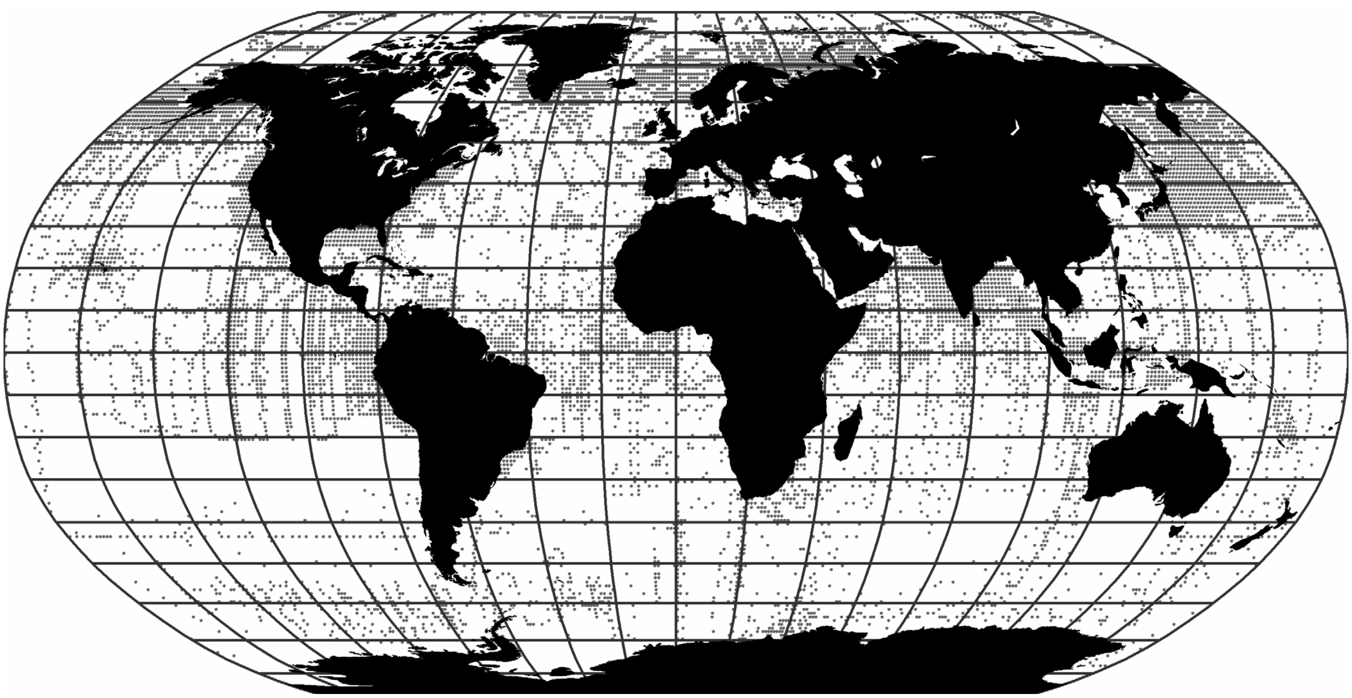
NMFS-COPEPOD

The **C**oastal & **O**ceanic **P**lankton **E**cology, **P**roduction & **O**bservation **D**atabase



COPEPOD: A Global Plankton Database

A review of the 2005 database contents and creation of new global zooplankton biomass fields.

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

NOAA Technical Memorandum NMFS-F/SPO-73
December 2005

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NMFS-COPEPOD is available online at:

http://www.st.nmfs.noaa.gov/plankton

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U.S. Department of Commerce
Carlos M. Gutiérrez, Secretary

National Oceanic and Atmospheric Administration
Vice Admiral Conrad C. Lautenbacher, Jr., USN (Ret.)
Under Secretary for Oceans and Atmosphere

National Marine Fisheries Service
William T. Hogarth, Assistant Administrator for Fisheries

ACKNOWLEDGEMENTS

The contents of this global plankton database would not be possible without the efforts and expertise of the original scientists and technicians that collected, identified and quantified its plankton content. The goal of COPEPOD is to make these plankton scientists' hard work more readily available to the scientific community in a common and useable data format which clearly identifies the original persons and entities responsible for collecting and preparing those data. Like a library, COPEPOD does not claim credit for its contents and strives to be valued for the breadth and comprehensiveness of its collection.

When using the contents of COPEPOD, we request that you acknowledge the original investigators of those data. We also encourage you to consider contributing your own data to this global effort. The back cover of this publication, **Appendix I**, summarizes the known individuals, institutions, and projects whose work is featured in this 2005 compilation summary.

A large portion of the COPEPOD content is keyed from original data reports and cruise summaries. COPEPOD is especially grateful for the help, support, and historical document and archive access granted by the staff of the NOAA Central Library (Silver Spring, Maryland), the WHOI-MBL libraries (Woods Hole, Massachusetts), the World Data Center for Oceanography - Silver Spring (*Charlotte Sazama*), and the Smithsonian Institution - Department of Invertebrate Zoology (*Frank Ferrari, Lana Ong*). COPEPOD's ongoing acquisition and digitization of historical plankton data manuscripts is possible through continued funding from the NOAA Climate Data Modernization Program (CDMP), and through previous funding from the NOAA Environmental Services Data and Information Management (ESDIM) program.

The *NMFS-COPEPOD* project was born on March 8, 2004, thanks to the efforts and foresight of Dr. Michael Sissenwine (retired, former *NMFS Director of Scientific Programs & Chief Science Advisor*) and continues under the leadership and encouragement of Dr. Ned Cyr (*Chief - Marine Ecosystems Division, NMFS Office of Science & Technology*). Finally, throughout the years, Dr. Peter Wiebe (*Senior Scientist, Woods Hole Oceanographic Institute)* has been a valuable scientific reference and friend.

The ***COPEPOD*** acronym, concept, graphics, and online data system were designed and developed solely by the author, Todd D. O'Brien.

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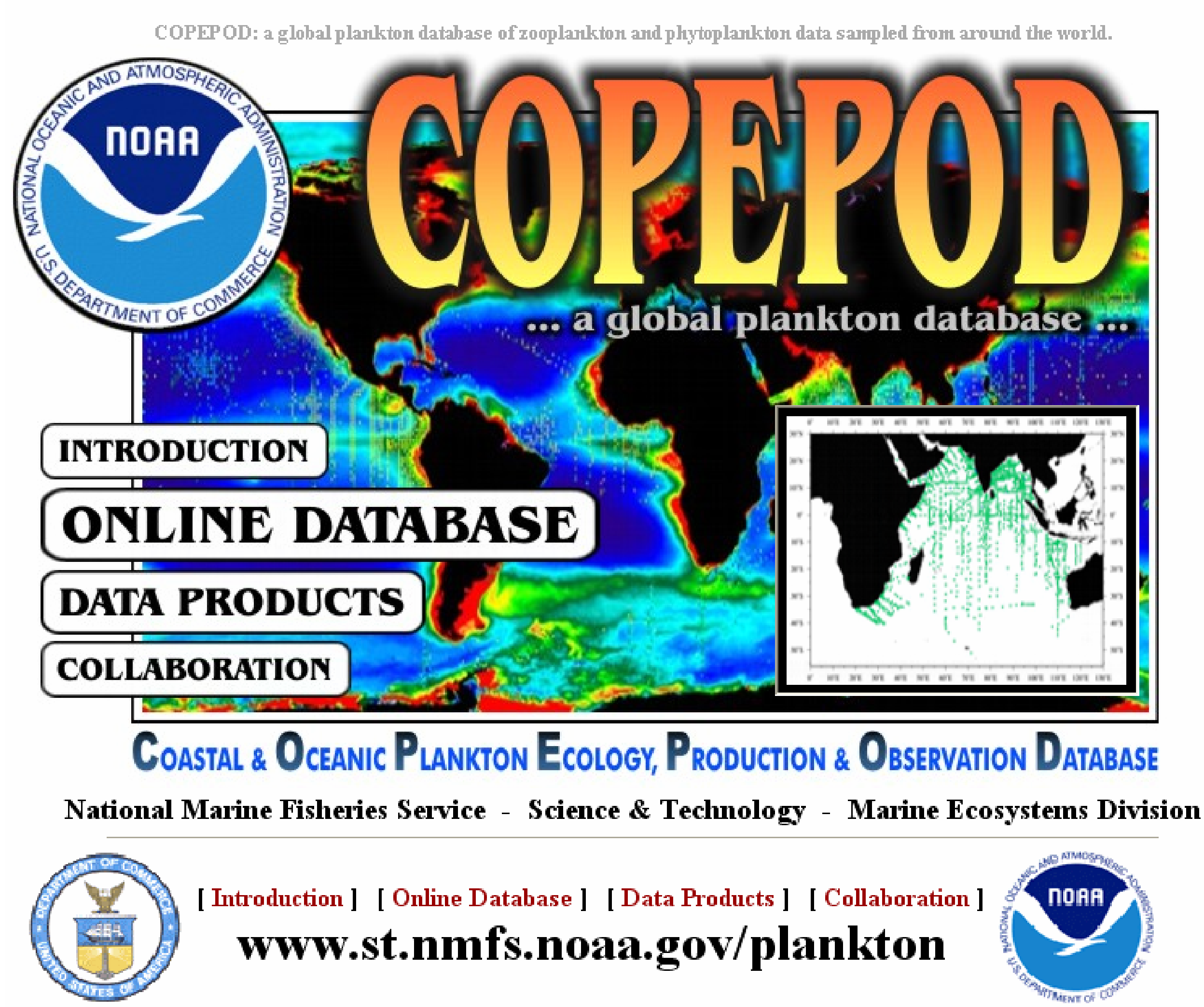
COPEPOD: a global plankton database of zooplankton and phytoplankton data sampled from around the world.
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE
COPEPOD
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INTRODUCTION
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COPEPOD: a Global Plankton Database

