u>
The species data derived from the proposed partnership will be shared amongst the partners and with the community at-large. In addition to supplying the data to the developing OBIS program, we will utilize the existing BATS public data distribution system, which is routinely successfully used to relay data via the Internet. The BATS data can be accessed via the World-Wide-Web by starting at the BBSR home page, http://www.bbsr.edu, and following the links to the BATS data repository (all of the data from the BATS program are made available publicly over the Internet within 12 months of collection). The BATS laboratory has extensive computing and data transferal capabilities to support our effort. The web site can be maintained and updated frequently to provide data to interested members of the community. This will also help to facilitate interactions which external scientists (or educators, technicians, or any other potential users of the data) who are ancillary users of the data.

<u>Education and outreach efforts</u>
The zooplankton species data obtained from this proposed project will be used in and directly benefit a number of ongoing educational and outreach programs at both BBSR and WHOI. Both institutions are committed to training graduate students; the WHOI/MIT Joint Program in Oceanography is considered one of the best oceanography programs in the country. A zooplankton census would afford multiple possibilities for student projects. In addition to its graduate program, WHOI offers Summer Fellowships to a select group of undergraduates, and paid and unpaid internships (Guest Students) to both college and high school age students. Since 1995, at least a dozen undergraduates have spent time in Madin's lab as Summer Fellows or Guest Students, often working on aspects of zooplankton and micronekton collections. The program proposed here lends itself well to short-term subprojects for undergraduates. Madin has also provided sample material to high school and college instructors for classroom and laboratory use, something that would also be possible with subsamples of the BATS collections. With funding from the NSF Department of Education, D. Steinberg and co-PIs developed a distance learning program using the BATS data entitled: 'Use of Web-Based Scientific Resources in Teaching and Teacher Training: Using Real Data Sets to Explore Oceanography and Global Environmental Change' (NSF DUE-9752494). The BATS data set is used in this program as a teaching tool for middle and high school teachers. The addition of zooplankton species data will be a tremendous asset to the program, allowing us to explore biodiversity issues as part of the curriculum. D. Steinberg is also co-PI on BBSR's REU (Research Experience for Undergraduates) program (NSF OCE-9619718) in which students participate in ongoing research programs at BBSR. The zooplankton census would allow multiple possibilities for student projects in this program. The census would also be used in other BBSR education activities. BBSR offers a variety of graduate and undergraduate courses that would incorporate this program into their curriculum, including biological oceanography (taught by D. Steinberg) and marine invertebrate zoology. BBSR also sponsors a range of community outreach programs including Elderhostel (courses in a marine or environment related topic for retired people) and a well-attended public lecture series which would benefit from the proposed project.

3.2 Broad Participation within the Oceanographic Community

Our proposed project will involve participation from both academia (BBSR, WHOI, Russian Academy of Sciences' Zoological Institute, St. Petersburg) and government (Smithsonian Institution's National Museum of Natural History). We feel one of the most important aspects of our project is that it will provide a high quality time series of zooplankton and micronekton species composition in what is arguably one the of the most intensively studied areas of the world's oceans. Thus we have developed a team that has significant experience in the study of the subtropical North Atlantic system, and collectively has expertise in the identification (and ecology of) all major taxa of zooplankton and micronekton. Besides the proposed partnership team described herein, a large number of oceanographers will ultimately be collaborators. The BATS program as a whole involves the participation of over one hundred investigators doing BATS-related research. The species abundance list that will be generated from this project has been considered critical missing data by the oceanographic community, simply because zooplankton community structure is so important to understanding food webs and cycling of elements in the sea. The partnership with the Museum of Natural History ensures that any new species discovered, or missing species from the current collection will be placed into the national archives to benefit future scientists. Finally, notable in our partnership is the important contribution from a scientist in the former Soviet Union, where support for science has become tenuous in an unstable economy. The participation of Dr. Markhaseva adds important taxonomic expertise, in an area where domestic experts are becoming fewer. We consider the collaboration and sharing of knowledge with her to be as valuable to us as it may be to her.

3.3 Long-Term Commitments to Proposed Objectives

The proposed partners have been dedicated to the objectives outlined in this proposal for much of their careers, as evidenced in their publications and current research activities. Dr. Steinberg has been studying zooplankton ecology for over a decade and at the BATS site for the last 5 years. Her projects at BATS have ranged from seasonal, interannual, and diel studies of zooplankton biomass and diversity, to the role of zooplankton in nutrient cycling and particle fluxes, to chemical defenses in zooplankton, to food web studies of the epi-pelagic and mesopelagic zooplankton communities at BATS. She has received in the past, and will continue to pursue grant monies in the future for other zooplankton research at BATS. Dr. Madin has nearly 30 years of experience in zooplankton ecology, with particular emphasis on gelatinous animals, and oceanic and mesopelagic species. He has been PI of the program of regular zooplankton sampling at the BATS station since 1994 (Madin et al. in press), and has participated in previous sampling and experimental work at the BATS site, including the Beebe Project in 1987 (Madin, 1988), the ZOOSWAT program in 1989-90 (Caron et al. 1995, Roman et al. 1995, Madin et al. 1996) and midwater sampling in 1992-93. His research interests include systematics and biogeography of zooplankton, as well as behavior, energetics, life histories, and the role of feeding and diel migration in material fluxes in the ocean. He has prepared one previous taxonomic guide to zooplankton (Madin, 1991). Dr. Elena Markhaseva has studied the taxonomy of pelagic copepods from different regions of the world's oceans for 2 decades. These studies have been based on zooplankton samples collected by Russian marine biologists in the Atlantic, northwestern Pacific, and Southern Ocean (samples deposited in Zoological Institute RAS, St. Petersburg, and Institute of Oceanology, Moscow), samples collected by DSRV Alvin in the eastern tropical Pacific in collaboration with Dr. Frank Ferrari (Smithsonian Institution, Washington D.C.), and in partnerships with German copepodologists in the Arctic and Southern Oceans. Her works has focused on the most abundant copepod taxa, order Calanoida. Dr. Ferrari has 25 years of research experience in systematics and ecology of copepods. He has been studying interannual variation in abundance of *Pleuromamma xiphias* and development of oceanic calanoid copepods at BATS for the last seven years.

The commitment to the collection of zooplankton (and measurement of biomass) at the BATS site will be continued beyond the scope of this proposed 2 year effort as part of the BATS core program. We are also optimistic that with the framework set up in the project proposed herein, we could procure funding to continue species composition analysis of the time series as a continuing part of the BATS core measurements.

