GUINEA CURRENT LARGE MARINE ECOSYSTEM PROJECT

REGIONAL DEMONSTRATION PROJECT

ON

PRODUCTIVITY

**Productivity Patterns in the Guinea Current Large Marine Ecosystem
with regard to its Carrying Capacity for Living Resources**

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Executive Summary

The Guinea Current Large Marine Ecosystem encompasses sixteen countries from Guinea Bissau in the north to Angola in the south, including the island states of Sao Tome and Principe[1]. These countries embarked on a project to combat living resources depletion and coastal area degradation of the region by employing the LME approach (Sherman and Anderson, 2002), which involved assessment of productivity, fish and fisheries, ecosystem health, governance and socio-economics. Nine demonstration projects, made up of three regional and six national projects, were designed to be carried out from August, 2004 to December, 2009. Evaluation of marine productivity of the GCLME with regards to its capacity to sustain living marine resources was one of the regional demonstration project.

In March, 2007 a mid-term review of the GCLME project was undertaken and a 5-member team was contracted to carry out prioritized activities in order to achieve the objectives set out in the regional demonstration project on productivity. These activities involved analyses of plankton samples collected with Continuous Plankton Recorder (CPR) from December, 1996 to November, 1999. This was the first time a survey using this technology was ever carried out in Africa, although it is very common in other parts of Europe and America. The team put in place to carry out the activities also processed benthic fauna samples and zooplankton samples collected by the Norwegian vessel *RV Fridtjof Nansen* between 2005 and 2007. Remote sensing data was also used to support assessment of primary productivity in the region.

The GCLME is characterised by a unique coastal upwelling off the coast of Ghana and Cote d'Ivoire from July to September. A minor upwelling also takes place over different time intervals between December and March. It was observed from the assessment that the intensity of the upwelling appears to be declining as a result of global climate change. Temperature was observed to play a key role in the composition and distribution of marine plankton. This was noted particularly for the copepod *Calanoides carinatus* which appears in the coastal waters only during the cold major upwelling season. Spatial variation in the distribution pattern of zooplankton was driven mostly by phytoplankton abundance in all seasons except the major upwelling, during which period water temperature governed most of the distribution.

From the CPR data, it was noticed that highest primary and secondary productivity shifted from Ghana and Cote d'Ivoire to Nigeria and Cameroun during thermal stratification of the water (i.e. October to December) from 1998 to 1999. Longer time series data could validate this observation. The species list of phytoplankton and zooplankton identified formed the basis for future assessment in the region. In view of this a user-friendly manual for identification of common zooplankton species was produced.

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[1] Angola, Benin, Cameroon, Congo, DRC, Cote d'Ivoire, Gabon, Ghana, Equatorial Guinea, Guinea, Guinea Bissau, Liberia, Nigeria, Sao Tome and Principe, Sierra Leone, Togo

The macrobenthic faunal biomass data that was used as surrogate for benthic productivity showed a general high productivity for Sierra Leone, Guinea-Bissau and Ghana in that sequence. The highest productivity generally occurred with polychates except Ghana where crustacean ranked highest at Sao Tome and Principe where productivity was associated with echinoderms. Baseline information for the region has been provided in this study, however, there is still some knowledge gap of macrobenthic fauna in the GCLME. This calls for pragmatic measures that will lead to increased research on basic biology (feeding, habitat preference etc.), species composition, taxonomy, abundance, community structure and also training to stimulate interest in the discipline. Collection of voucher specimens to be kept at the Regional Centre for Productivity and Biodiversity formed part of the project, and also serve as reference for scientists in the region.

Estimation of primary productivity from satellite remote sensing (i.e. MODIS and a MERIS) for the period July, 2002 to April, 2007, using depth integrated, vertically generalized model to complement in-situ assessment of phytoplankton revealed that mean monthly estimates of primary productivity ranged between 110-310 gC/m^2/month. The rate was obviously highest during the major upwelling period (i.e. July to September), quantifying the level of productivity for the first time in the region. On a spatial scale the shallow waters around Bijagos Islands in the Sierra Leone Guinea Plateau (SLGP) was relatively more productive all year round. Sea surface temperature was observed to be the primary controlling factor for spatial variation in primary productivity. Changes in water temperature from the Canary and the North Equatorial Counter Currents in the north, as well as the Benguela and the South Equatorial Currents in the south were also contributory to the spatio-temporal patterns in primary production.

From the short-term data analysed, it could not be ascertained whether primary and secondary production had reached the carrying capacity to support living resources. However, the results pointed to the fact that the current trend in global climate change would definitely affect the composition and distribution of marine plankton, as well as the strength of the major seasonal upwelling in the GCMLE. This is expected to negatively impact on abundance and distribution of fishery resources.

Despite limitations such as large mesh size, small entrance aperture and limited sampling depth of the CPR, it afforded an excellent means of sampling an extensive area in a cost effective manner. The Project has acquired two CPRs and also developed and tried its human capacity to deploy these instruments. The results has also provided invaluable primary and secondary trophic indices for ecosystem-based fishery modeling. Finally, the Productivity and Biodiversity Centre could improve on species image database with acquisition of a camera fitted to a microscope.

An integral element for successful implementation of the project was based on establishment of the regional centre of excellence for Productivity and Biodiversity at the University of Ghana.

Acknowledgement

General Introduction

The Guinea Current Large Marine Ecosystem (GCLME) comprises of Sixteen countries from Guinea Bissau to Angola. The region received base funding from the Global Environment Facility (GEF) and co-financing by the countries themselves to embark on a project on "*Combating Living Resources Depletion and Coastal Area Degradation in the Guinea Current LME through Ecosystem-based Regional Actions*" from August, 2004 to December, 2009. United Nations Industrial Development Organisation (UNIDO) was designated the executing agency, with United Nations Development Programme (UNDP) and United Nations Environment Programme (UNEP) acting as implementing agencies. Techincal support was to be provided by US - National Oceanic and Atmospheric Administration.

The strategy for carrying out the project was based on execution of three regional and six national demonstration projects. These projects were designed to be replicable and intended to demonstrate how concrete actions can lead to dramatic improvements. One of the regional demonstration projects sought to evaluate the productivity of the GCLME with regards to its capacity for living marine resources.

In March, 2009 a mid-term review was carried out and Dr George Wiafe, the Regional Expert for Productivity was contracted to constitute a team of local experts to complete prioritised objectives of the Regional demonstration project on Productivity. The four consultants appointed for the assignment were responsible for analyses of plankton and benthic fauna samples and application of remote sensing for productivity assessment. All analyses took place at the GCLME Productivity and Biodiversity Center at the Department of Oceanography and Fisheries, University of Ghana.

This report is the product of the Regional Producitivity Team and showcase the findings from analyses of samples collected in the GCLME. The report covers the following areas: Continuous Plankton Recorder surveys (1995 - 1999), zooplankton and benthic survey aboard the *RV Fridtjof Nansen*, productivity assessment from satellite remote sensing, Standard methodologies

for sampling plankton and benthic fauna in the GCLME, Manual for identification of Marine Plankton, and reports on two Regional Workshops on Productivity.

Productivity Demonstration Project in the Guinea Current Large Marine Ecosystem

The Guinea Current Large Marine Ecosystem (GCLME) is recognised as one of sixty-four Large Marine Ecosystems (LME) of the world, based on its distinctive bathymetry, hydrography, productivity and trophic dynamics. It owes its unity to the eastward flowing Guinea Current, which stretches from Guinea-Bissau (11°N, 16°W) to Gabon (0° 41'S, 8° 45'E). The hydrographic regime is also influenced by the Canary Current and Benguel Current which borders on the northern and southern margins of the Guinea Current, respectively. In addition, the Equatorial and Equatorial Counter Currents also contribute to oceanographic changes in the GCLME.

The northern subsystem of the GCLME is thermally unstable and is characterised by intensive seasonal upwelling while the southern half, which is generally thermally stable, depends on nutrient input originating from land drainage, river flood and turbulent diffusion, although less intensive and periodic upwellings have been reported.

The coastal and marine areas of the GCLME are richly endowed with abundant but rapidly depleting marine resources, especially of commercially valuable fish, as well as other living and non-living resources on which the economies of the countries are largely dependent. These coastal and marine areas are repositories of rich and unique biodiversity of global importance and also contribute significantly to the world's annual catches of fish and fisheries. The fishery resources comprise of both locally important resident stocks that support artisanal fisheries, and transboundary straddling and migratory stocks that attract large commercial offshore foreign fleets from Europe and the far East. Fishing is an important economic activity that provides livelihood for many coastal communities in the region and it is imperative that measures are put in place to forestall the decline in living resources so as to protect the livelihood of the over 280 million inhabitants in the region.

Issues of continuous depletion of living marine resources and loss of biodiversity, degradation, modification and destruction of critical marine habitats, and decline in water quality with its associated problems of eutrophication, anoxia, and algal blooms are of transboundary in nature and require regional effort in addressing them. These concerns, thus, culminated in a successful implementation of a six country[2] Pilot Phase GEF-sponsored project from 1995 to 1999. The main goal of the Project was to monitor and assess the health and biodiversity of the Gulf of Guinea Large Marine Ecosystem (GOGLME). The results obtained over the four year period provided evidence that the health of the West African coastal and marine environment was under severe stress.

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[2] Benin, Cameroon, Côte d'Ivoire, Ghana, Nigeria and Togo

Productivity surveys were carried out during the Pilot Phase Project using continuous plankton recorders (CPR) attached to ships of opportunity (SOOP). In all, over 2,960 samples were obtained from December, 1995 to November, 2009. The survey covered the coastal waters of Côte d'Ivoire to Cameroon. During the expanded phase from 2004 - 2010, all the CPR samples collected earlier were to be analysed, in addition to collection of new samples.

Terms of Reference for Consultants: 2009 - 2010

(a) Regional Productivity Demo Consultant

Main duties	**Expected results**
Productivity Module Workplan preparation and implementation (i) Assist the GCLME Regional Project Coordinator in the preparation of materials for detailed annual work plans and in the follow-up of their implementation; (ii) Coordinate and oversee the preparation of the substantive and operational reports from local consultants engages under the Productivity Demo project, integrating their reports into the overall project report;	Annual and quarterly workplans; substantive and operational project reports and annual status report on project progress
Productivity Demo Project implementation and management: (i) Coordinate the upgrading, harmonization and production of plankton identification manual. Supervise preparation and production of the following manuscripts: Plankton Identification manual for the GCLME; Manual on Standard Field and Laboratory Procedures; Comprehensive Report on Productivity Assessment in the GCLME (ii) Define detailed procedures for laboratory analysis of collected productivity and biodiversity samples and harmonization of QA/QC procedure. (iii) Establish a Harmful Algal Bloom regional reporting network for early warning, detection and prediction of blooms. (iv) Coordinate the acquisition and processing of satellite imageries to	Draft report of manuscripts on plankton identification, standard field and laboratory procedures and productivity assessment in the GCLME. Report on mechanism for establishing HAB regional reporting network for early detection of

complement in situ plankton and hydrological data and their entry into GIS format for analyses, interpretation and archival and creation of GIS format for marine plankton database for the GCLME region (v) Assist the Regional Project Coordinator in editing a regular information bulletin on the productivity component of the project (issued in English and French and widely distributed) and create outreach material for dissemination to coastal zone stakeholders to raise awareness of productivity issues and facilitate buy-in to the monitoring process (vi) Prepare materials for the organisation of a regional workshop for the 16 countries of the GCLME in 2010. The Workshop should include dissemination of results from the productivity demo project, introduction to tools in analysing plankton and benthic fauna samples, assessment of productivity using biological and remote sensing data.	blooms. Draft materials for regional workshop.
(i) Preparation and submission of a final report including recommendations for scientific research and management actions aimed at presentation of the productivity of the GCLME.	Final report prepared

(b) Plankton Analyst

Main duties	Expected results
Productivity Demo Project implementation and management: (i) Carry out laboratory analysis of CPR samples collected during the GOG/GCLME phases (ii) Carry out analysis and interpretation of results from plankton surveys (iii) Take pictures of plankton species for incorporation into plankton identification manual. (iv) Carry out collection and storage of voucher specimens	Database of plankton species composition and their abundance from survey routes, and voucher specimens

for the Biodiversity Museum.	
Preparation and submission of a final report including recommendations for scientific research and management actions aimed at presentation of the health and productivity of the GCLME.	Final report prepared

(c) Remote Sensing Analyst

Main duties	Expected results
Productivity Demo Project implementation and management: Retrieve MERIS imageries covering the GCLME region for processing Update methodology for retrieving chlorophyll a from MERIS data Update algorithm for computing primary productivity for the GCLME region. Compare primary production estimates between CPR and remote sensing data Estimate carrying capacity of GCLME for living marine resources	Maps of average chlorophyll a biomass and primary production by month or season, including anomalies throughout the time series
Preparation and submission of a final report including recommendations for scientific research and management actions aimed at presentation of the health and productivity of the GCLME.	Final report prepared

(d) Benthic Analyst

Main duties	Expected results
Productivity and Biodiversity Module implementation and management: (i) Carry out laboratory analysis of benthic fauna samples collected during the GCLME phase (ii) Carry out analysis and interpretation of results from benthic fauna surveys (iii) Carry out collection and storage of voucher specimens for the Biodiversity Museum.	Database of benthic fauna and flora species composition and their abundance from survey routes, and voucher specimens; biotope maps of benthic intertidal habitats.
Preparation and submission of a final report including recommendations for scientific research and management actions aimed at presentation of the health and productivity of the GCLME.	Final report prepared

Expected Outputs

Upon successful completion of their contracts, the consultants were to produce the following:

(A) Publication of the following documents:

Plankton manual for the GCLME

This would be updated to include photographs of common species and their distribution. It would serve as a reference for plankton studies in the region and provide baseline information of plankton distribution in a GIS format. It should be noted that such a document is non-existent in the region. The document would be peer reviewed before publication.

Standard Field and Laboratory procedures

The draft document on field and laboratory procedures for sampling and processing plankton and benthic fauna would be finalised and published after peer review.

Productivity assessment of the GCLME.

This would be published under peer review and would assess the productivity of the GCLME and its capacity to support living marine resources. This document would provide a scientific assessment to inform management of the ecosystem.

(B) Quantification of primary production from remotely sensed data

This is contingent upon installation of European Space Agency/Digital Direct System for acquisition of MERIS data. The University of Ghana, in partnership with European Space Agency, Plymouth Marine Laboratory of U.K. and the University of Cape Town of South Africa would put in place the DDS for acquisition of satellite data. Support for this initiatve is under the DevCoCast Project. Satellite data will be obtained and processed and information disseminated via project website. One personnel has been trained in South Africa for this assignment and it would be necessary to engage this person. The support provided by the GCLME project for this activity is limited to the engagement of the analyst through a timely limited service contract of two times two months.

(C) Estimation of primary and secondary production and benthic fluxes

All samples collected since 1995 (i.e. Pilot phase) would be processed and analysed. This would require part time engagement of two plankton analysts and part-time engagement of a benthic fauna analyst.

(D) Estimation of carrying capacity for living resources

There would be a regional workshop on scientific and technical aspects of environmental monitoring, data processing and modelling of the GCLME. Estimates of productivity of the GCLME would be used to derive estimates of the carrying capacity of the ecosystem to support living marine resources.

(E) Harmful Algal Bloom monitoring

Development of a regional operational capacity for monitoring of Harmful Algal Blooms, and establishment of a Harmful Algal Bloom regional reporting network for early warning, detection and prediction of blooms. Baseline sampling of HAB at selected hotspots in the region on a small scale would be carried out as part of the Fridtjof Nansen survey and the results would be disseminated at the regional workshop.

(F) Organise Regional Workshop for GCLME countries

The Regional Workshop on Productivity Assessment in the Guinea Current Large Marine Ecosystem (GCLME) was to present findings of the Regional Demonstration Project on Productivity to participating countries. It was to elicit the challenges in carrying out future assessment in the region.

Extent to which TOR was met

The activities set out in the TOR were successfully carried out with the exception of reporting on the status of Harmful Algal Bloom in the region. This activity was to have been carried out under contract a consultant. This person was identified but no contract was awarded. Thus, the work of the consultants could be considered as very successful.

Continuous Plankton Recorder Survey in the Gulf of Guinea

Summary

Continuous Plankton Recorder (CPR) survey was carried out from Cote d'Ivoire to Cameroon (i.e. Gulf of Guinea) from December, 1996 to November, 1999. This was the first time CPR survey had been carried out in Africa, although this technology has been in existence in other parts of the world since the 1950s. The coastal waters of the Gulf of Guinea is characterised by a unique upwelling from July to September each year. However, the intensity of the upwelling varies within the region, strongest off Côte d'Ivoire and Ghana. Temperature is directly related to seasonal changes in the hydrography and also plays a key role in the distribution pattern of plankton during the major upwelling. Despite limitations such as large mesh size, small entrance aperture and limited sampling depth, the CPR afforded an excellent means of sampling an extensive area in a cost effective manner. The showed that the the oceanographic regime is warming up as a result of climate change and contributing significantly to plankton distribution in the region. Phytoplankton and zooplankton abundance declined over the study period with consequent decline in primary and secondary productivity. The minor upwelling was still stronger in Ghana and the strength of major upwelling was still concentrated in Cote d'Ivoire and Ghana. The highest primary and secondary productivity shifted from Ghana and Cote d'Ivoire to Nigeria and Cameroun during thermal stability 2 season in 1998 and 1999. These changes in GOG marine environment could however be a simple anomaly or inter annual environmental variations and therefore could not be of considerable ecological significance in the GOG. There is the need for longer time series data to consolidate these findings. Spatial variation in the distribution pattern of zooplankton was driven mostly by phytoplankton abundance in all seasons except the major upwelling, during which period water temperature governed most of the distribution. The following taxa were identified as contributing significantly to the distribution patterns: H*yalochaete* spp., *Phaeceros* spp. *Thalassionema nitzschioides, Trichodesmium spp., Rhizosolenia hebetata semispina, Rhizosolenia calcar avis, Ceratium extensum* and *Ceratium minutum.* With regard to the zooplankton, their community structure during the major upwelling was significantly different from the other hydrographic seasons. Foraminifera, Chaetognath, *Oithona* spp., *Oncaea* spp, Echinoderm larvae, *Para-pseudocalanus, Temora stylifera, Eucalanus* spp., and *Clausocalanus* spp. contributed significantly to observed variations.

Keywords: phytoplankton, zooplankton, continuous plankton recorder, Gulf of Guinea, upwelling, productivity

Introduction

In 1995, six countries in the Gulf of Guinea (GOG) namely Cote d'Ivoire, Ghana, Togo, Benin, Nigeria and Cameroon took part in a pilot project funded by Global Environment Facility (GEF) aimed at reversing the degradation of coastal and marine environment and ensuring long term sustainable utilization of resources of the region (Ibe and Sherman, 2002). It was based on the ecosystem concept of managing resources of the marine environment (Sherman and Anderson, 2002). Monitoring of plankton as part of the productivity studies of the project was carried out using a Continuous Plankton Recorder (CPR) towed from merchant ships on their normal sailing.

The CPR is a device for collecting continuous horizontal samples of plankton at a standard depth. The device is towed behind a ship of opportunity at speeds of between 10 and 18 knots, at a depth of about 10 metres (Warner and Hays, 1994). The CPR has been used successfully in North Atlantic, North Sea, Mediterranean, Baltic, Southern Ocean and Pacific Ocean (Hays and Lindley, 1994). The close association of plankton to environmental variables makes plankton studies an important aspect of environmental monitoring. The CPR has established patterns of spatial and temporal changes in plankton of North Atlantic over many decades (John *et al.,* 2002). The CPR is one of the most important methods for assessing long term biological changes in the ocean and seasonal cycles and long term trend in plankton has been established in the Northwest Atlantic (Myers *et al*., 1994).

The coastal hydrography of GOG is generally divided into four regimes; a minor upwelling from December to January; long developed thermocline from February to June; major upwelling season from July to September; and another developed thermocline from October to November (Longhurst, 1962; Mensah and Koranteng, 1988). The Guinea Current flows offshore from west to east as a continuation of the Equatorial Counter Current in the middle part of Atlantic Ocean (Allersma *et al.,* 1993). The major upwelling in the GOG occurs between Cape Palmas (8°W) in Cote d'Ivoire and Cotonou (2°E) in Benin and it differs from other eastern boundary current system because of its proximity to the equator and its seasonality (Binet and Marchal, 1993).

There have been recent studies on plankton communities of the upwelling region of the GOG. Binet (1983) listed eight groups of phytoplankton species in the GOG associated with different ecological parameters. Reyssac (1993) observed that the greatest production of phytoplankton in the Gulf of Guinea (GOG) occurs each year during the major upwelling season. Diatoms dominated during the upwelling periods whilst dinoflagellates dominated in the period of thermal stratification of the hydrographic regime (Anang, 1976; Dovlo, 2008). In the GOG, there is high zooplankton abundance but less species diversity during the upwelling season (Bainbridge, 1972). The high zooplankton abundance is probably due to high primary productivity during the

upwelling season (Mensah, 1995). Wiafe (2002) observed that plankton communities of the GOG exhibited variable spatial and temporal patterns.

The main objective of this paper was to assess changes in plankton communities of the GOG and its implications on the marine environment. The other goals include investigating the seasonal and inter annual variability of the plankton communities. The interactions between phytoplankton and zooplankton communities are important to fisheries and other living marine resources.

Methodology

The coast of GOG stretches over 2,000 km between 8°W on the left boundary and 9°E on the right boundary (Allersma *et al*., 1993). The study area covered the waters between Cote d'Ivoire (8°W) and Cameroon (9°E) (Figure 1). The continental shelf is narrow with widths of 20 – 25 km along the coasts of Cote d'Ivoire, Togo, Benin and Western Nigeria. The shelf has its widest width of 20 – 80 km between Cape Three Points (Ghana) and the Volta Delta (Ghana), 50 – 65 km in front of the Niger delta (Nigeria) and the continental slope is steep (Allersma *et al.,* 1993).

Figure 1. Map of Gulf of Guinea showing the study area and Continuous Plankton Recorder (CPR) routes. Each sample from the route represents 10 miles of CPR tow. (CI – Cote d'Ivoire, GH – Ghana, TG – Togo, BN – Benin, NG – Nigeria, CM – Cameroon). (Source: Wiafe, 2002).

In addition to CPR samples, sea surface temperatures measured from a coastal observation station in Tema along the coast of Ghana were included as environmental data. This represented a ten-year time series data from 1990 to 1999. The monthly variations in sea surface temperature from 1996 to 1999 were also obtained.

The CPR samples were analysed according to standard laboratory procedures (Warner & Hays, 1994). Mean phytoplankton and zooplankton abundance calculated from each year's average were determined and bar charts were used to display the ten common phytoplankton and zooplankton groups in each year. The diatoms, dinoflagellates, copepods and total zooplankton were each pooled together separately for each year and trend over the study period was observed with bar chart. The spatial anomalies of phytoplankton and zooplankton distribution in the various hydrographic seasons of each year were also determined.

For plankton community structure analyses, the phytoplankton and zooplankton data were log(x+1) transformed to ensure homoscedasticity and reduce the numerically dominant groups. Species represented by at least 2% in any sample were used in data analysis. This measure excluded low numbers of certain species that occur occasionally. Hierarchical clustering analytical techniques were employed with Plymouth Routines in Multivariate Ecological Research (PRIMER) (Clarke and Warwick, 1994) using Bray-Curtis similarity matrix with respect to the four hydrographic seasons (U1- minor upwelling, S1- thermal stability 1, U2- major upwelling, S2- thermal stability 2) from 1996 to 1999. The minor upwelling was represented by the months of January and February; major upwelling by July to September; thermal stability 1 by March to June; and thermal stability 2 by October to December (Mensah, 1973). Cluster analyses was also done for the sampling areas (CI – Cote d'Ivoire, GH – Ghana, TG – Togo, BN – Benin, NG – Nigeria, CM – Cameroon) for the four seasons from 1996 to 1999. Plankton groups clustering at Bray-Curtis similarity measure greater than 70% were considered to show similar community structure.

Results

Sea Surface Temperature

Spatial interpolation of sea surface temperature showed that the cold minor upwelled waters of January and February were experienced only in the coastal waters between Côte d'Ivoire and western part of Nigeria (Figure 2a). By June, cold surface waters had began to accumulate near the equator, which later encompassed the whole gulf (i.e. major upwelling season) (see Figure 2b). As is often the case in the region, the duration of the minor upwelling was less than the major upwelling.
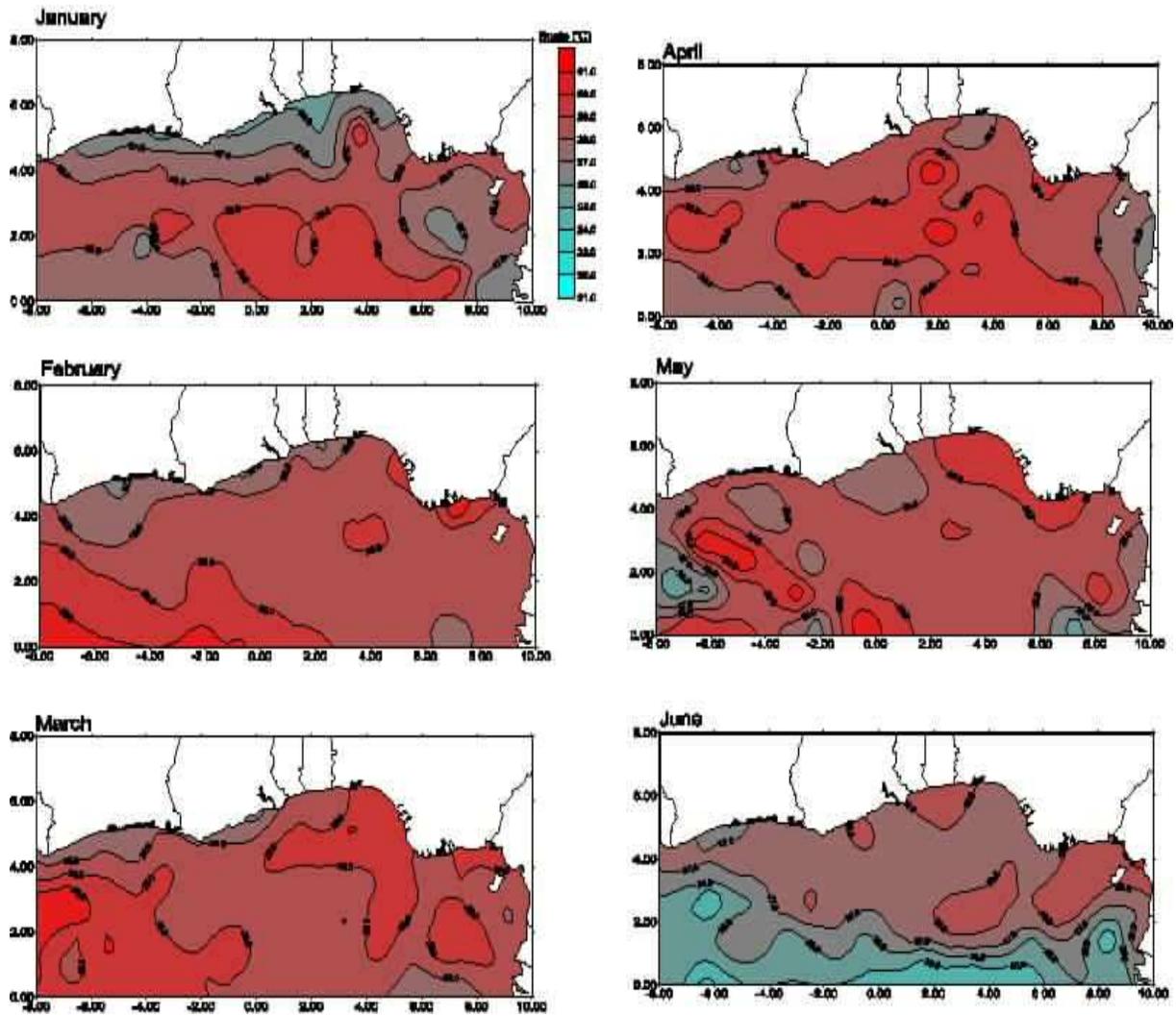
Figure 2a Spatial interpolation of monthly sea surface temperature in the Gulf of Guinea from January to June, 1997. (Data source: COADS, 1997)
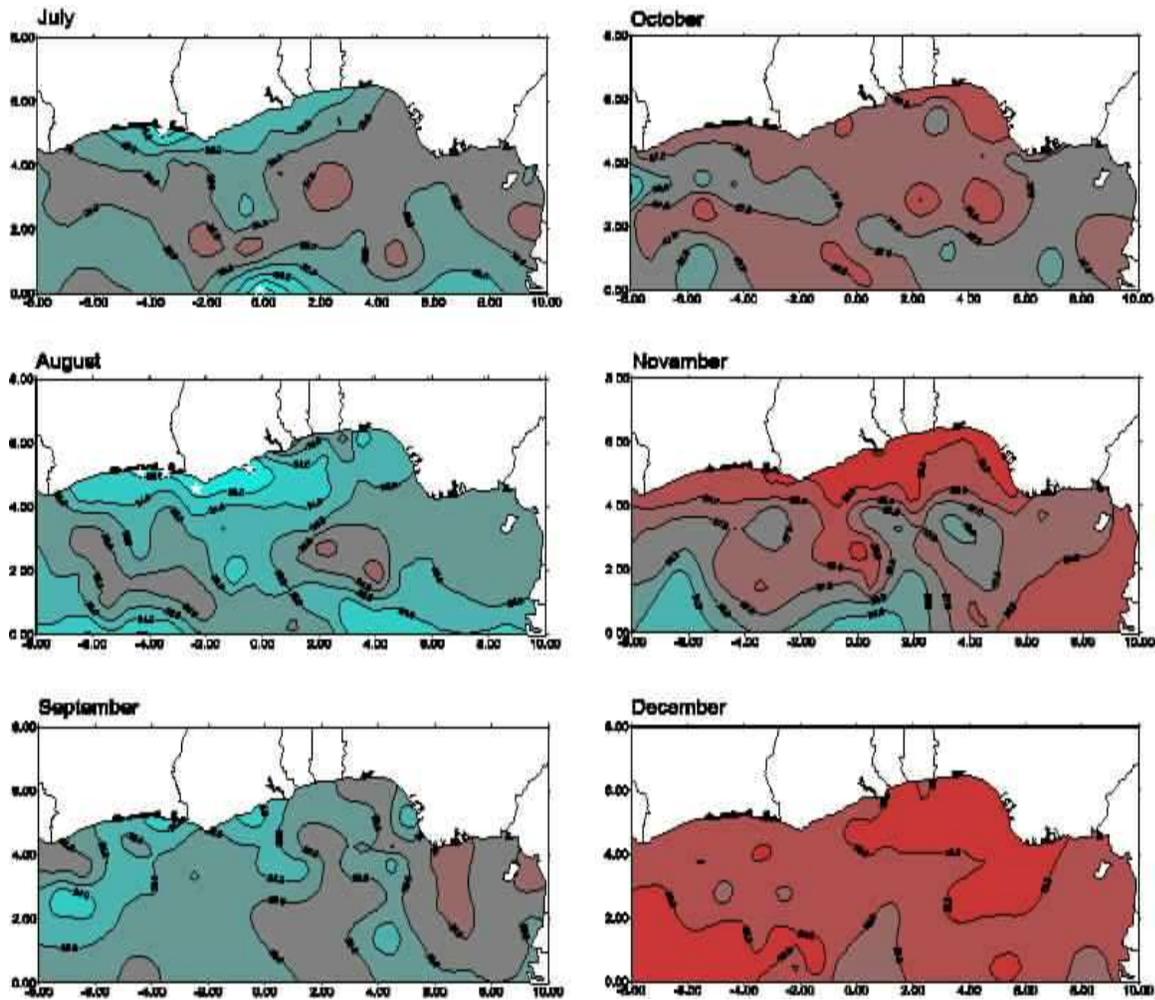
Figure 2b Spatial interpolation of monthly sea surface temperature in the Gulf of Guinea from July to December, 1997. Lowest sea surface temperature (<23 °C) was recorded off Côte d'Ivoire and Ghana (O) in August (Data source: COADS, 1997)

There was a general increase in sea surface temperature in the GOG from 1990 to 1999 (Figure 2).
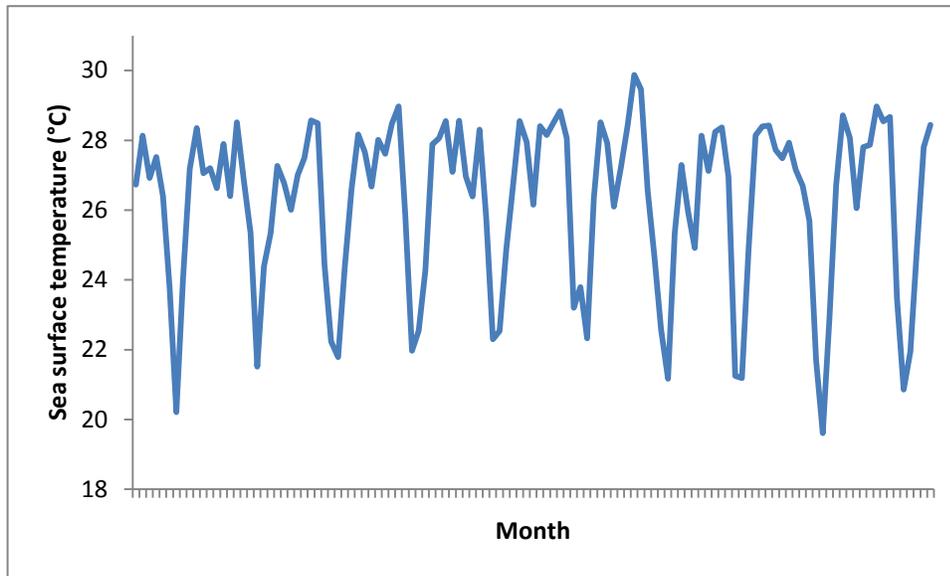
Figure 2c. Distribution of sea surface temperature from 1990 to 1999 from a coastal observation station in Tema, Ghana. There was a general increase in sea surface temperature in the Gulf of Guinea over the period.

During the minor upwelling in 1997, sea surface temperature decreased to 25°C. The major upwelling started early compared with the other years and the lower temperature maintained till August (Figure 3).
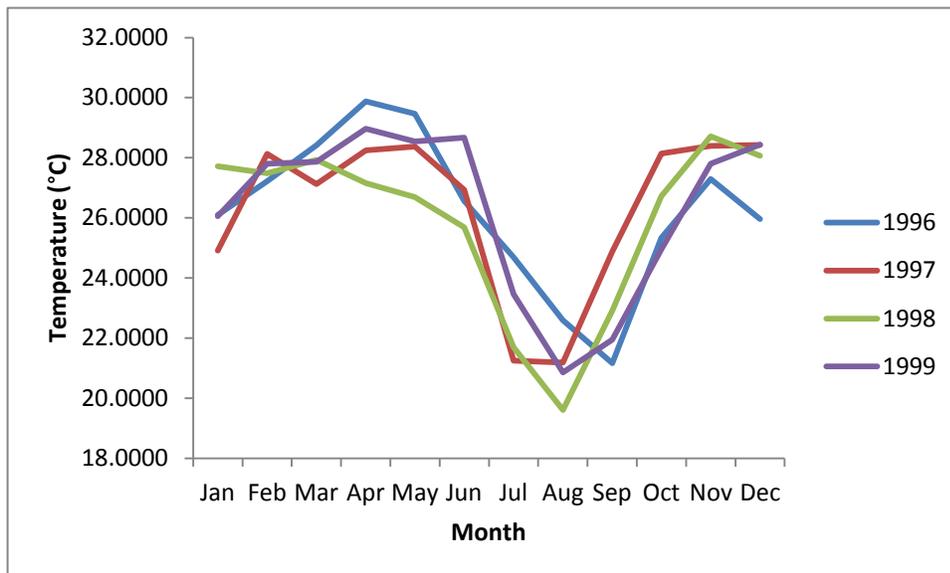
Figure 3. Monthly variations in sea surface temperature from 1996 to 1999 from a coastal observation station in Tema, Ghana. In 1997, sea surface temperature decreased to 25°C in the minor upwelling whilst the major upwelling started early and lower temperature maintained.

Plankton Composition and Abundance

A total of 66 phytoplankton taxa, 26 zooplankton (<2mm) taxa and 37 zooplankton (>2mm) taxa were identified from the samples (Appendix 1). Thus by species composition, phytoplankton constituted 51 percent whilst zooplankton (<2mm) and zooplankton (>2mm) formed 20 percent and 29 percent respectively.

The mean diatom abundance generally declined from 6030 cells /m3 of water in 1996 to 3618 cells /m3 of water in 1999. There was unusually high diatom abundance greater than 22000 cells /m3 of water in 1997 (Figure 4).
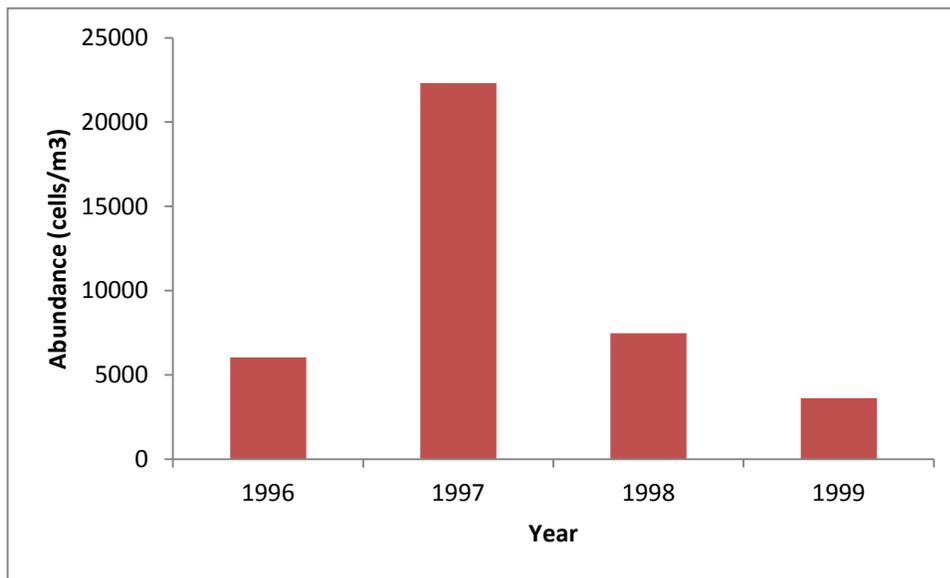
Figure 4. Mean diatom abundance calculated from each year's average from 1996 to 1997. The mean diatom abundance generally declined over the period.

Thalassionema nitzschoides dominated the diatoms in 1996 and 1997 but was replaced by *Rhizosolenia calcar avis* and *Thallassiosira* spp. in 1998 and 1999 respectively. The abundance of *Thalassionema nitzschoides* showed a considerable decline from 1300 cells / m3 of water in 1996 to 450 cells / m3 of water in 1999. The abundance of *Thallassiosira* spp. increased from 300 cells / m3 of water in 1996 to 890 cells / m3 of water in 1999 (Appendix 2a).

The mean dinoflagellates abundance increased from 4469 cells /m3 of water in 1996 to 4647 cells /m3 of water in 1999. There was however higher dinoflagellates abundance in 1997 and the trend line showed a little decline in abundance (Figure 5).
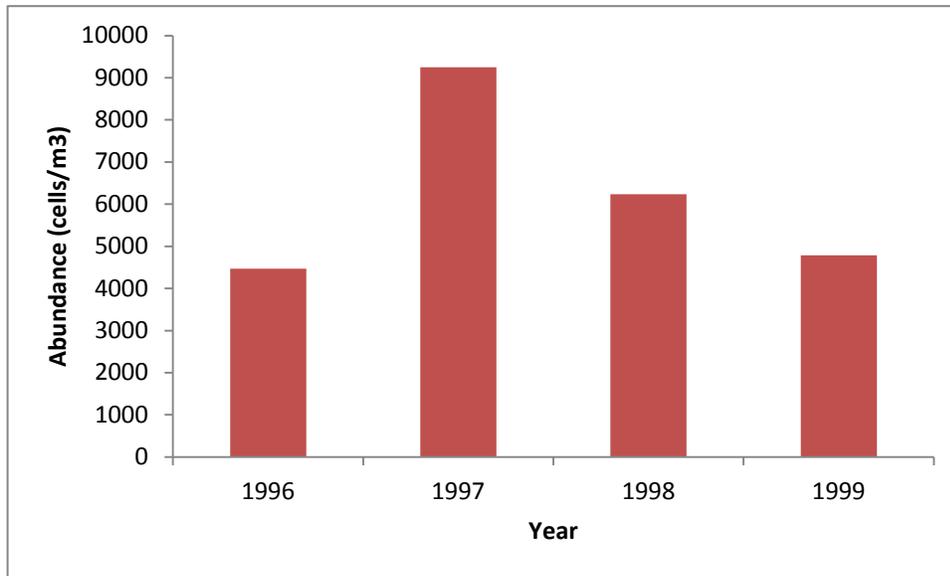
Figure 5. Mean dinoflagellate abundance calculated from each year's average from 1996 to 1997. The mean dinoflagellates abundance generally decreased over the period.

Ceratium massilliense dominated the dinoflagellates in 1996, 1997 and 1998 but was replaced by *Ceratium vultur* in in 1999. The genus Ceratium consecutively dominated from 1996 to 1999 and formed the ten common dinoflagellates group in 1998. The abundance of *Ceratium vultur* increased gradually from 600 cells / m3 of water in 1996 to 920 cells / m3 of water in 1999 (Appendix 2b).

The mean copepods abundance decreased from 172 individuals /m3 of water in 1996 to 153 individuals /m3 of water in 1999. The higher copepods abundance in 1997 was due to increase in abundance of the smaller copepods (<2mm) (Figure 6).
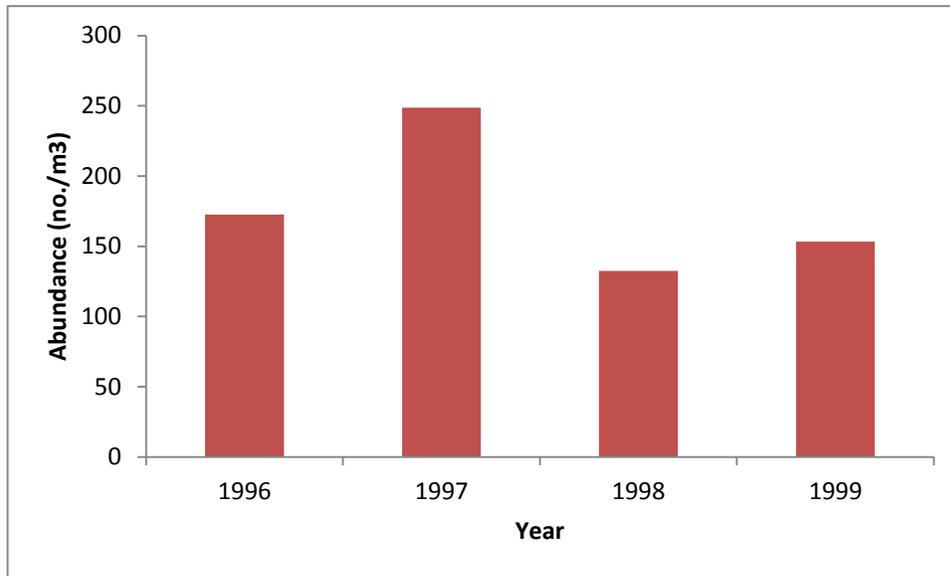
Figure 6. Mean copepod abundance calculated from each year's average from 1996 to 1999. The mean copepods abundance generally decreased over the period.

Temora stylifera dominated the zooplankton (<2mm) in 1996, 1998 and 1999 whilst Chaetognatha dominated in 1997 (Appendix 2c). Chaetognatha dominted the zooplankton (>2mm) in 1996 and 1999 whilst Lucifer and *Undinula vulgaris* dominated in 1997 and 1998 respectively (Appendix 2d).

The mean zooplankton abundance decreased from 200 individuals /m3 of water in 1996 to 185 individuals /m3 of water in 1999. The higher zooplankton abundance in 1997 was due to increase in abundance of the smaller zooplankton (<2mm) (Figure 7).
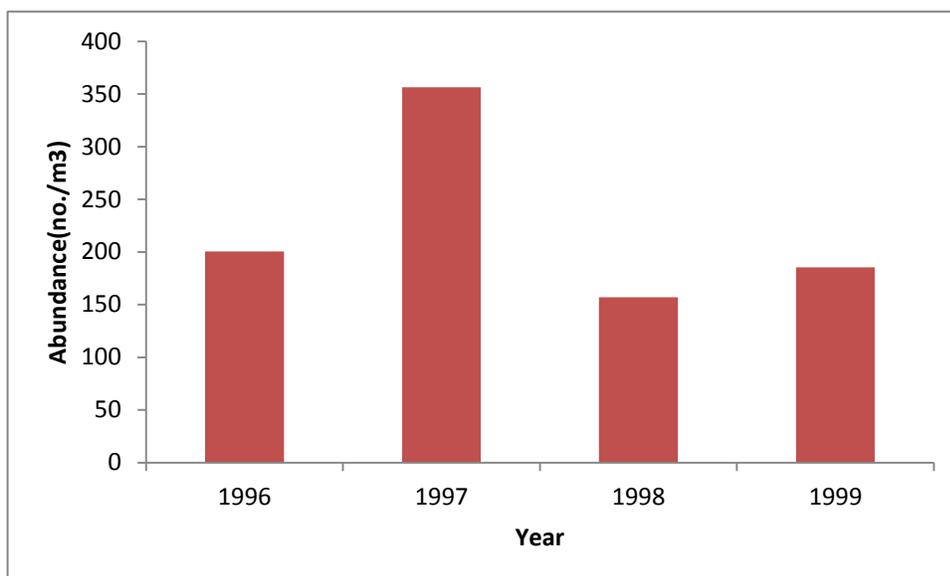
Figure 7. Mean total zooplankton abundance calculated from each year's average from 1996 to 1999. The mean zooplankton abundance generally decreased over the period.

Spatial Distribution of Plankton

The spatial analysis of plankton in minor upwelling season indicated that the minor upwelling is prevalent in Ghana but decreased in Cote d'Ivoire (Appendix 3a). The highest primary and seconday production during the thermal stability 1 seasons took place in Ghana (Appendix 3b). The strength of the major upwelling is still concentrated in Cote d'Ivoire and Ghana (Appendix 3c). The highest primary and seconday production during thermal stability 2 season shifted from Ghana and Cote'd Ivoire to Nigeria and Cameroun in 1998 and 1999 (Appendix 3d).

Plankton Community Structure

At Bray-Curtis similarity measure greater than 70%, the phytoplankton community structure between the four hydrographic seasons in 1996 were different. However, similar zooplankton community structures were observed between the four hydrographic seasons in 1996 (Figure 4). In 1997, similar phytoplankton community structures were observed between thermal stability 1 and thermal stability 2 seasons whilst similar zooplankton community structures were observed between the four hydrographic seasons (Figure 4). In 1998, similar phytoplankton community structures were observed between thermal stability 1 and major upwelling seasons whilst similar zooplankton community structures were observed between major upwelling, thermal stability 1 and thermal stability (Figure 4). In 1999, similar phytoplankton community structures were observed between minor upwelling and thermal stability 1 seasons whilst similar zooplankton community structures were observed between major upwelling and thermal stability 2 seasons (Figure 8).
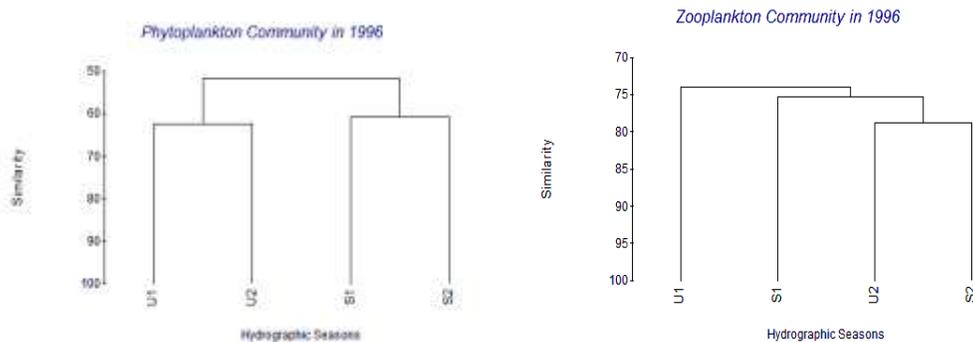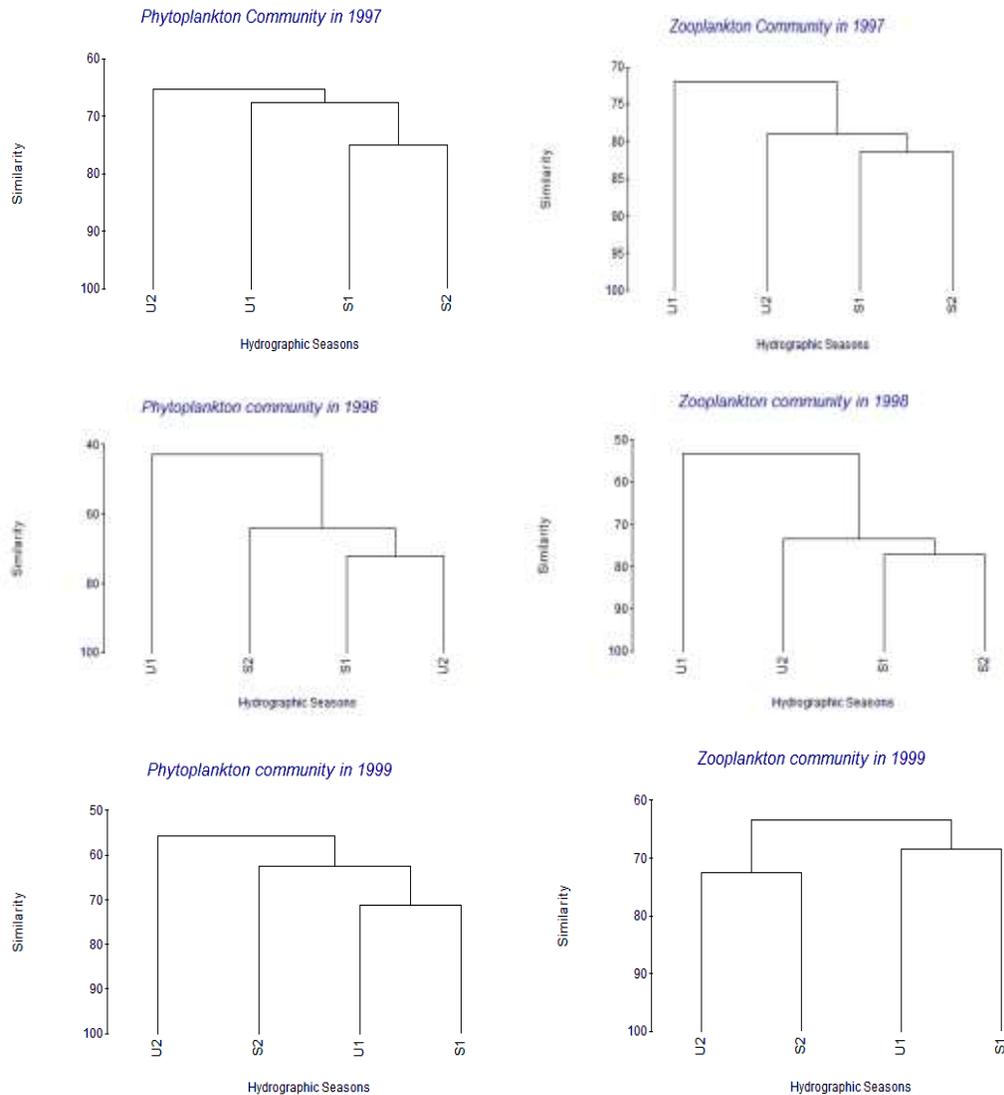
Figure 8. Cluster analysis using Bray-Curtis similarity measure with respect to hydrographic seasons (U1- Minor upwelling, S1- Thermal stability 1, U2- Major upwelling and S2- Thermal stability 2) from 1996 to 1999. Groups clustering at Bray-Curtis similarity measure greater than 70% were considered to show similar community structure.

During minor upwelling in 1996, 1997 and 1998, phytoplankton community structures between the sampling areas were different. However, similar phytoplankton community structures were observed between Cote d'Ivoire and Nigeria during the minor upwelling in 1999 (Appendix 4a). During the minor upwelling in 1996, 1997 and 1998, zooplankton community structures between the sampling areas were different. However, similar zooplankton community structures were observed between Nigeria, Ghana and Benin during the minor upwelling in 1999 (Appendix 4b).

During thermal stability 1 in 1996, phytoplankton community structures between the sampling areas were different. In 1997, the phytoplankton community structures between Ghana and Cote

d'Ivoire were similar whilst in 1998 similar phytoplankton community structures were observed between Togo and Benin. In 1999, phytoplankton community structures between Benin and Nigeria were similar (Appendix 4c). During thermal stability 1 in 1996 and 1998, the zooplankton community structure between the sampling areas was different. In 1997, the zooplankton community structures between Togo and Benin were similar. In 1999, the zooplankton community structures between Benin and Nigeria were similar (Appendix 4d).

During the major upwelling in 1996 and 1997, phytoplankton community structures between the sampling areas were different. In 1998, similar phytoplankton community structures were observed between Togo and Benin. In 1999, the phytoplankton community structures between Benin and Nigeria were similar (Appendix 4e). During major upwelling in 1996, the zooplankton community structures between Cote d'Ivoire and Ghana were similar. In 1997, the zooplankton community structure between the sampling areas was similar except Cameroun. In 1998, similar zooplankton community structures were observed between Cote d'Ivoire and Ghana. In 1999, different zooplankton community structures were observed between Benin and Nigeria (Appendix 4f).

In thermal stability 2, for all years different phytoplankton community structures were observed in the sampling areas except 1997 where similar community structures were observed between Cote d'Ivoire and Ghana (Appendix 4g). In thermal stability 2 in 1996 and 1997, the zooplankton community structures between Cote d'Ivoire and Ghana were similar. In 1998 and 1999, however different zooplankton community structures were observed in all sampling areas (Appendix 4h).

Relationship between Phytoplankton colour and Phytoplankton abundance

Comparison between phytoplankton colour, obtained from CPR analyses and actual phytoplankton abundance did not show any significant positive correlation (r = - 0.08). The highest phytoplankton colour greater than 1.8 standard deviation of the mean was observed during the major upwelling in 1996 but the actual phytoplankton abundance during the same season was less than 0.4 standard deviation of the mean (Figure 9). The highest phytoplankton abundance greater than 2.0 standard deviation of the mean was observed during thermal stability 2 in 1997 but phytoplankton colour during the same season was less than 0.7 standard deviation of the mean (Figure 9).
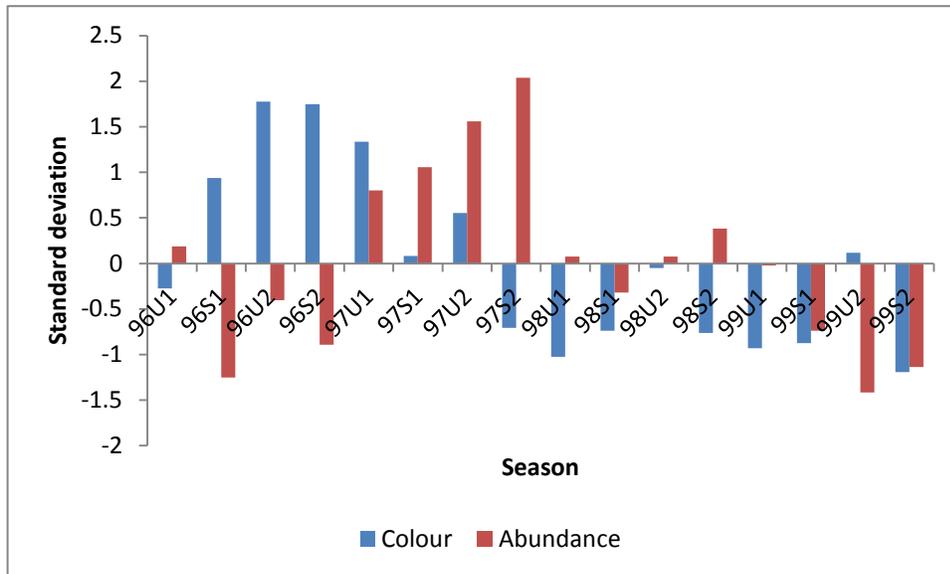
Figure 9. Comparison of seasonal distribution of phytoplankton colour and phytoplankton abundance from 1996 to 1999. There was no significant positive correlation between the phytoplankton colour and actual phytoplankton abundance.

DISCUSSION

Phytoplankton community structure analyses revealed that from 1997 to 1999, thermal stability 1 season shared similar community structure with the other three hydrographic seasons. There was also a similarity in zooplankton community structures between major upwelling season and thermal stability season 1 season from 1996 to 1998. This seems to suggest that thermal stability 1 season is gradually merging with the major upwelling season. This study also revealed that between 1990 and 1999, there was a gradual increase in sea surface temperatures in the GOG. Mensah (1973) observed that the distribution of sea surface temperature at Tema is characteristic of the entire coastal waters of Ghana. Demarcq and Aman (2002) showed that high quality coastal sea surface temperature picked by the existing network of oceanographic coastal stations that cover Cote d'Ivoire and Ghana can detect the coastal upwelling signal in the GOG. Wiafe *et al*. (2008) also showed that there was a gradual warming of sea surface temperature during the major upwelling season between 1969 and 1992. Pezennec and Bard (1992) also reported a reduction in strength of the major upwelling between 1970 and 1990. Thus the rise in temperature can be the mechanism driving the merging of thermal stability season with upwelling season.

Similar plankton community structures tend to occur during the thermal stability seasons than the upwelling seasons. The plankton community structure in adjacent sampling areas tends to be more similar than non-adjacent sampling areas. This suggests that there was less variability in plankton community structure from one sampling area to another than from one hydrographic

season to another. In all hydrographic seasons, the greater primary and seconday production took place in Ghana suggesting that Ghana is the most highly productive sampling area. The highest primary and seconday production during thermal stability 2 season however shifted from Ghana and Cote'd Ivoire to Nigeria and Cameroun. Wiafe (2002) observed similar high productivity in Cameroun during the thermal stability season. The minor upwelling is still stronger in Ghana. The minor upwelling has earlier been reported very weak in Ghana and considered as an extension of Ivorian upwelling (Demarcq and Aman, 2002). Pezennec and Bard (1992) reported of an intensification of the minor upwelling.

The mean diatoms, dinoflagellates, copepods and total zooplankton abundance decreased over the study period. The decline in plankton abundance is an indication of rising sea surface temperature in the GOG. The decline in zooplankton abundance has earlier been reported (Mensah, 1995). Production of organic materials by plankton is the source of energy for the growth of fish and other living marine resources. The decline in plankton abundance in the GOG can thus affect the abundance of fish and other living marine resources. The changes in individual phytoplankton and zooplankton species or groups are not readily explainable and more long time series data is needed to explain their long term trends. However the preponderance of the genus Ceratium among the dinoflagellates is an indication of increasing temperature in the GOG. The genus Ceratium is sensitive to temperature and is an indicator of temperature which is manifested in their morphology, phenology and biogeographic responses (Edwards *et al*., 2009). The genus Ceratium exhibit slow growth rate and is widely known to have low nutrients requirements. The preponderance of Ceratium may indicate decreasing nutrients levels in the GOG amidst the rising temperature. The higher plankton abundance in 1997 is attributable to temperatures of less than 25°C observed during the minor upwelling and the maintenance of the lower temperature between July and August 1997. The high levels of phytoplankton abundance might also be considered as a bloom.

The negative correlation between phytoplankton colour and phytoplankton abundance might be due to the bigger mesh size (270μm) which could not adequately sampled the phytoplankton to reflect the actual relative phytoplankton abundance. The CPR mesh size can thus be reduced to reflect the smaller plankton size of the tropics. Physical environmental variability is known to affect biological productivity (Mann and Lazier, 1996). The changing upwelling environment can thus be of considerable ecological significance in the GOG. However, they could be simple anomalies or usual inter annual environmental variations and as such long time series data is needed to consolidate these findings.

Conclusions

This study suggested that thermal stability 1 season is gradually merging with the major upwelling season and the mechanism driving this change is rising sea surface temperature in the

GOG. Similar plankton community structures tend to occur in the sampling areas during the thermal stability seasons than the upwelling seasons. Plankton community structure showed less variability from one sampling area to another than from one hydrographic season to another. Plankton abundance has declined over the study period and primary and secondary productivity has declined with expected decline in living marine resources of the region. The minor upwelling was still stronger in Ghana. The strength of the major upwelling however was still concentrated in Cote d'Ivoire and Ghana. The highest primary and secondary productivity shifted from Ghana and Cote d'Ivoire to Nigeria and Cameroun during thermal stability 2 season in 1998 and 1999. These changes in the GOG marine environment could however be a simple anomaly or inter annual environmental variations due to the short time series data. These environmental changes could not therefore be of considerable ecological significance in the GOG and there is thus the need for longer time series surveys to consolidate these findings.

Recommendations

There is the need for continual monitoring of plankton of the region using the continuous plankton recorder attached with sensors for measuring other environmental parameters such as temperature and salinity. It is important that such survey involves all countries in the Guinea Current region as the oceanographic conditions or changes offshore in any particular country in the region cannot be properly understood without considering the whole Guinea current region environment. The impacts of climate change and ocean acidification needs to be studied in the Guinea current region. The stability of Guinea Current Large Marine Ecosystem is also an important area recommended for study. There is the need for more studies in the biodiversity and invasive species of the region. The status of harmful algal bloom and eutrophication in the region needs to be reviewed. There is the need for more studies into the biological indicators of the region.

APPENDIX: CPR Species List

Phytoplankton		Zooplankton	
Diatoms	**Dinoflagellates**	**Traverse (<2mm)**	**Eyecount (>2mm)**
Asterionella japonica	*Amphisolenia spp.*	*Acartia danae*	*C. longimana*
Bacteriastrum	*Cer buceros*	*Acrocalanus spp.*	*C. pachydactyla*
Biddulphia	*Ceratium azoricum*	*Calocalanus spp*	*Calanoides carinatus*
Cerataulina pelagica	*Ceratium bucephalum*	*Candacia I-IV*	*Candacia bipinnata.*
Climacodium	*Ceratium candelabrum*	*Centropages spp.*	*Candacia curta*
Corethron criophilum	*Ceratium carriense*	CHAETOGNATHA	*Candacia spp.*
Coscinodiscus	*Ceratium declinatum*	*Clausocalanus spp.*	*Centropages chierchiae*
Ditylium brightwelli	*Ceratium extensum*	*Corycaeus spp.*	CHAETOGNATHA
Fragilaria spp.	*Ceratium furca*	ECHINODERM LARVAE	*Copilia mirabilis*
Guinardia delicatula	*Ceratium fusus*	*Eucalanus spp.*	*Corycaeus speciousus*
Guinardia flaccida	*Ceratium hexacanthum*	*Euchaeta spp.*	*Cumacea*
Hemialus membranaceus	*Ceratium horridum*	*Evadne spp.*	DECAPODA
Hemialus spp.	*Ceratium inflatum*	*Farranula gracilis*	*Eucalanus crassus*

Phytoplankton		Zooplankton	
Diatoms	**Dinoflagellates**	**Traverse (<2mm)**	**Eyecount (>2mm)**
Hyalochaete	*Ceratium lineatum*	*Larvacea*	*Eucalanus paraconcinna*
Navicula spp	*Ceratium massiliense*	*Lubbockia*	*Eucalanus pileatus*
Nitzschia closterium	*Ceratium minitum*	*Microsetella rosea*	*Eucalanus attenuatus*
Nitzschia delicatissima	*Ceratium pentagonum*	*Oithona spp.*	*Eucalanus monachus*
Nitzchia spp.	*Ceratium teres*	*Oncaea spp.*	*Eucalanus spp.*
Phaeceros	*Ceratium trichoceros*	OSTRACOD	*Euchaeta hebes*
Rhizosolenia alata indica	*Ceratium tripos*	*Paracalanus*	*Euchaeta marina*
Rhizosolenia calcar avis	*Ceratium vultur*	*Para-pseudocalanus*	*Euchaeta spp.* V-VI
Rhizosolenia hebetata semispina	*Ceratium lunula*	*Pseudocalanus*	EUPHAUSIACEA
Rhizosolenia styliformis	*Ceratium macroceros*	*Temora stylifera*	*Labidocera pavo*
Rhizosolenia alata alata	*Ceratocorys*	*Temora turbinata*	*Lucifer faxoni*
Thalassionema fraunfeldii	Dinoflagellate cysts	TINTINNIDAE	*Macrosetella gracilis*
Thalassionema nitzschoides	*Dinophysis spp.*	*Undinula spp.*	*Miracia efferata*
Thalassiosira spp	*Exuviaella spp.*		Mysid
Thalassiothrix longissima	*Gonyaulax*		*Nannocalanus minor*

Phytoplankton		Zooplankton	
Diatoms	**Dinoflagellates**	**Traverse (<2mm)**	**Eyecount (>2mm)**
	Ornithocercus spp.		*Neocalanus gracilis*
Other Phytoplankton	*Oxytoxum*		Ostracoda
Blue green algae	*Peridinium*		*Pleuromamma xiphias*
Coccolithaceae	*Podolampas spp.*		*Pontella gaboonensis*
Silicoflagellate	*Pro. micans*		*Pontellina plumata*
Trichodesmium (Oscillatoria)	*Prorocentrum spp.*		*Rhincalanus cornutus*
			Sapphirina spp.
			Sergestidae
			Undinula vulgaris

Plankton Abundance

Diatoms

Mean abundance of the ten common diatoms groups calculated from each year's average from 1996 to 1999. The genus Rhizosolenia, Chaetoceros and Nitzschia were among the ten common diatom groups encountered from 1996 to 1999.
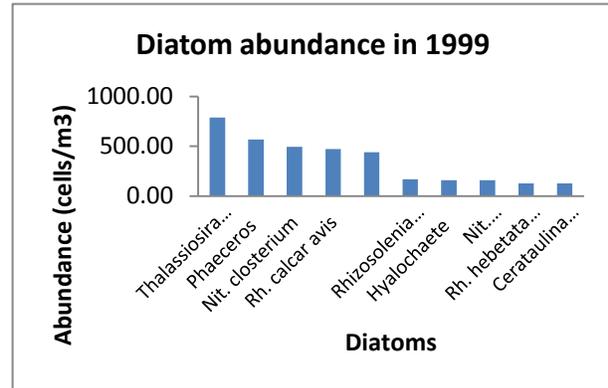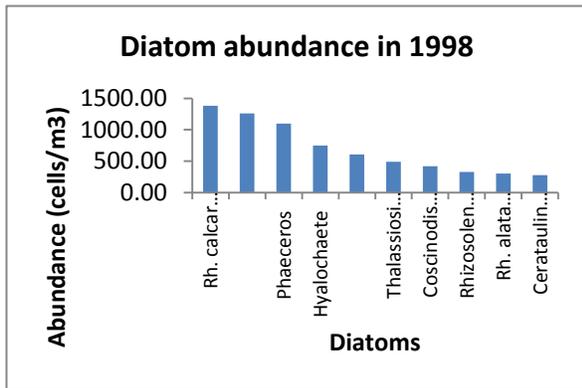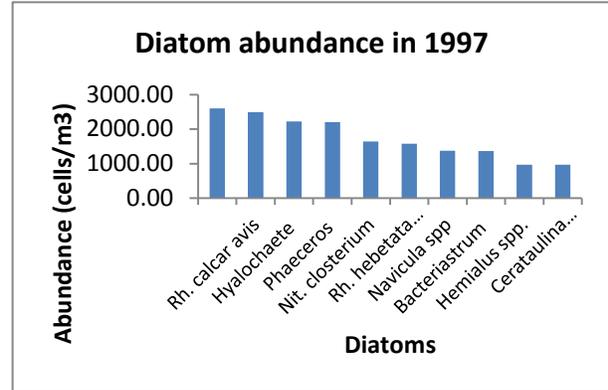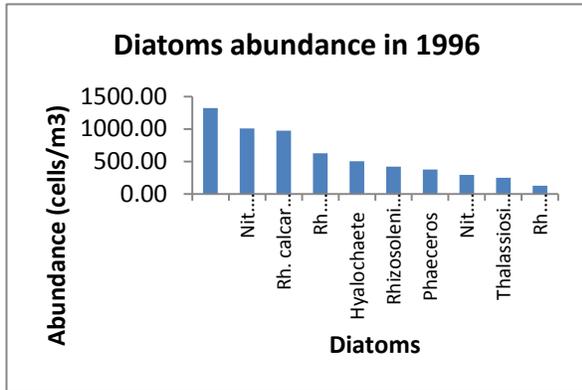

Dinoflagellates

Mean abundance of the ten common dinoflagellates groups calculated from each year's average from 1996 to 1999. The genus Dinophysis, Peridinium and Ornithocercus were among the ten common dinoflagellates groups encountered from 1996 to 1997.

Dinoflagellates abundance in 1996

Dinoflagellates abundance in 1997

Dinoflagellates abundance in 1998

Dinoflagellates abundance in 1999
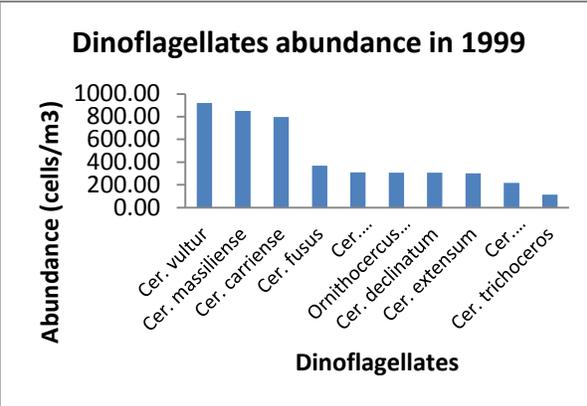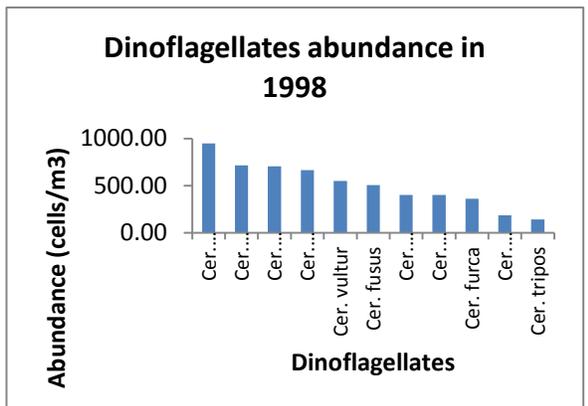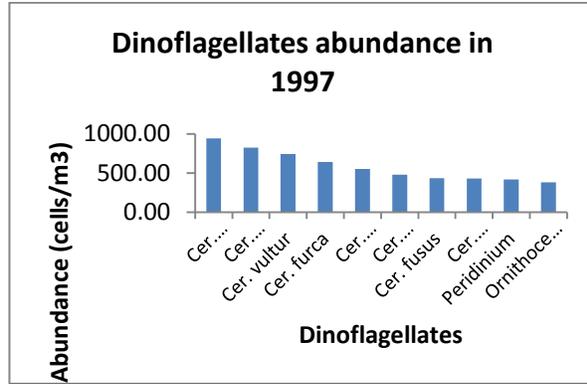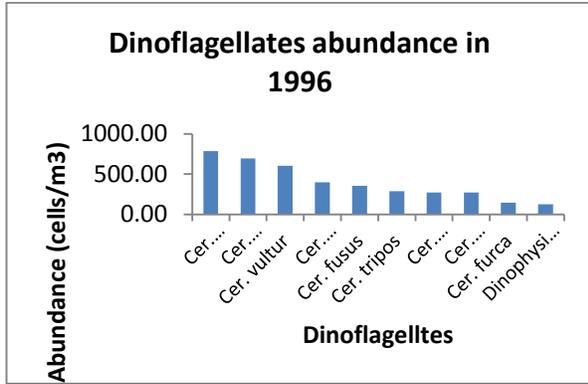
Zooplankton Traverse (< 2mm)

Mean abundance of zooplankton (< 2mm) calculted from each years average from 1996 to 1999. Chaetognatha, *Oncae* spp., *Oithona* spp., *Clausocalanus* spp., *Faranula gracilis* and *Corycaeus* spp. were among the ten common zooplankton (<2mm) encountered in all years from 1996 to 1999.

Abundance of Zooplankton (<2mm) in 1996


Abundance of Zooplankton (<2mm) in 1997
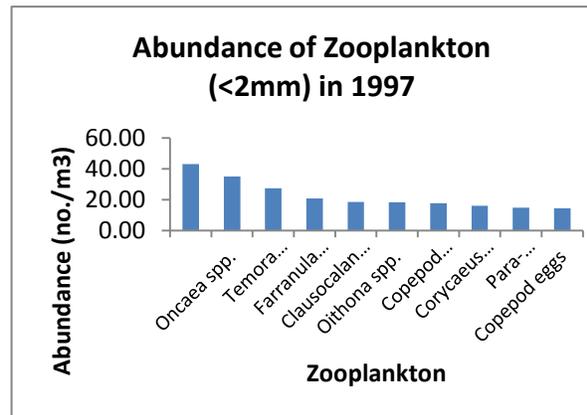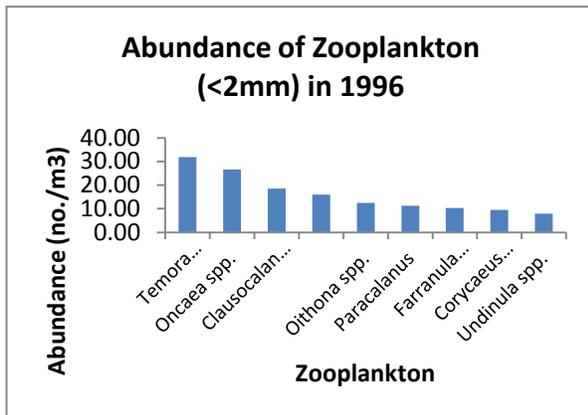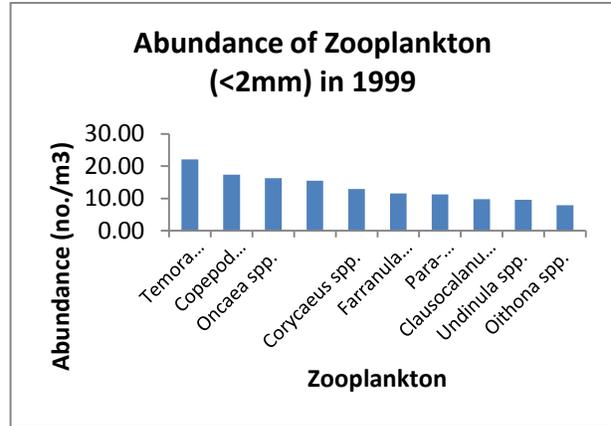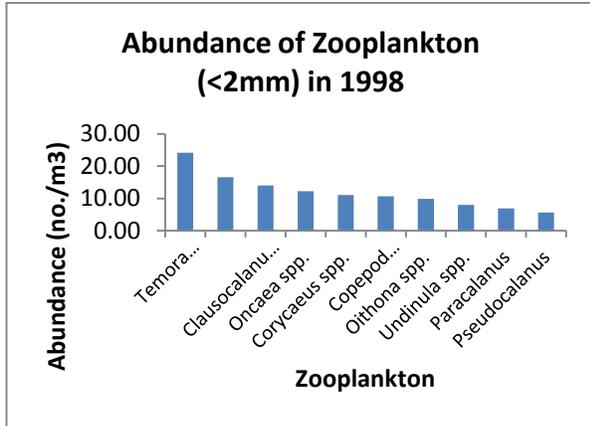
Zooplankton Eye count

Mean abundance of ten common zooplankton (> 2mm) calculated from each year's average from 1996 to 1999. *E. piliatus, Undinula vulgaris,* Chaetognatha and Lucifer were the groups were among the ten common zooplankton (>2mm) encountered in all years from 1996 to 1999.
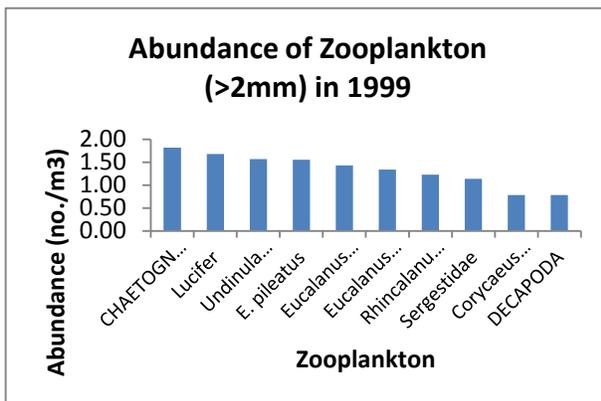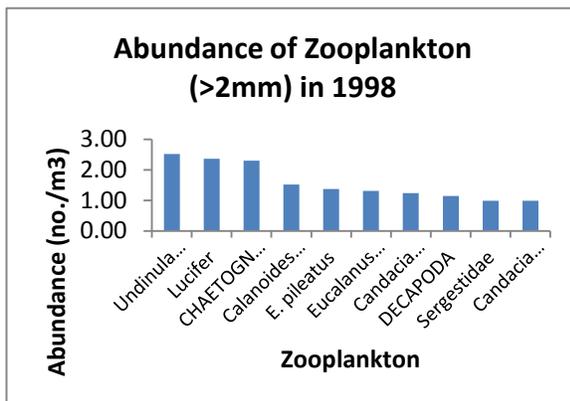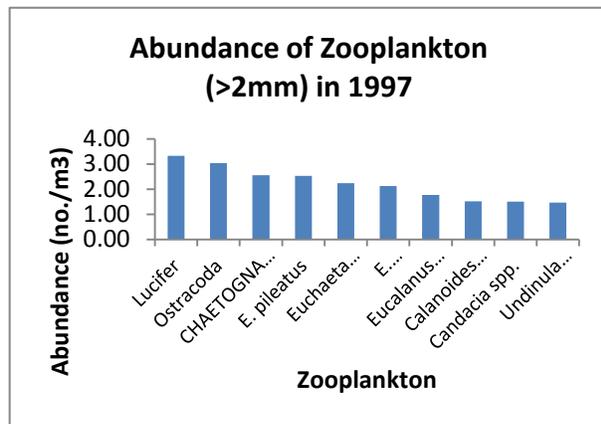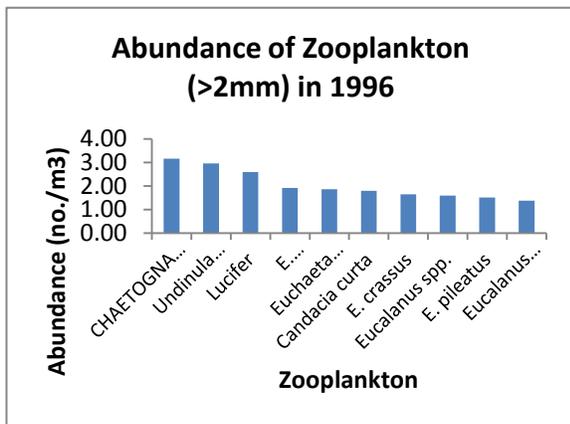

Spatial Distribution of Plankton

Spatial anomaly of plankton abundance for minor upwelling season from 1996 to 1999.   The minor upwelling is still prevalent in Ghana whilst decreasing in Cote d'Ivoire.
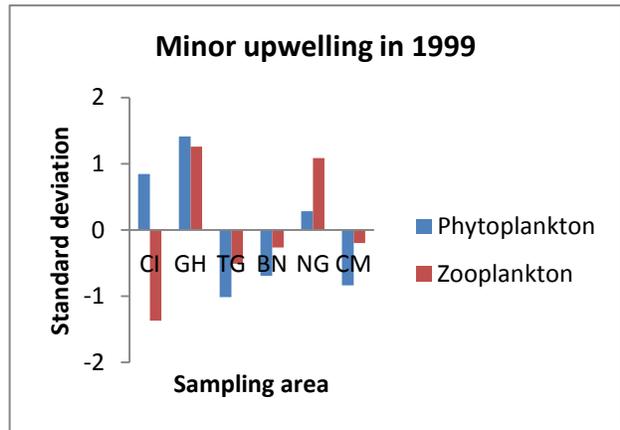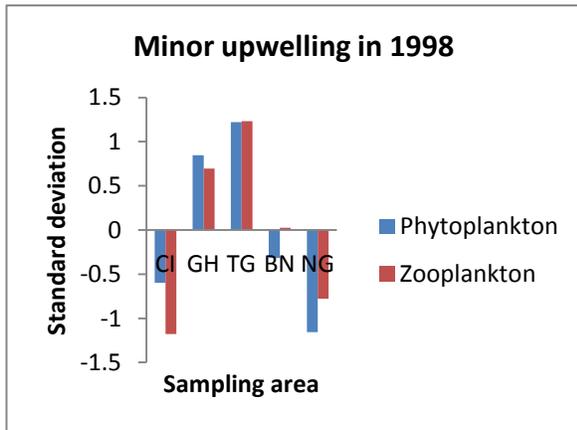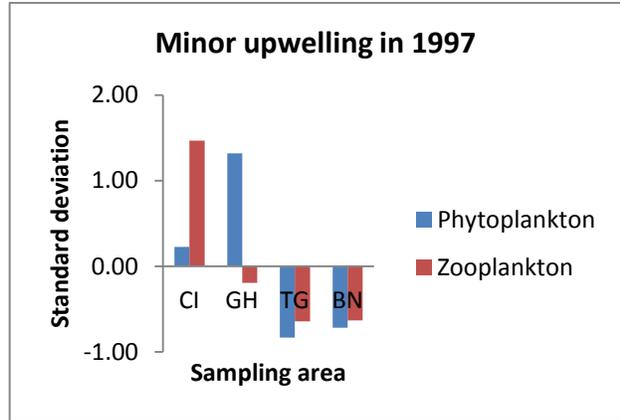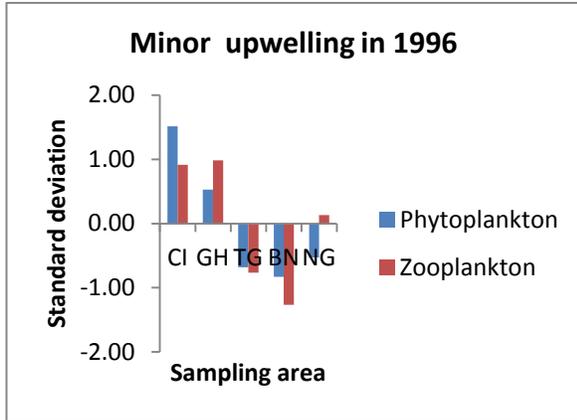
Spatial anomaly of plankton abundance for thermal stability 1 from 1996 to 1999. The highest primary and seconday production during the thermal stability 1 seasons took place in Ghana.
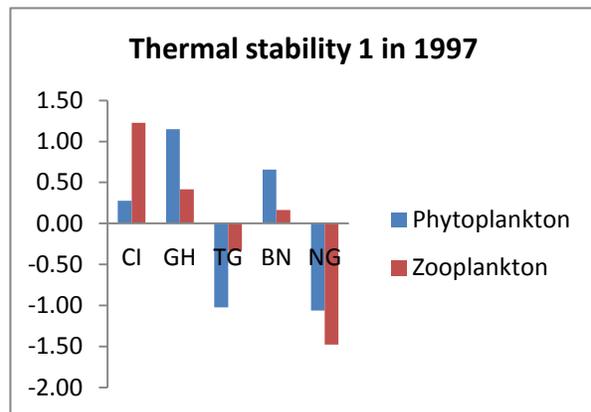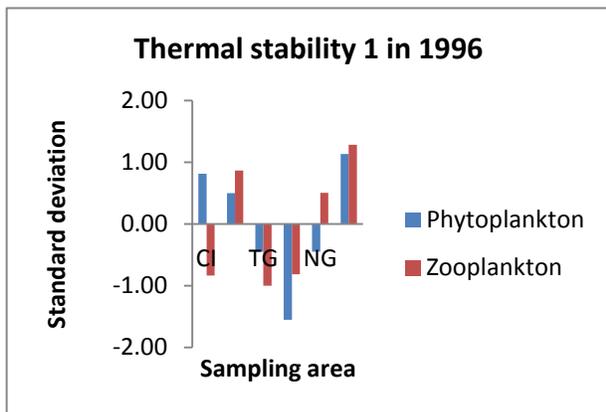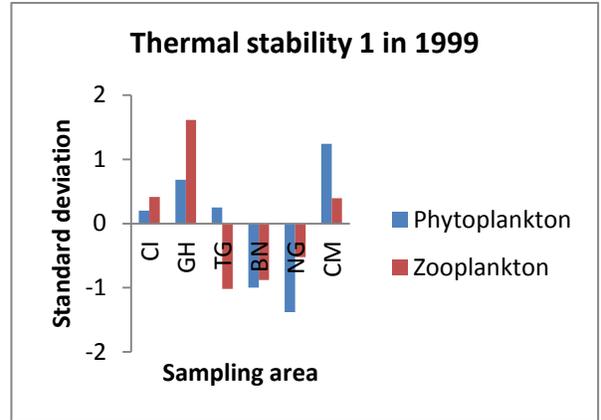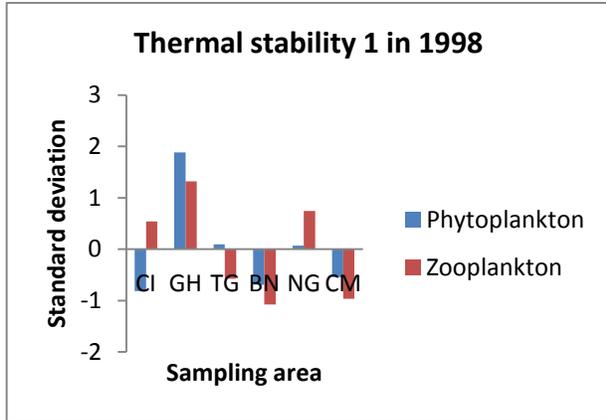
Spatial anomaly of plankton abundance for major upwelling from 1996 to 1999. The strength of the major upwelling is still concentrated in Cote d'Ivoire and Ghana
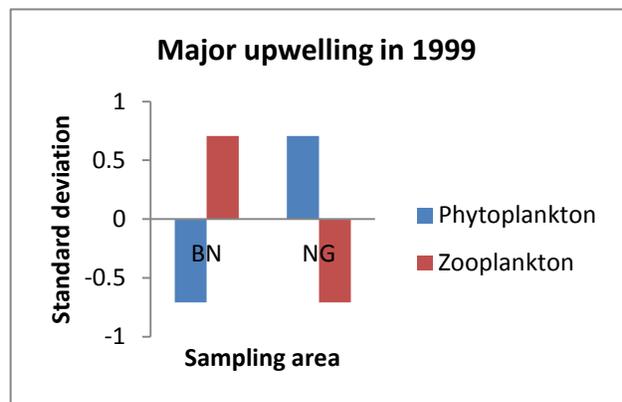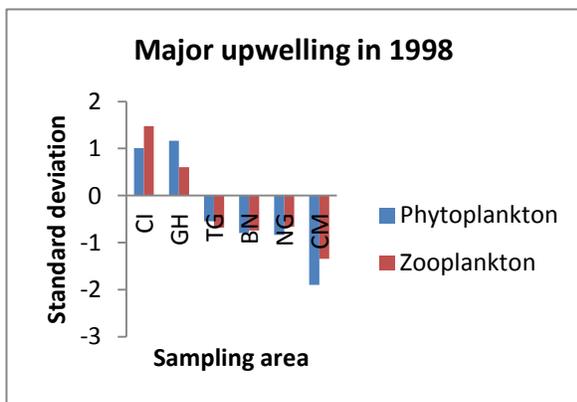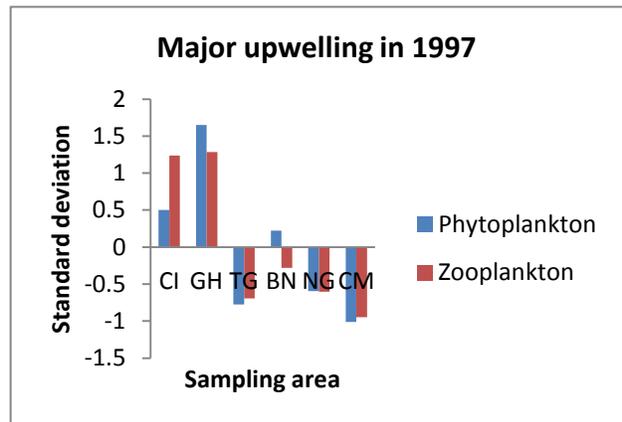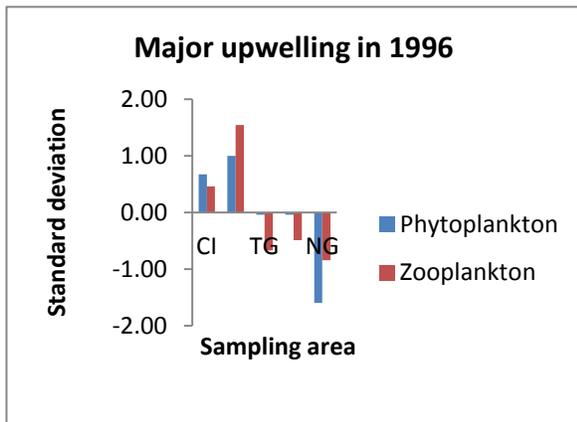
Spatial anomaly of plankton abundance for thermal stability 2 from 1996 to 1999. The highest primary and seconday production during thermal stability 2 season shifted from Ghana and Cote'd Ivoire to Nigeria and Cameroun.
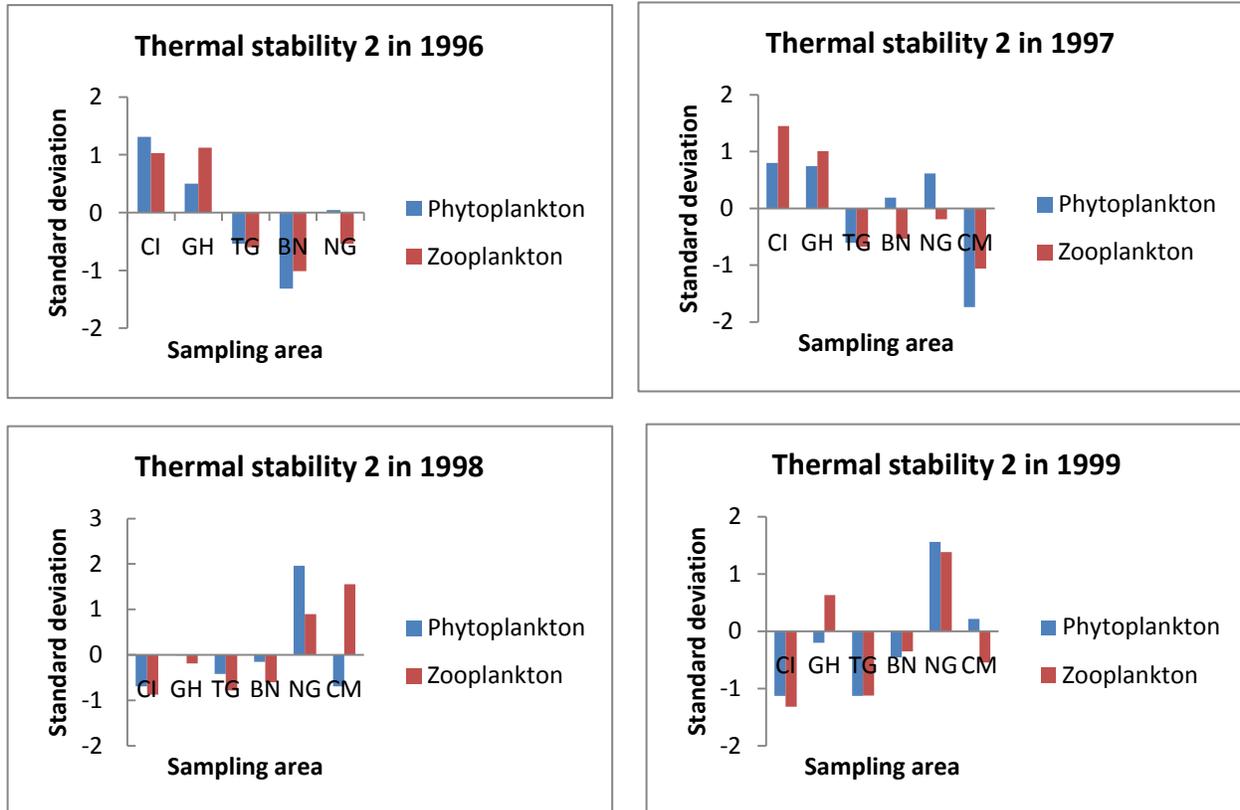

Plankton Community Structure

Cluster analysis using Bray-Curtis similarity measure with respect to sampling areas (CI- Cote d'Ivoire, GH- Ghana, TG- Togo, BN- Benin, NG- Nigeria and CM- Cameroon) in minor upwelling from 1996 to 1999. Phytoplankton groups clustering at Bray-Curtis similarity measure greater than 70% were considered to show similar community structure. In 1996, 1997 and 1998, phytoplankton community structures between the sampling areas were different. However in 1999, similar phytoplankton community structures were observed between Cote d'Ivoire and Nigeria.