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ABSTRACT

The **C**oastal & **O**ceanic **P**lankton **E**cology, **P**roduction & **O**bservation **D**atabase (**COPEPOD**) is an online, global coverage plankton database. Designed by the former lead-developer of the *World Ocean Database Plankton* (1998-2004), this new plankton database effort presents significant amounts of additional data content along with a renewed focus on providing better data access, integrated products, and acknowledgment of the original plankton investigator(s). This document presents the data sources and methods used in this new database and summarizes its contents as of the December 2005 monthly update. This document also presents a new methodology for building global zooplankton biomass fields, including improved techniques for combining data from different sampling gear and measurement methods. The results of this new methodology are compared to the *World Ocean Database 2001*, finding that previous work had over-estimated its zooplankton carbon mass by up to four times.

1. INTRODUCTION

The *World Ocean Database Plankton* (O'Brien *et al*., 2002a) was an attempt to build a plankton database by adding plankton tow data to an existing bottle and temperature database. While this effort was successful at some levels, the resulting system was not friendly to the end user or the original data provider. A database user's access and use of the data were challenged by the infrequency of database updates and the complex, code-based export format that required significant programming to extract and decode the data. For the data provider, any acknowledgement of their months of hard work and authorship was reduced to a simple numeric code, or often completely absent.

In 2004, a new global plankton database effort began, incorporating over ten years of plankton data management experience and user feedback into designing and building a new online data system designed specifically for plankton data. The **C**oastal & **O**ceanic **P**lankton **E**cology, **P**roduction & **O**bservation **D**atabase (**COPEPOD**) contains the entire *reprocessed* plankton content of O'Brien *et al.* (2002a), plus significant amounts of new plankton data. COPEPOD also represents a completely new approach to providing data access and investigator acknowledgement in an online database. This new approach to data presentation and management focuses on the individual data sets, highlighting each with a full summary of the exact content, sampling methods, and investigators associated with those data. Data compilations and products, based on these data sets, allow the user to examine global or regional features such as zooplankton biomass, abundance and other ecosystem variables. Finally, COPEPOD features *monthly* releases of additional plankton data, via a searchable online web interface, and offers these data in a variety of user-friendly, application-tailored formats.

This NMFS Technical Memorandum, *COPEPOD-2005*, summarizes the data processing, quality control, and content of the NMFS-COPEPOD plankton database as of December 2005. *COPEPOD-2005* also presents a correction and replacement to the one-degree latitude-longitude mean zooplankton biomass fields of the *World Ocean Atlas 2001* (O'Brien *et al.* 2002b). Since the creation of those initial biomass fields, significant new biomass data and refined analysis techniques have been incorporated to greatly improve the quality and coverage of this previous work (Figure 1).

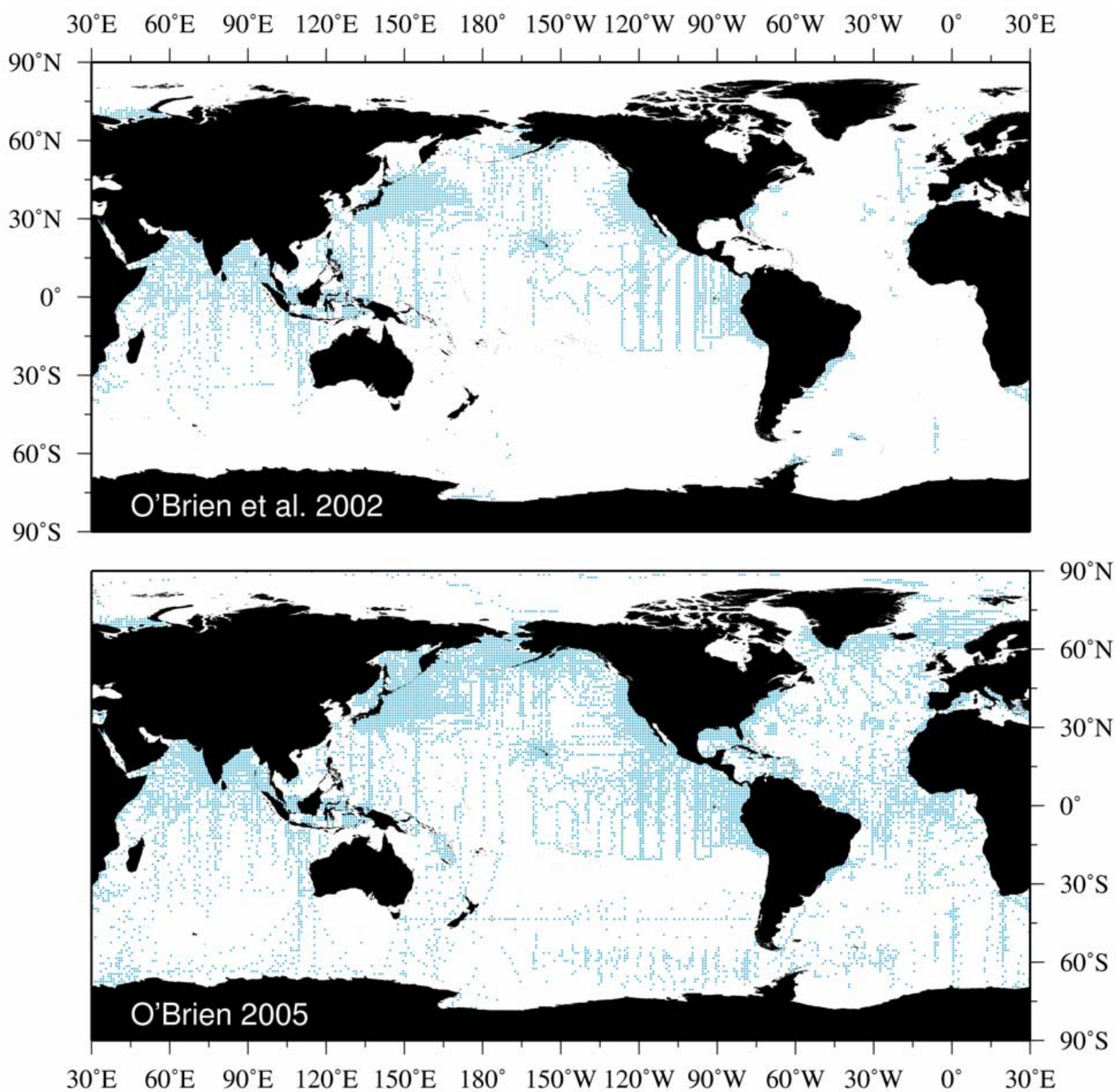


Figure 1: Comparison of zooplankton biomass coverage in *World Ocean Database 2001* (O'Brien *et al.* 2002) and *COPEPOD-2005* (O'Brien 2005).

2. DATA SOURCES

While COPEPOD is based on experience and lessons learned during the creation of the *World Ocean Database Plankton*, it is <u>not</u> just a reformatting of that previous database content. COPEPOD is a complete reprocessing of the original data sources, plus significant amounts of new data. This additional reprocessing effort was necessary to recapture the large amounts of plankton data lost in that previous database (most having been accidentally deleted or corrupted during the automated quality control of the physical and chemical data content).

The general plankton content of *COPEPOD-2005* comes from four sources:

- The NMFS Ecosystem Surveys;
- Ongoing Historical Plankton Data Search & Rescue work;
- Data Centers, Institutions & Project data;
- Direct Investigator Submissions.

2.1 The NMFS Ecosystem Surveys

The National Marine Fisheries Service (NMFS) regularly samples plankton as part of its Ecosystem Survey programs (*Figure 2*). These regional sampling efforts include zooplankton displacement volumes as well as zooplankton composition and abundance data.