3.4 Shared Resources

Extensive resources will be shared among our partnership. The partners are all committed to maintaining archived plankton samples at each institution. BBSR will continue to catalogue all BATS time-series zooplankton samples, and provide sample access to other interested users of the data. WHOI will maintain and provide access to silhouette images of the plankton time-series, and the BATS 0-1000 m MOCNESS samples (see section 4.1.2 below). The Smithsonian's National Museum of Natural History will add any rare, previously undescribed, or missing species to their catalogued collection for future users of the data (see attached letter). All partners will provide access to microscope and other laboratory facilities at their institutions, an example is the hosting of Dr. Markhaseva by the Smithsonian's Museum of Natural History. All partners will be committed to maintaining species reference materials as well.

<u>Degree of Cost-sharing by Partners</u>
This proposal provides a significant degree of cost sharing in the form of laboratory facilities, and personnel time. In addition, the complementary data set of biological, chemical, and physical measurements provided by the other BATS time-series measurements (see section 4.1.3, and Figures 3 & 4) have an exceptionally high value to the program.

4. Research Tasks

4.1 Scientific Background and Goals, Objectives, Approach, Timeline, and Tasks

4.1.1 Scientific Background

Importance of a Plankton Census

Planktonic communities comprise an incredibly wide diversity of organisms that form the basis of marine food webs (Table 2). The zooplankton and micronekton (larger zooplankton or those capable of increased locomotion) provide a direct link between primary producers (phytoplankton) and higher trophic levels such as fishes, sea birds, and some marine mammals. Zooplankton contain representatives of nearly every animal group (Table 2). There are more than 11,300 species of copepods (subphylum crustacea) (Humes, 1994); this number conservatively represents about 20% of the expected number of extant species. Pelagic copepods can reach abundances of 70,000/ m^3 in the surface waters of the North Sea (Huys and Boxshall, 1991), and individuals of *Dioithona oculata*, which form monospecific swarms in subtropical and tropical lagoons, can reach abundances of up to 100 million/ m^3 [100/ml] in swarms (Ambler et al., 1991; Buskey et al., 1995). A large variety of gelatinous zooplankton inhabits the sea, with prominent members including medusae, siphonophores, ctenophores, pelagic molluscs, and pelagic tunicates (e.g., salps, larvaceans). The pelagic members of the phylum Cnidaria, which include the medusae and siphonophores, include over 1,000 known species (e.g., Larson et al. 1988, Larson and Harbison 1990). The ubiquitous pelagic tunicates include more than 160 known species (Godeaux 1998, Fenaux 1998). Salps for example, are periodically encountered in swarms extending hundreds of kilometers (Berner 1967, Wiebe et al. 1979, Andersen 1998) and although patchy, can reach densities of 1000 animals/ m^3 (e.g., Roger 1982, Paffenhoffer and Lee 1987).

Table 2. Diversity of major marine zooplankton and micronekton taxa.

Taxon	Approximate Number of Described Taxa[1]	Source
Cnidaria (medusae and siphonophores)	>1,000	Larson et al. 1988, Larson and Harbison 1990
Ctenophores	60	Various unpublished
Molluscs	137	Lalli and Gilmer 1989
Chaetognaths	60	Pierrot-Bults and Chidgey 1988
Crustacea:		
Copepods	>11,300[2]	Humes 1994
Euphausiids	87	Baker et al. 1990
Decapods	200	Marshall 1979
Amphipods (e.g., hyperiids)	45	Bowman and Gruner 1973
Mysids	780	Mauchline 1980
Tunicates:		
Thalacia (salps, doliolids, pyrosomes)	94	Godeaux 1998
Larvaceans	69	Fenaux 1998

[1]Most groups also contain various numbers of undescribed/ undiscovered species
[2]Includes some parasitic forms

Two important values of a census of the diversity and abundance of the plankton are 1) the need to describe and understand patterns of distribution and abundance of organisms and to predict the impact of environmental change on those patterns and 2) to better understand their qualitative and quantitative role in the pelagic food web and the cycling of elements in the sea.

In the last few decades, one of the major concerns of environmental scientists has been to understand how potential climate changes in the earth's atmosphere will effect the oceans. One of the most sensitive indicators of environmental change is species diversity, abundance, and community structure. There are already indications of the effect of climate warming on planktonic populations. For example, the biomass of macrozooplankton in the waters off Southern California has declined by 80 percent since 1951 (Roemmich and McGowan 1995). During this same period the surface 100 meters of the water column has significantly warmed, causing enhanced stratification and thus suppression of nutrient input from deeper, nutrient rich waters (Roemmich and McGowan 1995). The two observations appear to be linked, as does a recent decline of zooplankton-feeding seabirds in the area. A warming trend has also been documented for the Antarctic Peninsula region since the 1940s, with an associated decrease in sea ice duration and extent (Loeb et al. 1997). Krill abundance in the region is positively correlated with the extent of sea ice cover, while salp abundance is negatively correlated, partially due to availability of ice-algae, an important food for larval krill. The decreased frequency of winters with extensive sea-ice cover is predicted to lead to longer-term decreases in krill abundance. A significant decline in penguin populations in some regions may be an affect of decreasing krill prey populations (Loeb et al. 1997). The management of the krill fishery will also likely be affected to reflect these longer-term changes (Loeb et al. 1997). These studies illustrate the need for a long-term species composition and abundance census.

The plankton are responsible for the regulation of material and energy flux in oceanic food webs. Zooplankton grazing plays a key role in the recycling of all biogenic elements, and the community structure of the pelagic food web determines the export of elements from the upper water column. The abundance of particular taxa can dramatically affect this structure (e.g., Michaels and Silver 1988). Zooplankton are food for commercially important fish. For example, copepods in the genus *Calanus* are the primary food source for larval and juvenile cod, one of the most important commercial species in the North Atlantic (Kane, 1984), and zooplankton even in tropical environments form an important link to forage fish and thus to larger commercial species.

Why an open ocean census of zooplankton? The oceans cover almost 70% of the surface area of the earth. The open ocean, that part of the sea beyond the continental shelves and deeper than ~ 1 km covers over 62 % of the area of the earth. By volume, the open ocean is estimated to be nearly 79 % of the living space on earth (Harbison 1992). Previous workshops on the Census of Marine Life have noted that although coastal area species distributions may be more sensitive to human impact, the most pressing need was for data from large, less well known biogeographical regions such as the open ocean. Data on the higher trophic levels such as the zooplankton, micronekton, and fish taxa in these areas are conspicuously sparse. The need is to focus on filling in the gaps on these large unknowns (Alldredge, Census workshop report).