Cluster analysis using Bray-Curtis similarity measure with respect to sampling areas (CI- Cote d'Ivoire, GH- Ghana, TG- Togo, BN- Benin, NG- Nigeria and CM- Cameroon) in minor upwelling from 1996 to 1999. Zooplankton groups clustering at Bray-Curtis similarity measure greater than 70% were considered to show similar community structure. In 1996, 1997 and 1998, zooplankton community structures between the sampling areas were different. However in 1999, similar zooplankton community structures were observed between Nigeria, Ghana and Benin.

Zooplankton community in minor upwelling in 1996
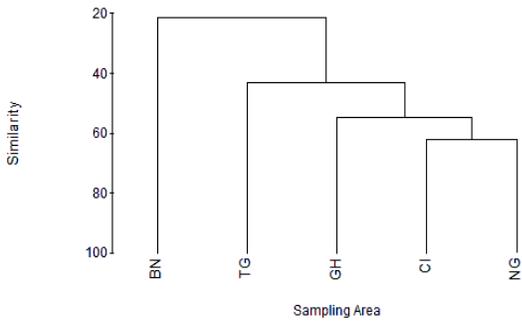
Zooplankton community in minor upwelling in 1997
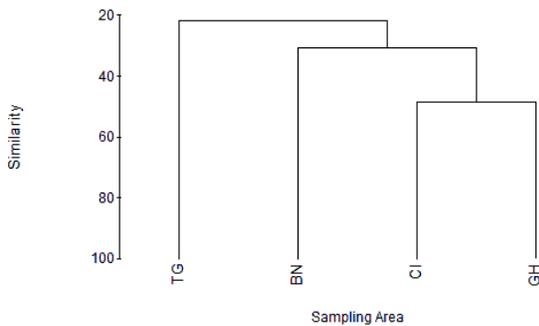
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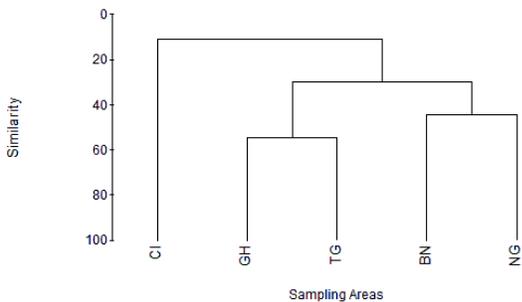
*Zooplankton community in minor upwelling in 1999*
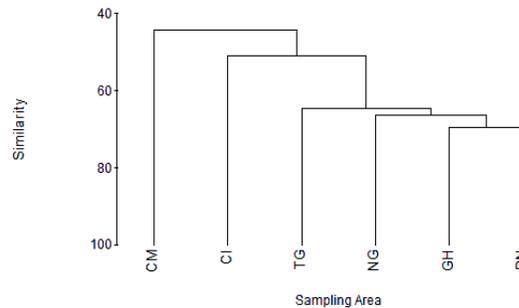
Cluster analysis using Bray-Curtis similarity measure with respect to sampling areas (CI- Cote d'Ivoire, GH- Ghana, TG- Togo, BN- Benin, NG- Nigeria and CM- Cameroon) in thermal stability 1 from 1996 to 1999. Phytoplankton groups clustering at Bray-Curtis similarity measure greater than 70% were considered to show similar community structure. In 1996, phytoplankton community structures between the sampling areas were different. In 1997, the community structures between Ghana and Cote d'Ivoire were similar. In 1998, similar community structures were observed between Togo and Benin. In 1999, community structures between Benin and Nigeria were similar.

Phytoplankton community in thermal stability 1 in 1996
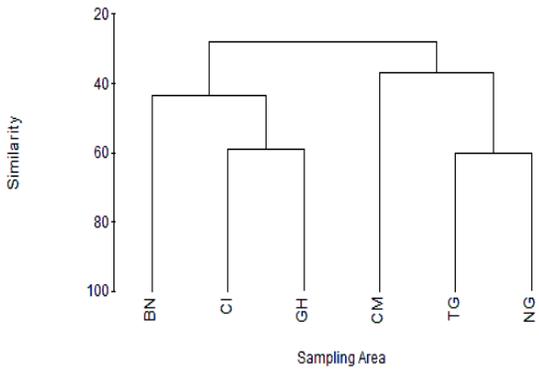
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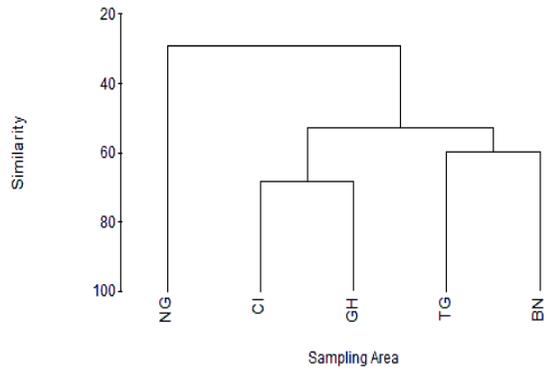
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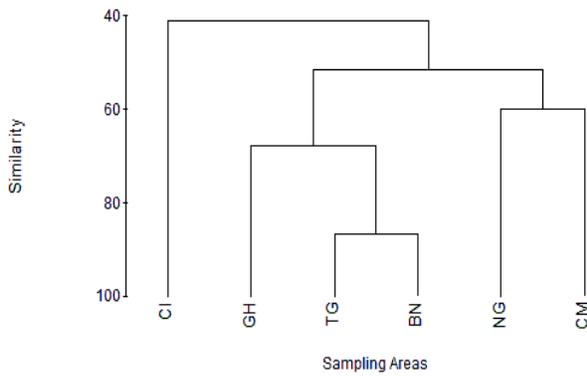
*Phytoplankton community in thermal stability 1 in 1999*
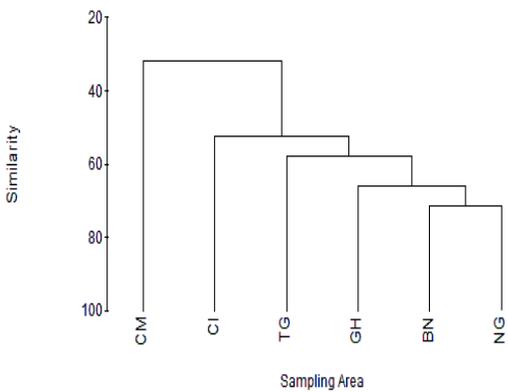
Cluster analysis using Bray-Curtis similarity measure with respect to sampling areas (CI- Cote d'Ivoire, GH- Ghana, TG- Togo, BN- Benin, NG- Nigeria and CM- Cameroon) in thermal stability 1 from 1996 to 1999. Zooplankton groups clustering at Bray-Curtis similarity measure

greater than 70% were considered to show similar community structure. In 1996 and 1998, the zooplankton community structure between the sampling areas was different. In 1997, the community structures between Togo and Benin were similar. In 1999, the community structures between Benin and Nigeria were similar.
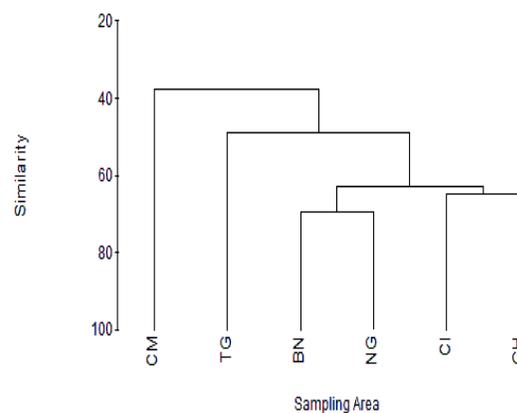
Cluster analysis using Bray-Curtis similarity measure with respect to sampling areas (CI- Cote d'Ivoire, GH- Ghana, TG- Togo, BN- Benin, NG- Nigeria and CM- Cameroon) in major upwelling from 1996 to 1999. Phytoplankton groups clustering at Bray-Curtis similarity measure greater than 70% were considered to show similar community structure. In 1996 and 1997, the phytoplankton community structures between the sampling areas were different. In 1998, similar community structures were observed between Togo and Benin. In 1999, the community structures between Benin and Nigeria were similar.
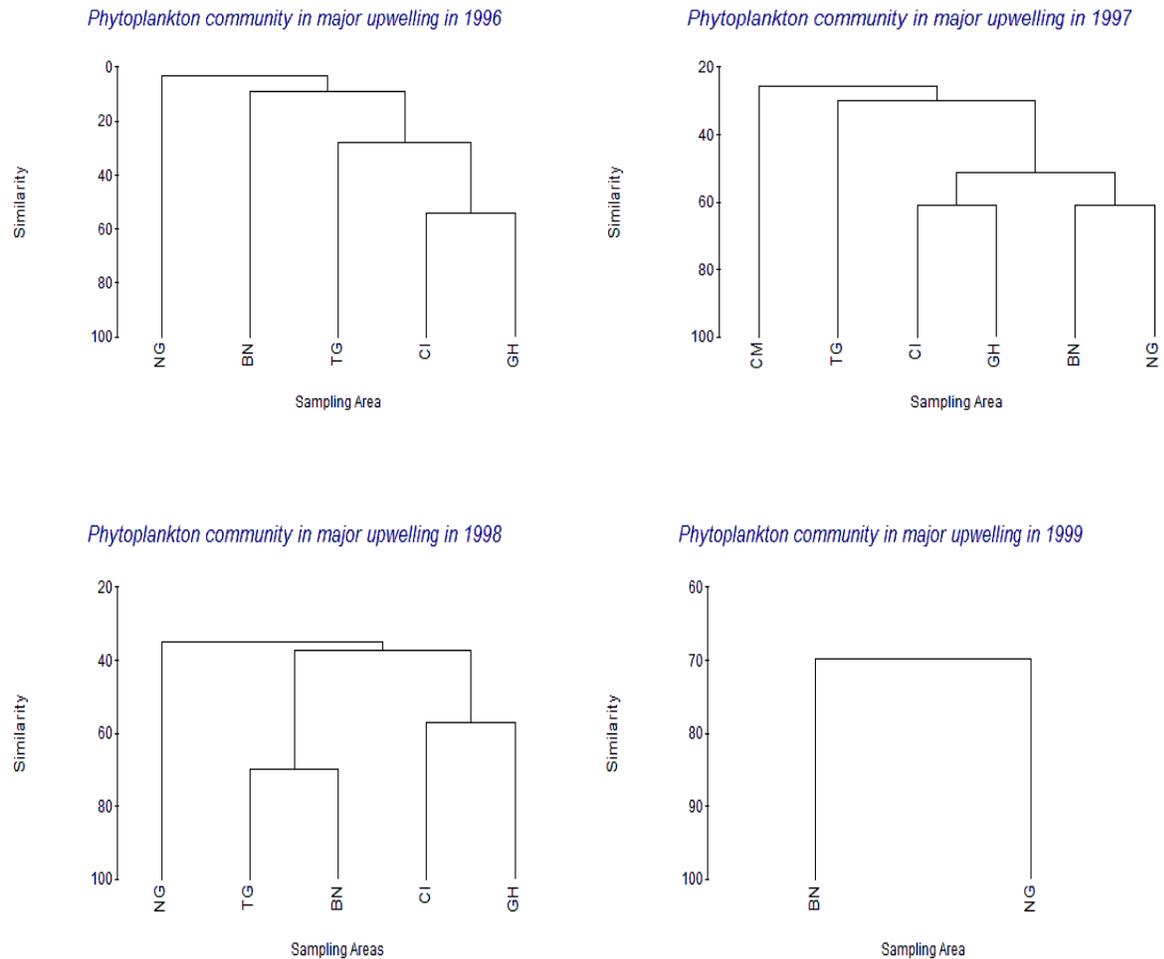
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Phytoplankton community in major upwelling in 1996

Phytoplankton community in major upwelling in 1997

Phytoplankton community in major upwelling in 1998

Phytoplankton community in major upwelling in 1999

Cluster analysis using Bray-Curtis similarity measure with respect to sampling areas (CI- Cote d'Ivoire, GH- Ghana, TG- Togo, BN- Benin, NG- Nigeria and CM- Cameroon) in major upwelling from 1996 to 1999. Zooplankton groups clustering at Bray-Curtis similarity measure greater than 70% were considered to show similar community structure. In 1996, the zooplankton community structures between Cote d'Ivoire and Ghana were similar. In 1997, the community structure between the sampling areas was similar except Cameroun. In 1998, similar community structures were observed between Cote d'Ivoire and Ghana. In 1999, different community structures were observed between Benin and Nigeria.
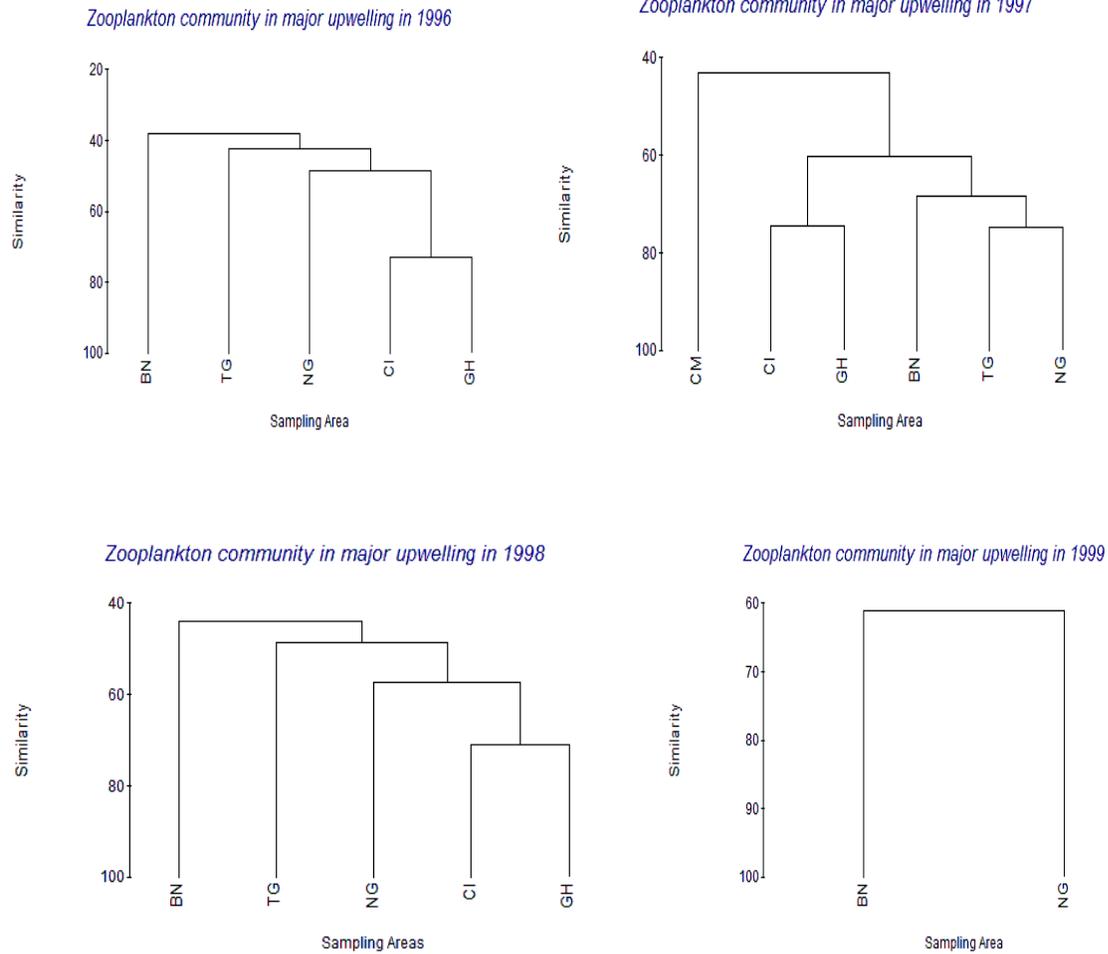
Zooplankton community in major upwelling in 1996

Zooplankton community in major upwelling in 1997

Zooplankton community in major upwelling in 1998

*Zooplankton community in major upwelling in 1999*

Cluster analysis using Bray-Curtis similarity measure with respect to sampling areas (CI- Cote d'Ivoire, GH- Ghana, TG- Togo, BN- Benin, NG- Nigeria and CM- Cameroon) in thermal stability 2 from 1996 to 1999. Phytoplankton groups clustering at Bray-Curtis similarity measure greater than 70% were considered to show similar community structure. In all years, different phytoplankton community structures were observed in the sampling areas except 1997 where community structures were observed between Cote d'Ivoire and Ghana.
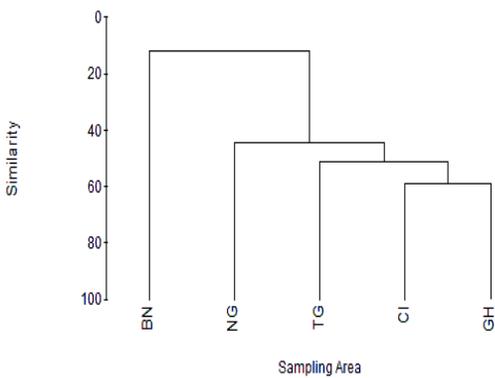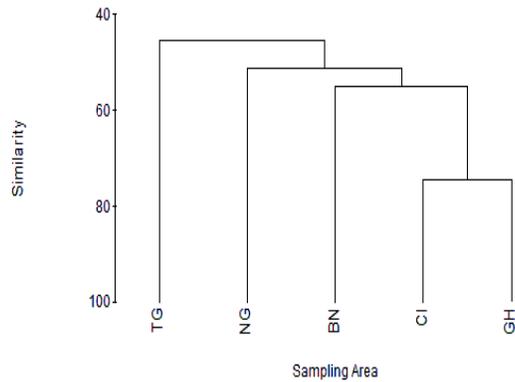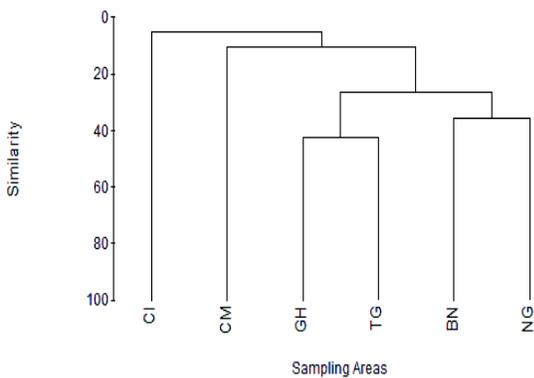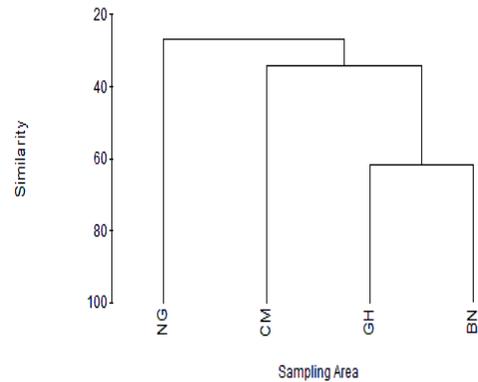
Cluster analysis using Bray-Curtis similarity measure with respect to sampling areas (CI- Cote d'Ivoire, GH- Ghana, TG- Togo, BN- Benin, NG- Nigeria and CM- Cameroon) in thermal stability 2 from 1996 to 1999. Zooplankton groups clustering at Bray-Curtis similarity measure greater than 70% were considered to show similar community structure. In 1996 and 1997, the zooplankton community structures between Cote d'Ivoire and Ghana were similar. In 1998 and 1999, however different community structures were observed in all sampling areas

Zooplankton community in thermal stability 2 in 1996
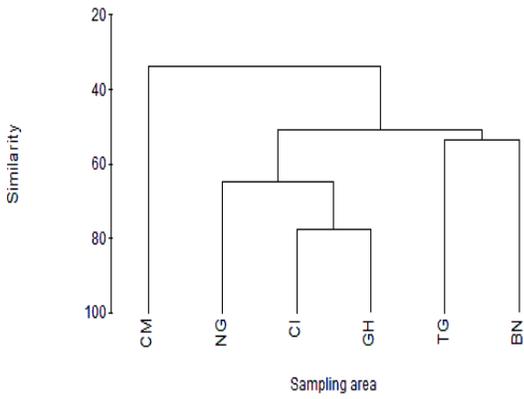
Zooplankton community in thermal stability 2 in 1997
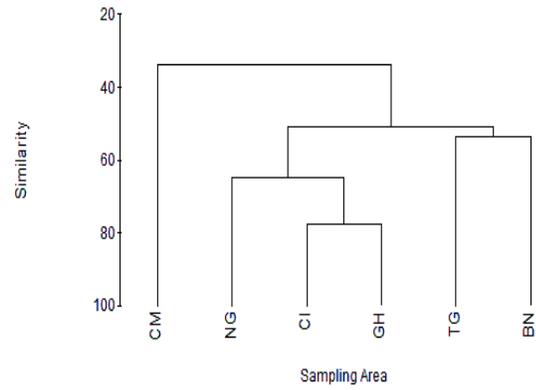
Zooplankton community in thermal stability 2 in 1998
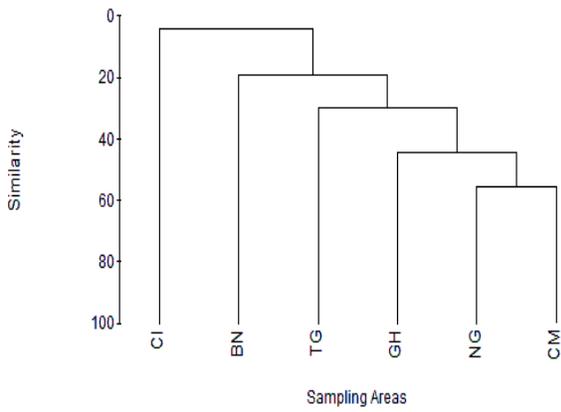
Zooplankton community in thermal stability 2 in 1999
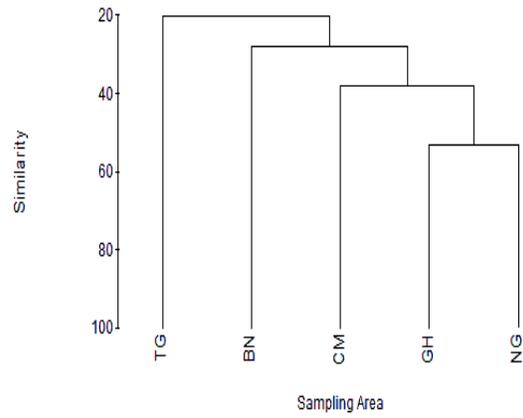
Literature cited

Allersma, E., M. Wiel and K. Tilman (1993): Coastal conditions in West Africa – A Review. *Ocean and Coastal Management*, 19, 199- 240.

Anang, E. R. (1976): Seasonal changes in the phytoplankton population in the coastal waters of Ghana. *M.Sc. Dissertation*, Botany Department, University of Ghana.

Bainbridge, V (1972): The zooplankton of the Gulf of Guinea. *Bulletin of Marine Ecology*, 8:61-97.

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saisonniers dans le Golf d   .   18:331-355.

Binet, D. and E. Marchal (1993): The large marine ecosystem of shelf areas in the Gulf of Guinea: Long-term variability induced by climatic changes. *In* Sherman, K., L. M. Alexander, and B. D. Gold (Eds.) Large Marine Ecosystems. Stress, Mitigation and Sustainability, AAAS Press.

Demarcq, H. and A. Aman (2002): A multi-data approach for assessing the spatio-temporal variability of the Ivorian-Ghanaian coastal upwelling: Understanding pelagic fish stock dynamics pp.83-92 *In* McGlade, J. M., P. Cury, K. A. Koranteng and N. J. Hardman-Mountford (Eds.) The Gulf of Guinea Large Marine Ecosystem, Elsevier Science.

Dovlo, E. K. (2008): Assessment of phytoplankton distribution in the Gulf of Guinea. *M.Phil Dissertation*, Dept. of Oceanography and Fisheries, University of Ghana.

Edwards, M., Beaugrand, G., John, A.W.G., Johns, D.G., Licandro, P., McQuatters-Gollop, A. & Reid, P.C. (2009): Ecological status report: results from the CPR survey 2007/2008. *SAHFOS Technical Report*, 6: 1-12. Plymouth, U.K. ISSN 1744-0750

-

                                            : validation with simultaneous fluorometry. *J. Plankton Res* 16:23-24.

Ibe, C. and K. Sherman (2002): The GOGLME Project: Turning challenges into achievements pp.27-39. *In* McGlade J. M., P. Cury, K. A. Koranteng and N. J. Hardman-Mountford (Eds.) The Gulf of Guinea Large Marine Ecosystem, Elsevier Science.

John, A.W.G, Reid, P.C., Batten SD, Anang ER (2002): Monitoring levels of 'phytoplankton colour' in the Gulf of Guinea using ships of opportunity. In: The Gulf of Guinea large marine ecosystem McGlade JM, Cury P, Koranteng KA, Hardman-Mountford NJ (eds.) Elsevier Science, Amsterdam, p 141-146

Longhurst, A. R. (1962): A review of the oceanography of the Gulf of Guinea. *Bulletin d'Institute franc Africain noire*, 24, 633 - 663

Mann, K. H. and J. R. N. Lazier (1996): Dynamics of marine ecosystems: Biological-physical interactions in the oceans. Blackwell Science Inc., Boston, 394p.

Mensah, M. A. (1973): The marine environment and fish production in Ghanaian waters. Marine Fisheries Research Division, Tema.

Mensah, M. A. (1995): The occurrence of zooplankton off Tema during the period 1969-1992. *In* Dynamics and Use of *Sardinella* resources from Upwelling off Ghana and Cote d'ivoire, pp. 279 – 289. Ed. By F. X. Bard and K. A. Koranteng. ORSTOM Editions, Paris.

Mensah M. A, Koranteng K. A. (1988): A review of the oceanography and fisheries resources in the coastal waters of Ghana, 1981 – 1986. Fisheries Research and Utilisation Branch, Fisheries Department, Tema, p 35

Myers, R. A., N. J. Barrowman, G. Mertz, J. Gamble, and H. G. Hunt. (1994): Analysis of continuous plankton recorder data in the Northwest Atlantic 1959-1992. Can. Tech. Rep. Fish. Aquat. Sci. 1966: iii + 246 p.

Pezennec, O. and F. X. Bard (1992): Importance ecologique de la petite saison d'upwelling ivoiri-ghaneenne et changements dans la pecherie de *Sardinella aurita*. *Aquatic Living Resources*, 5:249-259.

Reyssac, J. (1993): Phytoplancton et production primaire dans les eaux marines ivoiriennes. In: Environnement et ressources aquatiques de Cote d'Ivoire Le Loeuff P, Marchal E, Amon Kothias JB (eds.) ORSTOM, Paris, p 151–166

Sherman, K. and E. D. Anderson (2002): A modular approach to monitoring, assessing and managing LMEs pp.9-25. *In*. McGlade, J. M., P. Cury, K. A. Koranteng and N. J. Hardman-Mountford (Eds.) The Gulf of Guinea Large Marine Ecosystem, Elsevier Science.

Warner, A. J. and G. C. Hays (1994): Sampling by the Continuous Plankton Recorder survey. *Progress in Oceanography* 34, 237-256.

Wiafe, G (2002) Spatial and temporal dynamics of plankton communities in the Gulf of Guinea ecosystem. PhD Dissertation, Department of Oceanography & Fisheries, University of Ghana, Legon, Accra, p 188

Wiafe, G., H. B. Yaqub, M. A. Mensah and C. L. J. Frid (2008): Impact of climate change on long-term zooplankton biomass in the upwelling region of the Gulf of Guinea. *ICES Journal of Marine Science*, 65: 318-324.

Zooplankton Survey in the GCLME

Summary

The productivity module is one of five modules of the GCLME project in sustaining marine living resources through ecosystem approach in the Gulf of Guinea. In view of this plankton samples were collected from 13 locations (Guinea Bissau, Guinea, Sierra Leone, Liberia, Ghana, Nigeria, Cameron and Principe and Sao Tome. Some of the samples were just labeled PL Stations, Nansen's and SP samples) within the Gulf of Guinea for analysis. This report presents the findings of the analysis viz a viz, zooplankton dynamics - diversity and abundance, and community structure and the implications in the Gulf of Guinea Large Marine Ecosystem. This information is also relevant in understanding the ecosystem and productivity of the region.

About 159 species with a mean abundance of 3,923.7 identified were put into six(6) groups- Calanoides, Cheatognants, Cyclopods, Decapods and Others. Cladocera, Harpacticoids and Siphonophons were put into one group. The calanoides were the most diverse and abundant with *Temora stylifera, Eucalanus crassus and Centropages furcatus* having the highest number of individuals in that order. The least in abundance are the harpacticoids , *Chiridius poppei* and *Shrimp larvae.*

Seasonal and annual variations had the following species showing up strongly. They are in increasing order –May(*T. stylifera, P. avirostris* and *E. crassus),* June *(Euconchoecia chierchiea, T. stylifera* and Fish eggs,) July (*E. crassus, Decapod larvae,* and *E. pileatus),* 2005(*E. crassus, E. pileatus* and *Calanoides carinatus), 2006(Euconchoecia chierchiea T. stylifera* and *P. avirostris),* and 2007(*T. stylifera, P. avirostris* and *E. crassus.*

 Samples were collected in May, June and July 2005, 2006 and 2007. Samples collected in May / June are more diverse and low in abundance; however those collected in July are low in diversity with high abundance. Samples were collected with two different nets (ICITA and Multinet, towed vertically or horizontally). Samples collected with ICITA, and Horizontal tows were relatively more diverse and abundant than those collected with multinet and towed vertically respectively.

The highest abundance of zooplankton was recorded in Ghana and least in Gabon 2005. Species richness was maximal in the PL Station samples and minimal in Gabon 2005. The highest number of sample was from Cameroun (56) and the lowest from Ghana (8)

Primer analysis (cluster and MDS) reveals 6 and 3 communities at 60% and 50% similarities respectively with MDS stress of 0.17 which is very good. Temperature trends in the Gulf of Guinea have revealed persistence increase in warming which could be attributed to climate

change and global warming. This may be the main reason for the low occurrence of *Calanoide carinatus* in July samples .The specie only appear during upwelling season where temperature are lower than 23°C and this development could affect zooplankton abundance and diversity in general and the community structure especially during the upwelling season.

Introduction

Countries in the upwelling regions of the Gulf of Guinea can be described as coastal countries. As such life and survival of the population depends very much on marine and coastal resources and this, indicates the need for sustainable development and management of these resources.

Coastal waters have been found to be most productive areas of the global oceans, producing about 90% of the global fish catch. Fishing is therefore one of the prime occupations of these coastal communities and contributes to the economy of these countries. Fish is also the preferred source of animal protein in these countries making fisheries very vital resources in these countries. The resource is therefore for food security, employment and foreign exchange for these countries.

Fisheries, highly favoured within the upwelling regions are the small pelagics and notably the *sardinellas*, which is seasonal, is greatly influenced by environmental forcing. Their distribution, abundance and production appear to be controlled by these forcing such plankton as food, and for a well-managed fishery, the study and monitoring of the marine environment and their prey are of paramount importance.

Background - For effective management of fisheries resources, it is important that certain environmental parameters such as zooplankton are studied and monitored. The ecology of zooplankton is very important since most fish eggs and the larval forms of many marine fishes of commercial and economic importance starts life in the zooplankton community. Besides, almost all marine fishes depend directly or indirectly on the zooplankton for food. The *Sardinella* fishes, which are important commercial fishery in the region, feed directly on copepod zooplankton even as adult (Kwei, 1964; Brodskii, 1936 and, Brodskii and Yankovskaya 1935). The abundance of zooplankton in time and space could affect fish production, abundance, distribution and composition. Zooplankton, as food could also be affected by both biotic (i.e predators) and abiotic (i.e. climate change and global warming as a result of increase in global temperatures) in terms of abundance, diversity and distribution. Therefore the future of any fish stock would very much depend on the availability of zooplankton. This will also give relevant information on the carrying capacity / production of the Gulf of Guinea.

However, studying of zooplankton dynamics in the region is a bit limited since there are not many experts in the region. Though there had been some efforts through zooplankton research studies by Bainbridge, Vermont, Wiafe, Binet, Mensah, Yaqub and few others, more need to be

done. But then the Marine Fisheries Research Division of the Fisheries Department also collected zooplankton samples between 1962 and 1995 from a transect off Tema and the data is available.

To achieve environmental and resources sustainability especially fisheries in the Gulf of Guinea Current Large Marine Ecosystem, the ecosystem approach strategy was adopted through the Gulf of Guinea Current Large Marine Ecosystem Project. To be able to achieve this, it is important to know the carrying capacity of the ecosystem and this called for studying the biological productivity of the ecosystem.

In view of these plankton samples were collected on Dr. Fridjof Nansen Research Vessel between 2005 and 2007 under the auspices of the GCLME project. The samples were collected from May through June to July in the coastal waters of, Nigeria, Cameron, Principe and Sao Tome, Gabon, Ghana, Guinea, Guinea Bissau, Liberia and Sierra Leone. Other stations where samples were collected were the PLs, SPs and Nansen's. The 304 samples have been analyzed for zooplankton abundance and diversity. The community structure has also been investigated.

 The Study area – The Gulf of Guinea is the part of the Atlantic Ocean, west of Africa within 10 N 4° E. Countries within the Gulf of Guinea region extends from Guinea Bissau to Gabon, Principe and SaoTome (fig.1). The region is one the upwelling regions in the world for which the coastal oceanography has been described by many authors (Longhurst 1962, Ingham 1970,Hisard et al. 1986, Binet 1997, Bakun 1978,Verstraete 1992,Marchal and Picaut 1997, Mansah and Koranteng 1988) . Four well-defined hydrographic regimes have been explained: major upwelling (late June – early October), minor upwelling (December –March) normally interspersed with periods of stratification with the thermocline at 40m depth. The upwelling periods are characterized by low sea surface temperature, high salinity low dissolve oxygen and high biological production including zooplankton and fish. The current velocity could reach 100cm/s and wind speed of 1.5m/s. The reverse is the case in the non-upwelling / stable periods. Tides and tidal waves are moderate.
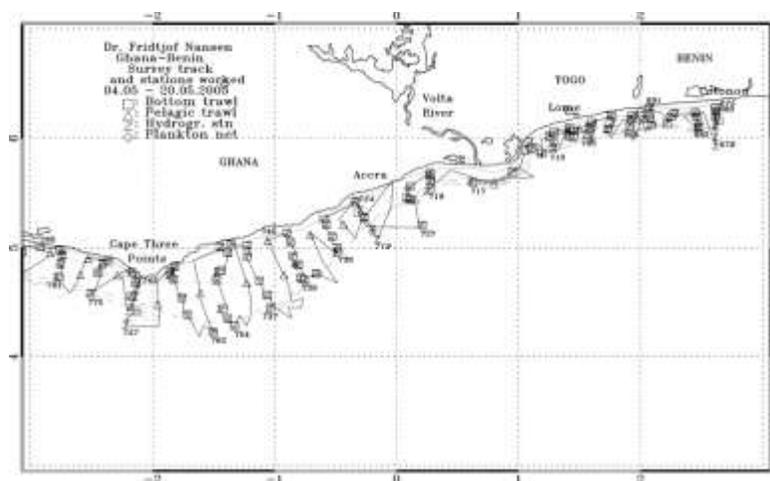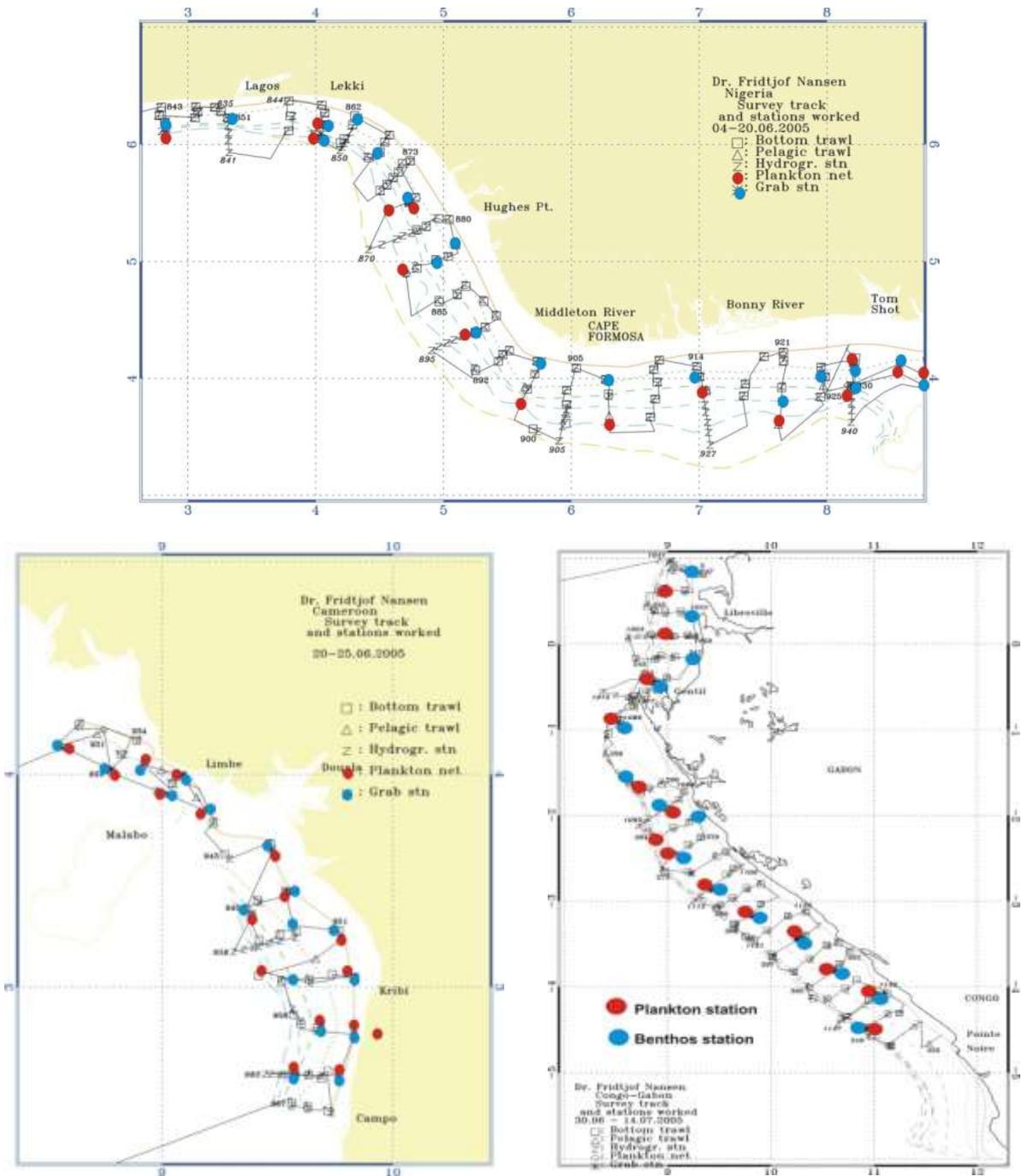
Materials and Method

Sample Collection - Zooplankton samples were collected with multinet and ICITA net as vertical and horizontal tow respectively. The multinet sampler towed 5 nets at a time at different depths with net mesh sizes ranging between 108um to 300um. The ICITA net has a mesh size of 330μm with a mouth diameter of 1m, filtering section of 2.4m, and is rigged with a flow meter, however not with this sampling. The net was towed step-oblique at five steps for 18minutes and

samples preserved in 120ml sample bottles and fixed with 5% formalin. The samples were then brought to the productivity centre /laboratory for analysis- identification and enumeration.

ICITA and Multinet being hauled after sampling on Nansen.

Analysis of samples - The displacement volumes of the entire samples were measured by first filtering the samples. A measuring cylinder was filled with water up to a volume (V1), the sample was then lowed into the cylinder and the volume (V2) was taken under the meniscus. T he displacement volume (V3) is (V2 – V1). Since a whole sample could not be analysed, the samples were divided and a sub-sample of 1/60 were taken using the Folson's plankton divider and the Stempel pipette respectively. Using a counting chamber and binocular microscope all species were identified and enumerated. Species have been put into 6 groups – calanoides, cheatognants, cyclopods, decapods and others. The cladocerans, haparticods and siphonophones were put together as one group.

Processing zooplankton samples

Data Analysis –Excel graphs have been used to depicts variations in abundance and species diversity with respect to the countries, method of sample collection (step-oblique, horizontal and

vertical) and type of net used (ICITA and multi). The months and year in which the samples were collected has also been considered in the analysis. PRIMER package has been used to subject the data to multivariate analysis in which two (2) analysis tools (cluster and MDS) have been employed. The application of these tools allows all species and relationships to receive equal consideration. Thus species, which are not abundant and are therefore ignore in data analysis, though they may provide important ecological information as they are likely to have a narrow tolerance to environmental changes to receive more attention.

Results

Species Abundance and diversity -About 159 species have been identified totaling 38,461 in abundance. They are made up of calanoides(63), decapods(17), cheatognants (18), cyclopods(21) and others(24). The clodoceras, hapaticoids and siphonophones have been put together (13). Species diversity and abundance in terms of sample location is shown in Tables 1 below/figs.2a-b.

Table 1

Countries	Nigeria	Cameron	Principe & S. Tome	Gabon	Guinea	Ghana.
Dates	6 / 05	6 / 05	6 / 05	6 / 05 7 / 07	5 / 07	5/6 / 06
Net /Tow	Multi	Multi	Multi		ICITA Multi	-
No. of samples	8	56	18	10 28	139	8

Countries	Guinea Bissau	Liberia	Sierra Leone	Nansen	SP samples	PL33-44
Dates	5 / 07	5 / 07	5 / 07	5 / 07	5 / 06	6 / 07
Net /Tow	ICITA Multi	ICITA Multi	ICITA Multi	-	H'tal V'cal	-
No. of samples	11 7	7 16	11 10	14	24 20	34
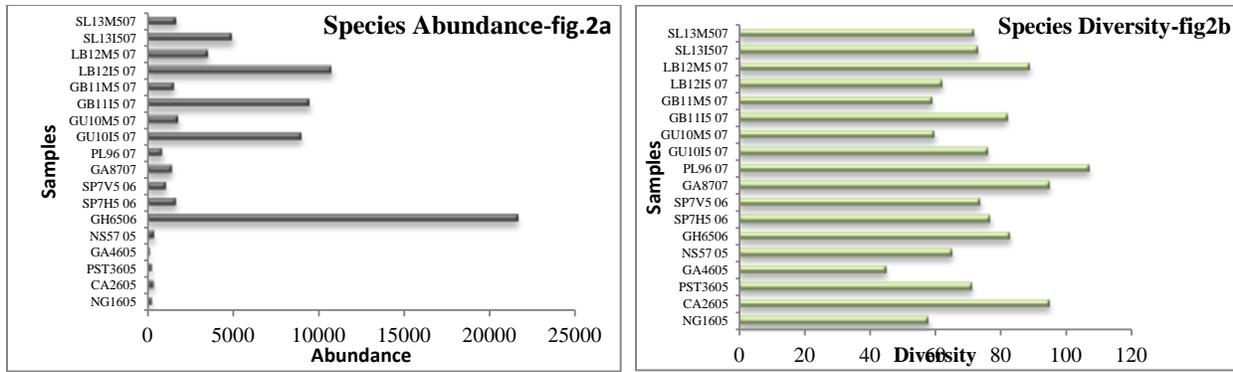
NG-Negiria, CA-Cameroun, PST-Princepe& Sao Tome, GA-Gabon, NS-Nansen samples, GH-Ghana, SP-SP samples, PL-PL samples,GU-Guinea, GB-Guinea Bissau, LB-Liberia, SL-Sierra Leone M-Multinet, I-ICITA net e,g SLM - Sierra Leone multinet sample, SLI- Sierra Leone ICITA net sample. V-Vertical tow, H-Horizontal tow.

The calanoides were the most diverse and abundant with *Temora stylifera, Eucalanus crassus and Centropages furcatus* having the highest number of individuals in that order. The least in abundance are *Chiridius poppei* and *Shrimp larvae.* The haparticods are the least abundance, however the two common species (*Miracia efferata* and *Macrosetella gracilis*) were identified.(fig3a-3b)
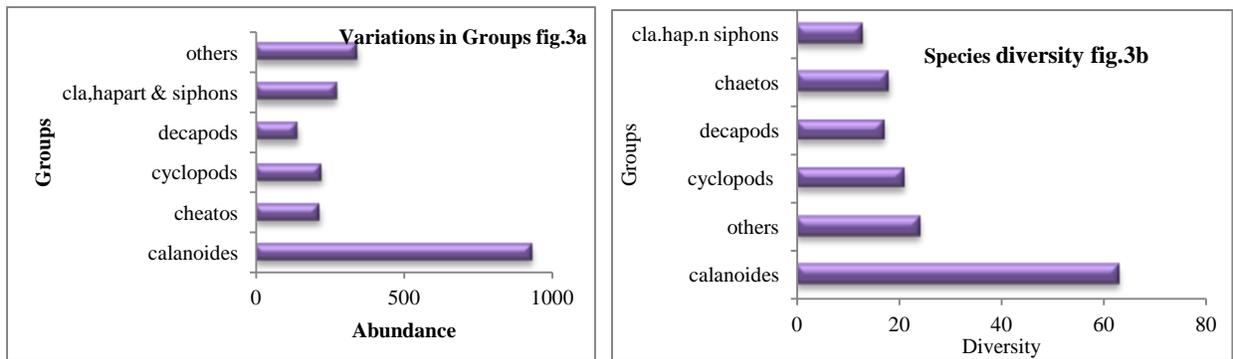

Seasonal and annual variations had the following species showing up strongly. They are in increasing order –May(*T. stylifera,   P. avirostris* and *E. crassus),* June *(Euconchoecia chierchiea, T. stylifera   and Fish eggs)* July(*E. crassus, Decapod larvae, E. pileatus and Calanoides carinatus),* 2005(*E. crassus, E. pileatus* and *Calanoides carinatus), 2006(Euconchoecia chierchiea T. stylifera* and *P. avirostris),* and 2007(*T. stylifera, P. avirostris* and *E. crassus.*(figs 4a-d). Samples collected in May / June and 2007are more diverse and low in abundance; however those collected in July and 2005 are low in diversity and abundance
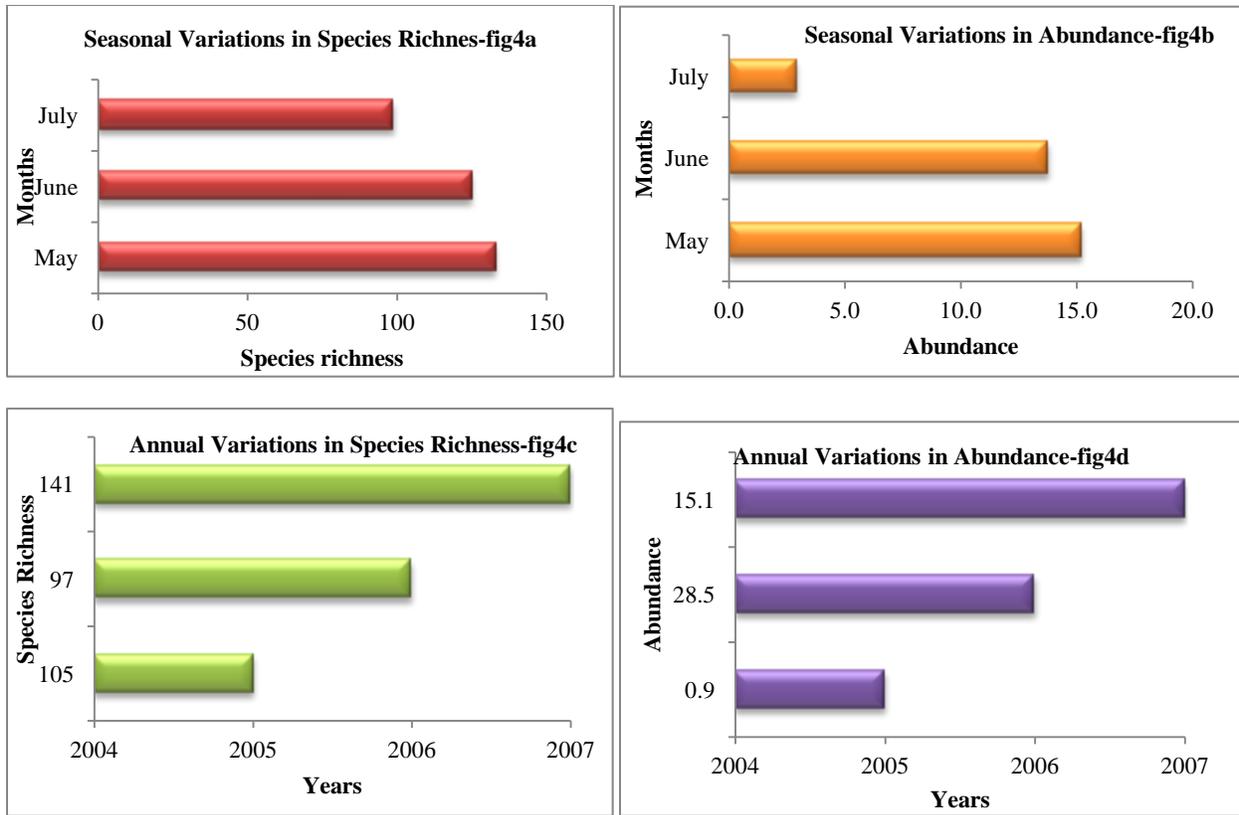
Seasonal Variations in Species Richnes-fig4a

Seasonal Variations in Abundance-fig4b

Annual Variations in Species Richness-fig4c

Annual Variations in Abundance-fig4d

Samples collected with ICITA, and Horizontal tows were relatively more diverse and abundant than those collected with multinet and towed vertically (table1,figs.5a-)

Multinet v ICITA-fig5a

Multinet v ICITA-fig5b
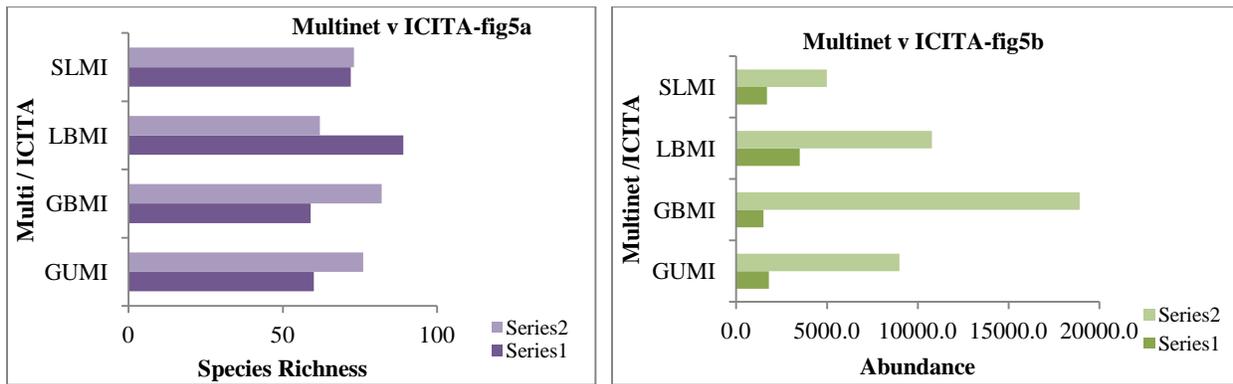
Series 1-Multinet,   Series 2-ICITA

Figs. 6a-f depicts the seasonal and annual Ten top species within the Gulf of Guinea.

Ten top species - May-fig.6a

Ten top species - June-fig.6b

Ten top species - July-fig.6c

Ten top species - 2005-fig6d

Ten top species - 2006-fig6e

Ten top species - 2007-figf
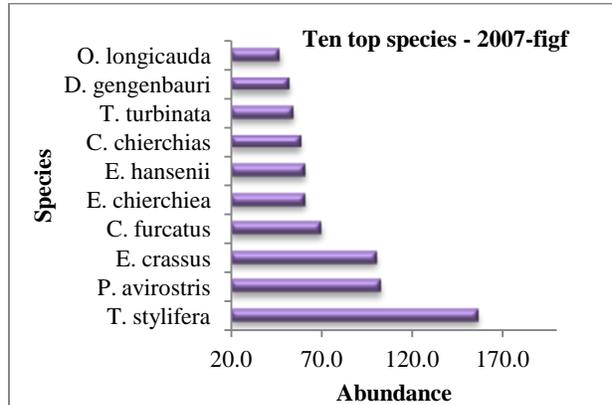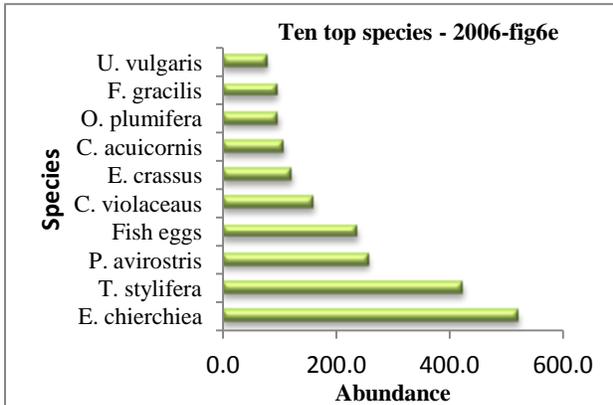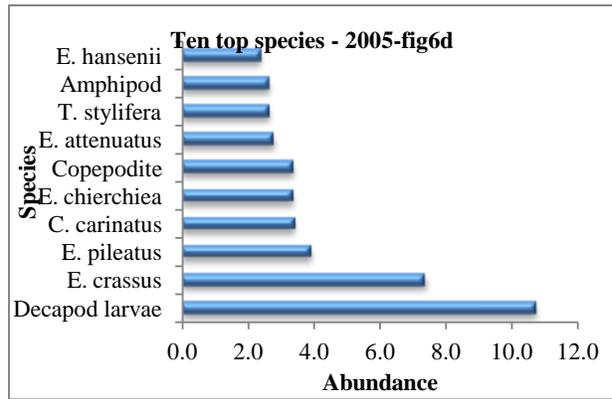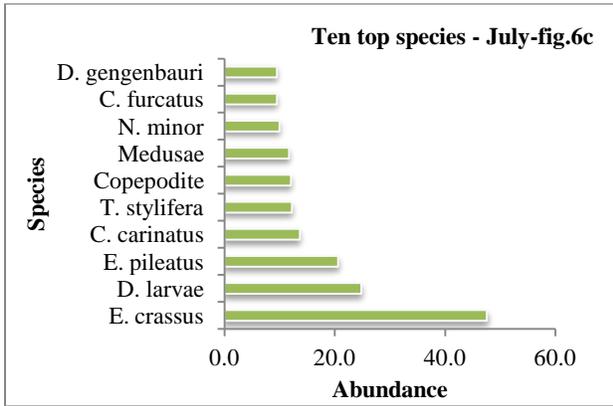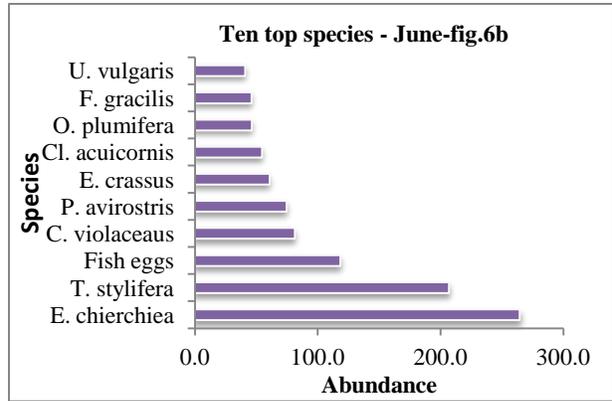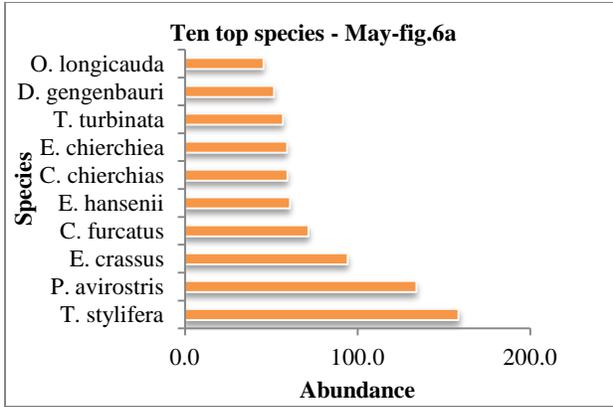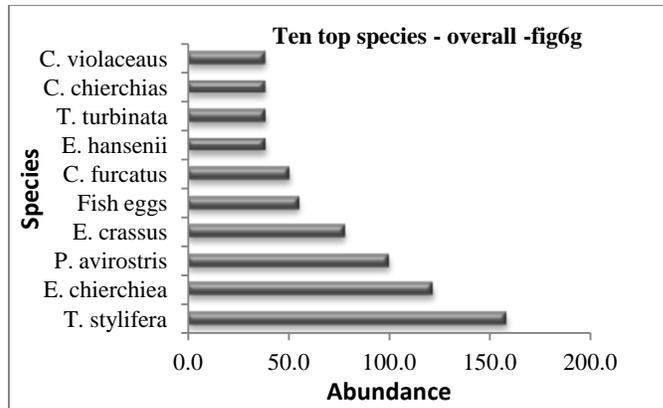
The cluster and MDS analysis depicts the community structure. The cluster analysis shows 6 and 3 communities at 60% and 50% similarities respectively with MDS stress of 0.17 which is very good(figs 7a-b), and is inclusive all species and this is to allow species with narrow tolerance to environmental changes to receive more attention.

fig.7a   fig7b
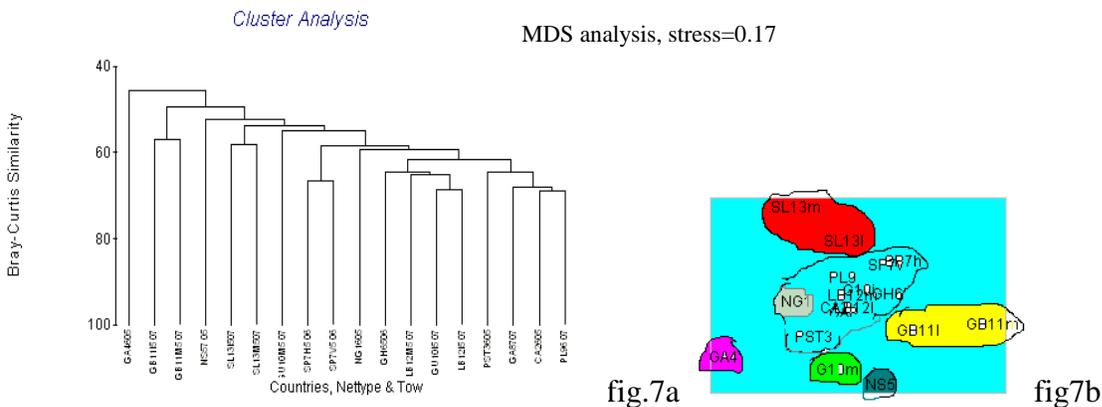
Figures 7c -7d show cluster and MDS analysis exclusive rear species that appeared from once to 4 times with just an individual. At 60% and 50%, six(6) and two(2) communities could be deduced
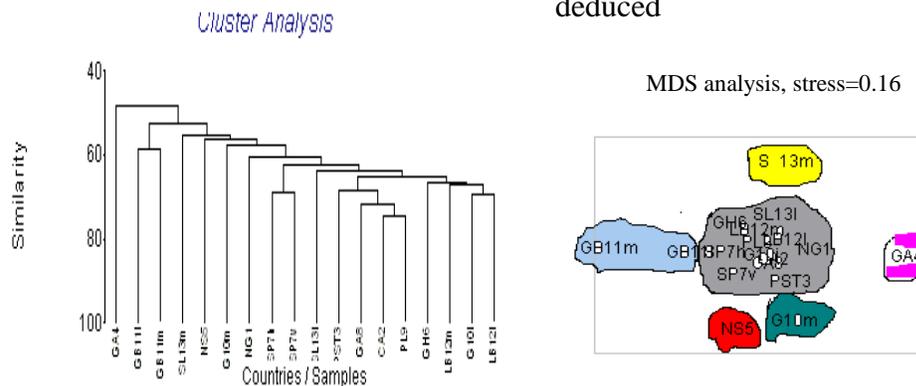
fig.7c   fig7d

Cluster and MDS analysis of species abundance as against months and years put June and May, and 2005 and 2007 together while July and 2006 stay on their own (fig8a-c)
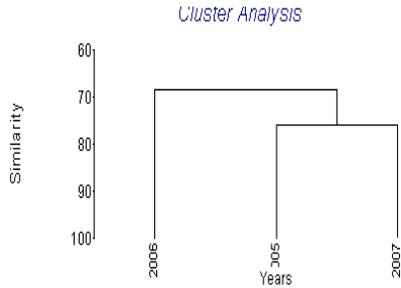
fig.8a
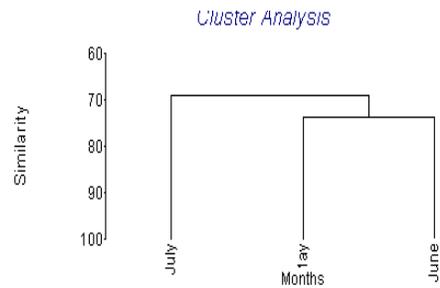
fig.8b
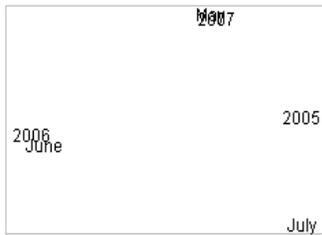
fig.8c

Average temperature in 2006(26.8°C) which is the highest is close to the average temperature for June (26.6) and the lowest average temperature (25.9°C) was recorded in 2005. July had the lowest average temperature (24.5°C) while May had the highest (28.3).

The top thirteen (13) species- at75 / 70% level of similarity, there are 4 and 3 groups respectively (figs9a-d).
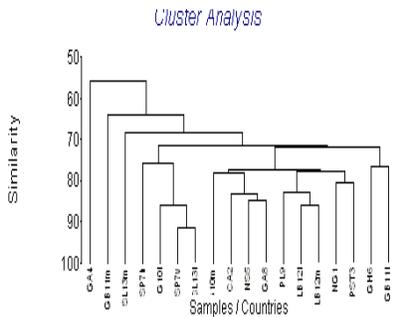
fig9a

9b (stress-0.14)

9c   9d (stress – 0.12)
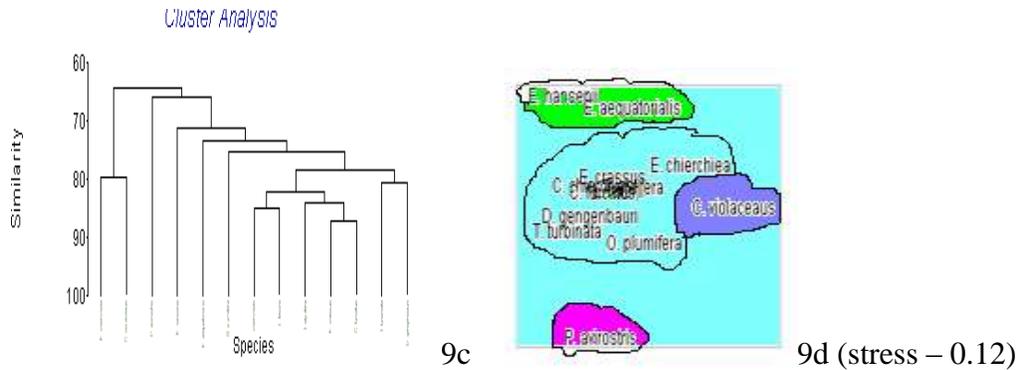
Discussions

Temperature has been found out to be the main driving force behind all the ocean processes and changes, currents systems, sea level changes, dissolve oxygen, salinity etc. It affects climatic patterns. The changes affect the physical, chemical and biological productions of the environments such as abundance, composition and distribution (Lalli and Parsons, 1997). It is therefore obvious under this study that temperature has been the main controlling factor in zooplankton abundance, diversity and community structure. Yaqub, 2000 also pointed out that temperature and oxygen were the main controlling factor in copepods abundance in Ghanaian coastal waters and the fact that copepod zooplankton has been on the decreasing side since the eighties. Zooplankton abundance appear to be seasonal, high during upwelling periods (July-September when temperatures are minimal) and minimal in the thermal periods (March-June when temperatures are maximal).

Species diversity is minimal in upwelling seasons with species such as the *Calanoides carinatus* dominating the copepods zooplankton. This species in a normal sample at the peak (August) of the season could constitute a significant proportion by number (60-80%) of the zooplankton (Houghton and Mensah,1978). The other way round is the situation in the thermal periods. However, low abundance of the species in this study could be due to the persistent increase in temperature in the Gulf of Guinea. A study on climatic trend with particular reference to temperature in the Gulf of Guinea by Koranteng and McClade, 2000 reveals this persistent increase in temperature which they attributed to climate change and global warming. *Calanoides carinatus* is favoured by temperatures below 23°C and any increase could cause the disappearance of the species, and development like this could affect community structure during the upwelling period (Wiafe,2002). The disappearance will then mare the usefulness of the species as an environmental discriminator especially the upwelling and even the intensity.

 Temora stylifera ,*Eucalanus crassus* and *E. Pileatus* dominated the samples irrespective of location, season and the year and could be concluded that these species are tolerance of wide range of environmental conditions and could do well in most environments. However, they are most abundant during the thermal periods. Bainbridge, 1972 and Vervoot, 1965 agreed that *Temora stylifera* is widely distributed the world over and the whole of Africa coast and with the

current trends in temperatures these species especially *T. Stylifera* could take over in upwelling periods thereby causing a shift in the community structure as well as the diet for the *sardinella* which, could be detrimental for the fishery.

The cluster and MDS analysis reveals that temperature may be the secret behind the groupings. Samples in the biggest cluster (CA205, LB12507, GH6506, SP7H5 06, PL96 07 and GA405) (figs7a&b) were all collected in May/June (thermal period). GA07 and NS505 are on their own, though both were collected in July (upwelling), the different years could be the reason. Temperature in 2005(25.9°C) was lower than 2007(26°C). Though temperature may be the cause for the grouping but then *T. stylifera* and *E. crassus* which were almost in abundance in all the samples could cause samples to be grouped together , as they show little discrimination between environmental conditions.

As much as community structure may be influenced by mainly environmental conditions, especially temperature, others like location, time and species could also be the cause for similarity and dissimilarity of samples and species. A rear specie could be the cause for which N1 (Nigeria) has been on its own when all species were inclusive in the cluster and MDS analysis (figs.4&5) but form part of the biggest group in the analysis where rear species were excluded (figs.8a&b) at 60%.

Cluster and MDS for monthly and yearly community structure reveal similarity between May/June (thermal period) and 2005 / 2007(at 75%) where most samples were collected in June and May (figs.,9a-d). July on its own is a clear evident of upwelling period and the prevalence of lowest temperature. 2005 on its own also reveals lower temperature of 25.9°C.

Fish eggs and larvae are studied under zooplankton to give an idea of the status of the fishery resources. For example, as the number of fish eggs and larvae decrease, the fishery may dwindle, Mensah (1972). Therefore the low fish eggs and larvae abundance could be an indication of dwindling fisheries in the Gulf of Guinea unless may be because the samples were collected in the thermal period.

Temperature has been the main driving force in the community grouping, but then environmental conditions may be cumulative results of variety of factors and the likelihood that grouping by clustering could be a bit misleading is possible. Species like *Temora stylifera and E. crassus* which, were almost in abundance in all the samples could cause samples to be grouped together and the fact that the specie are more abundance in the thermal period in which all the samples were collected except GA205 and NS07 which were collected in unstable period. Such species may show little discrimination between environmental conditions and for the purpose of environmental interpretation should be considered with caution. However *Calanoide carinatus* which is restricted by temperature is a good discriminator and could be used an indicator for environmental change.

The high abundance of copepodites confirms the existence of the major thermal period where the copepodites are yet to mature to coincide with the major upwelling.

Similarity level of 60 -75% and a stress of <0.17 and <0.16 are very good. Clusters are well defined when superimposed on the MDS making the result very reliable. Sampling strategy is very important and it's crucial that samples are collected either at the same place on different times or at different places at the same time. But then samples have been collected in different months, years, location with net and tows. The relatively higher abundance and species of samples collected with ICITA and towed horizontally may be due to the fact that larger area is covered and also the fat that zooplankton are patchy and move in oblique manner

Conclusion

 Samples from the Gulf of Guinea have been analysed and cluster and MDS analyzing tools used to analyse the zooplankton communities. The calanoides have been the most abundant among all the groups of which *Temora stylifera*   and *Eucalanus Crassus* are the most abundant. The least among all the groups are the harpaticoids and the cladocerans with only two species each respectively.

It is clear that the change in environmental conditions could cause a shift in the zooplankton community structure which would not be the best for the ecosystem. Consistent increase in temperature due to climate change and global warming could be a course   for worry especially for the *Calanoide carinatus* which is very sensitive to temperature and a good environmental discriminator for that matter. The fishes that feed on them could also be affected.

Finally, it could be concluded that climate change and global warming may be detrimental to ecosystem productivity and carrying capacity since colder species could be replaced by warming species and change the diet of some fishes like the *sardinella* that feed on copepods during the upwelling periods of which *C. carinatus* makes up about 70 – 80% of the abundance. Though it could increase diversity, the size structure will be small and cause fish size to be also small. The change could also cause a shift in species appearance and community structure of the whole Gulf of Guinea Large Marine Ecosystem.

For example, It's been observed that there is a northward shift of 1000 km of warmer-water plankton, with a similar retreat of colder water plankton, in the north-east Atlantic over the past 40 years as the seas around the UK have become warmer. *Calanus finmarchicus (*colder sp*)* being replaced by *C. helgolandicusi (* warmer sp*)* in the North-East Atlantic. There is a correlation between plankton shifts and changes in various fish stocks. Continued increase in sea temperature and acidification may exert a major influence on plankton variability, with implications for primary production.

Recommendations

It's recommended that for a sustainable environmental and resources development and management, zooplankton sampling in the Gulf of Guinea should be continuous even if its once a year. This is because studying and monitoring zooplankton is part of sustainable management and gives knowledge on the carrying capacity of an aquatic ecosystem. For a sustainable managed of the fisheries resources it's also important to have clear understanding of their prey including their abundance and production, composition, distribution, variations and trends through studies and monitoring.

Studying the marine environment especially zooplankton has become indispensable in marine fisheries management in the region. However, experts within the region are limited resulting in seemingly lack of research initiatives, and this has left more issues on the subject unresolved.

More experts and analysts could be trained within the Gulf of Guinea region through workshops and training courses.

Experts could also be given fellowship awards into sister research institutions for updates in new techniques in zooplankton identification such as DNA Barcoding.

 The last time that a serious and dedicated zooplankton research studies was made was in 2002 by Wiafe and since both climatic change and global warming, and environmental changes contribute to variations in zooplankton the way forward is more research studies to make more information available on zooplankton dynamics and productivity of the Gulf of Guinea.

Challenges

Some of the samples were badly labeled which made identification very difficult and this must be corrected in future sampling. Absolute zooplankton abundance could not be calculated for the samples collected with ICITA net because there were no flouro meter readings and this made impossible to calculate the volume of water filtered.

Appendix 1 – Species List

Calanoida	*Cheatognaths*	*Phyllosoma larvae*
Calanoides carinatus	*Sagitta enflata*	*Procellana larvae*
Temora stylifera	*S. serrantodentata*	*Porcellana*

T. turbinata	*Sagitta elegans*	*pltycheles*
Nanocalanus minor	*Sagitta minima*	*Pagurus bernhardis*
C. chierchias	*Sagitta fridrici*	*Cariden larvae*
Centropages furcatus	*Sagitta plantonis*	*Stomatopoda larvea*
C. hamatus	*Sagitta zetesios*	
C. violaceaus	*S. macrocephala*	**Cladocera, Haparcticoida & Sphonophores**
C. typicus	*Sagitta hispida*	
C. brachiatus	*Sagitta lyra*	*Evadne tergestina*
Paracalanus parvus	*Sagitta decipien*	*P. avirostris*
P. aculeatus	*Sagitta bipunctata*	*Cirriped nauplius*
P. denudatus	*Sagitta hexaptera.*	*Cirriped*
Paracalanus scoti	*Pterosagitta draco*	*Podon polyphemoides*
E. monachus	*Eukrohnia fawleri*	*Microsetella gracilis*
Eucalanus pileatus	*Krohnitta subtilis*	*Miracia efferata*
Eucalanus crassus	*Eukrohnia hamata*	*E. acutifrons*
E. attenuatus	*Sagitta maxima*	*Euterpina*
Eucalanus elongatus		*Chelophyes appendiculata*
Eucheata hebes	**Cyclopoda**	
Eucheata marina		*Lensia fowleri*
E. aequatorialis	*Corycaeus limbatus*	*Muggiea atlantica*
Eucheata hansenii	*Corycaeus typicus*	*Muggiea kochi*
E. paraconcina	*Corycaeus flaccus*	*Medusae*
Eucheata tonsa	*C. speciosus*	
Rhincalanus nasutus	*Corycaeus clausi*	**Others**
Rhincalanus cornutus	*Corycaeus lautus*	*Doliolium gengenbauri*

Clausocalanus acuicornis	Corycaeus venustus	*Thalia democratica*
Clausocalanus furcatus	*Farranula gracilis*	*Oikopleura longicauda*
Clausocalanus paululus	*Farranula carinatus*	*Oikopleura dioica*
Acatia danae	*Oithona plumifera*	*Amphipod*
A. nigligens	*Oithona satigera*	*Euconchoecia chierchiea*
Calocalanus styliremis	*Oncaea venusta*	*Conchoecia elegans*
Calocalanus pavo	*O. meditteranea*	*Eudoxid*
Neocalanus gracilis	*Oncaea media*	*Copepodite*
Neocalanus robustior	*Oncea conifera*	*Heteropoda*
Undinula vulgaris	*Oncea minuta*	*Fish eggs*
C. longimana	*S. nigromaculata*	*Fish larvae*
Candacia elongata	*S. ovatolanceolata*	*Polycheat(Sagitella sp)*
Candacia varicans.	*S. pyrosomatis*	*Pteropoda(Limacina*
Candacia curta	*Sapphirina scarlata*	*Brittlestar Larvae*
C. pachydactala	*Lubbockia Squillimana*	*Nareid larvae*
Candacia magna		*Stomatopoda larvae*
Acrocalanus longicornis	***Decapoda***	*Stomatoca pterophyla*
Acrocalanus andersoni	*Anapegurus hynamanni*	*Cryptoniscid larvea*
A. monachus	*Lucifer fexoni*	*Fritillaria*
Aetideopsis multiserrata	*Decapod larvae*	*Starfish lavae*
	Lucifer larvea	*Arachnactis larvea*
	Lucifer protozoa	*Cranchid squid*
	Megalopa	*Brachiopod larvea*
	zoea	

Aetideus armatus	*Euphausid sp*	
Pleuromama abdominalis	*Mysids*	
Pleuromama xiphias	*Sergestid sp. / protozoa*	
Scolecithrix bradyi	*Gastropod larvea*	
Scolecithrix danae	*Bivalve larvea*	
Pontella gaboonensis	*Shrimp larvae*	
Pontelina plumata		
Labidocera acuitifrons		
Ischnocalanus plumulosus		
Medridia princeps		
Chiridius poppei		
Ctenocalanus vanus		
Scottocalanus helene		
Copilia quadrata		
Euchirella splenders		
Mecynocera clausii		

References

Bainbridge,V.(1972) ; The zooplankton of the Gulf of Guinea: *Bulletins of Marine Ecology*; **8:** 61-97.

Bakun, A. (1978); Guinea current upwelling, Nature, 271:147-150.

Binet , D. (1995); Hypothesis accounting for the variability of *sardinella* abundance in the northern Gulf of Gunea. In Dynamics and uses of sardinella Resources from Upwelling off Ghana and Cote d' Ivoire, pp. 98 – 133. Ed. By F.X. Bard, and K.A. Koranteng. ORSTOM Edition, Paris

Boltger-Schnack, R., Schnack, D. and H. Weikert (1989); Biological observations on small cyclpoid copepods in the Red Sea; In: *Jour. Plank.Res*.**11** (5): 1089-1101.

Brodskii, K.A. (1967); *Calanoida of the Far Eastern Seas and polar Basin of the USSR.* Academy of Science, USSR. 440pp.

Brodskii, K.A. and A.I. Yankovskaya (1935); O'Pitanii dal' nevostochnoi sardiny (feeding of the Far Eastern sardine); Vestnik Dal' nevostchnogo Filila Academii Navk SSSR, No 13.

Colebrook, J.M. (1972); Changes in the distribution and abundance of zooplankton in the North Sea, 1948-1969; *Symp. Zool. Soc. Lond*. **29:** 203-212.

Frango, I.S., (1996); Zooplankton annual cycle in a Mediterranean coastal area; In: *J. Plank.Res*.**18** (2): 203-223.

Gaard, E. (1999); The zooplankton community structure in relation to its biological and physical environment on the Faroe shelf, 1989-1997; In: *Jour. Plank.Res*.**21** (6): 1133-1152.

Hassel, A. (1986); Seasonal changes in zooplankton composition in the Barents Sea with special attention to calanus spp (copepod); In: *Jour. Plank.Res*.**8** (2): 329-339.

Hirst, A.G. (1996); Zooplankton production and energy flow-Towards a biological model of Southampton Water: PhD thesis submitted to Dept. of Oceanography, Southampton University, Southampton-U.K.

Krebs, C.J. (1999). Ecological methodology,pp. 620. Menlo Park: Addison Wesley Longman.

Longhurst, A.R.(1962). A review of the oceanography of the Gulf of Guinea. Bulletin de l'Institute Africa Noire Series A, 24:633 -663.

Lalli, C.M. and Parson, T.R.(1997) Biological oceanography; An Introdcution, second edition.pp.314.

Mensah, M .A. and K. A. Koranteng (1988); Review of the oceanography and fishery resource in the coastal waters of Ghana, 1881-1986. Research Report No 8. 35pp.

Mensah, M A. (1972); Studies on the life-cycle of the marine copepoda Calanoides carinatus (Krφyer) in Ghanaian Waters; M.Sc. thesis presented to the Dept. of Zoology, University of Ghana-Legon.

Kwei, E.A. (1964); Migration of *Sardinella aurita*; *Ghana Journal of Science*. **4** (1): 34-43.

Vervoort, W. (1963); Pelagic Copepoda. Part 1 : Copepoda Calanoida of the families Calanidae up to and including Euchaetidae; *Atlantide report*, **7**: 77-194.

Vervoort, W. (1965);   Pelagic Copepoda. Part 11: Copepoda Calanoida of the families Phaennidae up to and including Acartiidae, containing the description of a new species of Aetidedae; *Atlantide report* **8**: 9-216.

Wiafe, G. and Frid, C.L.J. (1996); Short-term temporal variation in coastal zooplankton communities: the relative importance of physical and biological mechanims; In: *J. Plank. Res.***18** (8): 1485-1501.

Wiafe, G.(2002); Spatial and temporal dynamics of plankton communities in the Gulf of Gunea ecosystem. Department of Ocenaography and Fisheries, University of Ghana, Legon. 188pp.

Yaqub, H.B. (2000)   ; Copepods in Ghanaian Coastal Waters – Abundance and Diversity: MSc thesis submitted to School of Ocean and Earth Science, Southampton University, Southampton-U.K. 49pp.

Macrobenthic Faunal Communities of the Guinea Current Large Marine Ecosystem

Summary

Macrobenthic fauna samples were collected as part of the fisheries resource survey/assessment on the continental shelves of participating countries of the Guinea Current Large Marine Ecosystem (GCLME) programme. The surveys spanned from 2005-2007. The survey in 2005 was mainly restricted to the southern part of the region, but both the 2006 and 2007 were on large scale covering virtually all the countries albeit some countries (e.g.., Nigeria) were not assessed. Nonetheless, the analysis carried out and the results herein were for mainly samples collected in 2007 with one or two samples pooled from 2005 and 2006 just to ensure that information from each participating countries is factored into the analysis. The objectives of the analysis among others were to quantify the distributional abundance of the macrobenthic fauna and also estimate their productivity. In addition, collection of macrobenthic fauna vouchers specimens to populate the GCLME's biodiversity museum in the University of Ghana forms part of the overall objective.

In order to ensure unbiased analysis, four samples from each country were identified taxonomically and statistically analyzed. The organisms were identified as far as possible to the lowest taxonomic unit using high resolution microscope.

The results of the analyses carried out indicated a total of 2809 individuals (mean density=591 individuals per square meter) which comprised 320 different species belonging to five major taxonomic groups namely: polychaetes, crustaceans, mollusks, echinoderms and other taxa (e.g., cnidarians). Polychaetes contributed 57.7% to the total abundance, crustaceans 25.1%; 13.0% for species placed in "others" category, while mollusks and echinoderms accounted for 2.3% and 1.9% respectively. In terms of number of species, polychaetes were made up of 206 (64.4%) species, crustaceans consisted 52 (16.3%) species, 31 (9.7%) species belong to mollusks, whereas echinoderms and "others" category constituted 7 (2.2%) and 24 (7.5%) species respectively.

The results also showed that 15 species (11 polychaetes, 3 crustacean, & 1 species in other taxa category) occurred in >20% of the samplings stations with the highest occurred taxa being the crustacean, *Ampelisca* spp. (56.5%). Nonetheless, the polychaete with the highest frequency of occurrence was *Eunice vitata* (41.3%). This indicates that the distribution of the species were not widespread and restricted to narrow geo-range possibly due to barriers resulting from water masses. This assertion is consistent with the observed patterns in the multivariate clustering analysis of the countries based on macrobenthic faunal abundance and composition. The multivariate cluster analysis depicted a gradient in the station (i.e., country) clusters. The three major clusters observed were: cluster I (Guinea-Bissau to Cote d'Ivoire), cluster II (Togo & Benin) and cluster III (Cameroon &Principe & Sao-Tome) depicting a spatial gradient. The

highest similarity of the macrobenthos was realized between Togo and Benin and the lowest being between Cameroon and Principe & Sao Tome. The species composition of Ghana, Gabon and Nigeria were significantly ($p<0.05$) different from the rest of the countries and hence did not form structure with them.

The macrobenthic faunal biomass data were used as surrogate for benthic productivity shows a general high productivity for Sierra Leone, Guinea-Bissau and Ghana in that sequence. The highest productivity was generally occurred with polychates except Ghana where crustacean ranked highest and Principe & Sao Tome where productivity is associated with echinoderms.

The collection of voucher specimens for the marine biodiversity museum is ongoing but at phase I due to inadequate storage vials (glass jars) and other pertinent chemicals etc. Nonetheless, a good amount of specimens have been collected for the center.

There is a large knowledge gap of macrobenthic fauna in the GCLME, which calls for pragmatic measures that will lead to increased research on basic biology (feeding, habitat preference etc.), composition, taxonomy, abundance, community structure and also training to stimulate interest in that field of study.

Introduction

This report is the outcome of analysis of macrobenthic fauna samples collected during the GCLME fisheries resource surveys between 2005 and 2007. Nonetheless, the analyses were carried out mainly for the 2007 samples collected due to the time frame within which the report should be available. Also in order to ensure meaningful interpretation, four stations were selected for each of the GCLME countries. Nonetheless, since each of the surveys (2005-2007) were generally not comprehensive covering all the GCLME countries, some samples from different years (e.g., Nigeria samples used was for 2005) to ensure a good spatial representation and sound interpretation of the results. It is important also to indicate that most benthic samples collected during the surveys are still at Congo Brazzaville yet to come to the Productivity and Biodiversity center in Ghana.

The Guinea Current Large Marine Ecosystem is one of the major coastal upwelling sub-ecosystems of the world and constitutes an important system for marine biodiversity (e.g., fisheries & macro-invertebrates) and food production [Ukwe, 2006]. It is thus ranked among the most productive coastal and offshore waters of the world palpably due to its rich fisheries resources. However, the fisheries resources of the GCLME continue to face a declension in abundance as a sequel of pollution, habitats degradation and bad fishing practices and management, which is directly threatening the productivity and biodiversity foundation. Efforts to stem the tide or curb the dwindling trend to ensure sustainability, led to the trans-boundary diagnostic analysis to foremost understand the situation and subsequent management. The

GCLME project was aimed at addressing i) the fisheries decline, ii) ecosystem degradation and alteration, iii) land- and sea-based pollution, iv) loss of biodiversity, and v) coastal erosion.

An important aspect of the project is the fisheries resource assessment of the continental shelves of the participating countries. As part of this, it was agreed to include the assessment of the benthos with the object of understanding the productivity and coupling with fisheries, and also how they influence the overall ecosystem health. The assessment of indicators of the ocean health is a relevant issue of Chapter 40 of UNCED (United Nations Conference on Environment and Development) Agenda 21, which calls for a sustainable use of the marine environment and the coastal zone.

In shallow water, benthos dynamics are tightly related with processes occurring in the overlying water column [Fabiano et al., 2001; Magniet al., 2002]. Integrated measurements of physical, chemical and biological components of the benthos may thus represent important tools in the assessment and implementation of existing observing systems. The analysis of ecosystem health is aimed at identifying threshold levels of selected variables (composition, diversity abundance, biomass etc) that could serve as indicators, or ''warning signals,'' of related adverse environmental conditions leading to stress. Important attributes of such indicators should be: (i) reliability in their ability to detect stress and (ii) ease of use and broad applicability in different ecosystems. A global analysis on the relationship between macrobenthic fauna and total organic carbon (TOC) has provided compelling and statistically robust evidence of a marked reduction of species diversity along a gradient of organic carbon in sediments [Hyland et al., 2005]. As sediment organic matter increases, the oxygenated portion of the sediment can become limited to the sediment surface or be eliminated altogether, and dissolved oxygen concentrations can drop to levels that are lethal for some organisms [Nielson et al., 1996]. Under extreme conditions organic enrichment can lead to increased periods of hypoxia or even anoxia. Under such conditions, mobile organisms leave the affected area and sessile species die. Defaunated areas tend to be recolonized by a less diverse range of opportunisitic species tolerant of low oxygen conditions or those better at first exploiting open spaces left after all the original animals have died or migrated (*e.g.* small polychaete worms, nematodes and clams) [Nielson et al., 1996].

Currently, fisheries management is gravitating towards ecosystem approach, which ensures holistic ecosystem assessment. Ecological Quality Objectives (EcoQO's) is now used to assist in the movement toward an ecosystem approach to management [Frid and Hall, 2001]. With regard to the benthos, it is likely that the protection of ecological qualities, such as biomass, species abundance patterns and the presence of key species (indicator or sensitive) will be deemed important. Skjoldal *et al.* [1999] defined the EcoQ as *an overall expression of the structure and function of the aquatic systems.* It follows from the definition that the starting point for the development of ecosystem approaches to environmental management is to define the 'overall structure and function' desired for the ecosystem being considered. For marine benthos, the issues that need to be considered include (i) aspects of the composition and structure of the benthic community – species diversity, species abundance patterns (i.e., how individuals are

distributed between the species present), and biomass. We must then consider the functioning of this assemblage; and (ii) functional attributes such as the productivity of the community and the degree, rate and pathways of nutrient and carbon cycling.

1.2   Objectives

In connection with the above terms of engagement/scope of work the following objectives were developed to place the report in good perspective. Specifically, the restated objectives were:

a) Quantify the abundance and distribution of macrobenthic fauna in the GCLME.
b) Determine the spatial variability of macrobenthic faunal communities
c) Determine bio-indicator species for environmental monitoring of the health of the ecosystem.
d) Assess the biomass and hence the productivity of the macrobenthic faunal populations.
e) Populate the marine biodiversity museum with voucher specimens
f) Provide relevant recommendations for the purposes of scientific research and management options
g) Relate the distribution and abundance of the macrobenthic fauna to the environmental variables (i.e. sediment & water parameters) and fisheries abundance.

1.3.   Structure of the Report

The report is in four chapters. Chapter One introduces the report, outlining the terms of engagement/scope of work and objectives. The chapter also discusses the importance of macrobenthic fauna and their justification in environmental studies. Available literature of macrobenthic fauna studies in the GCLME was briefly reviewed. The chapter ends with a discussion on the Interactions between macrobenthic fauna and fisheries.

Chapter Two describes both the field and laboratory protocols followed and consequence quality assurance and control measures. Chapter Three describes and interprets the results. Sample collections and curatorship for the biodiversity museum forms part of the chapter. Chapter Four is the concluding part of the report and pertinent recommendations regarding scientific research and management options. References and Appendices form part of Chapter Five.

1.4   Macrobenthic Faunal Communities

Marine macrobenthos are a diverse group of organisms composed mainly of mollusks (shellfish and snails), polychaetes (bristle worms), crustaceans (amphipods, shrimps, and crabs) and echinoderms (sea cucumbers, brittle stars, sea urchins) [Gray, 1981]. These organisms are central elements of marine ecosystems and provide excellent indicators of environmental health. They

also play multiple ecological roles within the marine ecosystem and are a critical part of environmental monitoring and evaluation programmes. Most macrobenthic animals are relatively long lived (several years) and thus integrate changes and fluctuations in the environment over a longer period of time. Changes in soft bottom zoobenthic communities in response to the environmental impact have been successfully implemented world-wide in pollution assessment studies and monitoring programs [Pearson and Rosenberg, 1978]. Variations in species composition, abundance and biomass can be used to assess environmental disturbance. Comparatively rich and diverse shallow-water benthic communities are amenable for more sensitive analyses of eutrophication effects. The potential benefits of using macro-invertebrates include quick detection of pollution through differences between predicted and actual faunal assemblages [Ormerod and Edwards, 1987]. Of relative importance, benthic invertebrates are relatively sessile (therefore allowing spatial patterns to imply causation), can be sampled quantitatively without high cost, are well described taxonomically, and reveal ecologically meaningful and important patterns, even at coarse levels of taxonomic discrimination [Warwick, 1988].

In most environmental studies of impacts, benthic invertebrates are the principal targeted organisms (78 percent of all studies), reflecting their suitability as ecological indicators [Peterson and Bishop, 2005; Clarke and Warwick, 1994]. These organisms are operationally classified as microbenthos ($< 63 \ \mu m$), meiobenthos (from $63 \ \mu m$ to $500 \ \mu m$) and macrobenthos ($> 500 \ \mu m$ or $> 1000 \ \mu m$) according to the sieve mesh size used for extracting them from sediment cores or grabs. The macrobenthic infaunal communities are especially suited for long-term comparative investigations since many of the constituent species are of low mobility, relatively long lived and integrate effects of environmental changes over time. Consequently, macrobenthic fauna constitute good biological candidates for monitoring ecosystem health and processes. Cury and Roy [2002] has stressed that studies that link the different components of the trophic web or the spatial and temporal dynamics of the interaction between the environment and marine resources are needed as they have important implication for managing the resources.

1.5   **Macrobenthos-Fisheries Interactions**

The interactions of macrobenthic faunal communities and fisheries may be direct and indirect. Direct interactions are viewed in their coupling with fishes (serving as a good source food for most fishes of commercial importance). They are abundantly found in the stomach of commercial fish species such as (e.g. Sparids, Cloakers). The indirect interaction is viewed in different forms such as the benthos provides pristine habitats and refugia for many fishes. An important function of marine benthos is mineralization of nutrients, which indirectly drive fisheries. Nutrient (nitrate and orthophosphate) in the marine ecosystem form the basis for aquatic primary production, effect fisheries yield (e.g., upwelling seasons). Marine sediments supply up to 80% of the nitrogen required by phytoplankton in coastal ecosystems. If nutrient

cycling is reduced, nutrients derived from sinking pelagic organisms and their waste products, as well as those produced by the benthos themselves, would be more likely to remain in the benthic environment, resulting in a nutrient deficiency in the pelagic system, causing lower productivity, including reducing food available for fish.

The macrobenthic faunal organisms constitute an integral part of the Ecosystem Approach to Fisheries (EAF), productivity and biodiversity, all of which constitute the components underpinning the GCLME's mandate. The important commercial fishery in the Guinea Current Ecosystem (GCL) is predominantly demersal [Koranteng, 1998] with mean annual catch of 50, 000 tonnes. The demersal fishes (e.g. Sparids, Cloakers, Cephalopods) are very diverse. The abundance and distribution of these demersal species have been linked to environmental factors including the nature of bottom sediments, organic matter content, salinity, temperature and dissolved oxygen [(Koranteng, 1998] among others. Further, it has been documented that in upwelling areas, the total pelagic and demersal fish productivity is linked to environmental processes [Cury& Roy, 2002]. Marine soft-bottom macrobenthic fauna plays a significant/crucial role in organic matter production and other environmental processes. Assessing and quantifying the macrobenthic faunal community spatial structure is therefore a critical step towards understanding the fishery dynamics in the sub-region.

Sherman and Anderson [2002] indicated that an essential component of an ecosystem management regime is the inclusion of a scientifically-based strategy to assess the changing states and health of the ecosystem by monitoring changes in the key biological (e.g., benthic fauna) and environmental parameters. Consequently, the lack of a quantitative and unified integrative data is of a concern given the recent gravitation towards ecosystem approaches to fisheries management that are supposed to integrate the wider ecological dynamics of the ecosystem health. The health of marine ecosystems is often assessed in terms of the taxon composition of faunal communities, or on the distribution of abundance/biomass between the species present [e.g. Bonsdorff and Blomqvist, 1993; Warwick and Clarke, 1991]. Marine macrobenthic fauna are used in pollution and ecosystem health monitoring studies to ascertain pollution effects on the ecosystem [Sherman and Anderson, 2002]. Macrobenthic communities have the capabilities to integrate into their system both short-term and long-term environmental changes, which are observed in the species assemblages due to their limited locomotory abilities.