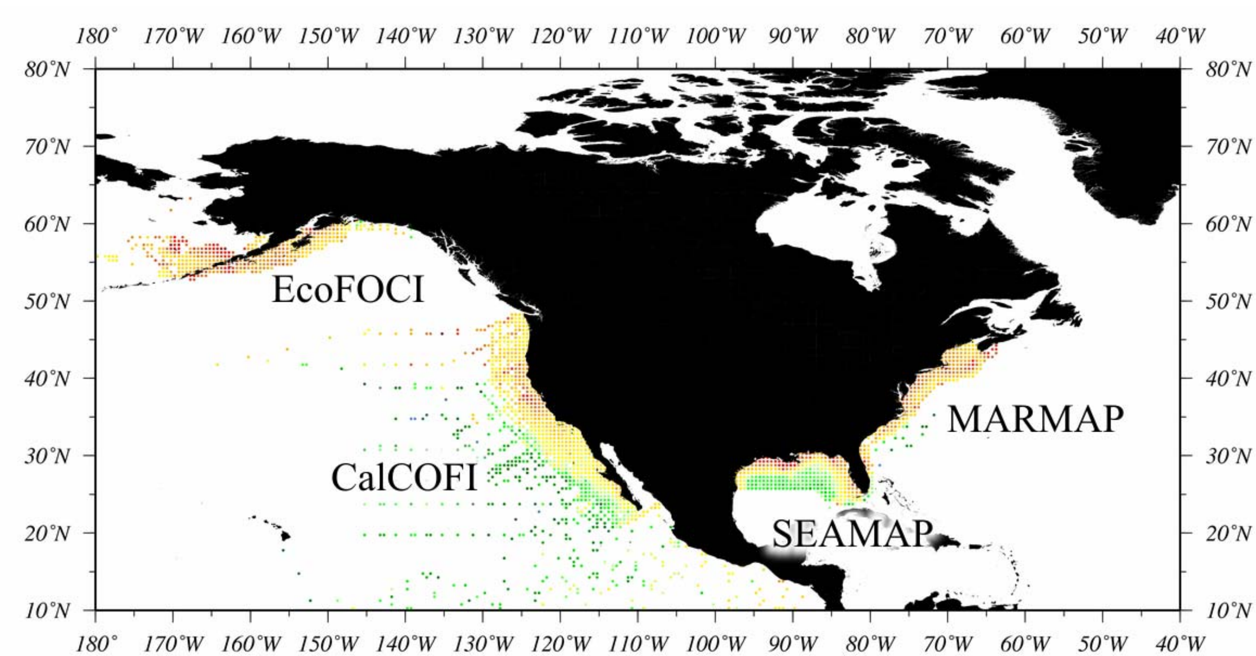


Figure 2: Map of zooplankton biomass and associated programs of the NMFS Ecosystem Surveys

CalCOFI - **Cal**ifornia **C**ooperative **O**ceanic **F**isheries **I**nvestigations (*1951- present*)
EcoFOCI - **Eco**systems & **F**isheries-**O**ceanography **C**oordinated **I**nvestigations (*1979-present*)
MARMAP - **Ma**rine **R**esources **M**onitoring, **A**ssessment, & **P**rediction (*1977-present*)
SEAMAP - **S**outh**Ea**st **M**onitoring & **A**ssessment **P**rogram (*1982-present*)

2.2 Historical Plankton Data Search & Rescue

Large amounts of plankton data exist in non-electronic, paper form. Some of these paper documents may be available through journals or in library collections, but large amounts remain completely inaccessible, hidden in institutional archives or investigators' filing cabinets and storage rooms. Some of the newest and most exciting content in *COPEPOD-2005* were discovered by the author at the Smithsonian Institution and the Woods Hole Oceanographic Institution libraries.

Once received by COPEPOD, these paper plankton data sources are then keyed into a digital form, quality reviewed, and then distributed via the online COPEPOD database. This ongoing work was accomplished through funding and participation in NOAA's Climate Data Modernization Program (CDMP), and through previous funding from NOAA's Environmental Services Data and Information Management (ESDIM) program, as summarized in Table 1.

Data Rescue Funding	Project Duration	Principal Investigators
CDMP 05-14	2005 – present	*T. O'Brien*
ESDIM 03-44	2003 – 2004	*T. O'Brien*
ESDIM 01-37	2001 – 2002	*T. O'Brien*
ESDIM 99-18	1999 – 2000	*O'Brien & Conkright*

Table 1: Summary of funding and projects used for COPEPOD plankton data search and rescue.

2.3 Data Centers, Institutions & Project Data

Globally sampled plankton data were acquired in various electronic formats from international and regional data centers (*e.g.,* the British Oceanographic Data Centre, the U.S. National Oceanographic Data Center, the Indian National Oceanographic Data Center, Japanese Oceanographic Data Center), research institutions (*e.g.,* Woods Hole Oceanographic Institute, Smithsonian Institution, Sir Alister Hardy Foundation for Ocean Science), and various oceanographic projects (*e.g.,* JGOFS, GLOBEC).

2.4 Direct Investigator Submissions

Some data are submitted directly by the collecting investigators to the COPEPOD project, in electronic or paper format. These data are extremely valuable, as the investigator can provide precise information on the exact sampling and processing methods used in their data collection.

Appendix I lists all known* investigators whose work is present in *COPEPOD-2005*. Full investigator, project, and institutional acknowledgement and data content summaries for each and every data set present in COPEPOD are available online at:

http://www.st.nmfs.noaa.gov/plankton

* **NOTE:** Some of the older data sets present in COPEPOD were found with little or no metadata. These missing pieces are added as discovered. COPEPOD users are invited to report missing or incorrect metadata when known.

3. DATA PROCESSING

3.1 Data Preparation

The plankton data in COPEPOD were originally present in hundreds of different formats (*e.g.,* tables, lists, forms) and file types (*e.g.,* from simple text files to miniature interactive databases). A major step in adding these data to COPEPOD involves carefully translating these formats and variables into a common definition set and data structure. This step also involves reviewing the data documentation and manuscripts to ensure all methods and metadata were accurately captured. Once this step is completed the data are loaded in a common database, but they do not necessarily have comparable (value) units or taxonomic indexing which would allow them to be easily applied by a database user.

3.1a Plankton group classification

COPEPOD has over 5000 unique taxonomic identifiers which preserve the original description of the organisms found in the plankton samples (*e.g.,* an individual species, or a general family, class or order). To allow for quick and simple access to large, generalized plankton groups such as “diatoms”, “copepods”, or even “phytoplankton”, a smart-key was also added to each record within the COPEPOD database. The Biological Grouping Code (BGC) is a seven digit smart-key which identifies the plankton taxa’s membership in up to four groupings. *Calanus finmarchicus*, a well known copepod found in the northern Atlantic regions, would be classified in COPEPOD as a “zooplankton” (Major Group = 4), “crustacean” (Minor group = 28), “Copepoda” (Focus Group-1 = 20), and as a “calanoid copepod” (Focus Group-2 = 10). Every record for *Calanus finmarchicus,* along with the over 700 other “calanoid copepod” group members found in the COPEPOD database, all share this same BGC code (“4282010”).

BGC	Major Group (##○○○○○○○)	Minor Group (○○##○○○○)	Focus G1 (○○○○##○○)	Focus G2 (○○○○○○○##)	Scientific Name
2010000	Phytoplankton	Diatom	n/a	n/a	*Skeletonema costatum*
4282010	Zooplankton	Crustaceans	Copepoda	Calanoida	*Calanus finmarchicus*
4282010	Zooplankton	Crustaceans	Copepoda	Calanoida	*Metridia pacifica*
4282040	Zooplankton	Crustaceans	Copepoda	Cyclopoida	*Oithona similes*
4288000	Zooplankton	Crustaceans	Euphausiacea	n/a	*Euphausia pacifica*
4310000	Zooplankton	Chaetognatha	n/a	n/a	*Parasagitta elegans*

Table 2: Examples of plankton sub-grouping inherent in the Biological Grouping Code (BGC).

The four sub-groupings of the BGC can be accessed by using simple math. For example the Major Group can be isolated by dividing the BGC by 1000000, indicating if an observation is a zooplankton (*e.g.,* “4282000” / 1000000 =4) or a phytoplankton (*e.g.,* “2010000” / 1000000 = 2). Minor groups can be isolated by dividing the BGC by 10000 (*e.g.,* “2010000” / 10000 = 201 = “Diatoms”), and Focus Group 1 is isolated by divided by 100 (*e.g.,* “4282010” / 100 = 42820 = “Copepoda”). In Table 2, dividing all of the example BGC’s by 10000 will indicate that four of the six examples are crustaceans (*i.e.,* if BGC / 10000 = 428). Table 6, located in the Results section, lists all of the major plankton groups and their associated Biological Grouping Codes as present and identified in *COPEPOD-2005*.*

* A prototype of the **Biological Grouping Code** was first introduced (by this author) in *World Ocean Database 2001*. While the Major and minor group codes should be “backward-compatible”, additional focus groups and “membership corrections” have been added to the COPEPOD version since that 2001 prototype.