The Bermuda Atlantic Time-series Study (BATS)

The Bermuda Atlantic Time-series Study (BATS) program is an 11-year, ongoing oceanographic time series situated in the western North Atlantic subtropical gyre or Sargasso Sea. The BATS station lies 82 km southeast of the island of Bermuda (31˚ 40' N, 64˚ 10' W). This program, in combination with the continuous 55-year Hydrostation S hydrographic time-series, makes the site one of the most intensively studied parts of the world's oceans (Steinberg et al. in press). BATS commenced sampling in October 1988 (along with a companion time series, the Hawaiian Ocean Time-series, HOT) as part of the U.S. Joint Global Ocean Flux Study (JGOFS) program. The goals of the U.S. JGOFS time-series research are to understand the basic processes that control ocean biogeochemistry on seasonal to decadal time-scales, determine the role of the oceans in the global carbon budget, and ultimately improve our ability to predict the effects of climate change on ecosystems (SCOR, 1987). The BATS program samples the ocean on a biweekly to monthly basis, a strategy that resolves major seasonal patterns and interannual variability. The core cruises last five days during which hydrography, nutrients, particle flux, pigments and primary production, bacteria abundance and production are measured, and samples are taken for phytoplankton and zooplankton community structure and biomass. All data are routinely posted on the World Wide Web [http://www.bbsr.edu - follow links to BATS data]

History of Zooplankton Studies at BATS

Studies of zooplankton species composition and seasonal dynamics in the vicinity of Bermuda date back several decades (Moore 1949, 1950; Sutcliff 1960; Menzel and Ryther, 1961; Beers, 1966; Deevey, 1971; Deevey and Brooks, 1971; Deevey and Brooks, 1977; von Bodungen et al., 1982, Wen-tseng and Biggs, 1996, Madin et al., 1996). Some more recent studies focused on seasonal changes in biomass or community structure and the effects of zooplankton on biogeochemical cycling at BATS (Dam et al., 1995; Roman et al., 1993, 1995; Steinberg et al. 2000, Madin et al. in press). The most comprehensive time-series study of seasonal and interannual variation in zooplankton biomass at BATS is described in Madin et al. (in press). Regular sampling for zooplankton biomass and species composition at BATS has been a part of the program from the beginning (see section 4.1.2) and the complete analysis and compilation of the results of this work is the focus of this proposal.

4.1.2 Scientific Objectives

The objectives of this proposal are to:

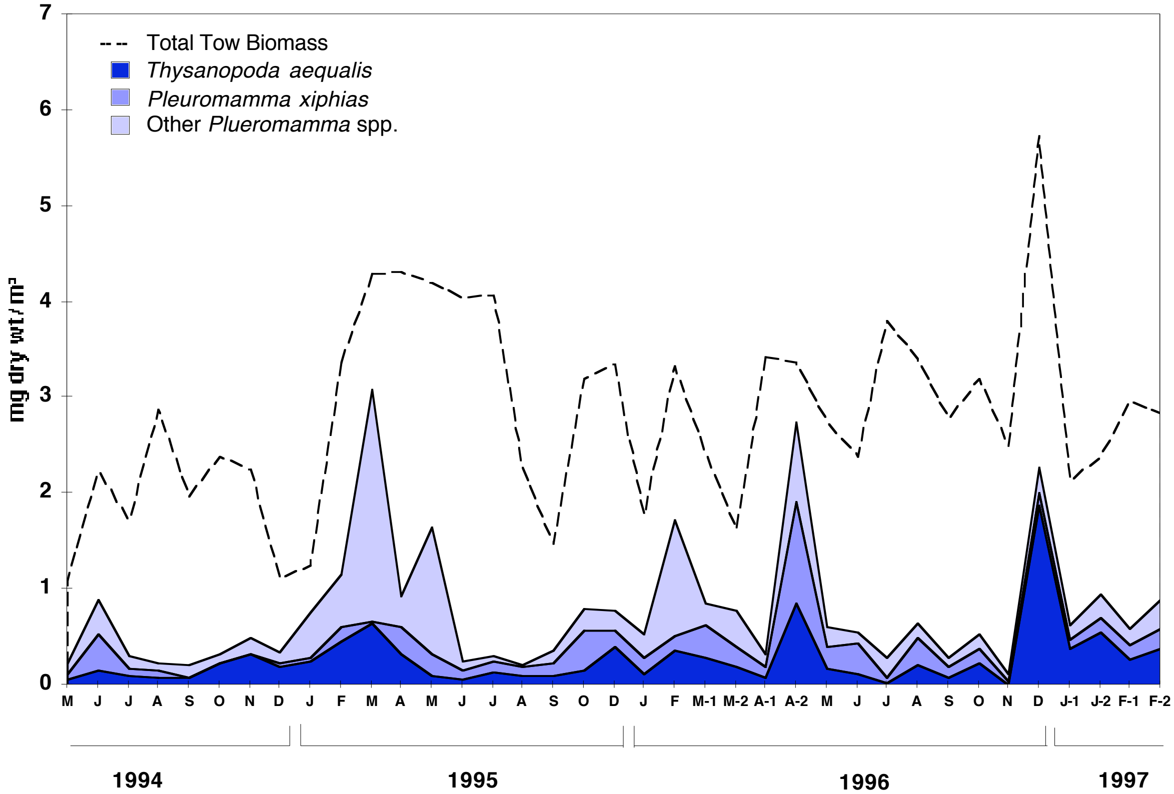
Complete a multi-species inventory of zooplankton and micronekton at BATS
Provide high-resolution data that covers diel, seasonal, interannual, and decadal time scales
Provide detailed accompanying "metadata" available from BATS cruises (e.g., water column temperature, oxygen, nutrients, plant pigment concentration)
Format both species and "metadata" for incorporation into the OBIS, using techniques already well developed and in use at BATS for organizing, archiving and serving data of this type.

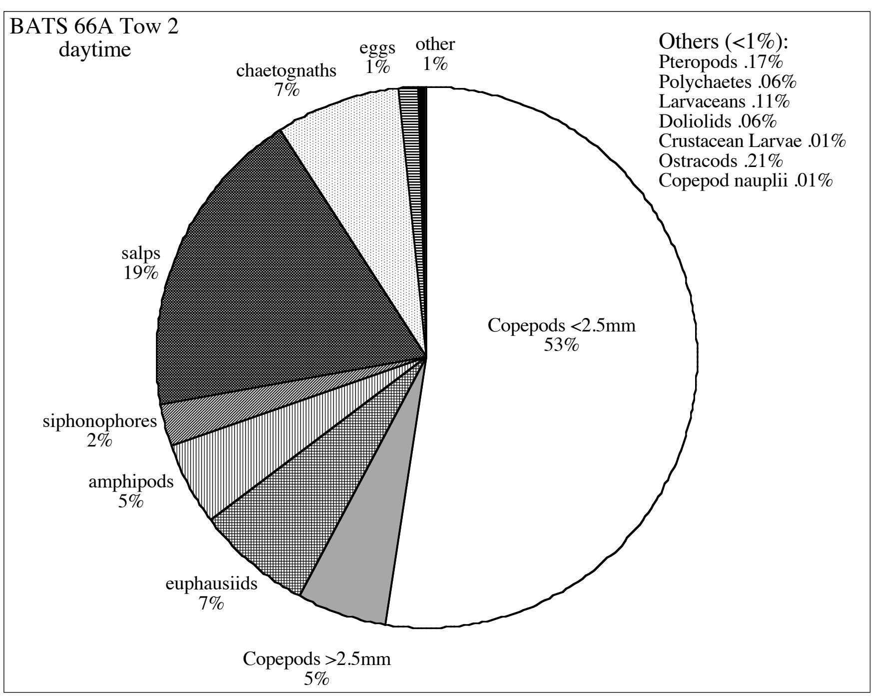
We propose to use three different BATS zooplankton and micronekton data and sample sets for our analysis:

