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Large Marine Ecosystems Monitoring Workshop Report

13-14 July 1991,
Cornell University, Ithaca, New York

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
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BACKGROUND

A workshop was convened at Cornell University in Ithaca, New York, on 13 and 14 July 1991 to consider the theoretical and pragmatic bases for a "core" strategy to monitor large marine ecosystems (LME).

The *ad hoc* Committee on Large Marine Ecosystems, at a meeting held at the United Nations Educational, Scientific, and Cultural Organization (UNESCO) headquarters in Paris, France, during March 1991, agreed that among the follow-on action items to the meeting would be a further development of a monitoring strategy for LMEs. A workshop on LME theory, modeling, and monitoring was to be organized during summer 1991 that would include experts on these topics from the Woods Hole Oceanographic Institution, Cornell University, and elsewhere where programs are underway to link the application of terrestrial and aquatic ecological theory to the needs of applied ecologists, working on problems of long-term sustainability of the biosphere [*e.g.*, Scripps Institution of Oceanography; Old Dominion University; Ministry of Agriculture, Fisheries, and Food (MAFF), Fisheries Laboratory, Lowestoft; Plymouth Marine Laboratory of the Natural Environment Research Council and the Sir Alister Hardy Foundation for Ocean Science, Plymouth; University of California at Davis; Food and Agriculture Organization (FAO); Intergovernmental Oceanographic Commission (IOC); Danish Institute for Fishery and Marine Science; POLARMAR; The World Conservation Union; Brookhaven National Laboratory; National Oceanic and Atmospheric Administration (NOAA)/ National Marine Fisheries Service (NMFS); and Environmental Protection Agency (EPA)].

TERMS OF REFERENCE

Terms of reference agreed to at the Paris meeting for the monitoring workshop included:

- development of strategies for monitoring the "health" of LMEs, and methods for comparing the relative health of LMEs;
- consideration for developing closer links to the international Global Ocean Ecosystems Dynamics (GLOBEC) Program and the research and monitoring efforts underway and planned for LMEs;
- review of the status of planning for LME regional workshops, and "twinning" projects between developed and developing countries;
- review of efforts by IOC to strengthen global ocean monitoring; and
- identification of funding sources to support extensions of present continuous plankton recorder (CPR) routes along with the organization of regional plankton sample-processing centers.

OBJECTIVE

This NOAA-sponsored workshop was convened to consider practical applications of state-of-the-art monitoring strategies, and to review state-of-the-art ecosystem theory and modeling, pertinent to the development and implementation of a "core" monitoring framework for LMEs.

PARTICIPATION

Twenty-six scientists from six countries and 19 institutions were present. The workshop agenda and list of participants is given in Appendix A. The venue at Cornell University was particularly advantageous, as several scientists who were involved in an intensive examination of "patchiness" in terrestrial and aquatic ecosystems, sponsored by the U.S. National Science Foundation (NSF) and other agencies, were also able to attend the monitoring workshop sessions.

ECOLOGICAL THEORY

Considerable discussion was focused on the application of ecological theory to issues relating to the research, monitoring, and management of LMEs. We are indebted to Tom Powell for his expert summary of the discussion on theory and LMEs.

HOLISTIC RESEARCH STRATEGY

Scientists increasingly recognize that ecological studies must be carried out in an ecosystem context. For example, fisheries studies that focus on single species do not account for compensatory changes in other species in the system, or for the modifications of the physical/chemical parts of the habitat. Moreover, we now know that ecotoxicological studies must focus on the fate and transport of materials within an entire ecosystem--not simply within an individual species or group of species. Note that traditional "lab-scale" bioassays can completely miss the essence of this effect.

A final, fertile example is provided by the growing interest in understanding the parallels and linkages between marine and terrestrial systems--studies that can only be carried out at the ecosystem level. We note parenthetically that professional organizations (*e.g.*, the Ecological Society of America) have begun to respond to these challenges by proposing research agendas for the next decade that incorporate this recognition.

ECOLOGICAL AND SPATIAL & TEMPORAL BIOPHYSICAL SCALES

The examples given above (plus many more) lead to two conclusions. First, investigations of biota (including especially information on individual species) **must** be performed in conjunction with studies of their physical and chemical environment; the two cannot be separated. Second, since physical and biological factors interact over a number of spatial and temporal scales, studies of pattern and process can proceed only if they incorporate investigations over multiple scales of space, time, and organizational complexity--and the physical and biological scales must be matched. Some of the ramifications of these two conclusions are not trivial.

Range of Studies

For example, future studies will have to extend over a very large range of spatial scales; *i.e.*, to include aggregation and patchiness at smaller scales, up to whole continent/ocean basin phenomena at large scales. Further, since the variations in physical processes are not merely random, but have more variance at low frequency (*i.e.*, the processes are said to have "red" spectra), as we extend our efforts to understand responses to longer time-scale fluctuations (*i.e.*, global-scale responses to climatic change), we should expect to find large shifts that we could not have anticipated by merely extrapolating our experience from shorter time-scale studies. This is a point that John Steele has been directing us to acknowledge for nearly a decade. Moreover, we will be forced to understand simultaneously the behavior of individuals, as well as the resultant responses of populations and communities.