3.1b Conversion to common units

The original plankton measurements in COPEPOD came in a variety of different units (*e.g.,* "number per ml", "number per 30-liter sample", "abundance per 100 m^3", "abundance per m^2", "number per sample", "total mass per tow", "total volume per haul"). Within COPEPOD, these values are first stored as originally measured with the minor following adjustments:

- multipliers in the unit numerator or denominator were calculated out to be just "number per unit" (*e.g.,* "35 chaetognaths **per 1000 m^3**" = "0.035 chaetognaths **per m^3**"; "15 diatoms **x 10^3 per m^2**" = 15000 diatoms **per m^2**");

- base units (*e.g.,* "per ml", "per liter", "per m^3") were changed if necessary keep the original values less than $1x10^9$ and greater than 0.00001 (*e.g.,* "bacteria = **1.5 x 10^9** per m3" could be stored as "bacteria = **1.5** per μL").

The variety of original units still do not allow for easy inter-comparison of the data, so a *Common Base-unit Value* (CBV) was calculated and added to each record. Based on the type or group of measurement (Table 3), the CBV provides a common, inter-comparable unit for plankton values in the database.

Measurement Type	CBV base unit
Biomass (wet mass, dry mass, AFDM)	mg / m^3
Biomass (displacement volume, settled volume)	ml / m^3
Zooplankton Abundance	# / m^3
Phytoplankton Abundance	# / mL
Bacterioplankton Abundance	# / μL
Ichthyoplankton Abundance	# / m^3

Table 3: Measurement types and associated target units for the Common Base-unit Value (CBV).

As necessary, the new common base unit was calculated using the metadata associated with that sample. For example, "per haul", "per tow", "per sample" zooplankton abundance measurements would use the flow meter 'volume of water filtered' to calculate the appropriate CBV. When the volume of filtered water was not provided, or if the flow meter had failed during sampling, the "volume of water filtered" was estimated by multiplying the mouth area of the net opening by the distance the net was towed in the water. For vertical tows, this towing distance was the lower depth minus the upper depth. For horizontal or oblique tows, towing distance was estimated by using the average towing speed and tow duration.

3.2 Data Quality Control

Plankton data are variable by nature, influenced by numerous physical and biological events. Unlike temperature or salinity values, there is not a tight range of typical values that one can use to easily qualify or disqualify these data. Plankton values are also greatly affected by the size of the net mesh and the depth of the tow. *COPEPOD-2005* applies very basic value range and statistical techniques to look for anomalous or non-representative data.

3.2a Range checks

Within COPEPOD, the CBV and BGC are used together to perform broad, taxonomic group-based value range checks. For *COPEPOD-2005*, only a single range (for the entire world ocean) was used for the major and minor taxonomic groups. Future COPEPOD work will divide these ranges into smaller taxonomic sub-groups and individual oceanographic basins or regions, allowing for tighter range checks.

Abundance	**n (obs)**	**Mean + 5*St.DEV**	***AUTO-FLAG* *("Out of Range")***	**CBV Units**
Phytoplankton	294,737	5,353	**> 15,000**	# / mL
Diatoms	204,843	1,848	**> 5,000**	
Zooplankton	961,389	733	**> 2,500**	# / m^3
Copepods	495,377	740	**> 2,000**	
Total Biomass				
Displacement Volume	105,726	3.3	**> 7.5**	ml / m^3
Settled Volume	9,556	37	**> 100**	
Wet Mass	40,090	2,025	**> 5,000**	mg / m^3
Dry Mass	2,225	457	**> 1000**	
AFDM	410	103	**> 250**	

Table 4: Examples of taxonomic group-based value ranges used in *COPEPOD-2005*.

The value ranges in Table 4 are very general and encompass the effects of different mesh sizes, day-vs.-night sampling, and the presence of smaller life stages ("number of adults" vs. "number of adults + juveniles"). These ranges will be adjusted as new data and better techniques are added to the database. The new ranges, as well as ranges for additional plankton sub-groups not shown in Table 4, will be available online.

3.2b Statistical checks

Basic statistical checks were used to search for questionable values, but were not used to automatically flag values (like the "auto-flag" ranges above). For each major and minor BGC group (*e.g.*, Table 4 – "Zooplankton", "Copepods"), the mean and standard deviation were calculated based on all observations (from that group) present in the COPEPOD database. Individual observations greater than five standard deviations from this mean were then investigated on a case by-case basis. While natural variability may account for many of these "outliers", this method also helped identify extreme values caused by misinterpreted units or typographic errors. In many of these cases, the values were off by a factor of 1000 and were readily detected by these simple statistical checks.

3.3 Biomass Mean Field Preparation

This atlas features a major update to the global zooplankton biomass fields of O'Brien *et al.* (2002b). In addition to significant new data content, improved calculation techniques were utilized. During the preparation of these new fields, the goal was to select the ideal temporal and spatial gridding, mesh size, and sampling depth interval to maximize the spatial coverage of the fields.

3.3a Choice of temporal grid

The biomass data present in *COPEPOD-2005* come from a mixture of spatially and temporally dense sampling programs (*e.g.,* the NMFS Ecosystem Surveys, Japanese fisheries surveys) and shorter duration (*i.e.,* a few years or seasons, a single month) projects or cruises. To create a global field of average zooplankton biomass for the entire world, we were forced to composite all data into a single mean value, regardless of the year of observation. Global mean fields of annual and seasonal zooplankton biomass fields are present in *COPEPOD-2005*. While data coverage is generally too sparse for the creation of monthly global fields, these fields are available for the NMFS Ecosystem Survey regions (Figure 2).

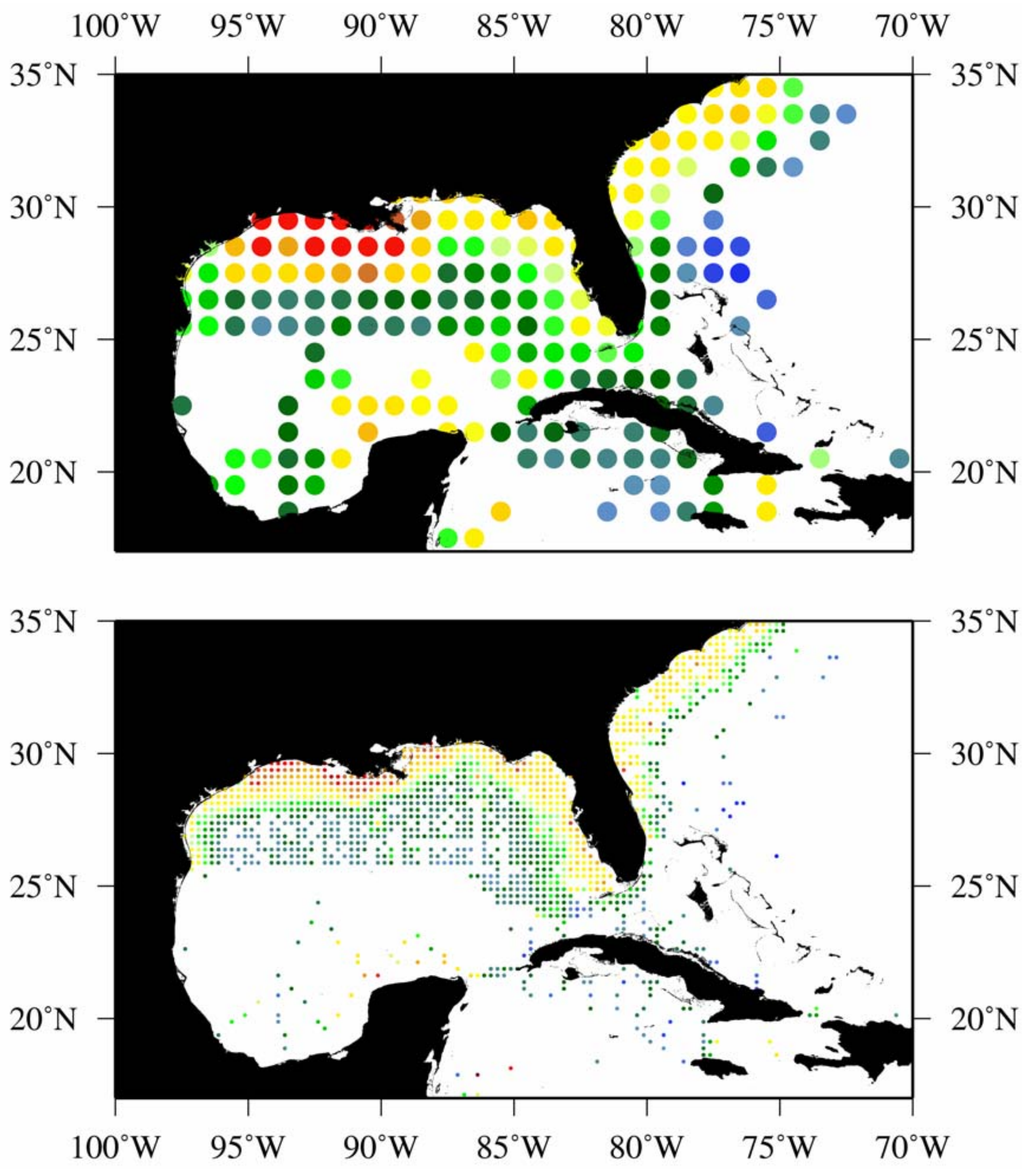


Figure 3: Comparison of 1-degree and ¼-degree latitude-longitude grid sizes used for plotting zooplankton biomass data in the Gulf of Mexico region.