Despite the immense direct ecological and indirect socio-economic importance of soft-bottom macrobenthic fauna, there is paucity of information in the Guinea Current Large Marine Ecosystem (GCLME) as a consequence of little attention given to their studies. This is partly due to the difficulty in accessing and sampling, laborious laboratory analysis, high cost of analysis and high spatial and temporal variability making statistical analyses complex.

1.6   Previous Studies

Knowledge of marine benthos on the GCLME region is fragmentarily poor in scientific literature with some restrictively limited in scope and coverage. Many of the studies of the marine benthos were either emanated from a fishery survey or baseline studies for environmental impact assessment. As a sequel many of the studies were not devoted mainly for macrobenthic fauna assessment. Notable example being the GCLME macrobenthos which formed part of a fisheries resource surveys. The inherent challenges associated with that include hasty benthic sample collections; inadequate samples for the purpose of unearthing spatial pattern; poor sampling regime as the sampling often follow fish trawl routes making statistical analysis difficult, and most often with deflated objective and focus. Nonetheless, these fisheries surveys have provided valuable macrobenthic samples in many respects, most especially epibenthic megafauna such as crabs, mollusks, lobsters, clams, cephalopods etc. which could not have been captured by the conventional grabs and corers.

Available studies of macrobenthos in the GCLME regions include Edmunds [1978] which gave a taxonomic description of coastal/intertidal mollusks in West Africa; Intes and Lœuff [1984], Kirkegaard [1988] studied marine polychaetes of West Africa with a good taxonomic description; Zabi and Lœuff [1992], Lœuff and Cosel [1998] investigated patterns of benthic faunal biodiversity and concluded that hydro-climatic conditions do not favor the establishment of stenohaline and stenotherm fauna in West Africa; Lœuff and Zabi [2002] discussed/demonstrated the major types of faunal bionomic variations at different spatial and temporal scales in benthic ecosystem of tropical Atlantic coast of Africa; Cosel [2006] gave a detailed taxonomic description of the West Africa bivalve Lucinidae; while Rakel [2007] studied the West Africa brittle stars and found that their distribution and abundance were influenced by salinity and water depth.

However, the limited number and scope of studies of the important Guinea Current ecosystem warrant further investigation and evaluation of the macrobenthic community structure to understand their potential effects on all aspects of the ecosystems (e.g., benthic and pelagic). The paucity of data or information among others is partly due to the difficulty in accessing, sample collection, laborious laboratory taxonomic analysis, high cost of analysis and high spatial and temporal variability making statistical analyses complex.

1.7   State of Knowledge of Marine Benthos

The state of knowledge regarding taxonomic, biological and ecology of marine macrobenthic invertebrates is generally poor in the GCLME. There is a modicum of information on shallow coastal waters though limited in scale and least known in deeper waters. The existing knowledge varies with location, habitat and taxonomic group. There are large gaps in our understanding of even the relatively well-studied macrofaunal groups while many taxa are very poorly known to

virtually completely unstudied. Many more marine invertebrate taxa remain undescribed than have names. Reasons why our marine invertebrate fauna is so poorly known include:

Many studies of marine organisms typically focus on fishes with, at best, only the largest of the invertebrates being considered.

There are very few experts on marine invertebrates in the GCLME region, despite the diversity of the fauna.

Very little funding is available for macrobenthic invertebrate research.

The available knowledge is not readily accessible, the few guidebooks dealing with only a small fraction of the common species and most of the literature is in relatively obscure scientific publications. For most groups there is not even and up to date, authoritative list of species available.

The intertidal and shallow water faunas are best known, while the deep-sea fauna is virtually unknown. Most parts of the GCLME marine environment are poorly sampled or unsampled for invertebrates, especially the deep-sea, offshore and nearshore environments

In general, the faunas in tropical ecosystems are more poorly known than temperate ones. The microscopic fauna in all habitats is very poorly studied, especially the interstitial fauna (meiofauna). There are no checklists for many groups. The majority of data relating to marine invertebrates resides in few museum collections. There is also great variation in the data (and thus our knowledge) available between groups of organisms, regions and habitats.

There is a need to synthesize existing data and collate biological data with physical/oceanographic data. There is a serious lack of resources in the provision of taxonomic studies and services. There seem to be very few specialists in the region and several significant groups have no Specialists. There is a serious lack of information about virtually all marine ecosystems and communities, including their composition, natural variability, biological processes within them etc. There is little or no information on the ecology and basic biology of most marine invertebrates, even for many abundant, ecologically or commercially important taxa.

Possibly the lack of infrastructure is impeding research effort. A major problem (for marine science in general) is the very small number of research vessels available to scientists in the region. The high cost and probably high demand on the very limited facilities available makes it almost impossible for most "basic" offshore and deep-sea research work to be undertaken. There is also little funding available to utilize the existing research vessels.

Methodology

Description of the Region

The macrobenthic faunal samples were collected as part of fisheries resource survey on the continental shelves of the participating countries of the Guinea Current Large Marine Ecosystem (GCLME). The GCLME extends from approximately 12^0N latitude south to about 16^0S latitude, and varies from 20^0 west to about 12^0east longitude. It extends from Bissagos Island (Guinea-Bissau) to Republic of Congo with its boundary extending in a north–south direction from the intense upwelling area of the Guinea Current (GC) south to the northern seasonal limit of the Benguela Current (BC). In an east–west sense, the GCLME includes the drainage basins of the major rivers seaward to the GC front delimiting the GC from open ocean waters (a time- and space-variable boundary).

The GCE shelf forms the narrow protrusion of the Equatorial Atlantic with major geomorphic features of continental shelf including bathymetric undulations of sand ridges, canyons, gullies, dead Holocene coral banks, pockets of hard ground and rocky bottoms [Ukwe, 2006]. Three narrow coastal sedimentary basins, with a few volcanic intrusions and outcrops of hard rock forming the major capes, have developed on the edges of the coastline along the GCE: from north to south, they include the Cote d'Ivoire basin, the Niger basin (Delta) and the coastal basins from Gabon to Angola [Allen and Wells,1962, Quelennec,1984]. The Volta, Niger and Congo basins dominate the coastal geology of the GCE.

The continental shelf of the GCE is quite narrow ranging between 15 and 105km with the widest part being off Guinea. Off Abidjan in Cote d'Ivoire, the shelf is divided into two sections by a ''bottomless pit'' (''le trou sans fond'') that extends almost to the shoreline and thereafter the shelf widens towards the east reaching its widest part of about 90km off Cape Coast in Ghana. The shelf narrows again further eastwards between Tema (Ghana) and Lagos (Nigeria). Off Nigeria, the middle shelf configuration is modified by the Avon, Mahin and Calabar canyons, as well as pockets of dead Holocene coral banks [Awosika and Ibe,1998;Williams,1968]. East of Lagos, the shelf widens to about 85 km off the Niger Delta beyond which it narrows to an average width of 30–40 km. The shelf generally breaks at depths of between 100 and 120m [Awosika and Ibe, 1998].

The GCE and adjacent areas of the eastern tropical Atlantic, bounded to the north by the Canary Current (CC) coastal upwelling region and to the south by the BC coastal upwelling region, are affected by five major basin-wide wind-driven cells of ocean circulation [Longhurst,1962]. These are the North Atlantic Subtropical (NAS), North Equatorial Cyclonic (NEC), Equatorial Anticyclonic (EA), and South Equatorial Cyclonic (SEC) gyres [Henin et al.,1986]. The

circulation cells are formed due to latitudinal variations in the wind stress that is due to the existence of the subtropical anticyclones and Inter-tropical Convergence Zone (ITCZ), which separates the belts of the northeast and southwest trade winds. The major surface currents forming the peripheries of the gyres are the North Equatorial Current (NEC), South Equatorial Current (SEC), North Equatorial Counter Current (NECC), South Equatorial Counter Current (SECC), GC, and Angola Current [Moroshkin et al., 1970; Stramma and Schott, 1999]. Other current systems that may affect near surface circulation in the region are the equator-ward CC feeding the NEC in the north and the BC feeding the SEC in the south [Arnault, 1987]. The NEC, SEC, NECC, and SECC are the westward and eastward cross-basin flows while the CC, GC, AC, and BC form the system of the tropical eastern boundary currents [Richardson and Walsh, 1986].

Generally, the northern subsystem of GCE is thermally unstable and is characterized by intensive seasonal upwelling (around Cote d'Ivoire—Ghana) while the southern subsystem is mostly stable depending on nutrient input originating from land drainage and river flood and oceanic turbulent diffusion, although periodic upwellings have been reported [Bakun, 1978;1998, Ukwe,2003]. The GC is a geostrophically balanced current with isotherms sloping upwards towards the coast and as the current intensifies, the slope becomes steeper bringing the thermocline closer to the surface near the coast (Henin et al.,1986).The coastal upwelling and the boreal summer intensification of the GC are thus related [Philander, 1979].

Field Collection of Macrobenthic Fauna Sample

The soft-bottom macrofauna benthic fauna sampling was carried out along pre-determined fisheries trawl transects of 40 nm intervals from Guinea-Bissau to Liberia in the Gulf of Guinea. The sediment samples were collected using a van Veen grab with a surface area of $0.1m^2$. At each of the stations (Figure 2.1), the grab was deployed from an operated winch onto the seafloor. A benthic grab station was located on each transect between the depth range of 20-40m. However, three additional stations were located on every other third transect within depth ranges of 20-40m, 50-70m and 90–150m to assess bathymetric distribution of the macrobenthic taxa.

Five replicate sediment samples were collected at each of the stations to ascertain the patchiness of the species distribution and to maximize spatial coverage. The sediment samples were washed on a sediment-washing table through 0.5mm mesh size sieve. The remaining sieved sediments were transferred in turns into inner and outer-labeled plastic sample holding containers. The containers were labeled using the station numbers (i.e. country initials using the first two letters), replicate type, date, and the type of preservative used (e.g. GB05C, 08/05/06, 1/3, Formalin). Three (3) out of the five replicate samples were fixed in 10% borax pre-buffered formaldehyde solution for taxonomic analysis later in the laboratory. The other two replicate samples were

preserved in 90% ethanol. The ethanol in these samples were decanted and refilled with fresh ethanol solution after 48 hours to avoid sample deterioration.

The samples were packed into carton boxes with reinforced under parts. The samples were packed by putting three (3) samples from each station including the two ethanol samples into one box. These samples were to be delivered to the University of Bergen Museum. The other two samples from each station were also packed into separate boxes and sent to the Marine Productivity and Biodiversity Center located the Department of Oceanography & Fisheries, University of Ghana.

2.2.1   Field Quality Assurance

Basic quality control measures were followed on the macrobenthic fauna sampling. These measures were based on far-famed Standard Operation Procedures (SOPs) in benthic sampling to ensure quality of the information gathered. Among others, the following field quality control procedures and measures were observed to the letter.

All collected sediment samples were ensured that they meet sample acceptance criteria. These include:

Incomplete closure of grab

Inadequate sediment samples

Lack of surficial water

Only experience personnel were in charge of sediment sampling, sieving and preservation.

Sediment was sieved with gentle flowing water hose to avoid squashing of organisms, although filtered seawater could not be used in the sieving.

All sieves were backwashed into storage containers after sieving.

Chemicals solutions for fixation and preservation were carefully and properly prepared.

Injurious and harmful chemicals were adequately labelled.

All used chemicals were disposed of properly.

2.3   Laboratory Processing of Samples

2.3.1   Sample Processing:

The processing and analyses of samples performed in the laboratory included sorting of organisms, benthic fauna identification and preservation, and sediment physical and chemical determination.

The content of the fixed sediment samples were emptied into sieve of mesh size less than 0.5mm and thoroughly washed with fresh water to get rid of all silt/clay particles as well as the formaldehyde solution used in the fixation. The samples were then put into a tray with a white background and sorting. The sorted organisms were preserved in vials with 70% ethanol premixed with glycerol.

2.3.2   Taxonomic Resolution

The preserved organisms were put into petri dishes and identified to the lowest taxonomic units as possible using Leica 2000 dissecting and compound microscopes. Enumerated of individual species was carried out after the identification.

2.3.3   Laboratory Quality Assurance

The quality assurance measures did not end in the field but were carried to the laboratory to ensure that the quality and the integrity of the data from the laboratory and the ensuing results were not compromised. As a sequel, the following procedures were pedantically pursued in the laboratory.

Each sorted sample was crosschecked by two other experts to ensure that all organisms have been picked.

Species identification was verified independently by partner taxonomists/experts.

Unidentified species were assigned the genus name followed by 'sp.' (if only one species, e.g. *Glycera* sp.) or 'spp.' (i.e. more than one species, e.g. *Eunice* spp.) and put separately into vials for later identification.

Organisms preserved in vials were annotated with information on non-wettable sheets.

Adequate ventilation was provided in the laboratory to ensure fresh air at all time.

Data entering into computers were verified by another person
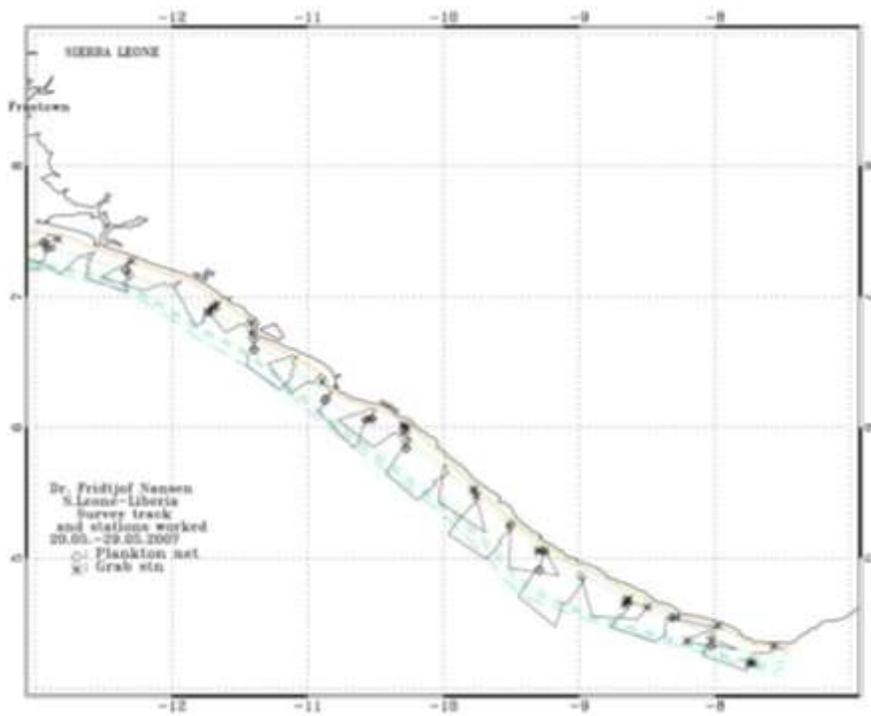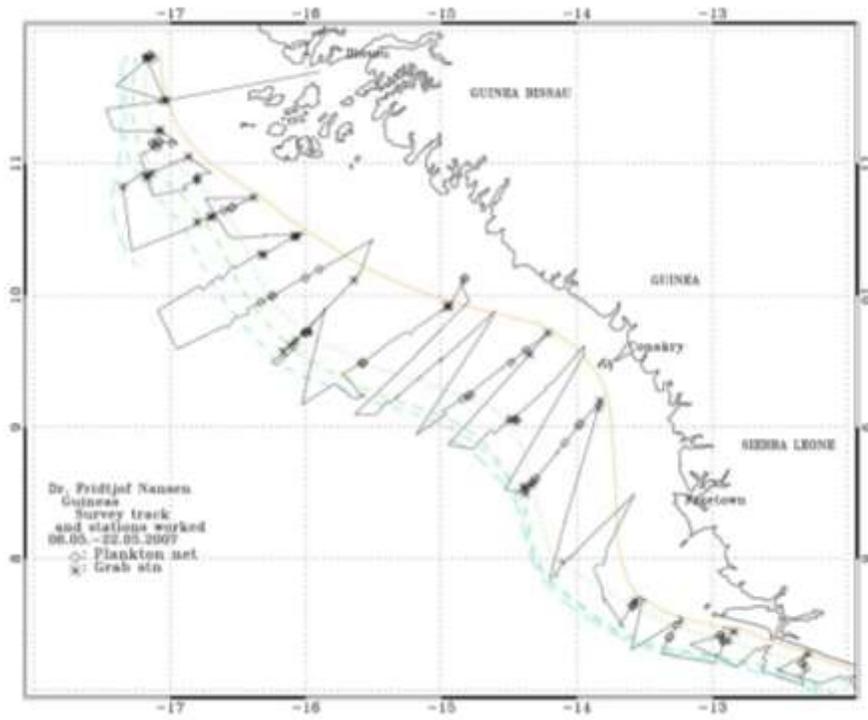
Figure 2.1 Course tracks with plankton and grab sample stations for the survey area. Depth contours are indicated.
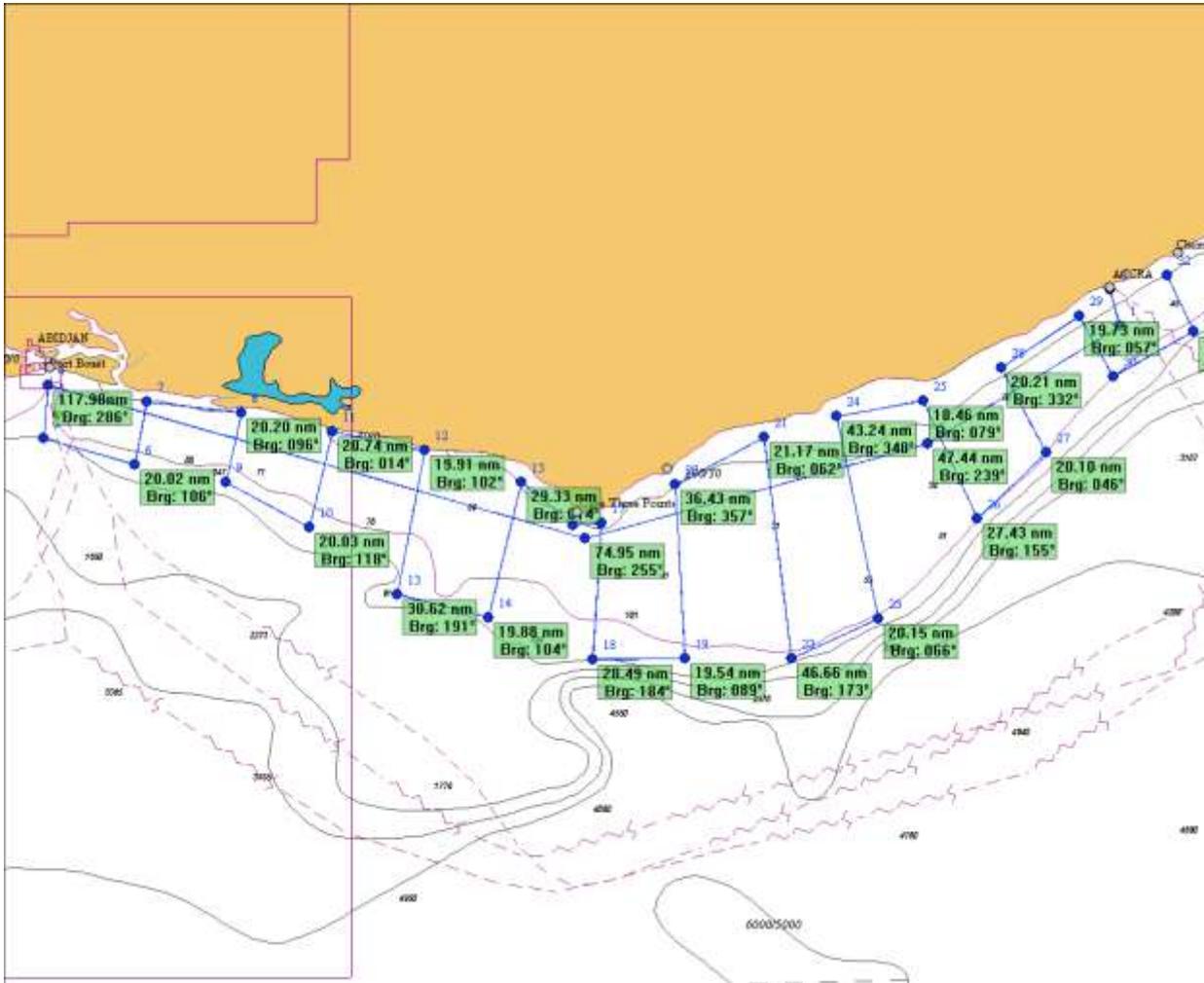
Figure 2.1 Course tracks with plankton and grab sample stations for the survey area.
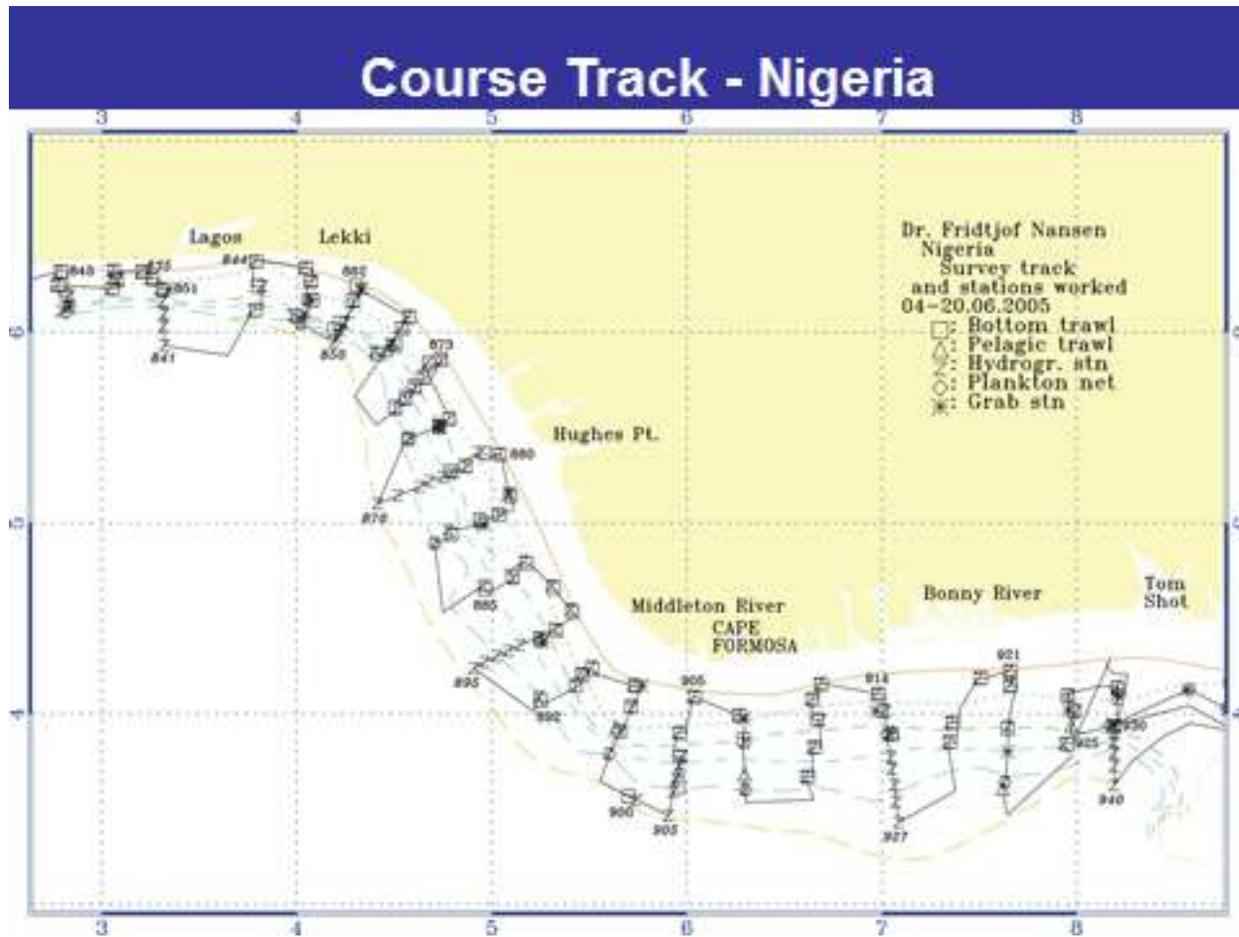
Figure 2.1 Course tracks with plankton and grab sample stations for the survey area.
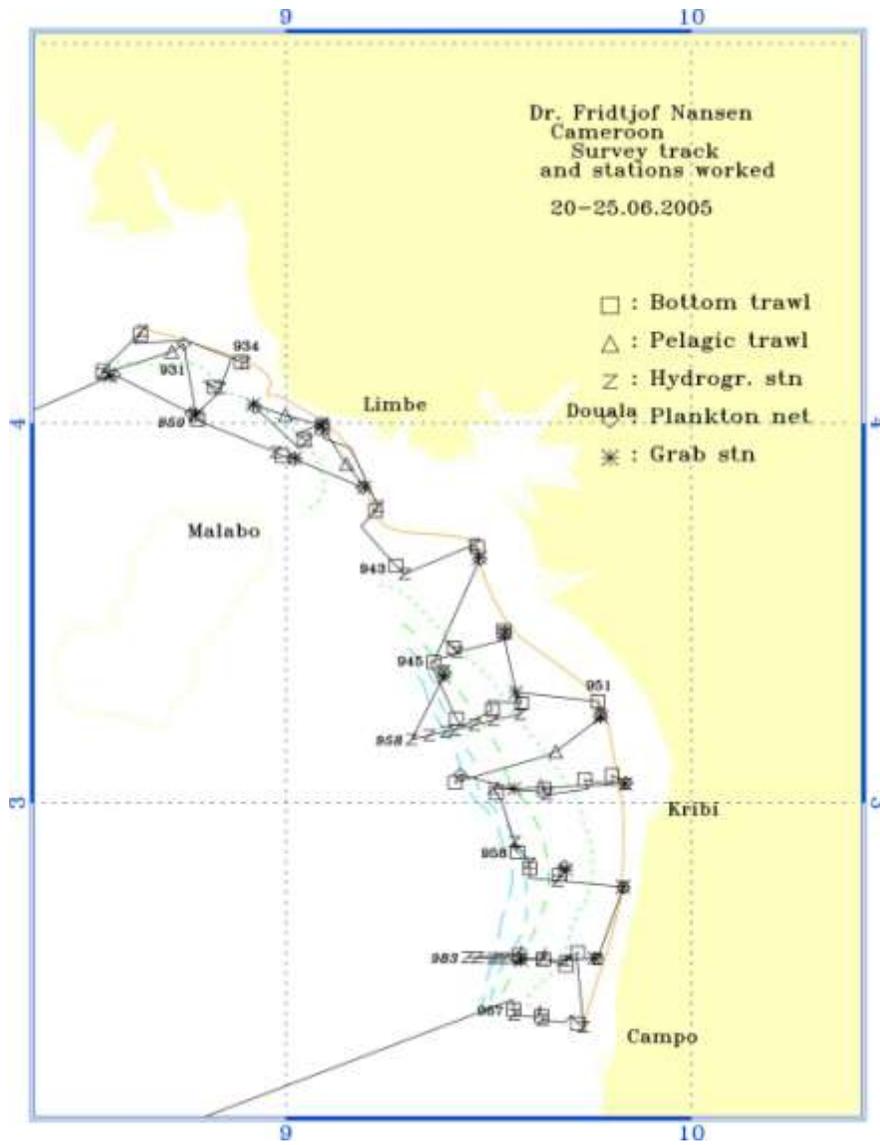
Figure 2.1 Course tracks with plankton and grab sample stations for the survey area.
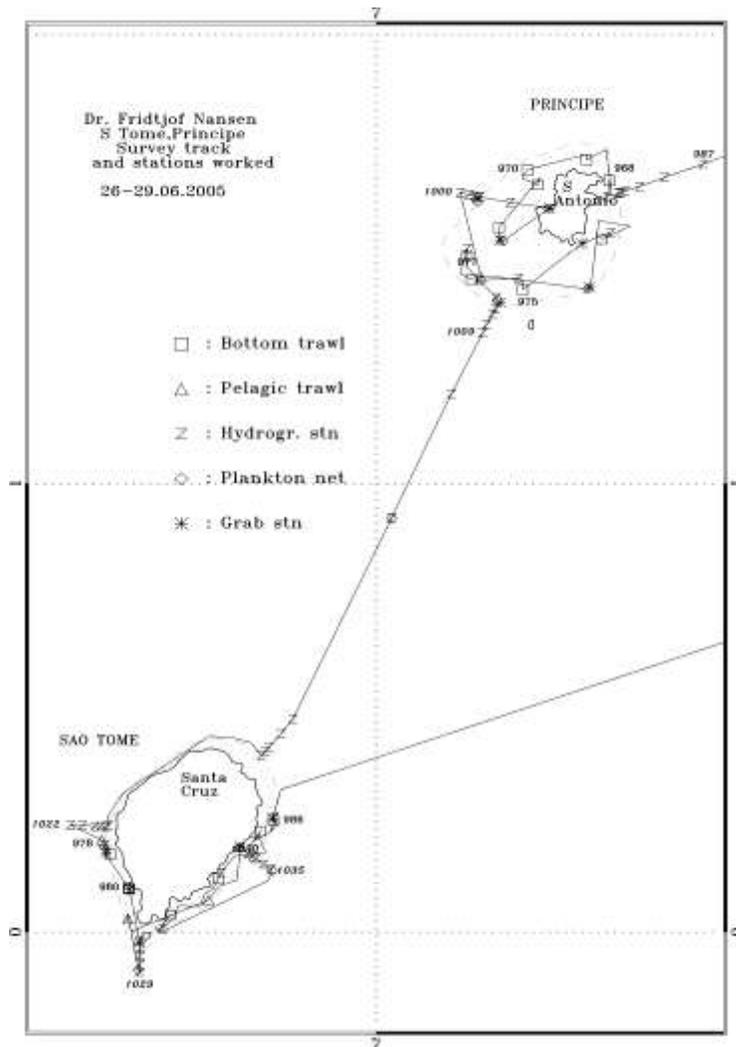
Figure 2.1 Course tracks with plankton and grab sample stations for the survey area.

2.4   Data Treatment and Analysis

The data set was analyzed using both univariate and multivariate statistics. Frequency of occurrence was calculated for all species using the F index [Guille,1970]: $F = p_a/P \times 100$, where: $\mathbf{p_a}$ is the number of sites where the species occurred and $\mathbf{P}$ is the total number of sites. Using this formula, the species are classified as: constant ($F > 50\%$), common ($10 \leq F \leq 49\%$) and rare ($F < 10\%$) species. Only species that $F > 20\%$ were used for the ecological statistical analyses. Differences in community structure within and between sites were quantified using suites of multivariate techniques. Similarity between sites based on dominance distance of cluster analysis using the Bray-Curtis similarity index after fourth-root transformation [Clarke and Green, 1988], and a group-average dendrogram produced [Clark, 1993]. At the same time, a similarity profile test [SIMPROF; Clarke and Gorley, 2006] was performed to test the null hypothesis that a specific subset of samples did not differ from each other in the multivariate structure.

Results

3.1   Community Composition & Abundance

The result of the study yielded a total of 2809 individuals made up of 320 different species belonging to five major taxonomic groups. Of the total abundance, polychaetes contributed 57.7%, crustaceans accounted for 25.1%; 13.0% was contributed by species placed in "others" category, while mollusks and echinoderms accounted for 2.3% and 1.9% respectively (Table 3.1).

In terms of number of species, polychaetes comprised 206 (64.4%) species, crustaceans consisted 52 (16.3%) species, 31 (9.7%) species belong to Mollusca taxa, whereas echinoderms and "others" category constituted 7 (2.2%) and 24 (7.5%) species respectively. Ostensibly, polychaetes taxa contributed substantially and ranked highest among the major macrobenthic taxa in the shelves on the GCLME. Further, crustaceans ranked second based on both species richness and numerical abundance. These observation and fauna composition were not only consistent with previous studies both on the GCLME and elsewhere, but constitute important food resources for many of commercially economic demersal fish species.

Table 3.1 Abundance and richness of major macrobenthic faunal groups.

Taxa	No. of Species	Abundance (No. of indiv.)	Percent Abundance
Polychaeta	206	1620	57.7
Crustacea	52	706	25.1
Mollusca	31	65	2.3
Echinodermata	7	52	1.9
Others	24	366	13.0
Total	320	2809	100

The distribution pattern of these macrobenthic fauna may therefore determine the abundance of demersal fish stocks on the continental shelves of the Guinea Current Ecosystem (GCE). The spatial pattern of all the major macrobenthic faunal taxa is shown in Figures 3.1-3.12

The distribution pattern generally depicts two abundance peaks especially for polychaetes, crustaceans and mollusks (i.e., low & high peaks). The lowest abundance peak spans from Guinea-Bissau to Sierra Leone while the highest abundance peak is between Ghana and Benin. Liberia, Cameroon and Gabon recorded the lowest numerical abundance (Fig. 3.1). The composite data indicated significant variations between Togo-Benin (TG-BN) and the rest of the countries except Guinea-Bissau (GB), Guinea-Conakry (GC) and Ghana (GH).
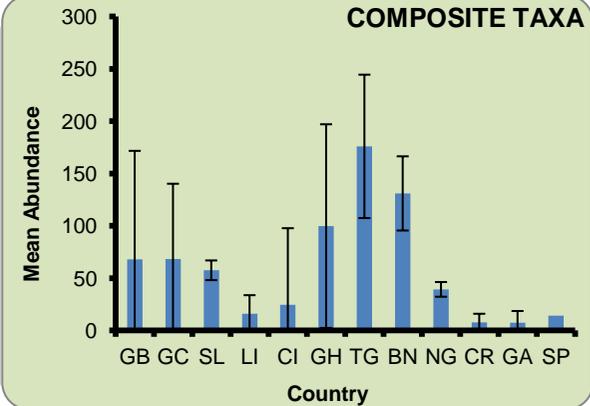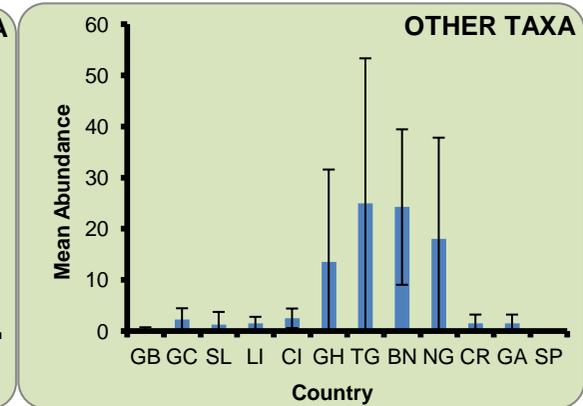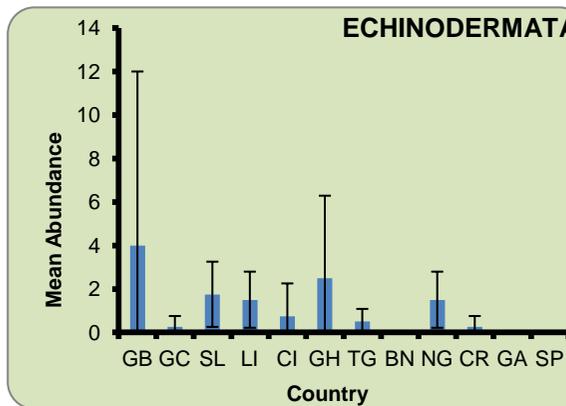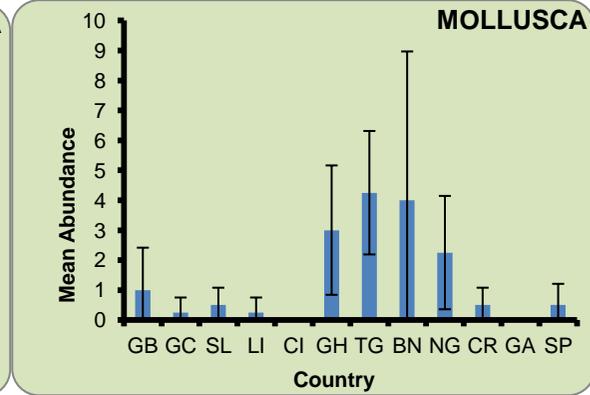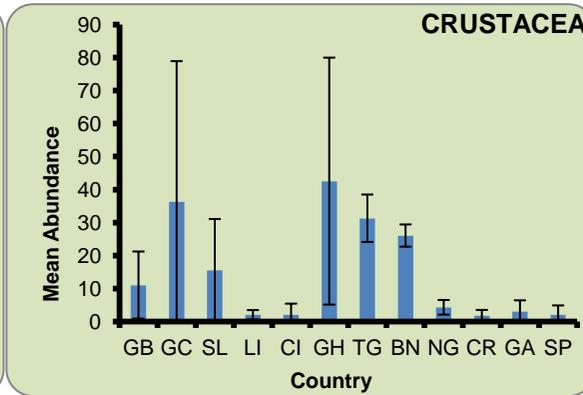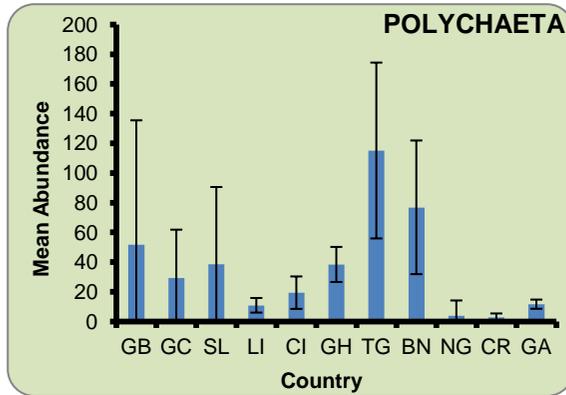
Figure 3.1 Spatial distribution of major macrobenthic fauna abundance on the continental shelves of the GCLME. Vertical barsindicate 95% confidence interval of abundance.
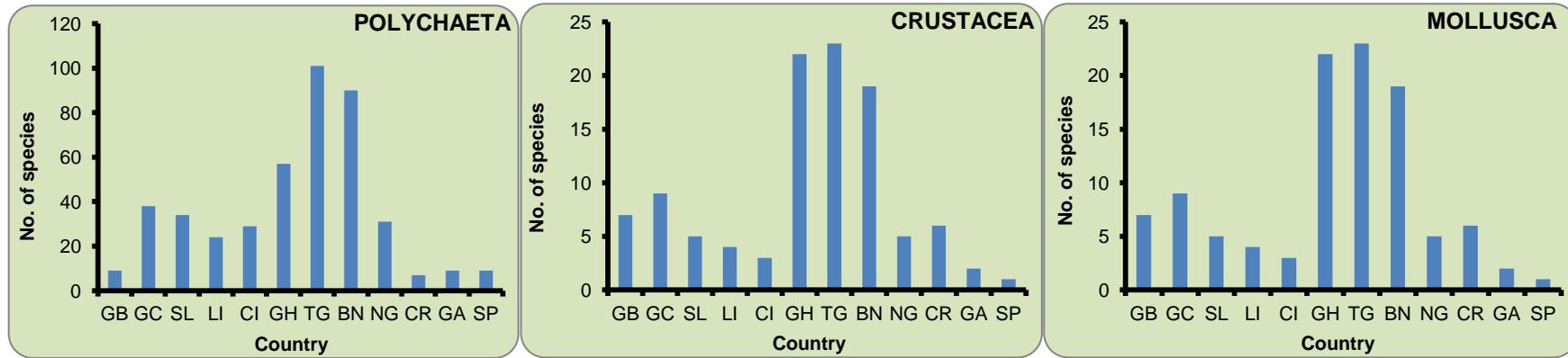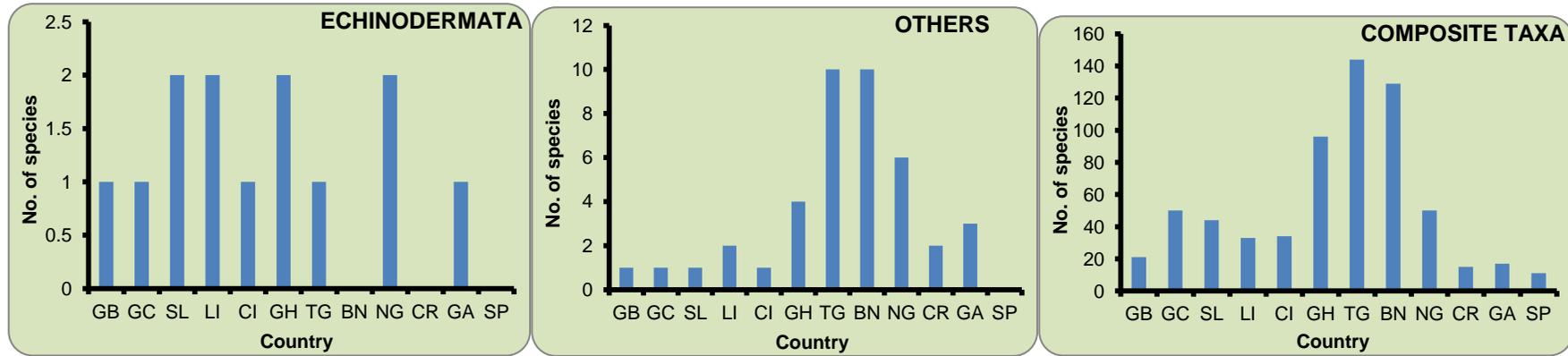
Figure 3.2 Spatial distribution of number of species across countries.

3.2   **Macrobenthic Faunistic Density**

The total densities for the respective countries are presented in Table 3.3. The overall total density for the study area was 7093 individuals per square meter (mean density=591 individuals per square meter). The number of individual polychaetes, crustaceans and mollusks in the countries follow the pattern revealed by the abundance data with two peaks/maxima (Low & high) and two troughs. The lowest peak existed between Guinea-Bissau and Sierra Leone, and the highest peak between Ghana and Benin. The troughs occurred in Liberia-Cote d'Ivoire, and Cameroon-Gabon-Sao Tome & Principe.

The highest densities were sequentially observed with polychaetes, crustaceans, other taxa, mollusks and echinoderms which are consistent with the observation for the abundance data.

Table 3.3 Densities of major macrobenthic faunal groups in the continental shelves of GCLME countries

TAXA	GUIINEA BISSAU (GB)	GUINEA CONAKRY (GC)	SIERRA LEONE (SL)	LIBERIA (LI)	COTE D'IVORE (CI)	GHANA (GH)	TOGO (TG)	BENIN (BN)	NIGERIA (NG)	CAMEROON (CR)	GARBON (GA)	SAO TOME & PRINCIPE (SP)
POLYCHAETA	517.5	292.5	385	107.5	192.5	382.5	1150.0	767.5	132.5	37.5	27.5	115.0
CRUSTACEA	110.0	362.5	155.0	20.0	20.0	425.0	312.5	260.0	42.5	17.5	30.0	20.0
MOLLUSCA	10.0	2.5.0	5.0	2.5	0.0	30.0	42.5	40.0	22.5	5.0	0.0	5.0
ECHINODERMATA	40.0	2.5	17.5	15.0	7.5	25.0	5.0	0.0	15.0	2.5	0.0	0.0

OTHERS	2.5	22.5	12.5	15.0	25.0	135.0	250.0	242.5	180.0	15.0	15.0	0.0
TOTAL	**680.0**	**682.5**	**575.0**	**160.0**	**245.0**	**997.5**	**1760.0**	**1310.0**	**392.5**	**77.5**	**72.5**	**140.0**

3.3   Community Structural Analysis

An agglomerative dendrogram of the pooled station (countries) species abundance revealed three significant groups distinguished at a Bray–Curtis similarity level of 25% (Fig. 3.3). Three of the countries showed no significant structure with the other countries. One-country group comprised countries located at the west part of the GCLME from Cote d'Ivoire to Guinea-Bissau. Interestingly, the high similarity of the macrobenthic faunal abundance and composition was found between Togo and Benin, followed by Sierra Leone and Guinea Conakry, and then together with Guinea-Bissau. Liberia and Cote d'Ivoire followed before Principe/Sao Tome. The pattern shows high degree of geographical restriction in the macrobenthic fauna distribution possibly due to water masses outside the tolerable range of the organisms.

Grassle and Grassle (1976) indicated that the adaptation of certain species to unpredictable environments can be related in part to their life history characteristics. Newell (1970) pointed out that where the tolerance limits for a particular environmental variable have been determined for an

organism, the organism's realized distribution is much more restricted than its potential distribution. It is reasonable, therefore, to presume that the spatial differences in abiotic variables probably ensured that only tolerant species are selected and hence their distribution.

Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
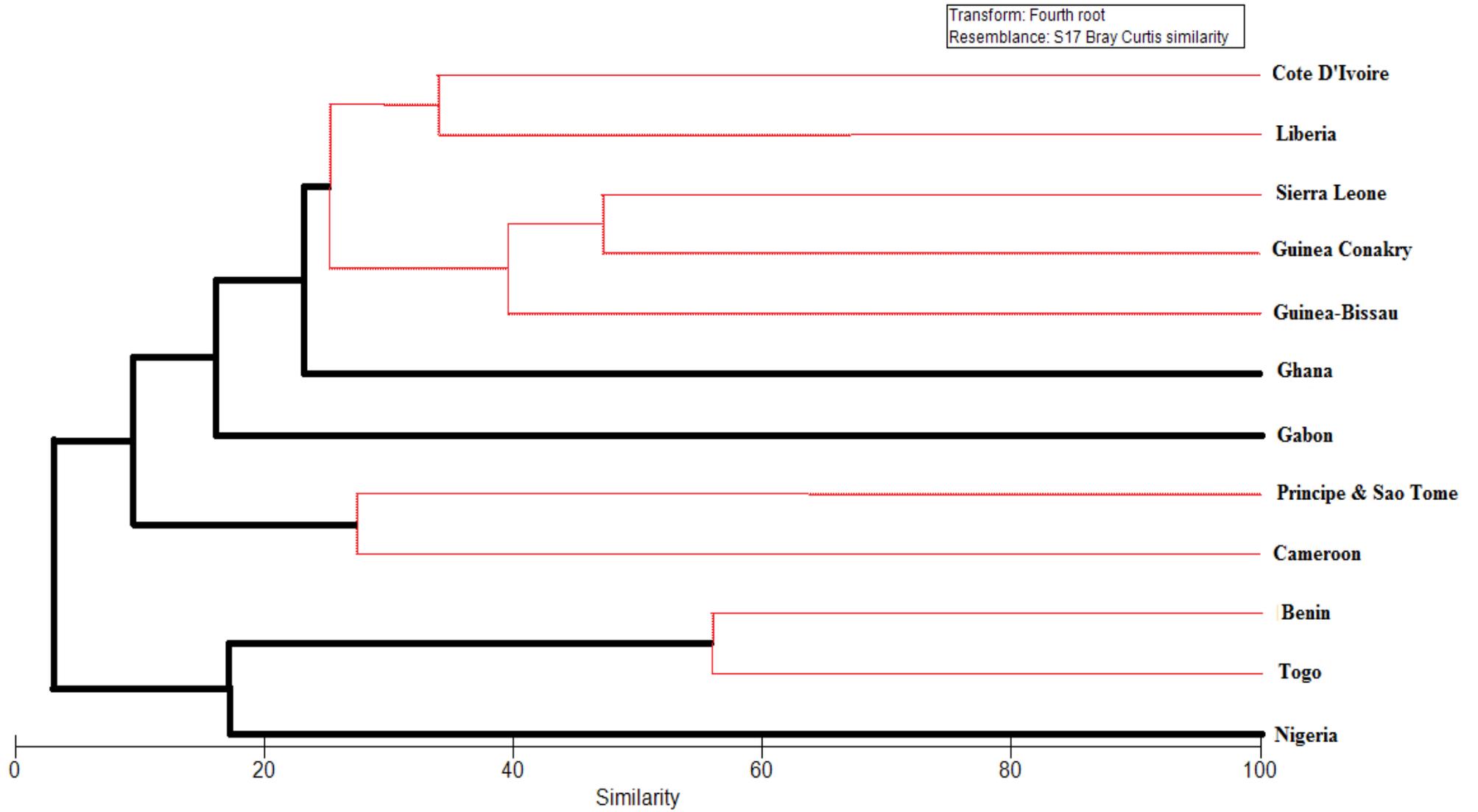
Figure 3.3 Complete-linkage of agglomerative dendrogram of Bray–Curtis similarity of macrobenthic faunal abundance data for GCLME countries. Thin red lines indicate significant evidence of structure (SIMPROF test, *p*<0.05) and thick black lines indicate no evidence of structure. Three outliers were discerned and did not show relations with the other countries.

3.4　　　　　**Dominant Macrobenthic Taxa**

The result of the frequency of occurrence of the macrobenthic fauna revealed that of the 320 species found across the 46 sampling locations, 15 species occurred in greater than 20% of the samplings stations. These species may be regarded as cosmopolitan with greater geographical coverage. They therefore will constitute an important species to monitor the health of the Guinea Current Ecosystem.

The species were dominantly polychaetes but the highest frequency of occurrence (56.5%) was recorded for *Ampelisca* spp. (crustacean). Nonetheless, the polychaete with the highest frequency of occurrence was *Eunice vitata* (Table 3.4).

Table 3.4　　　Frequency of Occurrence for macrobenthic fauna. For brevity on taxa contributing >20% were selected (N=46). P= Polychaete, C=Crustacean, O= Other taxa

Taxa	Frequency of Occurrence (%)
Ampelisca spp. (C)	56.5
Eunice vitata(P)	41.3
Glycera sp. (P)	39.1
Sipunculid spp. (O)	37.0
Lumbrinereis aberrans (P)	30.4
Tanaid spp. (C)	28.3
Armandia intermedia (P)	26.1
Scoloplo smadagascariensis (P)	26.1
Mysid (C)	26.1
Aricidea fauveli (P)	23.9
Lumbrinereis latrelli (P)	23.9
Prionospio pinnata (P)	23.9
Lumbrinereis coccinea (P)	21.7

Nepthys lyrochaeta (P)	21.7
Prionospio sexoculata (P)	21.7
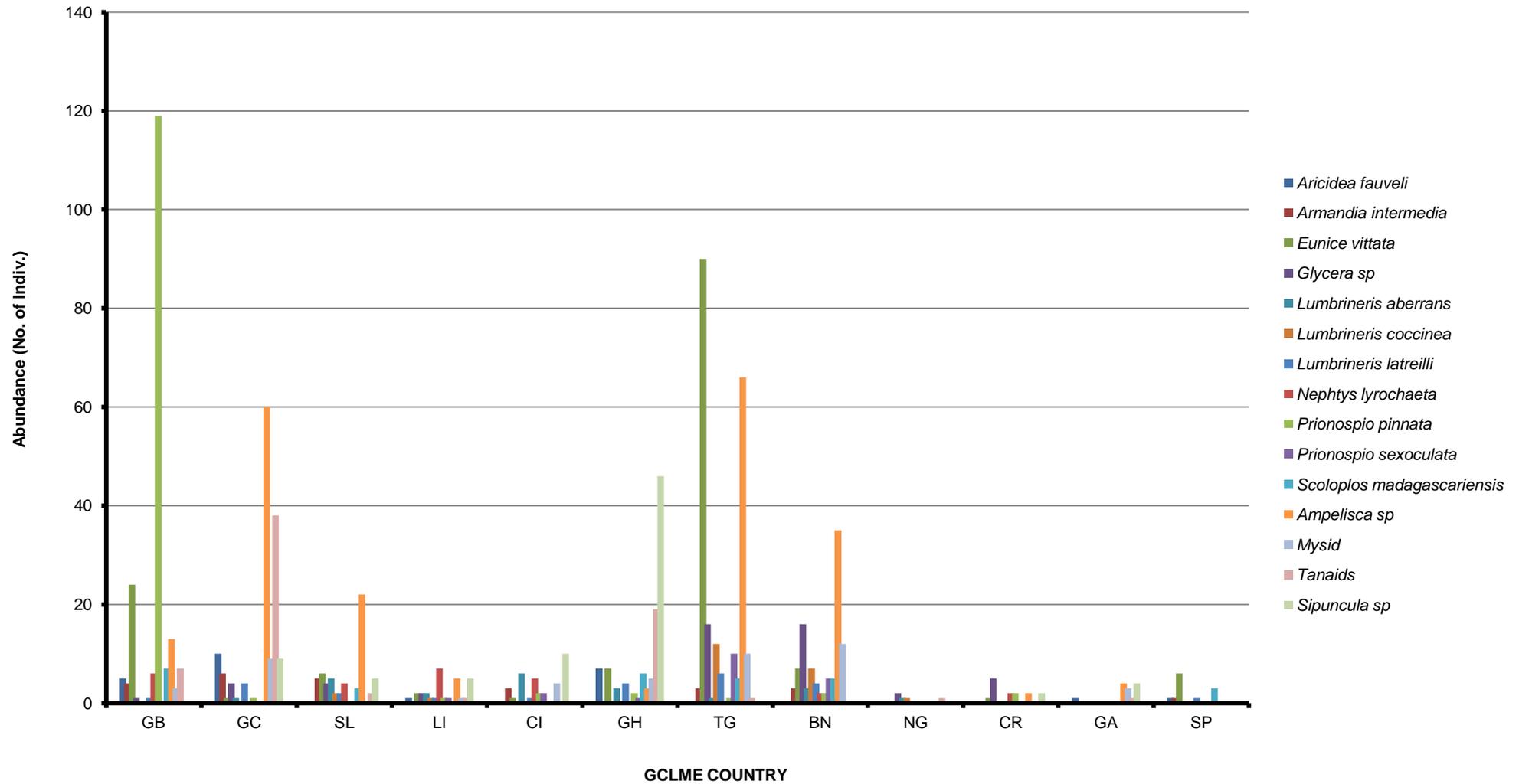
Figure 3.4 Abundant distribution of 15 most occurred macrobenthic fauna across the GCLME countries.

The abundant distribution of these dominant species across the GCLME countries is shown in Figure 3.4. A striking feature of the result was the high numbers of the *Prionospio pinnata* (Spionidae). *Eunice vitata* was also highest at Togo followed by Guinea-Bissau and the Sao Tome & Principe.

Different species were dominant for each country but the crustacean, *Ampelisca* spp. were visibly dominant in 4 countries namely Guinea Conakry, Sierra Leone, Benin and Garbon with substantial abundances in other countries. *Sipunculid* spp. dominated the macrobenthic fauna in the Ghanaian continental shelf but was absent in Guinea-Bissau, Togo, Benin, Nigeria, Sao Tome & Principe.

3.5   Macrobenthic Faunal Biomass & Productivity

The macrobenthic fauna productivity is an important component of energy flow and organic matter cycling in aquatic ecosystems. With respect to the exploitation of demersal fish and shellfish stocks, benthic secondary production is also of economic importance. A promising method of assessing productivity was proposed by Humphreys [1980] who used biomass and maximum individual weight to predict assimilation and production. Biomass has often been used as a surrogate for productivity of primary producers, which is the most commonly, cited ecosystem property in ecological studies (e.g. Loreau, 2000). Therefore a useful indicator in benthic productivity assessment could estimate the biomass turnover between two sets of species.

The macrobenthic faunal biomass data was used as surrogate for benthic productivity shows a general high productivity for Sierra Leone, Guinea-Bissau and Ghana in that sequence. The highest productivity was generally occurred with polychates except Ghana where crustacean ranked highest and Principe & Sao Tome where productivity is associated with echinoderms.
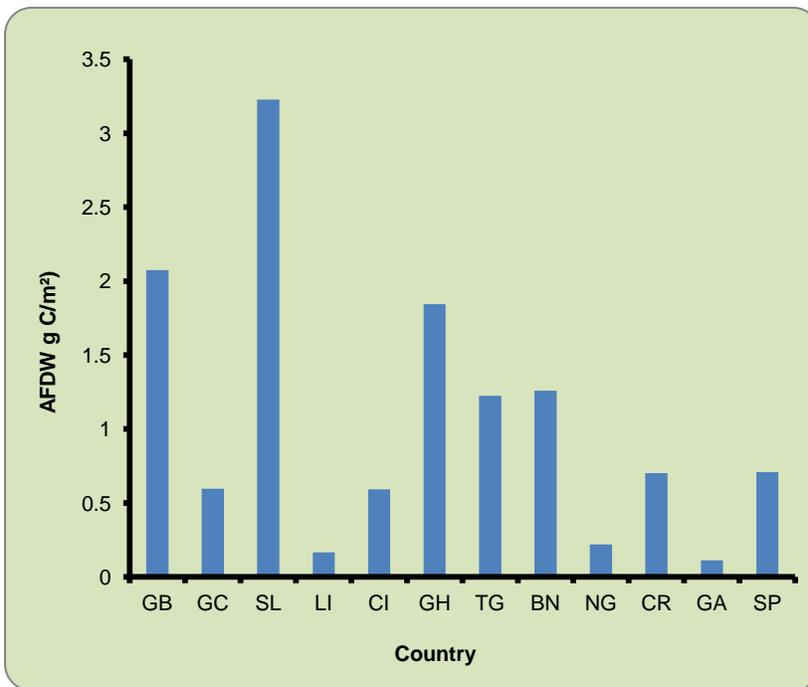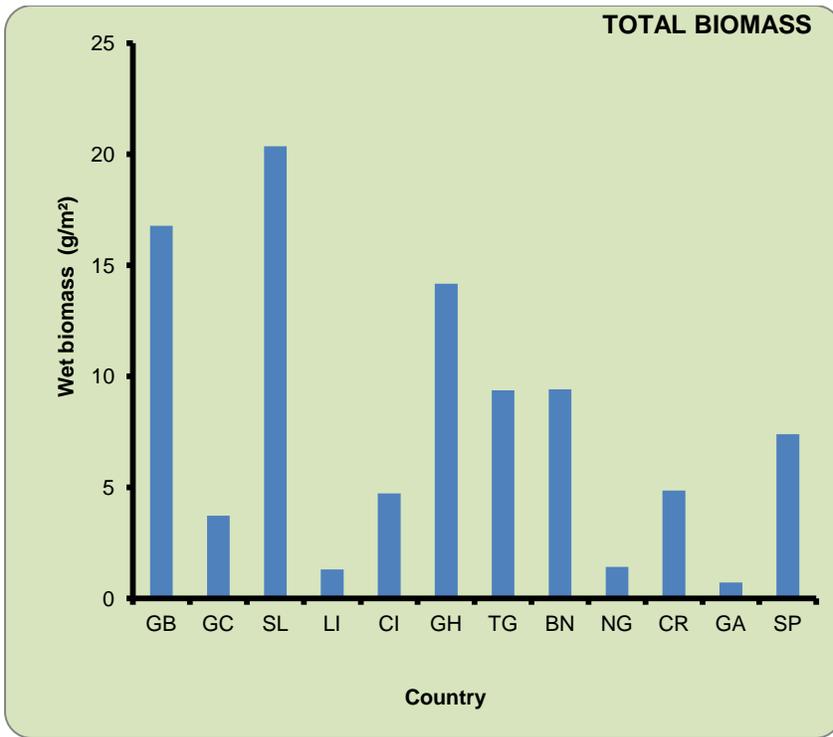
Figure 3.5 Biomass and Ash-Free Dry Weight (AFDW)

3.6   Collection of Voucher Specimens for the Biodiversity Museum

The collection, curation and nomenclature of marine benthic biodiversity samples to furnish the productivity center are ongoing and advanced. Substantial samples have been collected from offshore surveys. These samples are being named and shelved. It is also the intention to provide a database/metadata of these museum samples so that detailed information of each sample such as date collected, geographical location, collector, identifier etc. will be computerized. The following plates depict some of the collection and curation of the marine macrobenthic samples.

A survey on benthic information would be collected as a spreadsheet file and subsequently organized in the form of a common database with meta-data (i.e. data referring to the existence availability of different types of data without containing the actual values).

Museum of marine productivity and biodiversity center at the University of Ghana, Legon

Sample of marine invertebrates of the biodiversity museum.

Voucher specimen of the biodiversity museum

3.7   **Macrobenthic Fauna Assemblage of Nigerian's Shelf**

A total of 590 individuals belonging to 126 species were found from the preliminary 13 stations. Of the 590 individuals, polychaetes comprised 25.6%, molluscs constituted 22.9%, crustaceans and echinoderms constituted 10.8% and 1.7% respectively. Other taxa recorded included cnidarians, hirudinea, coelenterates, pteropods, foraminiferans and juvenile fishes which together constituted 39%.

However, out of the 126 species recorded, polychaetes accounted for 78 species (61.9%), molluscs constituted 16 species (12.7%), 19 species (15.1%) were crustaceans. Echinoderms and species placed in category of "others" comprised 2 species (1.6%) and 11 species (8.7%) respectively. Figure 1 depicts the proportions of such major taxa.
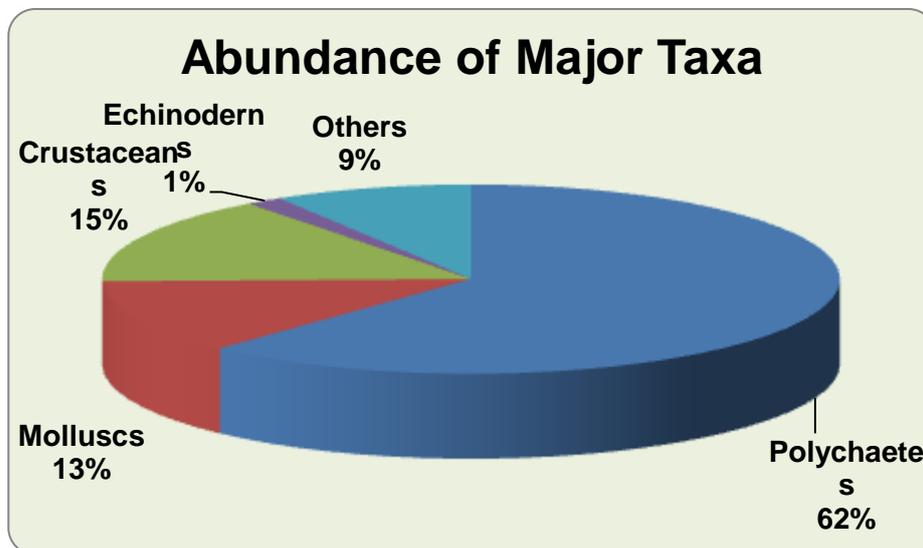
Figure 1. Percentage distribution of major macrobenthic taxa
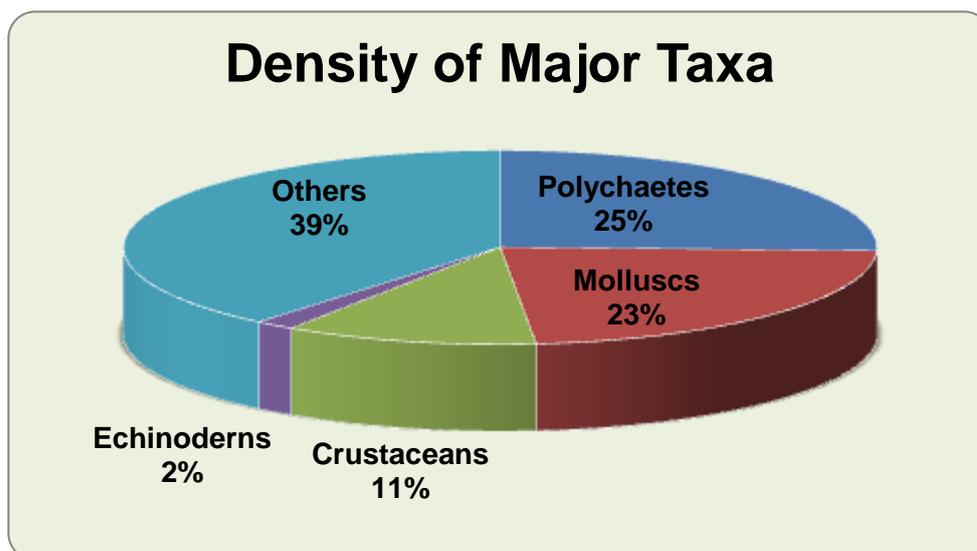
Figure Density distribution of Major Macrobenthic Taxonomic Group

The spatial distribution of the major macrobenthic taxa are shown in figure 2. The various taxa showed troughs and peaks across the stations. Essentially, species placed in "other" category recorded appreciable numbers at Stations N4, N6 and N13. The dominant species in this category was *Cavolina* sp. There were substantial numbers of molluscs recorded at Stations N13, N3 and N5. The spatial variations of crustaceans and echinoderms did not show any discernible pattern except that stations N11, N9 and N10 hierarchically ranked higher in abundance. The distribution of polychaetes mimics the distribution pattern exhibited by crustacean. However, the former showed higher abundance than the latter.
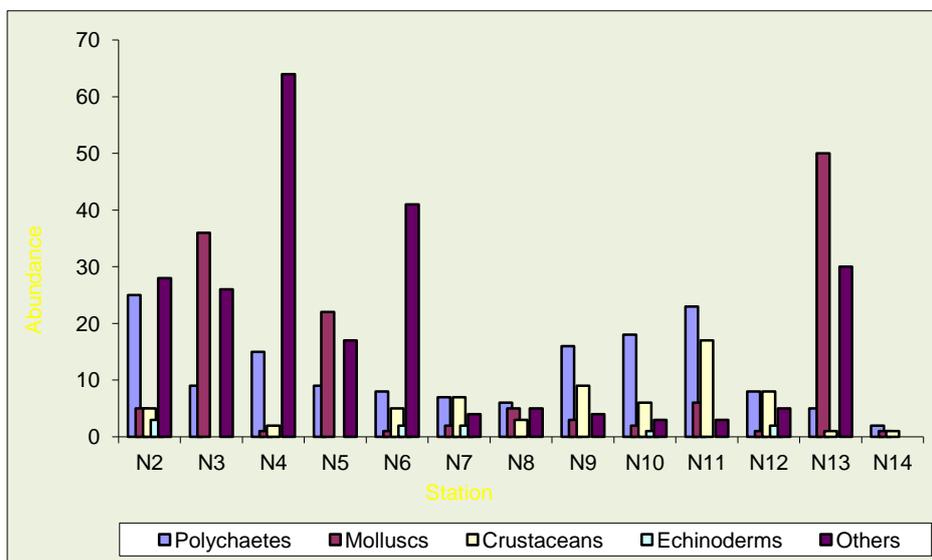
Figure Spatial distribution of major macrobenthic taxa off Nigeria continental shelf.

Species richness (d') and species diversity (H') calculated showed some spatial pattern. Highest values of H' and d' were obtained at Stations N2 and N11, whereas the lowest values were obtained in Stations N14 and N4 respectively (Figure 3).
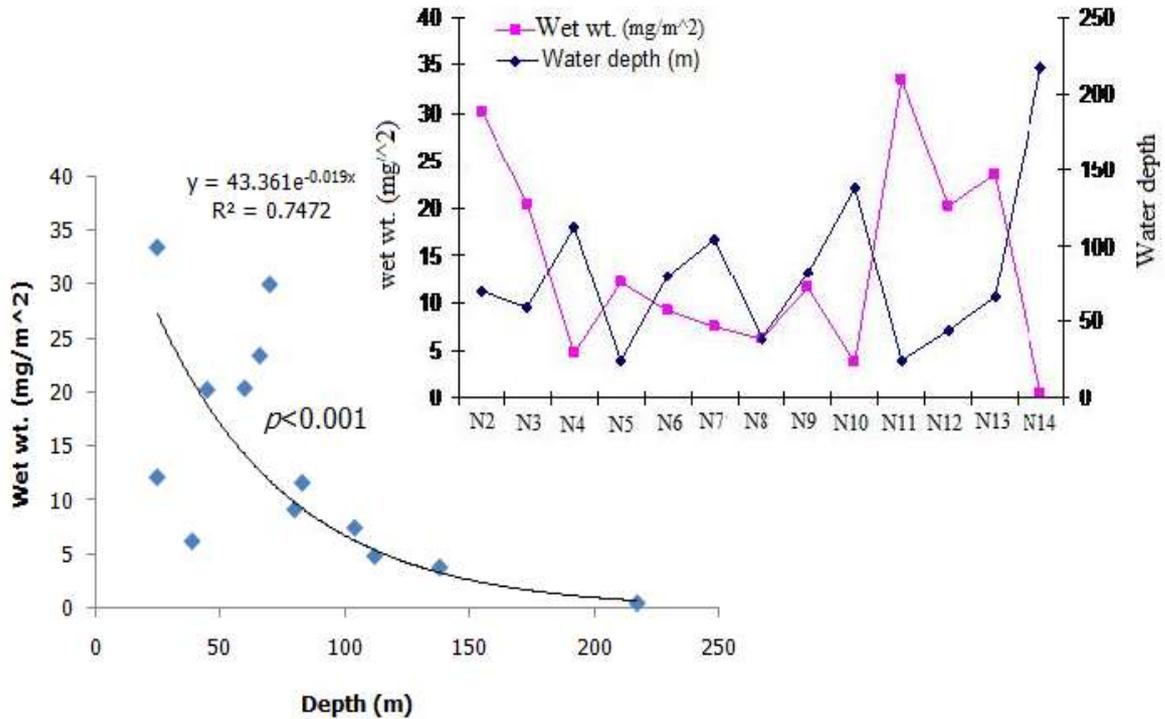
Macrobenthic fauna wet weight as a function of water depth (*p*<0.001)

Discussion & Conclusion

The results suggest that polychaetes are a dominant and major component of the soft-bottom benthic fauna. Low macrobenthic faunal abundance spanned from Guinea-Bissau to Sierra Leone while the highest macrobenthic faunal abundance peak was observed between Ghana and Benin. Liberia, Cameroon and Gabon recorded the lowest numerical abundance. This has profound ecological implications in terms of food for demersal fishes and also mineralization of nutrients for photosynthesis. There were three distict spatial groupings which are ecologically meaningful and an indicative of large scale patterns. The community patterns of the macrobenthos in the GCLME were patchy with few species like *Eunice vittata*, *Ampelisca* spp and *Glycera* sp showing widespread distribution. The observed pattern could be attributed to the crucial roles played by a suite of environmental variables.

From the management viewpoint an understanding of the structure and compositon of the GCLME's benthic communities will provide information about policy development.

The results further indicate patches of disturbances across the stations based on the species recorded. It important to note that stations N2 and N11 were quite stable as evident by the species recorded which indicated a stable climax community.

It is believed that suites of physicochemical parameters played crucial role in the observed distribution trends. It is also envisaged that a visible pattern will emerge if all the samples are analyzed.

Conclusions and Recommendations

4.1   **Conclusions**

The results suggest that polychaetes are a dominant and major component of the soft-bottom benthic fauna. Low macrobenthic faunal abundance spanned from Guinea-Bissau to Sierra Leone while the highest macrobenthic faunal abundance peak was observed between Ghana and Benin. Liberia, Cameroon and Gabon recorded the lowest numerical abundance. This has profound ecological implications in terms of food for demersal fishes and also mineralization of nutrients for photosynthesis. There were three distict spatial groupings which are ecologically meaningful and an indicative of large scale patterns. The community patterns of the macrobenthos in the GCLME were patchy with few species like *Eunice vittata*, *Ampelisca* spp and *Glycera* sp showing widespread distribution. The observed pattern could be attributed to the crucial roles played by a suite of environmental variables.

The macrobenthic faunal productivity of the region indicated highest for Sierra Leone, Guinea-Bissau and Ghana. Polychaetes ranked highest in productivity across all the shelves except for Ghana and Principe & Sao Tome where crustaceans and echinoderms dominated respectively.

From the management viewpoint, an understanding of the structure and composition of the GCLME's benthic communities will provide information about policy development.

4.2   **Recommendations**

Basic research is necessary for the gathering of adequate information for the formulation of informed management strategies.

Interpretation of the data needs to be done based on long-term data set as such recommend detail analyses of all the collected survey samples (i.e., 2005-2007). Further, identifying areas of high diversity and endemism is possible by accessing all the data set from the surveys (2005-2007).

Further work required (for data level and indicator level): The indicator will be updated annually, both in terms of the rapid assessment and the quantitative data.

Impacts of bottom trawling on epibenthic fauna and benthic environment should be integrated into fisheries resources surveys and management programme.

Assessment of the effects of anthropogenic changes in ecosystems (e.g., increased nutrients, effects of global warming etc.) should be considered.

Long-term monitoring and knowledge of the natural fluctuations in the environment are critical for understanding the dynamics of the systems and interpreting possible anthropogenic changes.

Future surveys should consider assessing the relationships between macrobenthic fauna (diversity and productivity) and fish abundance and diversity.

Increased basic research on the basic biology (feeding, breeding, habitat preferences, behaviour etc.) of marine invertebrates, especially the ecologically important groups.

Future surveys should ensure that physical and chemicals analyses of sediment and water are carried out for a better appreciation of the macrobenthic spatio-temporal dynamics.

The robustness of using surrogates (such as physical features – e.g., sediment, or other biota as the basis for predicting benthic invertebrate communities and productivity should be tested.

Future analysis should aim at a composite report with synergy between macrobenthic fauna, fisheries, plankton and water quality.

Curatorship of museum collection should be boosted with provision of glass jars, preservative chemicals and PC for database.

There is a need for increased basic taxonomic research on marine invertebrates, especially in those currently poorly known groups.

Training manuals on the macrobenthos should be developed for the GCLME to help whip up interest in the benthos

References

Arnault, S. (1987). Tropical Atlantic geostrophic currents and ships drifts. Journal of Physical Oceanography, 18, 1050-1060.

Awosika, L.F. and A.C. Ibe, (1998). Geomorphic features of the Gulf of Guinea shelf and littoral drift dynamics. In: A.C. Ibe, L.F. Awosika and K. Aka, Editors, *Nearshore dynamics and sedimentology of the Gulf of Guinea*, IOC/UNIDO, CEDA Press, Cotonou, pp. 21–27.

Bakun, A. (1978). Guinea current upwelling. Nature, 27, 147-150.

Bonsdorf, E. and Blomqvist, E. M. (1993). Biotic coupling on shallow water soft-bottom-examples from the northern Baltic Sea.*Journal of Oceanography and Marine Biology*, 31, 153-176.

Clarke, K. R., and Warwick, R. M. (1994). Changes in Marine Communities. An approach to statistical analysis and interpretation. Natural Environment Research Council, U.K. 144pp.

Clarke, K.R. (1993). Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology*, *18*, 117-143.

Clarke, K.R. andGorley, R.N. (2006). PRIMER v6: User manual/tutorial. Primer-E, *Plymouth*, UK.

Clarke, K.R. and Green, R.H. (1988). Statistical design and analysis for 'biological effects' study.*Marine Ecology Progress Series*, *46*, 213-226.

Cosel, R. V. (2006). Taxonomy of tropical West Africa bivalves. VI. Remarks on Lucinidae (Mollusc, Bivalvia), with description of six new genera and eight new species. *ZOOSYSTEMA,* 28 (4): 805-851.

Cury, P., and Roy, C. (2002). Environmental forcing and fisheries resources in Cote d'Ivoire and Ghana: did something happen? In: MacGlade J.M., Cury, P., Koranteng, K.A. and Hardman-Mountford, N.J. (eds.). The Gulf of Guinea large marine ecosystem: environmental forcing and sustainable development of marine resources. Amsterdam: Elsevier Science; 241-260.

Edmunds, J. (1978). Sea shells and other molluscs found on West African shores and estuaries. Ghana Univ. Press, pp. 144.

Fabiano, M., Sara`, G., Mazzola, A. and Pusceddu, A. (2001). Environmental constraints on pathways of organicdetritus in a semi-enclosed marine systems (W-Mediterranean), in Faranda, F. M., Guglielmo, L. and Spezie, G.(eds), Mediterranean Ecosystems: Structures and Processes. Springer-Verlag, pp. 435–445.

Frid, C. and Hall, S. (2001). Ecological quality objectives for benthic communities: If we protect the habitat do we need to do more? CM 2001/T:06. Theme session: Use and information content of ecosystem metrics and reference points.

Grassle, J.P., and Grassle, J.F. (1976). Sibling species in the marine pollution indicator Capitella (Polychaeta). Science 192: 567–569.

Gray, J. S. (1981). The Ecology of Marine Sediments. An Introduction to the Structure and Function of Benthic Communities, First ed. Cambridge University Press, Cambridge. 185 pp.

Guille, A. (1970). Benthic bionomy of continental shelf of the French Catalane Coast.II.Benthic communities of the macrofauna.*Vie et Milieu,*218: 149–280.

Henin, C., Hisard, P., and Piton, B. (1986).Observations hydrologiquesdans I' Ocean AtlantiqueEquitorial. ORSTOM FOCAL, 1, 1-191.

Hyland, J., Balthis, L., Karakassis, I., Magni, P., Petrov, A., Shine, J., Vestergaard, O. and Warwick, R. (2005).Organic carbon content of sediments as an indicator of stress in the marine benthos.*Marine Ecology Progress, Series*, 295, 91-103.

Humphrey, W.F. (1980). Towards a simple index based on live-weight and biomass to predict assimilation in animal populations. Journal of Animal Ecology, 50, 543-573.

Intes, A. and Lœuff P. (1984).Polychaeta of Ivory Coast III.Faunstic/Climatic relationship, regional units in the Gulf of Guinea.Oceanogra. Trop. 19 (1) pp 3-24.

Kirkegaard, J. B. (1988). The polychaeta of West Africa part II, Errant species, Nephtyidae to Dorvilleidae.Zoological Museum, University of Copenhagen, Denmark,pp 89.

Koranteng, K.A. (1998). The impacts of environmental forcing on the dynamics of demersal fishery resources of Ghana. PhD Thesis, University of Warwick (U.K.). 376 p.

Le Loeuff P, von Cosel R (1998) Biodiversity patterns of the marine benthic fauna onthe Atlantic coast of tropical Africa in relation to hydroclimatic conditions andpaleogeographic events. ActaOecol 19: 309-321.

LeLœuff, P and Zabi, G. S. F. (2002). Spatial and temporal variations in benthic fauna and communities of the Tropical Atlantic coast of Africa.

LeLœuff, P. and Intes, A. (1974).Les thalassinidea (Crustacea, Decapoda) Du Golfe de Guinéesystématique-Écologiè. Vol. **XII**, no. 1, pp 17-69.

Longhurst, A. R. (1962). A review of the oceanography of the Gulf of Guinea. Bull InstFrAfr Noire, 14A (3) 633-663.

Loreau M. 2000. Biodiversity and ecosystem functioning: recent theoretical advances. Oikos 91: 3–17.

Magni, P., Montani, S. and Tada, K. (2002).Semidiurnal dynamics of salinity, nutrients and suspended particulatematter in an estuary in the Seto Inland Sea, Japan, during a spring tide cycle.Journal of Oceanography, 58,389–402.

Moroshkin, K.V., Brunov, V.A. and Bulatov, R.P. (1970). Water circulation in the eastern South Atlantic ocean. Oceanology, 10, 27-34.

Newell, R.C. (1970). Biology of intertidal animals. 555. New York: Elsevier.

Nielson, J. and P. Jernakoff, P. (1996). A review of the interaction of sediment and water quality with benthic communities.*Port Phillip Bay Environmental Study. Technical Report No.* 25, 1-130.

Ormerod, S. J., and Edward, R.W. (1987). The ordination and classification**Error! Bookmark not defined.** of macro invertebrate assemblages in the catchments**Error! Bookmark not defined.** of the River Wye in relation to environmental factors. *Freshwater Biology,* 17, 533-546.

Pearson, T. H. and Rosenberg, R. (1978) Macrobenthic succession**Error! Bookmark not defined.** in relation to organic enrichment and pollution**Error! Bookmark not defined.** of the marine environment. *Oceanography and Marine Biology Annual Review*, 16, 229-311.

Peterson, C. H., and Bishop, M. J. (2005) Assessing the environmental impacts of beach nourishment. *BioScience,* 55, 887-896.

Philander, S.G.H. (1979). Upwelling in the Gulf of Guinea. *Journal of Marine Research*, 37, 23-33.

Quelennec R.E. (1984). Identification des problemesd'erosionsur le littoral sableux de Cote d'Ivoire.Propositions d'actionsprioritaires.Rapport du BRGM, 46pp.

Rakel, H. O. (2007). A study of West African brittle stars (Ophiuroidea) as abase for further benthic investigations in the Gulf of Guinea. MS. Thesis, University of Bergen, Institute of Biology, pp. 96.

Richardson, P.L., and Walsh, D. (1986).Mapping climatological seasonal variations of surface currents in the tropical Atlantic using ship drifts. Journal of Geophysical Research, 19, 10537-10550.

Sherman, K., and Anderson,E.D. (2002).A modular approach to monitoring, assessing and managing large marine ecosystems. Pages 9–26 in J. M.McGlade, P.Cary, K. A.Koranteng, and N. J.Hardman-Mountford, (eds.).*The Gulf of Guinea Large Marine Ecosystem*. Elsevier, Amsterdam.

Skjoldal, H.R., Gool, SV.,Offringa, H., Dam, C.V., Water, J., Degré, E., Bastinck, J., Pawlak, J., Lassen, H., Svelle, M., Nilsen, H.-G. andLorentzen, H. (1999). Workshop on Ecological Quality Objectives (EcoQOs) for The North Sea. Scheveningen- the Netherlands. 1-3 September 1999, TemaNord, The Hague, 1999:591.

Stramma, L., and Schott, F. (1999). The mean flow field of the tropical Atlantic Ocean. Deep Sea Research, 46, 279-303.

Ukwe, C.N. (2003). Implementing innovative best environmental practices and policy approaches for the reduction of nutrient pollution in transboundarywaterbodies in Western Africa: contributions of UNIDO technical assistance programmes. In: A.C. Ibe, C.N. Ukwe and P.C. Nwilo, Editors, *Proceedings of an expert group meeting on pollution and sediment sources in the Nigerian Inland waterways and strategies for their management*, Lokoja, Nigeria, pp. 198–224.

Ukwe, C.N., Ibe, C.A., and Sherman, K. (2006). A sixteen-country mobilization for sustainable fisheries in the Guinea Current Large Marine Ecosystem. *Ocean and Coastal Management*, 49, 385-412.

Warwick, R. M. (1988). Analysis of community**Error! Bookmark not defined.** attributes of the macrobenthos of Frierfjord/Langesundfjord at taxonomic levels higher than species**Error! Bookmark not defined.**. *Marine Ecology Progress Series*, 46, 167–170.

Warwick, R.M. and Clarke, K.R. (1991) A comparison of some methods for analyzing changes in benthic community structure. J Mar Biol Ass UK 71, 225-244.

Williams, F. (1968). Report on the Guinean Trawling Survey. Vols. I (828 p.), II (529 p) and III (551 p). Organization of African Unity Scientific and Technical Research Commission (99). Lagos, Nigeria.

Zabi, G.S.F. and Lœuff, P. (1992).Benthic fauna in "Margino-littoral" systems of West Africa, A review.Part 1: Biology and Ecology of the species. pp. 209-251.

Appendix I

Technical information & Metadata of the GCLME Macrobenthic Fauna

Data source: Data on macrobenthic community composition was obtained during monitoring cruises of the IMR/FAO/GCLME Nansen Program. The data produced by the program is kept at laboratories of University of Ghana (i.e., Productivity & Biodiversity Centre) and University of Bergen, Norway. At University of Ghana and University of Bergen, the contact persons are Emmanuel Lamptey and Jon Anderson Kongrud.

Description of data: The quantitative data are 2-4 parallel samples (sampler area 0.1 m^2). The data are collected within the framework of the IMR/FAO/GCLME COMBINE programme.

Geographical coverage:

2005-Nigeria-Congo

2006-Guinea-Bissau to Congo

2007-Guinea-Bissau to Angola.

Temporal coverage: From 2005 to 2007.

Methodology and frequency of data collection: Sampling is done based on standard protocols established by the GCLME programme in 2005. Sampling is performed once a year in May-July.

Laboratory Analysis: On-going at both University of Ghana and University of Bergen

Records of Sediment

Country	2005	2006	2007
Guinea-Bissau	NA	7	8
Guinea-Conakry	NA	5	5
Sierra Leone	NA	10	9
Liberia	NA	12	12
Cote d'Ivoire	NA	3	4
Ghana	NA	4	16

Togo	NA	1	2
Benin	NA	1	2
Nigeria	17	23	NA
Cameroon	18	23	4
Sao Tome & Principe	11	1	11
Gabon	16	22	29
Congo Brazzaville	2	10	5
Angola	NA	NA	7

Productivity Assessment in the GCLME using Remote Sensing

Summary

Photosynthetic production by phytoplankton is linked to global carbon regulation and conversion of inorganic carbon into organic components in the oceans surface layer which influence marine food webs. Estimation of primary productivity from satellite remote sensing provides an advantage of wider spatial coverage in a synoptic manner over ship-based point sampling. Sea surface temperature (SST) and sea wind stress (SWS) play important role in primary productivity, and the effect on primary production in the coastal waters of the Guinea Current Large Marine Ecosystem (GCLME) was investigated using satellite data obtained from Moderate Resolution Imaging Spectro-radiometer (MODIS-Aqua) and Quickscat, for the period from July, 2002 to April, 2007. Estimation of primary productivity was based on the depth integrated, vertically generalized model. Mean monthly estimates of primary productivity ranged between 110-310 gC/m^2/month, and was highest during the major upwelling period in the region (i.e. July to September). On a spatial scale the shallow waters around Bijagos Islands in the Sierra Leone Guinea Plateau (SLGP) was relatively more productive all year round. From the multiple regression model, 37.3% of the variability in primary production was explained by SST and SWS, with the latter contributing only 1.2%. Spectral analysis showed varying intensities with quarterly to annual peaks in SST and primary productivity. The alternating influence of the Canary and the North Equatorial Counter Currents at the north, as well as the Benguela and the South Equatorial Currents at the south significantly contributed to the spatio-temporal patterns in primary production.

Introduction

The oceans exert a major influence on the earth's meteorology and climate through its interactions with the atmosphere (IPCC, 2001; IPCC, 2007). This process of interaction is driven by the oceans' greater susceptibility for heat energy and carbon storage and transfer. For instance, it is presently absorbing an estimated 18-40 % of the CO_2 that is being released into the atmosphere by human activities (IPCC, 2001). Carbon, in this dynamic process, is mainly in the form of atmospheric carbon dioxide (CO_2), and as hydrated carbonate (CO_3^{2-}) and bicarbonate ions (HCO_2^-) in sea water. Increasing levels of CO_2 in the atmosphere is believed to be the prime contributor to global warming (IPCC, 2001), since CO_2 gas traps long-wave radiations (i.e. heat) leaving the Earth's surface. In the oceans, autotrophs (primary producers) photosynthesize using CO_2 and water (H_2O) to produce carbohydrate ($C_nH_{2n}O_n$) and oxygen (O_2) in a complex photochemical reaction.

The exchange of carbon between the important reservoirs of the biosphere, atmosphere and oceans is known as the carbon cycle. The global carbon cycle ensures that carbon distribution in all subsystems including oceans are kept balanced. However, with increasing industrialization and population explosion, there has been a steady and significant increase in CO_2 levels in the atmosphere (IPCC, 2007). Increases in atmospheric CO_2 results in the concentration of CO_2 in the oceans surface. CO_2 is chemically unreactive in the atmosphere but dissolves into the ocean from the atmosphere to form very reactive products:

$$CO_{2\ (aq)} + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \leftrightarrow H^+ + CO_3^{2-} \quad \text{(Equation 1)}$$

The liberation of free H^+ in solution decreases pH if the buffering capacity of the ocean is exceeded, as more CO_2 dissolves from the atmosphere. Acidification of the ocean is expected to put constrains at varying degrees on the internal physiology of organisms and external environment in which aquatic organisms live. Utilization of CO_2 by photosynthesis shifts the equilibrium to the left (see Equation 1), which removes H^+ from solution, thereby increasing pH. Phytoplankton are attributed to be capable of removing large quantities of CO_2 from the atmosphere (Gregg et al., 2003; Carr et al., 2006). By removing CO_2 and reducing its dissolution in seawater, phytoplankton subdue the instance of a possible reduction in pH of the ocean and improves the oceans capability to absorb more CO_2 from the atmosphere, leading to reduction in the rate of global warming.

Oceans use just 0.2% of the earth's photosynthetic biomass with a turn over of just six days compared to a turn over time of ten years in the terrestrial ecosystem (Falkowski, 1997). Global oceanic production of carbon has been estimated to range between 40-50 Pg C year^{-1}, almost equaling estimate for terrestrial production of 56 Pg C year^{-1} (Longhurst et al., 1995; Field et al., 1998). Productive marine systems have all the tendencies to support fisheries and to significantly contribute to carbon flux

regulation, and hence, long term studies in these systems have positive benefits to improve marine resource conservation and climate related problems. Such studies have seen great improvement with the use of remotely sensed ocean colour data, sea surface temperature, sea surface height, sea wind speed and direction, and other derived marine bio-optical data of photosynthesis from satellite platforms. Using the remotely sensed approach has made it possible for global estimates of primary production to be observed on a wider scale in a synoptic manner compared to discrete or point sampling with vessels, over relatively smaller spatial scales.

Human impact on the oceans either through exploitation of its resources, transportation or dumping of waste, has largely reduced the water quality of most marine ecosystems. The role of phytoplankton in synthesizing nutrients from water make them susceptible to poor water quality, and could eventually lead to collapse of a fishery. For example, the decline in anchovaeta off the Peruvian coast in the early 1970's has been attributed to the decline of zooplankton due to harsh environmental conditions from ecosystem instability and variability (FAO, 2005).

In the Gulf of Guinea, fisheries abundance have recorded drastic decline, and this has been attributed, among other factors, to the continual degradation of habitat quality through increased discharge of organic and inorganic waste, transport of nutrient rich waters into the coastal environment from estuaries and lagoons, and impact of climate change on zooplankton production (Armah and Amlalo, 1998; Wiafe et al, 2008). Apart from poor environmental state of the marine ecosystem, excessive fishing effort by fishers is significantly reducing fish stocks (Christensen, 2001; Pauly et al., 1998). Measures to regulate declining fish stocks from overfishing by mesh size regulation, total allowable catches and marine protected areas have failed to maximize fish yields (Bakun, 1993). A look at planktonic productivity in the Guinea Current Large Marine Ecosystem (GCLME) with its implication for fish recruitment as a vital component to improve fish abundance is thus, critical for fisheries management and assessing the carrying capacity for living resources. Productivity of oceans has economic and health implications for many countries in terms of food security (Sherman, 1994; FAO 2005) and employment for coastal dwellers. Hence, information of primary production of the GCLME from this study will become a resource for marine resource management and trophodynamic studies.

Ocean parameters capable of measurement from space include ocean colour, sea surface temperature, sea surface roughness and sea surface height. Remotely sensed data play very important role in the study of ocean phenomena and coastal processes. Conventional sampling platforms i.e. research vessels and buoys though still useful are limited in scope and coverage. Satellite remote sensing provides oceanographers with almost daily coverage of the world's oceans. The major drawbacks with remotely sensed data are the extent of atmospheric contaminations and the fact that sensors return information only on the surface skin layer of the ocean. MacIntyre (1977), in seeking to draw attention to the importance of the surface skin layer of the ocean, pointed out that on a logarithmic scale the first millimetre below the surface

represents the top half of the ocean. One of the uses of remotely sensed data is in the monitoring of marine productivity using ocean colour as an index for chlorophyll. Estimates of marine productivity offers the opportunity to calculate amount and rate at which atmospheric carbon is utilized by phytoplankton and other marine plants, which has considerable contribution to understanding the effect of carbon fluxes to climate variability.

Marine primary production is the photosynthetic utilization of carbon by all forms of algae to produce carbohydrate and oxygen. The total amount of carbohydrate produced after photosynthesis per unit space is the gross primary production (G_{pp}). Energy loss through metabolism and other processes like growth, reproduction and respiration (R) leaves what is termed net primary production (N_{pp}). This is the photosynthetically fixed carbon that is made available to the first trophic level and, as such, is the relevant metric for addressing environmental questions ranging from trophic energy transfer to the influence of biological processes on carbon cycling (Lindeman, 1942; Rogers et al., 2002). Marine primary productivity (PP) can be described by the relationship;

$$PP = \int (G_{pp} - R)dt = \int (N_{pp})dt. \qquad \text{(Equation 2)}$$

Marine primary production contributes 10-50 % of global photosynthetic production, and its carbon fixation helps to maintain steady state of atmospheric CO_2 (Falkowski 1998). Studies in marine primary production also enrich the knowledge in potential sustainability of fishery resources as phytoplankton form the major primary producing organisms in oceans.

1.1   Objectives

The aim of this study was to estimate primary production of the Guinea Current Large Marine Ecosystem, using SST and Chlorophyll a data estimated from remote sensing. This information has important use for estimating the carrying capacity of the ecosystem that supports fishery resources, and an estimate of a regional primary productivity index.

The specific objectives were:

To calculate primary productivity for the GCLME from Moderate Resolution Imaging Spectroradiometer (MODIS) data;

To assess seasonal and spatial variation in primary productivity;

To determine the role of environmental factors (SST and sea wind stress) on primary production estimate.

Background

The use of remote sensing in marine studies has improved the understanding of many complex processes that regulate marine systems. Improvement in operation of sensors has enhanced their ability to detect fine features over vast areas of the ocean and coastal waters. This allows scientists to assess the possible effect of many oceanographic and climatic processes at various scales.