Modeling Studies

Excellent examples come from the model studies of E. Hofmann and her students that link circulation models, detailed population biology, and individual behavior. Note that this is the use of theory at a still-different level--the level of the individual and, in Hofmann's case, how they exploit patches.

Finally, the comparison of physical and biological processes in both marine and terrestrial studies leads us to some generalizations about the state of our knowledge of both types of systems. First, classical ecological theory (and most terrestrial ecology) has ignored both the physical component and the spatial context of most ecosystem processes--areas in which oceanographic studies excel. Note further that the insights of food-web theory are little appreciated in oceanography, but, perhaps, one reason for this neglect is that food-web theory ignores the consequences of dynamic details in the statistical laws it provides. On the other hand, oceanographic studies have drawn little insight from evolutionary theory that derives largely from terrestrial studies. Surely some cross-fertilization is desperately needed.

LME Linkages

The theoretical and modeling subgroup (T. Powell, S. Levin, J. Steele), in their summary to the participants, argued that ". . . the Large Marine Ecosystem provides an unparalleled opportunity to broaden oceanographic and fisheries studies, and to build linkages between marine and terrestrial systems. We believe further that long-term empirical and monitoring studies have important insights for theoretical investigations; and, moreover, that together with such long-term initiatives, ecological theory can be utilized for management objectives."

MONITORING

BACKGROUND

Following the discussions on the status of ecological theory and modeling, several long-term monitoring programs were examined as case studies from which to apply pertinent strategies and technologies to an LME core monitoring program.

A limited time-space scale approach to marine ecological studies does not provide the kind of information required to manage LMEs. The CPR strategy was presented by R.R. Dickson. Examples were given of seven proposed global ocean problems for which the CPR strategy can provide important information on ecosystem productivity: (1) El Niño and eastern Pacific; (2) coastal upwelling and climate change; (3) Arabian Sea productivity and changing monsoon; (4) carbon dioxide drawdown and global warming; (5) cod and climate; (6) abnormal plankton blooms and avoidance of grazers; and (7) routine surveys.

CPR SAMPLING STRATEGY

This discussion was followed by a review of advanced CPR technology and a description of major ecosystem studies in which plankton monitoring using the CPR system is of crucial significance (Dickson 1991). These studies include:

- LMEs;
- Coastal Ocean Observing System/Global Ocean Observing System (GOOS) of the Intergovernmental Oceanographic Commission, the United Nations Environment Program, and the World Meteorological Organization;
- Ocean Margin Exchange Experiment of the Science Council of the European Community; and
- GLOBEC Program of the Scientific Committee on Oceanic Research and the Ocean Sciences and Living Resources Program of the IOC.

Options for implementing CPR coverage on a regional LME basis and on a global basis were reviewed. General consensus was reached on the utility of the CPR sampling strategy for LME monitoring effort. Several different kinds of CPR sampler configurations, including the instrumented standard 10-m CPR, and the instrumented undulating oceanographic recorder (UOR) (Appendix B), were reviewed with regard to the appropriate sensor packaging and deployment array.

It was agreed that instrumented CPR samplers and UORs would provide suitable sampling systems for measuring long-term trends in the productivity and physical characteristics of LMEs, and further, that expansion of CPR coverage of open-ocean seas should be encouraged as the deployment in the open ocean will provide information on productivity and species composition that will be of significant aid to understanding the plankton variability within LMEs, and essential for adding "zooplankton" to our current satellite-based estimates of net primary production at ocean scales.

CPRs FOR MONITORING LMEs

The group agreed to maintain contact with regard to the possible modifications to the draft document tabled by R.R. Dickson, "Monitoring the Health of the Ocean: Defining the Role of the CPR in Global Ecosystems Studies," based on the deliberations of the workshop participants (Dickson 1991). It was further agreed on the urging of K. Vagn Hansen to expedite changes to the document relative to the IOC Executive Council meeting scheduled for March 1992, and to a possible proposal to The World Bank for supporting prototype LME monitoring operations in the developing countries. Important considerations are the training component for new users of the CPR technology, and the need for establishing regional laboratories for servicing the instruments, processing the data, and analyzing the results.

Preliminary discussions along these lines have already been held with interested scientists in both developed and developing countries. Further dialogue will have to proceed as soon as possible to ensure that the proposal for LME monitoring is completed and submitted to The World Bank on schedule. T. Laughlin of NOAA's Office of International Interests will be serving as the principal contact on this matter, and he will maintain close liaison with R. Dickson, K. Vagn Hansen, J. Alheit, and other interested workshop participants over the next several weeks.

CalCOFI

The discussion on the California Cooperative Oceanic Fisheries Investigation (CalCOFI) time-series was led by M. Mullin. Considerable interest was centered around the opportunities presented by retrospective analysis of sediment cores in relation to natural variability of the California Current Ecosystem.