3.3b Choice of spatial grid

In O'Brien *et al.* (2002b), a one-degree latitude-longitude spatial grid was selected for the biomass fields to put them on a uniform grid with the other variables of the *World Ocean Atlas* series (Conkright *et al.* 2002a,b). While one-degree grids are useful for global examinations, they are not as amenable to the study of smaller regions such as the Gulf of Mexico (Figure 3). *COPEPOD-2005* therefore provides its biomass fields in both one-degree and quarter-degree resolutions, allowing the user to choose and apply the resolution that best fits the specific application.

3.3c Choice of depth interval

Because zooplankton populations are not evenly distributed over depth, it was necessary to use a common sampling depth interval for combining the different tows used in creating the zooplankton biomass fields. The most frequent biomass sampling interval of "0 - 200 meters" (Table 4) was selected. Because lower sampling depths were not always exactly 200 meters, a lower depth range from 175 to 225 meters was allowed. For nets with multiple depth intervals (*e.g., 0-100, 100-200, 200-500, 500-1000)*, only the values from the sub-nets falling inside the "0 – 200 meter" range were used to create a new single depth interval (*e.g., 0-100 + 100-200 = "0-200"*). In areas where the bottom depth was less than 200 meters (*e.g.,* near shore regions), the lower depth criteria was adjusted to include these shallower tows.

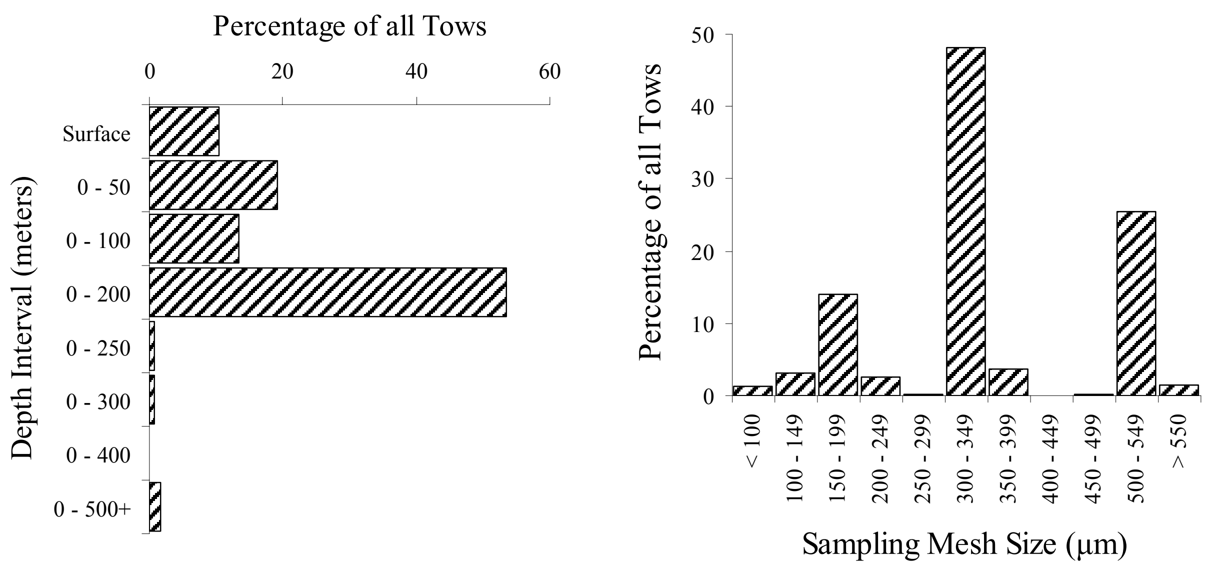


Figure 4: Summary of biomass sampling depth interval and mesh size frequencies in *COPEPOD-2005.*

3.3d Choice of mesh size

The frequencies of sampling mesh sizes present in *COPEPOD-2005* are shown in Figure 4. Three prominent size groupings were present: 150-200 µm; 300-350 µm; and 500-550 µm. Figure 5 illustrates the spatial coverage of each of these mesh size groups. A common net mesh size of "330 µm" was selected for *COPEPOD-2005* because it was the most abundant biomass mesh size in *COPEPOD-2005* (Figure 4) and because it had fairly comprehensive global coverage (Figure 5.1).

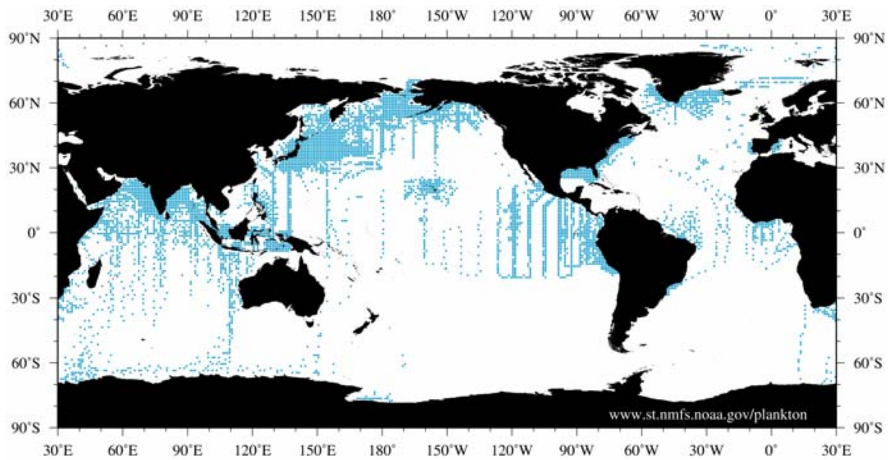


Figure 5.1: Distribution of 300 - 350 micrometer mesh observations.

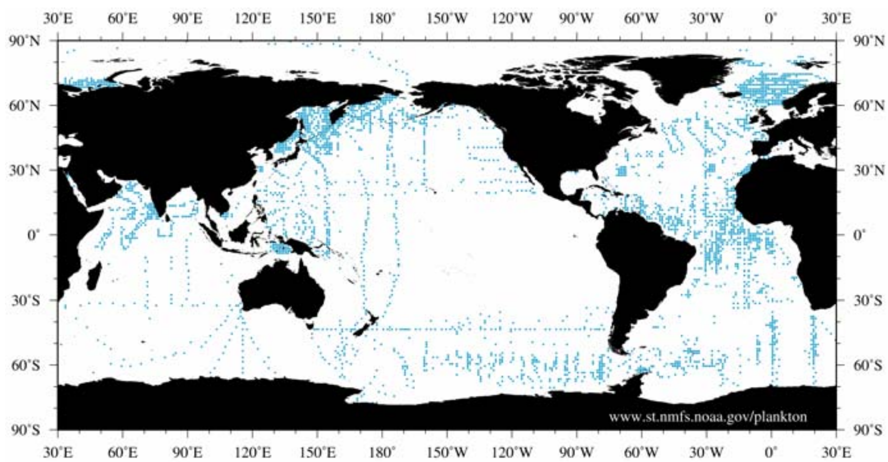


Figure 5.2: Distribution of 150 - 200 micrometer mesh observations.

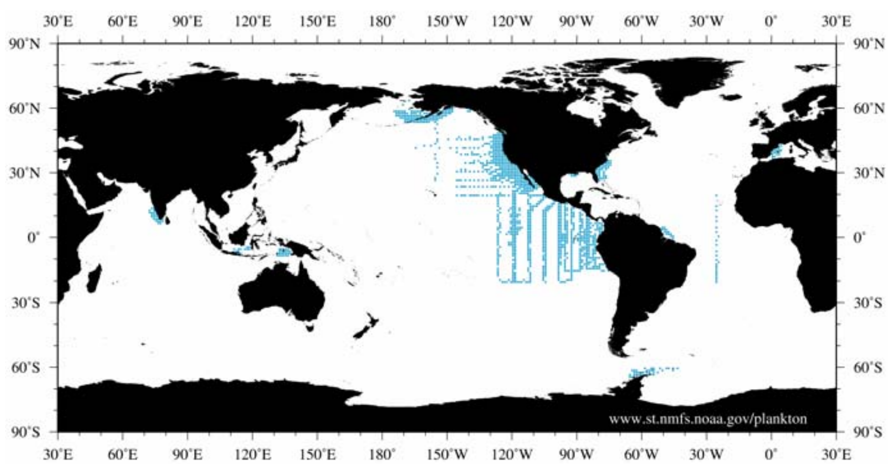


Figure 5.3: Distribution of 500 - 550 micrometer mesh observations.