Interest in the use of satellite remote sensing to map primary productivity began after the launch of the Coastal Zone Color Scanner (CZCS) in the late 1970's (Acker, 1994; Evans and Gordon, 1994). With four spectral bands in the visible spectrum, CZCS's ocean colour data demonstrated the feasibility of mapping synoptic phytoplankton concentrations to a good degree of accuracy in Case I waters (Smith and Wilson, 1981; Yentsch and Garfield, 1981). Combination of CZCS data with shipboard data and other measurements from other satellite sensors e.g. Advanced Very High Resolution radiometer (AVHRR), provided insights into linkages between physical and biological properties (Sathyendranath et al., 1991; Denman and Abbot, 1994). This permitted satellite-based estimates of regional and global primary production (Smith et al., 1982; Campbell and O'Reilly, 1988; Platt et al., 1991; Longhurst et al., 1995; Antoine et al., 1996; Behrenfeld and Falkowski, 1997b). Satellite-based ocean colour monitoring provides information for phytoplankton production which is essential in studies such as global carbon fluxes as well as other biogeochemical processes, and marine fisheries research.

2.1   Ocean colour from remote sensing

The role of phytoplankton in ocean colour measurement has been studied for several decades (Edgerton, 1974; Kiefer and Wilson, 1979; Prieur and Sathyendranath, 1981; Gower 1983; Gordon 1986; Holligan and Morel, 1987; Hooker et al, 1993; Ishizaka and Hofmann, 1993; O'Reilly et al., 1998; O'Reilly et al., 2000; Iluz et. al., 2003; Darecki et al., 2005; Gilerson et al., 2008). These studies have revealed that chlorophyll a, the main photosynthetic absorbing pigment, absorbs relatively more blue and red light than green, giving the oceans its green colour (Yentsch, 1960, O'Reilly, 1998; O'Reilly 2000; Fargoin and Mueller, 2000). High-altitude studies using airborne sensors relating ocean color to chlorophyll concentration (Clark et al. 1970, Hovis et al., 1980) and subsequent use of the Coastal Zone Color Scanner (CZCS) aboard Nimbus 7 satellite gave insight to the feasibility of using satellite scanners/sensors to map ocean colour. Mapping ocean colour using this approach is based on the fact that there is a relationship between ocean colour and phytoplankton pigment concentration for most open ocean waters (Sathyendranath et al., 1989).

Remote sensing of ocean colour is confined to the visible region of the electromagnetic spectrum. Bricaud et al. (1995), have shown that the phytoplankton absorption at every single wavelength in the visible domain can be parameterized as a function of chlorophyll a. The inverse approach, or reflectance ratios, of blue and green spectral bands estimate the quantity of chlorophyll present that interacts with incident solar radiation (O'Reilly et al., 1998). This inverse approach of pigment retrieval is not trivial, for various reasons: different photosynthetic pigment are present in phytoplankton populations; absorption bands of individual pigments overlap each other; and variations in pigment packaging in phytoplankton cells can influence their absorption efficiencies (Carder et al., 2004). Also, the use of band ratio diminishes residuals that may persist and are added to the marine signals at the two wavelengths.

Another possibility exists for passive remote sensing of chlorophyll a, through sun-induced fluorescence signal detected in the red part of the spectrum (Neville and Gower, 1977; Gower et al., 1984; Gower and King, 2007). This approach improves chlorophyll a estimation in Case II waters where optical properties are influenced by suspended sediments and coloured dissolved organic matter (Bricaud et al., 1981). Gege (1998) has shown that reflectance spectra can be used to estimate the concentrations of phytoplankton species by looking at the absorption spectra of phytoplankton, which are related to differences in their pigment composition.

2.1.1   Optics of ocean colour remote sensing

Optical characteristics of coastal and offshore regions of the ocean are regulated by their apparent and inherent optical properties (Kirk, 1983). Apparent optical properties (AOP) are properties that depend on the major constituents of the aquatic medium; that is, pure seawater, phytoplankton, gelbstoff and detritus that are affected by the geometry of the subsurface light field, and the wavelength of the electromagnetic radiation. Inherent optical properties are dependent on the medium, with no relation on the geometrical dimensions and ambient light field (Kirk, 1983; Mobley, 1994).

2.1.1.1   Apparent optical properties

The most commonly and easily measured AOPs are radiance and irradiance. Radiance (L) is the radiant light flux at a specified point in a given direction per unit solid angle, per unit area perpendicular to the direction of light propagation, at a specific wavelength, and is measured in W (or quanta s^{-1}) m^{-2} sr^{-1}. Important radiance quantities include the upwelling radiance, $L_u(\lambda)$, and water-leaving radiance, $L_w(\lambda)$. $L_u(\lambda)$ is the radiant light flux in the upward direction and $L_w(\lambda)$ is the water-leaving radiance extrapolated though the ocean surface. Irradiance is the radiant flux per unit surface area (units of W m^{-2} nm^{-1} or quanta (or photons) $m^{-2}s^{-1}$or mol quanta [or photons] $m^{-2}s^{-1}$). Downwelling irradiance, $E_d(\lambda)$, is the irradiance of a downwelling

light stream impinging on the top face of a horizontal plane and upwelling irradiance, $E_u(\lambda)$, is the irradiance of an upwelling light stream impinging on the bottom face of a horizontal plane. The important quantity that is measured by remote sensors, remote sensing reflectance $R_{rs}(\lambda)$, is simply taken just above the sea surface,

$$R_{rs}(\lambda) = L_w(\lambda)/E_d(\lambda) \qquad \text{(Equation 3).}$$

Radiance and irradiance measurements are important for quantifying the amount of light available for photosynthesis, heating of the upper ocean, radiative energy transfer, and the interpretation and quantification of remotely sensed data.

2.1.1.2 Inherent optical properties

Inherent optical properties (IOP) have properties that are dependent only on the medium itself, and are not on the ambient light field and its geometrical distribution. This is based on the principle that light energy as it travels in water can only be absorbed or scattered. These absorption and scattering properties are quantified as the absorption coefficient $a(\lambda)$, scattering coefficient $b(\lambda)$, attenuation coefficient $c(\lambda)$, (all with the units m^{-1}) and volume scattering function $\beta(\psi, \lambda)$, where ψ is the scattering angle and λ is the wavelength. $\beta(\psi, \lambda)$ is the scattered intensity of light per unit incident irradiance per unit volume of water at some angle (ψ) into solid angle element ($\Delta\Omega$), with units of $m^{-1}\, sr^{-1}$. Total absorption, scattering, and attenuation coefficients can be partitioned into the four constituents of the aquatic medium in natural oceanic waters: pure seawater (w), phytoplankton (ph), detritus (d), and gelbstoff (g):

$$a_t(\lambda) = a_w(\lambda) + a_{ph}(\lambda) + a_d(\lambda) + a_g(\lambda) \qquad \text{(Equation 4),}$$

$$b_t(\lambda) = b_w(\lambda) + b_{ph}(\lambda) + b_d(\lambda) \qquad \text{(Equation 5), and}$$

$$c_t(\lambda) = c_w(\lambda) + c_{ph}(\lambda) + c_d(\lambda) + c_g(\lambda) \qquad \text{(Equation 6).}$$

Detritus refers to the non-pigment containing particles of organic or inorganic origin (e.g., sediment, fecal material, plant and animal fragments). Gelbstoff (yellow matter or gilvin) is the term for optically active colored dissolved organic material (CDOM). The contribution of gelbstoff to scattering is negligible relative to phytoplankton and detritus in Case I waters (Kirk, 1983). The absorption coefficient of pure seawater is well characterized with greater absorption in the red than blue portions of the visible spectrum (Pope and Fry, 1997). Phytoplankton spectral absorption varies significantly in relation to pigmentation of particular species, community composition, and environmental changes (Bricaud et al,. 1995). Characteristic peaks are typically found near wavelengths of 440 nm and 683 nm and are related to chlorophyll-a.

Quasi-IOPs are the vertical diffuse attenuation coefficients for radiance ($K_L(z, \lambda)$) and irradiance ($K_d(z, \lambda)$), where z is depth. They are defined as the logarithmic derivative of the specified radiometric quantity with respect to depth.

$$K_d(z, \lambda) = [1/(z_2 - z_1)] * \ln(E_d(z_1,\lambda) / E_d(z_2,\lambda)) \qquad \text{(Equation 7)}$$

where z_1 and z_2 are two different depths.

The vertical diffuse attenuation coefficients provide information regarding vertical light intensity through the water column, and has significant effect on the quantity of light energy available for photosynthesis. $K_d(z, \lambda)$ can be separated into the four constituents of sea water (water, phytoplankton, detritus, and gelbstoff) (Morel, 1988; Morel and Maritorena, 2001).

2.1.1.3 Radiative transfer theory

The radiative transfer theory links IOPs and boundary conditions to AOPs of the water column (IOCCG, 2006). Thus, it is possible to know AOPs provided there is enough information of environmental forcing conditions and estimates of IOPs. Equally, given remotely sensed water-leaving radiance or remote sensing reflectance, IOPs can be estimated (i.e. inverse problem). The exact relationships that exist between IOPs and AOPs is defined in Gershun's equation (Mobley, 1994), and can be simplified and validated to the radiative transfer equation. For example, Gordon et al., (1975) confirm that reflectance, $R(\lambda)$, is a function of $b_b(\lambda)/(a(\lambda) + b_b(\lambda))$ or $b_b(\lambda)/a(\lambda)$.

2.1.1.4 Optical classification of ocean water and water quality parameters

Morel and Prieur (1977) introduced a classification scheme for oceanic waters that was later refined by Gordon and Morel (1983), and Sathyendranath and Morel, (1983). The classification refers to Case I and Case II waters. Case I waters are those in which phytoplankton and their associated materials (such as debris, heterotrophic bacteria, larger heterotrophic organisms and autochthonous yellow substances) play a dominant role in determining the optical properties of the water body. Case II waters are those in which other substances, such as resuspended sediments, terrigenous particles, terrigenous yellow substances or anthropogenic materials, vary independently of phytoplankton concentration and play a dominant role in determining the optical properties of the water body. This classification does not mean oceans are absolutely either Case I or II but brings to bear the continuous scale with the two water types at the extremes.

Water quality simply describes the contributing effect of physical, chemical and biological elements in an aquatic system. The major factors that affect water quality

in estuaries and oceans include suspended matter, chemical substances, dissolved organic matter, nutrients, chlorophylls and associated light harvesting pigments, thermal releases, oils etc. Suspended matter, chlorophyll, oils and dissolved organic matter change the spectra of reflected solar and/or emitted thermal radiation from water (Jain et al., 1980). Such changes in spectral signals from surface waters are measurable by remote sensing techniques from many platforms (Johnson and Harriss, 1980). The strength of remote sensing techniques lie in their ability to provide both spatial and temporal synoptic views of surface water at scales beyond in-situ measurements. These water quality parameters can be quantified using remote sensing techniques. The basic idea of remote sensing of water quality is to use the difference in spectral reflectance to estimate the amount of dissolve and suspended matter in the water. The relationship between spectral signature of the water and the amount of the substances in that water is still an active field of research. For this study the main water quality parameter of interest is chlorophyll.

Chlorophyll

Chlorophyll, the main photosynthetic pigment in marine phytoplankton gives colour to the ocean. Remote sensing has successfully been used to measure the chlorophyll concentrations and patterns over the oceans (Morel, 1980; Morel and André, 1991; Kirk, 1994; Bukata et al., 1995; Doerffer and Fischer, 1994; Roesler and Perry, 1995; Gilterson et al., 2000; Iluz et. al., 2003). Most remote sensing studies of chlorophyll in water are based on empirical relationship between radiance in narrow bands or band ratios and chlorophyll concentration. Chlorophyll has greater absorption in the blue and red regions and maximum reflection in the green region of electromagnetic spectrum. Reflectance ratio or measured absorbance of chlorophyll is used to quantify ocean phytoplankton concentrations.

For the remote sensing problem two useful approaches have been adopted, relying either on reflectance at null depth, R (0-), or on the normalized water-leaving radiance,$(Lw)_N$ Gordon and Clark (1980). R (0-) and ,$(Lw)_N$ are linked in the relation

$$[L_w]_N = (F_o R_o / Q_o) \, R(0^-) \qquad \text{(Equation 8)}$$

F_o = extraterrestrial irradiance (W m^{-2})

R_o = term accounting for all the reflection and refraction effects, its value is about 0.545

Q_o is calculated from the ratio of upwelling irradiance at null depth ($E_u(0-)$) and upwelling radiance at nadir and null depth ($L_W(0-,nad)$) (units, sr)

R(0-), an inherent optical property is linked to two apparent optical property (Preisendorfer, 1961) as

$$R(0^-) = f_1(b_b/a) \qquad \text{(Equation 9)}$$

b_b and a are backscattering and absorption coefficients, respectively, at the two wavelengths. f_1 cancels out when reflectance ratio for reflectance at two different wavelengths is computed.

Chlorophyll or ocean colour data is widely used in calculating primary production of aquatic ecosystems. Primary production models that use ocean colour data ranges from very simple to complex models. The simplest productivity model estimates time and depth-integrated primary production as a function of sea surface chlorophyll (Smith et al. 1982). Complex models incorporate surface irradiance and other photosynthetic parameters in the model to calculate primary production.

2.2   Remotely sensed ocean color data from moderate resolution imaging spectroradiometer (MODIS)

Moderate Resolution Imaging Spectroradiometer (MODIS) provides oceanographers radiometric measurements of visible-to-near-infra red wavelengths, hence apart from ocean colour there is also sea surface temperature data. Chlorophyll retrieval from MODIS is given as:

Log Chl a = log P_o * P_1 log aφ(675)

This step requires knowledge of the chlorophyll-specific absorption coefficient for phytoplankton at 675 nm, aφ*(675), for bio-optical properties that affect accessory pigment absorption at 675 nm. To evaluate variations of aφ(675) with [chl a] for subtropical to tropical waters, MODIS Ocean Science Team developed a data set to explore the more limited variation in surface values of aφ*(675) under high-light conditions. This data set came from surface-water samples from several cruises in the Gulf of Mexico and a cruise on the Arabian Sea, and chlorophyll a value at aφ*(675) was calculated as 0.0193 m^2 (mg chl)$^{-1}$.

When the semi-analytical algorithm does not return a value for aφ(675), a two-wavelength empirical algorithm for [Chl a] using L_w(488)/L_w(551) ratio is employed (Aiken et al., 1995). Also, $a_φ$(675) and a_g(400) is estimated using a multi-wavelength algorithm based on $a_φ$(440)and a_g(440) (Lee et al., 1998).

2.3   Bio-optical algorithms for chlorophyll a estimation

Development of bio-optical algorithms to estimate chlorophyll a from ocean radiance began in the 1970 (O'Reilly et al., 1998), of which most were empirical equations derived from statistical regression of radiance against chlorophyll. Improvements in theoretical studies and new parameterization of various optical properties have advanced the understanding in marine optics for modeling ocean colour (Morel, 1988; Sathyendranath et al., 1989; Bricaud et al., 1995). Such improvements have resulted in the emergence of semi-empirical or semi-analytical ocean colour algorithms that further give better understanding of the relationship between remote sensing

reflectance and backscattering to absorption ratio (Morel and Prieur, 1977; Carder et al., 1986).

Semi-analytical algorithms use analytical, optical, remote sensing reflectance models that can be inverted to derive chlorophyll, absorption coefficients of other optically active components in the water, such as gelbstoff, or the backscattering coefficients (O'Reilly et al., 1998). In the studies of chlorophyll algorithms for SeaWiFs (O'Reilly et al., 1998), empirical algorithms yielded better results compared to those from semi-analytical algorithms. Empirical algorithms employ information about the apparent optical properties i.e. radiance and reflectance and in water constituents (pigments, sediments, carbon dissolved organic matter). Semi-emprical algorithms may be limited because they require more than three radiance bands and consistent data sets with high spectral fidelity to accurately estimate various pigment indices. Again, some simplifying assumptions limit the number of unknowns making constant some parameters in semi-empirical models, e.g. specific absorption coefficient of phytoplankton, a^*_{ph}, that are dependent of phytoplankton community structure and the trophic status of the waters varies in the ocean. (Mitchell and Kiefer, 1988; Bricaud and Stramski, 1990; Cleveland, 1995; Sosik and Mitchell, 1995). O'Reilly et al., 1998 gave a list of several bio-optical algorithms for chlorophyll retrieval. These algorithms use ratios of normalized water-leaving radiance or remote sensing reflectance in the blue and green regions.

The Carder model (Carder et al., 1998; Carder et al., 2004), is a semi-analytical algorithm based on the $b_b/(a + b_b)$ to R_{rs} relationship (Gordon et al., 1988). It uses the R_{rs} at four SeaWiFS wavelengths to derive the absorption coefficient of phytoplankton at 675 nm, $a_{ph}(675)$, and the absorption coefficient of colored dissolved organic matter (CDOM) at 400 nm, $a_g(400)$. Chlorophyll a concentration is then calculated from an empirical relationship between $a_{ph}(675)$ and chlorophyll a. A default, two wavelength empirical algorithm (Rrs490/Rrs555) is used when $a_{ph}(675)$ is outside a predetermined search range. There are two versions of this model; an initial version parameterized for subtropical, unpackaged pigment data and a second version parameterized for more packaged pigments and global application (Carder et al., 1998).

Fell et al. (2000) made use of the sun induced chlorophyll fluorescence (SICF) to derive chlorophyll concentration from subsurface remote sensing reflectance at 708 nm from MERIS data. Comparison with pigment concentrations derived from SeaWiFS data using OC4v4 algorithm acquired for the same area indicated that the SICF approach has a significant potential for the retrieval of pigment concentration for both Case I and II waters.

The OC4v4 SeaWiFS algorithm is a polynomial relationship of water-leaving radiance ratios numerically fitted to global chlorophyll observations (O'Reilly et al., 1998), and uses maximum band reflectance ratios of 443, 490, 510 nm against 555 nm. O'Reilly *et al.* (1998), studied the comparison between Case I and Case II water

and found that the normal range of chlorophyll concentrations in Case II waters (i.e., 0-100µg/l) is often an order of magnitude lower than the normal range for Case I waters (i.e. 0-10µg/l).

Pigment concentration (chlorophyll a) estimates of CZCS have been made using band ratios of Lwn443, Lwn520 and Lwn550 in the Global Processing switching (GPs) algorithm (Gordon et al.,1983; Feldman et al., 1989; Evans and Gordon, 1994). GPs uses a ratio of Lwn443/Lwn550 at concentrations below ~1.5 µg/l and switches to Lwn520/Lwn550 when the former band ratio gets too low. The Clark three-band (C3b) uses a similar band relation as the GPs but avoids band switching by summing the 443 and 520 channels which compensates for the weakness of 443 nm at high pigment concentrations (Muller-Karger et al., 1990).

Aiken hyperbolic models use band ratios of Lwn490/Lwn555 by the combination of a hyperbolic function up to 2 µg/l, and a power function at higher concentrations (Aiken et al., 1995). The Garver/Siegel model is a semi-analytic algorithm based on the quadratic form of the $b_b/(a + b_b)$ to R_{rs} relationship (Garver and Siegel, 1997). The model uses predefined shapes for specific absorption and backscattering coefficients to derive, through a nonlinear statistical method, the chlorophyll a concentration, the absorption coefficient due to phytoplankton at 441 nm, $a_{ph}(441)$, the absorption coefficient due to other particulate and dissolved matter at 441 nm, $a_{dm}(441)$, and the backscattering coefficient of particles at the same wavelength, $b_b(441)$.

Maritorena et al., (2002), developed a globally optimized model (the Garver-Siegel-Maritorena version1, GSM01). The semi-analytic model that retrieves simultaneous estimates for chlorophyll concentration, the absorption coefficient for dissolved and detrietal material and the backscatter coefficient from measurements of Lwn443 nm. With the tuned semi-analytic parameters, the accuracy of the GSM01 improved and results were comparable with SeaWiFS algorithm for chlorophyll. The GSM algorithm considers that chlorrophyll, colored dissolved and detrital organic materials (CDM) and particulate abundances each independently affect ocean color and these properties are retrieved simultaneously from a water-leaving radiance spectrum (Maritorena et al., 2002; Siegel et al., 2002, 2005).

2.4   Marine primary production estimation

Marine primary productivity is the rate of carbon fixation by marine photosynthetic organisms. It has units of $gC/m^2/time$. Though in small quantity in terms of biomass, marine phytoplankton fix approximately 40% of the global total carbon (Falkowski et al. 1998). Measurements of marine phytoplankton production are carried out through out the world's ocean since the introduction of the radiolabelled carbon-14 uptake method (Steeman Nielsen 1952), and using remote sensing which began in the early

70's (Clark et al., 1970). Estimation of phytoplankton production has become so important considering the vast contribution phytoplankton photosynthesis has on global climate, nutrient and carbon fluxes and other biogeochemical processes. This has made it necessary for phytoplankton production to be estimated on large spatial scales and at short temporal rate. Using mathematical models (Bidigare et al., 1992), it is possible to relate satellite based estimates of chlorophyll to primary productivity.

2.4.1 Classification of marine primary productivity models

Productivity models generally have being delineated into three categories: empirical, semi - analytical, and analytical. Behrenfeld and Falkowski (1997b) further proposed a more rational scheme based on implicit levels of integration. Models for estimating primary production can be classified into 4 groups:

Wavelength resolved models (WRM) calculate net primary productivity within the euphotic zone as function of the wavelength specific absorption photosynthetic active radiation. WRMs convert absorbed radiation (photosynthetic utilizable radiation) into net photosynthesis using suite of empirical quantum efficiency models based on photosynthesis-irradiance variables or variables characterizing photosystems.

Wavelength integrated models (WIM) calculate net primary productivity by integrating photosynthetically active radiation over depth and time. WRMs and WIMs are the only models based on estimates of net primary photosynthesis.

The third model, the Time integrated model (TIM) retains vertical resolution but replace calculations of net photosynthesis with direct estimates of net primary production.

Depth integrated models (DIM) lack explicit description of vertically resolved component found in the other three models. DIMs use vertically integrated functions to relate environmental variables measurable at the sea surface.

2.4.1.1 Howard-Yoder Mixed Layer Production Model (HYMLPM)

Howard and Yoder (1995) productivity model requires similar parameters to the Vertically Generalized Productivity Model (Behrenfeld and Falkowski, 1997a and b). A maximum potential primary production, P_{max}, corresponds to P^B_{opt} (maximum carbon fixation rate). P_{max} is parameterized as a function of SST as described by Eppley (1972). Other parameters include surface chlorophyll, surface irradiance (in W/m^2), mixed layer depth (MLD) and the photoadaptive parameter α, which represents the initial slope of the photosynthesis-irradiance (P-E) curve.

The model first estimates mean daily photosynthetically active radiance (PAR) of the mixed layer, E_{bar} as

$E_{bar} = E_o (1 - \exp(K_{par} * MLD))/(K_{par} * MLD)$ (W/m^2)   (Equation 11)

K_{par} is a vertical attenuation coefficient calculated using Nelson and Smith's (1991) equation, developed for CZCS chlorophyll values. Integrated primary production for the mixed layer is then calculated from the product of mean mixed layer production and mixed-layer depth as follows:

$\sum PP = C_{surf} * [(P_{max} * E_{bar}) / (P_{max}/\alpha + E_{bar})] * MLD$ (mg C m^{-2} d^{-1})   (Equation 12)

2.4.1.2 Antoine and Morel Absorption-Based Algorithm (AMAB)

The Antoine and Morel absorption-based model uses the same fundamental parameters as the previous two models, namely light, phytoplankton biomass and a description of the photoadaptive state of the phytoplankton, to estimate primary productivity. The computation is based on the following equation:

$\Sigma PP = (1/J_c) * Chl_{tot} * E_\circ * \psi^*$ (Equation 13)

where Chl_{tot} represents column integrated chlorophyll content, the factor ψ^* integrates the two basic processes involved in the photosynthetic carbon fixation, the capture of radiant energy and the transformation of this harvested energy into chemical energy stored in the algal biomass (m^2 / g Chl). The constant J_c represents the energetic equivalent of photosynthetic assimilate (kJ / g C).

2.4.1.3 Behrenfeld and Falkowski's Vertically Generalized Production Model (BF-VGPM)

BF-VGPM relates surface chlorophyll to depth integrated euphotic zone primary production. The form of the BF-VGPM is that of many depth-integrated models (DIMs) which include a measure of depth-integrated phytoplankton biomass, estimated by the product of surface chlorophyll (C_{surf}) and euphotic depth (Z_{eu}), as well as inclusion of an irradiance dependent function F, and a photoadaptive yield term (P^B_{opt}) necessary to convert the estimated biomass into a photosynthetic rate (Behrenfeld and Falkowski, 1997b). P^B_{opt}, the maximum carbon fixation rate within the water column, is the only model parameter that is neither relatable to sea surface chlorophyll, nor possible to measure remotely. Attempts have been made to model this important photoadaptive parameter from sea surface temperature. Daylength (DL) is also included in the model, to scale observational data from hourly incubations to daily rates. The core equation of the BF-VGPM is then:

$$\Sigma\ PP = C_{surf} * Z_{eu} * P^b_{opt} * DL * F\ (mg\ C\ m^{-2}\ t^{-1}).\quad\quad \text{(Equation 14)}$$

The primary difference among DIMs is the description of F. In the case of the VGPM, measured integral production was normalized to measure P^B_{opt}, surface chlorophyll, daylength and euphotic depth and plotted as a function of surface irradiance (E_o). A best-fit equation was then calculated for F.

The fundamental differences in the three algorithms described above are related to depth and phytoplankton physiological parameterizations using SST. AMAB is different from HYMLPM and the BF-VGPM, first in the use of column-integrated chlorophyll content (Chl_{tot}, mg/m^2) against surface chlorophyll (mg/m^3). Secondly, photoadaptation is not based on an optimal (temperature-dependent) but on two fundamental characteristics of the photosynthetic process: the absorption of light by the photosynthetic apparatus (chlorophyll dependent) and the quantum yield or amount of carbon fixed per mol quanta absorbed. Although chlorophyll concentration alone may prove a sufficient indicator of change in global productivity, it will not provide an accurate estimate in the absolute change in carbon fixation, because the ratio of chlorophyll per unit carbon fixed is nonlinearly temperature-dependent (Behrenfeld and Falkowski, 1997). BF-VGPM differs from HYMLPM with regards to the shape of the exponential function for parameterizing P_{max} from SST (Eppley, 1972), compared to what was depicted from the seventh-order polynomial relationship between P^B_{opt} and SST adopted by Behrenfeld and Falkowski (1997a and b). The differences that exist between the temperature-dependent relationship described by Eppley (1972) and Behrenfeld and Falkowski (1997a) P^B_{opt} model are: first, the Eppley relationship was developed for maximum specific growth rate (μ; d^{-1}) and P^B_{opt} model for photosynthesis; second, the curve described by Eppley's relationship increases exponentially from -1 to 29°C, where as the model for P^B_{opt} decreases above 20°C capturing photoclimatization that results from increased solar radiation and the corresponding increase in temperature. Again, BF-VGPM integrates

photosynthetic production up to the euphotic depth and so accounts for production for regions of the ocean receiving enough solar energy. However, HYMLPM integrates photosynthetic production to the MLD, and this has the tendency of overestimating primary production.

For this study, a BF-VGPM was adopted based on the ability of P^B_{opt} to mimic in situ photosynthesis better and estimating primary production within the euphotic depth. Also, BF-VGPM was preferred based on the fact that input for photoadaptive parameters for the model can be determined from relationships with other parameters that can be determined from remotely sensed data. Pigment concentration as provided for from Level 3 MODIS data gives chlorophyll levels in ocean waters and is calculated from integration band ratio of reflectance of the wavelengths 488 nm, 551 nm and 675 nm.

The euphotic depth is the depth of water column that receives approximately 1% of surface radiance ($E_\circ$). Z_{eu} will be estimated from the equation below.

$Z_{eu} = 4.6/k_d$, where k_d is the attenuation coefficient for mean photosynthetic active radiation (PAR). Morel 1988, Morel and Maritorena (2001) developed empirical relationships between k_d and chlorophyll: $k_d(\lambda) = k_w(\lambda) + \chi(\lambda)Chl^{e(\lambda)}$.

Chlorophyll-specific carbon fixation is an enzymatically controlled rate process which should exhibit temperature dependence. P^b_{opt} is modeled based on sea surface temperature (T) using the following relationships proposed by Megard 1972 and Balch et al. 1992.

$P^b_{opt} = 0.118 * T + 1.25$ (Megard 1972)

$P^b_{opt} * DL = 10^{-0.054 * T + 2.21}$ (Balch et al. 1992)

Behrenfeld and Falkowski (1997a) measures P^b_{opt} from sea surface temperature from a seventh order polynomial function of the form:

$P^B_{opt} = -3.27 \times 10^{-8} T^7 + 3.4132 \times 10^{-6} T^6 - 1.348 \times 10^{-4} T^5 + 2.462 \times 10^{-3} T^4 - 2.05 \times 10^{-2} T^3 + 6.17 \times 10^{-2} T^2 + 2.749 \times 10^{-1} T + 1.2956$ (Equation 15)

DL is Day length and T is sea surface temperature in °C.

The oceanographic regime in the GCLME

The seasonal variability associated with the Guinea Current is believed to be related to changes in the North Equatorial Countercurrent (NECC) and the Canary Current (Longhurst 1962, Ingham 1970). The Guinea Current, like other eastern ocean boundary currents, is characterized by areas of upwelling (Bakun, 1978) and increased biological productivity (Binet, 1997) associated with the intensification of the current (Bakun 1978, Philander 1979). The Guinea Current is a geostrophically

balanced current (Philander, 1979) with isotherms sloping upwards towards the northern coast during part of the year. As the current intensifies, the slope steepens, thereby bringing the thermocline closer to the surface near the coast. The coastal upwelling and the summer intensification of the Guinea Current are thus related. However, the Guinea Current is unusual among upwelling regions in that there seems to be no correlation between sea surface temperature and wind patterns on a seasonal scale (Longhurst, 1962; Bakun, 1978). According to Binet (1997), the seasonal shallowings are not induced by local wind stress, but by geostrophic adjustment of isotherms (Ingham, 1970), Kelvin waves (Picaut, 1983; Verstraete, 1992), and cyclonic turbulent eddies (Marchal and Picaut, 1977). Comparatively, the Guinea current, flanked by the Canary current northward and Bengula current southward is less productive. This could be explained to some extent by the Guinea currents hydrographic regime affected by a relatively stable, shallow thermocline, an almost permanent presence of warm, low salinity tropical waters and the narrow continental shelf for most portions of the coastal area.

Tilot and King (1993), arbitrarily divided the Guinea Current into three subsystems, each defined by a particular characteristic which interact together to the functioning of the ecosystem. These subsystems are: Sierra Leone and Guinea Plateau (SLGP), which extends from the Bijagos Island (Guinea-Bissau) to Cape Palmas (Liberia/Cote D'Ivoire) and is characterized by the broadest continental shelfs and large riverine input, giving thermal stability; Central West African Upwelling (CWAU), which extends from Cape Palmas to Cotonou (Benin) is thermally unstable and characterized by seasonal upwelling of cold nutrient rich subthermocline water which dominates the annual cycle and drives the biology of the subsystem; Eastern Gulf of Guinea (EGOG), extending from Cotonou to Cape Lopez (Gabon) and the offshore islands of Bioko and Sao Tome and Principe is thermally stable with a strong pycnocline. Productivity in the EGOG depends on nutrient input from land via rivers and turbulent diffusion through a stable pycnocline.

Methodology

Description of Study Area

The study covers the Guinea Current Large Marine Ecosystem (GCLME) which extends from Guinea Bissau at the north to Angola in the south, and characterized by the Guinea Current (Figure 3.1). The Guinea Current flows eastward, along the western coast of Africa (Henin et al., 1986), with velocities reaching approximately 1m/s near 5°W (Richardson and Reverdin, 1987). The currents in the Guinea Current as a whole are influenced by the North Equatorial Counter Current and Canary Current (Senegalese Upwelling Influence, SUI) systems the seasonal instability of these two currents affect the seasonal variability of the Guinea Current (Longhurst 1962, Ingham 1970).

The climatology of the Guinea Current and its subsystems are characterized by high temperatures, high humidity and heavy rainfall, and two alternating seasons (dry season from November to April and wet season from June to October) greatly influences oceanographic conditions, affecting primary production and marine resource distribution. Surface waters of the Gulf of Guinea are warm (>24°C) (Binet, 1992). Salinity levels are mostly below 35 p.s.u. as a result of heavy rainfall and high river discharge during the wet season.

Conditions for coastal algal growth are also influenced by the numerous river runoffs, and both diffuse and point discharge of domestic and industrial waste. This to some extent have marked ecological implication for the marine waters of the Guinea Current as there are many instances of toxic waste discharge from industrial sources. River runoffs bring large loads of sediment enriched with nutrients into the shelfs carried from the fringing coastal lagoons and mangrove ecosystems along the coast of West Africa (Armah and Amlalo, 1998).
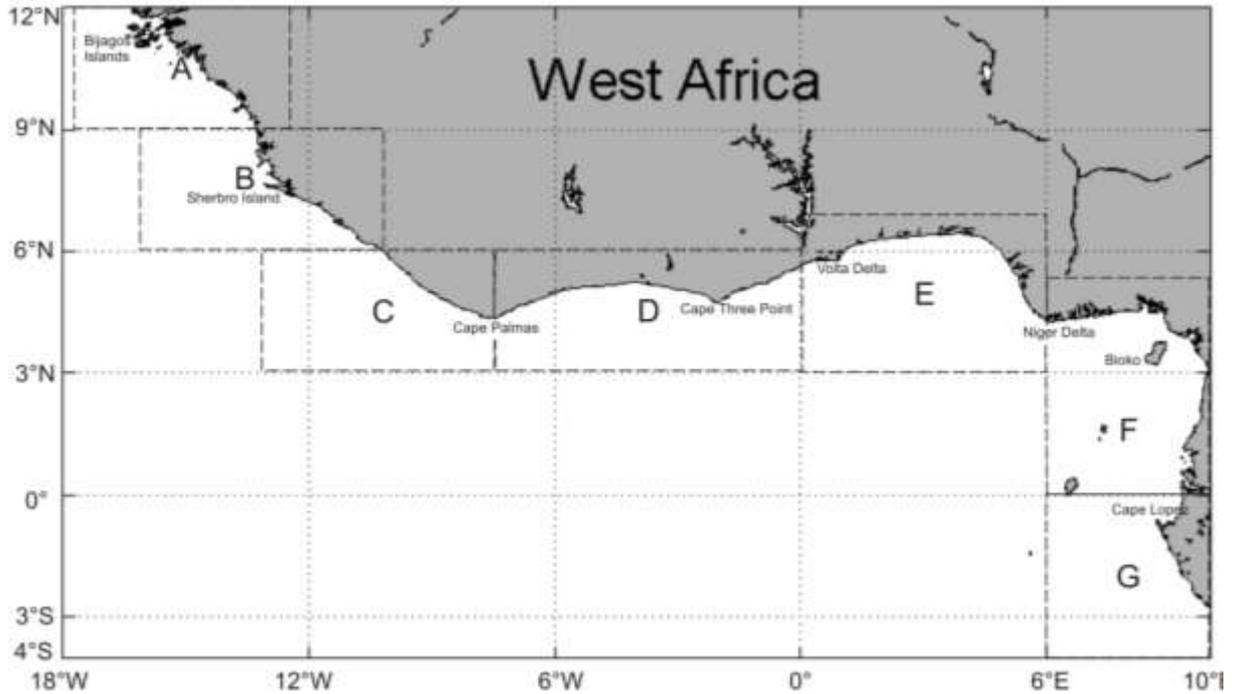
Figure 3.1   Map of the GCLME. Data for analysis were obtained from regions enclosed by broken lines (A, B, C, D, E, F and G).

3.2   Description of model

A depth integrated model (DIM) developed by Behrenfeld and Falkowski (1997b), was used for this study.   DIM is a Vertically Generalized Productivity Model that relates primary production (PP) to the surface chlorophyll concentrations (C_{surf}), integrated within the euphotic depth (Z_{eu}) for a day light period (DL). The model is of the form:

$$\sum PP = P^b_{opt} * f\,[PAR\,(0)] * DL * C_{surf} * Z_{eu} \qquad \text{(Equation 16)}$$

Since rate of carbon fixation gives a measure of efficiency of photosynthetic process, and an index of this (P^b_{opt}), was included in the model to factor in the rate of photosynthesis. Photosynthesis tends to decrease with depth due to decrease in the quality and quantity of light from absorption and scattering by dissolved and particulate matter. The f function in the model quantifies the fraction of carbon that is lost due to light limitation within the euphotic zone. This is an important parameter for a depth integration approach for estimating primary production.

The model for estimating primary production required derivation of Z_{eu} from attenuation coefficient, an F-ratio (f) function derived from irradiance at 551 nm, and P^b_{opt} from SST (see Equation 19). Z_{eu} was calculated from the relation between attenuation coefficient and the dimensionless value of optical depth (4.6) that received approximately 1% of surface irradiance:

$Z_{eu} = 4.6/k_d$ (Equation 17).

F-ratio was derived from the expression:

$F = [(0.66125 * E_o)/(E_o + 4.1)]$ (Behrenfeld and Falkowski, 1997b) (Equation 18), where E_o refers to surface irradiance at 551 nm.

Using Behrenfeld and Falkowski (1997a; 1997b) seventh order relationship between optimum chlorophyll fixation rate and sea surface temperature, P^b_{opt} from Equation 19.

$P^b_{opt} = 3.27*10^{-8}SST^7 + 3.4132*10^{-6}SST^6 - 1.348*10^{-4}SST^5 + 2.462*10^{-3}SST^4 - 0.0205SST^3 + 0.0617SST^2 + 0.2749SST + 1.2956$ (Equation 19)

Primary production was calculated as $\Sigma PP = C_{surf} * Z_{eu} * P^b_{opt} * DL * F$ (mg C m^{-2} t^{-1}), with day length (DL) approximated to 12 hours.

3.3   Data acquisition and processing

This study was carried out with remotely sensed 0.1 degree monthly composites ocean colour and sea surface temperature data from July 2002 to April 2007, obtained by the Moderate Resolution Imaging Spectroradiometer (MODIS - Aqua) and 0.25 degree monthly wind stress data obtained from QuickScat. Sea wind data had 113-by-65 matrix for each monthly scene. The primary data sets for estimating primary production were sea surface chlorophyll, attenuation coefficient at 490 nm, irradiance at 551 nm (i.e. photosynthetically available radiation), and sea surface temperature for the region extending between longitudes 18°W and 10°E, and latitudes 4°S and 12°N. The data were acquired using the GES-DISC Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni) as part of the NASA's Goddard Earth Sciences (GES) Data and Information Services Center (DISC).

ASCII data format acquired from Giovanni for all parameters were reshaped into a 161-by-281 matrix with all undefined and missing values replaced with NaN (Not-a-Number). Undefined and missing values were present largely at regions covering land and contaminated by cloud. Images were set to an equidistant cylindrical projection and overlaid with the coast of West Africa. Each different parameter for each month was concatenated along the third dimension to give a 3-D data of size 281-by-161-by-58.

Chlorophyll, primary productivity and SST were resized to a 113-by-65 matrix using nearest neighbour interpolation to enable sea wind data to match-up with the other four datasets for all statistical analyses in Matlab (Matlab, R2006b).

3.4   Data analyses

Monthly mean primary production (gC/m^2/month) and SST anomalies were generated to describe temporal and spatial variability patterns of primary production and SST. These images were examined to identify important oceanographic features as well as large scale patterns of seasonal. SST and sea wind stress were analyzed as potential climatic variables affecting ocean primary production.

In order to determine the possible effects of physical factors on primary production, the GCLME was segregated into seven sectors based on identifiable oceanographic characteristics of the region (Tilot and King, 1993) (Figure 3.1). Data for each grid was extracted by indexing the row and column numbers of the range of latitudes and longitudes for a grid through a 3-D matrix for a specific data along the third dimension. ANOVA and multiple comparison tests using Tukey's honestly significant difference criterion, were used to test differences in means of chlorophyll, SST and sea wind stress per grid.

Multiple regression analysis was used to assess how much variability in primary production was accounted for by SST and sea wind stress (SWS). The choice of these two factors was based on the fact that SST conveniently indicates availability of bottom nutrient-rich water during upwelling in tropical marine systems. Also, sea wind stress, though has been generally observed not to influence upwelling (Longhurst, 1962; Bakun, 1978; Binet, 1997), is believed to have localized impact on upwelling at some sections of the Guinea Current.

The model for the relationship is:

$$Y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \varepsilon,$$

where Y is estimated primary production, x_1 and x_2 indicate SST and SWS variables, respectively. β_1 and β_2 are the regression coefficient for SST and SWS, respectively, and ε represents the error or residual term. Statistical significance of all analysis were tested at alpha (α) = 0.05.

Power spectra analysis on SST and primary productivity was used to determine periodicity in data.

4.0   RESULTS

4.1   Seasonal and spatial distribution of primary productivity

4.1.1   Sierra Leone Guinea Plateau (SLGP)

Generally, primary production for oceanic regions for most periods did not exceed 100 gC/m^2/month and for coastal areas primary productivity ranged between 300 – 2000 gC/m^2/month. Spatial extent of chlorophyll was generally large in January increasing slightly between February and March around Bijagos Islands (Figure 4.1). This high level of primary production (approximately 300–2000 gC/m^2/month)

tapered, and moved as a tongue of bloom southwards to the Sherbro Islands. During April to May, spatial extent had decreased, with a slight increase in primary production in the western oceanic areas around Bijagos Islands (Figure 4.2). By June primary production levels were as low as 100 gC/m^2/month in the shelf regions of Sherbro Island, and with a narrow spatial distribution. Between July and September, primary production levels ranged between 100–1000 gC/m^2/month and were confined to the coastal margins extending south to Cape Palmas (Figure 4.3). During October to December coastal margins between Sherbro Islands and Cape Palmas had very high primary production levels (Figure 4.4).

4.1.2   Central West African Upwelling (CWAU)

In January, coastal regions had primary production levels ranging from 30–100 gC/m^2/month, but dropped considerably by March (Figure 4.1) where coastal oceanic waters seems to have almost the same primary production levels (not above 30 gC/m^2/month). High cloud cover at this region and in the EGOG during these months made no data available to estimate primary production. However, it is envisaged that primary production will be low since SST was generally warmer during those months. During April and May there was a very slight increase in primary production (Figure 4.2). Localized blooms can be seen at the Volta delta at levels approximately 100 gC/m^2/month. In June there was a sharp rise in production levels and a broader spatial distribution in primary production (Figure 4.2). There were numerous patches of blooms that ranged from 100 – 1000 gC/m^2/month on the continental shelfs, and a slight increase in primary production at the oceanic regions. Between July and September, coastal regions between Cote D'Ivoire and Ghana had high primary production, approximately between 1000-1200 gC/m^2/month (Figure 4.3). However, during July primary productivity on the coastal shelfs of Cote D'Ivoire were slightly higher than at the coast of Ghana though SST was lower of the coast of Ghana than in Cote D'Ivoire.   By October, primary production levels were receding. At the coast of Ghana primary production did not exceed 100 gC/m^2/month, however, at the eastern coast of Cote D'Ivoire production ranged between 100-200 gC/m^2/month (Figure 4.4). By December, primary productivity at CWAU was at its lowest not exceeding 100 gC/m^2/month.

4.1.3   Eastern Gulf of Guinea (EGOG)

Generally, April to June showed low production in the EGOG, except coastal margins off Niger Delta that had high primary production levels (Figure 4.2). During July to September there was slight increase in spatial distribution and levels in primary productions (Figure 4.3). Oceanic and coastal primary productions did not exceed 100 gC/m^2/month and 1200 gC/m^2/month, respectively. In October primary production levels not exceeding 1200 gC/m^2/month were confined to the coastal margins from Benin to Cape Lopez in Angola (Figure 4.4).

4.1.4 Equatorial Waters and north of the Angolan Front

Primary production peaked from July to September (Figure 4.3), and then receded drastically between January and March (Figure 4.1). Maximum primary production was approximately 500 gC/m^2/month during August at the Angolan front, and approximately 300 gC/m2/month along the stretch of water between 0-3°S (Figure 4.3).
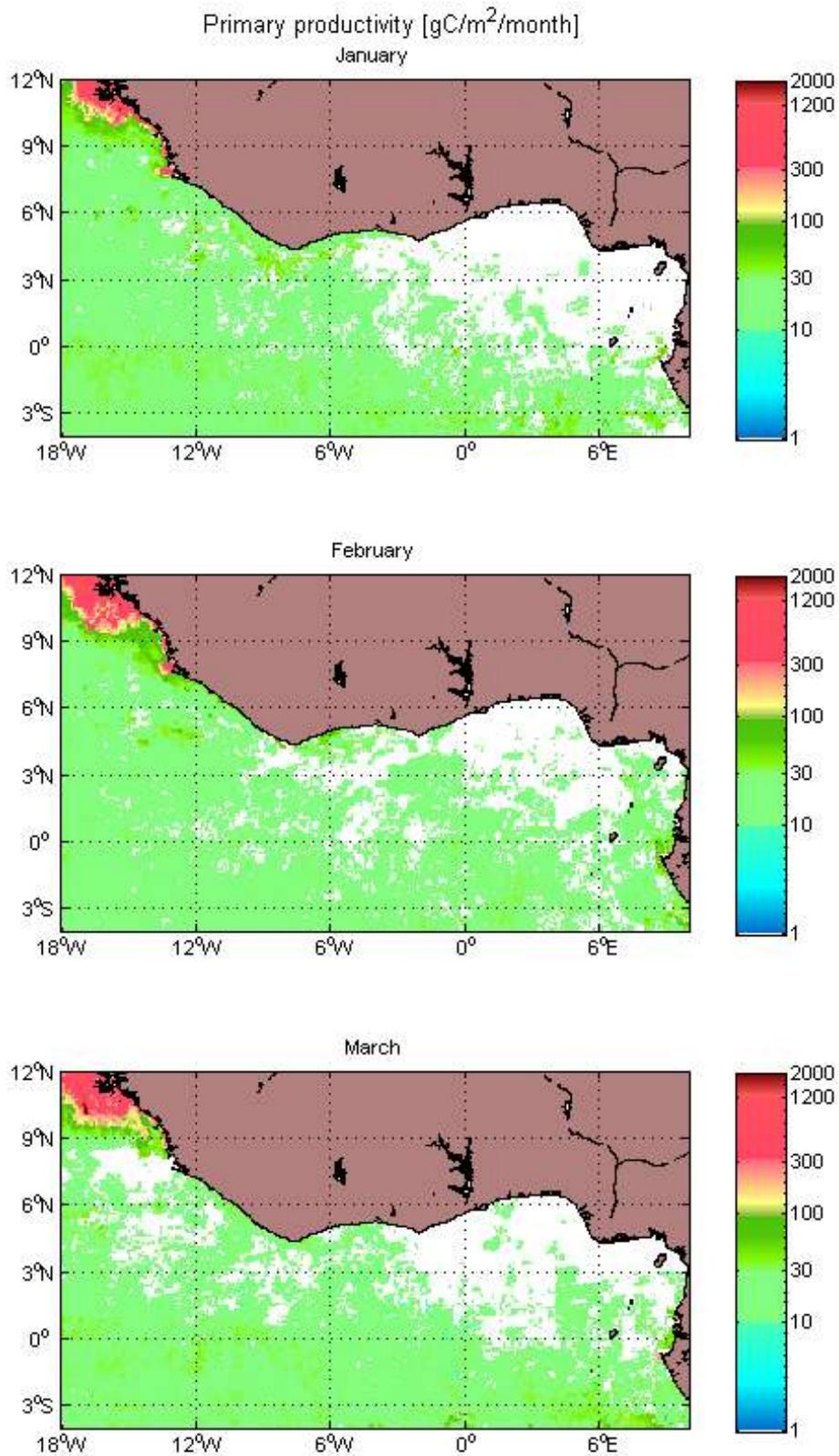
Figure 4.1 Monthly mean primary productivity (gC/m^2/month) for January to March in the GCLME from July 2002 to April 2007.
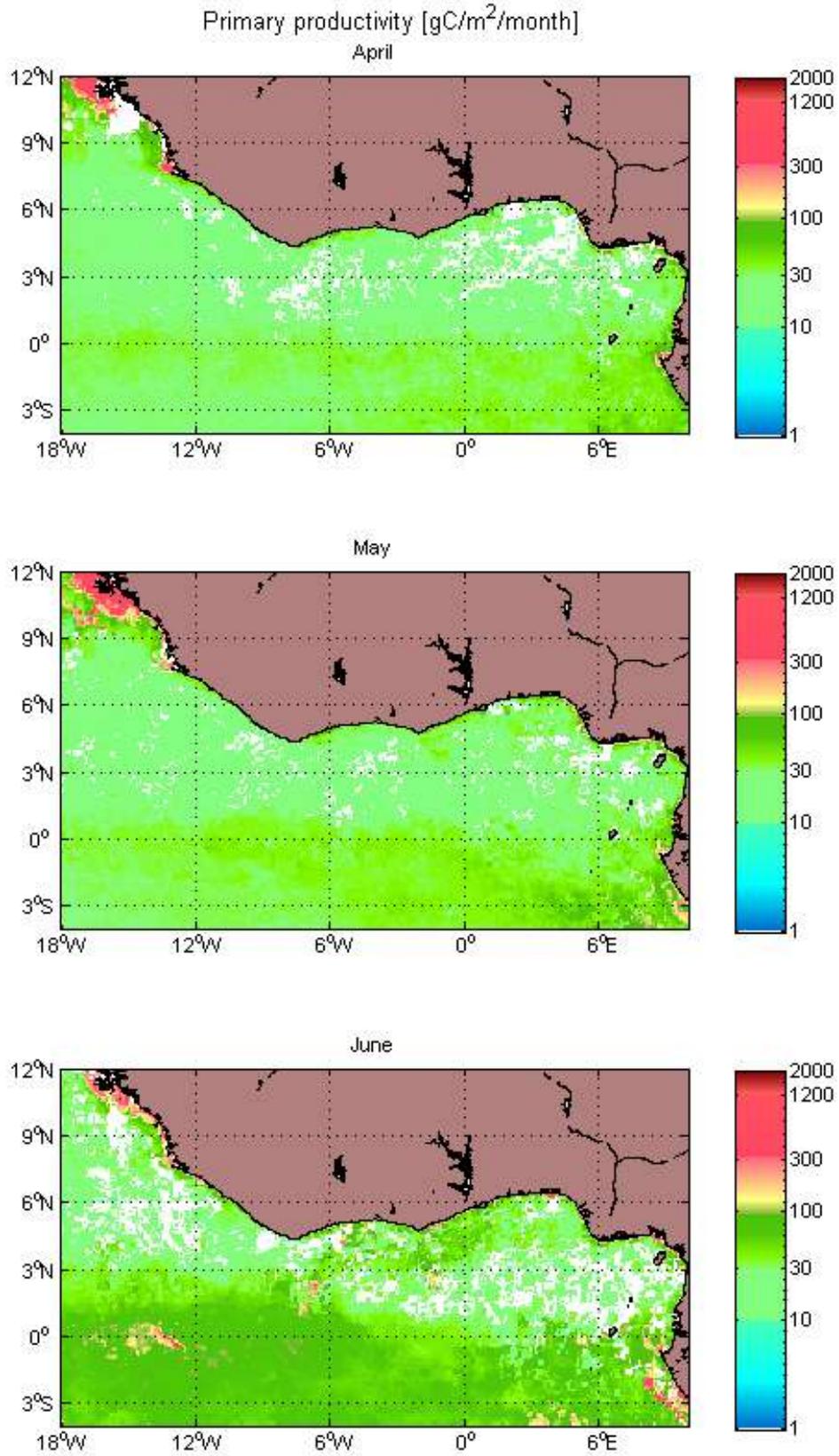
Figure 4.2 Monthly mean primary productivity (gC/m^2/month) for April to June in the GCLME from July 2002 to April 2007.
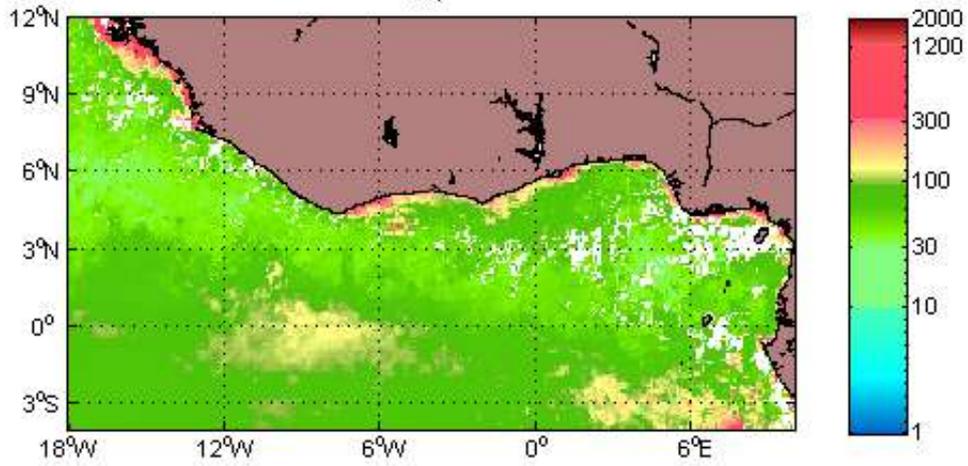
Primary productivity [gC/m^2/month]
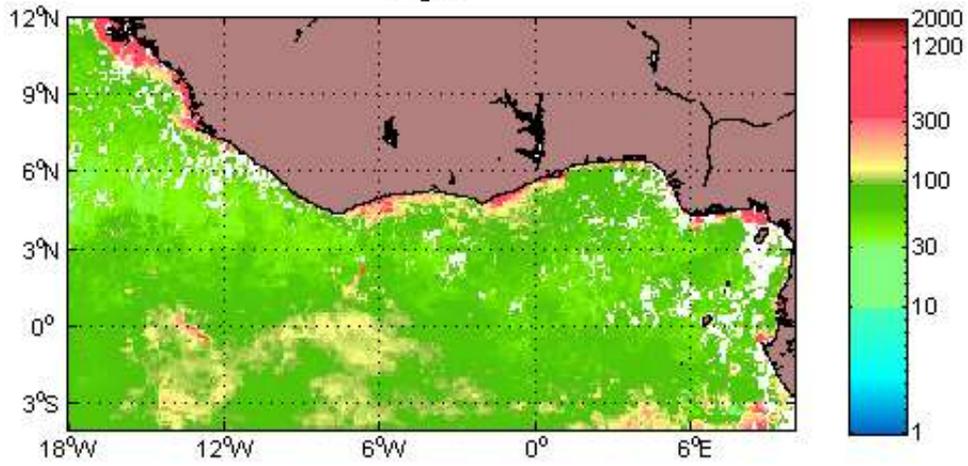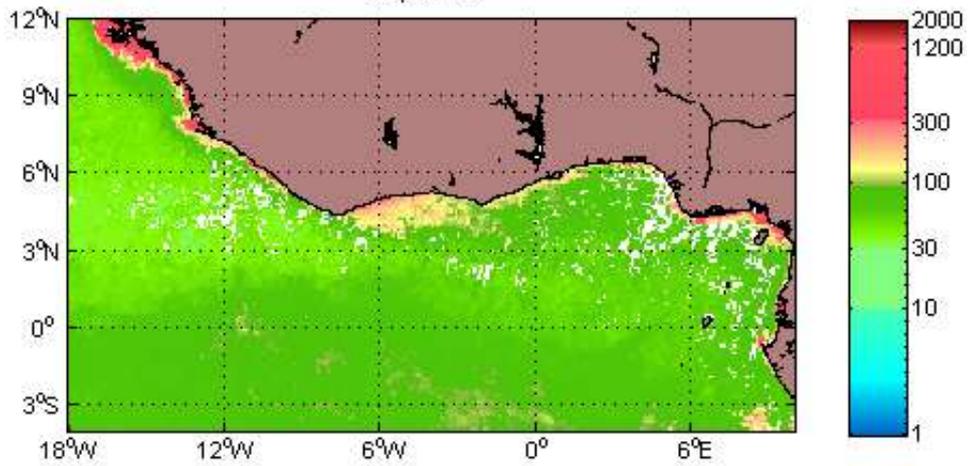
Figure 4.3 Monthly mean primary productivity (gC/m^2/month) for July to September in the GCLME from July 2002 to April 2007.
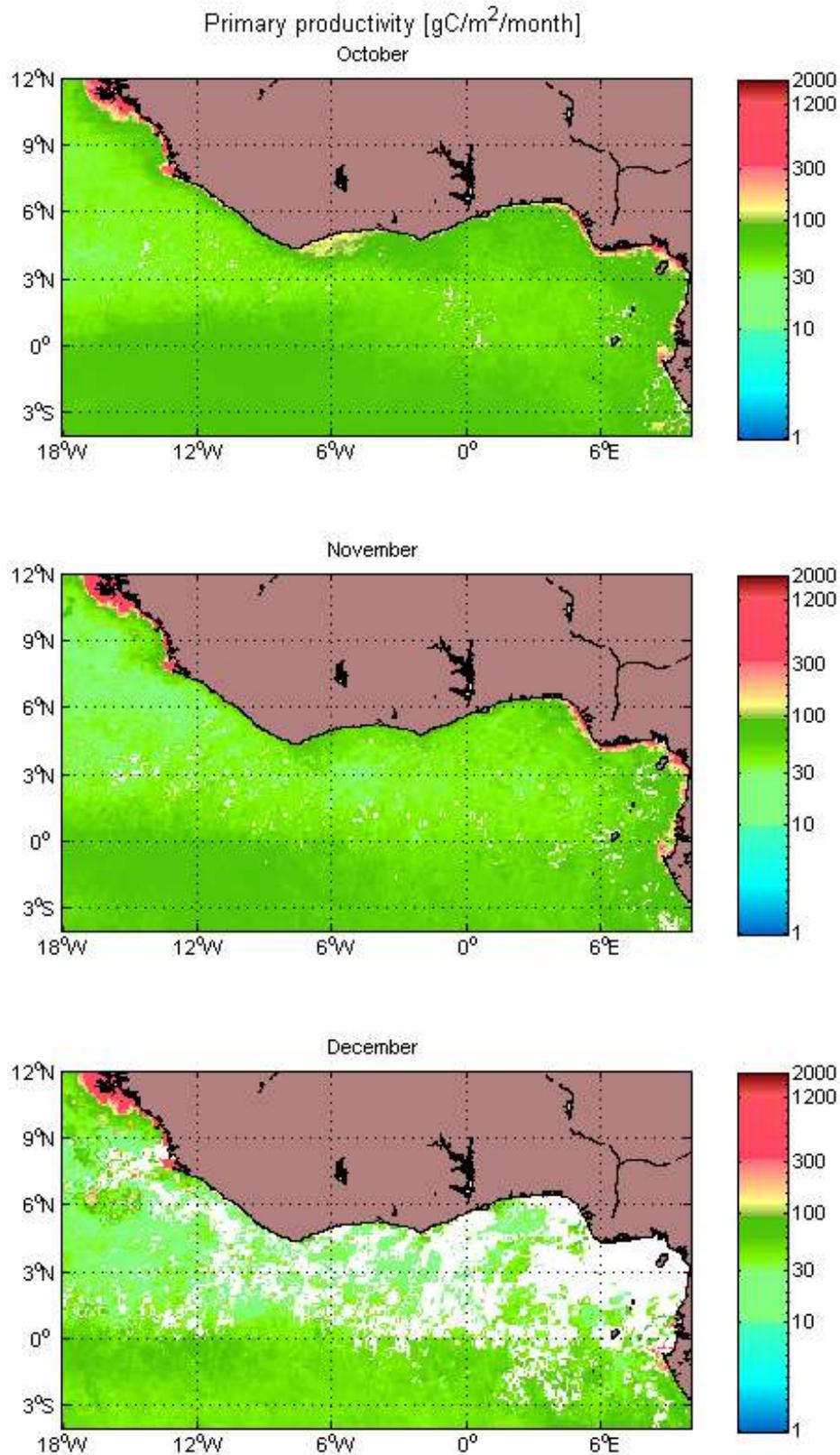
Figure 4.4   Monthly mean primary productivity (gC/m^2/month) for October to December in the GCLME from July 2002 to April 2007.

Primary productivity at grids

Highest primary production was observed at Grid A, and the lowest at Grid C (Figure 4.5, Figure 3.1). Apart from Grid A, with interquartile monthly production ranging between 200-400 gC/m^2/month, other maximum production for all other grids did not exceed 100 gC/m^2/month.
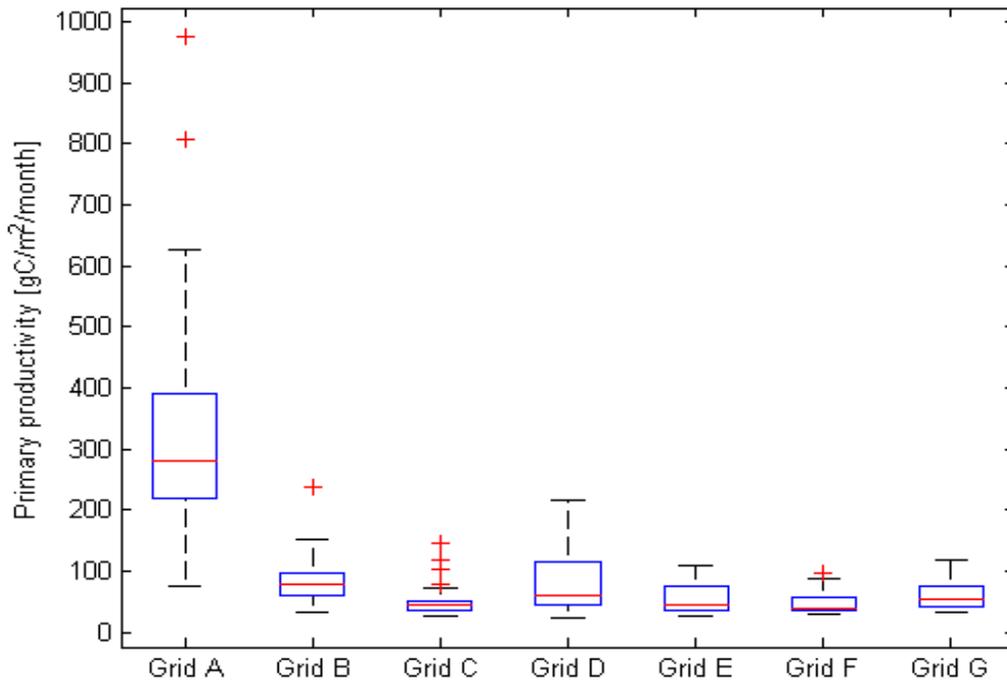
 Figure 4.5 Box plot for mean primary productivity per grid for all months between July 2002 to April 2007.

Results of mean primary productivity showed two distinct production regions: coastal and oceanic (Figure 4.6). Coastal productivity estimates ranged between 100–2000 gC/m^2/month, whiles oceanic productivity did not exceed 100 gC/m^2/month. Very low region of primary productivity between 30–50 gC/m^2/month were observed between the continental shelfs of Sierra Leone and Liberia as well as along the path of the North Equatorial Counter Current. Primary productivity in the equatorial waters was between 80 – 100 gC/m^2/month
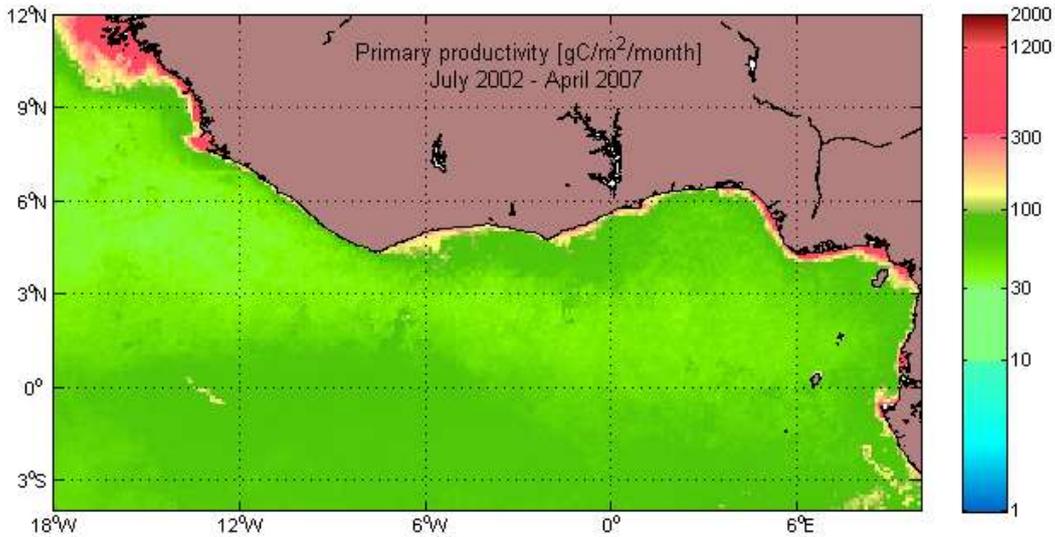
Figure 4.6 Mean monthly primary productivity in the GCLME between July 2002 to April 2007.

Regression analysis on primary production (PP) against SST and sea wind stress pooled for all grids and months indicated SST and sea wind stress significantly explained 36.1% and 1.2%, respectively of the variability in primary production distribution ($p<0.01$). Both SST and sea wind stress together significantly explained 37.3% of the variability.   The equations below give linear regression model for primary productivity estimated from of SST:

PP = -8.30 SST + 270.71   (Equation 20)

Results from time-longitude plots showed primary production spanned the entire year at Grids A & B (Figure 4.7(a-b)), which were characterized by two periods of minimum and maximum cooling and warming (Figure 4.20). Primary production at Grids C, D, E, F & G peaked between July and September (Figure 4.7(c-d)). Spatial extent of primary productivity increased from the end of maximum warming (October-December) to the end of minimum cooling (August), coinciding with influx of the SUI at Grid A (Figure 4.20). At Grid B slight increase in primary productivity occurred at a period when there was a very small decrease in temperature during February and August (Figure 4.7(b), Figure 4.20). Primary productivity at Grid C, D, E, F & G increased during periods of coastal upwelling between July and September, at the same period when equatorial and Benguela upwellings were intense (Figure 4.7(c-e))

4.1.6   Spectral analysis of primary production per grid

Power spectra generated from spatially averaged monthly primary productivity between July 2002 and April 2007 for each grid showed three distinct peaks at Grid A, two distinct peaks at Grids B and C, and a single peak at Grids D through to G (Figure 4.8).   The major peak in the spectral plot supports seasonal peaks in chlorophyll (Figure 4.18) and the associated drops in SST (Figure 4.20). Bi-annual to quarterly minor peaks at Grids A-C which are comparatively stronger than biannual peaks at Grids D-G explains almost an all year high primary productivity in the northern regions of the GCLME. The third peaking at 54 months at Grid B could be attributed to an anomaly in data.
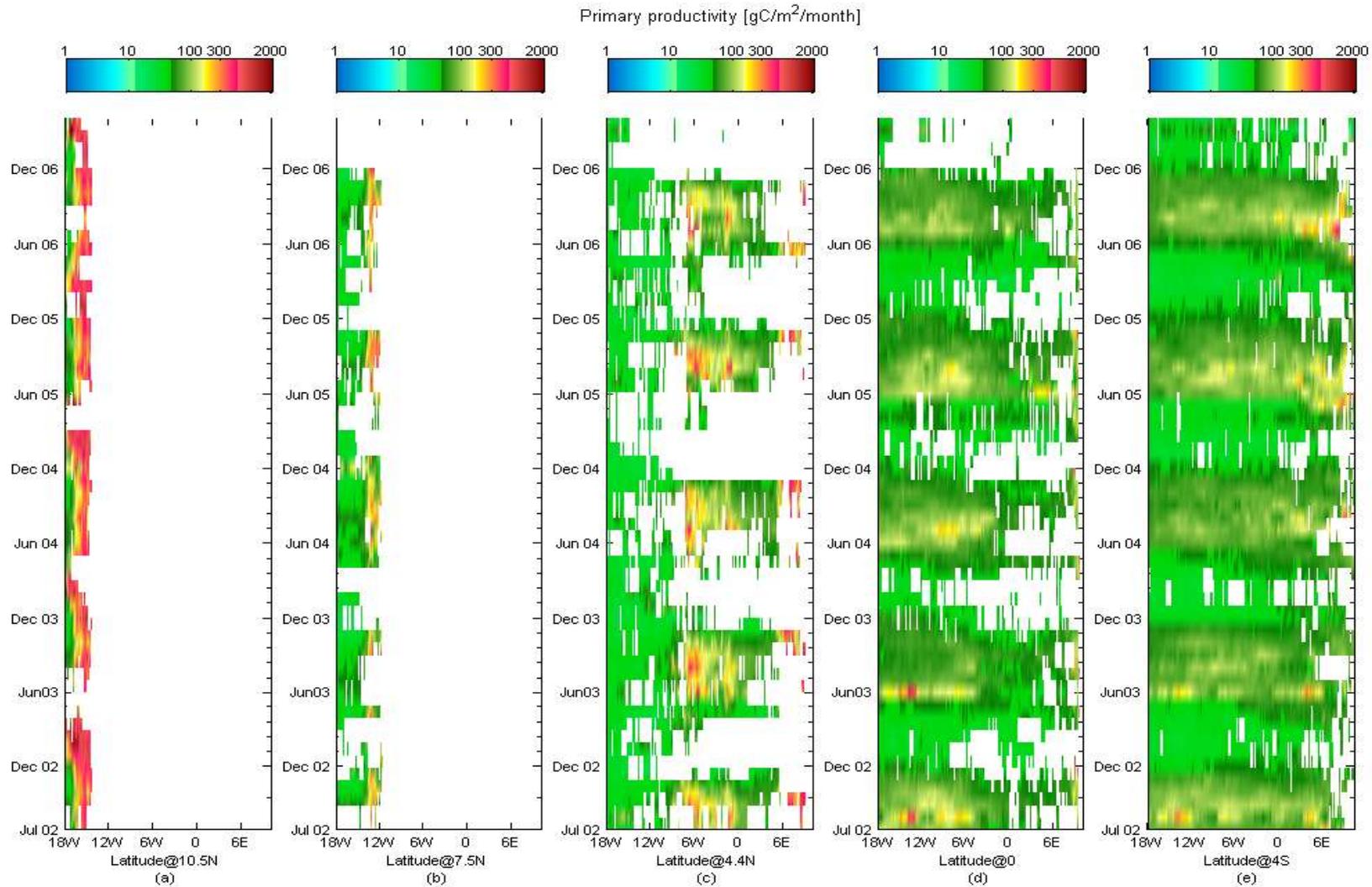
Figure 4.7 Spatially averaged latitudinal monthly primary productivity of the GCLME. White patches are regions with no data due to cloud contamination or land cover.
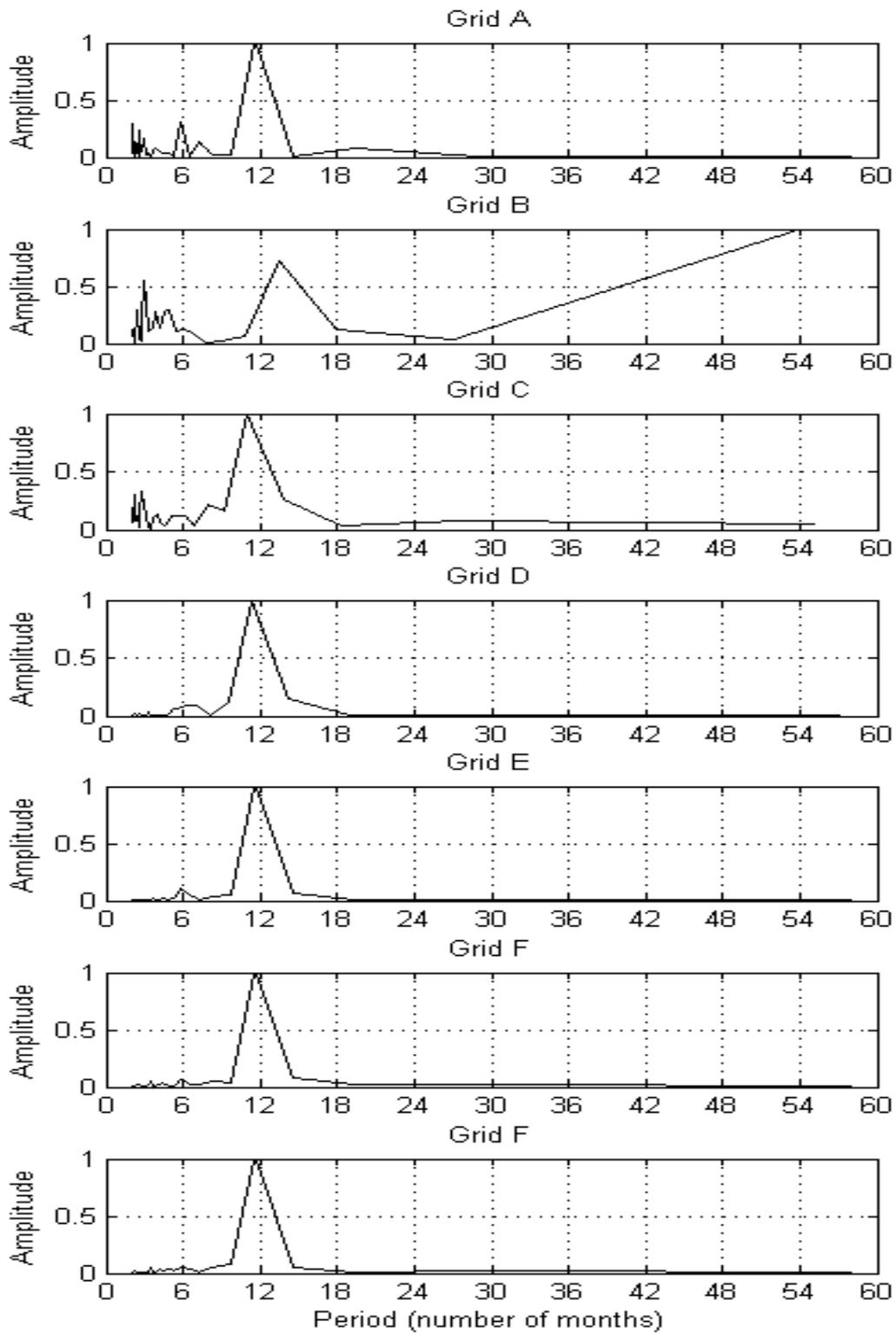
Figure 4.8 Power spectra of spatial mean primary productivity for each grid.

4.2   Seasonal and spatial variability in SST

4.2.1 Sierra Leone Guinea Plateau (SLGP)

During January, cold water not exceeding 23°C originating from the Senegalese-Mauritanian coastal upwelling (termed the Senegalese Upwelling Influence (SUI)) encircled the Bijagos Islands; this water gradually warms as it moved southwards to approximately 27°C at coastal and oceanic waters off Sierra Leone (Figure 4.9). Between February and April, there was significant drop in SST which developed as a strong thermal front with the southern warm water. Warming of coastal waters began in May (Figure 4.9). This is coincided with the broadening of the warm waters off the coast of Sierra Leone. Between June to September, SST fluctuated between 26-28°C (Figure 4.10-11)) until it stabilised during October to December at approximately 29°C (Figure 4.12). In December, SST around the Bijagos began to drop gradually and developed into a front in January.

4.2.2 Central West African Upwelling (CWAU)

Coastal waters with SST at 26°C in January gradually warmed to about 29°C in May (Figure 4.9), until in June when both coastal and oceanic waters reached temperatures between 25-26°C. From June till September, SST dropped as low as 21°C in August when the upwelling was intense (Figure 4.10-11). The coldest waters were on the continental shelfs off Ghana. There was a weak front during this period as SST in the entire CWAU was reduced from the coast to the equator. By October, SST had slightly increased, as coastal waters off the coast of Togo and Benin were between 27-28°C, and during November coastal waters were as high as 29°C (Figure 4.12). In December, there was a slight drop in SST relative to the surrounding oceanic waters at the western coast of Cape Palmas and Cape Three Points (Figure 4.12). At this period coastal SST were not below 26°C with oceanic regions reaching as high as 29°C which marked the beginning of the minor upwelling that last till January.

4.2.3 Eastern Gulf of Guinea (EGOG)

SST in January was approximately 28°C with few patches of colder water at the coast off Cotonou and warmer patches at coastal as well as oceanic regions off Cameroon (Figure 4.9). Between February and March the entire EGOG had SST ranging from 28 – 30°C (Figure 4.9). During April to May, there was gradual intensification in the northward flowing Benguela as well as the westward flowing South Equatorial Currents, respectively, which decreased SST to about 25°C at the southern fringes (Figure 4.10). By June SST at the oceanic regions were predominantly between 23–26°C with a few patches near Cotonou at about 28°C (Figure 4.10). In July SST decreased to approximately 25 °C and two weak fronts developed at the south along the equator and the north near the upwelling centers of the CWAU. There was a slight drop in SST in August, until in September when there was a steady rise in SST

(Figure 4.11). Between October and December, SST continued to rise as warm water, at approximately 28°C, pushed south reaching as far as Cape Lopez, Angola. Coastal SST were slightly higher during those months (Figure 4.12).

4.2.4 Equatorial Waters and north of the Angolan Front

During January SST at the eastern portions were warmer (at about 27°C) and steadily decreased towards the west to about 25°C. From February to March, there was significant change with two distinct temperature distributions; a relatively warmer eastern portion and a colder western portion. In April the entire region had an even SST distribution and had increased to about 28°C (Figure 4.10). By June SST in the entire region does not exceed 24°C with a few isolated patches at 21°C. During July and September the entire equatorial region had SST between 20 and 22°C (Figure 4.11). By October, SST began to increase and in December SST was approximately 25°C increasing slightly to about 27°C towards the coast of Angola (Figure 4.12).
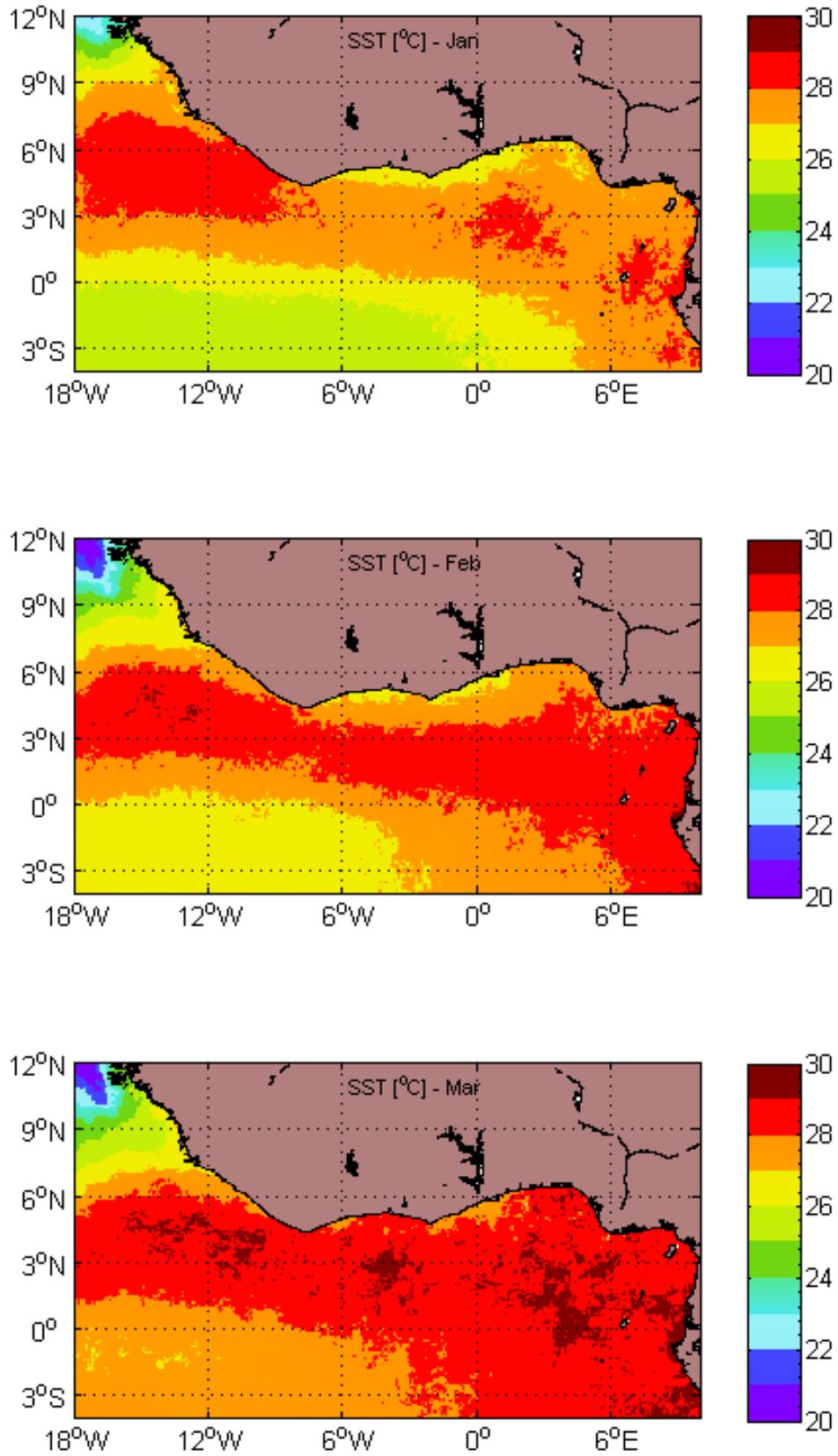
Figure 4.9 Monthly mean SST for January to March in the GCLME from July 2002 to April 2007.
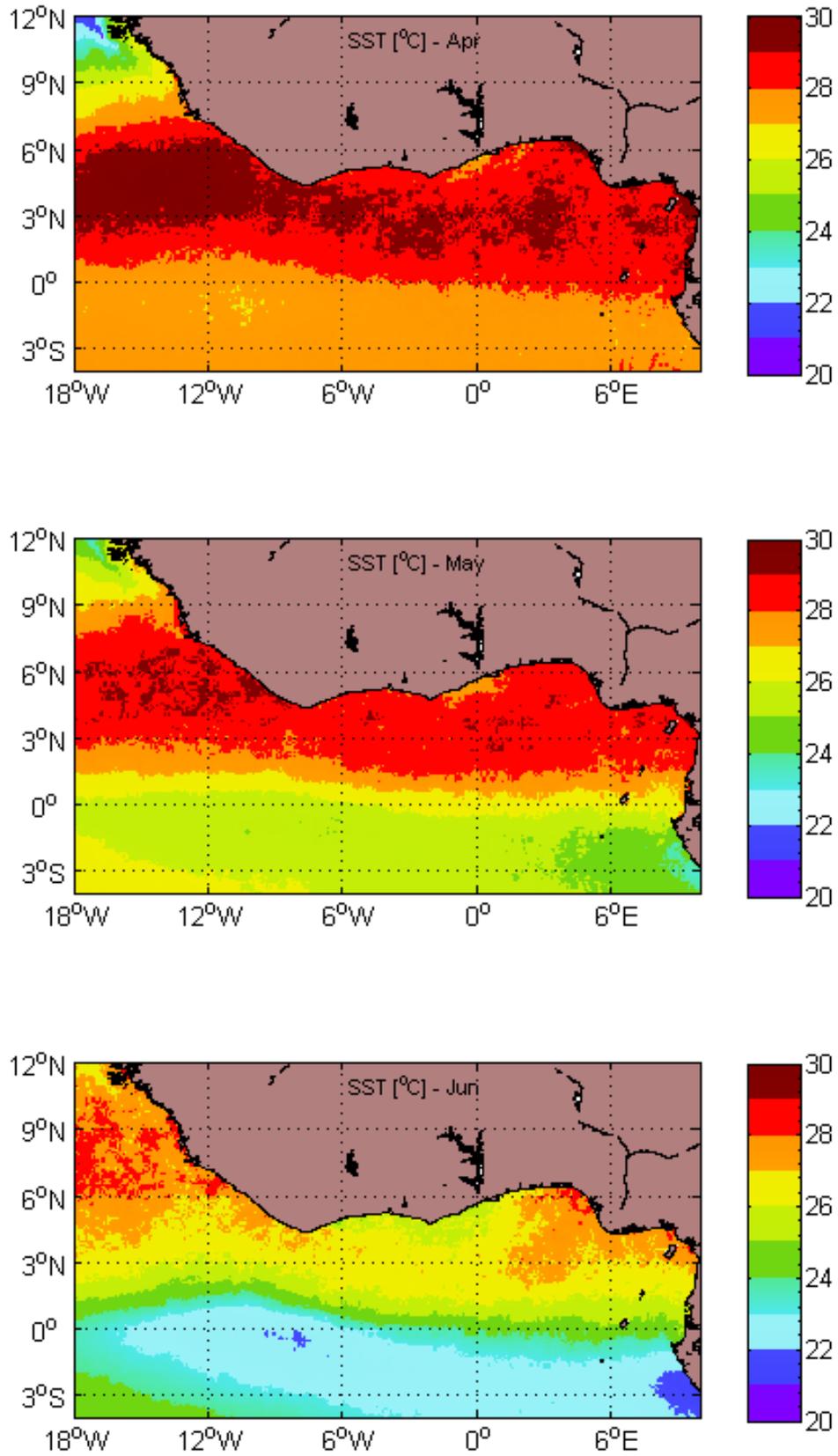
Figure 4.10 Monthly mean SST for April to June in the GCLME from July 2002 to April 2007.
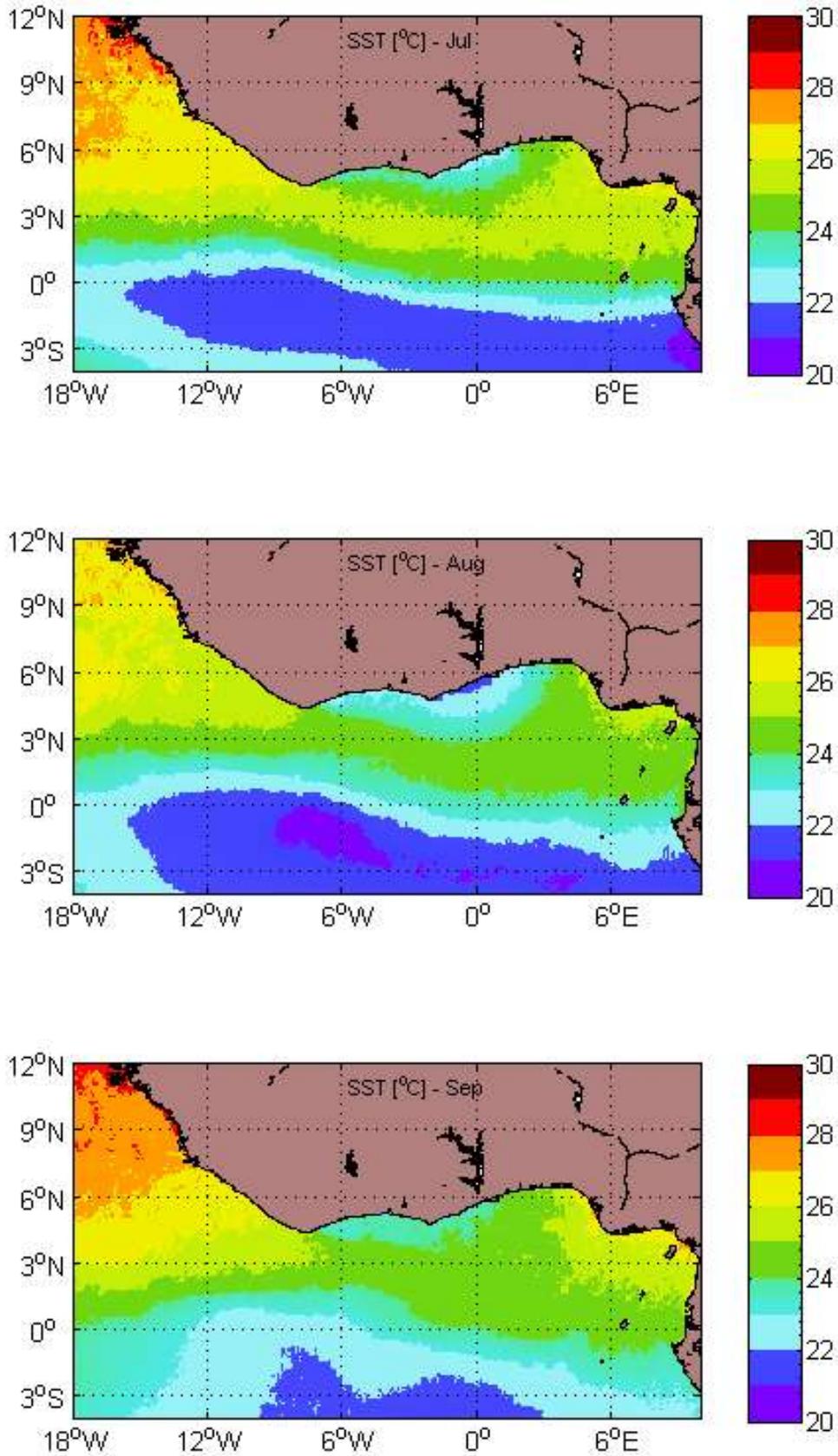
Figure 4.11   Monthly mean SST for July to September in the GCLME from July 2002 to April 2007.
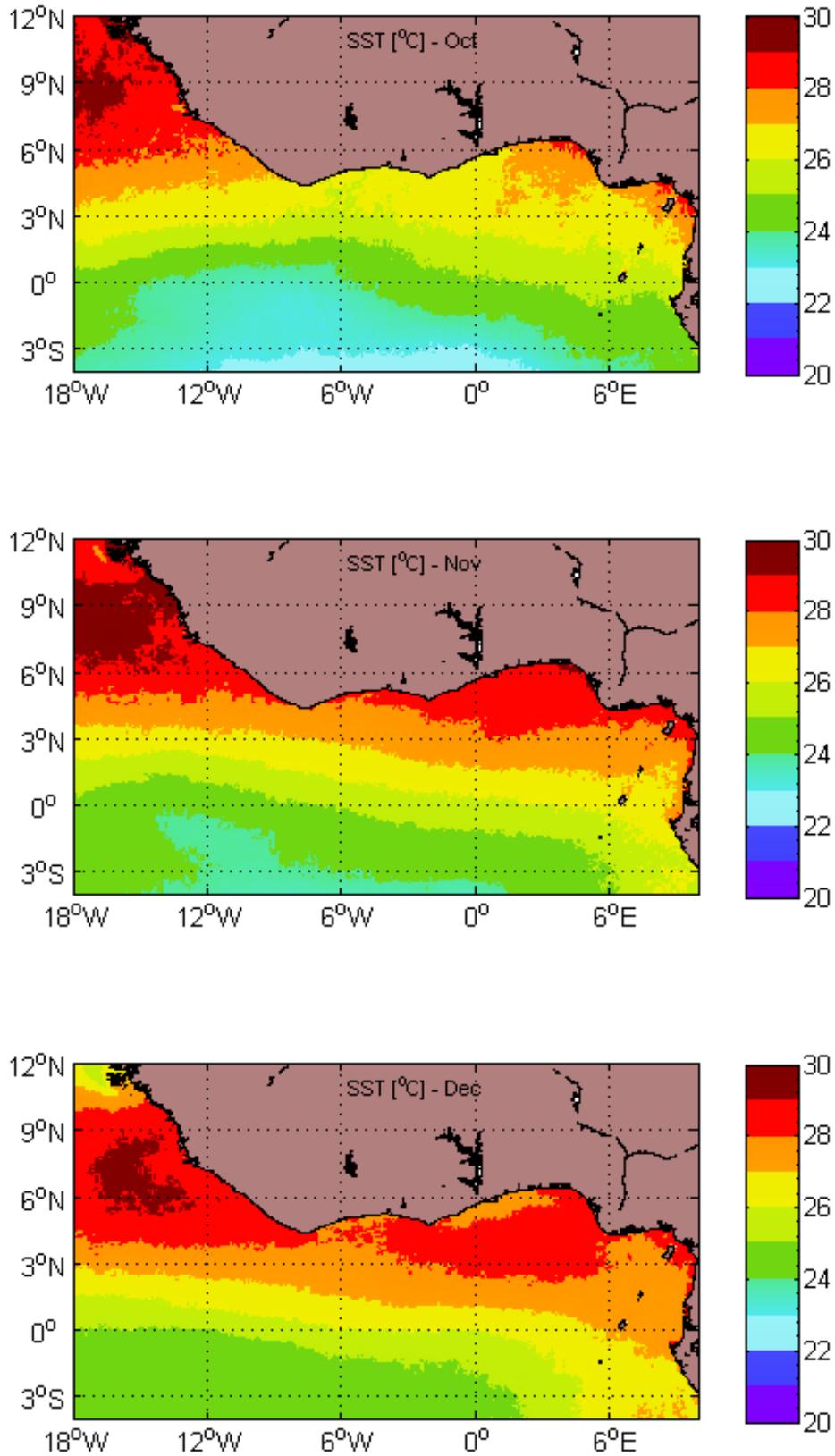
Figure 4.12 Monthly mean SST for October to December in the GCLME from July 2002 to April 2007.