Replicate, night zooplankton tows have been a component of every monthly BATS cruise since 1989. Tows are made in the top 150 meters using a 1m diameter 335 μm mesh net and flow meter. These samples are archived at BBSR, and although they have been sorted for a few groups (e.g., salps and some copepods), they are largely unanalyzed.
In April 1994, Dr. L.P. Madin began a complementary study of zooplankton biomass at BATS and since then monthly, replicate day and night tows are also made in the upper 200 meters on all BATS cruises using a 202 μm, 1m^2 plankton net and flow meter. (A time depth recorder is used on tows so the exact depth of the trawl is known) The complete data set including size fractionated wet and dry weight biomass for individual tows is available at the web site above, and is discussed in Madin et al (in press). Half of each sample was also preserved for subsequent species identification, and silhouette photographs made for future analysis of species composition. A small subset of these samples has been analyzed for species composition, and a new, computer-assisted method is being developed for rapid analysis of the silhouette photos. Examples of these data can be seen in Figures 1 and 2.
In addition, Dr. Madin has a set of BATS deep-water trawl samples made using a 10 meter, 3 mm mesh MOCNESS (Multiple opening/ closing net and environmental sensor system, Wiebe et al. 1985) from cruises at different times of the year during 1992- 1993. Trawls were made from 0-1000m in 4 depth strata. Fifty-six trawls and approximately 200 samples were collected on these cruises, of which more than half have been analyzed for species composition of macrozooplankton and micronekton, and are already in spreadsheet format. An example of these data can be seen in Table 3.

We believe these data sets are highly complementary and give a quite complete picture. They cover a long time period (#1 -over a decade), record diel changes in zooplankton species composition which is critical to any zooplankton species data set (#2, 3), include not only the surface ocean species (#1, 2, 3) but the deeper-living species as well (#3), and sample a wide range of size classes of zooplankton, including some of the micronekton (especially #3). We propose to analyze samples that have not been sorted to develop a multi-species inventory of the zooplankton and micronekton at BATS to provide to the OBIS, as well as compile and provide existing species data.

Figure 1. Example time-series of some of the important vertically migrating zooplankton species at BATS. (from Steinberg et al. 2000) Data are averages of replicate night tows taken in the upper 200 meters on BATS cruises. Numbered months denote >1 cruise in same month. The biomass of individual species was estimated by multiplying species counts in each tow by the mean dry weight determined for each species (Note- *Thysanopoda* is an euphausiid, *Pleuromamma* is a copepod).
Figure 2. Taxonomic composition of zooplankton from BATS time series tow, April 1994, daytime.





Identification of categories are from silhouette photo analysis. The analysis to be done in the current proposal will be to lower taxonomic levels - genus or species in most cases.

Table 3. Taxon list for 0-1000 m macrozooplankton and micronekton collected at the BATS station, June 1992. Data from 10 m^2 MOCNESS trawls, Endeavor cruise 238. Collections were stratified, but this list combines taxa collected at all depths. Fishes were also collected and identified but are not included in this list. Some identifications are still incomplete.

Sarcodina

- Radiolarian colonies

Cnidaria

Anthozoa

- Anthozoan larvae

Hydromedusae

- *Aegina* sp.
- *Aeginopsis* sp.
- *Aglaura* sp.
- *Bougainvilla platygaster*
- *Colobonema sericeum*
- *Cunina* sp.
- *Narcomedusa* sp.
- *Pandea conica*
- *Pandea* sp.
- *Pegantha* sp.
- *Rhopalanema* sp.
- *Rhopalanema* sp.
- *Trachymedusa* sp.

Scyphomedusae

- *Atolla sp*.
- *Pelagia* sp.
- *Periphylla periphylla*
- *Periphylla* sp.

Siphonophores

- *Abyla* sp.
- *Agalma okeni*
- *Amphicaryon* sp.
- *Bassia bassencis*
- *Bassia* sp.
- *Calycophoran* sp.
- *Ceratocymba* sp.
- *Chelophyes appendiculata*
- *Chuniphyes* sp.
- *Enneagonum* sp.
- *Hippopodus hippopus*
- *Lensia* sp.
- *Nectopyramis diomediae*
- *Physonect nectophores*
- *Physonect* sp.
- *Rosacea* sp.
- *Spheronectes* sp.
- *Sulculeolaria* sp.

Ctenophora

- *Beroe* sp.

Mollusca

Heteropods

- *Atlanta* sp.
- *Pterotrachea* sp.

Pteropods

- *Cavolinia gibbosa*
- *Clione* sp.
- *Cuvierina columnella*
- *Diacria trispinosa*
- *Euclio balantium*
- *Euclio cuspidata*
- *Euclio pyrimidata*
- *Euclio tricuspidata*
- *Gleba cordata*
- *Limacina inflata*
- *Limacina* sp.
- *Peraclis apicifulva*

Annelida

Polychaetes

- Alciopids
- Other polychaetes
- *Tomopteris* spp.

Crustacea

Copepods

- *Sapphirina* sp.
- *Augaptilidae* sp.
- *Eucalanus* sp.
- *Euchaeta* spp.
- *Lucicutia* sp.

Decapod crustaceans

- *Acanthephyra purpurea*
- *Bentheogennema intermedia*
- *Brachiostega* sp.
- Brachyuran larvae
- Brachyuran megalopa
- Caridean larvae
- Carideans
- *Ephyrina bifida*
- *Gennadas brevirostris*
- *Gnathophausia gigas*
- *Hymenopenaeus laevis*
- Lobster megalops
- *Lucaya bigelowi*
- *Notostomus compsus*
- *Notostomus vescus*
- *Oplophorous grimaldii*
- *Oplophorous spinicauda*
- *Parapandalus richardi*
- *Parapasiphae sulcutifrons*
- *Pasiphaea liocerca*
- *Pasiphaea multidentata*
- *Pasiphaea* sp.
- Phyllosome larve
- Scyllarid sp. larva
- *Sergestes armatus*
- *Sergestes armatus* larva
- *Sergestes atlanticus*
- *Sergestes corniculum*
- *Sergestes cornutus*
- *Sergestes cornutus* larva
- *Sergestes edwardsii*
- *Sergestes grandis*
- *Sergestes pectinatus*
- *Sergestes robustus*
- *Sergestes sargassi*
- *Sergestes* sp.
- *Sergestes* sp. larva
- *Sergestes splendens*
- *Sergestes splendens* larva
- *Sergestes talismani*
- *Sergestes tenuiremis*
- *Sergestes vigilax*
- Stomatopod larva
- *Systellaspis debilis*

Euphausiids

- *Euphausia* spp.
- *Euphausia/Thysanapoda*
- Euphausid larvae
- *Nematobrachion boopis*
- *Nematobrachion flexipes*
- *Nematobrachion sexpinosis*
- *Nematobrachion* spp.
- *Nematoscelis atlantica*
- *Nematoscelis flexipes*
- *Nematoscelis microps*
- *Nematoscelis* sp.
- *Stylocheiron abbreviatum*
- *Stylocheiron affine*
- *Stylocheiron elongatum*
- *Stylocheiron maximum*
- *Thysanoessa* sp.
- *Thysanopoda* sp.
- *Thysanopoda tricuspidata*

Mysids

- *Gnathophausia gigas*
- *Gnathophausia gigas* juv.