Figure 5: Distribution and spatial coverage of the major mesh size groupings in *COPEPOD-2005*.

3.3e Conversion to a common mesh size

Looking at Figure 5, no single mesh size by itself has data coverage for the entire world. To achieve full global coverage in the biomass fields, it was necessary to include 150-200 µm mesh biomass data in the "330 µm" fields. Mesh size affects the capture efficiency of smaller taxa and the smaller life stages of larger taxa (DeVries & Stein 1991; Hernroth 1987; Colton *et al.* 1980). The relationship between different mesh sizes and total biomass caught is complicated by changes in the sampling efficiency of the net due to clogging and by different towing speeds (Harris *et al. 2000*; Henroth 1987; Colton *et al. 1980*). A 330 µm net may therefore catch anywhere from 30% to 80% of the total biomass that a smaller mesh net might capture in the same location (Mackas *et al.* 2004; Verheye *et al.* 1998; Henroth 1987, Colton *et al* 1980, Vannucci 1968).

The majority of the 150-200 µm data used were Juday nets (168 µm) from former Soviet Union cruises and expeditions. Some of the Juday tows featured co-sampled biomass from 330 µm mesh ring nets. To convert these 168 µm biomass values to an approximate 333 µm value, the co-sampled biomass values were used to create a regression equation (Figure 6). This calculation was then applied to the 168 µm biomass values that were used in the 330 µm biomass fields.

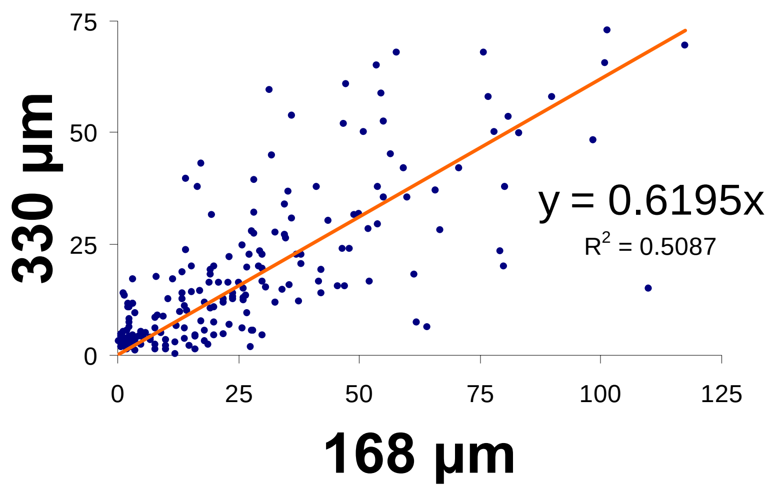


Figure 6: Mesh-size regression equation from co-sampled zooplankton biomass values present in *COPEPOD-2005*.

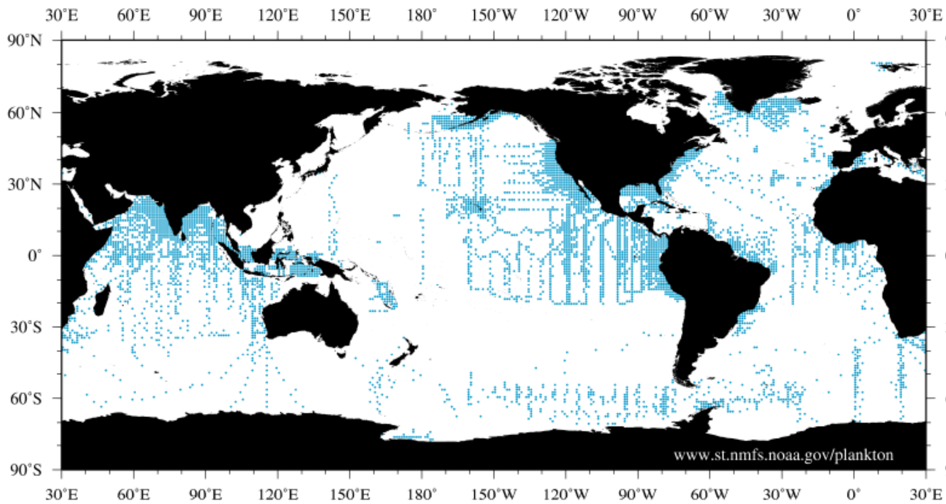
3.3f Calculation of mean biomass fields

Annual and seasonal zooplankton biomass fields were created for each biomass type (*e.g.,* displacement volume, wet mass, dry mass, settled volume). Within each quarter-degree and/or one-degree latitude-longitude grid, a mean biomass value was calculated using all of the unflagged biomass data present in that grid which satisfied the target season, depth and mesh criteria. Annual zooplankton fields were then created from the average of the four seasonal zooplankton fields. Within the NMFS Ecosystem Survey regions (Figure 2), monthly biomass fields were also created by replacing the season criteria with months.

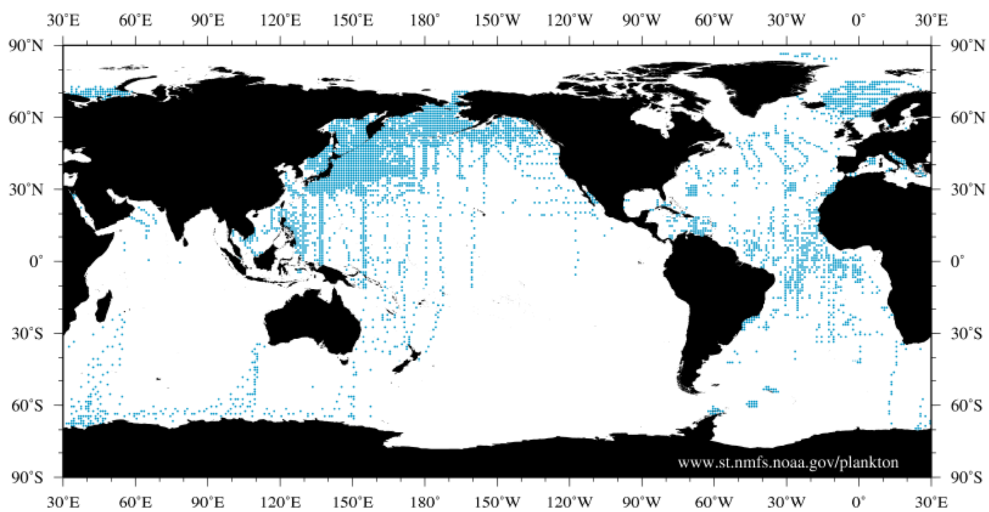
The *COPEPOD-2005* seasons are based on the meteorological seasons for the northern hemisphere and are defined as: Winter (Dec.–Feb.); spring (Mar.–May); summer (Jun.–Aug.); and fall (Sep.–Nov.).

3.3g Conversion and calculation of mean zooplankton carbon mass

After resolving the mesh size issues (*section 3.3e*), examining the two most abundant biomass types in *COPEPOD-2005* will show that neither type provides full global coverage by itself (Figure 7). To create a global-coverage zooplankton biomass field, it was necessary to convert and combine different biomass measurements into a common biomass proxy.



Distribution of Zooplankton Biomass (Displacement Volume) sampling tows



Distribution of Zooplankton Biomass (Wet Mass) sampling tows

Figure 7: Spatial coverage of the two dominant zooplankton biomass types in *COPEPOD-2005*.

Total carbon mass was selected as the common zooplankton biomass proxy because of its fundamental use in food chain and energy flow applications (Harris *et al.* 2000; Wiebe *et al.* 1975) and the abundance of published conversion equations to this biomass type (*e.g.,* Harris *et al.* 2000; Bode *et al.* 1998; Wiebe 1988; Balvay 1987; Cushing *et al.* 1958). *COPEPOD-2005* uses the non-linear biomass conversion equations of Bode *et al.* (1998), Wiebe (1988), and Balvay (1987), as summarized in Table 5.