Generally, SST in the entire GCLME showed four hydrographic seasons; two periods of both low and high temperature (Figure 4.13). The minimum and maximum low temperatures occurred in August and between January to February, whilst minimum and maximum high temperatures occurred in October and April, respectively.
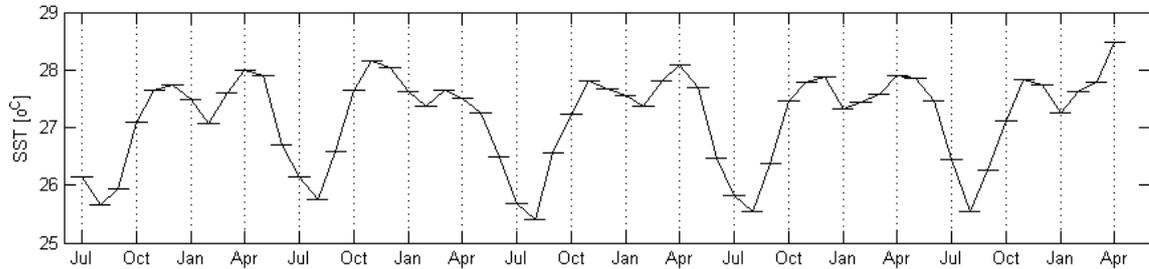
Figure 4.13   SST time series from spatial means of grids from July 2002 to April 2007.

Hovmuller plots further showed the magnitude of the hydrographic seasons in the GCLME, with certain areas showing varying time span. Along latitude 10.5°N the strong presence of cold water that possibly emanated from the Canary Current as the SUI lasted from December to June (Figure 4.14(a)). Between June and December there were two very brief moderately warm and cold periods. Southward at latitude 7.5°N there was slightly warm lengthy periods which were separated by a very slight drop is SST during March and August (Figure 4.14(b)). Along latitudes 4.4°N, 0° and 4°S drop in SST began in July till October to December when SST increased (Figure 4.14(c-e)). The cold periods marked the major coastal upwelling off the coast of Cote D'Ivoire-Ghana and the equatorial upwelling.
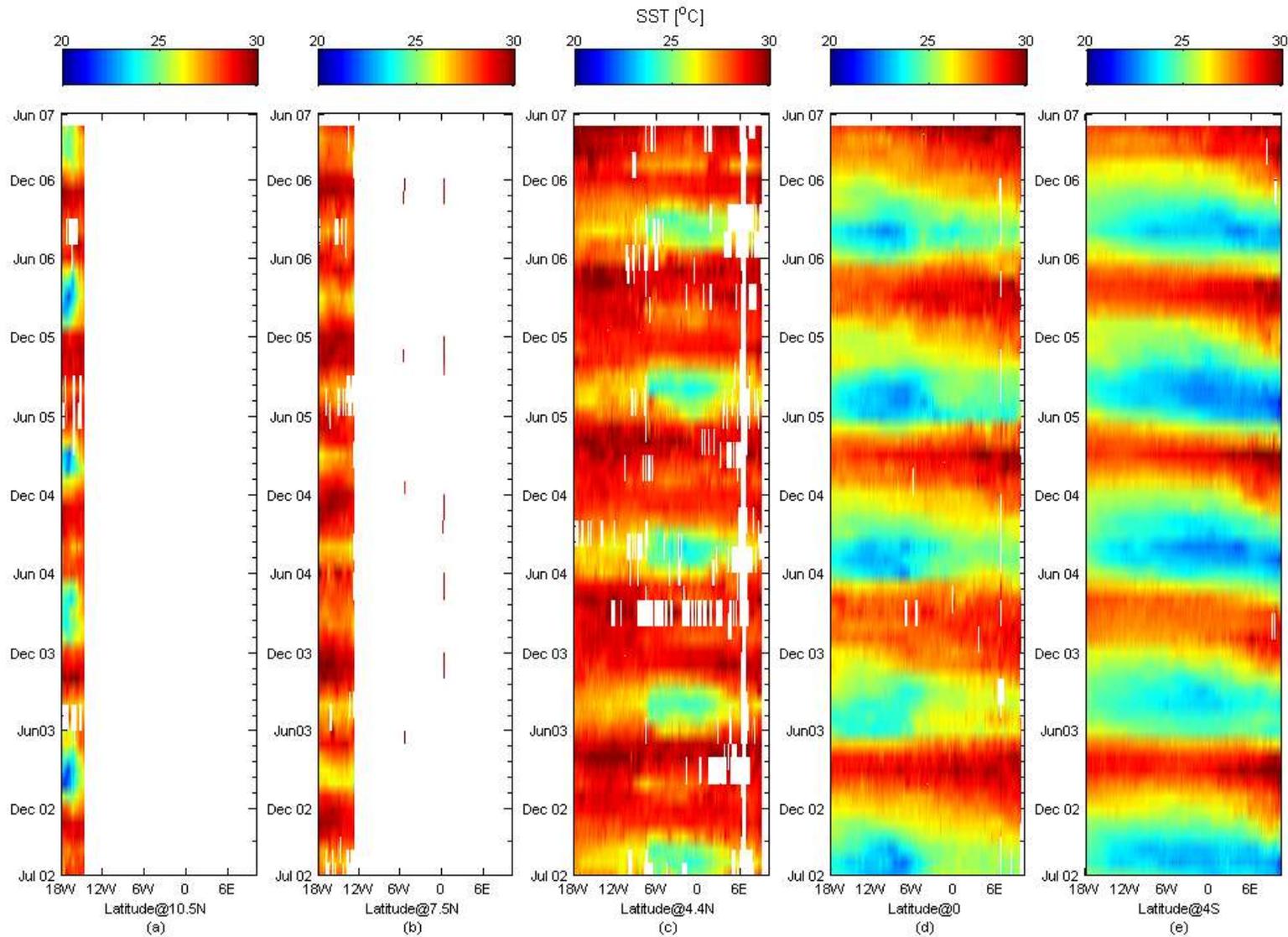
Figure 4.14 Spatially averaged latitudinal monthly SST of the GCLME. White patches are regions with no data due to cloud contamination or land cover.
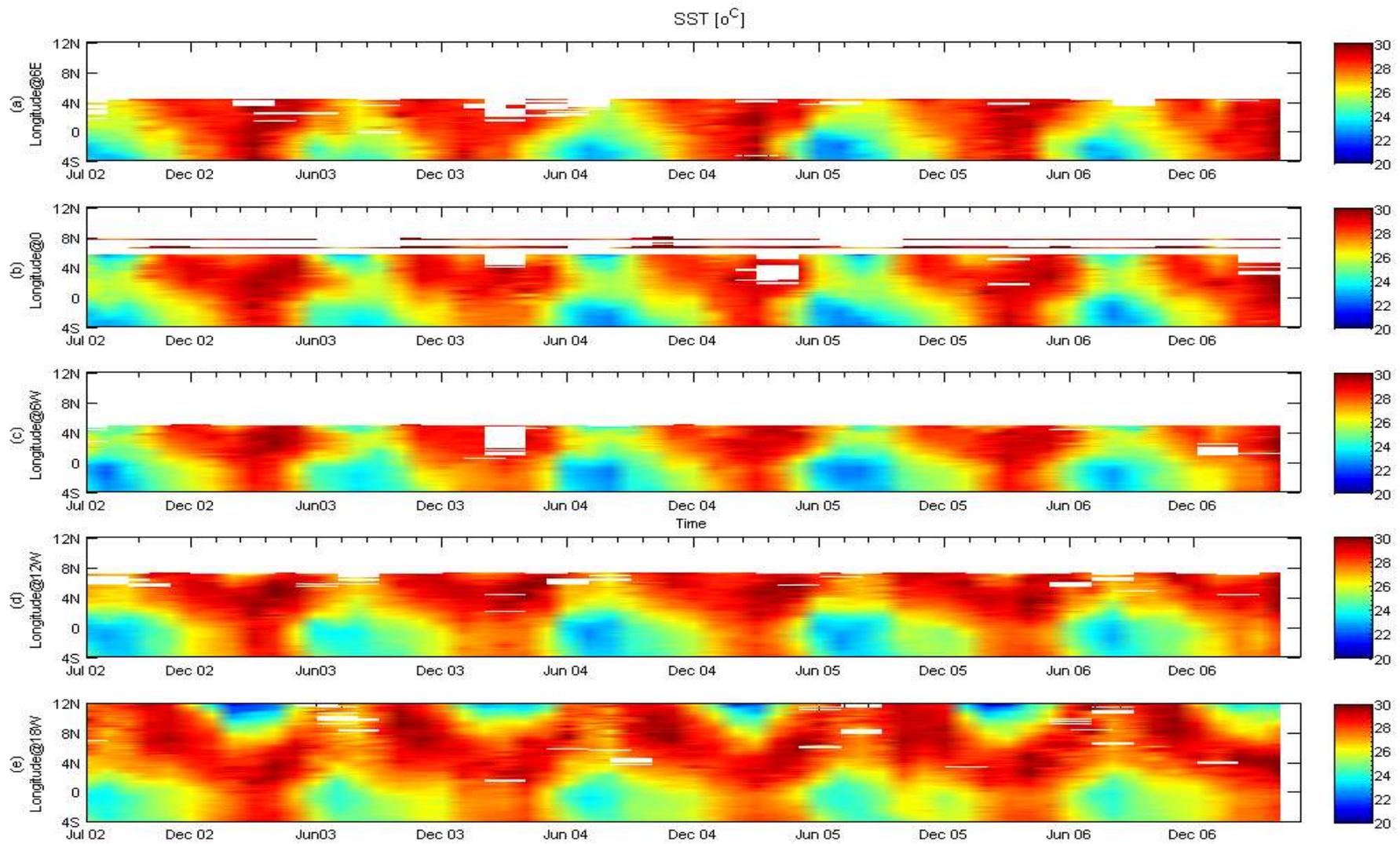
Figure 4.15 Spatially averaged longitudinal monthly SST of the GCLME. White patches are regions with no data due to cloud contamination or land cover.

Along longitude 6°E the almost perennial warming at the Niger Delta was evident (Figure 4.15(a)), except in August when the impact of the coastal upwelling off Cote D'Ivoire-Ghana broke this trend. From Figure 4.15(b-e) the alternating intensity and influence of the Canary at the northern limit as well as the Benguela and South Equatorial Currents was observed. Small deviations in SST observed off the coast of Sierra Leone and Liberia i.e. Grids B & C, is seen here as persistent warm water at all seasons between latitudes 4-8°N.

4.2.5   Spectral analysis of SST per grid

Power spectra generated for the spatial mean values for SST over the study period showed two distinct peaks for all grids, explaining seasonal fluctuations in SST (Figure 4.16). For all grids, there was a strong annual peak in SST and a slightly weaker bi-annual peak. This was different for Grid B which had a stronger bi-annual peak and a moderate annual peak within a season.
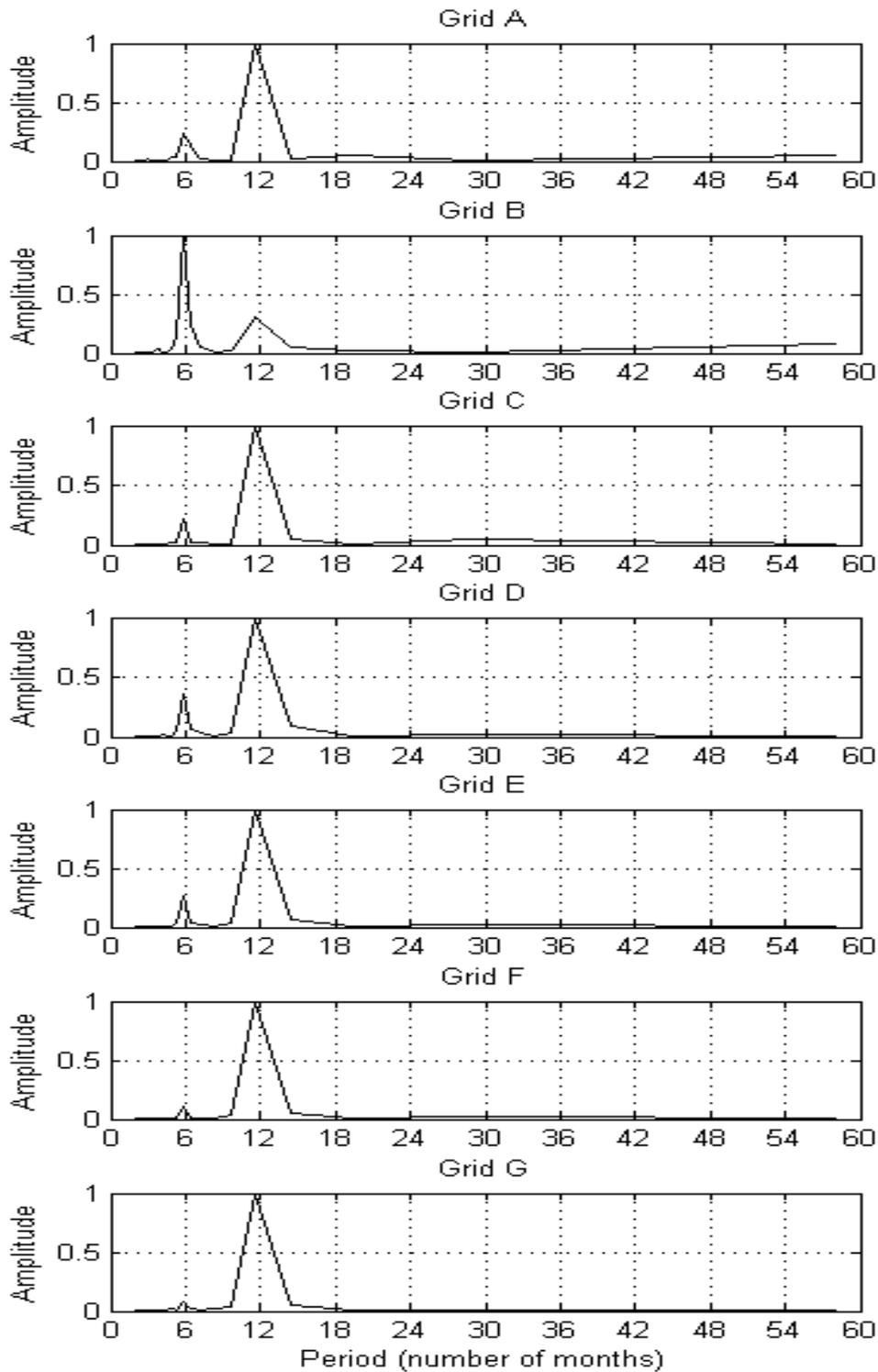
Figure 4.16 Power spectra of spatial mean SST for each grid.

DIFFERENCES IN CHLOROPHYLL, SEA SURFACE TEMPERATURE AND SEA WIND STRESS AT GRIDS

4.3.1 Chlorophyll

Chlorophyll level was highest at Grid A and lowest at Grid C. ANOVA test on mean chlorophyll levels for all months indicated significant difference between grids ($p<0.05$) (Figure 4.17). Further analysis using multiple comparison test indicated that chlorophyll levels at Grid A differed from all other grids ($p<0.05$).
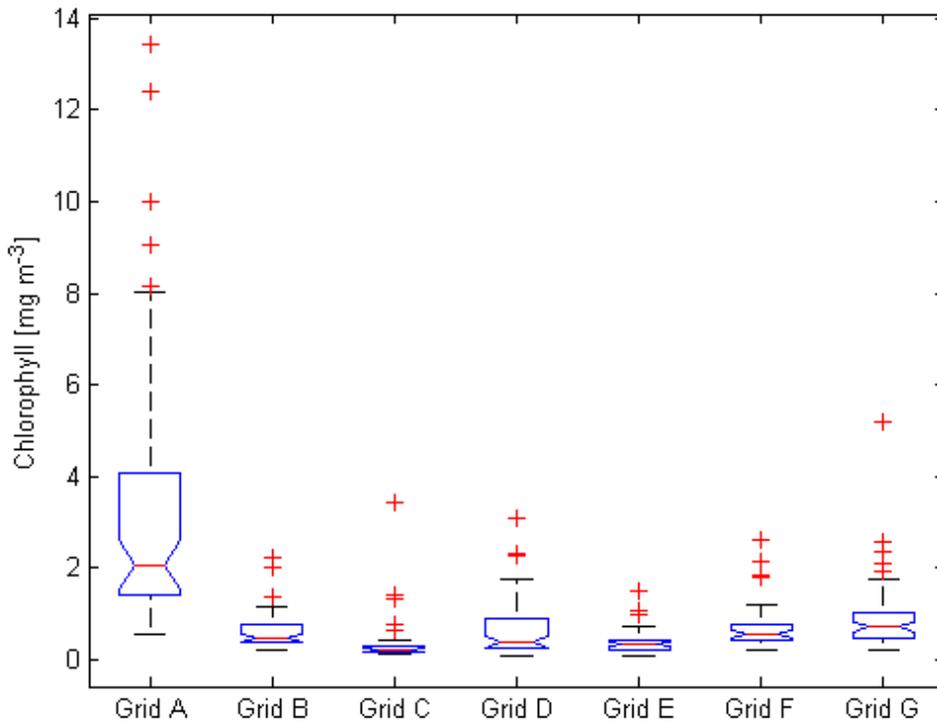
Figure 4.17 Box plot for mean primary productivity per grid for all months between July 2002 to April 2007.

At Grid A chlorophyll peaked during February and were lowest during July and October. Chlorophyll at Grids B, C, D, E, F & G for most periods did not exceed 2 mgC m^{-3}, peaking only between June and August (Figure 4.18).
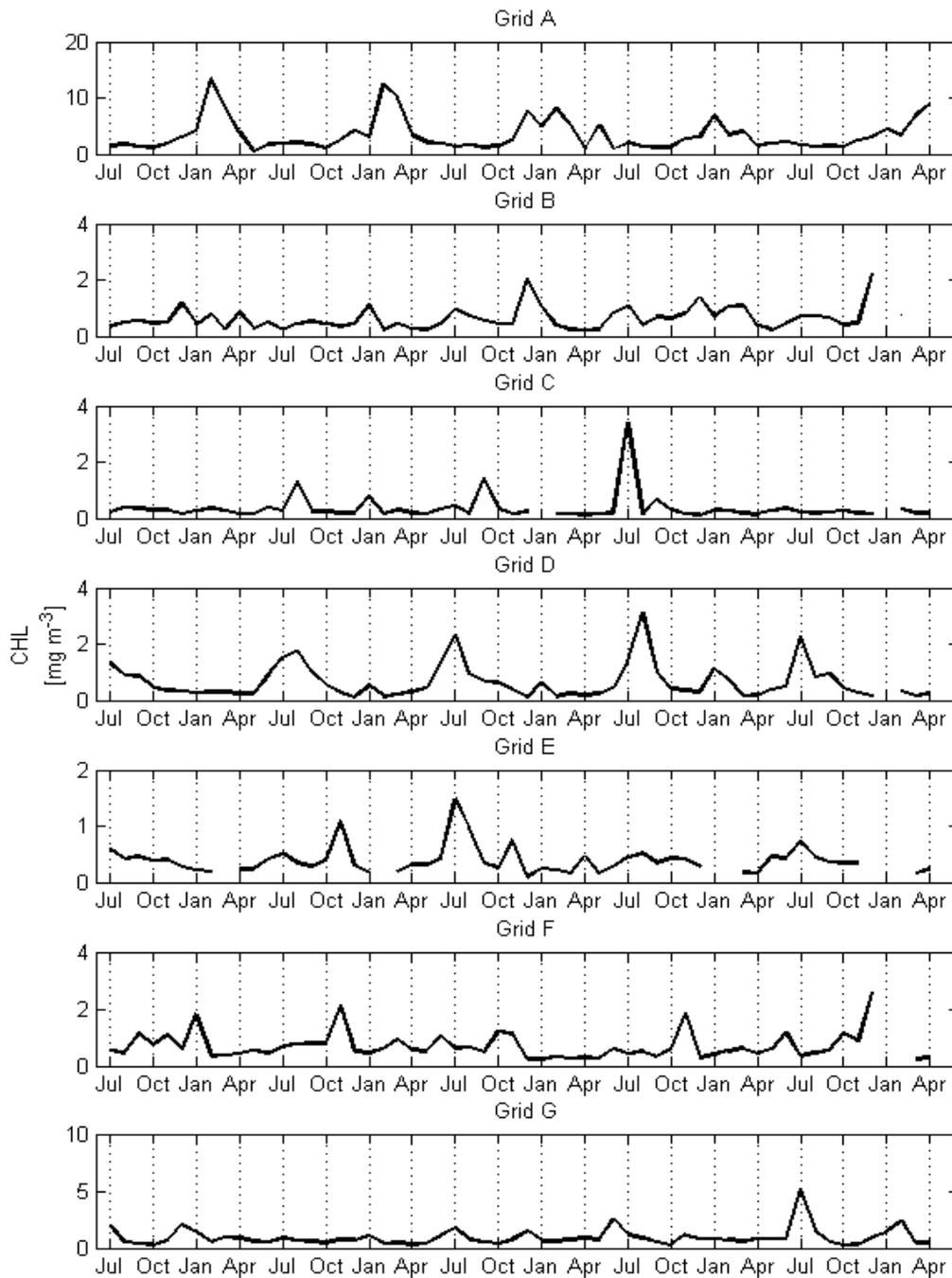
Figure 4.18 Spatially averaged monthly chlorophyll levels from July 2002 to April 2007 for Grids A – G.

Sea surface temperature

Comparatively, Grids A & G were colder whist Grid B was the warmest (Figure 4.19). Test of difference for all months at all grids showed significant difference in SST ($p < 0.05$). From the data shown in Figure 14, SST differed at grids shown in Table 4.1.
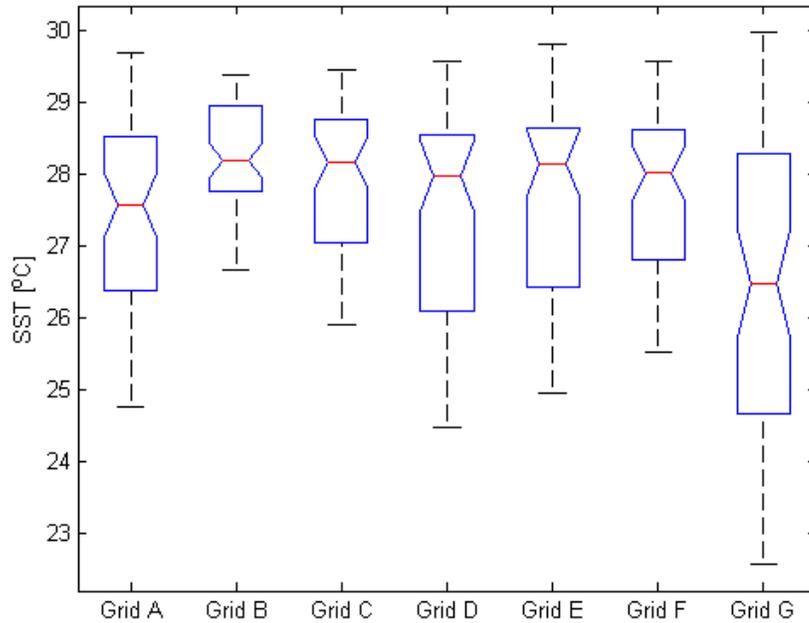
Figure 4.19 Box plot for spatial mean SST per grid for all month from July 2002 to April 2007.

Table 4.1 Difference in mean SST for all months (July 2002 - April 2007) per grid.

Differing SST at grids (p<0.05)	
Grid D	B & C
Grid G	A, B, C, D, E & F

Spatial mean SST for each grid indicated alternating peaks at Grids A & B, and drops at Grids C, D, E, F & G, implying about 6 months phase difference (Figure 4.20).   Grid A & D showed maximum and minimum peaks and troughs. At Grid A minimum trough occurred between February and March, whilst the maximum trough occurred between August and September. The warmer periods were during May and October. Whiles at Grid D minimum and maximum troughs occurred during August and February, respectively. Grids C, D, E, F & G were in phase, though Grid G showed about a month lag from the rest.
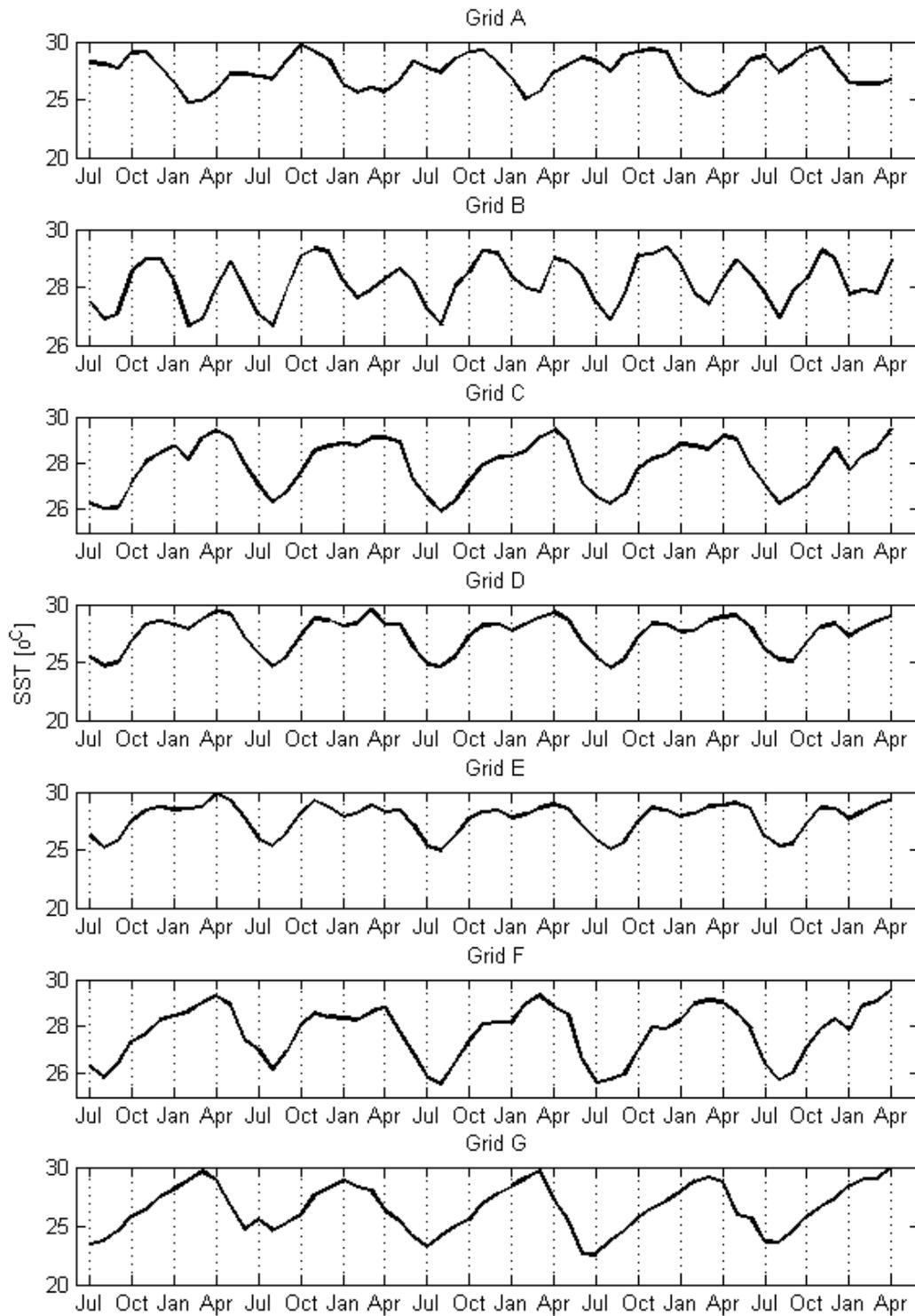
Figure 4.20 Spatially averaged monthly SST for Grids A – G.

4.3.3 Sea wind stress

Sea wind stress was lowest at Grid D and highest at Grid C (Figure 4.21). Significant difference were observed among the grids ($p<0.05$) (Table 4.2). Low sea wind stress at Grid D occurred between July to September, whiles at Grids A & B high sea wind stress were observed between April to January, peaking in June (Figure 4.21). At Grid G peaks in sea wind stress occurred in January.
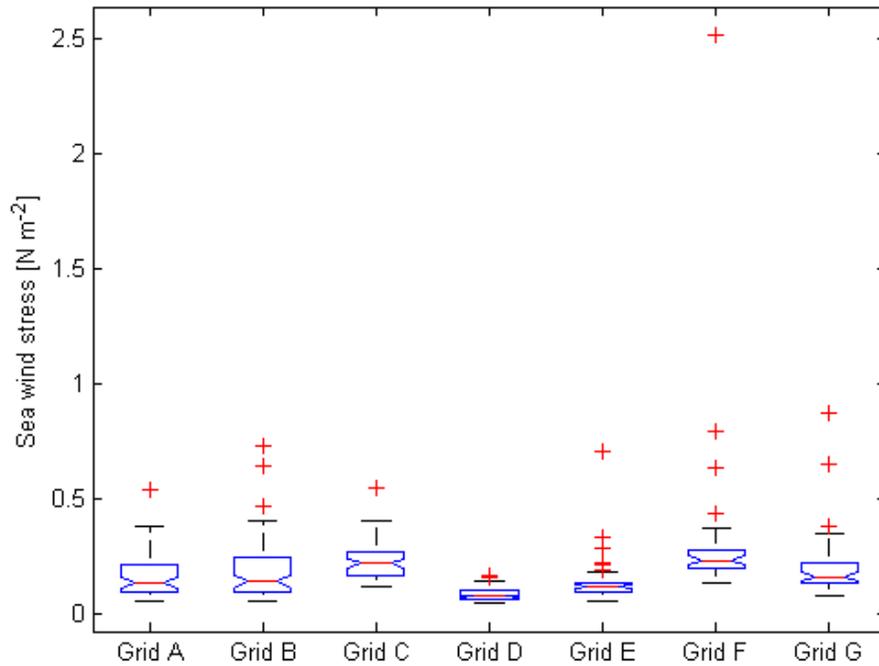
Figure 4.21 Box plot for spatial mean sea wind stress per grid for all months from July 2002 to April 2007.

Table 4.2 Difference in mean sea wind stress for all month (July 2002 - April 2007) per grid.

	Differing Sea wind stress at grids (p<0.05)
Grid C	D & E
Grid D	A & B
Grid G	F
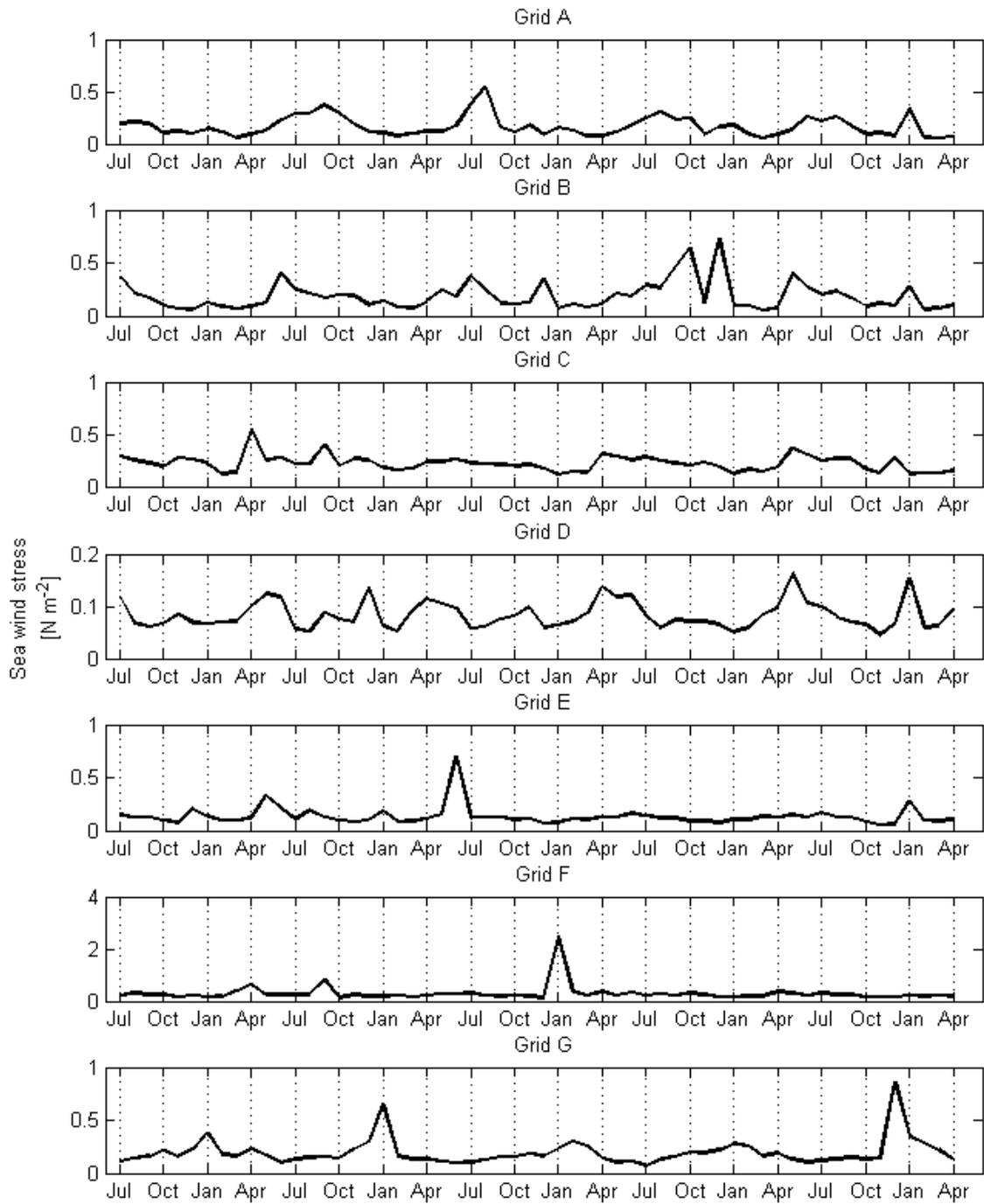
Figure 4.22 Spatially averaged monthly sea wind stress for Grids A – G.

Stability of surface currents

Variations in surface thermal structure showed two distinct features: regions with low deviation at the marine waters off Guinea to Liberia, as well as the coast of Nigeria to Cameroon, and regions around Bijagos Islands, coastal waters of Ghana-Cote D'Ivoire, adjoining waters of the equatorial and northern Benguela which showed high variability in SST (Figure 4.23). This observation indicates the presence of a strong thermal front off the coast Liberia-Sierra Leone through latitude 0-3°N to coastal regions of the Niger Delta.
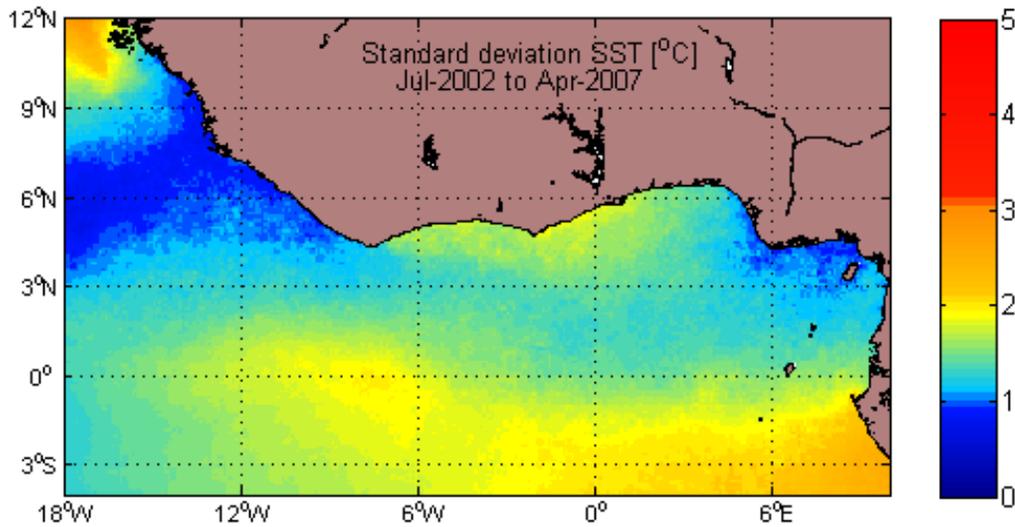
Figure 4.23   Standard deviations in SST in the GCLME between July 2002 and April 2007.

Environmental control of chlorophyll levels in the GCLME

Results of regression analyses based on chlorophyll levels averaged over the study period per grid revealed that at all grids SST explained much of the variability in chlorophyll distribution, except at Grid G where sea wind stress explained 5.3% of variability in chlorophyll distribution, an observation which can be expected due to its proximity with the Benguela (Table 4.3). Grid D which encompassed the main upwelling center in the GCLME had much of SST explaining the variability in chlorophyll.

Table 4.3 Explained variation in chlorophyll by SST and Sea wind stress at all seven grids between July 2002 and April 2007.

Grid	% variation in chlorophyll explained from regression analysis (p<0.05)		
	Sea wind stress	SST	Sea wind stress + SST
A	*	40	*
B	*	40.2	*
C	*	46	*
D	*	52.1	*
E	*	46.2	*
G	5.3	39.6	44.9

Results in Table 4.4 showed quarterly effect of SST explained between 16-78% variability observed in chlorophyll levels within the hydrographic season. Though sea wind stress did not contribute to variations in chlorophyll levels at most grids, it significantly explained about 65% variability in chlorophyll levels at Grid G between October and December when magnitudes in sea wind stress were highest (Figure 4.22). Grid A's chlorophyll level was significantly modulated by SST between January and March, and between July and September at Grids C, D and E. These months were periods of relatively lower SST (Figure 4.20). During the warmer periods changes in SST explained more than 40% variability in chlorophyll at all grids.

Table 4.4 Explained variation in chlorophyll by SST and Sea wind stress at all seven grids between for each quarter of the season from July 2002 and April 2007.

	Grid	**% variation in chlorophyll explained from regression analysis (p<0.05)**		
		Sea wind stress	SST	Sea wind stress + SST
JAN - MAR	A	*	48.0	*
	A	*	59.6	*
	B	*	40.4	*
	C	*	49.6	*
APR - JUN	D	*	78.1	*
	E	*	47.4	*
	F	*	38.1	*
	G	*	57.7	*
	C	*	49.3	*
JUL - SEPT	D	*	50.1	*
	E	*	30.8	*
	A	*	71.8	*
	B	*	63.4	*
	C	*	73.9	*
OCT - DEC	D	*	53.0	*
	E	*	63.2	*
	F	*	71.2	*
	G	65.3	16.3	81.6

DISCUSSION

5.1   Patterns in primary productivity in the GCLME

Globally, it has become pertinent for continuous assessment of phytoplankton production due to its key position in marine food production and CO_2 regulation (Perry, 1986). Satellite observations provide means for repeated coverage of ocean features including ocean colour to help understand the role of phytoplankton on biogeochemical cycling especially in the conversion of inorganic carbon to organic carbon and its transfer and utilization in the marine food webs, as well as climate change (Gregg and Conkright, 2001). Myriad of processes emanating from solar heating and wind stress (Daly and Smith, 1993) results in upwelling that drive marine primary production (Bakun, 1996; Bakun and Agostini, 2001). In the Guinea Current, upwelling is seasonal especially in the Gulf of Guinea where there are two periods of upwelling that are not wind induced (Longhurst, 1962; Bakun, 1978; Binet, 1997): the major upwelling between June to September and a minor upwelling in January (FRU/OSTROM, 1976; Pézennec and Koranteng, 1998) and have been observed to affect considerably the distribution of fishery resources.

The distribution patterns in primary productivity followed unique physical conditions of the subsystems of the GCLME. Coastal margins of the GCLME showed considerable levels of phytoplankton production for most periods of the season even when upwelling believed to be the driving force for increased phytoplankton growth had not commenced. The effect of large human population and industries discharging enormous quantities of nutrients via rivers and rain run off could be enriching the coast with nutrients. Scheren and Ibe (2002) have indicated numerous evidences of high population growth and industrialization that had led to eutrophication of most coastal lagoons in the subregion. These coastal water bodies exchange large volumes of water with the Guinea Current daily, discharging large quantities of nutrients into it. In the Black Sea, Cociasu et al. 1996, observed in addition to natural processes increased discharge of nutrients from river inputs and organic waste in the northwest shelfs had significantly resulted in vast increase on primary production in the coastal waters relative to primary production in the open ocean. Broad coastal shelfs off the northern portions of the Sierra Leone Guinea Plateau (SLGP) coupled with the Senegalese Upwelling Influence (SUI) also enhanced nutrient availability. Influx of nutrients from internal oceanographic processes has been reported to increase growth activity of phytoplankton (Gregg et al., 2003).

On the contrary, the narrow stretch of the continental shelf off the coast of Guinea to Liberia coupled with the stable surface thermal structure could have contributed to the low primary productivity in that region and the very vast difference in chlorophyll levels with the northern portions of the SLGP. Warmer ocean temperatures increase stratification of the surface mixed layer, which inhibits the entrainment of nutrients from

below to support ocean primary production (Sarmiento et al., 1998).   The Canary Current has been reported as one of the productive marine ecosystems (Barber and Smith, 1981; Carr, 2002) and the proximity of marine waters around Bijagos could be a factor that generates favourable oceanographic conditions that increased phytoplankton growth. Significant peaks in chlorophyll off the shelf regions of Bijagos occurred in January-February, a period when upwelling at the Canary was intensive (Demarcq, 1998). Low chlorophyll levels in the SLGP begun when the Canary was warm (April to November), suggesting potential reduction in nutrient levels in the SLGP. Demarcq (1998) reported of local SST maxima increasing from April to October that was influenced by the wind direction and local bathymetry.

High primary production of the CWAU between July and September occurred in the major upwelling, and in January the relatively low primary production occurred during the minor upwelling periods when nutrients are high (Philander, 1979).   Lowest primary productivity during the months of February to May, and October to December were periods of stratification (Wiafe et al., 2008).   The westward shift of high primary production regions were confined to the coastal shelf of Cape Palmas though SST signals in July indicated upwelling was intensive at the east of Cape Three Points.   This observation is consistent with westward propagation of upwelling in the Gulf of Guinea (Picaut, 1983). Surface eastward flow of the Guinea Current possibly drives nutrients to the relatively warmer regions of the EGOG to augment nutrients from land sources into the coastal waters off the Niger Delta. Equatorial upwelling which has been strongly linked to the eastward propagating equatorial waves (Picaut, 1984) was seen to be correlating with coastal upwelling in the CWAU and high primary productivity in the major upwelling season.

Relatively low primary productivity areas in the GCLME were associated with high SST and a stable surface thermal structure. The persistent low primary production along the path of warm North Equatorial Counter Current even during cold periods suggests a strong thermocline, reduced mixing processes and associated low nutrient conditions. In the open ocean phytoplankton growth are mainly sustained by the influx of nutrients from the oxic/suboxic lower layers by vertical mixing which is limited due to the presence of a strong pycnocline (Yilmaz et al., 1998).   The dynamic surface thermal structure at the northern portions of the Sierra Leone Guinea Plateau and the dominant upwelling regions of the Central West African Upwelling creates a favourable process that enhances upward movement of nutrient to the surface resulting in increased primary production. In the South Atlantic Bight, spatial and temporal variability in phytoplankton biomass and productivity is regulated by nutrient-rich waters associated with frontal eddies and meanders in the Gulf Stream (Verity et al., 1993; Pribble et al., 1994).

Single prominent peak in primary productivity spectral analysis suggest a seasonal increase in phytoplankton growth along the coast of the Guinea Current during upwelling

periods. However, the relatively weak quarterly to bi-annual peaks in primary production in the SLGP could be due to sporadic oceanographic processes including variability in SST and its effect on nutrient distribution in the subsystem. Phytoplankton production is highly variable owing to its dependency on a variety of meteorological, hydrological, hydrographical, chemical and biological determinants (Wasmund et al., 2005). In the CWAU, weak signals signify slight increase in phytoplankton growth during the minor upwelling which occurs approximately six months before the major upwelling.

Environmental control of primary production in the GCLME

In most studies relating SST and wind climatologies to upwelling, various theories have been promulgated that indicate that the major upwelling centers in the GCLME are not driven by wind, but influenced by oceanographic processes and coastal features e.g. Cape effect and remote forcing including Kelvin waves (Longhurst 1962, Ingham, 1970; Marchal and Picaut, 1977; Bakun 1978; Picaut, 1983; Verstraete, 1992; Binet, 1997). The absence of any substantial contribution of winds to upwelling in the Guinea Current is seen in this study with no significant variability in chlorophyll levels associated with the effect of sea wind stress in three subsystems (i.e. SLGP, CWAU and EGOG). More than 50% variability in chlorophyll levels accounted for by SST in the major upwelling centre off the coast of Cote D'Ivoire-Ghana suggest processes leading to changes in SST will have very significant effect on phytoplankton and fishery resources distribution and abundance. At the northern limits of the Guinea Current between January and March when the SUI is relatively stronger there is an appreciable increase in chlorophyll which can be attributed to high nutrient load of the southward flowing Canary Current. This also suggests that though the northern regions of the SLGP is close to the Canary, it is not close enough to feel the effect of winds at a direction and magnitude that can cause a wind-driven Ekman transport upwelling in the SLGP subsystem. However, at the southern portions of the Guinea Current there is a slight contribution of wind stress on chlorophyll distribution which was amplified in October to December when Benguela and South Equatorial Currents had intensified. This indicates that processes leading to increased phytoplankton growth in the southern limits of the GCLME had very strong link to sea wind stress. And in cold months of July to September CWAU SST had explained more than 30% of variability in chlorophyll levels in that region, signifying the effect of low SST and associated nutrient enrichment during upwelling on phytoplankton growth. Also, the strong variability in chlorophyll associated with SST during April to June and October to December, is an indication of warm SST of a stratified system and low phytoplankton growth that is expected when strong thermal stratification develops.

Seasonal variability in SST as observed from this study follows the intensification of Canary, Equatorial and Benguela currents. The warm climate of the tropics almost

through out the year favoured a thermally stratified system, and an insignificant upsurge of nutrient-rich bottom water (Monterey and Levitus, 1997; Sarmiento et al., 1998). Surface cooling of SLGP between January to April (Demarcq and Citeau, 1995; Hardman-Mountford and McGlade, 2002), and in CWAU between June to September (Roy, 1995; Amman and Fofana, 1998; Hardman-Mountford and McGlade, 2002) were observed in this study. Philander (1979) observed that in June the warm surface layer disappears for most of the eastern Atlantic so that the cold, saline subsurface waters are exposed bringing to the surface nutrients to drive phytoplankton production. In the Gulf of Guinea, variations in the hydrographic regimes are the major factors which determine fish stocks abundance and distribution (Williams, 1968; Fager and Longhurst, 1968; Longhurst 1969; Martos et al., 1991; Koranteng et al., 1996; Koranteng and McGlade, 2002). The abundance and distribution of the small pelagics in the western Gulf of Guinea are controlled mainly by the intensity of the coastal upwellings that occur in the subregion (Mensah, 1973; Koranteng et al., 1996). High phytoplankton biomass during periods of intensification of the SUI in the SLGP and coastal upwelling in the CWAU further emphasize observation of increased population of copepods *Calanoides carinatus* (Bainbridge, 1972; Mensah, 1974; Wiafe, 2002) and pelagics such as *Sardinella aurita, S. maderensis* and *Engraulis encrasicolus* (Mensah and Koranteng, 1988; Koranteng, 1995) in earlier studies in the Gulf of Guinea.

Southward flow of the SUI largely regulates the dynamics of the SLGP during the cold months. Influx of the cold SUI into the warm Guinea Current contributed to the development of a strong thermal front with both coastal and offshore waters off Guinea to Liberia. The dynamics of coastal waters coupled with the shallow waters at Bijagos enhanced nutrient distribution fluxes with the warm regions south. In the CWAU, the observed surface cooling during July to September coincided with reduced intensity of the North Equatorial Counter Current and an increased intensity of the westward moving South Equatorial Current and the Benguela Current at the south of the GCLME. On the contrary, Longhurst (1962), Boisvert (1967), Ingham (1970), Bakun (1978), and Richardson and Philander (1987) agree that the Guinea Current experiences a minimum during November through February and a maximum during May through September. Longhurst (1962) and Boisvert (1967) also observed a reversal in current direction during the minima. They attributed this change to variations in the flow of the North Equatorial Counter Current, the Canary Current, and the Benguela Current (Longhurst 1962, Ingham 1970) to the weakening of the easterly winds (Boisvert 1967, Ingham 1970). A month lag between the troughs of the equatorial SST and other coastal areas of the GCLME could be an indication of the effect of Kelvin waves that travel along the equator carrying along cold subsurface water to the coast (Picaut, 1983; Verstraete, 1992). The one month lag could be less due to low resolution of the data used in this study. Remnants of oceanographic processes impacting on SST distribution in the CWAU could be influencing the EGOG, and the contribution of winds to upwelling in the equatorial

regions explains the significant difference in SST south of Cape Lopez and the other subsystems. The eastward flow of the Guinea Current and large input of warm fresh water from land discharged at the Niger Delta explained the very warm surface temperatures in the EGOG, whilst the persistently warm southern portions of the SLGP was linked to the influence of the North Equatorial Counter Current.

Four hydrographic seasons observed in this study follow trends earlier described by Mensah (1991) and Wiafe (2002) in the Gulf of Guinea. The intensity and direction of flow of the major currents in the GCLME explained the occurrence of these hydrographic seasons. Minor upwelling season (in the CWAU) occurred between January and March, when the SUI was intensive at the north of the Guinea Current and a reduced effect of the North Equatorial Counter Current (NECC) on the Guinea Current. The period of first thermocline formation occurred between April and May when the NECC was strong. During the major upwelling (in the CWAU), the South Equatorial Current (SEC) had intensified in its westward flow, whilst the influence of the SUI and NECC had diminished. The second thermocline formation occurred between October and December when the SUI was absent, SEC was receding and NECC had intensified. Marine waters at the south and north of the GCLME did not strictly follow this trend.

SST signals showed weak and strong peaks per season in all subsystems signifying periods of intense and relatively moderate cooling or warming in the GCLME, except in the region off the coast of Sierra Leone. In areas off the coast of Sierra Leone, stronger bi-annual peak in SST was due to the intrusion of SUI or Canary from the south and the net upward shift of the Guinea Current when the SEC intensified. This oscillating effect brought in cold water, slightly lowering the almost perennial warm surface temperature from the NECC connecting the Guinea Current off the coast of Sierra Leone.

Conclusion and Recommendation

Conclusion

Results from this study shows the usefulness of using remotely derived SST, chlolophyll-a as well as derived photosynthetic parameters to estimate primary productivity. By matching up SST and sea wind stress with primary production in the GCLME, physical processes known to exist in the region especially upwelling, dynamics of the major currents and periodicity in primary production have been related to SST. Some of these observations buttress early theories promulgated to be regulating oceanographic processes in the region including the link between equatorial and coastal upwelling in the Gulf of Guinea (Picaut 1983). Additionally, moderate variability in chlorophyll was explained by a combination of sea surface temperature in the SLGP, CWAU and EGOG,

and in regions close to Equatorial waters and north of the Angolan Front, sea wind stress contributed significantly together with SST.

Primary productivity was highest in the SLGP which was influenced by SUI, and lowest in the EGOG which is a thermally stable subsystem. In the CWAU where a major upwelling last for approximately 3 months, primary production levels were intermediate.

Chlorophyll showed two distinct groups based on estimates from the subsystems. Highest chlorophyll at the northwestern fringes of the GCLME exceeds 3 mg m^{-3}. Chlorophyll did not exceed 0.5 mg/m^3 for each month on the average for the rest of the region. Monthly mean primary productivity ranged between 100-1200 gC/m^2/month.

Phytoplankton biomass followed a distinct pattern, an alternating peak and drop which coincided with the influence of the Canary (Senegalese Upwelling Influence) at the north and South Equatorial Current (SEC) at the south. These currents were associated with peaks in primary production. Influx of warm water into the GCLME when the North Equatorial Counter Current (NECC) intensified resulted in a strong thermal stratification leading to drop in primary production. The SUI was intensive between January and April, whilst the SEC and the Benguela intensified between July and September. NECC was intensive between February and April.

Periodic peaks in SST and primary production showed quarterly, bi-annual and annual peaks which emphasizes the alternating effect of the dominant currents in the region.

Four hydrographic seasons (Mensah, 1995; Wiafe, 2002) is not restricted only to the Gulf of Guinea subsystem, it is a regional oceanographic phenomenon.

Thermally stable regions were found at the south of the SLGP and the fringes of the Niger Delta in the EGOG. These thermal regimes have been described by Tilot and King (1993) and Hardmam-Mountford and McGlade (2002).

At the southern portions of the GCLME sea wind stress explained variability in chlorophyll signifying some contribution of sea winds to chlorophyll distribution.

6.2   Recommendation

This study was done based solely on remotely sensed data, hence it was constrained by no reference to nutrients as well as winds data, and in situ measured chlorophyll, SST and primary productivity due to limited funds to embark on sea campaigns. However, results from this study provide wealth of information about distribution patterns in relation to the oceanography of the GCLME.

In order to observe oceanographic and biogeochemical processes within shorter time scales, higher temporal resolution data are required. Oceanographic institutions in the West African subregion should be equipped with research vessels, ocean data receiving stations connected to the internet or telecommunication satellites and offshore platforms to measure oceanographic parameters to better understand processes that impact our marine ecosystem.

In order to make accurate estimates of primary productivity from models, regional specific chlorophyll-a retrieval algorithm must be developed to feed primary productivity models to improve their estimates. Developing a regional specific chlorophyll-a retrieval algorithm will require extensive sampling and fluorometric or spectophotometric analysis of both coastal and open ocean for a robust and high performance algorithm. Again to improve primary productivity model predictability, local parameterization of photosynthetic parameters such as α* (the initial slope of P-E curve), P*m (maximum photosynthetic rate), β*(photoinhibition parameter) must be measured for the dominant phytoplankton groups in the GCLME.

REFERENCES

Acker, J. G. (1994). The heritage of SeaWiFS: A retrospective on the CZCS NIMBUS Experiment Team (NET) Program, NASA Tech. Memo. 104566, vol. 21, edited by S. B. Hooker and E. R. Firestone, 44 pp., NASA Goddard Space Flight Cent., Greenbelt, Md., .

Aiken, J., Moore G. F., Trees, C. C., Hooker, S. B., and Clark, D. K. (1995). The SeaWiFS CZCS-type pigment algorithm, NASA Tech. Memo. 104566, vol. 29, 34 pp.

Amman, A. and Fofana S. (1998). Spatial dynamics of the upwelling off Cote D'Ivoire. pp 139-147. *In* M. H. Durand, P. Cury, R. Mendellsohn, C. Roy, A. Bakun and D. Pauly (eds). *Global versus local changes in upwelling systems.* Editions ORSTROM, Paris.

Antoine, D., André, J.M. and Morel, A. (1996). Oceanic primary production: II. Estimation at global scale from satellite (Coastal Zone Color Scanner) chlorophyll. *Global Biogeochem. Cycle* 10: 57-69.

Armah, A.K. and Amlalo,D.S. (1998). Coastal Zone Profile of Ghana. Gulf of Guinea Large Marine Ecosystem Project. Ministry of Environment, Science and Technology, Accra, Ghana.

Bainbridge, V. (1972). The zooplankton of the Gulf of Guinea. Bulletin of Marine Ecology. 8: 61-67.

Bakun, A. (1978). Guinea Current Upwelling. **Nature**, 271: 147-150.

Bakun, A. (1993). The California Current, Benguela Current and Southwestern Atlantic Shelf Ecosystems. A comparative approach to identifying factors regulating biomass yields. pp 199-221. *In* K. Sherman, L. M. Alexander and B Gold (eds). *Large Marine Ecosystems-Stress, Mitigation and Sustainability*. American Association for the Advancement of Science, Washington, DC.

Bakun, A. (1996). *Patterns in the Ocean: Ocean Processes and Marine Population Dynamics.* University of California Sea Grant, San Diego, California, USA, in co-operation with Centro de Investigaciones Biolgicas de Noroeste, La Paz, Baja California Sur, Mexico. 323 p.

Bakun, A. and Agostini, V. N. (2001). Seasonal patterns of wind-induced upwelling/downwelling in the Mediterranean Sea. *Scientia Marina* 65(3):243-257.

Balch, W., Evans, R., Brown, J., Feldman, G., McClain, C. and Esaias, W. (1992). The remote sensing of ocean primary productivity: Use of a new data compilation to test satellite algorithms. *J. Geophys. Res.,* 97: 2279-2293.

Barber, R. T. and Smith, R. L. (1981). Coastal upwelling ecosystems. *In* Longhurst, A. R. (Ed.), Analysis of Marine Ecosystems. Academic Press, New York, pp 31-68.

Behrenfeld, M. J., and Falkowski, P. G. (1997a). Photosynthetic rates derived from satellite-based chlorophyll concentrations. *Limnol. Oceanogr.* 42(1): l-20.

Behrenfeld, M. J., and Falkowski, P. G. (1997b). A consumers guide to phytoplankton productivity models. *Limnol. Oceanogr.* 42(7): l479-1491.

Bidigare, R.R., Prézelin, B.B. and Smith, R.C. (1992). Bio-optical models and the problem of scaling, p. 175-212. *In* P.G. Falkowski (ed.) *Primary productivity and biogeochemical cycles in the sea.* Plenum.

Binet, D. and Marchal, E. (1993). The Large Marine Ecosystem of the Gulf of Guinea: Long-Term Variability Induced by Climatic Changes. Pp104-118. *In:* K. Sherman, L. M. Alexander, and B. Gold (eds.) *Large Marine Ecosystems – Stress, Mitigation and Sustainability*. American Association for the Advancement of Science. Washington DC.

Binet, D., (1997). Climate and pelagic fisheries in the Canary and Guinea currents 1964-1993. The role of Trade Winds and the Southern Oscillation. **Oceanologia Acta**, 20: 177-190.

Boisvert, W.E. (1967). Major currents in the North and South Atlantic Ocean between 64°N and 60°S, *Tech. Rep. Hydrogr. Off. Wash.*, TR-193, 92 p.

Bricaud, A. and Stramski, D. (1990). Spectral absorption coefficients of living phytoplankton and nonalgal biogenous matter: A comparison between the Peru upwelling and the Sargasso Sea, *Limnol. Oceanogr.,* 35(3): 562-582.

Bricaud, A., Morel, A. and Prieur, L. (1981). Absorption by dissolved organic matter of the sea (yellow substance) in the UV and visible domains. *Limnol. Oceanogr.,* 26(a): 43-53.

Bricaud A., M. Babin, A. Morel, and Claustre, H. (1995). Variability in the chlorophyll-specific absorption coefficients of natural phytoplankton: Analysis and parameterization, *J. Geophys. Res.*, 100: 13,321- 13,332.

Bukata, R. P., Jerome, J. H., Kondratyev, K. Y. and Pozdynyakov, D. V. (1995). Optical properties and remote sensing of inland and coastal waters. CRC.

Campbell, J.W. and O'Reilly, J. E. (1988). Role of satellites in estimating primary productivity on the northwest Atlantic continental shelf. *Cont. Shelf Res*: 8: 179-204.

Carder, K. L., Steward, R., G. Paul, J. H., and Vargo, G. A. (1986). Relationships between chlorophyll and ocean color constituents as they affect remote-sensing reflectance models, *Limnol. Oceanogr.*, 31(2): 403-413.

Carder, K.L., Chen, F.R., Cannizzaro, J.P., Campbell, J.W., and Mitchell, B.G. (2004). Performance of the MODIS semi-analytical ocean color algorithm for chlorophyll-a. *Adv. Space Res*. 33: 1152-1159.

Carr, M. E. (2002). Estimation of potential productivity in Eastern Boundary Currents using remote sensing. Deep-Sea Research II, 42: 59-80

Carr M. E., Friedrichs, M. A. M., Schmeltz, M., Aitac, M. N., Antoine, D., Arrigo, K. R., Asanuma, I., Aumont, O., Barber, R., Behrenfeld, M., Bidigare, R., Buitenhuis, E. T., Campbell, J., Ciotti, A., Dierssen, H., Dowell, M., Dunne, J., Esaias, W., Gentili, B., Gregg, W., Groom, S., Hoepffner, N., Ishizaka, J., Kameda, T., Quéré, C. L., Lohren, S., Marra, J., Me′lin, F., Moore, K., Morel, A., Reddy, T. E., Ryan, J., Scardi, M., Smyth, T., Turpie, K., Tilstone, G., Waters, K., and Yamanakac, Y. (2006). A comparison of global estimates of marine primary production from ocean color. *Deep-Sea Research II*, 53: 741-770.

Christensen, V. (2001). 100 years ICES: Where are the stocks? Poster presented at the ICES Centenary Science Conference, 26-29 September 2001, Oslo, Norway.

Clark, G. L., Ewing, G. C., and Lorenzen, C. J. (1970). Spectra of backscattered light from the sea obtained from aircraft as a measure of chlorophyll concentration, *Science*, 167: 1119-1121.

Cleveland, J. S. (1995). Regional models for phytoplankton absorption as a function of chlorophyll a concentration, *J. Geophys. Res.*, 100: 13333 - 13344.

Cociasu, A., Dorogan, L., Humborg, C., and Popa, L. (1996). Long-term ecological changes in Romanian Coastal Waters of the Black Sea. *Mar. Poll. Bull.* 32:32-38.

Daly, K. L. and Smith Jr., W. O. (1993). Physical-biological interactions influencing marine plankton production . *Annu. Rev. Syst.* 24:555-85.

Darecki M., Kaczmarek, S., and Olszewski, J. (2005). SeaWiFS ocean colour chlorophyll algorithms for the southern Baltic Sea. *International Journal of Remote Sensing,* 268: 247-260

Demarcq, H. (1998). Spatial and temporal dynamics of the upwelling off Senegal and Mauritania: Local change and trend. pp 149-165 *In*: Durand M. H., Cury P., Mendelssohn R., Roy C., Bakun A. and D. Pauly (Eds) *Global versus local changes in upwelling systems.* Orstrom, Paris.

Demarcq, H. and Citeau, J. (1995). Sea surface temperature retrieval in tropical area with METEOSAT: the case of the Senegalese coastal upwelling. *Int. J. Remote Sensing*, 16: 1371-1395.

Denman, K. L., and Abbott, M. R. (1994). Time scales of pattern evolution from cross-spectrum analysis of Advanced Very High Resolution Radiometer and Coastal Zone Color Scanner imagery, *J. Geophys. Res.*, *99*(C4): 7433–7442.

Doerffer, R.,and Fischer, J. (1994). Concentrations of chlorophyll, suspended matter and gelbstoff in case 2 waters derived from satellite coastal zone color scanner data with inverse modeling methods. J. Geophys. Res. 99: 7457-7466.

Edgerton, C. F. (1974). Ocean color analysis. *Sci. and Tech. Aerospace Reports*, 12: 2945-2946.

Eppley, R. W. (1972). Temperature and phytoplankton growth in the sea. *Fish. Bull.*, 70: 1063-1085.

Evans, R. H. and Gordon, H. R. (1994). Coastal Zone Color Scanner 'system calibration': A retrospective examination, *J.Geophys. Res.,* 99: 7293 -- 7307.

Fager, E. W. and Longhurst, A. R. (1968). Recurrent group analysis of species assemblages of demersal fish in the Gulf of Guinea. *Journal of the Fisheries Research Board of Canada*, 25(7): 1405-1421

Falkowski, P. (1997). Evolution of the nitrogen cycle and its influence on biological sequestration of CO_2 in the oceans. *Nature*, 387: 272-273.

Falkowski, P. G., Behrenfeld, M. J., Esaias, W. E., Balch, W., Campbell, J. W., Iverson, R. L., Kiefer, D. A., Morel, A. and Yoder, J. A. (1998). Satellite Primary Productivity Data and Algorithm Development: A Science Plan for Mission to Planet Earth, SeaWiFS Technical Report Series, S. B. Hooker and E. R. Firestone (eds.) TM-104566, 42, 36pp.

FAO (2005). FAO Marine Resources Service, Fishery Resource Division. 'Review of the state of the world fishery resources'. FAO Fisheries Technical Paper. No. 457, Rome 235p

Fargion, G.S., and Mueller, J.L. (eds.) (2000). Ocean Optics Protocols for Satellite Ocean Color Sensor Validation, Vol. Revision 2, National Aeronautical and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland, 184 p.

Feldman, G., Kuring, N., Ng, C., Esaias, W., McClain, C.R., Elrod, J., Maynard, N., Endres, D., Evans, R., Brown, J., Walsh, S., Carle, M. and Podesta, G. (1989). Ocean colour. Availability of the global data set. *EOS Trans. Am. Geophys. Union.,* 70**:** 634-635.

Fell F., Dilligeard E, Olbert C., Babin M., and Ferrari, G. M. (2000). "Using the sun-induced chlorophyll fluorescence for the remote retrieval of phytoplankton in case-II waters: a case study". *Ocean Optics XV*, Monaco.

Field, C., Behrenfeld, M., Randerson, J. and Falkowski, P. (1998). Primary production of the biosphere: integrating terrestrial oceanic components. *Science* 281 (5374): 237-240.

FRU/OSTROM (1976). Rapport du Groupe de Travail sur la sardinelle (*Sardinella aurita*) des cotes ivoiro ghaneenes, 28 juin – 3 juillet, 1976, Abidjan, Cote d'Ivoire. OSTROM Editions, Paris. 62p.

Garver, S. A. and Siegel, D. A. (1997). Inherent optical property inversion of ocean color spectra and its biogeochemical interpretation, 1. Time series from the Sargasso Sea, *J. Geophys. Res.,* 102: 18,607-18,625,

Gege, P. (1998). Characterization of the phytoplankton in Lake Constance for classification by remote sensing. *Archiv. Hydrobiol.* 53: 179-193

Gilerson, A., Zhou, J., Hlaing, S., Ioannou, I., Gross, B., Moshary, F., and Ahmed, S. (2008). Fluorescence component in the reflectance spectra from coastal waters II. Performance of retrieval algorithms. *Optics Express* 16**:** 2446-2460.

Gitelson, A., Yacobi, Y. Z., Schalles, J. F., Rundquist, D. C., Han, L., Stark, R., and Etzion, D., (2000). Principles of remote estimation of phytoplankton density in

productive waters, algorithm development and validation. *Archiv für Hydrobiologie – Advances in Limnology*, 55: 121-136.

Gordon, H.R. (1986). Ocean color remote sensing: influence of the particle phase function and the solar zenith angle. *EOS Trans*., AGU, 14, 1055.

Gordon, H.R. and Clark, D.K. (1980). Remote sensing optical properties of a stratified ocean: an improved interpretation. *Appl. Optics,* 19: 3428-3430.

Gordon, H.R. and Morel, A. (1983). Remote Assessment of Ocean Color for Interpretation of Satellite Visible Imagery. *A Review, Lecture Notes on Coastal and Estuarine Studies, R. T. Barber, N. K. Mooers, M. J. Bowman and B. Zeitzschel (eds.),* Springer-Verlag, New York, 114 p.

Gower, J. and King, S. (2007). Validation of chlorophyll fluorescence derived from MERIS on the west coast of Canada. *International Journal of Remote Sensing* 28(3): 625 – 635 DOI: 10.1080/01431160600821010

Gower, J.F.R. (1983). Water colour imaging from space (satellite photography). Remote sensing of shelf sea hydrodynamics, J.C.J. Nihoul (ed.) Elsevier Oceanography Series, 38, 1-24.

Gower, J.F.R., Lin, S., and Borstad, G.A. (1984). The information content of different optical spectral ranges for remote chlorophyll estimation in coastal waters. *Intl. J. Rem. Sens.,* **5:** 349-364.

Gregg, W. W., and Conkright, M. E. (2001). Global seasonal climatologies of ocean chlorophyll: Blending in situ and satellite data for the Coastal Zone Color Scanner era, *J.Geophys. Res*. 106: 2499-2515.

Gregg, W. W., Conkright, M. W., Ginoux, P., O'Reilly, J. E. and Casey, N. W. (2003). Ocean primary production and climate: Global decadal changes. *Geophys. Res. Lett..* 30(15): 1809

Hardman-Mountford N. J. and McGlade J.M. (2002). Variability of physical environmental processes in the Gulf of Guinea and implications for fisheries recruitment. An investigation using remotely sensed SST. *In* J. M. McGlade, P Cury, K. A. Koranteng and N. J. Hardman-Mountford (eds). *The Gulf of Guinea Large Marine Ecosystem.* Elsevier Science B.V.

Henin, C., Hisard, P. and Piton, B. (1986).. **Observations hydrologiques dans l'ocean Atlantique Equatorial**, Ed. ORSTOM, FOCAL, **1**, 1-191.

Hill, A.E., Hickey, B.M., Shillington, F. A., Strub, P.T., Brink, K.H., Barton, E.D., and Thomas, A.C. (1998). Eastern ocean boundaries. *In*: Robinson, A.R. and K.H. Brink (eds.) *The Sea,* 11: 29-67.

Holligan, P.M., and Morel, A. (1987). Remote sensing of ocean colour for studies of biological productivity and biochemical cycles. Ocean Color Workshop, T.D. Guyenne, Ed., Villefranche-sur-Mer, France, Nov. 5-6, 1986, 19-22.

Hooker, S.B., McClain, C.R., and Holmes, A. (1993). Ocean color imaging: CZCS to SeaWiFS. *Mar. Tech. Soc. J.*, 27: 3-15.

Hovis, W.A., Clark, D.K., Anderson, F., Austin, R.W., Wilson, W.H., Baker, E.T., Ball, D., Gordon, H.R., Mueller, J.L., El-Sayed, S.Z., Sturm, B., Wrigley, R.C. and Yentsch, C. S. (1980). Nimbus-7 coastal zone color scanner: system description and initial imagery. *Science,* 210**:** 60-63.

Iluz. D., Y. Z. Yacobi and A. Gitelson (2003). Adaptation of an algorithm for chlorophyll-a estimation by optical data in the oligotrophic Gulf of Eliat. *Int. J. Remote Sensing.* 24(5) 1157-1163.

Ingham, M.C., (1970). Coastal upwelling in the northwestern gulf of Guinea. **Bulletin of Marine Science**, 20, 1-34.

IOCCG (2006). Remote Sensing of Inherent Optical Properties: Fundamentals, Tests of Algorithms, and Applications. Lee, Z.-P. (ed.), *Reports of the International Ocean-Colour Coordinating Group,* No. 5, IOCCG, Dartmouth, Canada.

IPCC (1990). *Climate Change: The IPCC scientific assessment*. J.T. Houghton, G.J. Jenkins, and J. J. Ephraums (Eds.), Cambridge Univ. Press, 365 pp.

IPCC (2000). *Special Report on Emission Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK

IPCC (2001). The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press: Cambridge, UK, and New York, USA

IPCC. (2007). Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. 35 pp.

Ishizaka, J, and Hofmann, E.E. (1993). Coupling of ocean color data to physical-biological models. In: V. Barale and P.M. Schlittenhardt (eds.) *Ocean Colour: Theory and Applications in a Decade of CZCS Experience*, Kluwer Academic, Dordrecht, The Netherlands, 271-288.

Jain, S.C., Zwick, H.H., McColl, W.D., Bukata, R.P. and Jerome, J.H. (1980). Combined coastal zone color scanner (CZCS), aircraft, and in-situ water quality remote sensing experiment in Lake Ontario. *Ocean Optics* VI, SPIE, 178-188.

Johnson, R.W., and Harriss, R.C. (1980). Remote sensing for water quality and biological measurements in coastal waters. *Photogrammetric Engineering and Remote Sens.*, 46: 77-85.

Kiefer, D.A. and Wilson, W.H. (1979). Reflectance spectroscopy of marine phytoplankton: Part 2. A simple model of ocean color. *Limnol. Oceanogr.*, 24: 673-682,

Kirk, J.T.O. (1983). Light and photosynthesis in aquatic ecosystems. Cambridge University Press, Cambridge, 401 pp.

Koranteng K. A. and McGlade, J. M. (2002). Physico-chemical changes in continental shelf waters of the Gulf of Guinea and possible impacts on resource variability. *In* J. M. McGlade, P Cury, K. A. Koranteng and N. J. Hardman-Mountford (eds). *The Gulf of Guinea Large Marine Ecosystem.* Elsevier Science B.V. pp 93-102

Koranteng K. A., McGlade, J. M. and Samb, B. (1996). A review of the Canary Current and Guinea Current Large Marine Ecosystems. pp 61 – 83. In: ACP –EU Fisheries Research Report No. 2. ISBN 1025.

Koranteng, K. A. (1995). The Ghanaian fishery for sardinellas. *In* (Eds. F. X. Bard and K. A. Koranteng) Dynamics and Use of *Sardinella* Resources from Upwelling off Ghana and Ivory Coast, pp. 290-299. OSTROM Edition, Paris.

Koranteng, K. A. (1998). The impacts of environmental forcing on the dynamics of demersal fishery resources of Ghana. PhD Thesis. University of Warwick, UK.

Lindeman, R. L. (1942). The trophic dynamic aspect of ecology. *Ecology* 23:399-418.

Longhurst, A. R. (1969). Species assemblages in tropical demersal fisheries. pp 147-168. *In: Proceedings of the symposium on the oceanography and fisheries resources of the tropical Atlantic.* Results of ICITA and GTS, Abidjan, Ivory Coast, 2-28 October 1966. UNESCO Publications. Paris.

Longhurst, A., Sathyendranath, S., Platt, T. and Carverhill, C. (1995). An estimate of global primary production in the ocean from satellite radiometer data. *J. Plankton Res.* 17: 1245-1271

Longhurst, A.R. (1962). A review of the oceanography of the Gulf of Guinea. **Bull. Inst. Afr. Noire**, 24:633-663.

MacIntyre, F. (1977). The top millimetre of the ocean. In: Menard, H. W. (ed.) , *Ocean Science,* San Francisco, W. H. Freeman, pp. 145-155.

Marchal, E. and Picaut, J. (1977) Repartition et abondance evaluees par echo-integration des poissons du plateau ivoiro-ghaneen en relation avec les upwellings locaux. **J. Rech. Oceanogr.**, 2: 39-57.

Maritorena, S., Siegel, D. A. and Peterson, A. R., (2002). Optimization of semianalytical ocean colour model for global-scale applications, *Applied Optics*, 41(15):2705-2714.

Martos, A. R., Yraola, I. S., Peralta, L. F. and Jiminez , J. F. G. (1991). The 'Guinea 90' Survey. CECAF/ECAF SERIES 91/52. 295p.

Megard R.O. (1972). Phytoplakton, photosynthesis, and phosphorus in Lake Minnetonka, Minnesota. *Limnol. Oceanogr.* 17: 68-87.

Mensah M. A., and Koranteng K. A. (1988). A review of the oceanography and fisheries resources in the coastal waters of Ghana, 1981-1986. Marine Fisheries Research Report, 8. 35pp.

Mensah, M. A. (1973). The marine environment and fish production in Ghanaian waters. *The Ghanaian Fishing Industry.* Fishery Research Unit, Tema, Ghana.

Mensah, M. A. (1974). The occurrence of the marine copepod *Calanoides carinatus* (KrØyer) in Ghanaian waters. Ghana Journal of Science, 14: 147 – 166.

Mensah, M. A. (1991). The influence of climatic changes on the coastal oceanography of Ghana. OSTROM, Abidjan.

Mitchell, B. G., and Kiefer, D. A. (1988). Variability in pigment specific particulate fluorescence and absorption spectra in the northeastern Pacific Ocean, *Deep Sea Res.*, 35(5): 665-689

Mobley, C. D. (1994). *Light and Water; Radiative Transfer in Natural Waters,* Academic Press, SanDiego, 592 pp.

Monterey, G., and Levitus, S. (1997). Seasonal variability of mixed layer depth for the world ocean, NOAA Atlas NESDIS, 14.

Morel A. and Prieur, L. (1977). Analysis of variations in ocean color. *Limnol. Oceanogr.*, 22: 709-722.

Morel A., (1988). Optical modeling of the upper ocean in relation to its biogenous matter content (Case 1 waters). *J. Geophys. Res.*, 93: 10749-10768.

Morel, A. (1980). In-water and remote measurement of ocean color. *Boundary-Layer Meteorol.,* 18**:** 177-201.

Morel, A. and André, J.M. (1991). Pigment distribution and primary production in the western Mediterranean as derived and modeled from Coastal Zone Color Scanner observations. *J. Geophys. Res.,* 96**:** 12,685-12,698.

Morel, A., and Maritorena, S. (2001). Bio-optical properties of oceanic waters: A reappraisal. *J. Geophys. Res.* 106: 7163-7180.

Muller-Karger, F. E., McClain, C. R., Sambrotto, R. N. and Ray, G. C. (1990). A comparison of ship and coastal zone color scanner mapped distribution of phytoplankton in the southeastern Bering Sea, *J. Geochem. Res.,* 95: 11,483-11,499.

Nelson, D. M. and Smith, W. O. (1991). Sverdrup revisited: critical depths, maximum chlorophyll levels, and the control of Southern Ocean productivity by the irradiance-mixing regime. *Limnology and Oceanography* 36: 1650-1661.

Neville, R.A. and Gower, J.F.R. (1977). Passive remote sensing of phytoplankton via chlorophyll a fluorescence. *J. Geophys. Res.,* 82**:** 3487-3493.

O'Reilly, J. E., Maritorena, S., Mitchell, B. G., Siegel D.A., Carder K. L., Garver S.A., Kahru M., and McClain C. (1998). Ocean color chlorophyll algorithms for SeaWiFs. *J. Geophys. Res.,* 103: 24937-24953.

O'Reilly, J.E., Maritorena, S., Siegel, D., O'Brien, M.C., Toole, D., Mitchell, B.G., Kahru, M., Chavez, F.P., Strutton, P., Cota, G., Hooker, S. B., McClain, C.R., Carder, K.L., Muller-Karger, F., Harding, L., Magnuson, A., Phinney, D., Moore, G.F., Aiken, J., Arrigo, K.R., Letelier, R., and Culver, M. (2000). Ocean color chlorophyll a algorithms for SeaWiFS, OC2, and OC4: Version 4. *In: SeaWiFS Postlaunch Technical Report Series, edited by Hooker, S.B and Firestone, E.R. Volume 11, SeaWiFS Postlaunch Calibration and Validation Analyses, Part 3. NASA, Goddard Space Flight Center, Greenbelt, Maryland.* 9-23.

Pauly, D., Christensen, V., Dalsgaard, J., Froose, R. and Torres Jr., F. (1998). Fishing down marine foodwebs. *Science*, 279: 860-863.

Perry, B. J. (1986). Assessing marine primary production from space. *Bioscience. Ecology from Space.* 36(7): 461-467

Pézennec, O. and Koranteng, K. A.. (1998). Changes in the dynamics and biology of small pelagic fisheries off Cote d'Ivoire and Ghana: the ecological puzzle. pp 329 – 343. *In:* M. H. Durand, P Cury, R. Mendellsohn, C. Roy, A. Bakun and D.Pauly (eds). *Global versus local changes in upwelling systems.* Editions OSTROM Paris.

Philander, S.G.H. (1979). Upwelling in the Gulf of Guinea. **Journal of Marine Research**, 37:23-33.

Picaut, J. (1983). Propagation of the seasonal upwelling in the eastern equatorial Atlantic. *Journal of Physical Oceanography*, 13, 18-37.

Picaut, J. (1984). On the dynamics of thermal variations in the Gulf of Guinea. *Oceanogr.trop.*, 19(2):127-53

Platt, T., Sathyendranath, S. and Caverhill, C.M. (1991). Basin-scale estimates of oceanic primary production by remote sensing - The North Atlantic. *J. Geophys. Res*., 96: 15147-15159.

Pope, R., and Fry, E. (1997). Absorption spectrum (380 - 700 nm) of pure waters: II. Integrating cavity measurements. *Appl. Opt.* 36: 8710-8723.

Preisendorfer, R. W. (1961). Application of radiative transfer theory to light measurements in the sea. *Union Geod. Geophys. Int. Mon.* 10 11-29. Reprinted in: Tyler, J. E. (ed.), *Light in the sea.* Stroudsburg, Pennsylvannia, Dowden, Hutchinson and Ross Inc. (1977) p. 46-64.

Pribble, J.R., Walsh, J.J., Dieterle, D.A., Muller-Karger, F.E., (1994). A numerical analysis of shipboard and coastal zone color scanner time series of new production within Gulf stream cyclonic eddies in the South Atlantic bight. Journal of Geophysical Research-Oceans 99, 7513–7538.

Prieur, L., and Sathyendranath, S. (1981). An optical classification of coastal and oceanic waters based on the specific spectral absorption curves of phytoplanktoin pigments, dissolved organic matter, and other particulate materials. *Limnol. Oceanogr.*, 26:671-689.

Richardson, P.L. and Philander, S.G.H. (1987). The seasonal variations of surface currents in the tropical Atlantic Ocean: A comparison of ship drift data with results from a general circulation model. *Journal of Geophysical Research*, 92, 715-724.

Richardson, P.L. and Reverdin, G. (1987). Seasonal cycle of velocity in the Atlantic North Equatorial Countercurrent as measured by surface drifters, current meters, and ship drifts. *Journal of Geophysical Research*, 92, 3691-3708.

Rogers Jr, H. H., Davis, M., Pritchard, S., Schlesinger, W., Runion,

G.B., Prior, S.A.. and Gjerstad, D. (2003). Carbon and nutrient flow through multiple trophic levels in a CO_2-enriched southern pine forest community. Southeastern Regional Center, National Institute for Global Environmental Change, Annual Report for Fiscal year 2002. The University of Alabama, Tuscaloosa, AL. 10 pp.

Roesler, C., and Perry, M. J. (1995). In situ phytoplankton absorption,fluorescence emission, and particulate backscattering spectra determined from reflectance. J. Geophys. Res. 100: 13,279-13,294.

Roy, C. (1995). The Cote D'Ivoire and Ghana Coastal Upwellings: Dynamics and Changes. pp 346-361. *In*: F. X. Bard and K. A. Koranteng (eds). *Dynamics and Use of Sardinella Resources from Upwelling off Ghana and Ivory Coast.* OSTROM Editions, Paris.

Sarmiento, J. L., Hughes, T. M. C., Stouffer, R. J., and Manabe, S. (1998). Simulated response of the ocean carbon cycle to anthropogenic climate warming, *Nature*, 393: 245 –249.

Sathyendranath, S. and Morel, A. (1983). Light emerging from the sea — interpretation and uses in remote sensing. In: *Remote Sensing Applications in Marine Science and Technology,* A. P.Cracknell (ed.), D. Reidel Publishing Company, Dordrecht, 323-357.

Sathyendranath, S., Platt, T., Horne, E. P. W., Harrison, W. G., Ulloa, 0., Outerbridge, R., and Hoepffner, N. (1991). Estimation of new production in the ocean by compound remote sensing, *Nature*, 353:129-133.

Sathyendranath, S., Prieur, L. and Morel, A. (1989). A three-component model of ocean colour and its application to remote sensing of phytoplankton pigments in coastal waters. *Int. J. Rem. Sens.*, 10:1373-1394.

Scheren, P. A. G. M. and Ibe, A. C. (2002). Environmental pollution in the Gulf of Guinea: Aregional approach. . *In* J. M. McGlade, P Cury, K. A. Koranteng and N. J. Hardman-Mountford (eds). *The Gulf of Guinea Large Marine Ecosystem.* Elsevier Science B.V.

Sherman K 1994. Sustainability, biomass yields, and health of coastal ecosystems: an ecological perspective. Mar. Ecol. Prog. Ser. 112:277-301

Siegel, D.A., Maritorena, S., Nelson, N.B., Behrenfeld, M. J. and McClain, C.R. (2005). Colored dissolved organic matter and its influence on the satellite-based characterisation of the ocean biosphere. *Geophys. Res. Lett.*, 32**:**, L20605:doi:10.1029/2005GL024310, 2005

Siegel, D.A., Maritorena, S., Nelson, N.B., Hansell, D.A., Lorenzi-Kayser, M. (2002). Global distribution and dynamics of colored dissolved and detrital organic materials. *J. Geophys. Res. (Oceans),* 107(12): 10.1029/2001JC000965

Smith, R. C., and Wilson, W. H. (1981). Ship and satellite bio-optical research in the California Bight. In: J. F. R. Gower (ed.) *Oceanography from Space* (New York: Plenum), pp. 281–294.

Smith, R. C., Eppley, R. W. and Baker, K. S. (1982). Correlation of primary production as measured aboard ship in Southern California coastal waters and as estimated from satellite chlorophyll images. *Mar. Biol.*, 66:281-288,.

Sosik, H. and Mitchell, B.G. (1995). Light absorption by phytoplankton, photosynthesis pigments and detritus in the California Current System. *Deep-Sea Research* 42: 1717-1748.

Steeman Nielsen, E. (1952). The use of radio-active carbon (C^{14}) for measuring organic production in the sea. *J. Cons. Int. Explor. Mer.* 18: 117-140.

Tilot, V. and King, A. (1993). A review of the Subsystems of the Canary Current and Gulf of Guinea Large Marine Ecosystems. IUCN Marine Programme.

Verity, P.G., Yoder, J.A., Bishop, S.S., Nelson, J.R., Craven, D.B., Blanton, J.O., Robertson, C.Y., Tronzo, C.R., (1993). Composition, productivity, and nutrient chemistry of a coastal ocean planktonic food web. *Continental Shelf Research* 13 (7), 741–776.

Verstraete, J.M. (1992): The seasonal upwellings in the Gulf of Guinea. Progress in Oceanography, 29, 1-60.

Wasmund, N., Lass, H. U and Nausch, G. (2005). Distribution of nutrients, chlorophyll and phytoplankton primary production in relation to hydrographic structures bordering the Benguela-Angolan frontal region. *African Journal of Marine Science*, 27(1):177-190.

Wiafe, G. (2002). Spatial and temporal dynamics of plankton communities in the Gulf of Guinea ecosystem. PhD Thesis. University of Ghana, Legon, Ghana. 188 pp.

Wiafe, G., H. B. Yaqub, M. A. Mensah, Frid C. L. J. (2008). Impact of climate change on long-term zooplankton biomass in the upwelling region of the Gulf of Guinea. *ICES Journal of Marine Science*, 65.

Williams F. (1968). Report on the Guinean Trawling Survey, Organisation of African Unity Scientific and Technical Research Commission (99).

Yentsch, C.S. (1960). The influence of phytoplankton pigments on the colour of sea water. *Deep-Sea Res. I,* **7:** 1-9.

Yentsch, C.S. and N. Garfield 1981. Principal areas of vertical mixing in the waters of the Gulf of Maine, with reference to the total productivity of the area. In: Gower, J. F. R. (ed.), Oceanography from space, New York and London, Plenum Press, p 263-283.

Yilmaz A., Tugrul, S., Polat, C., Ediger, D., Coban, Y. and Morkoc, E. (1998). On the production, elemental composition (C,N,P) and distribution of photosynthetic organic matter in the southern Black Sea, *Hydrobiologia*, 363:141-156.

Standard Operating Procedure for Plankton Sampling and Preservation

SAMPLING PROTOCOL FOR SITE OPERATORS

This standard operating procedure describes the sampling and preservation of phytoplankton, zooplankton (small and large), and icthyoplankton (i.e. fish larvae) for the GCLME.

<u>**Phytoplankton**</u>

Note: for quantitative investigation of phytoplankton, plankton nets are not recommended for sampling. They are size selective and very non-quantitative. They can be used however for identification of the species present as the higher density assists in the taxonomic work, particularly of rarer species. Their use in quantitative studies is to provide relative distribution of dominant taxa.

1. Objective:

The objective is to collect pelagic phytoplankton for qualitative and quantitative assessment.

2. List of materials and equipment:

Phytoplankton net (64 microns mesh) fitted with flowmeter

Lugol solution (see preparation below).

Sampling bottles (preferably plastic screw-cap bottles of more than 500 ml). *DO NOT USE POLYETHYLENE BOTTLES, IODINE WOULD PENETRATE THROUGH THE WALLS*.

3. Sampling strategy

Samples will be taken from specified stations

Sampling should be synchronized with sampling for chemical analysis (organic carbon, phosphorus, nitrogen, silicate) and with temperature profiling

Phytoplankton should be collected by tow method within the upper mixed column. The net (P-200) should be towed within 2 – 5 m at ship speed of 1.5 knots for 5 minutes. The

speed and time should be modified should the net be clogged as a result of bloom condition. Samples are to be fixed with acidic Lugol solution.

4. Labelling

Cruise ID

Contents: PHY

Date:

Coordinates (and station name if applicable)

Depth

Gear:

5. Fixative preparation (to be carried out in a fume hood):

a. Lugol solution: Dissolve 100g of KI and 50 g of crystal iodine in approximately 800 ml of reagent water in a 1-L volumetric flask. Mix until the chemicals are completely dissolved. Add 100 ml of glacial acetic acid and bring volume up to 1 L with distilled water. Store preservative in an opaque bottle labeled with the contents and date of preparation.

b. Acidified formalin solution: This is a solution of equal volumes of formaldehyde (37%) and glacial acetic acid.

6. Fixation:

For prolong storage, phytoplankton samples should be preserved by both Lugol solution and an acidified formalin solution. The content should be stored in glass vials, opaque glass would increase shelf life, fitted with a polyethylene screw-cap lid. For best results, it is recommended that algal samples be preserved first with Lugol's (0.05-1% by volume) followed immediately by acidified formalin solution (2% by volume).

Pour at least 500 ml of sample (need not be measured exactly) into the bottle, add approximately 0.5 ml of Lugol solution (the resultant colour should be that of 'tea'). Different water chemistry and density of algal material require different concentration of

preservative. A general guideline is that there be sufficient Lugol's to turn the sample the colour of weak tea.

Label sample and store at a dark place.

SAMPLING FOR PHYTOPLANKTON

Sample Preservation

Lugol's iodine, also known as acid Lugol's was chosen as a preservative for the phytoplankton sample preservation in this study for a number of reasons. Primarily this fixative ensures the stability of diatom frustules due to the low pH of the solution. The preservative is present in the samples in a concentration of 2%. An alkaline preservative will tend to allow silicates associated with cell wall structure to go into solution resulting in cells disappearing from the samples over time (Sournia, 1978). Although the Lugol's is light sensitive, unlike Formalin Acetic Acid (FAA), which has a longer shelf life, the storage of samples in opaque bottles reduces the sample exposure to light. The Lugol's does provide some degree of staining for cell material enhancing the visual detection of cells. The wide spread usage of Lugol's as a preservative world wide also permits some limited comparison of sample collection protocols and identifications over a wider geographical range. It should also be noted that many preservatives, including those mentioned above may generate cell distortions in the case of unarmoured dinoflagellates, and in fact the disappearance of cell components in the case of coccolithophores. There are limitations to all of the preservation methods available for use.

SAMPLING FOR ZOOPLANKTON AND ICHTHYOPLANKTON

The following standard protocols are to be used for routine sampling of zooplankton at fixed and transect stations. At all stations, at least one standard zooplankton vertical tow with 200-μm mesh net (i.e. WP2) is taken.

At the time of capture, gelatinous zooplankton are removed from the catch, identified according to major taxonomic category (e.g. siphonophore, ctenophore, medusae), measured volumetrically and a subsample of this gelatinous zooplankton catch is preserved separately for confirmation of identification. The remainder of the sample is preserved in a 4% solution of buffered formaldehyde.

Objective

Sampling for qualitative and quantitative assessment of zooplankton and ichthyolplankton

List of materials and equipment

Multinet (200 microns meshes) fitted with flowmeter

Bongo net (200 and 500 microns) fitted with flowmeter

Sampling bottles (preferably plastic screw-cap bottles of 100 – 500 ml capacity.

Buffered formaldehyde

Sampling

Multinet should be hauled vertically from the bottom at a towing speed of 0.5 m/sec. Net should be opened 10 m from the bottom. Samples will be taken from specified stations

Sampling should be synchronized with sampling for chemical analysis (organic carbon, phosphorus, nitrogen, silicate) and with temperature profiling

After each haul the inner surface of the net must be rinsed carefully by applying water from a hose to the sides of the net (from top to bottom).

Filter the contents of the sample in a 60 micron sieve, and empty contents into a sampling bottle. Fix with buffered formaldehyde.

Labelling 1. (ZOOPLANKTON – small and large)

Cruise ID

Contents: ZOO

Date:

Coordinates (and station name if applicable)

Depth:

Gear: 200 microns

Labelling 2. (ICHTHYOPLANKTON)

Cruise ID

Contents: ICTHY

Date:

Coordinates (and station name if applicable)

Depth:

Gear: Bongo 500 microns

Fixing samples

Buffered formalin: The fixative is prepared by stirring 30 g of borax (sodium tetraborate) in one litre of 40% analytical reagent grade of formalin. The solution is allowed to stand for about four weeks and any sediment formed is removed by filtration using a filter paper. An equal volume of propylene glycol (with a tinge of propylene phenoxytol) is then mixed with the formalin.

Preserve with formaldehyde to the final concentration of 4% v/v. Do not leave too much air in the bottles. After preservation the bottles should be almost full.

Vertical tow:

(a).   Standard nets (WP2 or WP3)

The net should be deployed on the end of hydrowire, using a winch capable of lifting a minimum of 200 kg. Once the net is clean and the cod end firmly attached, it should be launched and lowered slowly into the sea. The net is sent to depth open, as it will not collect organisms during payout. The net can be lowered at 50 m min^{-1}, and retrieved at a constant speed of 45 m min^{-1}. This is equivalent to a towing velocity of 1.5 knots. The wire angle should be maintained as nearly vertical as is possible during retrieval, as any deviation from the vertical will result in greater distance traveled and thus in a biased sample.

In waters < 200 m deep the net should be lowered to within 10 m of the bottom and then retrieved. At depths between 200 and 400 m clogging should be carefully monitored.

As the net approaches the surface, raise it immediately but gently through the sea surface. While the net is suspended in air alongside the ship, zooplankton adhering to the mesh should be gently and rapidly washed down into the cod end using a seawater stream from a small diameter hose. The net is then brought quickly inboard and on-deck and contents filtered with a 60 μm sieve.