Ostracods

- *Macrocypridina* sp.

Chaetognatha

- *Eukrohnia* sp.
- *Sagitta* sp.

Hemichordata

- Hemichordate larvae
- *Planctosphaera* sp.

Urochordata

Pyrosomes

- *Pyrosoma* larva
- *Pyrosoma* sp.

Salps

- *Iasis zonaria*
- *Pegea confederata*
- *Pegea socia*

Salps (continued)

- *Ritteriella retracta*
- *Salpa aspera*
- *Salpa fusiformis*

(Table 3 continued)

4.1.3 Technical Approach

Species analysis

Madin, Steinberg, and Ferrari have all worked on Sargasso Sea zooplankton extensively, and Markhaseva also has extensive experience in Atlantic zooplankton taxonomy. Thus, in addition to the existing historical species data from BATS (e.g., for copepods, Sutcliffe, 1960 & Deevey and Brooks, 1977; for siphonophores- Wen-tseng and Biggs 1996; for salps- Madin et al. 1996), and the samples from BATS that have already been analyzed for species composition, each of us has compiled additional species lists as well as archived many type specimens from the Sargasso Sea. We will begin by sharing this information and distributing replicate type specimens from the Sargasso Sea for many of the common species of each group. The rarer, more difficult species identifications will be sent to a member of our team with particular expertise (e.g., Madin's lab for the gelatinous groups, amphipods, and molluscs, Markhaseva and Ferrari for copepods, Steinberg for other crustaceans) or sent to a colleague. We will also make use of the ease of sending images across the Internet, and have requested digital cameras for microscopes at BBSR and WHOI for compilation of an on-line species database. Both Steinberg and Madin already have numerous existing images of common zooplankton at BATS. Once a working list of species has been compiled and common type specimens traded, we will begin the analysis of time series samples that have not yet been analyzed completely.

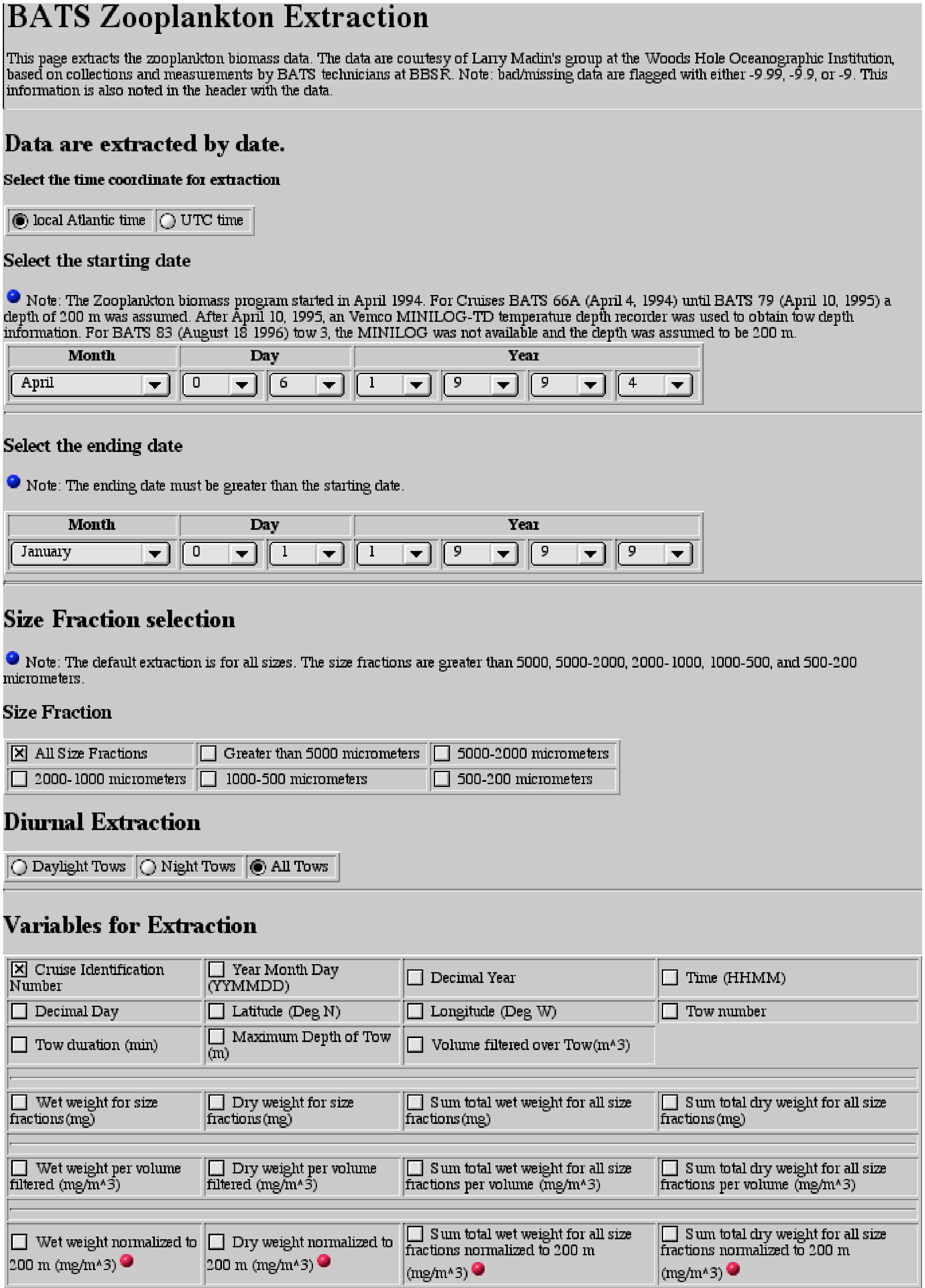
As described above (section 4.1.2) we have three different complementary data sets for provision to the OBIS. For those samples with species lists already compiled (e.g., half of data set #3, 0-1000 m MOCNESS samples) we can begin to compile data immediately. We will next analyze samples from data set #2 above, the day/night, monthly zooplankton time-series for which we already have accompanying biomass information that is available in the BATS data base. Silhouette photos are available for all these samples (and have been analyzed for some), with taxonomic resolution possible down to the species level for some groups and genus for others, from the photos alone. Silhouette photos are essentially contact prints on 8x10" high-resolution black and white film, made by distributing the fresh plankton sample directly onto the film surface, and exposing the film with a very short duration electronic flash (Ortner et al. 1979). The method preserves an exact image of the organisms, allowing the film to be examined microscopically for measurement, enumeration and identification of the sample. Previously, we have done the analysis by examination of photos with a dissecting microscope and measurement of images on a digitizing tablet. We are currently working with P. Wiebe and others to develop a new method, in which the films will be scanned into image files, and the images will be subsequently marked, measured and counted with image processing software. Taxonomic identifications will still be done by human experts, but working with images on a computer screen rather than seen through a microscope. Data will be entered directly into spreadsheet files, from which abundance, size distributions and species diversities can be calculated. This computer-aided method will be used for all silhouettes analyzed in the proposed project.