Original Biomass Measure	Equation	Reference
Displacement Volume (DV) to Carbon Mass (**CM**)	log **CM** = (log **DV** + 1.434) / 0.820	Wiebe 1988
Wet Mass (WM) to Carbon Mass (**CM**)	log **CM** = (log **WM** + 1.537) / 0.852	Wiebe 1988
Dry Mass (DM) to Carbon Mass (**CM**)	log **CM** = (log **DM** – 0.499) / 0.991	Wiebe 1988
Settled Volume (SV) to Dry Mass (**DM**) Dry Mass to Carbon mass (CM)	log **DM** = 0.843 * log **SV** + 1.417 log **CM** = (log **DM** – 0.499) / 0.991	Balvay 1987, Wiebe 1988
Ashfree Dry Mass (AFDM) to Carbon Mass (**CM**)	log **CM** = (log **AFDM** – 0.410) / 0.963	Bode *et al.* 1998

Table 5: Original biomass types and carbon mass conversion equations used in *COPEPOD-2005.*

During the preparation of the various biomass fields (*e.g.,* displacement volumes, wet masses), each value was also converted to a carbon mass value using the appropriate conversion factors (Table 5). Seasonal and annual carbon mass fields were then calculated using the methods summarized in section 3.3f.

4. RESULTS

4.1 Data Distribution Plots

Data content summaries and distribution maps, as illustrated in Figure 8, were created for all of the major plankton groups represented in *COPEPOD-2005* and are provided in Appendices A-F. Each graphical dot in the distribution map indicates the presence of at least one tow in which at least one member of that plankton group was found and measured. Each map also includes a summary table which indicates the years of sampling coverage and the top twenty most frequent taxa present for that group. Seasonal distribution maps (*e.g.,* winter, spring, summer, and fall) are also provided for each major group.

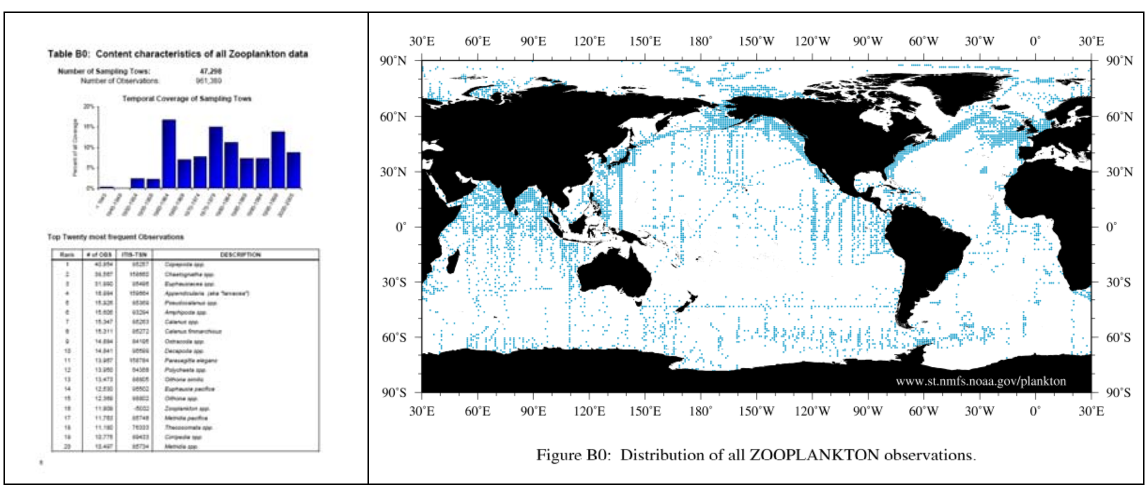


Figure 8: Example of the data content tables and plots found in Appendices A-F.

Table 6: COPEPOD-2005 Plankton Content

Code	Group	TOTAL Stations	WINTER (Dec.-Feb.)	SPRING (Mar.-May)	SUMMER (Jun.-Aug.)	FALL (Sep.-Nov.)	APPENDIX
TOTAL BIOMASS:							
-400	***ALL BIOMASS TYPES***	***156,895***	***32,147***	***50,732***	***43,542***	***30,474***	**A0**
-401	Total Displacement Volume	109,406	24,166	36,488	26,959	21,793	**A1**
-402	Total Settled Volume	9,027	1,751	1,998	3,079	2,199	**A2**
-403	Total Wet Mass	39,127	6,685	12,002	13,484	6,956	**A3**
-404	Total Dry Mass	2,670	365	961	806	538	**A4**
-405	Total Ash-free Dry Mass	396	-	47	89	260	**A5**
-410	Total Carbon Mass Mass	109	43	32	34	-	**A6**
ZOOPLANKTON:							
4000000	***ALL ZOOPLANKTON SUB-GROUPS***	***47,298***	***9,714***	***14,251***	***13,702***	***9,631***	**B0**
4030000	CNIDARIA	18,522	3,487	5,350	5,854	3,831	**B1**
4032000	Hydrozoa	12,885	2,382	3,922	4,135	2,446	
4036000	Scyphozoa	848	168	233	330	117	
4038000	Anthozoa	1,334	371	323	384	256	
4040000	CTENOPHORA	2,134	267	787	713	367	**B2**
4170000	BRYOZOA (Ectoprocta)	1,445	286	377	510	272	
4200000	MOLLUSCA	18,156	3,417	5,139	6,045	3,555	**B3**
4202500	Gastropoda	14,955	2,759	4,535	4,930	2,731	***B3.1***
4205000	Bilvalvia	2,220	249	584	1,039	348	***B3.2***
4207500	Cephalopoda	3,261	868	785	1,157	451	***B3.3***
4240000	ANNELIDA	13,905	2,491	4,142	4,429	2,843	**B4**
4245000	Polychaetes	12,771	2,450	3,698	3,898	2,725	
4270000	ARTHROPODS (non-Crustacea)	210	62	33	105	10	
4280000	***CRUSTACEANS***	41,891	8,272	13,067	11,947	8,605	**B5**
4280010	Branchiopoda	3,077	503	1,003	955	616	
4280020	Cumacea	562	107	203	155	97	
4280040	Stomatopoda	1,451	245	334	628	244	
4281000	Ostracods	11,111	2,641	2,700	3,338	2,432	***B5.1***
4282000	Copepods	38,011	7,632	11,245	11,179	7,955	***B5.2***
4283000	Cirripedia (barnacles)	6,123	881	2,252	2,075	915	***B5.3***
4284000	Mysidacea	3,075	715	795	911	654	***B5.4***
4286000	Isopods	2,393	644	621	673	455	***B5.5***
4287000	Amphipods	18,898	3,449	5,321	5,872	4,256	***B5.6***
4288000	Euphausiacea	23,314	4,389	7,330	6,692	4,903	***B5.7***
4289000	Decapoda	15,597	2,300	5,890	4,696	2,711	***B5.8***

Table 6: COPEPOD-2005 Plankton Content *(continued)*

		TOTAL Stations	WINTER (Dec.-Feb.)	SPRING (Mar.-May)	SUMMER (Jun.-Aug.)	FALL (Sep.-Nov.)	APPENDIX
ZOOPLANKTON *(continued)* **:**							
4300000	ECHINODERMATA	4,102	472	1,350	1,615	665	**B6**
4310000	CHAETOGNATHA	27,871	5,720	7,756	8,364	6,031	**B7**
4320000	HEMICHORDATA (Enteropneusta)	600	182	112	179	127	
4330000	TUNICATES	19,138	3,629	5,597	5,795	4,117	**B8**
4335000	Thaliacea (Salps & Doliolids)	5,794	1,275	1,612	1,712	1,195	***B8.1***
4337500	Larvacea (Appendicularia)	15,144	2,884	4,530	4,514	3,216	***B8.2***
4339000	Leptocardia	1,110	214	271	363	262	
PHYTOPLANKTON:							
2000000	***ALL PHYTOPLANKTON SUB-GROUPS***	***25,648***	***4,948***	***7,518***	***8,941***	***4,241***	**C0**
2010000	DIATOMS	21,063	4,233	6,260	7,193	3,377	**C1**
2011000	Centric Diatoms	18,548	3,617	5,732	6,308	2,891	
2015000	Pennate Diatoms	13,998	2,882	4,169	4,928	2,019	
2020000	DINOFLAGELLATES	14,548	1,960	4,529	5,990	2,069	**C2**
2030000	CHROMOPHYTES	5,193	570	1,544	2,181	898	
2040000	CHLOROPHYTES	1,469	204	600	552	113	
2050000	COCCOLITHOPHORES	3,357	442	896	1,563	456	**C3**
BACTERIOPLANKTON:							
1000000	***ALL BACTERIA SUB-GROUPS***	***1,691***	***255***	***252***	***706***	***478***	**D0**
1010000	CYANOPHYCOTA (Cyanobacteria)	1,160	146	126	605	283	
PROTIST-PLANKTON:							
3000000	***ALL PROTIST-PLANKTON SUB-GROUPS***	***13,730***	***2,196***	***4,159***	***4,775***	***2,600***	**E0**
3030000	FORAMINIFERA	5,387	787	1,708	1,940	952	**E1**
3050000	RADIOLARIANS	4,250	744	1,067	1,681	758	**E2**
3060000	CILIOPHORA	3,875	475	1,345	1,349	706	**E3**
ICHTHYOPLANKTON:							
5000000	***ALL ICHTHYOPLANKTON SUB-GROUPS***	***13,985***	***2,774***	***4,871***	***3,964***	***2,376***	**F0**
5010000	"Fish Larvae" (unidentified)	8,263	1,855	2,365	2,565	1,478	
5020000	Fish Larvae (identified)	6,236	963	2,709	1,558	1,006	

Values in the first column indicate the NMFS-COPEPOD Biological Grouping Code (BGC) for the taxonomic group described.