Store samples in bottles and preserve with buffered formaldehyde.

Flowmeters attached to the net should be read before and after deployment.

(b)   Multinet Sampling

Multinet should be hauled vertically from following specified depths:

200m – 100m

100m – 50 m

50m – surface

The above is applicable for stations with depth beyond 200m. For shallower areas, net to be hauled as appropriate. The towing speed of 0.5 m/sec is recommended.

Zooplankton should be preserved with formaldehyde to the final concentration of 4% v/v.

Step-oblique tow (Bongo net):

The net should be lowered at 50 m min^{-1} to 50m whiles the ship steams ahead at 3 knots. The net should be towed at this depth for 5 minutes. Thereafter, it is brought to 25 m depth, and towed at this depth for 5 minutes. The net is again brought to 5 m and towed for further 5 minutes. Finally the net is retrieved onto the deck. During final retrieval the ship should slow to 2 knots, and the net should be retrieved at 30 m min^{-1}.

During towing, sufficient weight should be used such that the wire angle never exceeds 45°. For oblique tows each net frame should certainly include at least one flowmeter to monitor distance traveled. In addition, some form of depth indicator will be useful to monitor and record the tow profile. Once the sample has been rinsed into the cod end, the net can be brought on deck and sample processing begun. Store samples from 200 microns an 500 microns net in different bottles and preserve with buffered formaldehyde.

Flowmeters attached to the net should be read before and after deployment.

Sample processing, preservation and labeling onboard ship.

All zooplankton are delicate and easily damaged, so sample handling should be as gentle as possible. The best sample storage containers are plastic jars with inert cap liners. The jars should be of sufficient size so that when filled, the volume of fixation fluid will be at least 3 times greater than the volume of the sample (i.e. the sample volume should be no more than 25% of the volume of the storage jar). Sample labels made from waterproof paper should be placed inside and on the outside of the jars. Writing should be done with a lead pencil. Labels should contain all pertinent information for each sample, such as data, time, station, net type, latitude, longitude, vessel, tow depths, etc. Latitude and longitude should not be omitted, as georeferencing the samples is very important for interpretation of the data.

Immediately after arrival on deck, the cod end should be removed from the net and the sample poured gently into a sample jar(s). A wash bottle of filtered seawater can be used to rinse all animals out of the cod end and into the sample jar. The jar is then filled to 3/4 of full capacity with filtered seawater, and 50-ml of full-strength formaldehyde added to achieve a final concentration (when the jar is filled) of 4%. To maintain neutral pH of the formaldehyde-seawater solution, 20-ml of a saturated solution of sodium borate in seawater is then added and the jar filled to the top with filtered seawater. After the jar is inverted several times to insure complete mixing of fixative and sample, it is returned to its storage box and kept in cool, dark conditions in a stable area of the ship.

Since the zooplankton samples may not be counted for some time after they are returned to the laboratory, and since I hope these samples serve as a long-term, archive of national and international importance, the long-term maintenance of all of the organisms in each sample is a high priority. This means that the osmotic strength and pH of the samples must be maintained within bounds necessary for full organism preservation. Therefore, the formaldehyde solution used for initial fixation of the samples in the field must be carefully buffered. In addition, I recommend strongly the transfer of each sample, after a minimum of 6 weeks following collection, into Steedman's solution (often called "PPG") for long-term storage (Steedman, 1976). Samples stored in this solution experience minimal loss of gelatinous taxa and organisms with calcareous shells. The solution is also less volatile than formaldehyde so the samples can be more easily counted. However, phenoxetol is highly toxic, so the solution and the samples should be handled carefully, in full accordance with international standards of laboratory and workplace safety. For every liter of Steedman's solution, 5 ml of propylene phenoxetol is dissolved in 45 ml of propylene glycol, and the mixture brought up to 1 liter with 950 ml of filtered seawater.

The original samples are drained over 200 ▢m nylon mesh, and then rinsed off the mesh and into rinsed, 1-liter sample jars. Each sample jar then should be filled to the top with Steedman's solution before storage. The samples should be archived in the dark in a well-ventilated area with some measure of temperature control. The samples should be checked every 6 months for loss of fluid volume and any loss replaced with Steedman's Solution.

Fixation

Sodium thiosulphate ($Na_2S_2O_3$): dissolve 45 g $Na_2S_2O_3$ in approximately 90 ml of distilled water and add up to 100 ml with 40 % formaldehyde.

Fixing samples

Preserve with formaldehyde to the final concentration of 4% v/v. The bottle must be filled up at least to two thirds.

Buffered formaldehyde

LABORATORY ANALYSIS

Phytoplankton Samples

Phytoplankton samples will be processed for phytoplankton species identification and enumeration using microscopic methodology. A standard phase contrast microscope equipped with oil immersion capability will be used for observations at a variety of magnifications (i.e. 10X, 40X, 100X). Water samples containing phytoplankton will be prepared for microscopical examination using settling chambers. Phytoplankton settling chambers were first described by Utermohl (1958) and later by Hasle (1978) and others. The fundamental technique allows the placement of a known sample volume over a settling site, a glass cover slip or specialised microscope slide, for a given period of time. The samples generally settle overnight and the water column is then carefully removed leaving the cells on the sample site to be observed on an inverted microscope.

Taxonomic Identifications

Efforts will be made to identify all phytoplankton species present. This is always a daunting task complicated by morphological variations within species, preservation artefacts, magnification limitations of the light microscope and the presence of species

not as yet identified at all. Extensive literature does however exist for a great deal of the species that will be encountered such as primary reference material associated with the local geographical area, ie. Berard-Therriault et al. (1999), as well as a multitude of other reference sources (see Taxonomic Reference List). Cells will be identified to genus and species if possible using light microscopy. The possibility does exist to examine phytoplankton specimens at the sub-microscopic level using electron microscopy. It may be important in some cases, particularly when presence of potentially harmful algal species is concerned, that identifications are confirmed or verified as they may make a unique contribution to the phytoplankton assemblage.

Zooplankton

Accurately separating samples into size fractions has frequently proven to be very difficult because of the high concentrations of phytoplankton, appendicularians, jellies, salps, etc. This results in unreliable measurements. Therefore in order to reduce the difficulty of separating large and small plankton for biomass measurements, the following protocol is to be used. After pouring off the formalin, all organisms larger than 1 cm are manually separated out. The remainder of the sample (i.e. all organisms less than 1 cm) is split once using a Folsom or Matoda splitter. One half of the sample is used for dry weight where the animals are collected on a pre-weighed shark skin filter, dried at 60⁻C for 48 hours and weighed. The other half is used for abundance/composition determinations as discussed below.

Abundance and composition

The second split is used to estimate zooplankton abundance and composition. The sub-sampling methodology must be one of the techniques described in Van Guelpen et al. (1982). The "bulb pipette" technique, however, is unacceptable. Subsamples are such that a minimum of 200 organisms per sample are counted and identified according to criteria a - c. Once the 200 organism count has been obtained, additional aliquots shall be taken until approximately 75-100 Calanus spp have been identified and staged. If several stages and/or all species are present, a total of 150-200 Calanus should be counted. a. Copepods are to be identified to species whenever possible. *Pseudocalanus* should be identified as *Pseudocalanus* spp.

b. All developmental stages of *Calanus finmarchicus, Calanus glacialis* and *Calanus hyperboreus* copepodites are to be identified.

c. All other zooplankton are to be classified according to the following taxonomic categories:

Amphipods (genus)

Bivalves

Chaetognaths (genus)

Coelenterates (genus where possible)

Ctenophores (genus)

Cladocerans (genus)

Decapods (adults: genus; larvae: group)

Echinoderms (larvae, juvenile)

Euphausiids (species)

Fish eggs (species)

Fish larvae (species)

Larvaceans (genus)

Mysids

Ostracods

Polychaetes

Pteropods

If a taxon not listed is encountered, the level of identification will be established after consultation with the scientific authority.

SAFETY PRECAUTIONS WITH FIXATIVES AND PRESERVATIVES:

Splashes in eyes - wash in cold running water for 10-15 min, then seek medical attention

Splashes on skin wash off with cold water

Swallowing - give the victim milk, water or dilute ammonium acetate solution and induce vomiting; seek immediate medical attention

Vapour inhalation (of formaldehyde)- remove the victim to fresh air and provide stimulants such as smelling salts or hot drinks if the patient is conscious

Spills-wash away with copious amounts of water. Concentrated formaldehyde can be neutralized with a dilute ammonia (ammonium hydroxide) solution if required before being washed away.

Caution: Formaldehyde and hydrochloric acid should never be mixed together. The product is carcinogenic !!!

ROUGH OUTLINE OF DIFFERENT STAGES IN THE CPR SURVEY

Preparation of filtering silk (with graduations) and covering silk (with folds) – cutting to correct length, marking up, folding etc.

Load silk into CPR inside mechanism (must be correct length for tow).

Fit 'fusee' wire to inside mechanism.

Put cotton wool, then 40% formalin into storage tanks in inside mechanisms.

Load inside mechanism into correct CPR 'body'.

Check towing wires for faults.

Find out from ship's agent at the harbour when ship is docking.

Arrange for transporting the CPR, plus heavy towing wires, to the ship. Ship tows the CPR on the next voyage.

Arrange for custom clearance if necessary.

Collect CPR from ship after it has been towed. Also collect 'Log Form' from the ship' Master.

Remove inside mechanism from CPR body and mark the silk. Comment on any obvious faults. Make out 'ilk reading chit'.

Unload silk from inside mechanism and store in 4% formalin in sealed container. Label container with machine number, date etc.

Using the ship's 'Log Form' and the 'silk reading chit', enter the 'Record Information' into the computer and calculate the 'Cutting Points' and sample positions.

Allocate the samples to analysts on a random basis (the same analyst should not analyze two adjacent samples) and mark analyst number on cutting points.

Unroll the silk and mark the 'cutting points' on the silk using a blue pencil.

Visually assess the amount of 'Phytoplankton Colour' on the silk.

Cut the silk into 10-mile samples ('blocks') and distribute to analysts.

Analyze the samples, then label and store samples carefully.

Write up the results; process the data.

Clean up and 'service' the CPR body and inside mechanism. Repair any damaged parts.

Back to stage 1 again.

CONTINUOUS PLANKTON RECORDER

The method of processing CPR samples in the laboratory follows the description of Colebrook (1960). First the CPR silk band was unrolled and, from the position it was deployed and recovered, marks were written on the silk corresponding to each 10 nautical miles of tow. The silk was then cut into sections (or 'blocks') at the 10 nautical-mile marks. The green coloration of each 10-mile (18.5 km) section was then assessed visually and given numerical index of 0, 1, 2 or 6.5 (i.e. nil, very pale green, pale green, and green, respectively). The numbers are a visual indication of relative phytoplankton abundance and the procedure is referred to as phytoplankton colour analysis.
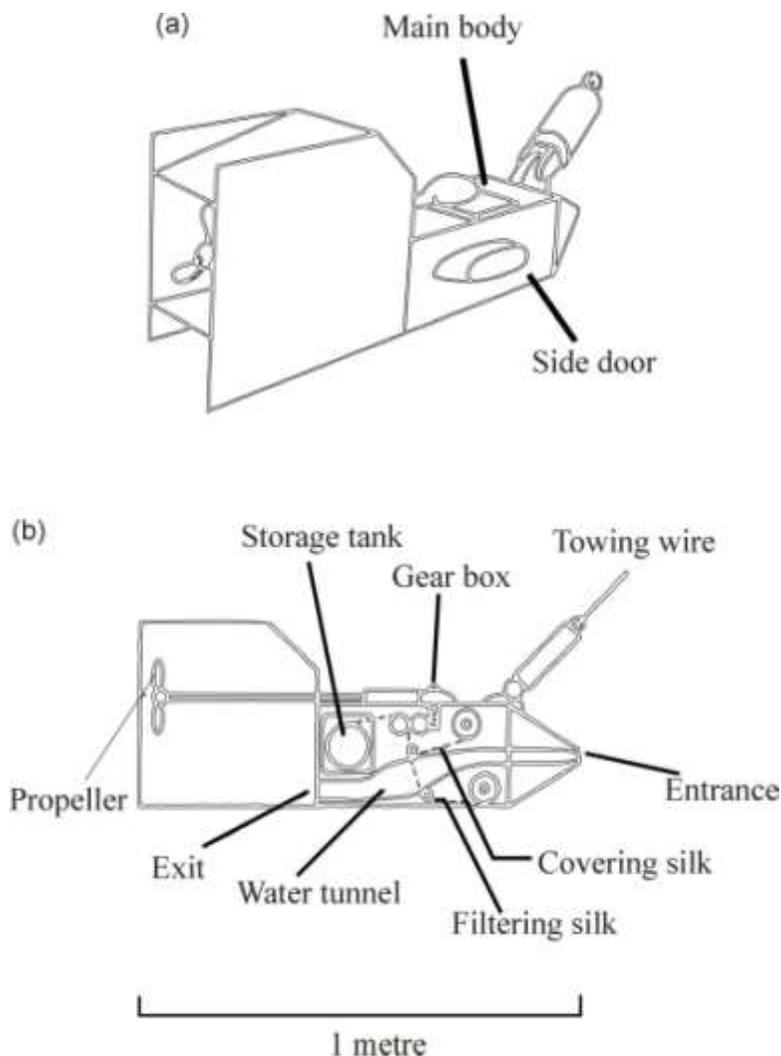
Figure 2. Continuous plankton recorder (CPR). (a) Three dimensional view of the CPR showing the position of the side door through which the internal plankton mechanism is inserted into the main body. (b) Schematic illustration of the internal and external layout of the CPR.

PROCEDURE FOR ANALYZING A CPR SAMPLE

It is a good idea to wear gloves when handling the samples, since formalin is toxic. Wear laboratory coats when analyzing samples.

Place one sample with its supporting polythene sheet on the glass stage, with the graduations (numbered black lines on the filtering silk) facing left to right, not up and down. It helps to spray a little water on the glass first. Remove air bubbles from under the polythene sheet.

Open out the sample by separating the two pieces of silk, placing the top, covering, silk (with folds at the sides) on the left-hand side of the glass stage and the filtering (or graduated) silk (with divisions marked on it) on the right-hand side. Make sure that the silk is not 'upside down'.

Put the left-hand edge of the covering silk close to the left-hand edge of the glass stage and roughly square on the stage. Check that the folds of the silk are facing upwards.

Turn the filtering silk so that it lies at approximately 45° on the glass stage (see Figure 1).
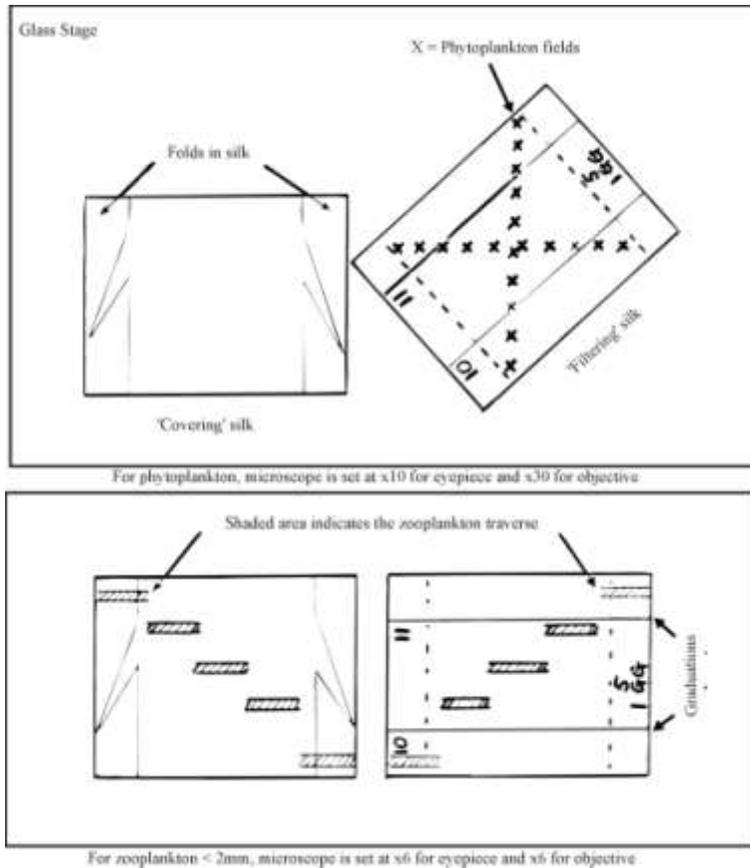
Figure 0. Orientation of CPR covering- and filtering-silks in phytoplankton and zooplankton analysis (John, 1996)

Check that the correct eyepieces (*10) and objective (*30) for phytoplankton are in place. This should give a phytoplankton field size of 0.295 mm ± 0.01mm (i.e. 295 µm) and a magnification of *450.

Examine 20 phytoplankton fields, in two diagonals each of 10 fields, excluding the outside 20 mm on the left-hand and right-hand edges of the filtering silk (see Figure 1). This represents a sub-sample of roughly 1/10,000[th] of the silk.

For each phytoplankton field, make sure that the mesh (hole) of the silk is centered in the field.

If the mesh of the silk does not lie in the center of the field, move to the mesh which has the greatest area showing in the field.

If the mesh is mostly obscured by zooplankton (e.g. copepod), move to the next clear mesh.

Count phytoplankton species if the following appear in the field:- for elongate diatoms (e.g. *Rhizosolenia*) the end of a cell;for other diatoms, dinoflagellates and other groups, the body of the cell.

When you move to the next field, select a field at random.

After you have done one diagonal on 10 fields, you need to turn the filtering silk through roughly 90° to the other diagonal.

Make a mark in your analysis book each time you examine a phytoplankton field, so that you examine the correct number of fields.

For each field, count each phytoplankton species only once – therefore the maximum count, if a species is present in every field, can only be 20.

When entering the results of your analysis on the Analysis Sheet, all phytoplankton is entered on sheet 1, all small 'traverse' zooplankton (mainly less than 2 mm) on Sheet 2, all 'eyecount' plankton other than copepods on Sheet 4.

If you record any species/groups of phyto- or zooplankton which are not already printed on the Analysis Sheet, write them in on the appropriate sheet (Sheet 1 for phytoplankton, etc.)

When you have completed the phytoplankton analysis, change the eyepieces to *6 and the objective to *6 for the zooplankton 'traverse' (zooplankton less than 2 mm); this will give a field size of 2.06 mm ± 0.05 mm, and a magnification of *54.

Reorientate the filtering silk so that it lies parallel with the covering silk and immediately adjacent to it on its right-hand side. (see Figure 1).

Move the stage so that the microscope objective lies above the top right-hand edge of the filtering silk.

Now move the glass stage from left to right (horizontally) underneath the microscope using the knurled knob, counting and identifying all small zooplankton as you go.

When you have move approximately one-fifth of the way across the filtering silk, move the stage vertically 'up' (away from the analyst, do that the microscope moves further down the silk) roughly one quarter of the height of the silk and continue counting. **Do not count** whilst moving the stage vertically.

Repeat items 21and 22 so that you do five traverse 'steps' on the filtering silk (Figure 2).

Continue straight across onto the covering silk and do an approximate 'mirror image' traverse of five 'steps' on the covering silk. The whole zooplankton 'traverse' represents a sub-sample of 1/50th of the silk (Figure 1).

If you see any species of phytoplankton during zooplankton 'traverse' which were not recorded in the 20 phytopl;aankton fields, record them as a '+' on Sheet 1.

Organisms seen in zooplankton 'traverse' are only counted if the parts shown in the table below are seen in the microscope field.

Organism	Identification point
All Crustacea	Base of the antenna
Thecosomata	Apex of the shell
Lamellibranchia	Hinge of the shell
Chaetognatha	The head
Cyphonautes larvae	Apex of the shell
Echinoderm larvae	Dorsal apex
Larvacea	Body mass

Do not count any copepods or other zooplankton lying underneath the silk.

'Total copepods traverse' includes all copepods seen in traverse, including large copepods.

For the zooplankton 'eyecount', when all 'large' zooplankton over 2 mm are counted, examine both the filtering and the covering silks for large zooplankton . do not forget to look underneath the folds at the side of the covering silk.

If you see any small 'traverse' zooplankton in 'efecount' which were not recorded in zooplankton 'traverse', record them as '+' on sheet 2.

In zooplankton 'eyecount', Decapoda includes Sergestidae (*Lucifer* is a sergestid);chaetognaths are only counted if they are over 8 mm.

Enter all your analysis results into a notebook, always in pencil, so that you can alter them if necessary. Also enter results on the Analysis Sheet in Pencil.

Note anything unusual about the silks – e.g. the presence of parasites, fungus, detritus, any softness of the plankton (e.g. poor preservation?), deformed abnormal animals, plant cells, etc. Also note if you remove any plankton (e.g. into a tube) for reference purposes. Remarks can be entered in the 'Comments' section on the Sheet 4 of the Analysis Sheet.

During analysis, keep the samples moist by spraying with formalin. **This is important**, otherwise the silk will dry and make microscopic observation very difficult.

When analysis is complete, wrap up samples in polythen sheets, after squirting with formalin labeling. Make sure that when the sample is folded up into its polythene 'envelope' for storage, the fold in the silk is at the bottom, so that liquid drains down into the fold.

Be very careful always to re-seal the plastic box in which the samples are stored. Otherwise

formalin fumes will escape and

the samples will start to dry out.

Manual for Identification of Marine Plankton in the GCLME

Oceanography of the GCLME

Marine Ecology

Species Distribution

Species Description

Manual for Identification of Marine Zooplankton

Zooplankton Ecology

The existence of planktonic forms in the oceans was suspected by ancient Greek seafarers as early as the 4th century B.C. It was only in the last century that documentation on the subject began. In 1887, Victor Hensen coined the term 'plankton', which he derived from the Greek word planktos (planao) meaning drifting. He used the term plankton to represent all the organisms that drift about in the water, in contrast to the fixed, creeping or swimming organisms which moved independent of wind and water currents. Thus, zooplankton is the collection of the animal forms of drifting organisms in both marine and freshwaters.

Zooplankton convert the bulk of primary production to secondary production. This does not mean that the whole population feed on primary producers (i.e. phytoplankton), although the majority of members (herbivores) in the community do. The rest are carnivores, omnivores, detritivores and filter feeders. Some typical herbivores have been found to prey on small animals during food scarcity. Thus, zooplankton are referred to as 'opportunistic feeders'. This presents considerable compexity when constructing trophic relationships in the community.

Interaction between zooplankton and phytoplankton in aquatic systems is directly or indirectly linked to the fisheries. Virtually all commercial fish start life in the plankton and spend the first two to three months of their life in it after hatching. Since they cannot prey on larger organisms at this stage, they inevitably depend on the plankton for their sustenance. This means that the success of future exploitable fish stocks partly depend on availability and abundance of plankton as fish food.

Zooplankton abundance also carry along with it a potential problem to future fish stocks. Among the community are predators on fish larvae, such as large medusae, ctenophores and salps which feed on fish larvae and eggs. In great abundance, therefore, these predators are a great threat to the fisheries.

Locomotion in plankton is limited to use of flagella, cilia or change in specific weight by ion exchange or incorporation of oil droplets (in protozoans); use of cilia (in larvae of polychaetes, molluscs and echinoderm); parapodia and swimming limbs (in pelagic polychaete, crustaceans); peristaltic contraction (in medusae); flapping of lobes and wings (in ctenophores and pteropods); contraction of longitudinal muscles and use of fins (in chaetognaths); tails (as in appendicularians); jet propulsion (in cephalopods) and rudimentary fins (in fish larvae).

Classification

The zooplankton is rich in species diversity and it has representatives of almost every major group of animals. The members in the community, with the exception of bacteria and other micro-organisms, could be classified under eight phyla: Cnidaria (or Coelenterata), Ctenophora, Mollusca, Annelida, Arthropoda, Chaetognatha, Echinodermata and Chordata (Diagram).

They may be present in the aquatic environment as holoplankton (typically spending their entire life in the plankton), or as meroplankton (spending only the early stages of their life in the plankton).

Besides systematic classification, the zooplankton may be ecologically grouped according to their depth range, body size, habitat or life span

Size classification

First attempt of size classification was by Schutt, (1892). Several authors proposed different size classification; e.g. Cushing (1958), and Dussart (1965). Recent classification by Sieburth et al. (1978) seem to be widely accepted.

Zooplankton size ranges from 2 microns (e.g. flagellates) to 2 m (e.g. jellyfish). There are five size classes: nanozooplankton (2 - 20 mm), micro zooplankton (20 - 200mm), mesozooplankton (0.2 - 20 mm), macrozooplankton (2 - 20cm) and megalozooplankton (20 - 200 cm). These size classes span an order of six magnitudes; volume and weight spans 18 orders of magnitude (Diagram).

Diversity

Diversity indicates the degree of complexity of community structure, and the number of species and their relative abundances are described by terms such as 'simple', 'complex', or 'dominated by one or few species' (Omori and Ikeda, 1984).

Zooplankton are distributed in all the oceans, from the cold polar waters to the warm equatorial waters. There is, however, a clear distinction in their diversity from one geographic location to the other. Zooplankton diversity and distribution in the oceans is greatly influenced by a combination of climatic and environmental factors, as well as the evolutionary age of the ocean areas. Among the hydrographic factors, temperature, salinity and depth (which determines water pressure and light penetration) play key role in zooplankton diversity.

Information on plankton diversity, on a global scale, has shown that species diversity is generally greater in the warmer and more stable waters of lower latitudes than in higher latitudes (e.g. Mayer, 1910; Ekman, 1953; Fleminger and Huselman, 1973; Pierrot-Bults, 1976; van der Spoel and Pierrot-Bults, 1979; Parsons et al., 1984). It is often higher in marine environments than in fresh water and is lowest in brackish water regions. Diversity is also reported to be higher in the deep sea than in shallow waters, although the deep-sea diversity then declines in the great depths (Omori and Ikeda, 1984; Dumbar, 1960; Patten, 1962; Paine, 1966; Hessler and Sanders, 1967; Menge and Sutherland, 1976).

Following from the premise that the water condition influences species distribution, certain zooplankton species have also been observed to serve as indicator species for particular water masses. In the Gulf of Guinea, for example, the appearance of a particular copepod, Calanoides carinatus, in the surface layers is an indication of the onset of the major upwelling in the area.

A tentative measure of the number of zooplankton species in the oceans has been estimated to be about 36,000, comprising of 16% protozoan, 11% metazoans, and 73% lesser known meroplankton (Harris et al., 2000).

In the Gulf of Guinea, the seasonal upwelling, localised off Cote d'Ivoire and Ghana, is normally marked by abundant phytoplankton, followed by zooplankton which is mostly dominated by a few herbivorous species. Generally, the coastal waters off tropical West Africa are associated with a relative high floral and faunal diversity and low abundance during thermal stratification and low diversity and high abundance during the upwelling (Bainbridge, 1972).

Vertical migration

A characteristic feature of zooplankton in general is vertical migration. This is the phenomenon in which they move to the surface waters in larger numbers at night, swim long distances downward during or around sunrise and return to the surface at dusk. Several hypothesis have been put forward to explain this phenomenon. It is generally accepted that light plays an important role in this behaviour and it is probable that the breaking of dawn serves as a cue which initiates movement from surface waters downward, where zooplankton are at the greatest risk from visual predators.

Vertical migration, however, does not occur in all species. There are some species which exhibit reverse vertical migration, i.e. they are found in the surface layers during the day. In this group of species, the predator-avoidance hypothesis will not hold. Rather, a demographic advantage to such a behaviour has been proposed. It has been observed, for example, that some calanoid copepods exhibit a reverse diel vertical migration concurrently with a normal vertical migration by nocturnal invertebrate predators to reduce spatial overlap.

In the Gulf of Guinea, the zooplankton is concentrated in the upper 25 m of the water column. They become uniformly distributed down to about 75 m during the daytime. Euphausiids are rarely found in the upper 25 m during the daytime (Diagram).

Nutrition

In the open ocean and in the upper layers of shallower seas the zooplankton provide the main route for the conversion of primary to secondary production. This does not mean that the whole population feed on phytoplankton, although the majority of members in the community do (i.e. herbivorous). The rest are carnivores, omnivores, detritivores and filter feeders. Some typical herbivores have been found to prey on small animals during food scarcity. Thus, zooplankton are referred to as opportunistic feeders. This presents some amount of complexity when constructing trophic relationships in the community (An example of a food web in the Gulf of Guinea).

Feeding mechanisms

Essentially zooplankton feeding is trapping particles out of suspension, this may involve a filtering of the water or the active selection and capture of particles.

Filter feeding.

Filter feeding involves pumping water through a filtering organ and then transferring the edible particles to the mouth for ingestion and, usually, some means of rejecting non-food particles.

There are two main types of filter feeding mechanisms involving cilia (e.g. protozoans), and those involving cirri (e.g. crustaceans).

Simple ciliary filters.

Many larvae, e.g. the echinopleutus larvae of echinoderms use a simple cilia filter. A single set of cilia set up the water current, drawing particles through the cilia tract which also acts as a ciliary filter. Particles are transferred to the mouth by the cilia.

Cirral feeding.

Cirri are the fine hair like projections of the exoskeleton of arthropods. As the crustaceans are one of the dominant groups in the plankton it follows that cirral feeding mechanisms are also widespread.

Salps (Thaliacea)

These are pelagic tunicates with a barrel shaped test of elastic material which supports a series of incomplete muscle bands. As these contract they generate a current through the test. Particles are trapped on a mucus net, which is supported by and secreted by the peri-pharyngeal band of cilia, particles are passed to gill bar and mouth by cilia. The mechanisms is by internal trapping of food.

Appendicularians (Larvacea)

e.g. Oikipleura longicaudaa use an external mucus trap. They essentially construct a mucus 'house' in which they sit. The 'house' has 2 inhalant channels which lead into 3 filtering lobes, water passes in through these in response to the beating of the tail, particles are trapped on to the corrugated membranes of the filter. Cilia then pass the particles to the mouth. The water current continues through the gills and out through a gap in the bottom of the house (Diagram).

Pteropod

Pelagic gastropod which swim up through the water column by beating their wing plates covered in ciliated tracts with mucus glands on the forward edge. At the top of the swim, these secrete a mucus web, which is transferred by the cilia to the proboscis. The web may be 2 m across. The pteropod then slowly sinks, passively, filtering the water column as it does so. Trapped particles are transferred to the lateral grooves of the proboscis, by the cilia, and then to the mouth (Diagram).

Crustaceans.

The crustaceans are probably the dominant group in most plankton samples. Some individuals of most crustacean groups are carnivorous to some extent, e.g. species of Centropages, Lapidocera. Many copepod species will preferentially take particles rather than filter feeding and this is also true for many species of Euphausia.

The dominant group of specialist crustacean predators are the Hyperiid Amphipods. In near shore waters many benthic amphipods appear temporarily in the plankton, especially at night, but the Hyperiids are specialist haloplankton predators.

Copepods

In copepods, filtration is facilitated by their swimming strokes which produce eddies around the body and aid in the bringing of particles.

There are two modes of swimming, and hence two modes of feeding, obviously they can swim without feeding.

(i) Steady glide - Calanoides

(ii) Jerky motion - Acartia

In Calanoides the antennae are most important in swimming. Both the endo- and exopod are of equal length and covered in fine setae. Forward notion is by the alternate beating of endo- and exopod resulting in a smooth glide.

Calanoides also tends to rotate as it swims. This swimming action produces eddies which carry water and particles into the 'filtering basket'. This is composed of long setae coming off the 2nd maxilla, which form the filter, it's roof is the body, the floor is formed by the forward extension of the tips of the abdominal appendages. Water is drawn in under the tips of the abdominal appendages, drawn forward and out through the filter of the 2nd maxilla. The current in the filtering basket is generated by the maxillipeds beating. Basal spines of 1st maxilla draw particles off the filter and pass them to the mouth (Diagram).

In Acartia clausi the endopod and exopod antennae are of different lengths, and swimming is achieved by them working together, hence a jerky motion is produced.

During feeding the 2nd maxilla is moved, cf Calanoides it is stationary, acting as a 'scoop net'. The maxillipeds, which are longer than the maxilla in most copepods, are short and very close together, they form a back wall to the filter area.

Most copepods are able to take larger particle by selective or raptorial feeding. In Calanoides when raptorially feeding it uses the 2nd maxilla like that of Acartia as a scoop net.

Cirral spacing controls the food which can be taken, such that in Centropages furcatus, an omnivore, the l or 2 cirri on the maxilla are much stronger with stronger cirri for grasping prey.

Euphausiids

They are essentially carnivores or large particle feeders, they feed either by filtering or raptorialy. When only swimming they beat the abdominal appendages, this also generates the respiratory current.

The 1st and 2nd thoracic appendages are used in feeding. They are composed of a long endopodite and a. short exopodite. These are rotated to generate the feeding current. Water flows in between the thoracic and forward under the body passing out through the rotating 1st and 2nd limbs. Particles are trapped on the cirri between the legs and passed forward along the mid-line.

Planktonic predators.

Those few studies which a have addressed the role of planktonic predators in the ecology of the zooplankton have revealed that typically 50 % of the copepod production at certain time of the year may be utilized by planktonic predators, particularly ctenophores, chaetognathes and medusae (Reeve & Walter, 1978).

Coelenterates.

Come in two forms, the medusae which are the free living stage of the Hydroids, i.e, the Hydrozoa, and the true jelly fish, the Scyphozoa.

Medusae are all carnivorous and are the mobile, sexually reproducing form of the sessile hydroids (which produce the medusae asexually).

Scyphozoa.

These are the largest zooplankton with some species regularly reaching 2m in diameter. All are voracious carnivores, some species have a major impact on the fisheries through consumption of fish larvae.

Scyphomedusae are solitary and lack a velum.

Ctenophores.

All ctenophores are voracious predators. There are two classes, tentaculate (Tentaculata) and naked (Atentaculata/Nuda) ctenophores. The later lack tentacles and tend to be highly specialized predators of other ctenophores or medusae.

Chaetognathes.

Chaetognathes have a muscular body with a straight through gut and lateral fins. they actively pursue pry which are detected by vibrations picked up on the sensory hairs at the anterior end and by chemo-receptors. prey are subdued by the armoured hooks in the mouth and there is some evidence of secretion of a paralysing toxin.

How to use this guide

It is important to note that the descriptions provided refer to adults of the species. There are some groups which are represented in the plankton by their juvenile or larval stages and spend only the early stages of their life in the plankton (i.e. meroplankton), and it is very difficult, if not impossible to identify many of them at this stage. This category includes some annelids, molluscs, echinoderms and decapods. Description of only a few of these juveniles, commonly found in the zooplankton community, have been provided.

It is recommended that anyone with no prior knowledge of zooplankton identification should first become familiar with the general description of the major groups and then determine which group a specimen to be identified belongs to (see Pictorial Key to Taxonomic Groups). For each species, the general characteristics should first be verified before proceeding to look for taxonomic details. Where one is unsure of identifying to species level, the specimen should be listed under the lowest possible rank. ***It is a dangerous practice to force a specimen to fit a description without confirming all taxonomic details***. It should be noted that a Guide such as

this cannot cover all the zooplankton species occurring within the GCLME. It is the hope that the list will be updated from time to time as more information become available.

Species described in this Guide

PHYLUM CNIDARIA

Ectopleura dumortieri, (van Beneden, 1844)

Euphysilla pyramidata, Kramp, 1955

Turritopsis nutricula, McCrady,1857

Cytaeis tetrastyla, Eschscholtz, 1829

Pandea conica, (Quoy and Gaimard, 1827)

Bougainvillia carolinensis, (McCrady, 1857)

Dipurena strangulate, (McCrady,1857)

Annatiara affinis, (Hartlaub, 1913)

Stomotoca pterophylla, Haeckel, 1879

Phialidium hemisphaerica Linnaeus, 1767

Phialella quadrata (Forbes, 1848)

Obelia Peron & Leseuer, 1809

Eirene viridula (Péron and Lesueur, 1809)

Eutima gracilis (Forbes and Goodsir, 1851)

Laodicea undulata (Forbes and Goodsir, 1851)

Eucheilota cirrata (Haeckel, 1879)

Aequorea aequorea (Forskål, 1775)

Octophialucium medium Kramp, 1955

Rhacostoma atlanticum Agassiz, 1850

Proboscidactyla ornata (McCrady, 1859)

Pochella oligonema Kramp, 1955

Olindias phosphorica (Chaje, 1841)

Aglauropsis jarli Kramp, 1955

Liriope tetraphylla (Chamisso and Eysenhardt, 1821)

Rhopalonema velatum Gegenbaur, 1856

Amphogona apsteini (Vanhöffen, 1902)

Aglaura hemistoma (Péron and Lesueur, 1809)

Halicreas minimum Fewkes, 1882

Colobonema sericeum Vanhöffen, 1902

Pantachogon haeckeli Maas, 1893

Arctapodema amplum (Vanhöffen, 1902)

Geryonia proboscidalis (Forskal,)

Solmaris corona (Keferstein and Ehlers, 1861)

Solmundella bitentaculata (Quoy and Gaimard, 1827)

Aegina citrea Eschscholltz, 1829

Maas,1904 Cunina octonaria McCrady, 1857

Pegantha clara Bigelow, 1909

Pegantha martagon (Haeckel, 1897)

PHYLUM CTENOPHORA

Pleurobrachia pileus (Müller, 1776)

Bolinopsis infundibulum (Müller, 1777)

Beroë cucumis Fabricius, 1780

PHYLUM MOLLUSCA

Limacina trochiformis d'Orbigny, 1836

Peraclis reticulata d'Orbigny, 1836

Hyalocylix striata Rang, 1828

Creseis virgula Rang, 1828

PHYLUM ANNELIDA

Tomopteris septentrionalis Quatrefages, 1865

PHYLUM ARTHROPODA

CLASS CLADOCERA

Penilia avirostris Dana, 1846

Evadne tergestina Claus, 1877

Evadne spinifera Muller, 1859

Podon polyphemoides Leuckart, 1859

CLASS OSTRACODA

Conchoecia elegans (Sars, 1908)

Euconchoecia chierchiae Muller, 1912

CLASS COPEPDA

ORDER CALANOIDA

Acartia danae Giesbrecht, 1889

Acartia negligens Dana, 1849

Acartia plumosa Scott, 1894

Acartia tonsa Dana 1849

Acartia grani Sars, 1904

Euchirella splendens Vervoort, 1963

Aetideus armatus (Boeck, 1872)

Aetideopsis multiserrata (Wolfenden, 1904)

Chiridius poppei Giesbrecht, 1892

Calanoides carinatus Krøyer, 1849)

Nannocalanus minor (Claus, 1863)

Neocalanus gracilis (Dana, 1849)

Neocalanus robustior (Giesbrecht, 1888)

Undinula vulgaris (Dana, 1849)

Calocalanus pavo (Dana, 1849)

Calocalanus styliremis Giesbrecht, 1888

Ischnocalanus plumulosis (Claus, 1863)

Mecynocera clausii Thompson, 1888

Candacia magna Sewell, 1932

Candacia curta (Dana, 1852)

Candacia elongata (Boeck, 1872)

Candacia pachydactyla (Dana, 1849)

Candacia bipinnata (Giesbrecht, 1889)

Candacia tenuimana (Giesbrecht, 1889)

Candacia longimana (Claus, 1863)

Candacia varicans (Giesbrecht, 1892)

Centropages chierchiae Giesbrecht, 1889

Centropages furcatus (Dana, 1849)

Centropates violaceus (Claus, 1863)

Eucalanus crassus Giesbrecht, 1888

Eucalanus pileatus Giesbrecht, 1888

Eucalanus attenuatus (Dana, 1849)

Eucalanus monachus (Giesbrecht, 1888)

Eucalanus elongatus (Dana, 1849)

Rhincalanus cornutus (Dana, 1849)

Rhincalanus nasutus Giesbrecht, 1888

Euchaeta marina (Prestandrea, 1833)

Euchaeta marina (Prestandrea, 1833)

Euchaeta aequatorialis (Tanaka, 1958)

Euchaeta tonsa Giesbrecht, 1895

Metridia princeps Giesbrecht, 1892

Pleuromamma xiphias (Giesbrecht, 1889)

Pleuromamma abdominalis (Lubbock, 1856)

Gaussia princeps (Scott, 1893)

Paracalanus parvus (Claus, 1863)

Paracalanus aculeatus Giesbrecht, 1888

Paracalanus denudatus Sewell, 1929

Paracalanus scotti Fruchtl, 1923

Acrocalanus andersoni Bowman, 1958

Labidocera acutifrons (Dana, 1849)

Pontella gaboonensis Scott, 1894

Clausocalanus arcuicornis (Dana, 1849)

Clausocalanus furcatus (Brady, 1883)

Clausocalanus paululus Farran, 1926

Ctenocalanus vanus Giesbrecht, 1888

Scolecithrix danae (Lubbock, 1856)

Scottocalanus helenae (Lubbock, 1856)

Temora stylifera (Dana, 1849)

Temora turbinata (Dana, 1849)

Temoropia mayumbaensis Scott, 1894

ORDER CYCLOPOIDA

Oithona plumifera Baird, 1843

Oithona setigera (Dana, 1852)

Lubbockia squillimana Giesbrecht, 1891

Pachos punctatum (Claus, 1863)

Oncaea venusta Philippi, 1843

Oncaea media Giesbrecht, 1891

Oncaea conifera Giesbrecht, 1891

Oncaea mediterranea Claus, 1863

Oncaea minuta Giesbrecht, 1892

Corycaeus speciosus Dana, 1849

Corycaeus clausi Dahl, 1849

Corycaeus flaccus Giesbrecht, 1891

Corycaeus lautus Dana, 1852

Corycaeus limbatus Brady, 1883

Corycaeus venustus Dana, 1849

Farranula gracilis (Dana, 1853)

Farranula carinata (Giesbrecht, 1891)

Sapphirina (Thompson, 1829)

Sapphirina nigromaculata Claus, 1863

Sapphirina scarlata Giesbrecht, 1891

Sapphirina ovatolanceolata Dana, 1852

Sapphirina pyrosomatis Giesbrecht, 1892

Copilia mirabilis Dana, 1852

Copilia quadrata Dana, 1852

ORDER HARPATICOIDA

Microsetella norvegica (Boeck, 1864)

Microsetella rosea Dana, 1848

Macrosetella gracilis (Dana, 1852)

Oculosetella gracilis (Dana, 1852)

Euterpina acutifrons Dana, 1848

Clytemnestra scutellata Dana, 1848

Miracia efferata Dana, 1846

CLASS CIRRIPEDIA

Balanus spp. da Costa, 1778   Krohnitta subtilis (Grassi, 1853)

SUB-CLASS MYSIDACEA

Eucopia sculpticauda Faxon, 1893

Boreomysis microps Sars, 1883

Longithorax fuscus Hansen, 1908

SUB-CLASS DECAPODA

Lucifer faxoni (Nobili,1901)

PHYLUM CHAETOGNATHA

Sagitta Quoy and Gairmard, 1827

Sagitta enflata Grassi, 1883

Sagitta friderici Ritter-Zahony, 1911

Sagitta hispida Conant, 1895

Sagitta serratodentata Krohn, 1853

Sagitta lyra Krohn, 1853

Sagitta hexaptera d'Orloigny, 1934

Sagitta bipunctata Quoy & Graimard, 1827

Sagitta planctonis Steinhaus, 1896

Sagitta zetesios Fowler, 1905

Sagitta macrocephala Fowler, 1905

Sagitta decipiens Fowler, 1905

Sagitta minima Grassi, 1881

Pterosagitta Costa, 1869

Pterosagitta draco (Krohn, 1853)

Eukrohnia Ritter-Zahony, 1909

Eukrohnia fowleri (Ritter-Zahony, 1909)

Eukrohnia hamata (Möbius, 1875)

Krohnitta Ritter-Zahony, 1910

Ectopleura dumortieri, (van Beneden, 1844)

Dome-shaped umbrella with eight longitudinal tracts of exumbrella nematocysts. Four tentacles arises from large basal bulbs. Tips of tentacles are coiled into a spiral after fixation. Manubrium is thick and blunt and extends about two-thirds the distance from the inner apex of the bell-cavity to the velar opening. Size: 1.5 mm - 2.0 mm high ; Recorded: Ghana and Benin.

Euphysilla pyramidata, Kramp, 1955

Conical umbrella with bluntly rounded apex. No nematocyst tract on the upper surface of the umbrella. Stomach shaped like a pyramid with broad four-sided base. Manubrium is about two thirds the height of the bell cavity. The four tentacles are short and stout and ends in a bulb. Size: 2.3 mm; Recorded: Benin

Turritopsis nutricula, McCrady,1857

Marginal tentacles are numerous about ninety in number. The stomach appears bright red and has no peduncle. Size: 4 - 6 mm high; Recorded: Ghana, Nigeria, Sierra Leone

Cytaeis tetrastyla, Eschscholtz, 1829

The umbrella is dome-shaped with a flask-like manubrium, mounted on a peduncle. The mouth is in line with the umbrella opening. There are four marginal tentacles. Size: 3 mm in diameter; Recorded: Senegal to Gabon

Pandea conica, (Quoy and Gaimard, 1827)

The mouth bears lobe-like lips separated by sharp notches. Nematocyst ribs are borne on the outer surface of a conical-shaped bell. The gonad is networked like a coarse mesh. The base of the marginal tentacles are laterally compressed and the tip of the tentacles end in spirals. Size: 3 - 5 mm high; Recorded: Ghana, Nigeria

Amphinema dinema, (Péron and Lesueur, 1809)

Apical part of the umbrella is conical in shape and the lower part is almost spherical. It possess two long, diametrically opposite tentacles which are highly contractile. The stomach is oval in shape and reaches to the mid-point of the umbrella opening. The marginal bulbs are rudimentary and hardly visible. Size: 1.5 mm - 1.7 mm diameter; Recorded: Ghana

Bougainvillia carolinensis, (McCrady, 1857)

The apical part of the umbrella is very thick and spherical in shape. There are three to six tentacles arising from small and globular marginal bulbs, each with a dark pigment in the interior. The oral tentacles are dichotomously branched and the manubrium is cylindrical and could be as long as the height of the umbrella cavity. The gonads reach from the top to the mouth. Size: 4 mm high; Recorded: Ghana

Dipurena strangulate, (McCrady,1857)

Umbrella is dome-shaped and terminal ends of tentacles are swollen. The manubrium appears contracted when dead (can be extended when alive). Gonads are two elongated, thickly swollen and separated by a portion of the manubrium. Size: 2.0 - 3.5 mm in diameter; Recorded: Ghana and Sierra Leone.

Annatiara affinis, (Hartlaub, 1913)

The gonads are folded between the radial canals. The manubrium ends in a much folded lips. The marginal tentacles (about 24 in number) are very long and thin, and arise from elongated and strongly compressed basal bulbs. Size: 10 mm diameter; Recorded: Liberia

Stomotoca pterophylla, Haeckel, 1879

The umbrella is conical in shape with an apical projection. There are two long, tapering, marginal tentacles which are situated at opposite sides on the bases of two of the radial canals. There are about 60 rudimentary tentacle bulbs along the umbrella margin. The manubrium is large and swollen and lies outside of the umbrella cavity, and the mouth lips are folded. Size: 5.5 mm diameter; Recorded: Ghana

Phialidium hemisphaerica Linnaeus, 1767

Umbrella is flat, the stomach is four-sided and is not situated on a peduncle. It bears four short and simple lips. The gonads are four in number and are oval to linear in shape and they are situated on the radial canal, very close to the ring-canal. There are 32 tentacles with two marginal statocysts between each tentacle. Size: 2 - 8 mm in diameter; Recorded: Liberia, Ghana

Phialella quadrata (Forbes, 1848)

Umbrella is nearly spherical in shape. Stomach is short, four-sided and bears four short lips with slightly folded margins. The gonads are elongated and oval in shape and are borne on the radial canal towards the umbrella opening but not reaching it. There are eight marginal vesicles, each with between two to eight concretions, on cushion-like swellings. Marginal tentacles are 24 in number. Size: 4 - 5 mm in diameter; Recorded: Ghana

Obelia Peron & Leseuer, 1809

There is no satisfactory method of distinguishing species of medusae of this genus. The umbrella of Obelia is flat, the stomach is four sided and is not borne on any peduncle. The gonads are spherical or ovoid and hangs from middle of the radial canals. There are eight marginal vesicles and about 140 marginal tentacles, which are solid and not extensile. Size: 2 - 4 mm in diameter; Recorded: Ghana

Eirene viridula (Péron and Lesueur, 1809)

Umbrella is hemispherical in shape. The stomach is short and is situated on elongated conical gastric peduncle which reaches beyond umbrella margin. Mouth possesses four long folded lips. The gonads are linear and extend almost the whole length of the four radial canals but not onto the gastric peduncle. The number of tentacles varies with size and probably, with stage of development. The large and small tentacles frequently alternate in arrangement around the margins. Small specimens of about 3 mm wide may have about four tentacles with up to eight radial bulbs of different sizes, while some larger specimens up to 12 mm may have as many as 32 tentacles. Size: 8 - 12 mm in diameter; Recorded: Cote d'Ivoire to Congo

Eutima gracilis (Forbes and Goodsir, 1851)

Umbrella is high in the young stage and becomes flatter when fully grown. The stomach is short and cross-shaped in section. The gastric peduncle is narrow with a conical base and it extends far beyond the umbrella margin. The gonads are linear and arranged along almost the whole length of the peduncle and some parts of the radial canal. There are four marginal tentacles. Size 10 - 13 mm in diameter; Recorded: Guinea, Ghana, Gabon

Laodicea undulata (Forbes and Goodsir, 1851)

Stomach is small and attached to the radial canals. Wavy gonads lie on radial canals and are contiguous with stomach. The mouth has four simple folded lips. Marginal tentacles are very numerous (> 200), with slight basal swellings. Size : 4 - 11 mm diameter; Recorded: Ghana.

Eucheilota cirrata (Haeckel, 1879)

The umbrella is hemispherical in shape.

Aequorea aequorea (Forskål, 1775)

It is saucer-shaped, thick in the centre and gradually thinning towards the margins. The exumbrella is smooth and without rows of papillae. There is no gastric peduncle and the stomach is half the width of the umbrella. Radial canals are very numerous (between 60 - 120). Marginal tentacles are less numerous than radial canals. There are usually two statocysts between successive developed tentacles. Size: 45 mm in diameter; Recorded: Ghana

Octophialucium medium Kramp, 1955

The stomach is short and the mouth bear eight folded lips which are long and pointed. The radial canals are eight in number and narrow. Gonads occupy more than half the length of the radial canal towards the umbrella opening. There are 16 marginal tentacles, and as a rule, between each two successive tentacles there are three small bulbs, the median one slightly larger than the others. Size: 17 - 22 mm diameter; Recorded: Nigeria

Rhacostoma atlanticum Agassiz, 1850

The upper surface of the umprella is flat or slightly concave in center. The stomach is broad, flat and sac-like, and terminates below in a cylindrical tube. The mouth is surrounded by tapering oral tentacles. The radial canals are about 90 in number. Size: 85 mm in diameter; Recorded: Senegal

Proboscidactyla ornata (McCrady, 1859)

There are sixteen marginal tentacles of varying lengths which are very contractile and capable of great elongation. They are covered with ring-like clusters of nematocyst on the umbrella which become apparent only during periods of contraction. Radial canals are four in number and gonads are located on the inter-radial walls of the stomach. The manubrium is flask-shaped and the mouth is nearly at level with the velar opening. The radially recurved lips on the mouth have folded lips. Size: 3 - 4 mm in diameter; Recorded: Ghana and Congo.

Pochella oligonema Kramp, 1955

The umbrella is dome-shaped with thick gelatinous substance, especially in the apical portion. Stomach is pyramidal, mounted on a broad gelatinous peduncle, and reaching almost to the level of the umbrella margin. The mouth is quadrangular and posses four very and simple lips. There are four inter-radial, cushion-like gonads completely covering the four sides of the stomach, from the peduncle almost to the mouth rim. The radial canal are four and unbranched, and the ring canals are narrow. The four tentacles arise from spherical basal bulb, along the radial canals. Differs from Proboscidactyla ornata in the absence of nematocyst on the umbrella. Size: 2 - 3 mm high; Recorded: Ghana

Olindias phosphorica (Chaje, 1841)

The umbrella is flatter than hemispherical. The gonads are linear, swollen with surfaces covered by branched processes and extend almost the entire length of the radial canal. The number of primary marginal tentacles can reach 100. Numerous secondary tentacles arise from the lower side of the umbrella margin. Size: 50 - 53 mm in diameter ; Recorded: Nigeria and Congo

Aglauropsis jarli Kramp, 1955

Umbrella is dome-shaped, as high as wide. The stomach is small and has a cross-shaped base. The mouth is four-sided with broadly rounded corners and no distinct lips. The gonads, along the four radials canals, increases in thickness outwards from their base and end in a hanging sac-like manner beyond the umbrella margin. There are eight marginal tentacles, with numerous nematocyst rings, and between these tentacles are smaller ones. Size: 4 mm in diameter; Recorded: Liberia

Liriope tetraphylla (Chamisso and Eysenhardt, 1821)

This species is distinguished by its long, cylindrical peduncle with a conical base. The peduncle is three to four times as long as the bell radius. The gonads are egg-shaped and they do not touch the ring-canal. There are four long marginal tentacles. Size: 12 - 18 mm in diameter; Recorded: Senegal to Congo

Rhopalonema velatum Gegenbaur, 1856

The umbrella is slightly hemispherical with conical apical thickening. The stomach is narrow and elongated, reaching almost to the umbrella opening, with four short and simple lips. The gonads are oval and elongated along the middle third of the radial canal. There are eight marginal tentacles with eight smaller tentacles between successive tentacle. Size: 4 - 5 mm in diameter; Recorded: Liberia to Nigeria

Amphogona apsteini (Vanhöffen, 1902)

There are no distinct tentacles opposite the radial canals, but numerous small warts on the umbrella margin. Eight small spherical gonads are present in the distal parts of the radial canals. Size: 3 - 4 mm in diameter; Recorded: Ghana.

Aglaura hemistoma (Péron and Lesueur, 1809)

The umbrella is columnar and flattened at the apex. The marginal tentacles are stiff and about 50 in number. They are normally broken when the animal is dead. The stomach bears four ciliated lips, and is mounted on a conical peduncle, which does not reach the margin of the umbrella. The gonads are situated between the junction of the eight radial canals and the stomach. Size: 3 - 4 mm high; Recorded: Liberia, Cote d'Ivoire, Ghana, Togo, Benin and Nigeria.

Halicreas minimum Fewkes, 1882

Umbrella is hemispherical and slightly flattened, with apical conical process of varying size which may be completely absent. Eight radial canals each with five to ten conical structures at their margins. The stomach is broad and flat. Gonads are oval, each situated on radial canal. There are eight large marginal tentacles placed evenly and between them are very numerous (>100) smaller tentacles. Size: 20 - 24 mm in diameter; Recorded: Ghana, Liberia

Colobonema sericeum Vanhöffen, 1902

Umbrella is bell-shaped with no apical process. Mouth possess four short lips. The gonads are lcoated on eight radial canals which widens slightly towards the umbrella apex. The marginal tentacles are stump-like and thirty two in number. Size: 30 - 35 mm high; Recorded: Liberia, Nigeria

Pantachogon haeckeli Maas, 1893

Umbrella is bell-shaped and flattened at the apex. The stomach is short and eight-sided at the base with no peduncle. The mouth is pointed and bears four simple lips. Gonads form linear discontinuous swellings along the sides of each of the eight radial canals. The marginal tentacles are stump-like and sixty four in number. Size: 7 - 11 mm in diameter; Recorded: Senegal, Liberia, Ghana

Arctapodema amplum (Vanhöffen, 1902)

Umbrella is flatter than hemispherical. There are eight spherical gonads upon the radial-canals adjacent to a short which ends in four short, simple lips. There are ninety six marginal tentacles. Size: 6 mm in diameter; Recorded: Liberia

Geryonia proboscidalis (Forskal, 1775)

Gonads are elongated and located on eight radial canals. The marginal tentacles are long and arise from the base of each radial canal. The pedunlce is elongated and bears terminal lips. Size: 15 - 17 mm in diameter; Recorded: Liberia

Solmaris corona (Keferstein and Ehlers, 1861)

Umbrella with up to thirty-five rectangular marginal lappets, each up to twice as long as broad. A tentacle arises from each lappet. The species possess no stomach pouches. Size: 1.2 - 3 .5 mm in diameter; Recorded: Ghana

Solmundella bitentaculata (Quoy and Gaimard, 1827)

The apex of the umbrella is sharp-edged and keel-shaped. The line of the keel is in the axis of the two characteristic long tentacles. The two tapering tentacles project from the sides of the bell, at

a zone nearer to the apex than to the margin. The stomach is flat. Size: 5 - 6 m in diameter; Recorded: Ghana

Aegina citrea Eschscholltz, 1829

Stomach large, circular with eight rectangular pouches. There are four to six (typically four) tentacles arising from the upper ends of the peronia at level of top of stomach. No secondary tentacles on umbrella margin but there are up to 50 sensory clubs without hairs. Size: 7 - 8 mm in diameter; Recorded: Liberia, Ghana, Nigeria

Aeginura grimaldii Maas,1904

Stomach large, circular with sixteen rectangular pouches. Eight large primary tentacles arise at level of top of stomach, and between successive tentacles are three to five small, marginal secondary tentacles. Size: 18 mm in diameter; Recorded: Liberia

Cunina octonaria McCrady, 1857

The stomach pouches are broad and square-shaped, separated by very narrow spaces. There are between seven and nine tentacles which alternate with the marginal lappets. The nematocyst pad below the base of the tentacles is more prominent than in C. peregrina Size: 3 - 5 mm in diameter; Recorded: Liberia to Gabon

Pegantha clara Bigelow, 1909

Umbrella is a double convex. About 28 marginal lappets with peripheral canals. Size: 40 mm in diameter; Recorded: Ghana

Pegantha martagon (Haeckel, 1897)

Umbrella hemispherical or higher. Marginal lappets are ten in number and are rounded at the edges. Size: 14 mm in diameter; Recorded: Senegal

Pleurobrachia pileus (Müller, 1776)

The body is ovoid to spherical in shape; tentacular diameter is slightly wider than the sagittal; there are four pairs of ciliary combs which are equal in length and beginning near the aboral pole, they extend to about three-quarters of the distance to the mouth; in newly hatched specimens comb rows form four inter-radial pairs of parallel clusters; at this stage the body is pear-shaped and the tentacles develop at the surface; the body becomes more spherical as it grows. Size: 15 mm length. Recorded: Ghana

Bolinopsis infundibulum (Müller, 1777)

The adult is milky in appearance and the body is laterally compressed in the tentacular plane. Large oral lobes comprise one third of the body height. The tentacles are situated on each side of an elongated mouth. They are not sheathed and cannot be retracted. There are accessory tentacles present at the edge of the mouth. Size: Up to 150 mm high. Recorded: Ghana

Beroë cucumis Fabricius, 1780

The body is slender and cylindrical with slight lateral compression. There is a row of branched papillae in the form of a figure "8" around the pole plate at the aboral end. Size: up to 30 mm high. Recorded: Ghana

Oxygyrus keraudreni Leseur, 1817

Shell compressedly coiled, cartilaginous with a calcified layer in the inner wall; shell appear brownish. Size: 2 - 4 mm Recorded: Senegal to Cameroon

Limacina trochiformis d'Orbigny, 1836

Body in the form of a short cone with thin and transparent shell rounded at the apex; spire with five coils; shell sutures distinct. Size: 1- 2 mm Recorded: Cote d'Ivoire

Peraclis reticulata d'Orbigny, 1836

Elongated shell with three and a half coils of spire; surface of shell almost covered entirely with mesh-like texture. Size: 2 - 4 mm. Recorded: Senegal; bottom dwelling species.

Hyalocylix striata Rang, 1828

Horn-like, transparent shell, slightly flattened with ring-like shrinkages on the surface; apex of shell bends slightly backwards; left tentacle is bigger than the right one; characteristic transparent area on the dorso-lateral margin of the fin. Size: 3 - 4 mm Recorded: Senegal to Cameroon

Creseis virgula Rang, 1828

Anterior two-thirds of the shell is straight, the rest bending backward; shell usually slightly transparent with two constrictions, the anterior being more consipicuous than the posterior. Size: 3 - 5 mm Recorded: Senegal to Cameroon

Tomopteris septentrionalis Quatrefages, 1865

The body is slightly transparent and the prostomium is produced into a pair of lateral antennae. There are a pair of small eyes situated at the ventral side of the head. The parapodia are well developed, biramous paddles which lack setae but are expanded into foliaceous pinnules, presumably an adaptation to the planktonic existence. The second segment bears a pair of very long streamers (antennae), and in between the prostomium and antennae, there are other lateral processes on the first segment. The long antennae are probably tactile and chemosensory, as are the prostomial palps. Size: 30 mm - 50 mm. Recorded: This species is cosmopolitan and abound in the upper layers to 200 m.

Penilia avirostris Dana, 1846

Female: bivalve-shaped body with frontal margin of carapace serrated; there are two spines at the edge of the carapace, the larger one is located at the infero-posterior angle; rostrum is pointed; antennule is truncated and small. Size: 0.5 mm - 1.2 mm; Male: similar to female but rostrum is rounded and antennule is as long as length of carapace Size: 0.7 mm - 1.0 mm Recorded: Cote d'Ivoire, Ghana, Nigeria

Evadne tergestina Claus, 1877

Female: round body with large pair of eyes in front of antennule. Size: 1.0 - 1.1 mm; Male: resembles female but body is oval and tapers broadly posteriorly. Size: 0.8 - 0.9 mm. Recorded: Cote d'Ivoire, Ghana, Nigeria

Evadne spinifera Muller, 1859

Female: similar to female E. tergestina but oval body tapers into a spine. Size: female 0.7 - 0.8 mm. Male: similar to male E. tergestina but body tapers into a long spine Size: 0.5 - 0.6 mm. Recorded: Cote d'Ivoire, Ghana, Nigeria

Podon polyphemoides Leuckart, 1859

Female: head bears a large eye in front of the antennule: junction of head and body is marked by a dorsal depression. Size: 0.7 - 0.8 mm. Male: resembles female but there is a hook at the distal end of the endopodite of first pair of legs and the carapace is smaller than in the female. Size: 0.5 - 0.6 mm. Recorded: Cote d'Ivoire, Ghana, Nigeria

Conchoecia elegans (Sars, 1908)

Female: this species is distinguished by the single spine at the corner of the elongated dorso-posterior shell; frontal organ undifferentiated, straight and round-ended. Size: 1.5 mm - 1.8 mm. Male: resembles female but frontal organ is partially. Size: 1.3 - 1.6 Recorded: Ghana

Euconchoecia chierchiae Muller, 1912

Female: thin shell, boat-shaped with dorso-posterior spine; frontal organ long; first antenna with only 20 -25 filaments; 6th limb with shorter, slender claws Size: 1.0 mm - 1.4 mm. Male: resembles female but 6th limb possess 3 long, plumose bristles and the two of the terminal bristles of the first antenna are very long. Size: 10.9 - 1.2 mm Recorded: Cote d'Ivoire and Ghana

Acartia danae Giesbrecht, 1889

Female: body is narrow and elongated; cephalon is broadly triangular and bears a median eye; antennule reaches to the tips of the caudal rami and first segment bears a spine; corners of 5th thoracic segment bears prominent spines posteriorly; second segment of P5 is longer than wide; there is a distinguishable slender plumose setae at the base of the fifth leg. Size: 1.1 - 1.2 mm Male: resembles female; P5 is paired, uniramous and bears spines on the distal segment. Size: 0.7 - 0.8 mm. Recorded: Guinea, Cote d'Ivoire, Ghana, Nigeria Congo; epiplanktonic

Acartia negligens Dana, 1849

Female: resembles A. danae but spines on 5th thoracic segment are smaller; P5 bears a plumose seta on 5th basipodite which is about five times as long as the terminal segment. Size: 1.1 - 1.2 mm Male: posterior lateral margins of 5th thoracic segment is rounded and bears small spines and hairs. Size: 0.8 - 1.0 mm. Recorded: Ghana, Nigeria; epiplanktonic

Acartia plumosa Scott, 1894

Female: cephalon triangular and bears median eye; corners of 5th thoracic segment are rounded posteriorly; posterior margins of genital segment and first thoracic segment bears five short spinules; distal margins of P5 bears long recurved spines. Size: 1.0 - 1.2 mm Male: posterior margins of genital segment and first thoracic segment bears three to four short spinules; P5 is chelate. Size: 1.0 - 1.1 mm. Recorded: Congo; epiplanktonic

Acartia tonsa Dana 1849

Female: cephalon rounded; antennule reaches to middle of genital segment; 5th thoracic segment are rounded posteriorly; each of distal segments of paired P5 terminates in a long recurved spines; basipodite bears long, lateral apical bristle. Size: 1.2 - 1.4 mm Male: lateral parts of genital segment bears short bristles; basipodite of left P5 with rounded process and the distal segment bears an apical spine Size: 1.0 - 1.2 mm. Recorded: Liberia, Ghana, Congo; epiplanktonic and enters brackish waters

Acartia grani Sars, 1904

Female: Genital segment symmetrical with widest part, in dorsal view, posterior to middle of segment. P5 with a heavy terminal spine and very small external plumose setae. Size: 1.0 - 1.29 mm Male: Right antennule with middle segments swollen, outer middle spine on segments 19 - 21 very large extending almost to end of antennule. Size: 0.8 - 1.1 mm. First record off the coast of Ghana by George Wiafe.

Euchirella splendens Vervoort, 1963

Female: cephalon is fused to first thoracic segment and is rounded anteriorly; antennule reaches the distal margin of the anal segment; fourth and fifth thoracic segments are fused (a line of

fusion is visible on the dorsal surface); genital segment is as long as wide and the left side is slightly swollen and rounded when viewed dorsally, but it is distinctly dented on the right side. P5 is absent. Size: 4.2 - 5.1 mm Male: Similar to female but differs in shape of P5. Size: 4.0 - 4.8 mm Recorded: Senegal to Congo; offshore

Aetideus armatus (Boeck, 1872)

Female: cephalon fused to first thoracic segment; antennule reaches to end of caudal furca; 4th and 5th thoracic segments are fused; postero-lateral thoracic segment with acute points reaching to end of genital segment; genital segment slightly swollen laterally. Size: 1.8 - 2.0 mm Male: resembles female but points of thoracic segments are reduced in length; antennule reaches to second urosome segment. Size: 1.4 - 1.6 mm Recorded: Ghana; mesopelagic

Aetideopsis multiserrata (Wolfenden, 1904)

Female: cephalon fused with first thoracic segment; antennule reaches end of caudal furca; spines of 5th thoracic segment reaches about middle of genital segment; apical spines of distal exopodite segment of swimming legs are serrated. Size: 2.7 - 2.8 mm Male: resembles female but P1 bears a long spine. Size: 2.5 - 2.6 mm Recorded: Ghana; bathypelagic

Chiridius poppei Giesbrecht, 1892

Female: cephalon rounded anteriorly and fused to first thoracic segment; 4th and 5th thoracic segments are fused and produced into a spine which reaches middle of genital segment; genital segment as long as wide. Size: 1.4 - 1.7 mm Male: resembles female but posterior end of last thoracic segment is less produced; P5 is uniramous, elongated and slender. Size: 1.2 - 1.6 mm Recorded: Congo; mesopelagic

Calanoides carinatus Krøyer, 1849)

Female: cephalon is keeled and separated from first thoracic segment; antennule is shorter than body; fifth thoracic segment is rounded posteriorly; all five pairs of legs are of swimming type and similar; inner margin of first basipodite of P5 with a straight edge. Size: 2.3 - 2.8 mm Male: resembles female; left P5 is composed of a single joint without setae. Size: 2.0 - 2.4 mm. Recorded: Cote d'Ivoire to Congo

Nannocalanus minor (Claus, 1863)

Female: orange colouration noticeable along thoracic margins; cephalon is fused with first thoracic segment; antennules are shorter than body; fifth thoracic segment rounded posteriorly; distal margin of the second basipodite of P2, P3 and P4 armed with spines; inner margin of first basipodite of P5 with serrated straight edge. Size: 1.8 - 2.3 mm Male: slightly smaller than female; antennule is S-shaped. Size: 1.7 - 2.0 mm Recorded: Senegal to Congo

Neocalanus gracilis (Dana, 1849)

Female: robust body; cephalon is fused with first thoracic segment; antennule is one and half times as long as the body and with plumose setae at distal end; fifth thoracic segment is rounded posteriorly; second basipodite joint of P1 each with prominent hook on anterior surface; inner margin of first basipodite of P5 symmetrical and with smooth edges; genital segment slightly produced laterally; second inner marginal seta on the left side of the caudal ramus is very long and curved. Size: 3.0 - 3.4 mm. Male: cephalon is separated from first thoracic segment; third exopodite joints of P2, P3 and P4 with toothed outer edges; P5 asymmetrical and endopodite bears setae. Size: 2.5 - 2.8 mm. Recorded: Cote d'Ivoire to Congo

Neocalanus robustior (Giesbrecht, 1888)

Female: genital segment strongly produced laterally; P5 is symmetrical. Size: 3.5 - 4.0 mm Male: P5 asymmetrical and endopodite is without setae. Size: 2.8 - 3.0 mm. Recorded: Cote d'Ivoire to Congo

Undinula vulgaris (Dana, 1849)

Female: cephalon fused with first thoracic segment; antennule reaches as far as the caudal rami; fifth thoracic segment with pointed posterior corners and turned ventrally; outer margin of second exopodite with a deep notch at its proximal corner; dark spot on genital segment. Size: 2.4 - 2.9 mm Male: cephalon is fused with first thoracic segment; antennule S-shaped and a little longer than in the female; left P5 is greatly elongated and the terminal segment tipped with a worm-like process; caudal rami extends outwards. Size: 2.2 - 2.5 mm. Recorded: Cote d'Ivoire to Congo

Calocalanus pavo (Dana, 1849)

Female: stout body; cephalon is widely triangular and is fused to first thoracic segment; antennule is longer than the body; last segment of the antennule is about five times longer than the preceding segment; P5 is symmetrical 4-segmented; urosome is 2-segmented; genital segment is wider than long; species characterised by caudal rami turned outward at right angles to the body axis. Size: 0.9 - 1.2 mm. Male: caudal rami is not turned outwards as in female; urosome is 4-segmented; left and right P5 are 5- and 4-segmented respectively. Size: 0.9 - 1.0mm Recorded: Liberia to Nigeria

Calocalanus styliremis Giesbrecht, 1888

Female: stout body; cephalon is rounded and fused to first thoracic segment; P5 is uniramous and 3-segmented. Size: 0.9 - 1.1 mm Male: abdomen 3-segmented. Size: 0.9 - 1.0 mm Recorded: Ghana, Nigeria

Ischnocalanus plumulosis (Claus, 1863)

Female: when specimen is intact it is recognised by an enormous plume on the left caudal ramus; cephalon fused to first thoracic segment; antennules are shorter than in C. pavo, and each has a single plume on the anterior margin of the basal segment; P5 is 4-segmented with hairy edges and the terminal segment bears a single plumose seta and three spines. Size: 0.9 - 1.25 mm Male: urosome is 5-segmented. Size: 0.9 - 1.2 mm. Recorded: Senegal

Mecynocera clausii Thompson, 1888

Female: body is elongated and slender; cephalon is rounded anteriorly; antennule is twice the body length; penultimate segment of P5 bears single seta and terminal segment bears five setae; genital segment is globular in shape and as wide as long. Size: 1.0 - 1.2 mm Male: body and appendages similar to female, but smaller. Size: 0.8 - 0.9 mm Recorded: Senegal, Ghana

Candacia magna Sewell, 1932

Female: cephalon and first thoracic segments are partly fused, a line of fusion is visible on the dorsal surface; distinct hump on the mid-dorsal line at the end of the cephalon; antennule is longer than the body; postero-lateral thoracic margin is produced into a triangular spine on each side, covering the beginning of the genital segment; P1 to P4 have terminal spines, that of P3 is rather short and curved inwards. Size: 4.4 - 4.6 mm Male: cephalon is not fused with the first thoracic segment; the hump in the mid-dorsal line is bigger than in the female; the genital

segment has a rounded protusion on the right side; right P5 is chelate. Size: 3.9 - 4.4 mm. Recorded: Cote d'Ivoire to Congo

Candacia curta (Dana, 1852)

Female: cephalon and first thoracic segments are fused; postero-lateral thoracic segment is produced into a spine on each side; genital segment bears a spine-like process on genital surface. Size: 2.2 - 2.4 mm Male: antennule is geniculate; postero-lateral thoracic segment is produced into a spine on each side, but recurved on the right side (in dorsal view); genital segment bears a spine-like process. Size: 1.9 - 2.0 mm. Recorded: Senegal to Congo

Candacia elongata (Boeck, 1872)

Female: 5th thoracic segment is rounded posteriorly; 3rd joint of P5 is slender and bears two terminal and two minute outer-edge spines Size: 3.2 - 3.5 mm Male: fifth thoracic segment bears finger-like process on right side, left side is rounded; the genital segment bears a blunt projection overlapping a smaller projection on the 2nd segment. Size: 3.6 - 3.8 mm. Recorded: Liberia to Congo

Candacia pachydactyla (Dana, 1849)

Female: genital segment with two asymmetrical latero-ventral spines; P5 with three setae on the inner margin of the terminal segment. Size: 2.5 - 2.9 mm Male: fifth thoracic segment recurved posteriorly on right side, left side is pointed; right P5 chelate. Size: 2.4 - 2.6 mm. Recorded: Senegal to Congo

Candacia bipinnata (Giesbrecht, 1889)

Female: genital segment bears two symmetrically arranged lateral spines; second urosomal somite is produced ventrally. Size: 2.4 - 2.7 mm Male: resembles female and in lateral view the projection on right posterior corner of 5th thoracic segment is truncated distally. Size: 2.2 - 2.5 mm. Recorded: Senegal to Congo

Candacia tenuimana (Giesbrecht, 1889)

Female: antennule is shorter than body; spines of 5th thoracic segment are asymmetrical; distal segment of P5 terminates in three long spines; genital segment is produced ventrally. Size: 2.2 - 2.4 mm Male: 5th thoracic segment is produced into a spine on the right side, left side is straight and pointed; right P5 is chelate and the left is uniramous and 4-segmented; genital segment bears a spiny recurved projection. Size: 2.2 - 2.3 mm. Recorded: Senegal to Congo, offshore species

Candacia longimana (Claus, 1863)

Female: antennule reaches to end of thoracic segment; distal segment of P5 terminates in three short spines. Size: 2.9 - 3.5 mm Male: outer margins of 2nd to 4th segments of the antennule bears spines; viewed dorsally, P5 is chelate and the left is uniramous and 4-segmented; distal end of projection on the right side of the genital segment is rounded. Size: 2.6 -3.2 mm. Recorded: Senegal to Congo, offshore species

Candacia varicans (Giesbrecht, 1892)

Female: 5th thoracic segment bears acute spines; distal segment of P5 terminates in three unequal spines. Size: 2.3 - 2.5 mm Male: resembles female in shape of 5th thoracic segment; P5 is chelate and the left is uniramous and 4-segmented. Size: 2.3 - 2.4 mm. Recorded: Senegal to Congo, offshore species

Centropages chierchiae Giesbrecht, 1889

Female: cephalon broadly triangular in shape and is separated from first thoracic segment; cephalon bears a large median eye; antennule is as long as the body and it bears teeth on the 1st, 2nd and 5th segments; 5th thoracic segment terminates posteriorly in a spine at each lateral end; genital segment swollen at the right and ventral sides; P5 is absent. Size: 1.6 - 2.0 mm Male: right antennule is prehensile; right P5 is chelate and the inner margin is denticulate. Size: 1.6 - 1.9 mm. Recorded: Cote d'Ivoire to Congo

Centropages furcatus (Dana, 1849)

Female: closely resembles C. chierchiae but possesses two assymetrical spines distally on each side of the 5th thoracic segment (a longer outer spine and a smaller inner one). Size: 1.5 - 1.9 mm Male: chela of P5 is not denticulate as in C. chierchiae. Size: 1.4 - 1.7 mm. Recorded: Senegal to Congo

Centropates violaceus (Claus, 1863)

Female: posterior corners of 5th thoracic segment rounded; no teeth on 1st, 2nd and 5th segments of antennule; ventral swelling on genital segment and the one following it; caudal furca broad. Size: 1.8 - 1.9 Male: chela of P5 with slender sigmoid claw. Size: 1.5 - 1.8 mm Recorded: Senegal to Nigeria

Eucalanus crassus Giesbrecht, 1888

Female: robust body; cephalon rounded anteriorly and constricted at the mid-point; antennule is as long as the body and the fifth thoracic segment is barely discernible, and is rounded posteriorly; genital segment wider than long and is fused to furca. Size: 2.9 - 4.0 mm Male: right P5 is absent and the left is uniramous, 4-segmented and bears hair on the distal segment. Size: 2.6 - 3.5 mm. Recorded: Liberia to Congo

Eucalanus pileatus Giesbrecht, 1888

Female: similar to E. crassus but cephalon is keeled, without distinctive constriction on the dorsal surface. Size: 2.5 - 3.8 mm Male: P5 is similar to E. crassus but lack hair on the distal segment. Size: 2.0 - 3.5 mm. Recorded: Guinea to Congo

Eucalanus attenuatus (Dana, 1849)

Female: body is slender and the cephalon is triangular and constricted near the base of the antennule; antennule is as long as the body; genital segment wider than long. Size: 3.5 - 5.8 mm Male: right P5 is 3-jointed and shorter than the 4-jointed left leg. Size: 3.0 - 4.2 mm. Recorded: Senegal to Congo

Eucalanus monachus (Giesbrecht, 1888)

Female: cephalon is ellipsoid; second inner seta of the left ramus is elongated; genital segment is wide. Size: 2.0 - 2.4 mm Male: resembles female but cephalon is rounded anteriorly Size: 2.0 - 2.3 mm. Recorded: Congo

Eucalanus elongatus (Dana, 1849)

Female: body elongated; cephalon is triangular; fifth thoracic segment terminates in blunt points; genital segment longer than broad Size: 4.4 - 6.5 mm Male: P5 paired and asymmetrical Size: 3.6 - 5.0 mm Recorded: Liberia to Congo

Rhincalanus cornutus (Dana, 1849)

Female: distinguished by the anchor-shaped frontal projection of the cephalon; antennule is much longer than the body; each thoracic segments bears two small dorsal and lateral spines; genital segment with two similar dorsal spines near the middle of the segment; caudal rami slightly asymmetrical. Size: 3.0 - 3.8 mm Male: left P5 is biramous and right is uniramous and ends in a straight claw. Size: 2.5 - 2.8 mm. Recorded: Liberia to Congo

Rhincalanus nasutus Giesbrecht, 1888

Female: similar to R. cornutus but cephalon is much produced and triangular, not anchor-shaped as in R. cornutus. Size: 4.0 - 5.5 mm Male: similar to female but antennule considerably shorter; left P5 biramous and right is uniramous and ends in a curved claw. Size: 3.0 - 4.0 mm. Recorded: Senegal

Euchaeta marina (Prestandrea, 1833)

Female: a pointed process projects forward just above the base of the rostrum; antennule reaches the second urosome segment; genital segment asymmetrical, ventral process on the right of the genital opening is much larger than the one on the left; second pair of caudal setae is longer than twice the body length. Size: 3.2 - 3.6 mm Male: body more slender than in the female; genital segment symmetrical; endopodite of P5 is long and greatly modified. Size: 3.0 - 3.3 mm.

Recorded: Senegal to Congo

Euchaeta aequatorialis (Tanaka, 1958)

Female: cephalon is fused to first thoracic segment and is short and squat; genital complex is swollen in the ventral view. Size: 4.5 - 5.1 mm Male: lamella on the second exopodite of P5 is flat, and both its edges are set with small fairly obtuse teeth, gradually increasing in size towards the apex. Size: 4.0 - 4.3 mm.

Recorded: Senegal to Congo

Euchaeta tonsa Giesbrecht, 1895

Female: posterior corners of 5th thoracic segment is produced and narrowly rounded posteriorly; ventral protuberance of genital segment very prominent and notched at the center. Size: 5.5 - 8.0 mm Male: corners of 5th thoracic segment not so prominent as in the female; P5 is longer than the urosome; exopodite of left P5 is 3-segmented and the distal segment is widened and ends in tufts of hair and short spines. Size: 4.5 - 6.5 mm. Recorded: Senegal to Congo

Euchaeta hebes Giesbrecht, 1888

Female: Genital segment without protuberance on left side but with pronounced step in the dorsal outline. Size: 2.8 - 3.0 mm Male: Row of spines on serrated lamella extends along exopodal segment. Size: 2.7 - 2.8 mm

Metridia princeps Giesbrecht, 1892

Female: anterior cephalon has no anterior horns and the caudal rami is about five times as long as wide; coxa of P5 bears row of long hairs Size: 5.0 - 8.2 mm. Male: terminal segment of right P5 bears long appendix, originating proximally and lying parallel to outer border Size: 4.9 - 7.8 mm. Recorded: Ghana, mesopelagic species occasionally caught in surface waters.

Pleuromamma xiphias (Giesbrecht, 1889)

Female: Anterior cephalon is prolonged downward into a point. Size: 3.9 - 4.4 mm

Male: Cephalon similar to female but directed forward and not downward.

Size: 4.0 - 5.7 mm. Recorded: Senegal to Congo; mesopelagic species occasionally caught in surface waters.

Pleuromamma abdominalis (Lubbock, 1856)

Female: Pigment spot usually on left side of body. Proximal joints of antennule bearing several small and two large denticles (on first and second joints). P5 is four-jointed with distal joint bearing three apical bristles of very unequal length and two thin spines. Size: 2.7 - 3.5 mm Male:

Pigment spot like in female. Genital aperture and denticles of inner margin of endopodite of second pair of legs situated on left side. Right antennule is geniculate. Abdomen is assymetrical, with long thick bristles. Left P5 bears wide distal joints. Size: 2.4 - 3.7 mm. Recorded: Senegal to Congo; mesopelagic species occasionally caught in surface waters.

Gaussia princeps (Scott, 1893)

Female: Forehead pointed anteriorly, in lateral view with anterdorsal triangular process. Posterior corners of prosome is more or less symmetrical and divergent. Size: 7.0 - 9.1 mm Male: Third segment of left P5 bears blunt and short spine directed proximally. Size: 8.1 - 9.5 mm. Recorded: Cote d'Ivoire to Nigeria; mesopelagic species occasionally caught in surface waters.

Paracalanus parvus (Claus, 1863)

Female: body short and stout; cephalon rounded anteriorly and is fused to thoracic segment; antennule reaches to middle of the urosome; 4th and 5th thoracic segments are fused; both pair of P5 are uniramous and non-natatory. Size: 0.8 - 1.0 mm Male: P5 is assymetrical; the right is two-jointed as in the female but the left is much longer and is five-jointed, with two minute terminal spines. Size: 0.9 - 1.0 mm. Recorded: Senegal to Congo

Paracalanus aculeatus Giesbrecht, 1888

Female: antennules are relatively longer than in P. parvus; urosome is short and stout, with longer setae on the inner edge of the furcal rami; P5 is single, uniramous, and 2-segmented. Size: 1.1 - 1.2 mm Male: paired P5, uniramous, right one 2-segmented, left one 5-segmented. Size: 1.1 - 1.3 mm. Recorded: Senegal to Congo

Paracalanus denudatus Sewell, 1929

Female: more slender than P. parvus; cephalon fused with first thoracic segment; antennules same as body length; genital segment is laterally produced; P5 not paired, uniramous and 2-segmented. Size: 0.7 - 1.0 mm Male: resembles female but genital segment is not produced laterally. Size: 0.7 - 1.0 mm Recorded: Liberia

Paracalanus scotti Fruchtl, 1923

Female: body is compact and humped; cephalon is fused with first thoracic segment; antennule reaches the caudal furca; 5th thoracic segment is acute posteriorly; 2nd and 3rd exopodites of P2 to P4 bears spines on the outer edges; P5 is uniramous, paired and 2-segmented; genital segment is wider than long. Size: 0.7 - 0.9 mm Male: resembles female. Size: 0.7 - 0.9 mm Recorded: Liberia, Nigeria

Acrocalanus andersoni Bowman, 1958

Female: cephalon is fused to first thoracic segment and rounded anteriorly; antennule is shorter than body; 4th thoracic segment is fused to 5th and rounded posteriorly. Size: 1.2 - 1.3 mm Male: resembles female but proximal segment of antennule is very long; P5 is uniramous and 5-segmented. Size: 1.1 - 1.2 mm

Labidocera acutifrons (Dana, 1849)

Female: crest on the forehead is characteristic; abdominal segment is longer than the other segments and the fifth legs are rudimentary. Size:3.4 - 4.3 mm. Male: right antennule is geniculate and the P5 is assymetrical Size: 3.3 - 4.1 mm. Recorded: Senegal to Cameroon

Pontella gaboonensis Scott, 1894

Female: cephalon is nearly triangular, with a pair of distinct lateral hooks; it is fused with thoracic segment, and narrowly rounded in lateral view; antennules reaches to the fifth thoracic segment; abdomen is composed of two segments - the genital complex and the anal segment; P5 absent. Size: 2.8 mm - 2.9 mm Male: resembles female, but is slightly slender, and the rostral lens is strongly swollen and clearly visible in lateral view; P5 is a clasping organ. Size: 2.5 mm - 2.7 mm. Recorded: Senegal to Cameroon

Clausocalanus arcuicornis (Dana, 1849)

Female: body elliptical in outline, widest posteriorly, narrowed anteriorly; second basipodite of P2 and P3 bear teeth (i.e. crown of thorns); P5 is uniramous, symmetrical and 3-segmented; genital segment is longer than the abdominal segments; the caudal furca is about as wide as long. Size: 1.2 - 1.6 mm Male: urosome is 5-segmented, the 5th segment is very short and difficult to see; P5 is assymetrical. Size: 1.1 - 1.3 mm. Recorded: Senegal to Congo

Clausocalanus furcatus (Brady, 1883)

Female: second basipodite of P2 and P3 bear teeth (i.e. crown of thorns) as in C. arcuicornis; genital segment is shorter than either of the two segments posterior to it; caudal rami is twice as long as wide. Size: 0.8 - 1.2 mm Male: second segment of urosome longer than either of the two segments posterior to it. Size: 0.8 - 1.0 mm. Recorded: Guinea to Nigeria

Clausocalanus paululus Farran, 1926

Female: resembles C. arcuicornis but it is smaller in size. Size: 0.8 - 1.0 mm Male: resembles female but P5 is asymmetrical. Size: 0.7 - 0.9 mm Recorded: Guinea to Nigeria

Ctenocalanus vanus Giesbrecht, 1888

Female: antennule is longer than body; proximal segment of antennule is longer than the rest; outer edges of exopodites of P2 and P3 bear spines with pectinate distal margins; right P5 is absent. Size: 0.9 - 1.3 mm Male: left P5 is 5-jointed, right side bears a small tubercle. Size: 1.2 - 1.3 mm. Recorded: Ghana, Nigeria

Scolecithrix danae (Lubbock, 1856)

Female: body is robust and with a characteristis shovel-shaped protuberance on the ventral surface of the genital segment; antennule reaches to the genital segment. Size: 2.0 - 2.3 mm Male: resembles the female but genital segment is uniform; right P5 is uniramous and 5-segmented, the basipodite distally and exopodite proximally swollen. Size: 1.9 - 2.1 mm. Recorded: Senegal to Congo

Scottocalanus helenae (Lubbock, 1856)

Female: body is robust, though fairly slender in dorsal view; cephalon is triangular and is fused with the first thoracic segment; there is a characteristic helmet-like crest (clearly distinct in lateral view) on the head; antennules reaches to the end of caudal rami; 4th and 5th thoracic segments are fused and pointed posteriorly; P5 is symmetrical. Size: 3.4 - 3.9 mm. Male: resembles female but P5 is asymmetrical. Size: 3.8 - 4.0 mm. Recorded: Senegal to Congo

Temora stylifera (Dana, 1849)

Female: body is short and compacted; cephalon fused with frst thoracic segment which appears convex in the lateral view; fourth thoracic segment is fused to the fifth and terminates posteriorly in a stout spine at the corners which reaches behind the posterior margin of the ventrally flattened segment; caudal rami is symmetrical and elongated. Size: 1.5 - 1.9 mm Male: right antennule is geniculate and is shorter than the body; terminal exopod of right P5 is greatly swollen and subspherical and bears four apical spines. Size: 1.4 - 1.6 mm Recorded: Senegal to Congo

Temora turbinata (Dana, 1849)

Female: they are more laterally compressed than T. stylifera; 5th thoracic segment not produced into spine posteriorly; caudal rami is about seven time as long as wide. Size: 1.4 - 1.6 mm Male: terminal segment of the left P5 is a little wider than the basal segment and possess two stout apical spines. Size: 1.3 - 1.5 mm.

Recorded: Senegal to Congo

Temoropia mayumbaensis Scott, 1894

Female: P5 3-segmented and asymmetrical; genital segment with large ventral sac. Size: 1.1 - 1.3 mm Male: paired lenses on cephalon; P5 uniramous; right leg is 2-segmented and terminates in a long, curved, naked spine; left leg is 3-segmented with a long, curved spine arising from the distal anterior border of the first segment. Size: 1.0 - 1.2 mm. Recorded: Ghana

Oithona Baird, 1843

Female: The shape of the prosome range between short oval to long fusiform in dorsal view. The urosome is 5-segmented and the atennule is symmetrical. Male: These are usually smaller than the females. The urosome is 6-segmented and and antennule is geniculate.