The accompanying preserved samples will be analyzed for those taxa that cannot be satisfactorily identified via silhouette analysis. Most samples are already in appropriate size splits for counting. From our experience, splits ranging from 1/2 to 1/4 are necessary for enumeration of larger gelatinous zooplankton and micronekton, and 1/64 splits are necessary for samples with high numbers of copepods, as occurs in spring. The silhouette analysis will be performed at WHOI, and Steinberg and Madin's laboratory teams will divide the samples that need to be microscopically examined. In order to extend the time series to cover a full decade, we will begin with the samples from data set #1 starting with the earliest samples and working forward. We will include sufficient overlap with data set #2 to determine if species composition is comparable (i.e., as data set #1 was collected with a 335 μm mesh vs. data set #1 with a 202 μm mesh), but do not foresee needing to "double up" on the entire overlapping period between both monthly zooplankton time series sets.

Provision of data to OBIS

All species data will be placed into spreadsheets and formatted as is data in the BATS database. Every BATS cruise is already coded with a cruise identification number, and any accompanying "metadata" can instantly be supplied along with any species list from a given cruise. After some minor programming to match the characteristic time and space scale lengths of the two different data sets, we will be able to make the zooplankton species database synoptic with the existing BATS hydrographic data base. This means that however OBIS develops we should be able to easily format our species data for instant placement, along with accompanying environmental data regularly collected on BATS cruises including: pressure, temperature, salinity, dissolved oxygen, nutrients (nitrate, nitrite, phosphate, and silicate), carbon dioxide, dissolved organic carbon, particulate organic carbon and nitrogen, bacterial abundance, and phytoplankton pigments. Rate measurements such as primary productivity, bacterial growth, and sediment trap flux are also available. This data dissemination can be used for education as well as research. The data extraction interface at BATS utilizes an HTML front-end document with a computer graphic interface (CGI). This spawns off C programs in the background, which read both binary MATLAB and ASCII text files. Currently the output format is ASCII. The design of the HTML interface is modular so additions, such as zooplankton species composition at BATS, can easily be made. Figure 3 shows the existing data extraction user interface for zooplankton biomass on the BATS web site. The extraction possibilities for accompanying metadata are shown in Figure 4. Species data can easily be added to our system to provide data to OBIS in any combination/ format desired.

Figure 3. Zooplankton data extraction page from BATS web pages. The user selects the time period of interest with drop menus, then selects the data of interest. Any combination of variables desired can be selected.



BATS Zooplankton Extraction

This page extracts the zooplankton biomass data. The data are courtesy of Larry Madin's group at the Woods Hole Oceanographic Institution, based on collections and measurements by BATS technicians at BBSR. Note: bad/missing data are flagged with either -9.99, -9.9, or -9. This information is also noted in the header with the data.

Data are extracted by date.

Select the time coordinate for extraction

local Atlantic time | UTC time

Select the starting date

Note: The Zooplankton biomass program started in April 1994. For Cruises BATS 66A (April 4, 1994) until BATS 79 (April 10, 1995) a depth of 200 m was assumed. After April 10, 1995, an Vemco MINILOG-TD temperature depth recorder was used to obtain tow depth information. For BATS 83 (August 18 1996) tow 3, the MINILOG was not available and the depth was assumed to be 200 m.

Month	Day		Year			
April	0	6	1	9	9	4

Select the ending date

Note: The ending date must be greater than the starting date.

Month	Day		Year			
January	0	1	1	9	9	9

Size Fraction selection

Note: The default extraction is for all sizes. The size fractions are greater than 5000, 5000-2000, 2000-1000, 1000-500, and 500-200 micrometers.

Size Fraction

All Size Fractions	Greater than 5000 micrometers	5000-2000 micrometers
2000-1000 micrometers	1000-500 micrometers	500-200 micrometers

Diurnal Extraction

Daylight Tows | Night Tows | All Tows

Variables for Extraction

Cruise Identification Number	Year Month Day (YYMMDD)	Decimal Year	Time (HHMM)
Decimal Day	Latitude (Deg N)	Longitude (Deg W)	Tow number
Tow duration (min)	Maximum Depth of Tow (m)	Volume filtered over Tow(m^3)	
Wet weight for size fractions (mg)	Dry weight for size fractions (mg)	Sum total wet weight for all size fractions (mg)	Sum total dry weight for all size fractions (mg)
Wet weight per volume filtered (mg/m^3)	Dry weight per volume filtered (mg/m^3)	Sum total wet weight for all size fractions per volume (mg/m^3)	Sum total dry weight for all size fractions per volume (mg/m^3)
Wet weight normalized to 200 m (mg/m^3)	Dry weight normalized to 200 m (mg/m^3)	Sum total wet weight for all size fractions normalized to 200 m (mg/m^3)	Sum total dry weight for all size fractions normalized to 200 m (mg/m^3)

Figure 4. Example of "metadata" that can be supplied along with zooplankton species data. Taken directly from a list of data extraction variables on the BATS web pages. Any combination of variables desired can be selected. The user selects the time period of interest (between Oct. 1988 and the present), and the depth range (the BATS data are nominally sampled at the following depths: 1, 10, 20, 40, 60, 80,100, 120, 140, 160, 200, 250, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1600, 1800, 2000, 2200, 2400, 2600, 3000, 3400, 3800, 4000, and 4200 meters).

Discrete Data

Note: Total Organic Carbon (TOC) data began in February of 1994. If you have any questions reguarding TOC data, they should be addressed to either Dr. Dennis Hansel (dennis@bbsr.edu) or Dr. Craig Carlson (ccarlson@bbsr.edu).