4.2 Global Zooplankton Biomass Fields

Global fields of zooplankton biomass were created for each zooplankton biomass type (*e.g.,* displacement volume, wet mass, *etc.*) and for calculated (combined) carbon mass values.

- Appendix G shows the annual mean biomass values (by original type).
- Appendix H shows the annual and seasonal mean biomass values (calculated carbon mass).

Due to the extreme costs of color printing, the Appendix G – H figures in this document are available as a paper (black-and-white) technical memorandum and in an online, electronic (color) form. Due to the limitations of grayscale printing, the figures in the paper document use a six category plot in which the size and shading of the graphical circles represent value ranges of biomass plotted on a five-degree latitude-longitude grid (Figure 9). In the color version, these fields are replaced with a one-degree latitude-longitude gridded plot with ten color-based value range categories.

Zooplankton biomass values gridded on a quarter-degree latitude-longitude grid are also available. While these data points are too fine to be illustrated in a global plot, a sample of this field (for the Gulf of Mexico region) was featured in Figure 3 of this document. The quarter degree data, along with the color version of this document, are all available online at: http://www.st.nmfs.noaa.gov/plankton .

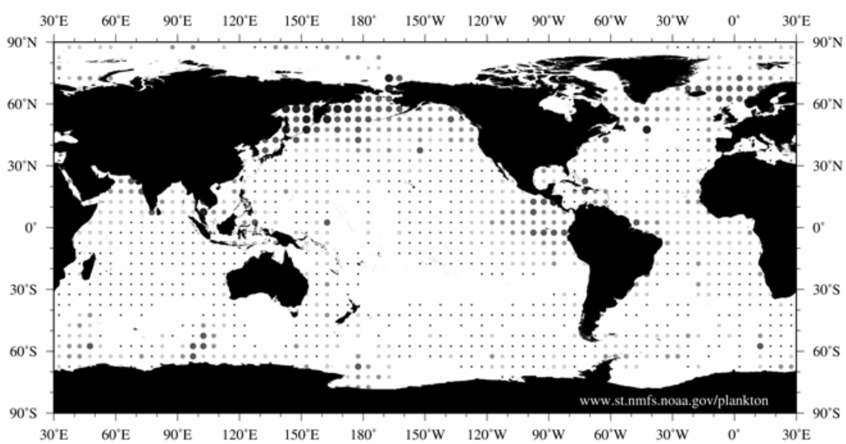


Figure 9: Annual mean zooplankton Carbon Mass (mg/m^3)

(Sampling depth interval: 0 - 200 meters; Sampling mesh: ~330 micrometers)

4.3 Comparison with the *World Ocean Atlas 2001* Biomass Fields

The zooplankton carbon mass fields of *World Ocean Atlas 2001* (O'Brien *et al.* 2002b) were calculated with the widely-used compilation of linear biomass equations of the ICES Committee on Terms and Equivalents (Cushing *et al.* 1958). Since both of these publications, better references and methods have been compiled (*e.g.,* Harris *et al.* 2000; Bode *et al.* 1998; Wiebe 1988; Balvay 1987, Wiebe *et al.* 1975), and most discourage the use of such linear methods for these conversions. For example, Wiebe *et al.* (1975) notes that the relationship between biomass types is not linear due to factors such as the differences in interstitial water present in the biomass samples. The amount of interstitial water is inversely proportional to the amount of biomass (*e.g.,* smaller biomass samples have a larger relative amount of interstitial water) which causes the error to be greater at smaller values.

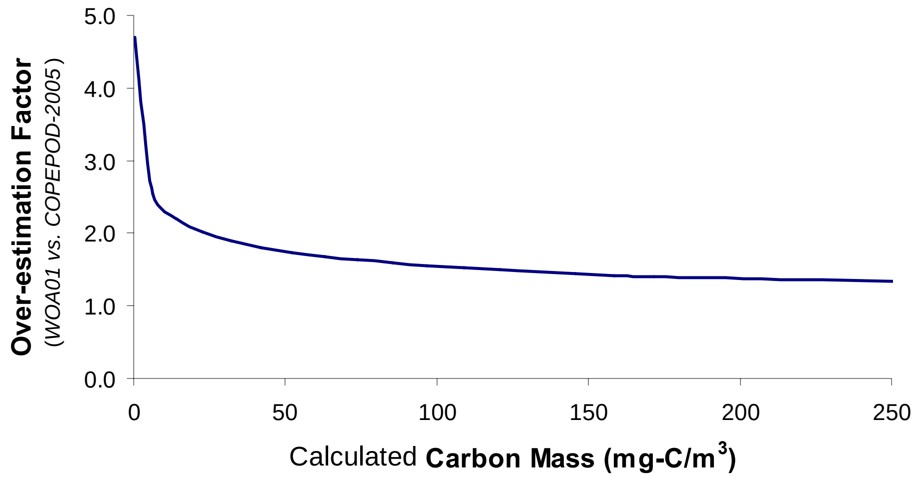


Figure 10: Comparison of the *WOA01* and *COPEPOD-2005* biomass conversion equations.

To compare the difference in the two conversion methods, zooplankton biomass values were converted to carbon mass using the respective equations of the *World Ocean Atlas 2001* (WOA01) and *COPEPOD-2005*. An "over-estimation factor" was then calculated by dividing the WOA01 carbon mass estimate by its corresponding *COPEPOD-2005* carbon mass estimate. The difference in final value between the two calculation methods ranged from 1.6 to nearly five times larger in value. As predicted by Wiebe *et al.* (1975), the difference between these two calculation methods was greatest at smaller values (Figure 10).

5. SUMMARY

The new zooplankton biomass fields presented in this document feature significant new data coverage and improved methodology which uncovered a large over-estimation of carbon mass by the biomass fields of *World Ocean Atlas 2001*. It is important to note that globally over 90% of all zooplankton biomass values would fall into the 0 to 50 mg-C/m^3 range of Figure 10. Further, over 80% of the biomass values present in the original *World Ocean Atlas 2001* biomass fields fell in the < 15 mg-C/m^3 range where the over-estimation is the greatest. If these fields were used for food chain or energy flow applications, the *World Ocean Atlas 2001* fields could lead to a 3-4 times over-estimation of global zooplankton carbon. The corrected *COPEPOD-2005* fields are a recommended replacement for this earlier work.

The zooplankton biomass mass fields presented here were still created using generalized equations for inter-calculation between different biomass types and net mesh sizes. It is hoped that future versions of this work will feature improved equations which will account for regional differences (*e.g.*, North Atlantic vs. Indian Ocean, coastal vs. open-ocean) and other sampling-dependent biases. In the meantime, the raw biomass data used to create all of these fields are also available in the COPEPOD online database, allowing the user to recreate or calculate their own fields using methods or equations of their choice.

NMFS-COPEPOD was designed to provide plankton data in an online database that serves the needs of the database user *and* acknowledges the investigators, associated projects and institutions who originally collected those data. Offering a broad selection of individual data sets, regional compilations and global mean fields, COPEPOD hopes to serve a wide variety of users ranging from the large-scale global modelers to the regional process scientist.

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Help us grow!

The contents of this database would not be possible without the efforts and expertise of the original scientists and technicians that collected, identified and quantified its plankton content. The goal of COPEPOD is to make these plankton scientists' hard work more readily available to the scientific community in an easy-to-use data format that also clearly identifies the original persons and entities responsible for collecting and preparing those data.

We are actively searching libraries, archives and file cabinets for long lost plankton data in paper or electronic form. The more eyes searching the better! Did you know that COPEPOD also gives credit to individuals that refer or contribute data? Perhaps you managed to keep one of the last remaining copies of your old advisor's or colleague's data tables that haven't seen the light of day since the project ended or its collector retired 30 years ago.

If you have content that could become part of the COPEPOD collection, please contact us. Our goal is to also make the data contribution process as easy for you as possible. We will gladly do any necessary data reformatting, file sorting, paper digitizing, and associated processing that is necessary to get these data into COPEPOD and out to the public. All you have to do is dig it out, dust it off, and send it to us.

Todd O'Brien - Project Leader
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Appendix I: Listing of Investigators associated with the "*COPEPOD-2005*" data content.

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