Oithona plumifera Baird, 1843

Female: Body is elongated and cephalon is pointed anteriorly; antennule is plumose, brownish and reaches as far as the anal segment; 5th thoracic segment bears setae on the sides; caudal rami is three times as long as wide; urosome is long and thin Size: 1.0 - 1.5 mm Male: Broader part of body is ovoid and flattened anteriorly; antennule reaches as far as the anal segment and it is

twice geniculate; genital segment is longer than broad. Size: 0.7 - 1.0 mm. Recorded: Senegal to Congo; epipelagic

Oithona setigera (Dana, 1852)

Female: Body is elongated and cephalon is pointed anteriorly; antennule reaches as far as the anal segment but genital segment is not as broad anteriorly Size: 1.2 - 1.9 mm Male: Not recorded Recorded: Ghana

Lubbockia squillimana Giesbrecht, 1891

Female: Resembles Oithona but anterior end of cephalon is not pointed; antennule does not reach beyond metasome; urosome is 5-segmented and very thin; P5 reaches beyond posterior end of genital segment Size: 1.4 - 1.6 mm Male: Cephalon is triangular anteriorly; antennule reaches beyond metasome; urosome is 6-segmented Size: 1.8 - 2.1 mm Recorded: Cote d'Ivoire to Cameroon

Pachos punctatum (Claus, 1863)

Female: Cephalon is pointed anteriorly; posterior ends of metasome are pointed; paired spines on dorsal surface of metasome Size: 1.9 - 2.2 Male: Resembles female but without dorsal spines Size: 1.8 - 2.0 Recorded: Ghana

Oncaea Phillipi, 1843

They can be distinguished from other cyclopoida by the following: Female: antennule is 6-segmented; maxilliped is 4- segmented; urosome is 5-segmented; 2 segments between genital segment and anal segment; genital segment apertures are dorsal Male: antennule is 4-segmented; maxilliped is 3- segmented; urosome is 6-segmented; 3 segments between genital segment and anal segment; genital segment apertures are ventral

Oncaea venusta Philippi, 1843

Female: Cephalon slightly swollen and broader at posterior end; second genital segment more than one-and-half times longer than wide; caudal rami is four times as long as wide Size: 1.1 -

1.2 mm. Male: Genital segment is bulbous in shape; caudal rami is more than twice the length of the anal segment Size: 0.8 - 1.0 mm Recorded: Senegal to Congo

Oncaea media Giesbrecht, 1891

Female: Caudal rami is more than three times the length of the anal segment. Size: 0.5 - 0.8 mm Male: Second antennae bears 3 setae and 1 spine on proximal end of terminal segment; Size: 0.5 - 0.7 mm Recorded: Ghana

Oncaea conifera Giesbrecht, 1891

Female: Second thoracic segment with a hump on the dorsal mid-line; endopodite of P4 bears spines Size: 0.7 - 1.3 mm Male: Caudal rami shorter than anal segment

Size: 0.6 - 0.8 mm Recorded: Ghana

Oncaea mediterranea Claus, 1863

Female: Length of genital segment is about one-and-half times the width; length of caudal rami is three times the width Size: 1.0 - 1.3 mm Male: Caudal rami longer than anal segment Size: 0.7 - 1.1 mm Recorded: Cote d'Ivoire to Ghana

Oncaea minuta Giesbrecht, 1892

Female: Genital segment is twice as long as the posterior segment of urosome Size: 0.4 - 0.6 mm Male: Not recorded Recorded: Ghana

Corycaeus Dana, 1845

The body is slender; cephalosome is much longer than the metasome and bears large eye lenses placed together; third metasome segment is produced backward at each posterior corner in an acutely pointed lappet; 4th segment is narrower than the 3rd, may be fused to it dorsally in some species Female: terminal spine of second antenna is less than two-thirds length of longest basal spine Male: terminal spine of second antenna is mores than two-thirds length of longest basal spine

Corycaeus speciosus Dana, 1849

Female: Lappets of posterior corners of metasome reaches beyond the posterior margin of the genital segment and is spread distally; caudal rami is as long as genital segment and anal segment combined. Size: 1.8 - 2.2 mm. Male: The body is narrower than in the female; lappets of posterior metasome reaches to the center of genital segment and is not spread distally Size: 0.7 - 0.9 mm Recorded: Cote d'Ivoire to Cameroon

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Corycaeus clausi Dahl, 1849

Female: Cephalon separated from first thoracic segment; caudal rami is aproximately two-thirds the length of genital and anal segments combined

Size: 1.6 - 1.7 mm Male: Cephalon separated from first thoracic segment but the separation is not distinct on the dorsal surface; caudal rami approximately half the length of the urosome Size: 1.3 - 1.4 mm. Recorded: Cote d'Ivoire to Cameroon

Corycaeus flaccus Giesbrecht, 1891

Female: Urosome is pear-shaped in dorsal view with a central `button' best seen in lateral view Size: 1.7 - 1.9 mm Male: Genital segment is not as long as anal segment and caudal rami combined Size: 1.4 - 1.7 mm. Recorded: Cote d'Ivoire to Cameroon

Corycaeus lautus Dana, 1852

Female: Third thoracic segment is wider than the second; caudal rami is as long as the anal segment Size: 0.8 - 1.2 mm Male: Genital segment is bulbous and is approximately as long as anal segment and caudal rami combined Size: 0.7 - 0.9 mm. Recorded: Ghana

Corycaeus limbatus Brady, 1883

Female: Caudal rami approximately half the length of the urosome Size: 1.2 - 1.4 mm Male: Eye lenses touch each other genital segment; genital segment is barrel-shaped Size: 0.8 - 1.0 mm Male: Cephalon separated from first thoracic segment and the frontal part is flattened so that the eye lenses point forward rather than upward; lappets of 3rd thoracic segment reaches to the center of the genital segment Size: 0.7 - 0.8 mm. Recorded: Cote d'Ivoire to Cameroon

Farranula gracilis (Dana, 1853)

[i.e. *Corycella gracilis*]

Female: Cephalon fused with first thoracic segment; metasome appears 2-segmented in dorsal view; viewed laterally, the one-segmented urosome is widest anteriorly; lappets on the 3rd thoracic segment are pointed and reaches beyond the center of the urosomeSize: 0.8 - 1.0 mm Male: Cephalon fused with first thoracic segment; eye lenses are hemispherical and touches each other; urosome is widest at the center Size: 0.7 - 0.8 mm. Recorded: Cote d'Ivoire to Cameroon

Farranula carinata (Giesbrecht, 1891)

Female: Cephalon fused with first thoracic segment; viewed laterally, the dorsal margin of the urosome is irregularly humpbacked. Size: 0.8 - 0.9 Male: Closely resembles male of Farranula gracilis but there is a slight distinction between second and third thoracic segments. Size: 0.7 - 0.8 Recorded: Ghana

Sapphirina (Thompson, 1829)

Cephalon is separated from first segment and bears a pair of eye lenses located on dorsal, ventral or on frontal margins; entire body is strongly depressed; metasome is much widened; urosome is 5-segmented and narrower than metasome Female: maxilliped is short and 2-segmented Male: maxilliped is long and 3-segmented

Sapphirina nigromaculata Claus, 1863

Female: first and second thoracic segments are as wide as cephalon; the urosome is slender and more narrower than in the male; 4th segment of 2nd antenna three times as long as the third segment, the two together the same length as the 2nd segment. Size: 1.9 - 2.0 mm Male: resembles female but the urosome is broader; the 2nd segment of the second antenna bears two spines of unequal sizes on the outer edges Size: 2.1 - 2.5 mm Recorded: Ghana

Sapphirina scarlata Giesbrecht, 1891

Female: Similar to S. nigromaculata, however, the species are larger in size and the eye lenses are more closer together; second thoracic segment is wider than the first. Size: 3.3 - 4.7 mm Male: Resembles female but eye lenses are separated on the frontal margin; lateral margins of the metasome are much smoother than in the female; Size: 3.4 - 3.8 mm. Recorded: Ghana

Sapphirina ovatolanceolata Dana, 1852

Female: Cephalon is wider than long, widest just behind the center; 3rd and 4th segments of second antenna are of the same length; metasome gradually tapers posteriorly; caudal rami is twice as long as wide Size: 2.1 - 3.8 mm Male: Cephalon narrows anteriorly; eye lenses on the ventral surface are some distance behind the frontal margin; second antenna is longer and more slender than in the female. Size: 3.5 - 4.5 mm. Recorded: Ghana

Sapphirina pyrosomatis Giesbrecht, 1892

Female: Cephalon is slightly wider than long; eye lenses are small and separated; margins of metasome are even; caudal rami is three times as long as wide and bears a minute spine on the inner margin near the tip Size: 2.0 - 2.3 mm Male: Eye lenses are invisible on the dorsal surface; 2nd thoracic segment rounded at posterior corners; urosome broader than in female Size: 1.7 - 2.2 mm. Recorded: Ghana

Copilia mirabilis Dana, 1852

Female: Cephalosome is rectangular in shape and is widened posteriorly; eye lenses are at the corners of the cephalon; 3rd and 4th thoracic segments each bears a median spine on the dorsal surface; caudal rami is linear, very long and spread distally Size: 3.3 - 3.5 mm Male: Body is similar to Sapphirina spp., widens anteriorly and tapers posteriorly; eye lenses are absent; posterior margin of 4th segment with a median knob; caudal rami is linear and shorter than in the female Size: 5.2 - 5.5 mm. Recorded: Senegal to Congo, epipelagic.

Copilia quadrata Dana, 1852

Female: Cephalome almost squarish in shape Size: 3.2 - 4.4 Male: Resembles male of Copilia mirabilis but second segment of maxilliped is more slender Size: 4.2 - 5.6 Recorded: Senegal to Congo, epipelagic.

Microsetella norvegica (Boeck, 1864)

Female: body linear and strongly compressed; cephalon fused with the first thoracic segment; antennule not geniculate; segments of urosome with transverse rows of minute spinules; inner setae of P5 equal in length; caudal setae shorter than the body Size: 0.4 - 0.5 mm Male:

resembles female but smaller and the antennule is geniculate; P5 is reduced and inner setae of P5 unequal in length Size: 0.3 - 0.4 mm. Recorded: Cote d'Ivoire to Cameroon

Microsetella rosea Dana, 1848

Female: resembles M. norvegica but caudal setae is almost twice as long as the body; inner setae of P5 approximately equal in length Size: 0.7 - 0.9 mm Male: antennule geniculate; P5 is reduced and inner setae is unequal in length Size: 0.6 - 0.8 mm. Recorded: Cote d'Ivoire to Ghana

Macrosetella gracilis (Dana, 1852)

Female: frontal margin of cephalon without cuticular lenses; antennule reaches the genital segment; caudal setae is elongated Size: 1.4 - 1.5 mm Male: antennule is geniculate with the 4th segment greatly elongated and thickened; Size: 1.1 - 1.3 mm. Recorded: Cote d'Ivoire to Cameroon

Oculosetella gracilis (Dana, 1852)

Female: resembles M. gracilis but the cephalon bears a pair of brightly coloured cuticular lenses; caudal setae is relatively shorter than in M. gracilis Size: 1.2 -1.4 mm Male: resembles female but slightly smaller; antennule is prehensile Size: 1.2 - 1.3 mm. Recorded: Ghana

Euterpina acutifrons Dana, 1848

Female: cephalon is fused with first thoracic segment and pointed anteriorly; caudal rami is shorter than anal segment; length of caudal setae is equal to last four body segments combined. Size: 0.6 - 0.8 mm Male: endopodite of P2 is 2-segmented; P5 modified into a rectangular Size: 0.5 - 0.6 mm. Recorded: Cote d'Ivoire to Cameroon

Clytemnestra scutellata Dana, 1848

Female: cephalon fused with first thoracic segment with posterior corners; cephalosome and metasome with large epimeral plates; caudal setae is relatively short Size: 1.0 - 1.2 mm Male: spine on distal segment of maxilliped longer than in the female Size: 1.0 - 1.3 mm. Recorded: Cote d'Ivoire to Ghana

Miracia efferata Dana, 1846

Female: elongated body tapers gradually backward; cephalon fused with first thoracic segment and bears a pair of cuticular lenses; urosome is 4-segmented; caudal setae about the length of the caudal rami Size: 1.7 - 2.0 mm. Male: resembles female but antennule is geniculate and urosome is 5-segmented. Size: 1.4 - 1.6 mm. Recorded: Cote d'Ivoire to Cameroon

Balanus spp. da Costa, 1778

Mostly present in the plankton as larval stages (nauplii stages). Seen from the dorsal view, the body is triangular in shape, and in later stages has a pair of posterior spines. The tip of the labrum is truncated. Size: Naupliar stages between 0.3 mm - 0.9 mm Distribution: Cosmopolitan in temperate to tropical parts of the oceans.

Eucopia sculpticauda Faxon, 1893

Body is robust and slightly convex; dorsal surface of carapace is ornamented with a series of honeycomb ridges; there is a fellow pigment in the eye of juveniles, turning dark red in adults; possess no statocyst. Size: 15 - 20 mm Recorded: Ghana

Boreomysis microps Sars, 1883

Slender body with small eyes and large ocular papilla protruding beyond the cornea; statocyst is present. Size: 20 - 23 mm Recorded: Ghana

Longithorax fuscus Hansen, 1908

Anterior part of body is very large in proportion to the abdomen as a result of prolongation of last thoracic segment and a large marsupium; anterior margin of the head is produced to form a low triangle with its apex at right angle with a small, rounded, rostral projection; statocyst is present. Size: 18 - 22 mm Recorded: Ghana

Lucifer faxoni (Nobili,1901)

This species is distinguished by the greatly elongated thorax, and a small, anteriorly pointed head bearing long-stalked eyes. Size: 12 mm - 15 mm in length. Distribution: It is neritic and found in coastal waters of tropical seas.

Sagitta Quoy and Gairmard, 1827

Two pairs of lateral fins, sometimes connected, and two paired rows of teeth.

Sagitta enflata Grassi, 1883

The body is transparent in formalin. The collarette is small and a gut diverticulae is absent. The anterior fins originate far behind the ventral ganglion and they are partially rayed. The seminal vesicle is round and is nearer to the caudal fin than posterior fin. Epiplanktonic. Max. size: 30 mm. Recorded: Senegal to Congo

Sagitta friderici Ritter-Zahony, 1911

The body is slightly transparent in formalin. The collarette is small and a gut diverticulum is absent. The anterior fin is located near the ventral ganglion and they are completely rayed. The seminal vesicle is wedge-shaped being mid-way between the posterior fin and caudal fin. Max. size: 15 mm. Recorded: Guinea, Liberia, Cote d'Ivoire, Ghana, Nigeria

Sagitta hispida Conant, 1895

It appears stout and opaque in formalin. The collarette is medium in size and a gut diverticulum is present. The origin of the anterior fin is close to the ventral ganglion and they are completely rayed. The seminal vesicle is wedge-shaped and is nearer to the caudal fin than the posterior fin. Max. size: 15 mm. Recorded: Guinea to Congo

Sagitta serratodentata Krohn, 1853

They are thin, needle-shaped and appear opaque or chalky in formalin. The collarette is very small and they have no gut diverticulum. The characteristic feature of importance is the very conspicuous wedge-shaped seminal vesicle situated exactly between the posterior and anal fins. The fins are partially rayed. Max. size: 17 mm Recorded: Senegal to Ghana

Sagitta lyra Krohn, 1853

Appears transparent in formalin. The collarette and gut diverticulum are absent. The anterior fin is long and rounded, beginning near the posterior end of the ventral ganglion. The fins are partially rayed. The seminal vesicle is oval and near to the posterior fin. Max. size: 38 mm Recorded: Senegal, Liberia, Cote d'Ivoire

Sagitta hexaptera d'Orloigny, 1934

The body is transparent in formalin. The collarette and gut diverticulum are absent. The anterior fin begins well below the ventral ganglion and they are partially rayed. The seminal vesicle is small and rounded and is nearer to the caudal fin than the posterior fin. Max. size: 60 mm. Recorded: Senegal, Sierra Leone, Cote d'Ivoire

Sagitta bipunctata Quoy & Graimard, 1827

The body is opaque in formalin. The collarette is medium in size and a gut diverticulum is absent. The anterior fins begin at the end of the ventral ganglion and they are completely rayed. The seminal vesicle is wedge-shaped and is nearer to the caudal fin than the posterior fin. Max. size: 19 mm. Recorded: Senegal, Sierra Leone, Cote d'Ivoire

Sagitta planctonis Steinhaus, 1896

The body is opaque in formalin. The collarette is well developed and the gut diverticulum is small. The anterior fins begin about half way along the ventral ganglion and they are partially rayed. The seminal vesicle is oval and equidistant from posterior and caudal fins. Max. size: 37 mm. Recorded: Senegal, Sierra Leone, Cote d'Ivoire

Sagitta zetesios Fowler, 1905

The body is opaque in formalin. The collarette is well developed and the gut diverticulum is small. The anterior fins begin about half way along the ventral ganglion. Fins are partially rayed. This species is similar to S. plactonis, the only difference is that the oval-shaped seminal vesicle is nearer to the posterior fin than the caudal fin. Max. size: 40 mm. Recorded: Liberia, Cote d'Ivoire

Sagitta macrocephala Fowler, 1905

The body is opaque in formalin. The collarette is small and a gut diverticulum is absent. The anterior fin is small, round and begins well below the ventral ganglion. The fins are partially rayed. The seminal vesicle is wedge-shaped and nearer to the posterior fin than the caudal fin. Max. size: 21 mm Recorded: Liberia, Cote d'Ivoire

Sagitta decipiens Fowler, 1905

The body is slightly opaque in formalin. The collarette is very small and a gut diverticulum is present. The anterior fins are long and narrow and begin at the posterior end of the ventral ganglion. The fins are partially rayed. The seminal vesicle is wedge-shaped and slightly nearer the caudal fin than the posterior fin. Max. size: 20 mm Recorded: Liberia, Cote d'Ivoire, Congo

Sagitta minima Grassi, 1881

The body is transparent in formalin. The collarette is absent and a small gut diverticulum is present. The anterior fins begin below the ventral ganglion and they are partially rayed. The seminal vesicle is wedge-shaped and touches the caudal fin. Max. size: 10 mm. Recorded: Sierra Leone, Ghana, Nigeria

Pterosagitta Costa, 1869

One pair of lateral fins situated entirely on caudal segment; collarette very large.

Pterosagitta draco (Krohn, 1853)

The body is opaque in formalin. The collarette is very large and broad and a gut diverticulum is absent. The lateral fins are entirely on the caudal segment and completely rayed. The seminal vesicle is wedge-shaped and touches the lateral fins. Max. size: 10 mm. Recorded: Senegal, Liberia, Cote d'Ivoire

Eukrohnia Ritter-Zahony, 1909

One pair lateral fins beginning at level of ventral ganglion; one paired row of teeth

Eukrohnia fowleri (Ritter-Zahony, 1909)

The body is slightly transparent in formalin. It bears pigmented eyes. A collarette is present and a gut diverticulum is absent. The lateral fins are partially rayed. The seminal vesicle is large and ovoid, and nearer to the lateral fins than the caudal fin. Max. size: 40 mm. Recorded: Senegal, Liberia, Cote d'Ivoire

Eukrohnia hamata (Möbius, 1875)

The body is opaque in formalin. The eyes are not pigmented. Both the collarette and the gut diverticulum are absent. The lateral fins are partially rayed. The seminal vesicles are elongated and nearer to the lateral fins than the caudal fin. Max. size: 45 mm. Recorded: Senegal, Liberia, Cote d'Ivoire

Krohnitta Ritter-Zahony, 1910

One pair of broad lateral fins beginning well below the ventral ganglion; one paired row of teeth which is long and covers anterior of head.

Krohnitta subtilis (Grassi, 1853)

The body is slender and transparent in formalin. Collarette and gut diverticulum are absent. The lateral fins begin far below the ventral ganglion and they are partially rayed. The seminal vesicle is elongated and touches both the lateral and caudal fins. Max. size: 16 mm. Recorded: Liberia, Cote d'Ivoire.

General Conclusion and Recommendation

The Productivity and Biodiversity Centre of the GCLME Project which was made available by the University of Ghana was commissioned in June, 2007 by the Minister of Fisheries of Ghana, and supported by the Minister of Rural Development, Local Government and Environment. This was accomplished on the basis of a Memorandum of Understanding signed between the University and the GCLME Project. Based on the achievements made so far, the following recommendations have been put forward to enable achievement of the overall objective of the regional demonstration project on productivity and biodiversity.

1.   Installation of the DDS system for downloading satellite data from the European Space Agency (ESA). The permission for the installation of the DDS was given by the ESA in October, 2007.

2.   Recruitment of one Plankton Analyst and one Remote Sensing expert

3.   Training of essential support staff and national experts in plankton analysis and biodiversity mapping

4.   Engagement of Ships of opportunity and fitting of relevant equipment and continuation with CPR survey.

5.   Procurement of additional equipment and consumables (see Appendix 9).

6.   Marine biodiversity status assessment and conservation planning and Ecosystem mapping and biodiversity consultative workshop

7.   Comprehensive and integrated regional assessment of oceanographic conditions and productivity indicators (chlorophyll a, water temperature, photosynthetically active radiation, nutrient concentration, phytoplankton biodiversity, zooplankton biodiversity and biomass, ichthyoplankton biodiversity and biomass), and field validation of remotely sensed parameter from satellite platform

8.   Quantitative and qualitative surveys of coastal communities to assess nutrient loading and productivity patterns and changes in diversity, abundance and distribution of organism

9.   Regional training Workshop in scientific and technical aspects of environmental monitoring, data processing and modeling of the GCLME, including remote sensing

10.   Development of a regional operational capacity for monitoring of Harmful Algal Blooms, and establishment of a Harmful Algal Bloom regional reporting network for early warning, detection and prediction of blooms.

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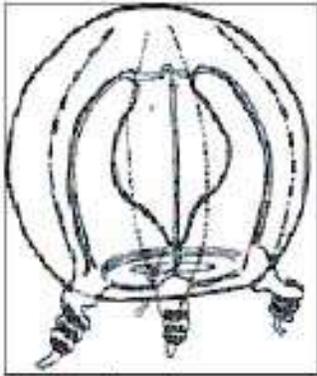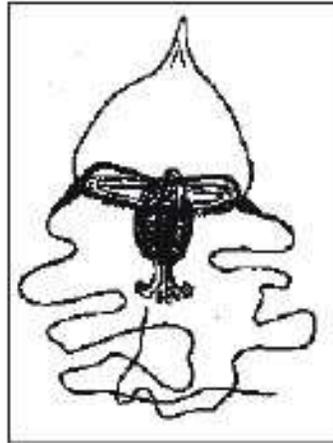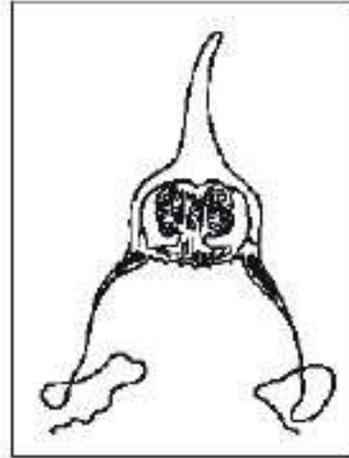
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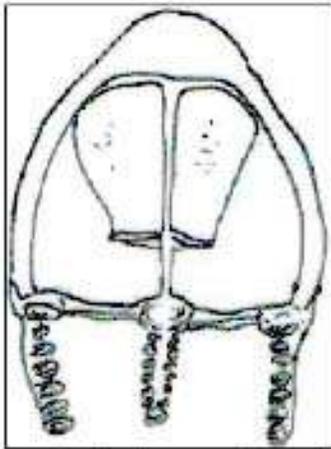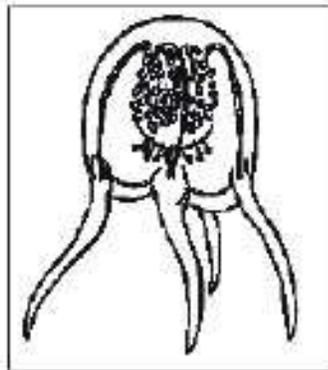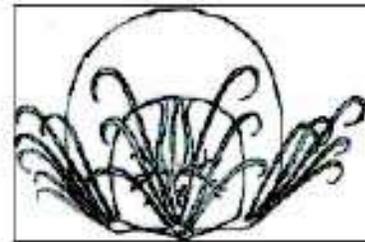
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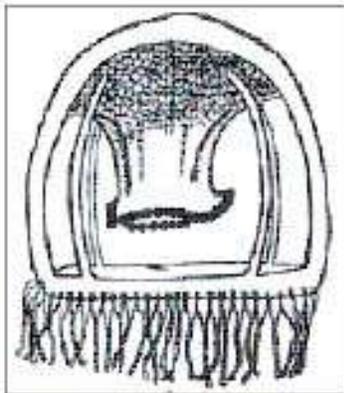
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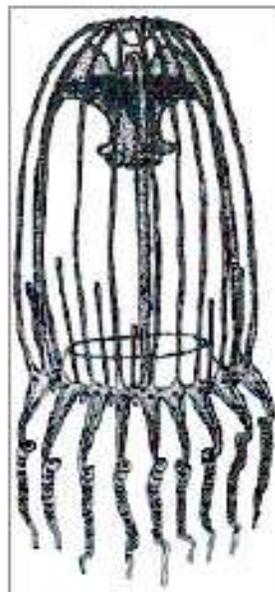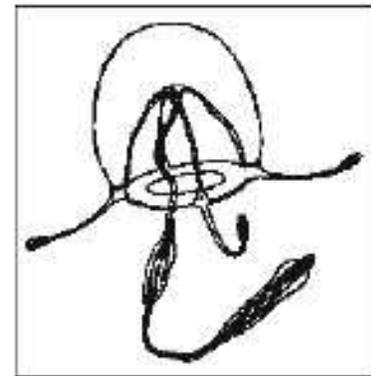
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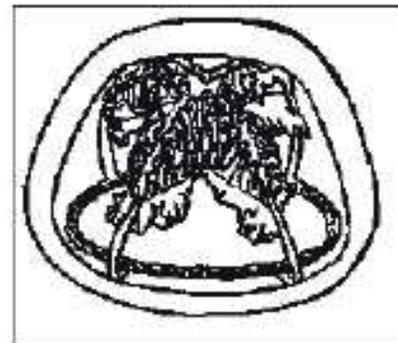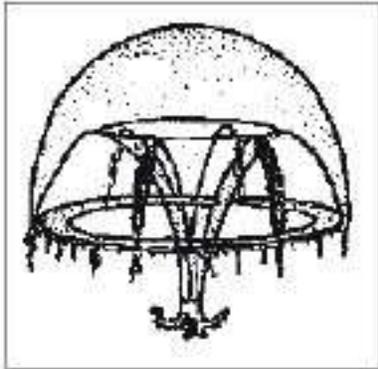
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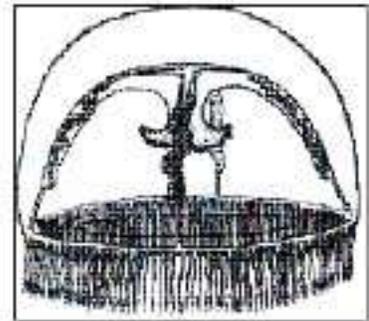
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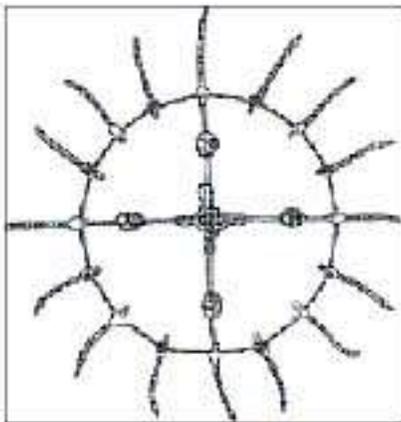
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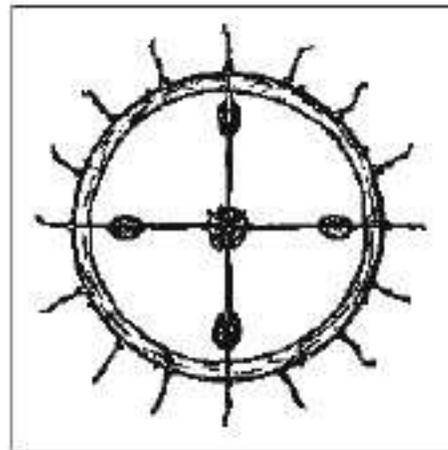
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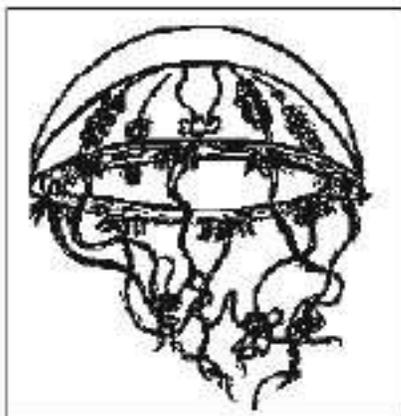
Euc heilota cirrata
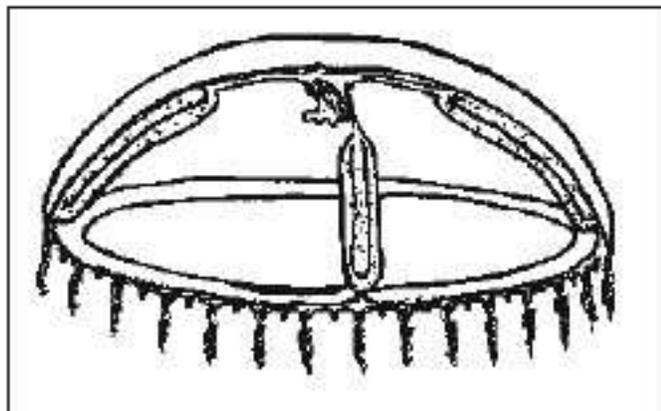
Phialidium hemisphaericum
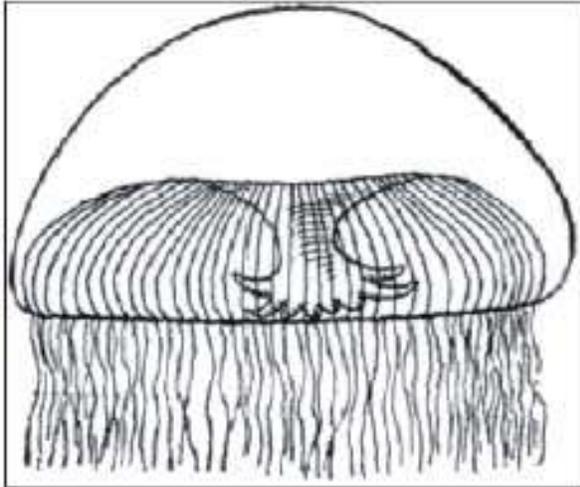
Aequorea aequorea
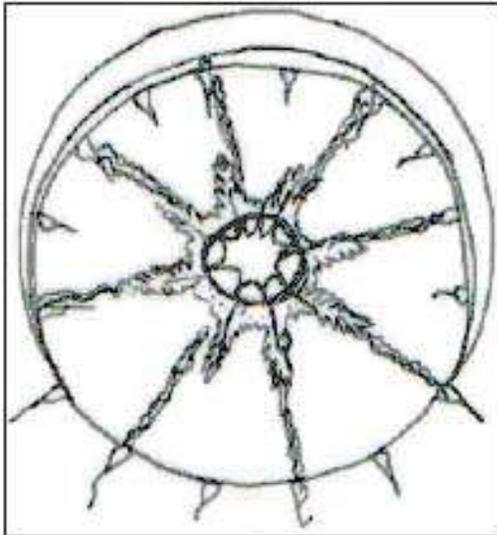
Octophialucium medium
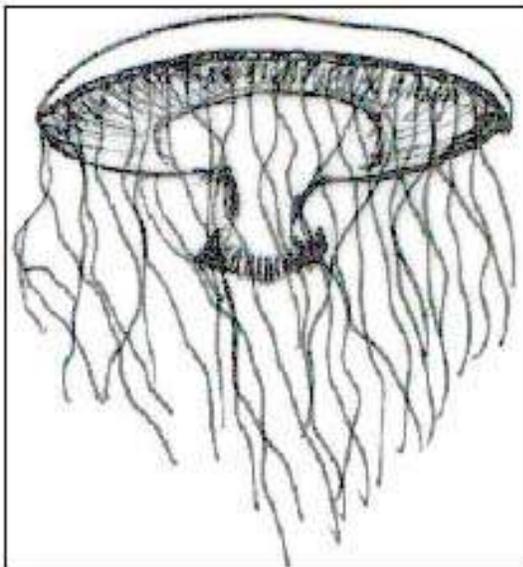
Rhacostoma atlanticum
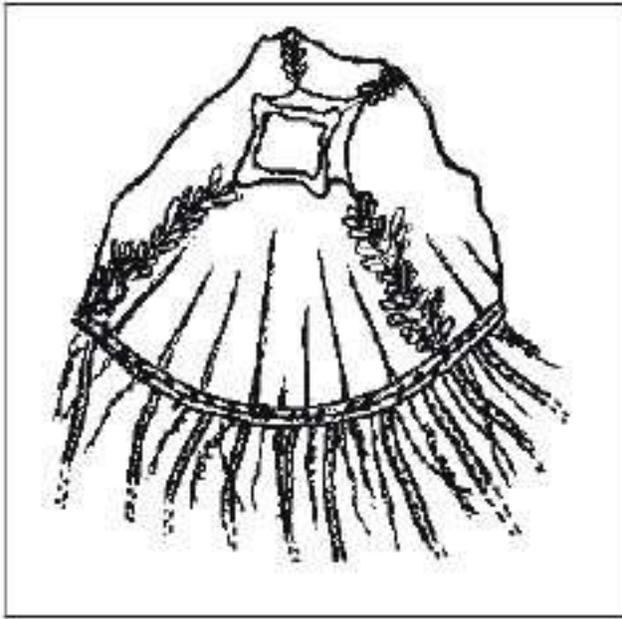
Clindias phosphorica
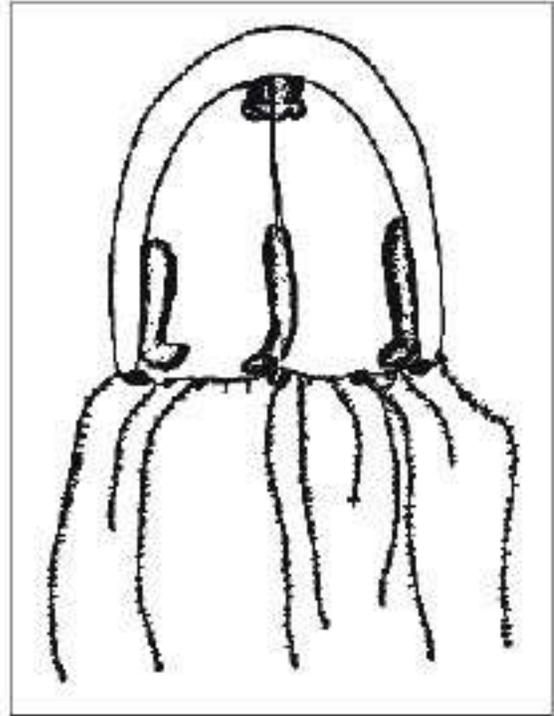
Aglauropsis jarli
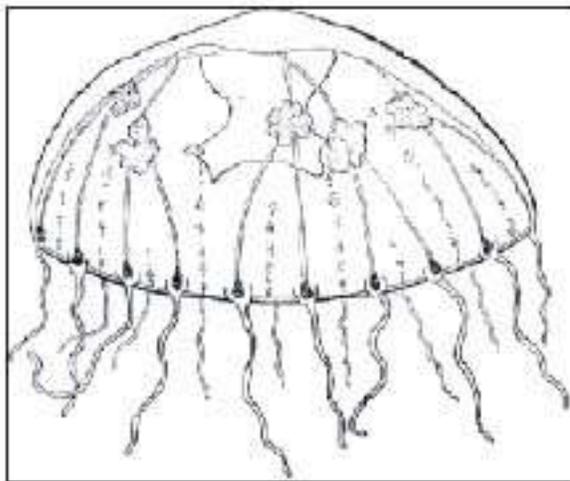
Proboscidactyla ornata
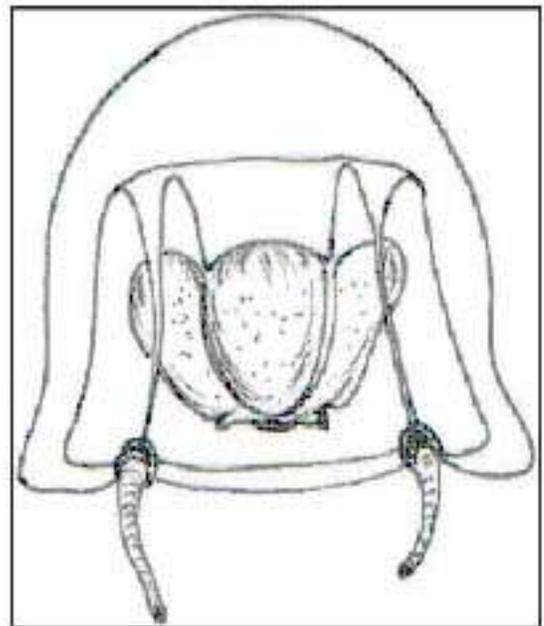
Pochella oligonema
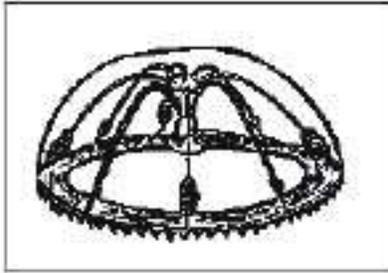
Amphogona apsteini

Colobonema sericeum

Arctapodema ampium
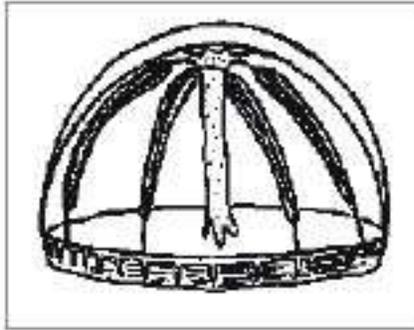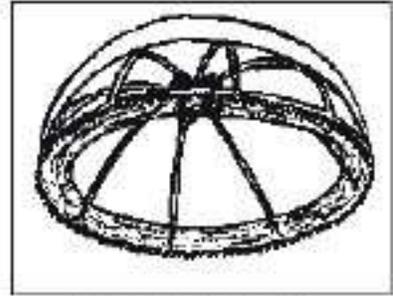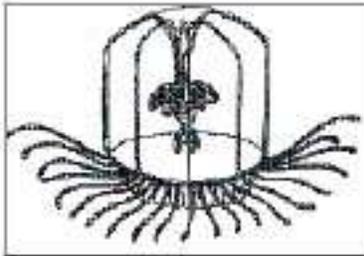
Aglaura hemistoma

Liriope tetraphyla

Halicreas minimum
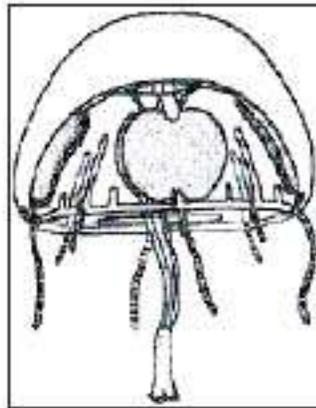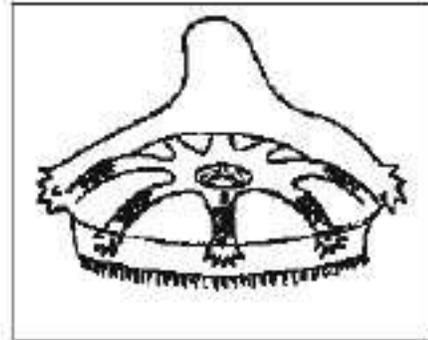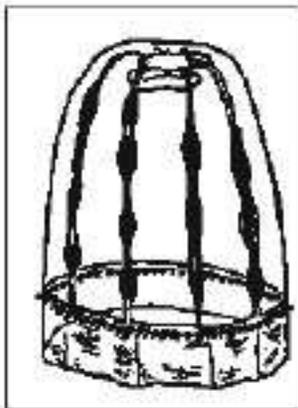
Pantachogon haeckeli

Geryonia proboscidalis

Rhopalonema velatum
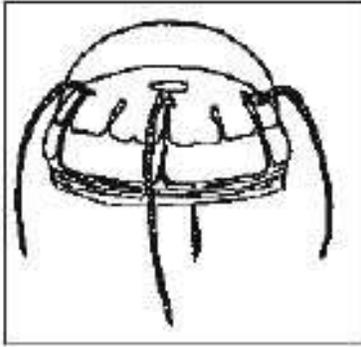
Aegina citrea
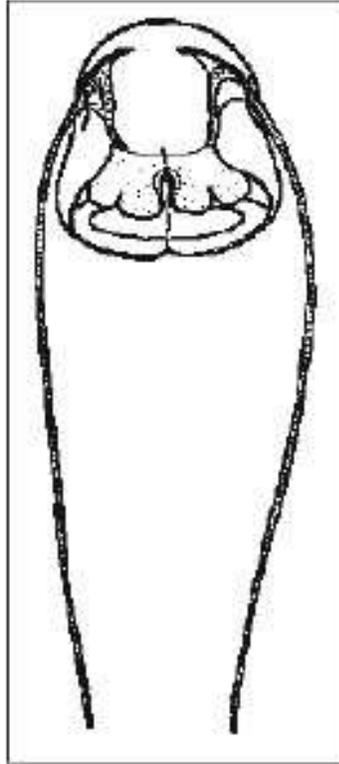
Solmundella bitentaculata

Aeginura grimaldii

Cunina octonaria

Pegantha martagon
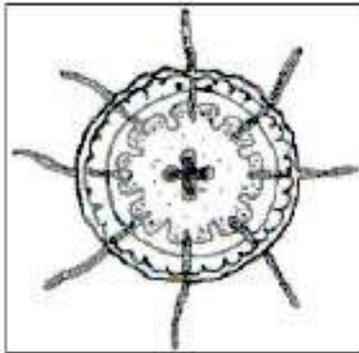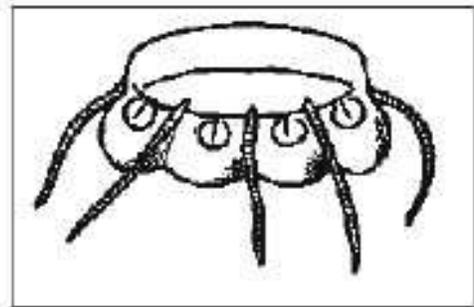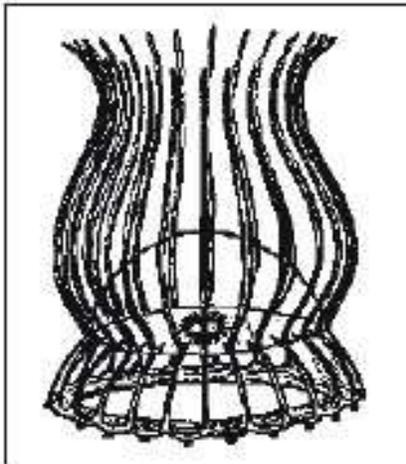
Solmaris corona
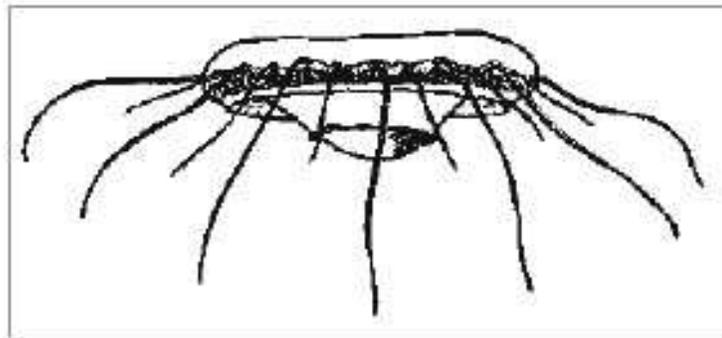
Pegantha clara
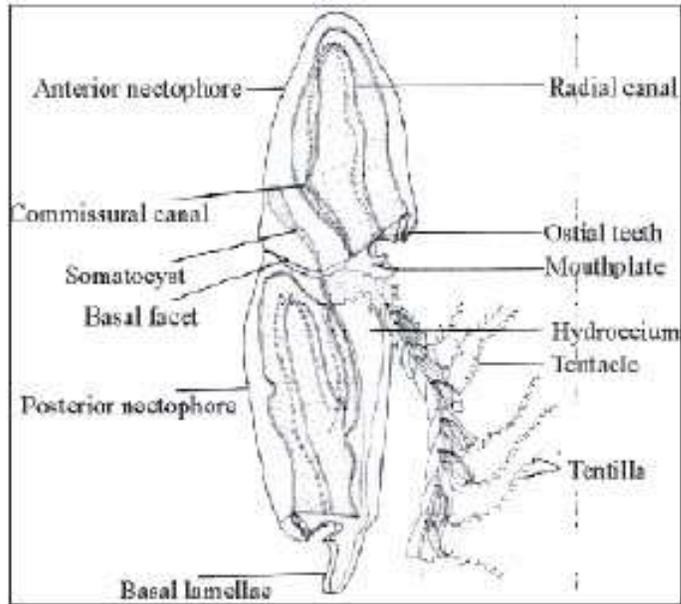
Polygastric stage of a calycophoran siphonophore showing anterior and posterior nectophores
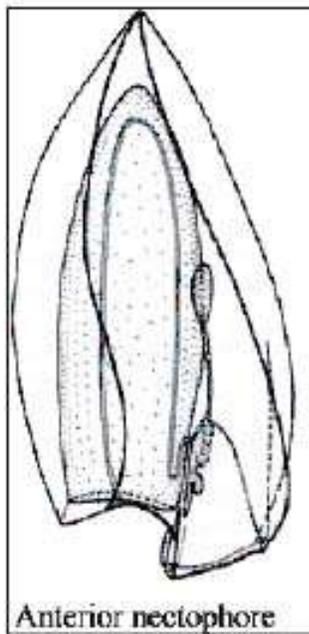
Anterior nectophore

Muggiaea kochi
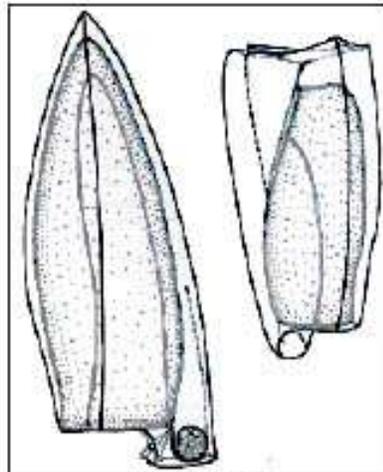
Lensia fowleri
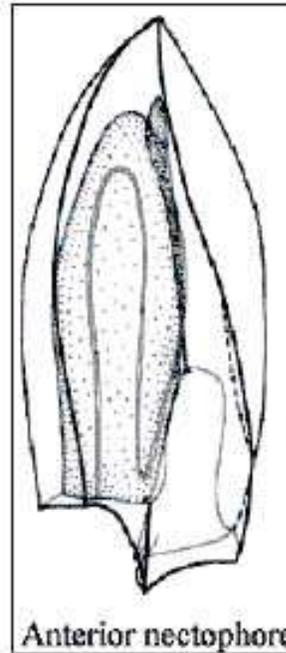
Anterior nectophore

Muggiaea atlantica
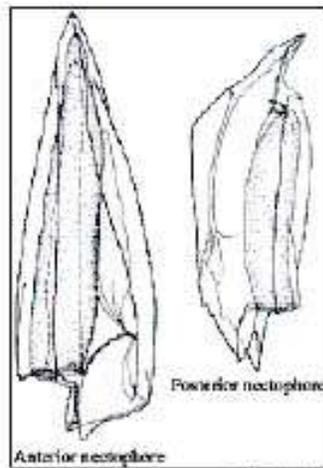
Anterior nectophore

Posterior nectophore

Chelophyes appendiculata
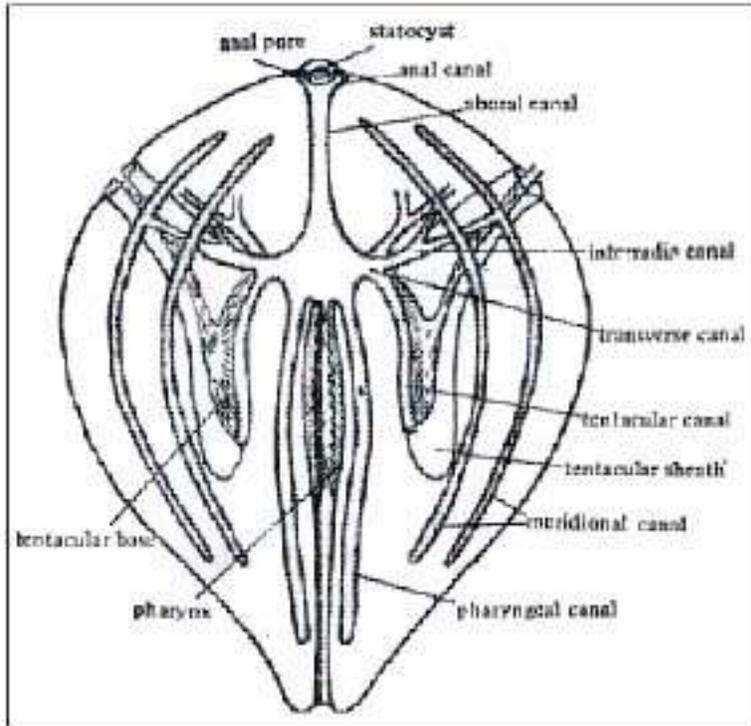
Diagram of a tentaculate ctenophore

Beroe cucumis
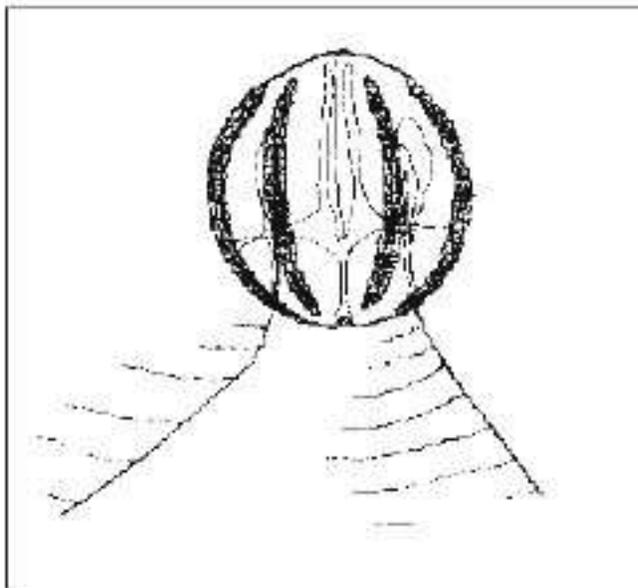
Pleurobrachia pileus
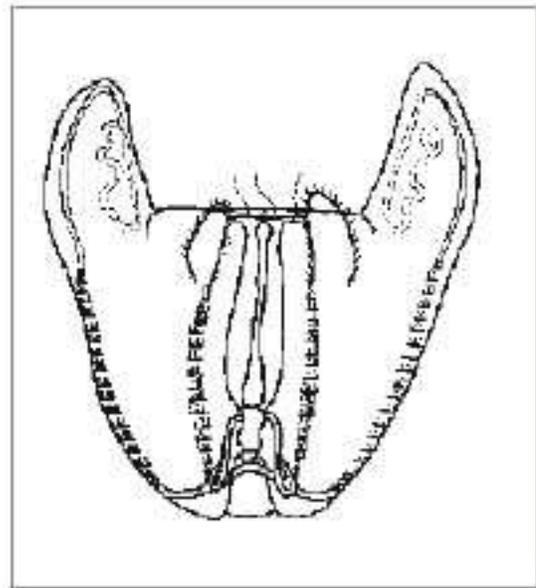
Bolinopsis infundibulum
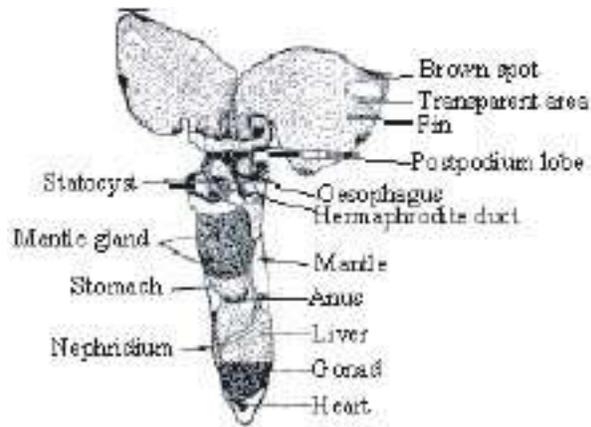
Internal structure of gymnosome
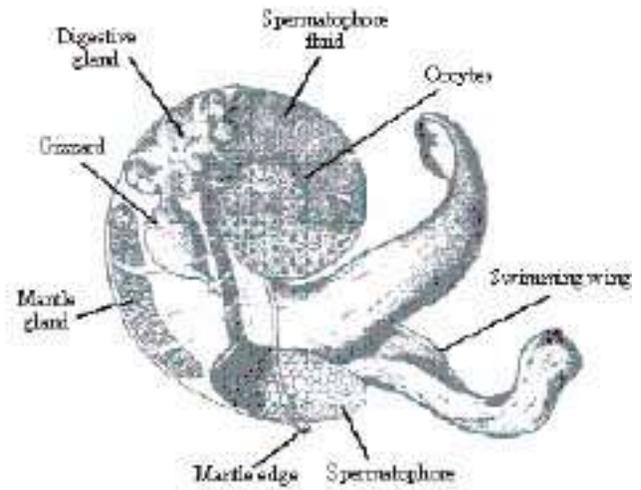
Internal structure of thecosome

Cavygyrus keraudreni
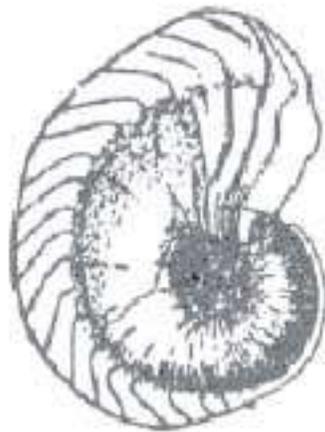
Creseis virgula

Hyalocylix striata
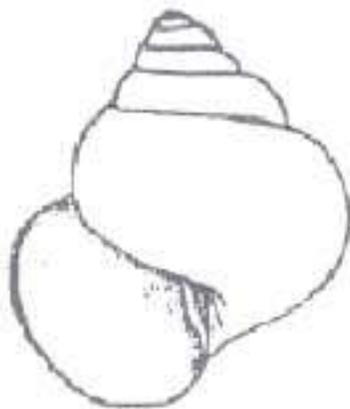
Limacina trochiformis
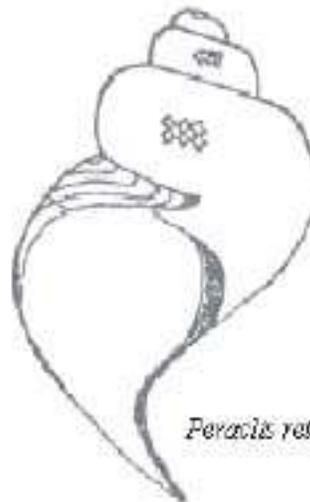
Peraclis reticulata
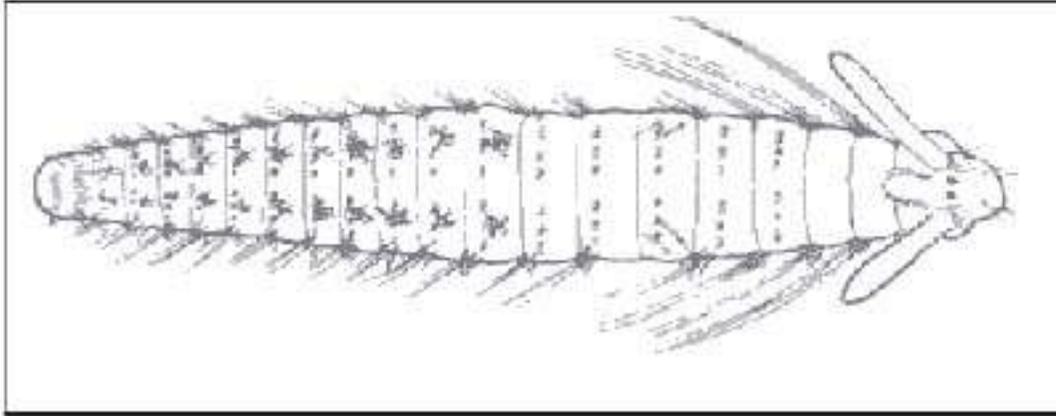
Polychaete larva
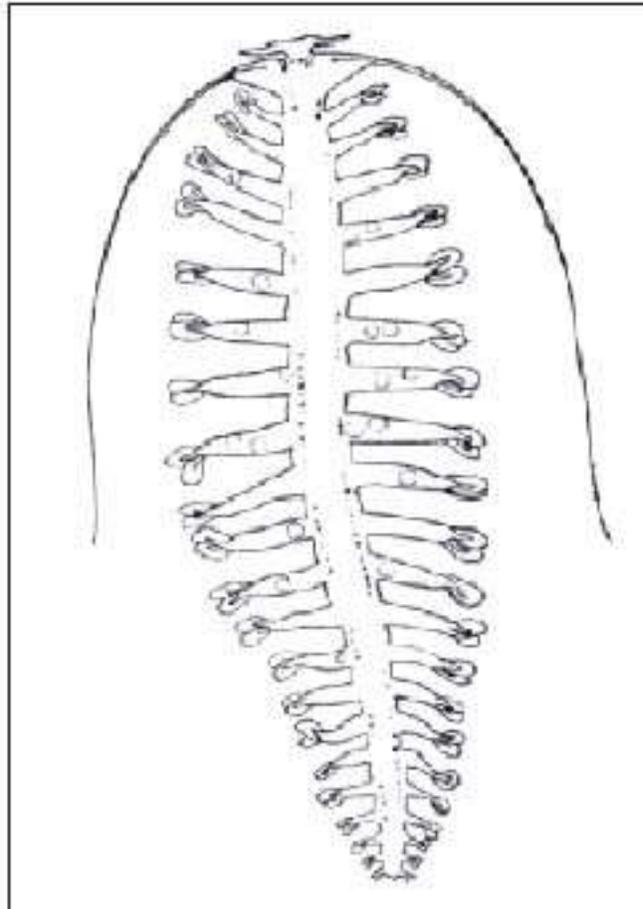
Tomopteris septentrionalis
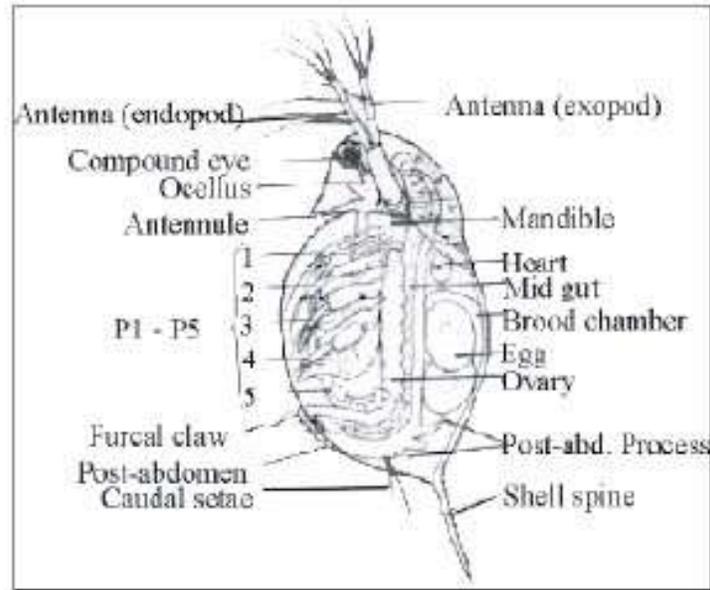
Internal orgas of cladoceran.
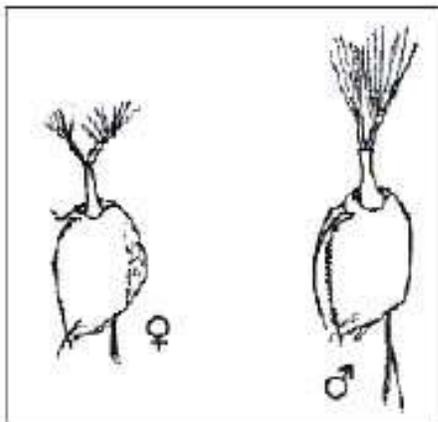
Penilia avirostris
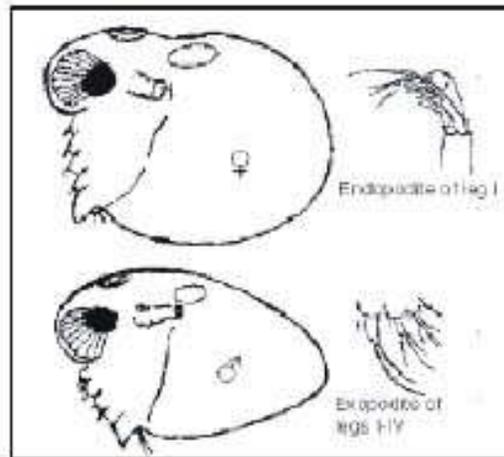
Evadne tergestina
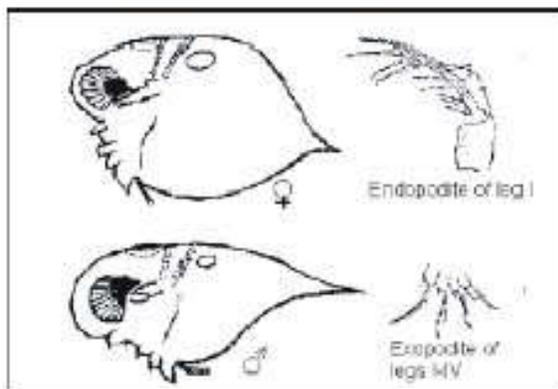
Evadne spinifera
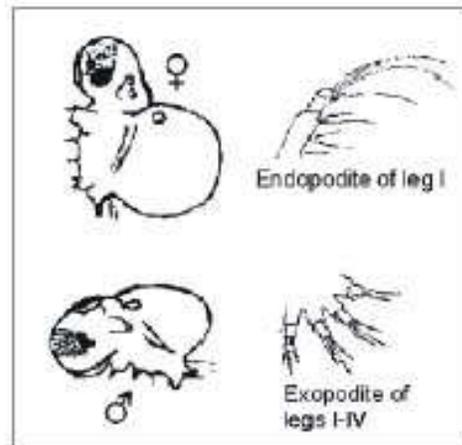
Podon polyphemoides
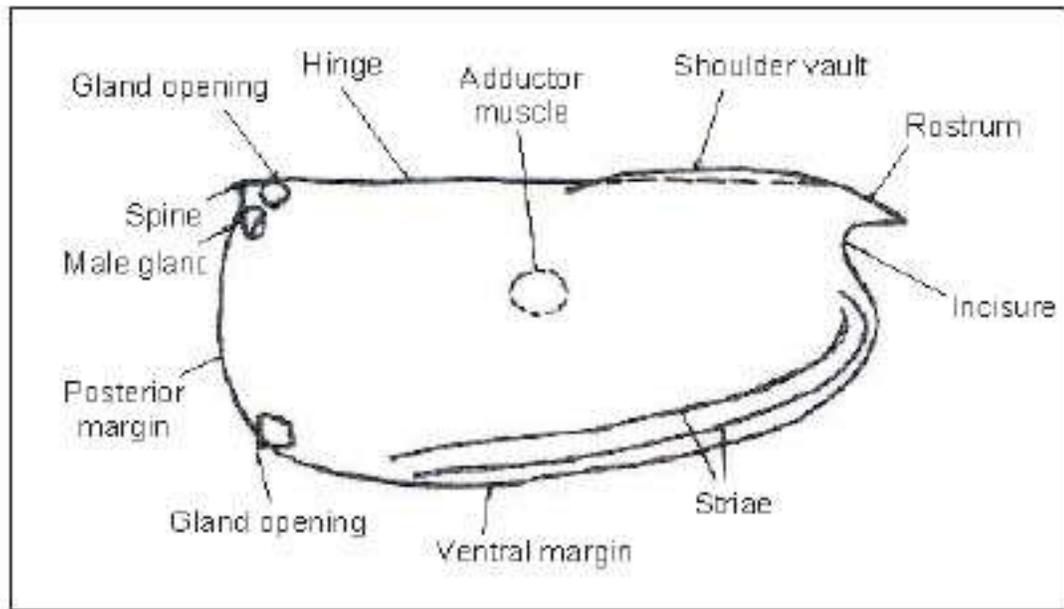
Lateral view of a typical ostracod showing main features of carapace used in identification
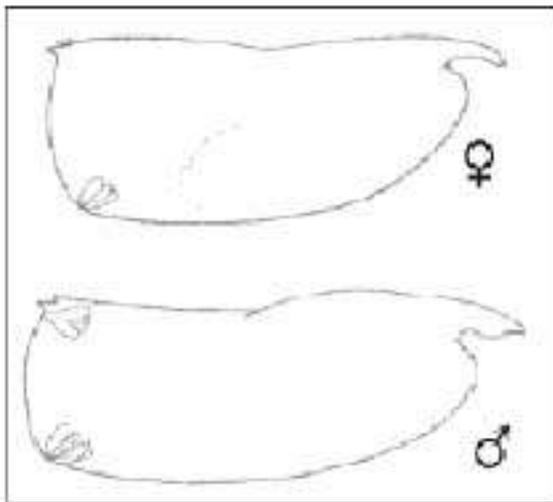
Conchoecia elegans

Euconchoecia chierchiea
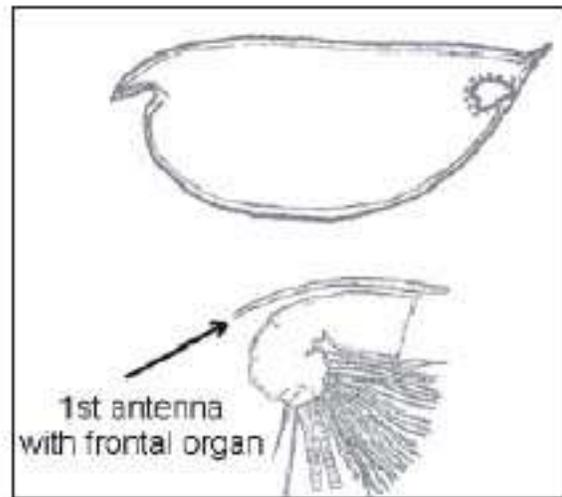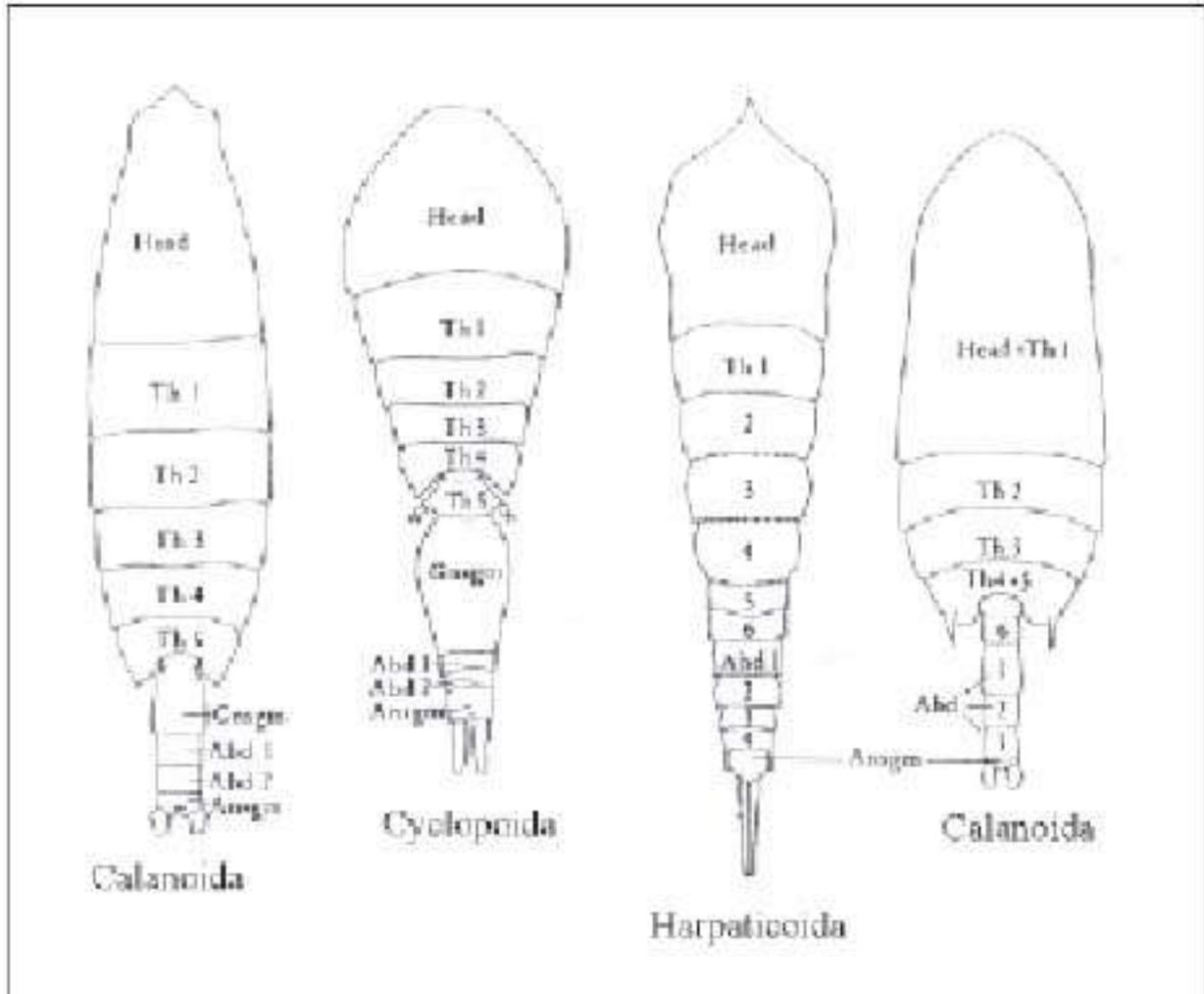
Comparison of body forms of Copepods.
(In the calanoids, there may be fusion of cephalon and first thoracic segment
or between 4th and 5th thoracic segments. Fusion also occurs in
abdominal segments.)

Rostrum
Antennule
Antenna
Mandible
Maxilla 1
Maxilla 2
Maxilliped
Cephalosome
Perciopod 1(P1)
P2
Exopodite
Endopodite
P3
Basipodite
P5
P4
LEG
Genital segment
Abdominal segment 1
Abdominal segment 2
Anal segment
Caudal ramus
Metasome
Urosome

TYPICAL CALANOID

Normal antennule
Geniculate antennule
ANTENNULE

Nauplius
I
II
III
IV
V
Adult
Copepodites
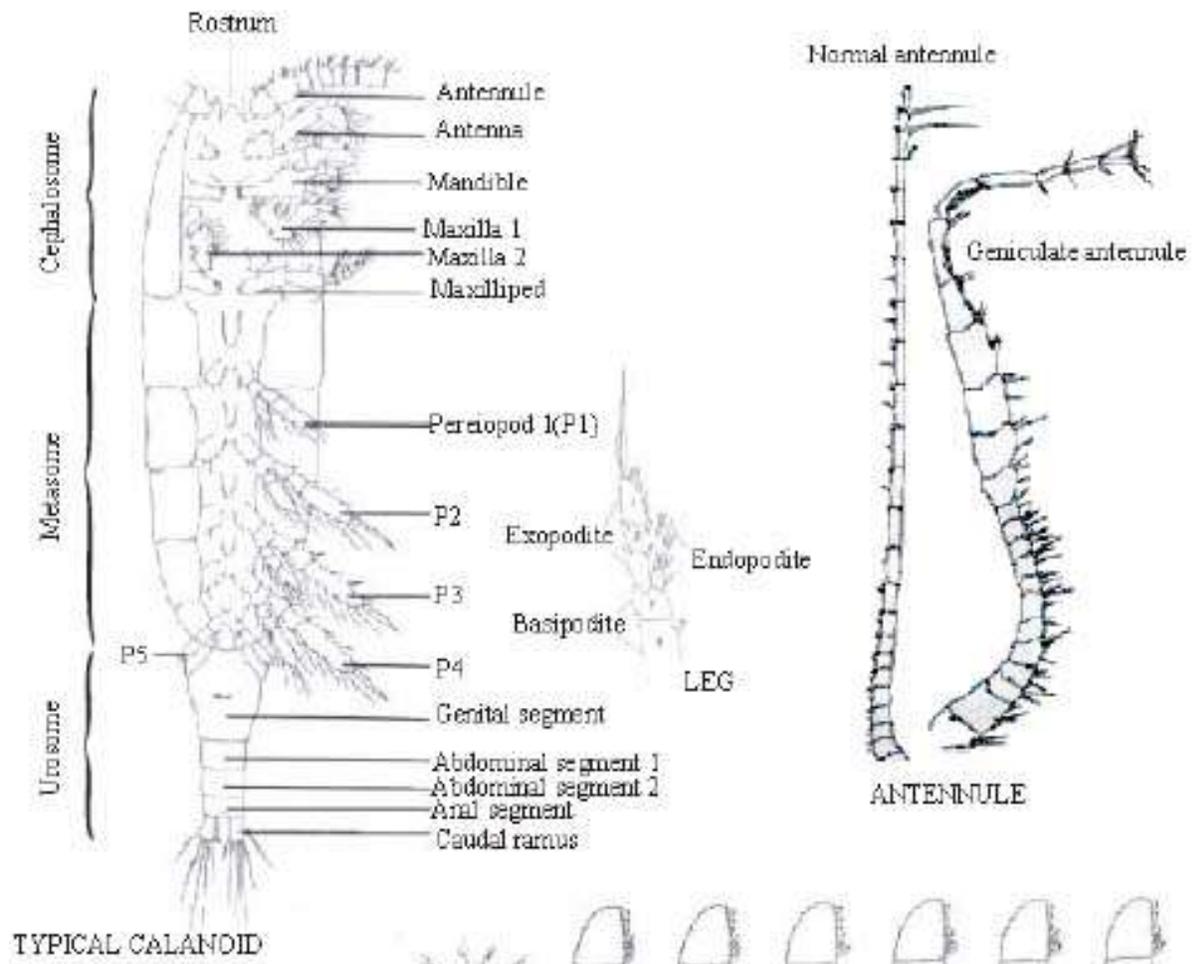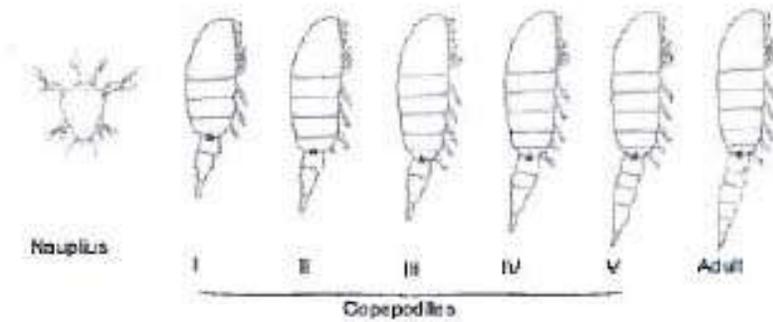
ANTERIOR SHAPES OF CALANOID HEADS

Round
Pappilate
Crested
Spiny
Rectangular
Forward-projecting
Triangular
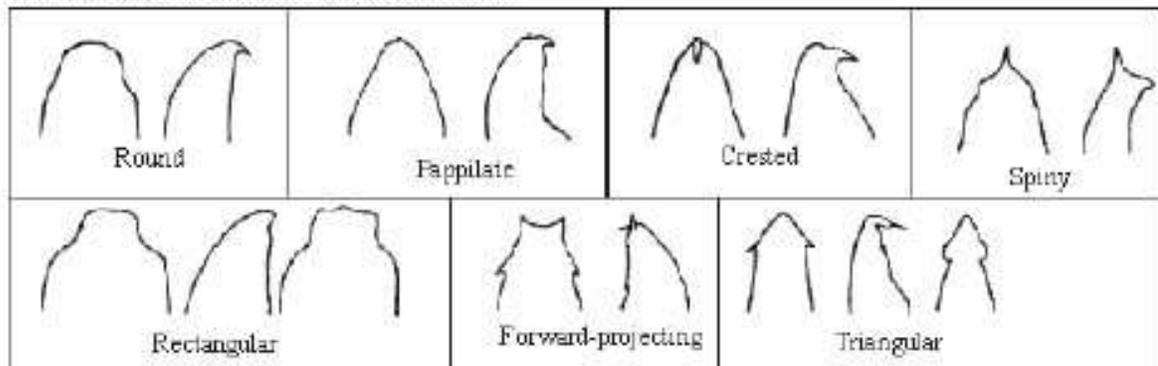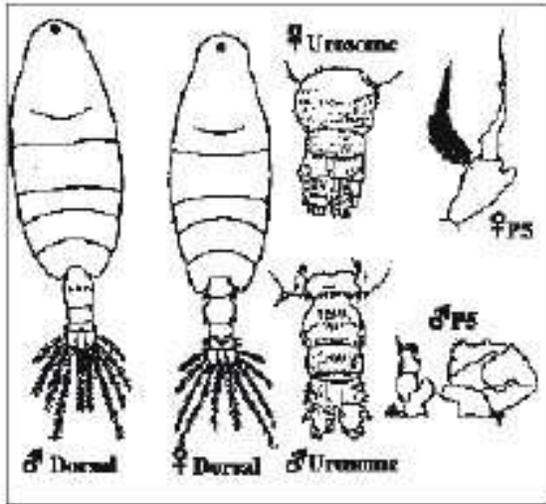
Acartia tonsa
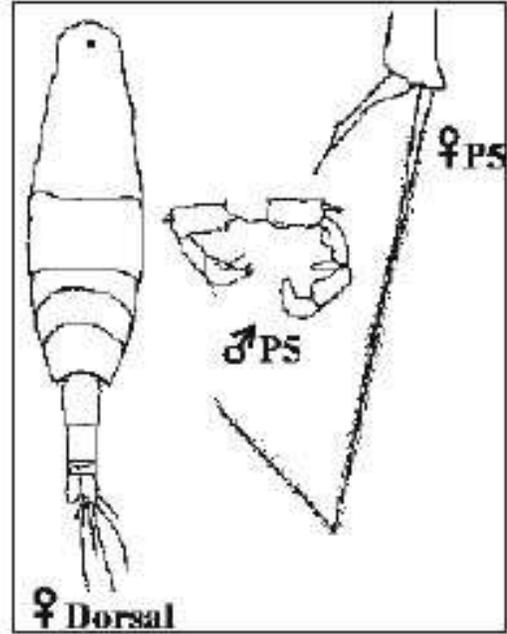
Acartia plumosa

Acartia negligens
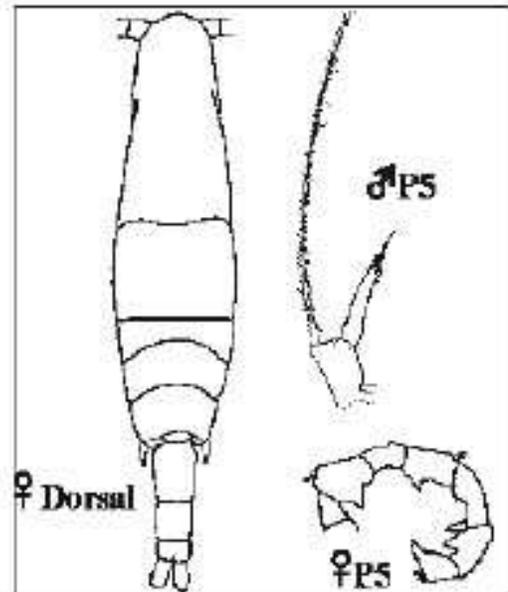
Acartia danae
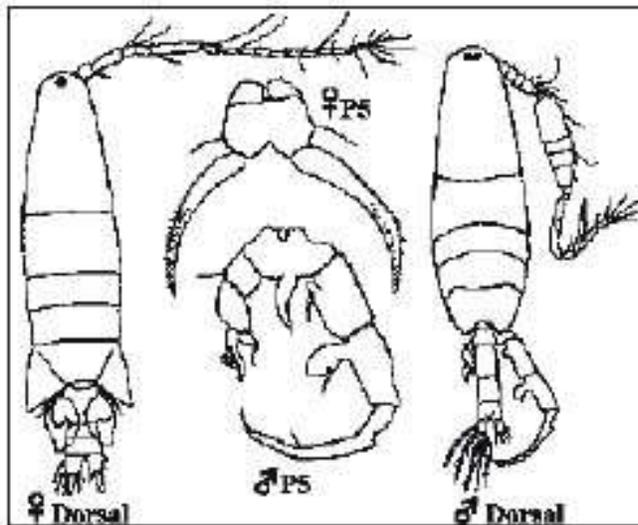
Acartia grani
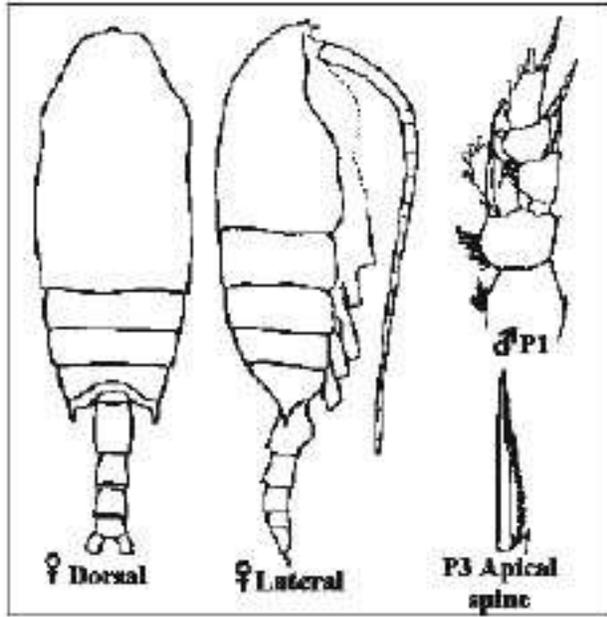
Aetideopsis multiserrata
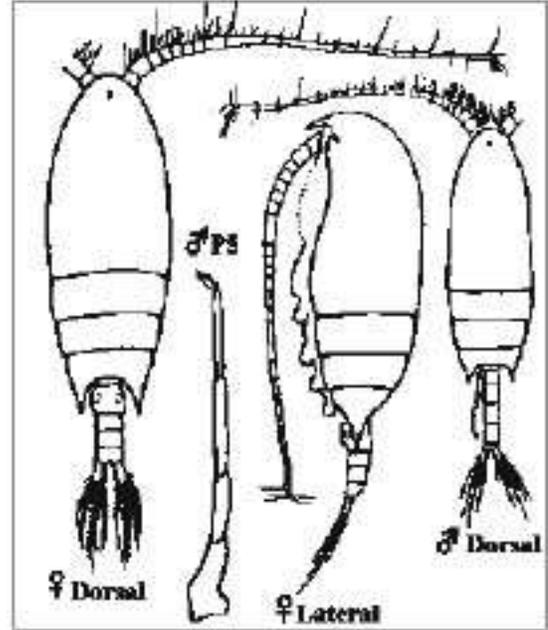
Aetideus armatus
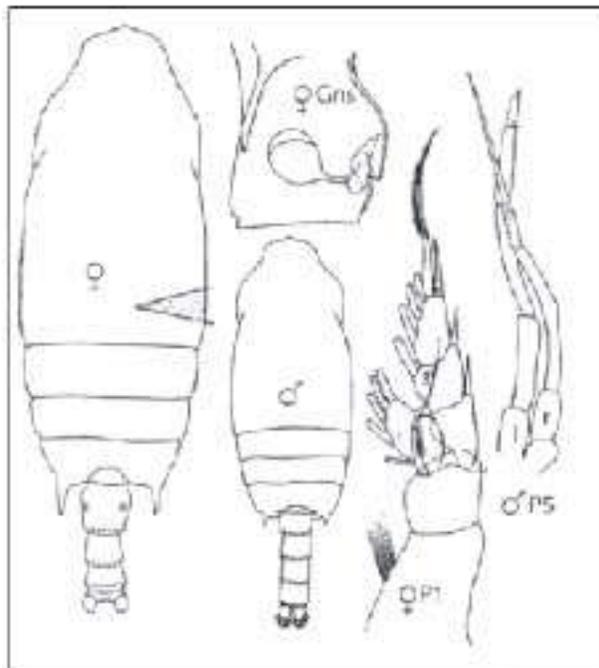
Chiridius poppei
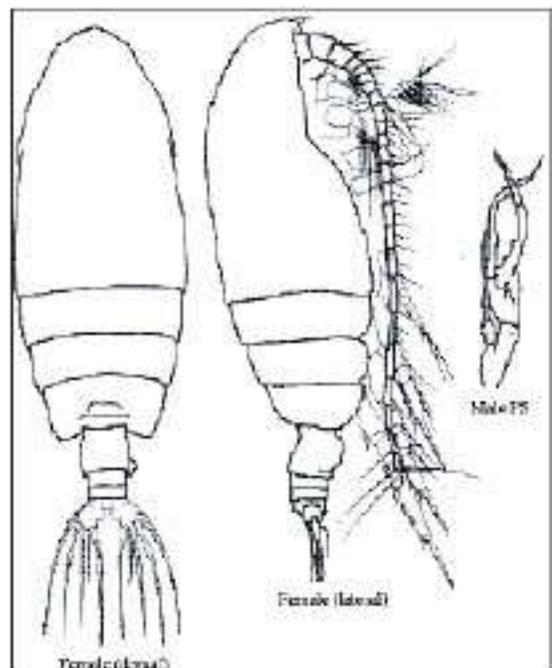
Euchirella splendens
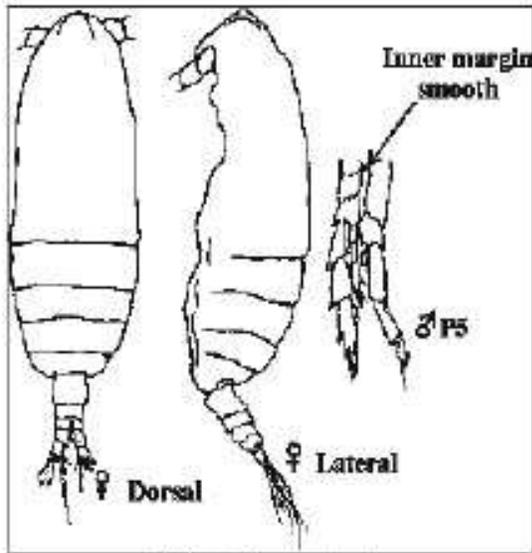
Calanoides carinatus
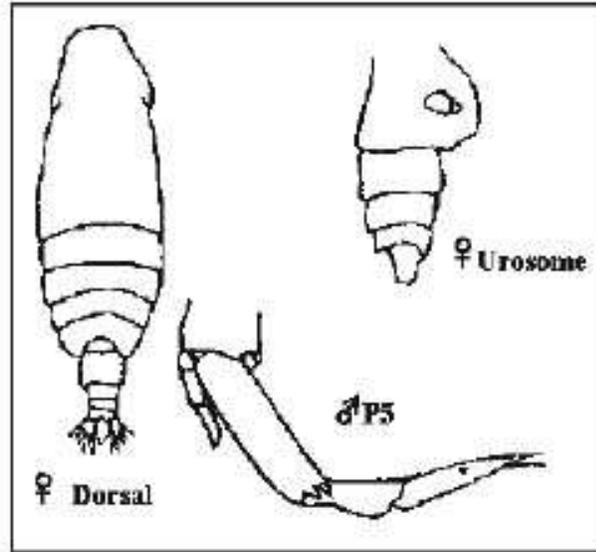
Neocalanus robustior
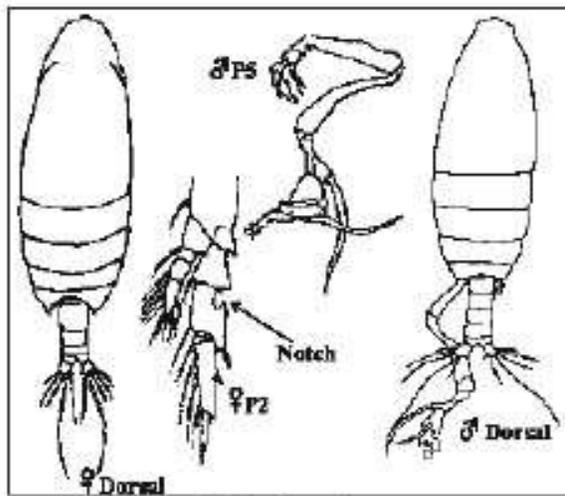
Undinula vulgaris
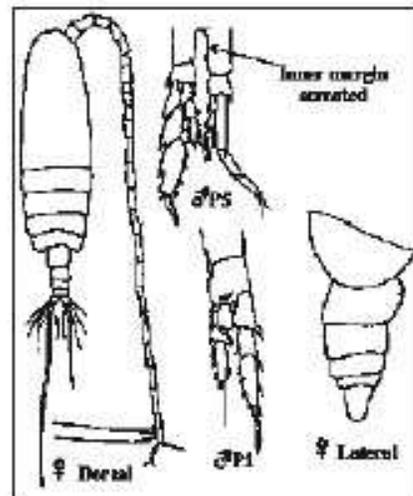
Neocalanus gracilis
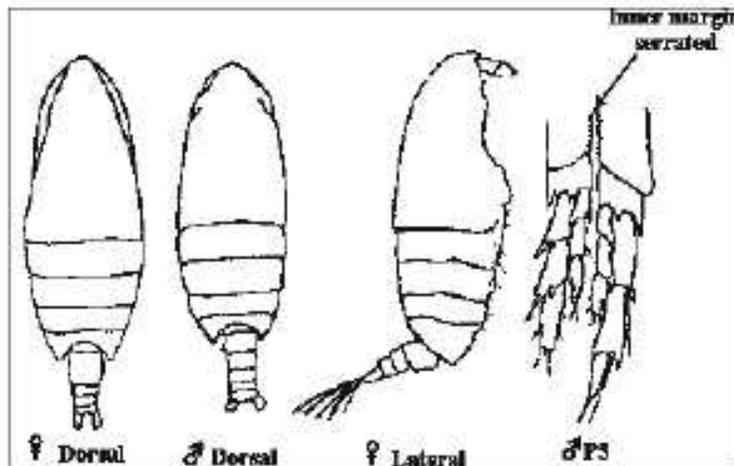
Nannocalanus minor
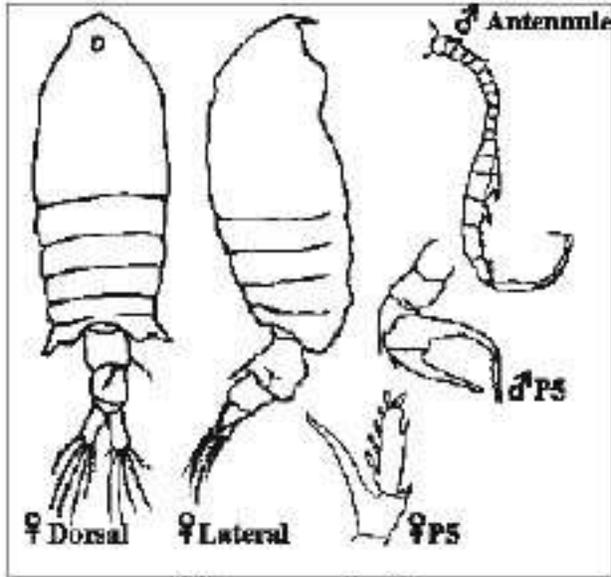
Centropages chierchiae
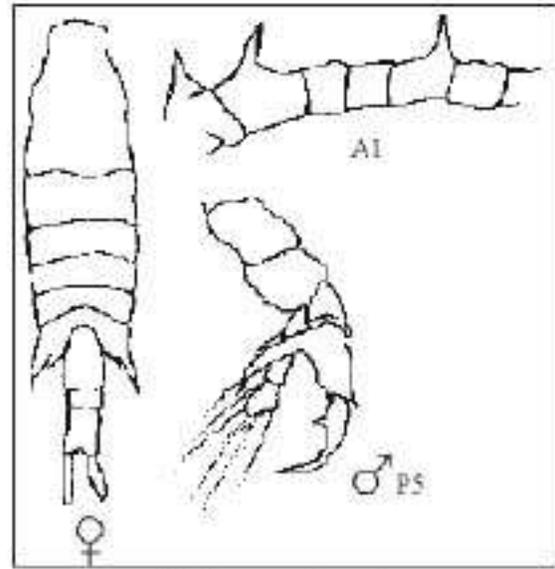
Centropages furcatus
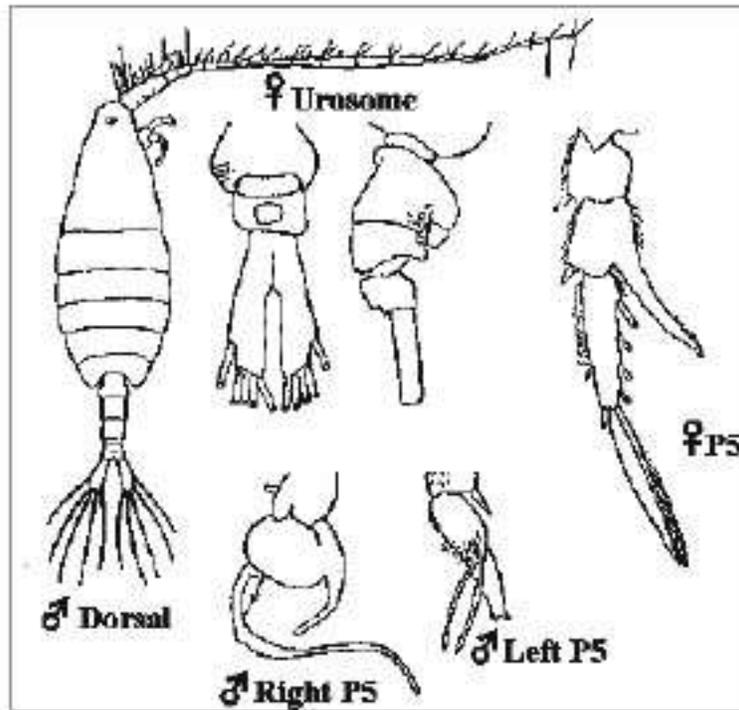
Centropages violaceus
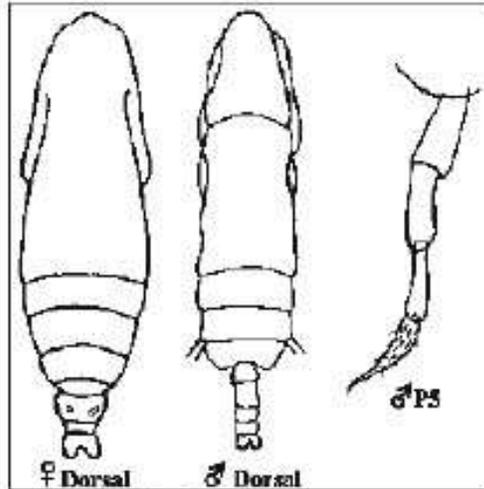
Eucalanus crassus
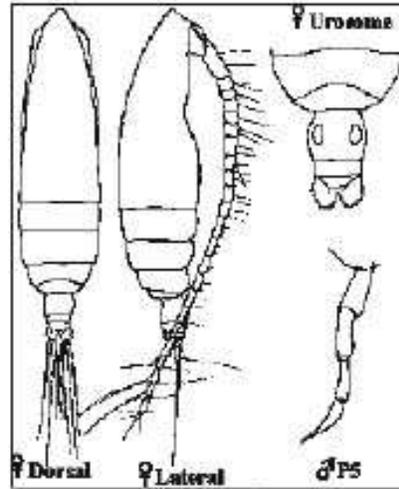
Eucalanus pileatus
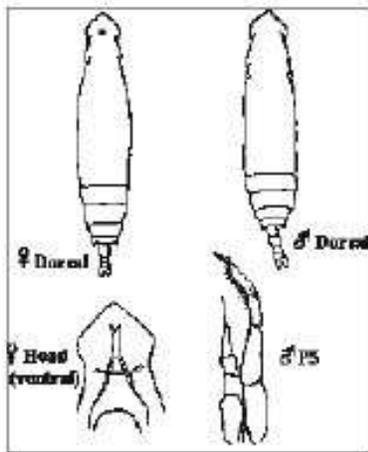
Eucalanus elongatus
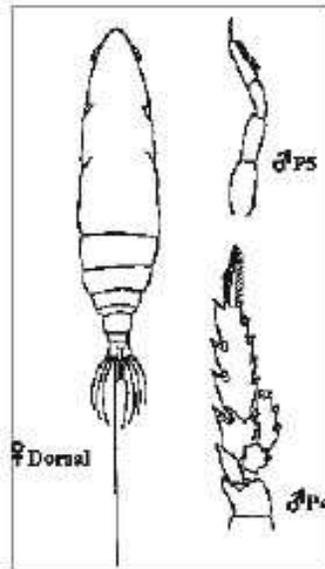
Eucalanus monachus
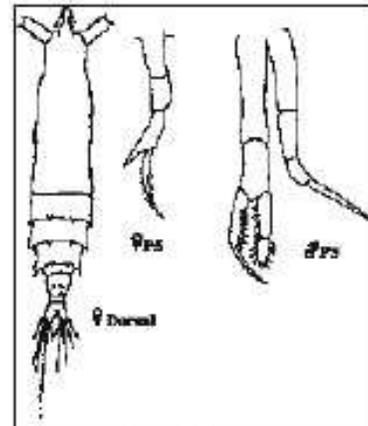
Rhincalanus cornutus
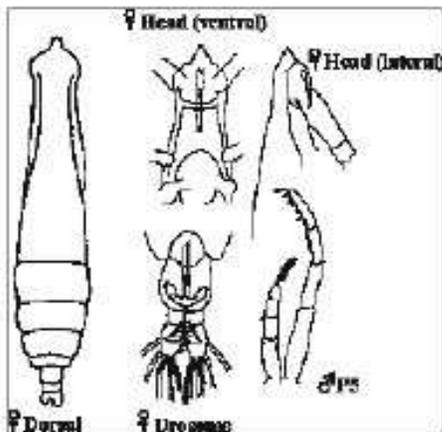
Eucalanus attenuatus
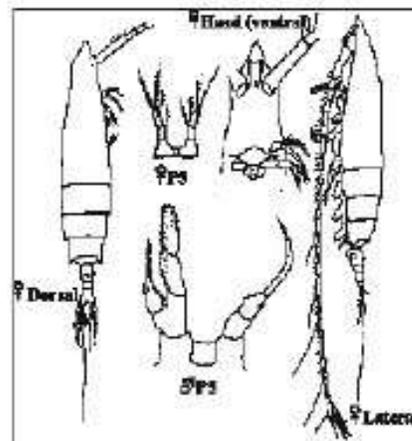
Rhincalanus nasutus
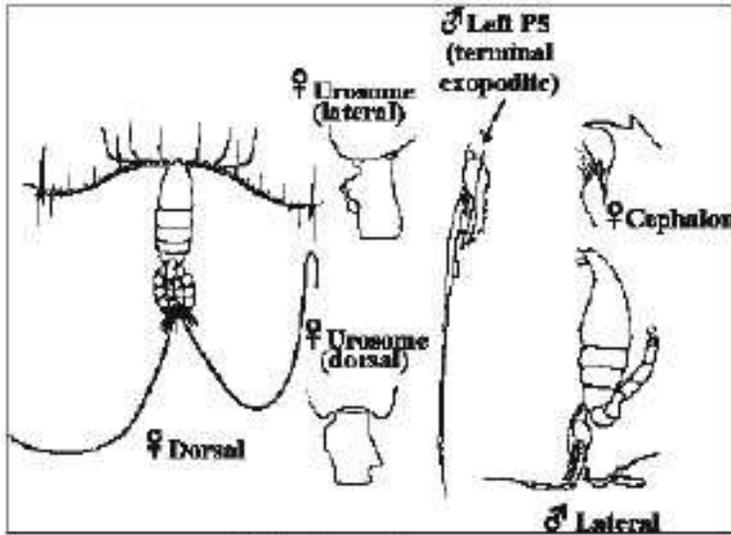
Euchaeta marina
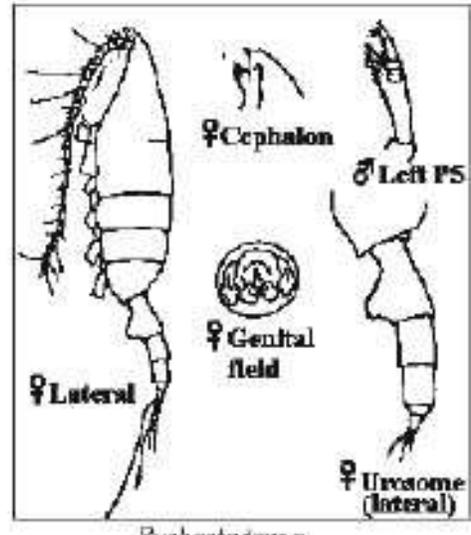
Euchaeta tonsa
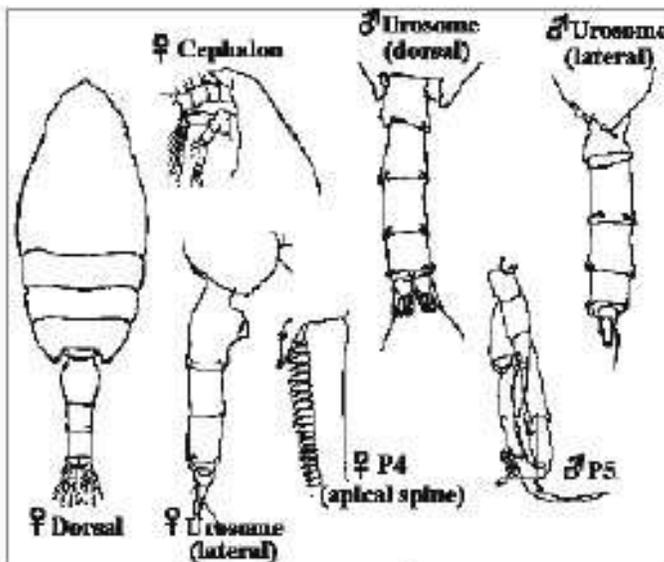
Euchaeta aequatorialis
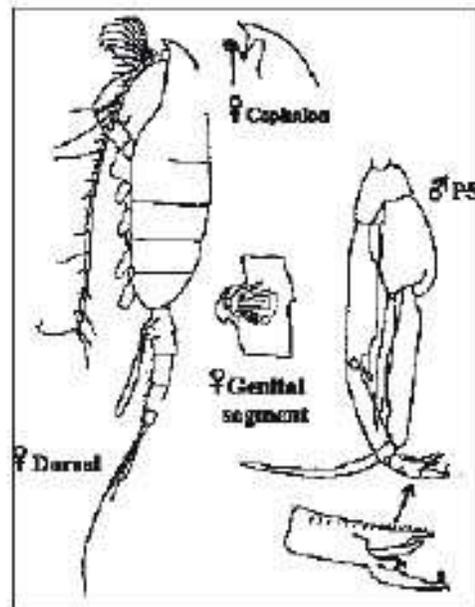
Euchaeta hebes
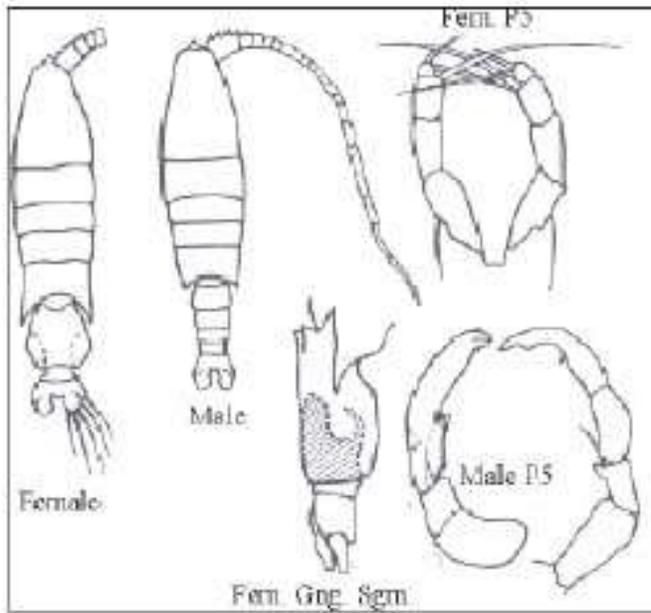
Gaussia princeps
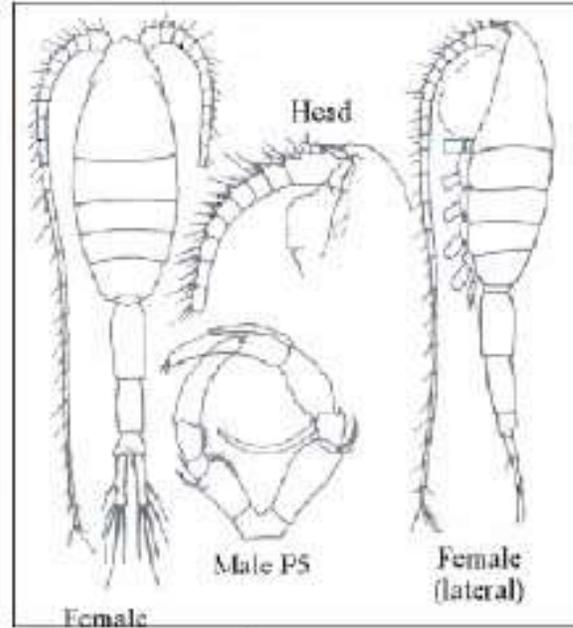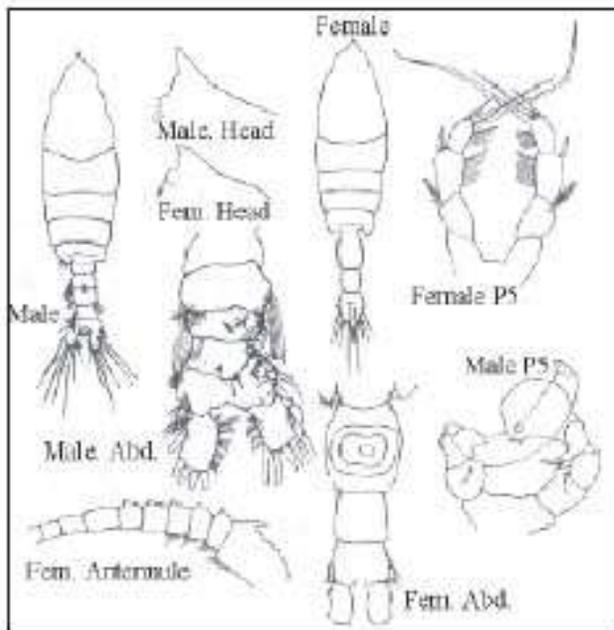
Metridia princeps