☐ Year Month Day (YYMMDD)	☐ Decimal Year	☐ Decimal Day
☐ Time (HHMM)	☐ Latitude (deg N)	☐ Longitude (deg W)
☒ Sample Identification Number	☐ Quality Flag	☒ Depth (m)
☐ Pressure (db)	☐ Temperature (C) (IPTS-68)	☐ CTD Salinity (PSS-78)
☐ Potential Temperature (C)	☐ Salinity-1 (PSS-78)	☐ Salinity-2 (PSS-78)
☐ Sigma-theta (kg/m^3)	☐ Oxygen-1 (umol/kg)	☐ Oxygen-2 (umol/kg)
☐ Oxygen fix Temperature	☐ Oxygen anomaly-1 (umol/kg)	☐ Oxygen anomaly-2 (umol/kg)
☐ Total Carbon Dioxide (TCO2) (umol/kg)	☐ Alkalinity (uequiv)	☐ Nitrate+Nitrite-1 (umol/kg)
☐ Nitrate+Nitrite-2 (umol/kg)	☐ Nitrite-1 (umol/kg)	☐ Nitrite-2 (umol/kg)
☐ Phosphate-1 (umol/kg)	☐ Phosphate-2 (umol/kg)	☐ Sillicate-1 (umol/kg)
☐ Sillicate-2 (umol/kg)	☐ POC (ug/kg)	☐ PON (ug/kg)
☐ TOC (umol/kg)	☐ TON (umol/kg)	☐ Bacteria (cells *10^8/kg)
☐ Chlorophyll c3 (ng/kg)	☐ Chlorophyllide a (ng/kg)	☐ Chlorophyll c1+c2 (ng/kg)
☐ Peridinin (ng/kg)	☐ 19-Butanoyloxyfucoxanthin (ng/kg)	☐ Fucoxanthin (ng/kg)
☐ 19-Hexanoyloxyfucoxanthin (ng/kg)	☐ Prasinoxanthin (ng/kg)	☐ Diadinoxanthin (ng/kg)
☐ Alloxanthin (ng/kg)	☐ Diatoxanthin (ng/kg)	☐ Zeaxanthin+Lutein (ng/kg)
☐ Chlorophyll b (ng/kg)	☐ Chlorophyll a (ng/kg)	☐ a+b Carotene (ng/kg)
☐ Turner Chlorophyll a (ug/kg)	☐ Turner Phaeopigments (ug/kg)	☐ Lutein (ng/kg)
☐ Zeaxanthin (ng/kg)	☐ a-Carotene (ng/kg)	☐ b-Carotene (ng/kg)

4.1.4 Specific Objectives and Timeline for Implementation and Execution of NOPP

This proposal requests support for 2 years. The first 6 mos. will focus on compilation of existing species data, the next 12 mos. on analysis of remaining time series samples, and the last 6 mos. on compilation of the newly analyzed species data into the existing database.

Apr. 1, 2000- Project initiated

Apr. 2000- Oct. 2000: Objective I- Compile known species lists from literature and already analyzed BATS samples. Place known species database into BATS database. Distribute lists and common type specimens (preserved samples and images) amongst partners.

Nov. 2000- Oct. 2001: Objective II – Analysis of remaining time series samples, beginning with silhouette analysis. Markhaseva goes to Smithsonian for 1 month to work on samples.

Nov. 2001- March 2002: Objective III - Compilation of newly analyzed species data into the existing BATS database. Markhaseva goes to Smithsonian for 1 month to finish work on samples.

4.1.5 Summary of Tasks of Individual Partners

Dr. Deborah Steinberg and her technicians will be primarily responsible for Project coordination; species identification of some taxa, and compilation and integration of species data into the existing BATS database. She will also oversee the logistics of archiving time-series samples at Bermuda. Dr. Madin and his technicians will be primarily responsible for species identifications of other taxa, including silhouette photo analysis and compilation of the species database. Dr. Craddock and his assistant will be responsible for identification of small fishes and compilation of fish data for the database. Dr. Markhaseva will be primarily responsible for species identifications of copepods and compilation of this database. Dr. Ferrari will provide laboratory facilities and resources for visiting Dr. Markhaseva and will be available to consult on species identifications.

4.2 Rationale for Support

Most of the support requested is technician time for compilation of known species data into a database and analysis of unsorted samples. BBSR requests a Video system and digital camera for an existing Olympus dissecting microscope to aid in species analyses and sharing of species data images amongst partners. Support for miscellaneous supplies (e.g., jars, microscope slides), and travel funds for one trip annually to WHOI or Washington D.C. is also included. WHOI also a requests digital camera for use with existing Wild stereomicroscopes and computers, and travel funds for two trips annually to BBSR. Dr. Markhaseva requests travel, subsistence, and salary for work at the Smithsonian Institution and salary for work at her home institution.

4.3 Facilities available for Work

BBSR: All of the major equipment required for the project is available at BBSR. BBSR has a number of compound, dissecting, and epifluorescence microscopes. We have recently acquired a state of the art Olympus AX70 research microscope platform which supports superior optical elements, epifluorescence system, and accompanying image analysis system. BBSR has considerable computer resources, including a network of UNIX workstations, and software licenses (including MATLAB) available for shared use. BBSR is connected to the Internet via a 56-KB connection (funded by NASA) and hosts a public WWW server and anonymous ftp site. BBSR employs a full-time systems administrator and assistant. Bermuda is served by international air mail and document delivery service including FedEx and DHL for any necessary shipping of samples. The BBSR E.L. Mark Library contains more than 20,000 volumes with 250 current scientific journals and abstracts representing the main disciplines in marine science. In addition, the library's "Bermuda Collection" contains all historical taxonomic research done in the Bermuda region. Access to computer library resources in the US is available via DIALOG and Internet. Aquatic Sciences and Fisheries Abstracts are available on CD-ROM.

WHOI: Facilities available in the labs of Drs. Madin and Craddock also include all equipment (except the requested digital camera) for this work. This includes several dissecting microscopes, and both standard and inverted compound microscopes. In addition, the WHOI Biology Department will have by early 2000 a state-of-the-art light microscopy facility incorporating a Zeiss Axiomat system. Adequate computers (PC, Mac) are available, with Excel and Matlab. Madin and Craddock have extensive taxonomic reference libraries for zooplankton and fishes, respectively, as well as other resources at WHOI and the WHOI/MBL Library.

Smithsonian Institution: The catalogued collection of planktonic calanoid copepods at the National Museum of Natural History is unrivaled for comparative taxonomic studies. Specimens identified and deposited by Dr. George D. Grice and Dr. Taisoo Park form the backbone of that collection. The Charles Branch Wilson Copepod Library is the most complete taxonomic library of its kind in the world; it also houses a significant number of papers on copepod biology. Dr. Ferrari's lab is set up for both bright field and differential interference contrast microscopy; epifluorescent microscopy for visualizing cell nuclei and scanning electron microscopy for examining the exoskeleton also are available.

Russian Academy of Sciences Zoological Institute: The institute houses systematic collections of copepods from all over the world obtained throughout the last several decades. Microscope facilities are also available for taxonomic studies.

4.4 Anticipated Results, Products, and Benefits of Proposed Effort

Below are summaries of anticipated results, products, and benefits of the project:

<u>Anticipated Results</u>
A multiple species inventory covering diel, seasonal, interannual, and decadal time scales, as well as several depth strata, will allow proper coverage of zooplankton community structure, which is intensely dependent upon these variables.
New species will likely be discovered.
Data sets will capture important phenomena of scientific interest, such as intense 'blooms' of gelatinous zooplankton, or appearance of unusual species.
Use of the 10 year data set will be enable us to dissect the difference between natural variability and real 'change' in plankton communities.

Products
Species lists with accompanying images will become available for use of the broader scientific and education community for many different applications.
Species abundance and size spectra made available for use in ecological modeling.
Species composition of zooplankton at the BATS location at monthly, seasonal and interannual time scales, and depth-stratified species occurrence of larger zooplankton and micronekton with seasonal and annual resolution.

Benefits
Tie in with larger environmental data set from BATS (among the highest quality oceanographic data sets in the world) will benefit the oceanographic research community.
Information on seasonal and interannual variability in zooplankton biomass and species composition is crucial for testing and validation of ecosystem models, and for understanding the effects of long term climate change on ecosystems.
Addresses other socioeconomic issues of importance such as improved prediction of variability and impact of fisheries
Long-term benefits as sampling will continue into the future
Information from data set will benefit both the research and educational communities by providing high quality, long term species composition data

5. Capabilities, Related Experience, and Facilities

Members of this partnership team have all developed research programs at their institutions which encompass the study of zooplankton biodiversity – either through basic taxonomy, natural history and ecology of specific groups, planktonic food web analysis, or the role of planktonic community structure in cycling of elements in the sea. They have all played roles in major research programs and published their results (please see vitae). This combination of expertise and institutional involvement not only provides a sound basis for developing a unique zooplankton species data base, but also access to accompanying environmental data at a site of broad interest to the oceanographic community.

6. Investigators' Qualifications

The proposed partners in this program include the Bermuda Biological Station for Research, Inc. (BBSR) (Dr. Deborah Steinberg), the Woods Hole Oceanographic Institution (Dr. Laurence Madin and Dr. James Craddock), the Russian Academy of Sciences Zoological Institute in St. Petersburg (Dr. Lena Markhaseva) and the Smithsonian Institution's National Museum of Natural History (Dr. Frank Ferrari). Dr. Steinberg is an Associate Research Scientist and coordinates the BATS program at BBSR. She is a zooplankton ecologist and biological oceanographer and most recently has worked on vertically migrating zooplankton at BATS. Dr. Madin is a senior scientist and Chair of the Biology Department at WHOI who has studied zooplankton ecology for nearly 30 years. He is an expert in gelatinous zooplankton biology, but like Steinberg has worked with all different taxonomic groups of zooplankton, and has written a taxonomic guide to zooplankton (Madin, 1991). His technicians, E. Horgan and M. Butler, have worked up an extensive collection of macrozooplankton from the Arabian Sea during the last 4 years. Steinberg and Madin have already worked together on several projects using the BATS zooplankton data. We also to bring in expertise to for identification of some of the copepods by Dr. Lena Markhaseva. Dr. Markhaseva is a senior scientist at the Zoological Institute in St. Petersburg and has been studying copepod taxonomy for more than 20 years. She is an expert on deep-sea calanoids and has worked on specimens from all over the world. Dr. Frank Ferrari at the Smithsonian Institution is sponsoring Dr. Markhaseva by providing state of the art taxonomic laboratory facilities for her to work. Dr. Ferrari is a research zoologist and curator at the Smithsonian Institution's National Museum of Natural History where he works on development, homology and phylogeny of copepods, particularly free-living calanoids and cyclopoids. He will also be available for consultation.

8. Supporting Information

8.1 List of other current and pending research projects being undertaken by the principal investigators:

Steinberg:

"The Bermuda Atlantic Time-series Study (BATS)" [current, NSF OCE-9617795]

P.I.s: Anthony Knap, Deborah Steinberg, Craig Carlson, Nick Bates
Period Covered: 5/1/98 -4/30/01 ($2,099,992) (6 mos.)

“Open ocean and sub-tropical marine research experiences for undergraduates at the Bermuda Biological Station for Research” [current, NSF OCE-9619718]
P.I.’s: Deborah Steinberg, Henry Trapido-Rosenthal, Norman Nelson, David Malmquist
Period Covered: 4/1/97 – 3/31/00 ($157,621) (0 mos.)

“The Effective Use of Web-Based Scientific Resources in Teaching and Teacher Training: A Collaborative Pilot Program Using Real Data Sets to Explore Oceanography and Global Environmental Change” [current, NSF DUE--9752494 -Dept. of Undergraduate Education]
PIs: David Malmquist, Deborah Steinberg, Kristina Bishop, Luis Martinez-Perez, Anthony Knap.
Period Covered: 5/15/98 – 4/30/01 ($207,253) (2 mos/ 1 mo last year)

"Comparative dynamics of colored dissolved organic matter in open ocean environments" [current, NSF OCE 9977399]
PI’s: Norm Nelson, Craig Carlson, Deborah Steinberg
Period Covered: 9/1/99 – 8/31/02 ($450,529) (1.5 mos)

Neutrally-buoyant sediment traps for direct sampling of the upper ocean export flux [pending NSF OCE]
P.I. Jim Price, subcontract to Deborah Steinberg
Period Covered: 2/1/00-1/31/02 ($67,550) (1 mo)

Controls and rates of particulate export in the upper ocean [pending NSF OCE]
P.I. Ken Buesseler, subcontract to Deborah Steinberg
Period Covered: 2/1/00 - 1/31/02   ($67,550) (2 mo)

THIS PROPOSAL [pending]

Madin:

" U.S. GLOBEC: Predation Impacts on Target Species: Roles of Frontal Processes and Small Predator Species " [current, NSF OCE 9806465]
PI: L. Madin
Period Covered: 1/1/99 – 12/31/01 ($274,969) (2 mos)

“Replacement and Upgrade of a Nutrient Analyzer” [current, ONR N00014-98-1-0032]
PIs: L.P. Madin, C. Taylor
Period Covered: 1/4/99 – 12/31/99 ($50,000) (0 mos)

“Systematics of Campanulariid Hydroids” [current, Duke University subcontract]
L.P.Madin & A. Frese- Subcontract to Duke Univ.
Period Covered: 10/1/99 – 9/30/02 ($49,050) (0 mos)

W.H.O.I. Proposal No. BI10603 - THIS PROPOSAL [pending]

8.2 Extent of institution participation and support for the program.

As described in previous sections, the participating institutions will provide a significant amount of support for the program in the form of laboratory facilities, equipment, and personnel time.

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