Pleuromamma xiphias
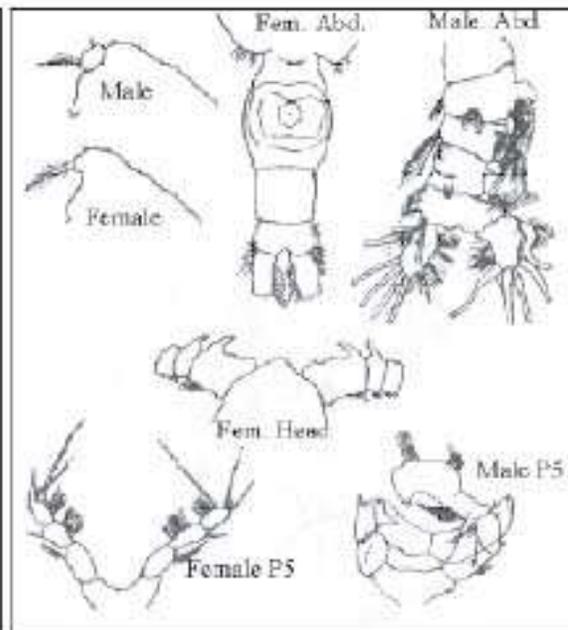
Pleuromamma abdominalis

♀ Lateral   ♀ Dorsal   ♂ Lateral   ♂ Dorsal

♀ P5   ♀ P4   ♂ P5

Paracalanus parvus

♂ Lateral   ♂ Dorsal

Acrocalanus andersoni

♀ Urosome

♀ Lateral   ♀ P5   ♀ Dorsal

Paracalanus denudatus

♀ Genital segment

♂ Lateral   ♂ Dorsal

♀ PS
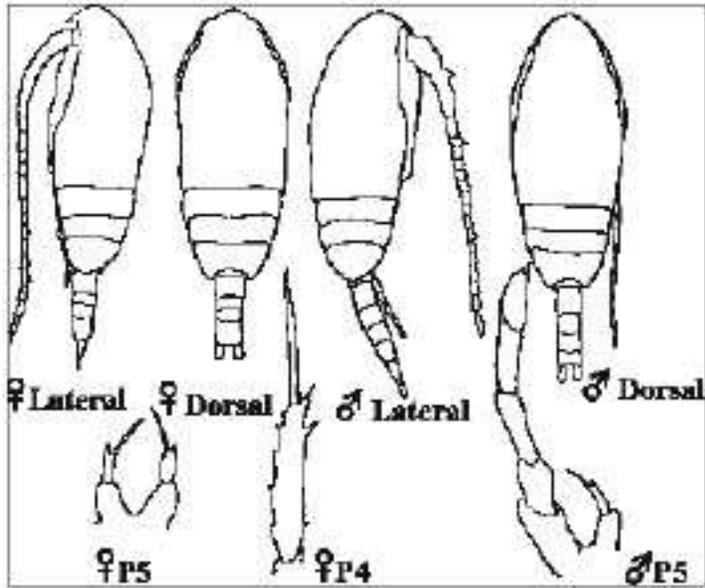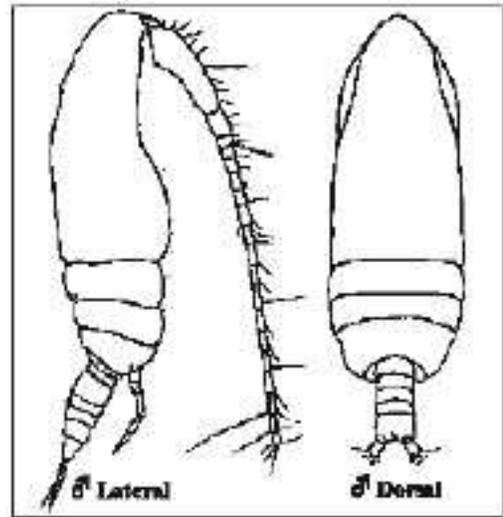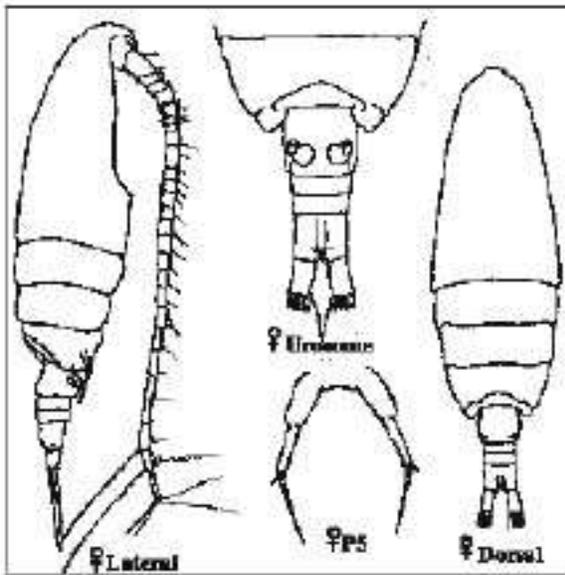
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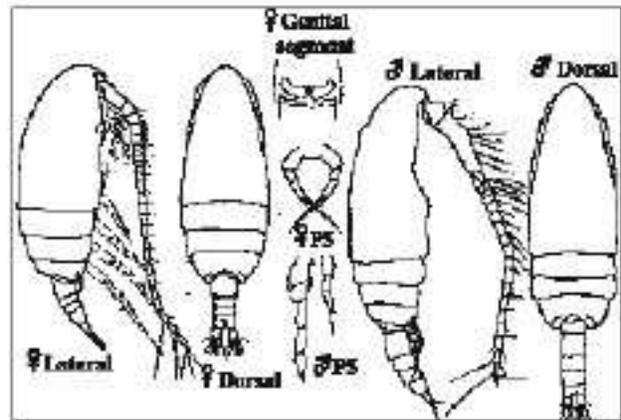
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♀ PS

♂ PS

♀ Lateral   ♀ Dorsal
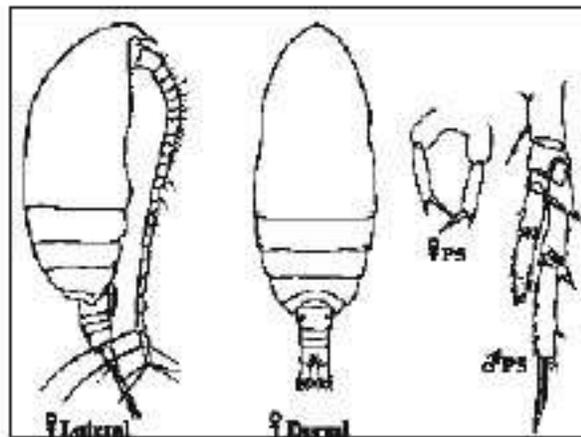
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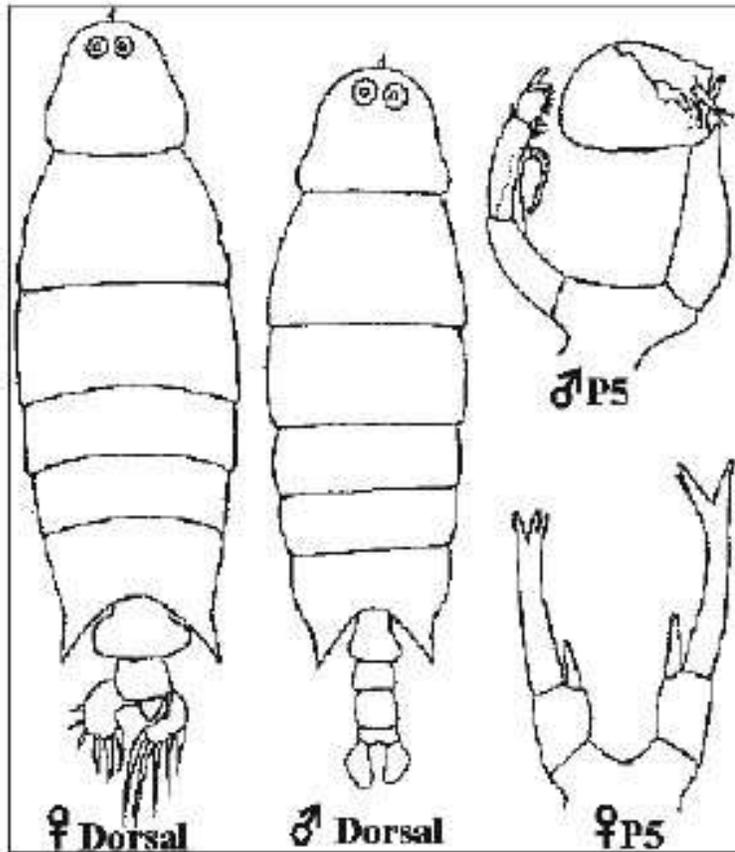
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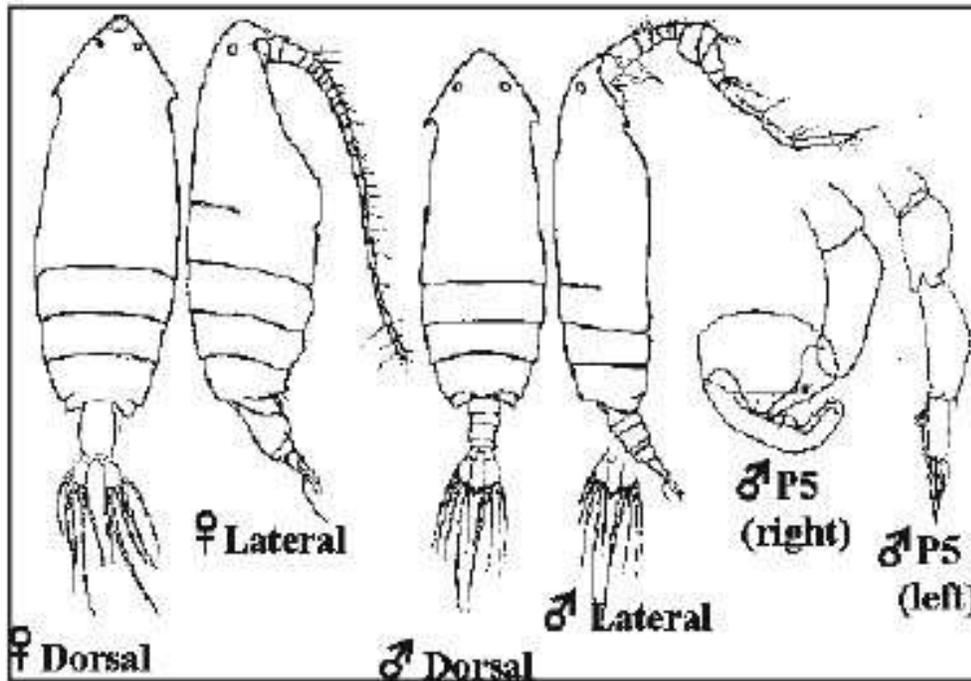
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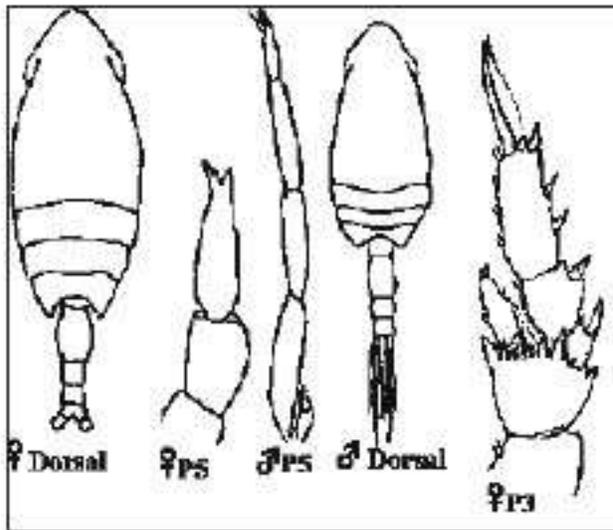
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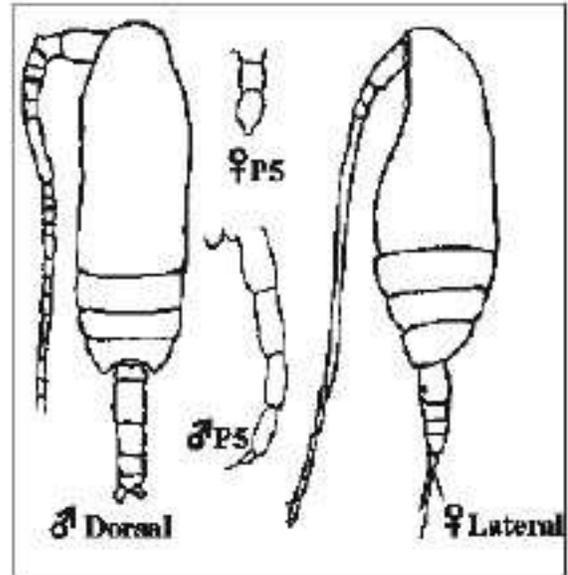
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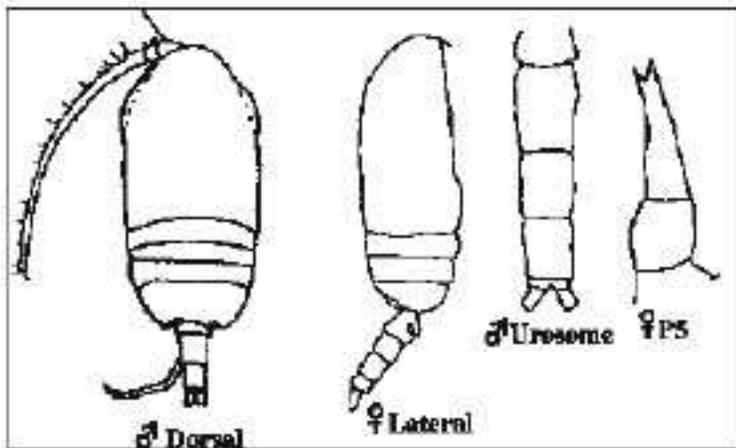
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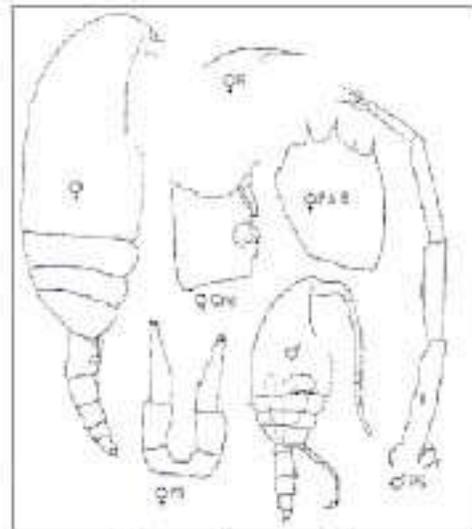
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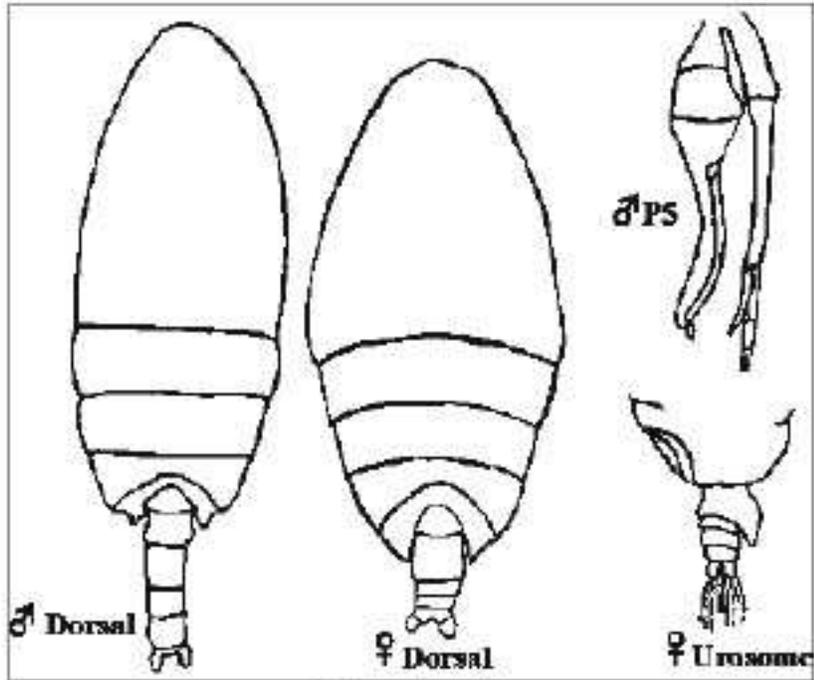
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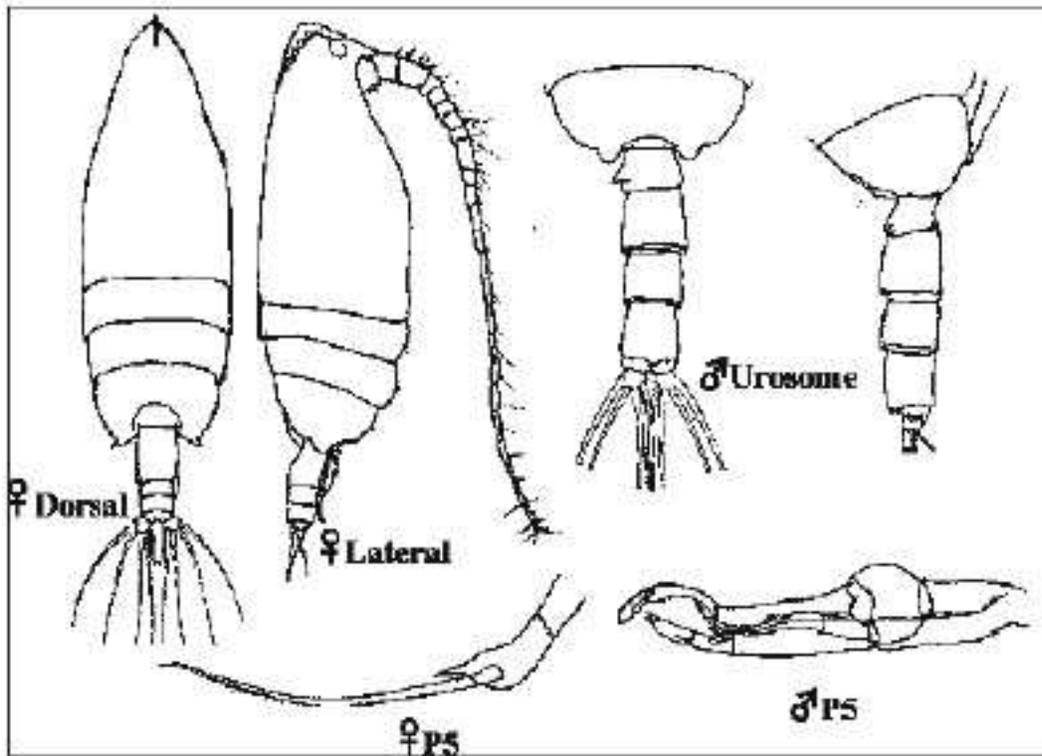
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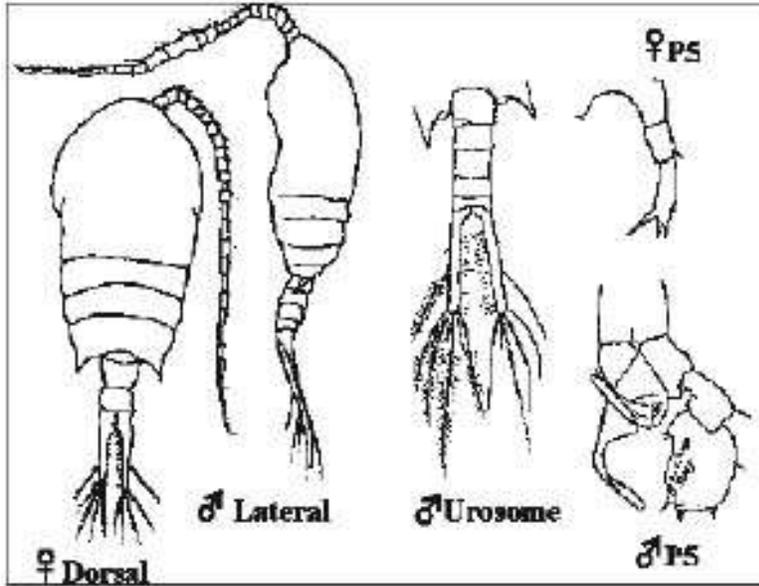
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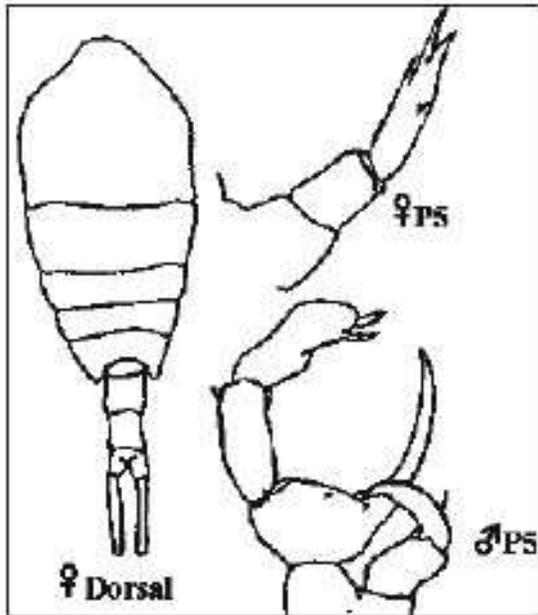
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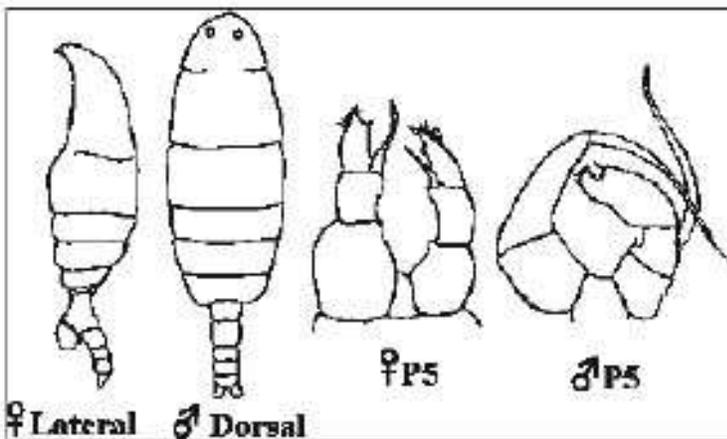
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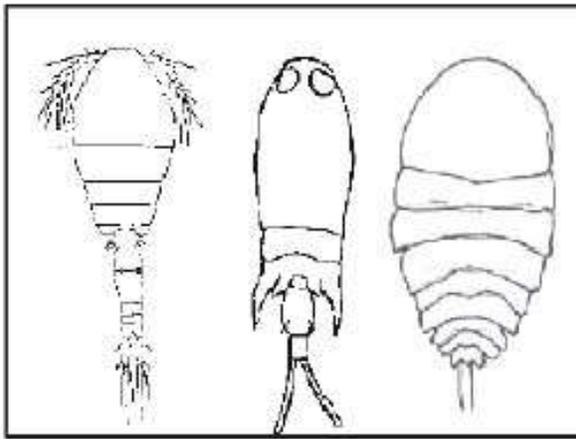
Different types of Cyclopoid
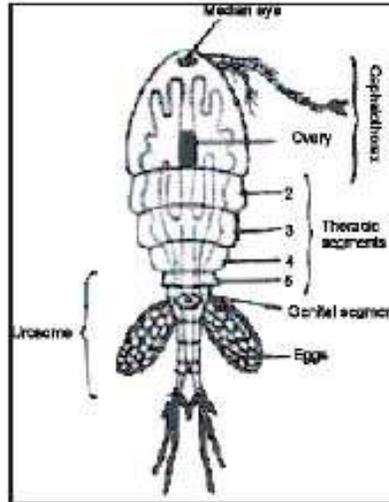
General body shape of cyclopoid with eggs
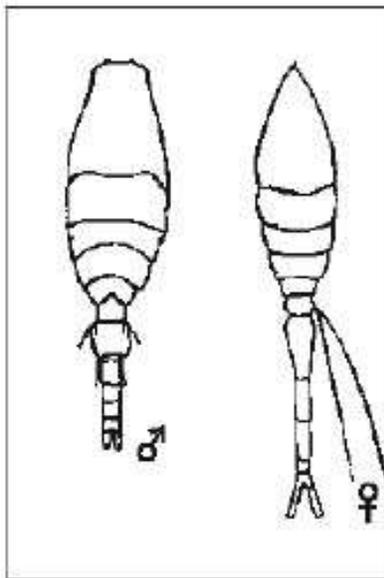
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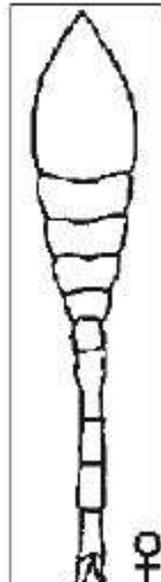
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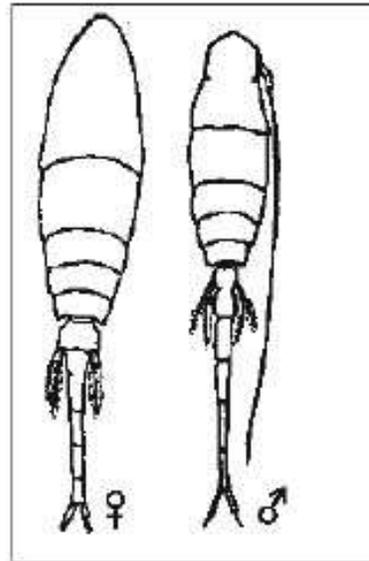
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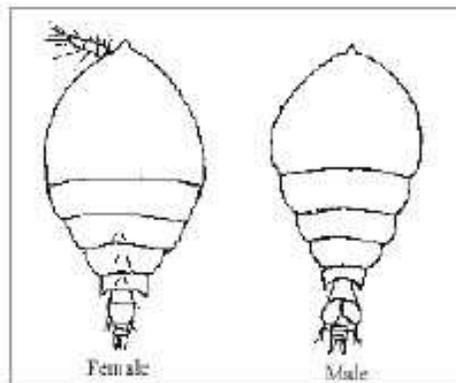
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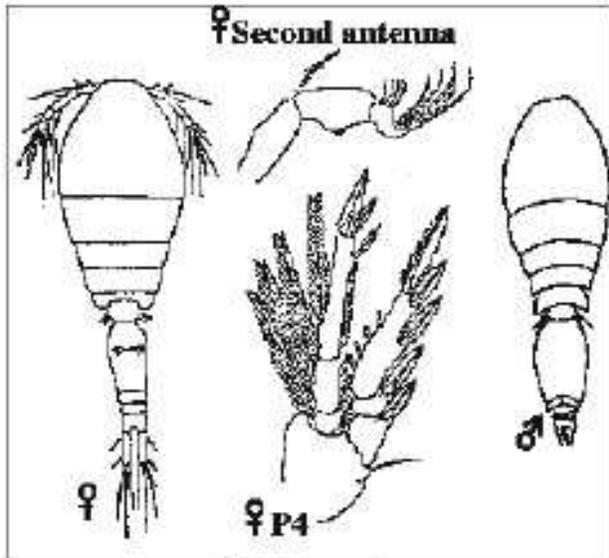
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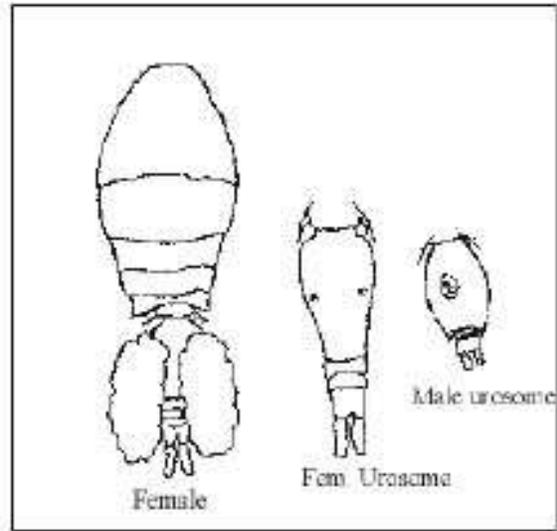
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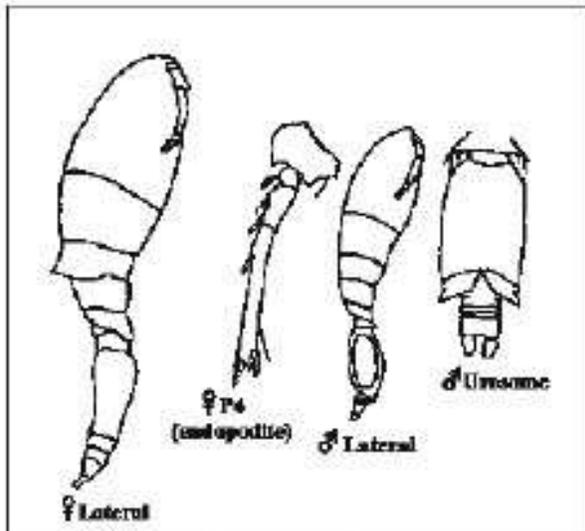
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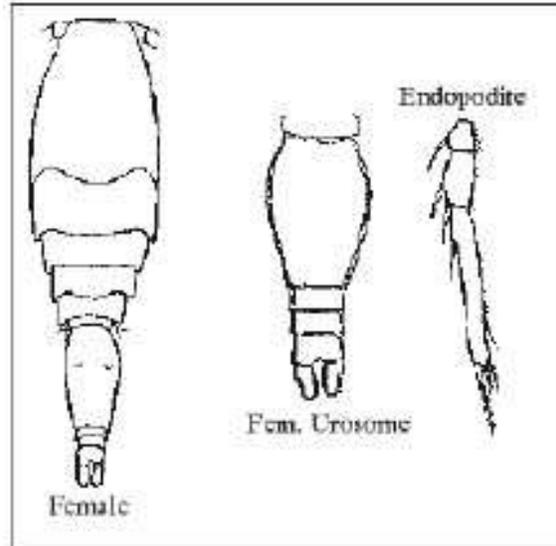
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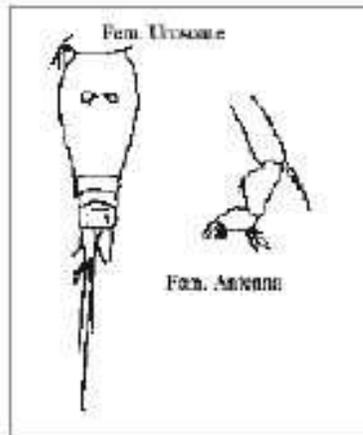
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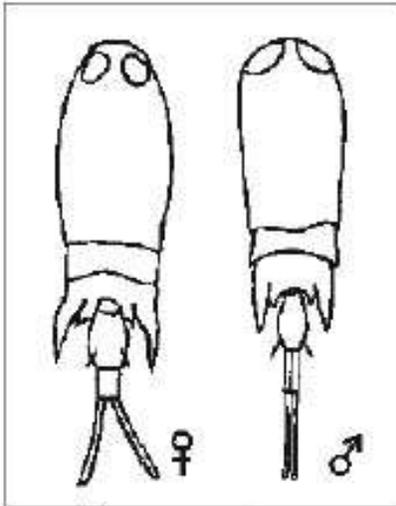
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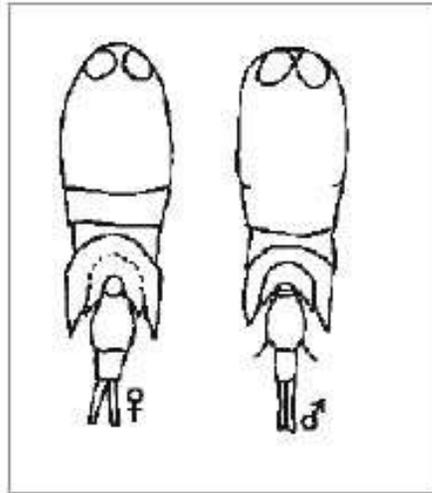
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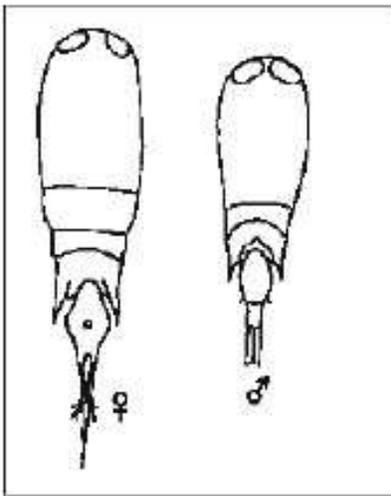
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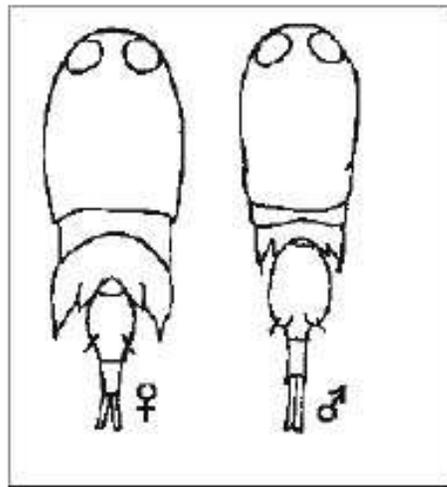
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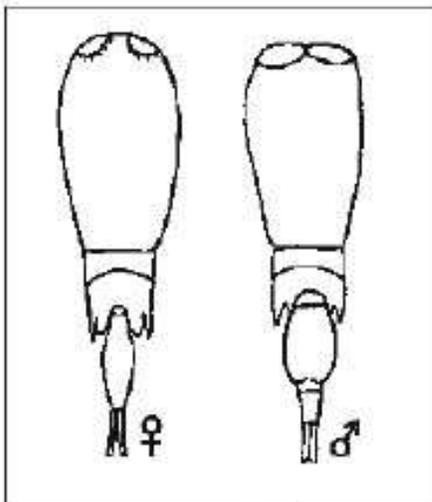
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Corycaeus venustus
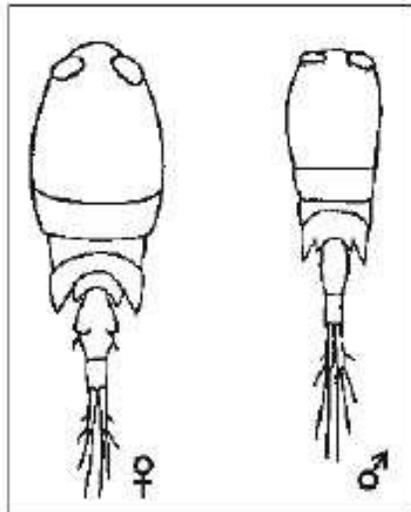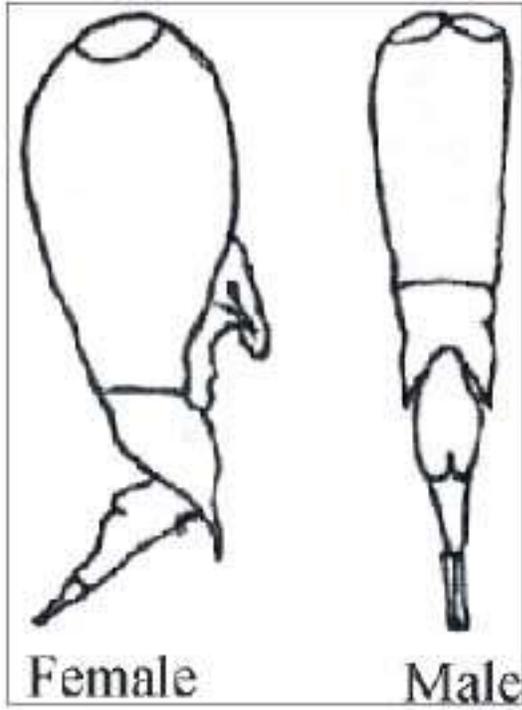
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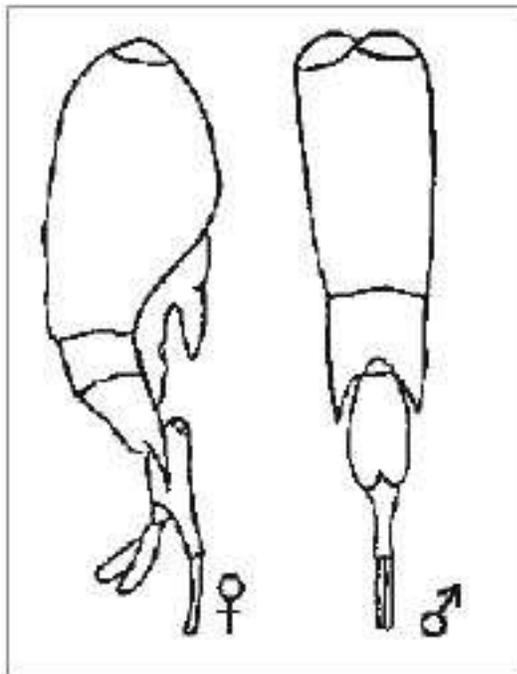
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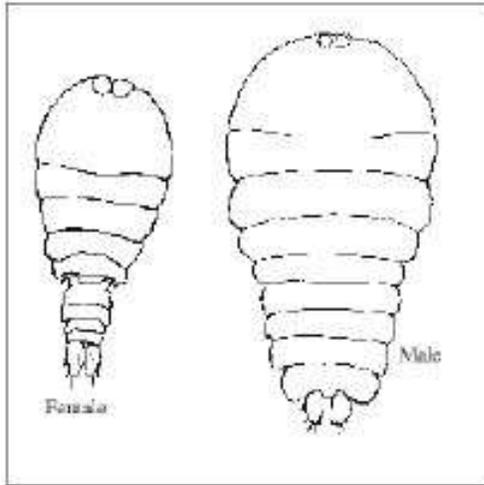
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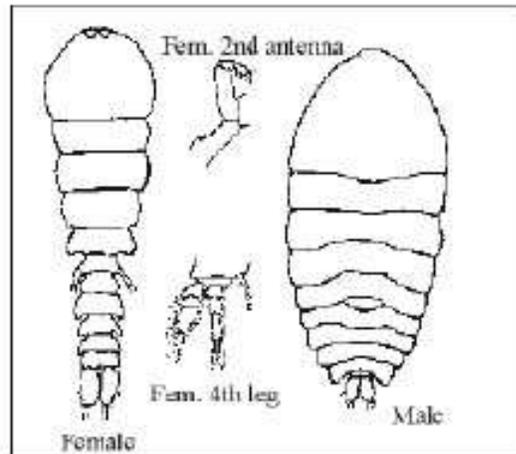
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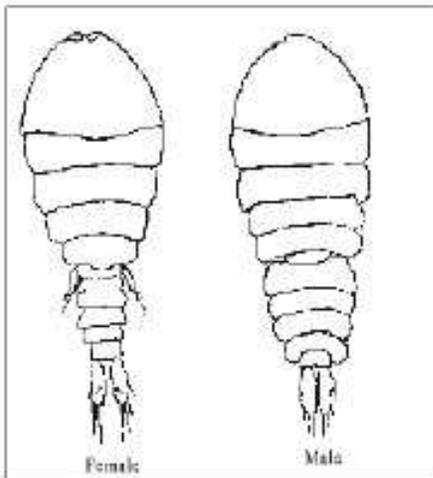
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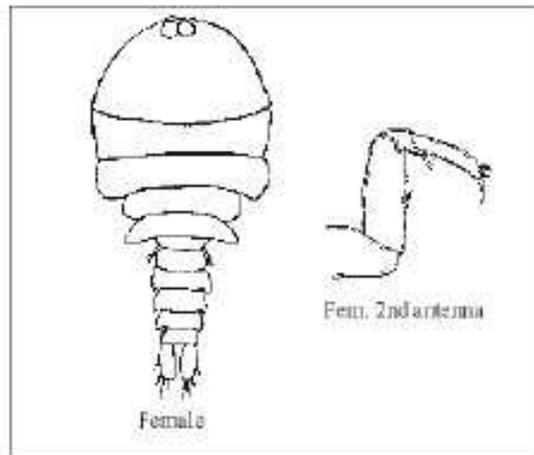
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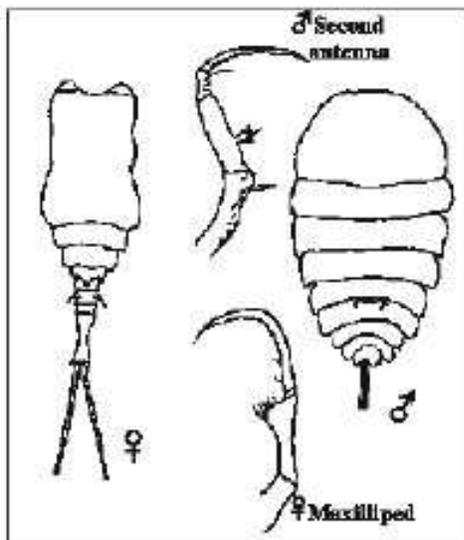
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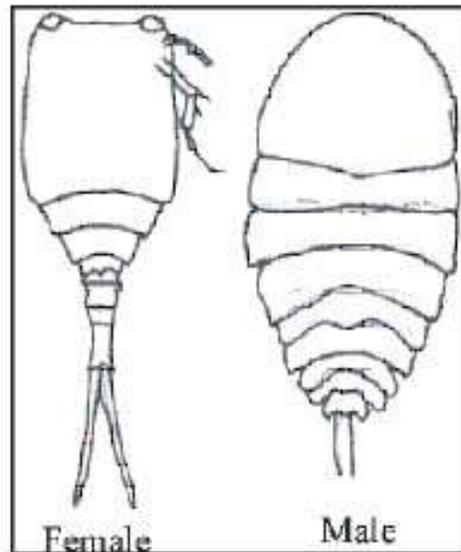
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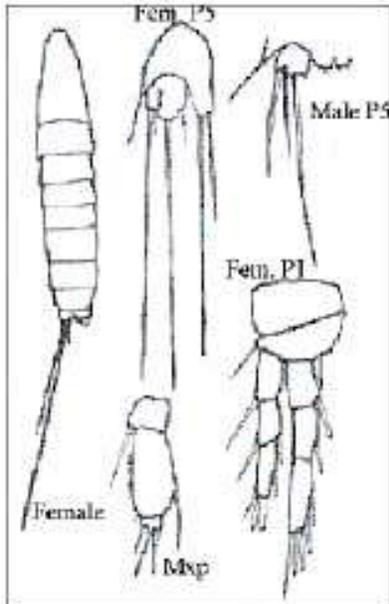
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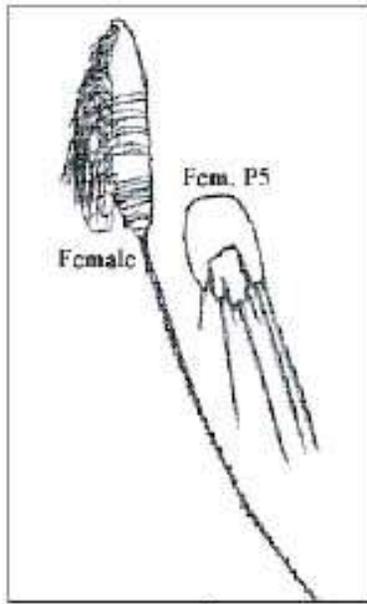
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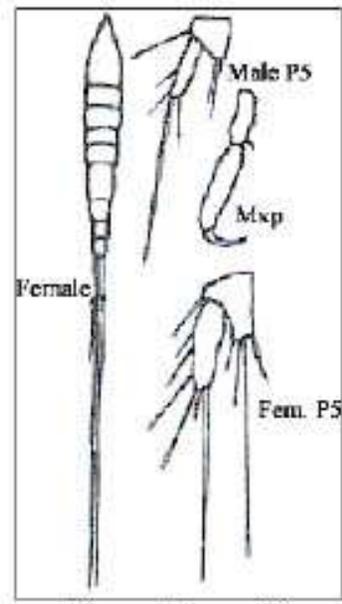
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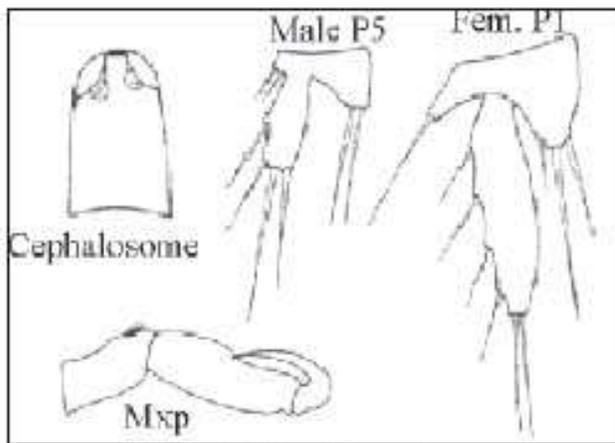
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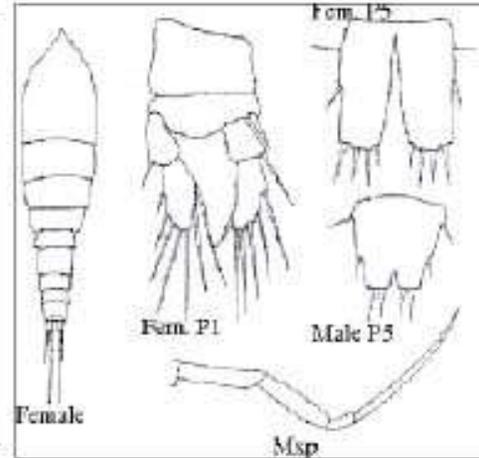
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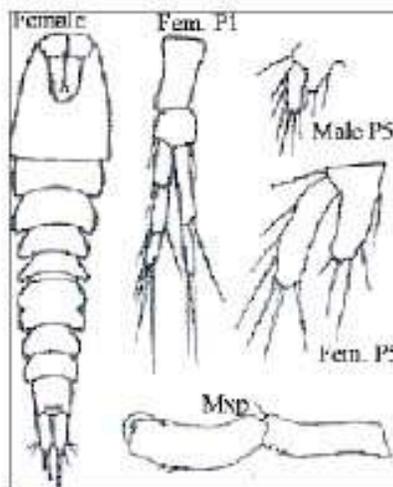
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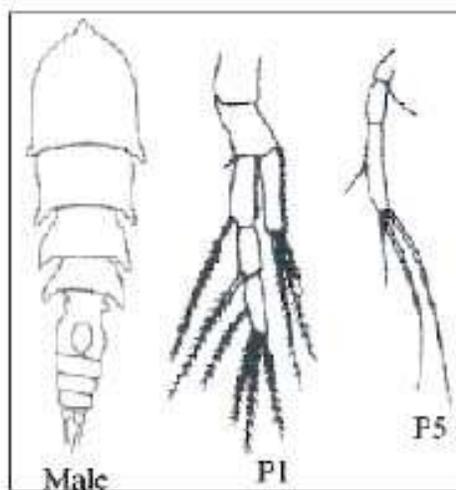
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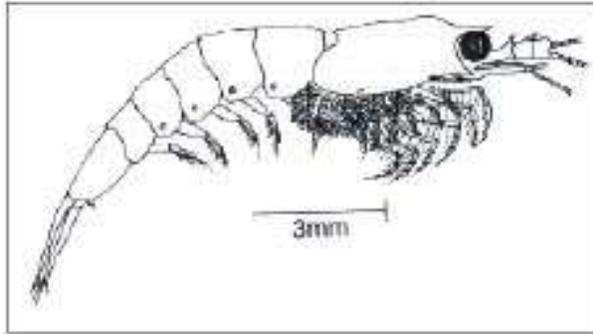
Euphausia spp.
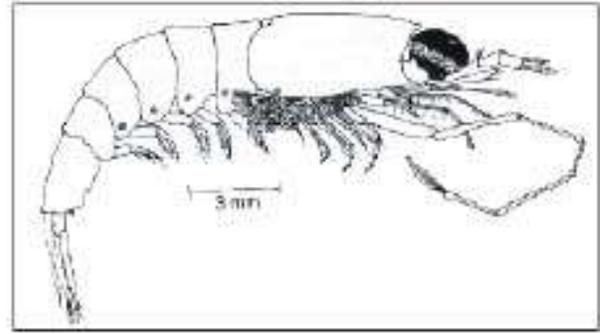
Nematobrachion spp.
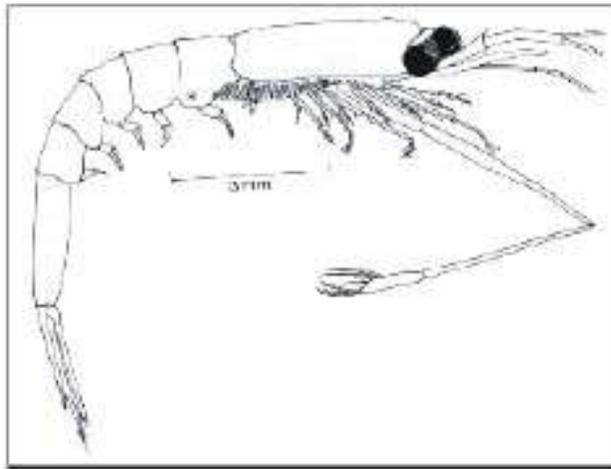
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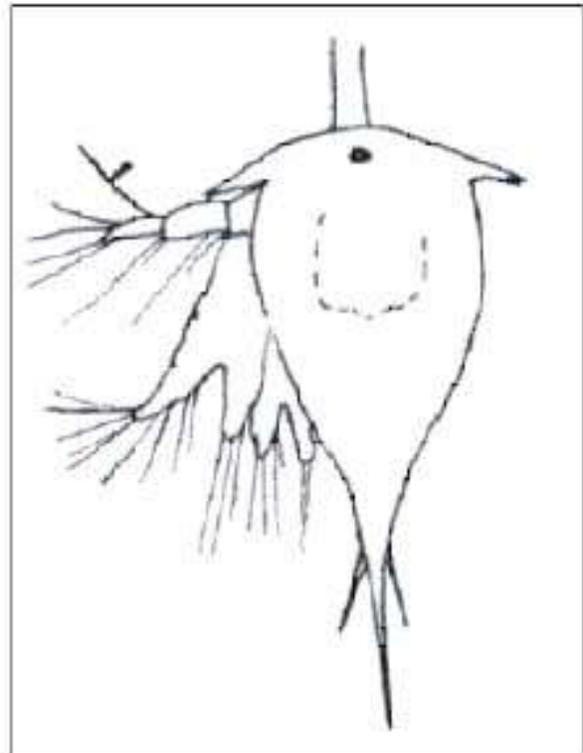
Cirriped larva
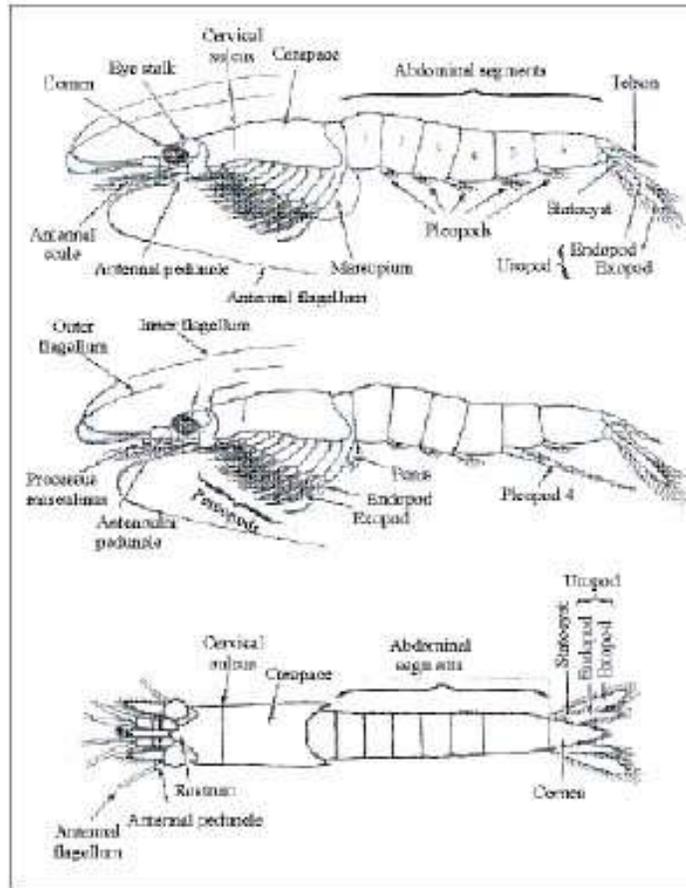
Diagram of mysid showing lateral view of female (top), male (middle) and general dorsal view (bottom)
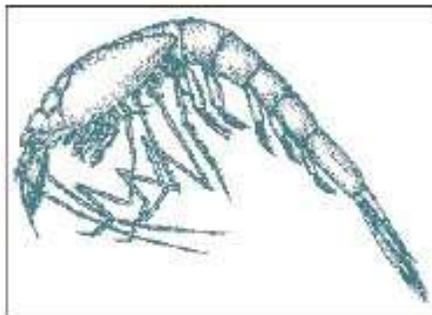
Eucopia sculpticauda
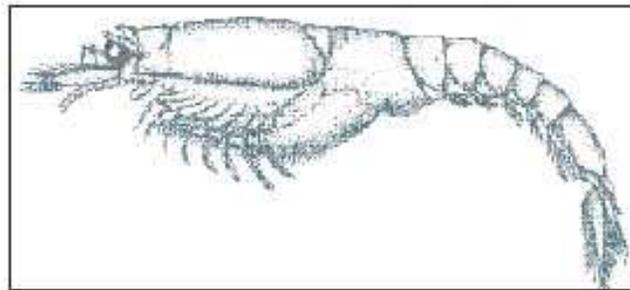
Longithorax fuscus

Boreomysis microps

Decapod zoea

Lucifer faxow

Thalassinidea

Decapod megalopa

Scyllaridae

Polychelidae

Hippidae

Stenopodidea

Caridea

Penaeidea

Portunidae

Diogenidae

Sergestoidea

Nephropidae

Paguridae

Porcellanidae

Mouth
Vestibular pit
Vestibular ridge
Vestibule
Hood
HEAD (ventral view)

Eye
Corona ciliata
HEAD (Dorsal view)

Tip
Shaft
Base
GRASPING HOOK

Anterior teeth
Posterior teeth
Mouth
Hooks
Oesophagus
Alimentary diverticulum
Collarette
Intestine
Ventral ganglion
Anterior fin
Ovum
Ovary
Seminal receptacle
Posterior fin
Anus
Testis tissue
Seminal vesicle
Sperm
Tail fin

Sagitta enflata

Sagitta friderici

Sagitta hispida

Sagitta serratodentata

(NOT DRAWN TO SCALE)
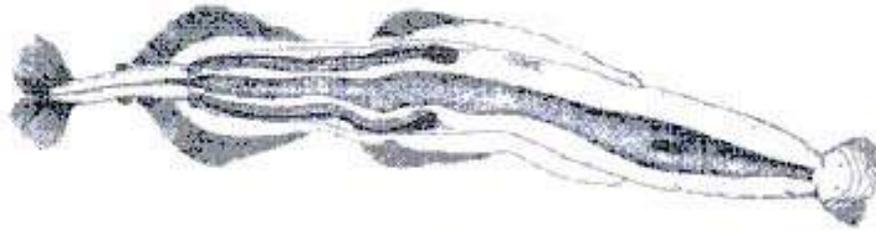
Sagitta lyra

Sagitta hexaptera

Sagitta bipunctata

Sagitta planctonis

Sagitta zetesios
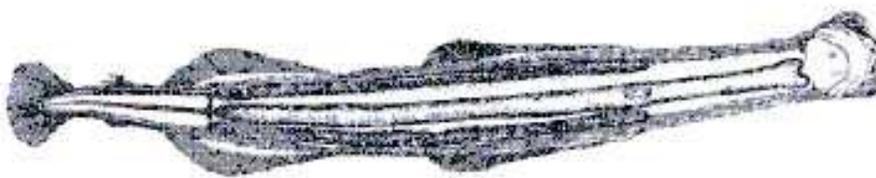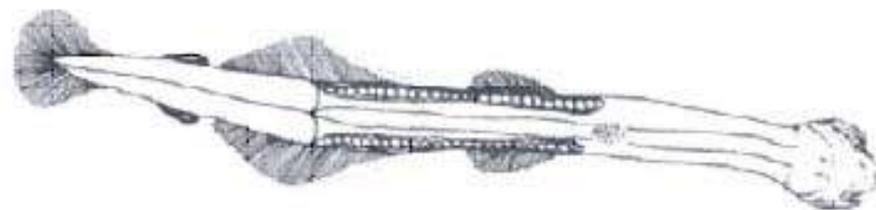
Sagitta macrocephala
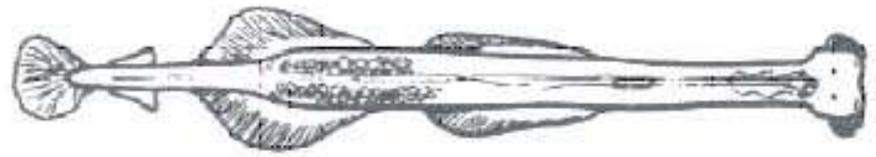
*Sagitta decipiens*

*Sagitta minima*

(NOT DRAWN TO SCALE)
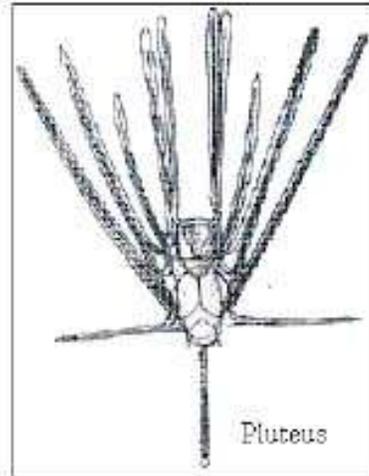
Echinoderm Pluteus
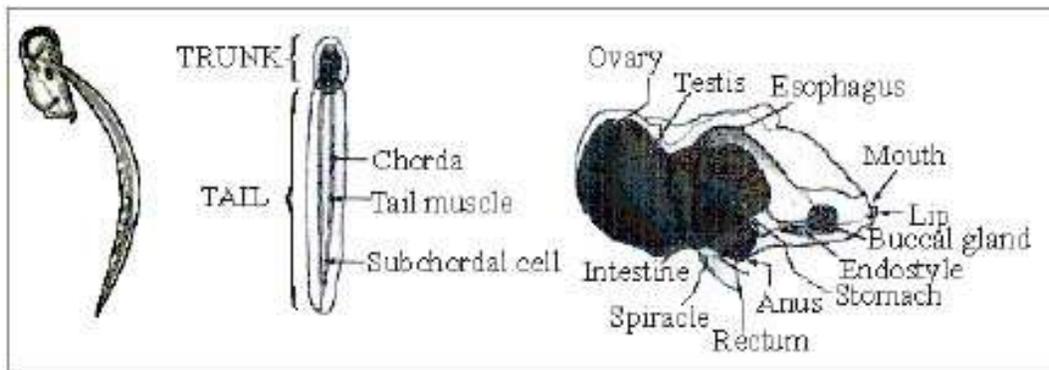
Appendicularia (Larvacea)

Thaliacea

 Regional Workshop Reports

GUINEA CURRENT LARGE MARINE ECOSYSTEM PROJECT

Report of

2nd Regional Workshop on Productivity Assessment in the GCLME

EXPERTS WORKSHOP

ACCRA, 24 – 26 NOVEMBER, 2010

INTRODUCTION

The S*econd Regional Workshop on Productivity Assessment* in the Guinea Current Large Marine Ecosystem (GCME) took place from the 24 to 26 November, 2010 at the GCLME Productivity Centre, University of Ghana, Accra, Ghana. The Workshop was organised by the Productivity Centre in collaboration with the Regional Co-ordination Unit of the GCLME Project and supported by UNIDO.

Each of the 16 member countries comprising the GLCME was invited to nominate a participant with requisite expertise in productivity for the Workshop. In all, 13 countries participated in the Workshop. The representatives from Angola, Equatorial Guinea and Guinea Bissau were unable to attend.

The goal of the Workshop was to present findings of the Regional Demonstration Project on Productivity to participating countries.

Specifically, the following reports were to be discussed:

1. Estimation of primary and secondary production and benthic fluxes. This was to be achieved by carrying out processing and analyses of continuous plankton recorder samples collected from Cote d'Ivoire to Cameroon during the period December, 1995 to November, 1999; zooplankton and benthic samples collected by the *RV Fridtjof Nansen* from 2005 to 2007 in the GCLME
2. Quantification of primary production from remotely sensed data. An appropriate algorithm was to be developed for the GCLME and used in estimating primary production from available satellite data.
3. A report on the assessment of productivity in the GCLME with consideration of the carrying capacity for living resources.
4. Review and update of Manual on Plankton identification in the GCLME. This is expected to enable experts and non-experts to carry out routine identification of plankton in the region.
5. Standard Field and Laboratory procedures for plankton and benthic fauna.

In addition, a framework for integration of national activities into the regional assessment programme and recommendation for future activities with regards to productivity in the region was to be discussed.

DAY ONE: 24th November, 2010

The Workshop was opened by the Dean of the Faculty of Science of the University of Ghana at a brief Opening Ceremony. The Faculty of Science has oversight responsibility of the Department of Oceanography and Fisheries, which hosts the GCLME Productivity and Biodiversity Centre. In his speech read on his behalf by the Vice-Dean, Prof. D.K. Owusu, the Dean expressed the

satisfaction of the University of Ghana in the role being played by the Department of Oceanography and Fisheries in the implementation of the GCLME project.

The Executive Secretary of the Interim Guinea Current Commission and Regional Co-ordinator of the GCLME Project, Dr. Maxwell Donkor, in his speech read on his behalf by Dr. Mohamed Seisay, the GCLME Fisheries Experts at the Regional Co-ordination Unit, thanked the University of Ghana for hosting the Productivity and Biodiversity Centre and also congratulated the experts assigned to carry out various tasks under the regional demonstration project on productivity. He further charged the participants to work assiduously in order to achieve the objectives of the Workshop.

The meeting was chaired by the Head of the Department of Oceanography and Fisheries, Dr. F.K.E.Nunoo. Also present was the GCLME Environment Officer, Dr. J. Abe.

The Opening Ceremony was followed by a group photograph. The Plenary session for the first day began at 10.20 am.

The Regional Expert for Productivity, Dr. G. Wiafe, invited participants Workshop to introduce themselves and later called for the adoption of the Agenda for Proceedings, after some few amendments.

In his overview of the Regional Demonstration Project, Dr. Wiafe informed participants that UNIDO contracted five experts, including himself, to carry out specific tasks in line with the implementation of the Regional Demonstration Project on Productivity in the GCLME. He emphasised that the contract was for the period 2009 – 2010, and was specifically to complete laboratory analyses of plankton and benthic fauna samples collected during the Pilot Phase (1995 – 1999) and Expanded Phase (2005 – 2007) of the GCLME Project.

He introduced the experts as follows:

1. Mr. Emmanuel Dovlo – Continuous Plankton Recorder survey
2. Ms. Hawa Yaqub-Bint – Plankton Survey by *RV Fridtjof Nansen*
3. Mr. Emmanuel Lamptey – Benthic Fauna Survey by *RV Fridtjof Nansen*
4. Mr. Kwame Agyekum – Primary Productivity Assessment from Remote Sensing

Dr Wiafe informed participants that the decision to engage experts from Ghana was very strategic and aimed at cutting down cost, yet maintaining high standards in execution of tasks. Participants attested to the high level of expertise demonstrated by the team.

During the afternoon session, Dr. Wiafe took participants through the Manual on Plankton Identification in the GCLME. He made mention that this aspect of the assignment was inherited from the Darwin Initiative Project carried out by the Department of Oceanography and Fisheries

in collaboration with institutions in the United Kingdom. In that project, a user-friendly guide for the common zooplankton species in the Gulf of Guinea was designed. The current task sought to expand the species list to cover the natural limits of the GCLME.

In his presentation, Mr. Emmanuel Dovlo took participants through the steps involved in Continuous Plankton Recorder (CPR) analyses. He mentioned that the approach is the most cost-effective in monitoring large marine ecosystems.

The samples covered the period December, 1995 to November, 1999 from the GG, GH, GI and GJ routes (Figure 1).

Ghana is one of five centres in the world that has the capability to carry out CPR survey. The Productivity Centre, through the GLCME Project, has acquired 2 CPR, 6 cassettes for the CPR, 2 Aquapacks for water quality monitoring, and 2 customised microscopes for plankton analyses

All the presentations have been attached as appendix to the Report (and also given to participants on CD-ROM prior to their departure).

DAY TWO: 25th November, 2010

Ms Hawa Yaqub-Bint was responsible for analysing zooplankton samples collected by the Norwegian vessel RV Fridtjof Nansen. She gave a presentation on the findings of annual zooplankton survey carried out from 2005 to 2007. The zooplankton samples were collected with an ICITA net (of mesh size 330 microns), as part of the fish trawl survey in the GCLME.

Mr. Emmanuel Lamptey followed with a presentation on macrobenthic faunal survey in the GCLME. Mr. Lamptey informed participants that the inclusion of benthic fauna with the productivity demonstration project was unique to the GLCME. Under the 5-modular approach in the LME concept, the benthos is not assessed. However, the GCLME included this aspect to the project because it will provide the region with valuable information on food source for demersal fish. The findings covered the period 2005 – 2007.

Both the ICITA zooplankton and macrobenthic faunal surveys were carried out by the *RV Fridtjof Nansen* along the same track (Figure 2).

COUNTRY PRESENTATION

Each of the participants presented the status of productivity in their country. The emphasis was on human capacity, equipment, institutions involved in marine productivity, and any other relevant information.

Benin

There is a level of collaboration between research institution and the University in Benin. Research is however constrained by lack of vessel and low level human capacity in marine plankton assessment. Productivity research is mainly focussed on freshwaters plankton

Cameroon

There is a laboratory for fisheries and marine science research in Limbe, and a University which offers courses in marine science. However, scientific equipment are obsolete and inadequate. There are few microscopes available. Scientists trained in marine productivity and related fields have almost reached retiring age. Low capacity of expertise available, and most of them are into freshwater research. There is no plankton monitoring programme.

Congo, Republic of

There is no institution responsible for marine research. ORSTOM carried out some activities on primary productivity (i.e. chlorophyll a) measurement in the 1960s. There is a laboratory for quality control monitoring of fishery products. There are no scientists involved in marine scientific research. No marine science courses offered in any university.

Cote d'Ivoire

There are three universities which are actively engaged in marine productivity and fisheries research. However, human capacity is grossly inadequate: 3 Phd, 2 of them in plankton science; 5 fisheries scientists, 1 benthic ecologist. CURAT and CRO actively engaged in marine research. The PROPAO programme has also contributed to human capacity development in marine sciences. There has been historical survey of plankton in marine waters. This has given way to lagoon research in recent times. Fisheries survey is very active, as well as ballast water assessment and monitoring of *Enteromorpha* spp., a nuisance macroalgal bloom that extend into Ghanaian coastal waters.

Democratic Republic of Congo

University of Kinshasha received funding from the Belgian government to set up a Hydro-biological laboratory. There are other two universities also carrying out research in

hydrobiology. Most of the equipment have broken down with time. Three experts are currently at post carrying out studies in fishery biodiversity of lagoons and estuaries.

Gabon

No institute specialised in marine sciences. Ministry of Fisheries has oversight responsibility in fisheries-related research. It has a centre equipped to carry out vessel monitoring responsible. The Centre also has developed capacity for GIS application for vessel monitoring.

Guinea

The country boasts of CERESCOR, a research institution with high calibre staff in plankton and benthic studies. Currently, most of the scientists are about to retire and research efforts has declined. Guinea has a well-equipped research vessel (RV Lasagna Conte). This particular vessel was earmarked to support Productivity surveys in the GCLME as part of the implementation of the regional demonstration project. The Co-ordinator of the Productivity Centre (Dr. Wiafe) was in Guinea in 2005 to negotiate for the use of the vessel and prepared a report. But this did not materialise.

Liberia

The country do not have any expertise nor existing facility to handle marine sciences. The war has had a severe toll on its infrastructure. There are two scientists handling fisheries-related studies in the country. One of them graduated from the Department of Oceanography and Fisheries, University of Ghana.

Nigeria

Nigeria Institute for Oceanography and Marine Research (NIOMR) is the main federal centre responsible for marine sciences. There are other academic institutions and State laboratories carrying out research in marine sciences and fisheries. NIOMR has an ocean-going vessel for research. There is a large pool of experts in fisheries and marine sciences in Nigeria.

Sao Tome and Principe

The country has no equipped laboratories for marine sciences and fisheries research. There is a low human capacity for research.

Sierra Leone

The Institute of Marine Biology and Oceanography in Fourrah Bay University carries our research in productivity and fisheries. It has been carrying out a monitoring programme since

2008. It also carries out seasonal assessment of fishery stock and collects plankton samples as part of the survey. There is limited capacity in marine sciences. Sierra Leone currently has several on-going collaborative projects with countries such as the Netherlands.

Togo

The Ministry of Environment, Fisheries and Agriculture is responsible for marine science related research, including fisheries and productivity. The country played a key role in the productivity assessment during the West Africa Gas Pipeline project. There is limited capacity in terms of infrastructure and personnel.

No representation from Angola, Equatorial Guinea and Guinea Bissau was received.

DAY THREE: 26th November, 2010

Discussion of Reports

Participants made useful comments on the Draft Productivity Report submitted by the experts. These were to be considered during the update and finalization of the Report.

Recommendations:

Participants agreed on the following recommendations:

1. That the Productivity Centre has demonstrated high level of capacity and should serve as a centre of excellence and should help strengthen capacity of other personnel in the region;

2. That either the Productivity Centre or someone be tasked at the national level to serve as focal points to carry out indepth ssessment of country needs, and make recommendation on how to address them;

3. That focal points be identified for each country. In view of the inauguration of the Working Group, participants became focal points for their respective countries. However, they could identify other persons from their countries as well

4. That countries should try and reach bilingual status to foster communication and integration

5. That a management plan be developed between the Productivity centre and national laboratories

6. That a strategy for countries to coordinate with productivity centre is developed

7. That countries be provided with the raw data from the surveys (this was duly carried out)

Inauguration of Productivity Working Group

Dr. Mohammed Seisay inaugurated the Productivity Working Group on behalf of the Executive Director of the IGCC. It was agreed that each participant would serve as the focal point for productivity in their respective countries.

Closing

The Workshop was closed by Dr. Seissay. He expressed his satisfaction of the high level of participation by the countries and the work done by the experts.

ACKNOWLEDGEMENTS

Sincere gratitude goes to the Director and staff of the Regional Co-ordination Unit of the GCLME Project/IGCC. Special thanks to Dr. Mohammed Seissay for participating in the 3-day meeting. Also, thanks goes to UNIDO office in Vienna for support in organising the workshop. To all the participants from the various countries, kudos. Last but not the least, to the Productivity Team for their tireless effort in a successful workshop.

APPENDICES (Given out on CD-ROM)

Appendix 1   Aide-Memoire

Appendix 2   Work Programme

Appendix 3   Participation

Appendix 4   Presentations

Appendix 5   Draft copy of Plankton Guide

Appendix 6   Workshop photos

Prepared by

Dr. G. Wiafe
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GUINEA CURRENT LARGE MARINE ECOSYSTEM PROJECT

AIDE-MÉMOIRE

2ᴺᴰ REGIONAL WORKSHOP ON PRODUCTIVITY IN THE GCLME

ACCRA, 24 – 26 NOVEMBER, 2010

Preamble:
Predictions on present and future availability of living marine resources in the GCLME region for economic and food security purposes will depend on knowledge of the productivity patterns of the ecosystem. With funding from the Global Environment Facility (GEF), the United National Industrial Development Organisation (UNIDO) is executing the Guinea Current Large Marine Ecosystem (GCLME) Project involving 16 West and Central African[3] countries. Evaluation of the productivity of the GCLME with regards to its carrying capacity for living resources is one of four regional demonstration under the project. The GLCME Productivity and Biodiversity centre of the University of Ghana was established in July, 2006 to co-ordinate the regional demonstration project on productivity.

The upcoming workshop is aimed at dissemination findings of the demo project, provide participants with opportunity to acquire new knowledge and skills and comment on the Draft Productivity Assessment Report from the project. Participants would also be expected to provide comments on other key documents in preparation - Plankton Identification Manual for the GCLME, Standard Field and Laboratory procedures for benthic fauna research, and Standard Field and Laboratory procedures for plankton research.

The workshop
The Workshop will take place at the University of Ghana, Legon under the auspices of the IGCC and GCLME Regional Productivity and Biodiversity Centre from 27 – 29 October, 2010. Participants for the Workshop would be drawn from the 16 member countries of the GCLME Project.

Financial and Administrative Arrangements:
Invited participants from the sixteen GCLME countries will be issued with a round-trip economy class air tickets from their country of departure using the most direct and economical route.

Participants will be met on arrival at the Kotoka International Airport, Accra and conveyed to their respective hotels. To facilitate this service it would be appreciated if participants could send their travel itinerary to Mr. Napoleon Gbolonyo at gbolonyo@yahoo.com, n.gbolonyo@gclme.org Tel: +233 21 768593, +233 21 781225 or +233 244 524298.

UNIDO will pay standard UN rate per diem for Accra. This amount covers board, lodging and incidentals and is payable on arrival for the period of attendance at the workshop. Participants should indicate in their request for PTA unavoidable transits in other countries. Participants arriving by road should also indicate the kilometres covered to and from Accra.

Please note that UNIDO will not pay DSA to participants other than the approved number of days. There will be two Coffee / Tea breaks as well as a communal lunch everyday to be served to all participants at the Workshop venue.

Participants will be required to bear the following costs: all expenses in their home country incidental to travelling abroad, including expenditure relating to passport, visa and any other miscellaneous items.

UNIDO and the RCU will not assume responsibility for any of the following costs, which may be incurred by the participant while attending the meeting:

- Compensation for salary or related allowances during the period of the Meeting;
- Any costs incurred with respect to insurance, medical bills and hospitalization fees;
- Compensation in the event of death, disability or illness;
- Loss or damage to personal property of participants while attending the Meeting.

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[3] Angola, Benin, Cameroon, Congo, DRC, Cote d'Ivoire, Gabon, Ghana, Equatorial Guinea, Guinea, Guinea Bissau, Liberia, Nigeria, Sao Tome and Principe, Sierra Leone, Togo

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Background information:
The Guinea Current Large Marine Ecosystem (GCLME) is one of 64 LMEs, of ther world, extending from Guinea Bissau in the north to Gabon in the south. The GCLME is considered a highly productive ecosystem, primarily due to a seasonal coastal upwelling off Cote d'Ivoire to Benin. An approximate 40% of the region's 300 million people live in the coastal areas and depend on fishery resources as their major source of animal protein. However, this resource is currently under threat of over-exploitation, and thus, poses great food security within the region. In order to address the issue, countries bordering the GCLME have embarked on a region-wide project aimed at "c*ombating living resources depletion and coastal area degradation in the GCLME through ecosystem-based actions*". The project is financed partly by the Global Environment Facility and participating countries over the period 2004 to 2009 (*http://www.gclme.org/*).

The long-term development goals of the project are: 1) recover and sustain depleted fisheries; 2) restore degraded habitats; and 3) reduce land and ship-based pollution by establishing a regional management framework for sustainable use of living and non-living resources in the GCLME. Priority action areas include reversing coastal area degradation and living resources depletion, relying heavily on regional capacity building.   The project focuses on nine demonstration projects, designed to be replicable and intended to demonstrate how concrete actions can lead to dramatic improvements. Sustainability will derive from this improved capacity, strengthening of national and regional institutions, improvements in policy/legislative frameworks, and the demonstration of technologies and approaches that will lead to improved ecosystem status.   The private sector will be a focus for cooperation, as they also hold the key for long-term sustainability of actions.

In accordance with the LME modular concept, assessment of productivity constitutes one of three regional demonstration projects under execution. The current project is an expanded activity of an earlier pilot phase project which involved Cote d'Ivoire, Ghana, Togo, Benin, Nigeria and Cameroon. During the pilot-phase, continuous plankton recorders (CPRs) were, for the first time, towed within the upwelling region (i.e. Gulf of Guinea). Monthly plankton samples, over the period 1995 to 1999, were collected by ships-of-opportunity from Cape Palmas in Cote d'Ivoire to Doula in Cameroon (**Figure 1)**.

Figure 1. Continuous Plankton Recorder (CPR) routes towed during the pilot phase project (yellow lines). Additional tow routes (red lines) have been included to cover the entire GCLME, including the coastal areas of Angola.

The GCLME Project has set up a regional centre of excellence for productivity and biodiversity studies in the Department of Oceanography and Fisheries of the University of Ghana. The Centre is expected to co-ordinate the implementation of all productivity surveys on a regional scale, and to develop standardised methodologies for field and laboratory activities. A regional Working Group on Productivity and Biodiversity has been set up with representatives from each of the 16 participating countries.

To complement the CPR tows within the region, annual plankton survey are being undertaken with the Norwegian vessel *RV Fridtjof Nansen*, as well as analysis of satellite imageries to investigate primary productivity patterns.

DRAFT PROGRAMME

WEDNESDAY, 24 NOVEMBER, 2010

Programme for Opening Ceremony (08.00 – 11.00)

08.00 – 08.55	
08.55 – 09.00	Registration
09.00 – 09.10	
09.10 – 09.20	Welcome of Participants and Introduction of Chairman
09.20 – 09.30	
09.30 – 09.40	Opening Remarks by Chairman
09.40 – 09.50	
09.50 – 10.20	Statement by University of Ghana
10.20 – 11.00	
	Statement by UNIDO
	Statement by GCLME Regional Coordinator
	Overview of Productivity Assessment in the GCLME
	Keynote Address
	Group Photograph and Refreshment

WORKING SESSIONS (INVITED WORKSHOP PARTICIPANTS ONLY)

11.00 – 12.30   **Plenary Session**
Introduction of Participants
Adoption of Agenda
Presentation of Regional Demo Project on Productivity
Discussion

12.30 – 1.30   **Lunch**

1.30 – 5.00   **Plenary Session**
Country Reports by participants (Assessment and Needs)
Presentation by Consultants:
  ➢ Primary production
  ➢ Secondary production
  ➢ Benthic fluxes
  ➢ Application of Remote Sensing in Productivity Assessment

DAY 2: THURSDAY 25 NOVEMBER, 2010

09.00 – 12.30   **Reports Review**
  ➢ Evaluation of the Carrying Capacity of the GCLME
  ➢ Manual for Identification of Plankton in the GCLME

       ➢   Benthic Fluxes in the GCLME
       ➢   Standard for plankton sampling and processing
       ➢   Standard for benthic fauna sampling and processing

12.30 – 1.30   **Lunch**

1.30 – 5.00   **Continuation of Reports Review**

DAY 3: FRIDAY 26 NOVEMBER, 2010

09.00 – 12.30   **Continuation of Reports Review**

12.30 – 1.30   **Lunch**

1.30 – 2.00   **Final Discussion and Adoption of Report**

2.00 – 4.00   **Productivity Research in the GCLME – Way Forward**

4.00 – 4.30   **Closing Ceremony**

2ND REGIONAL PRODUCTIVITY WORKSHOP

Opening Ceremony

(24 - 26 September, 2010)

P R O G R A M M E

	WEDNESDAY, NOVEMBER, 24
9.00 - 10.30	Opening Ceremony
10.30 - 1.00	Plenary Session: Project Overview
	Introduction of Participants
	Adoption of Agenda
	Presentation of Regional Demo Project on Productivity
	Discussion
1.00 - 2.00: Lunch	
2.00 - 3.30	Plenary: Country Presentations
	Angola
	Benin
	Cameroon
	Cote d'Ivoire
	Democratic Republic of Congo

	Equatorial Guinea
	Gabon
	Ghana
	Guinea
	Guinea Bissau
3.30 - 4.00: Coffee Break	
4.00 - 5.00	Plenary: Country Presentations
	Liberia
	Nigeria
	Republic of Congo
	Sao Tome and Principe
	Sierra Leone
	Togo

	THURSDAY, NOVEMBER, 25
9.00 - 10.30	Plenary Session: Results Presentations
	CPR survey
	Zooplankton survey
10.30 - 11.00: Coffee Break	
11.00 - 1.00	Benthic fauna
	Remote Sensing
1.00 - 2.00: Lunch	
2.00 - 3.30	Plankton (Laboratory analyses)
3.30 - 4.00: Coffee Break	
4.00 - 5.00	Benthic fauna (Laboratory analyses)
	FRIDAY, NOVEMBER, 26
9.00 - 10.30	Break out Session:Reports Discussion
10.30 - 11.00: Coffee Break	
11.00 - 1.00	Break out Session:Reports Discussion
1.00 - 2.00: Lunch	
2.00 - 2.30	Working Group Presentation
2.30 - 3.30	PRODUCTIVITY NEEDS ASSESSMENT & RECOMMENDATION
3.30 - 4.00: Coffee Break	
4.00 - 4.30	Closing Ceremony

REGIONAL WORKSHOP ON PRODUCTIVITY ASSESSMENT IN THE GUINE CURRENT LARGE MARINE ECOSYSTEM

24 - 26 NOVEMBER, 2010

WELCOME BRIEF BY DEAN OF FACULTY OF SCIENCE

Mr. Chairman
Executive Secretary and Co-ordinator of Interim Guinea Current Commission
Director of Fisheries
Distinguished Ladies and Gentlemen

It gives me great pleasure to welcome you all to the University of Ghana and to this workshop on marine productivity assessment in the Guinea Current Large Marine Ecosystem (GCLME), which comprise of 16 countries from Guinea Bissau to Angola.

The University of Ghana is the oldest university in Ghana, and has established its academic leadership among the other universities in the country. With a student population of over 37,000, the University continues to develop world-class human resources and capabilities to meet national development needs and global challenges through quality teaching, learning, research and knowledge dissemination. For its 62 years of existence, the University is the place to pursue academic excellence.

The Faculty of Science of the University of Ghana comprise of 13 Departments, and a School for Nuclear and Allied Sciences. The Department of Oceanography and Fisheries which hosts the GCLME Productivity and Biodiversity Centre is part of the Faculty of Science. In 2007, the University of Ghana signed a Memorandum of Understanding with the GCLME Project to host the Regional Centre for Productivity and Biodiversity. The Centre was commissioned by the Minister of Environment and Science and the Minister of Fisheries. Since then, the Centre has been actively engaged in research focussed at supporting activities of the GLCME Project among others.

I am reliably informed that the Centre carried out a successful survey of plankton in 2007, using Continuous Plankton Recorder (CPR). This feat has never been performed by an African country. Hitherto, this activity was given under contract to Sir Alister Hardy Foundation of

Ocean Science in the United Kingdom. ***I can confidently say that the Productivity and Biodiversity Centre is among 5 centres in the whole world with the capability to carry out CPR survey.*** Ecosystem-wide time series of plankton measurements using CPRs deployed by ships-of-opportunity provides requisite information in a cost effective manner to help in assessment of productivity of the marine ecosystems.

I wish to recommend to the Centre Co-ordinator in the person of Dr. George Wiafe to continue to work hard so as to foster collaboration with other Centres of Excellence and thereby also encourage exchange of scientists from other parts of the world. This will contribute to a large extent in the scientific development of resources in our maritime domain for economic empowerment.

To the participants of the workshop, I wish you fruitful deliberation and hope you will also find time to visit parts of the city of Accra to enjoy a spectacular scenery.

Thank you.

Prof. D.K. Asiedu
Dean, Faculty of Science
University of Ghana, Legon

List of Participants
Productivity Workshop
24th -26th November 2010

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