In response to questions on the utility of the CalCOFI effort, M. Mullin cited the use of ichthyoplankton data in managing both the anchovy, and more recently, the resurgent sardine fisheries. The time-series has also provided the basis for recognizing the importance of advective processes in shaping the seasonal and annual patterns of zooplankton abundance within the California Current Ecosystem because complete hydrographic measurements were made as well as plankton collections.

Some consideration was given to the relationship between process-oriented mesoscale studies and the long-term monitoring effort designed to observe changes in the demography of plankton species. The new funds being made available for process studies in relation to climate change and recruitment are likely to be more productive when nested within an ecological CalCOFI-type time-series, than in areas that are less well-known.

In addition to the pelagic effort of CalCOFI, the NMFS Southwest Fisheries Science Center has initiated studies of the demographies of coastal bottom fish, thereby enlarging the scope of time-series sampling within the California Current Ecosystem. Also, the southward extension of plankton monitoring from the CalCOFI box toward the west coast of South America is envisaged by Dickson (1991) in order to assess the full spatial coherence of changes in the planktonic ecosystem of the East Pacific.

FISH SURVEYS

J. Pope provided several excellent examples of how fish survey data and historical catch records can be used to assess changes in the demersal and pelagic fish communities of the North Sea. The application of the MAFF's demersal surveys was prompted by successes of bottom trawl surveys in the Gulf of Thailand and Northeast U.S. Shelf Ecosystems.

It was emphasized that in developed countries, research vessels are the best platforms for conducting the survey. In developing countries where funding limitations may be a constraint, it is possible to conduct groundfish surveys using relatively small vessels, thereby reducing operating costs associated with the operation of large research vessels.

Various size-based indices were presented that can serve as the basis for comparing different states of fish population and communities within LMEs. In addition to sampling the stocks with nets and acoustics for abundance estimates, sampling protocols should include fish collections for age and growth information, and stomach sampling for predator-prey and general ecological information, to provide a basis for monitoring trends of both economically important and ecologically significant species. Biological sampling should include collections for pathological examinations.

MARMAP

The Marine Resources Monitoring, Assessment, and Prediction (MARMAP) study of the Northeast U.S. Shelf Ecosystem was described. Evidence, based on multidecadal time-series of measurements of the fish, plankton, and physical oceanography of the system, implicated predation and excessive fishing effort as major factors in the large-scale shifts observed in both the pelagic and demersal fish communities. Subsequent to the late 1960s, when the monitoring effort was well established, it has been possible to identify the major causes of the observed flips occurring in the populations of the dominant fish species.

It has been possible to initiate and maintain a balanced monitoring effort that encompasses the major ecosystem components (*e.g.*, plankton, fish, mammals, birds, physical oceanography) for several decades. Present process-oriented studies are focused on gadoid recruitment, in cooperation with NSF's GLOBEC Program (the U.S. component of the international GLOBEC Program) and with NOAA's Global Climate Change Program. Based on the results of MARMAP monitoring, a projection was put forward listing the key ecosystem components to be measured as part of a core monitoring program for LMEs (Tables 1 and 2).

Table 1. Candidate parameters for the core marine ecosystem monitoring program based on samples, measurements, and observations collected during transect sampling with UORs or instrumented CPRs, supplemented by satellite measurements

Chlorophyll fluorescence[a]
Primary production[a,b]
Diatom/flagellate ratio[a]
Zooplankton composition & biomass
Copepod diversity[a]
Salinity structure[a]
Nutrients, including NO_2 as well as NO_3[a]
Pollution index (*e.g.*, hydrocarbons, sewage)
Temperature structure[a]
Stratification index[a]
Transparency[a]
Photosynthetically active radiation[a]
Rainfall or runoff
Wind strength & direction

[a] From UOR/instrumented CPR sensors.
[b] With a double-flash pump and probe system.

Table 2. Candidate parameters for the core marine ecosystem monitoring program based on samples, measurements, and observations collected during systematic bottom trawl and pelagic acoustic surveys

Stock assessment & biology	
	Distribution
	Abundance
	Length
	Age & growth
	Predator-prey interactions
	Gross pathologic conditions
Physical oceanography	
	Temperature
	Salinity
Chemical oceanography	
	Water samples for nutrients, productivity, & pollutants

STATUS & TRENDS AND EMAP POLLUTION MONITORING PROGRAMS

A. Robertson presented a brief on the NOAA Status and Trends Program which is focused on measurements of pollution effects on living marine resources, including bivalve mollusks and demersal fish. Concentration levels of toxic compounds are greatest in coastal waters adjacent to urban centers. Studies are continuing on development of diagnostic probes for monitoring the physiological condition of marine organisms.

J. Paul described EPA's Environmental Monitoring and Assessment Program (EMAP). The effort is designed to assess the stress levels of pollution on biological communities within the nearshore margins of LMEs along the eastern seaboard. The program will monitor contaminant loadings in organisms, sediments, and the water column. It will be conducted in cooperation with NOAA and the coastal states.

M. Fogarty closed the day's proceedings with a fine presentation on efforts underway to examine "Uncertainty and Risk in an Exploited Ecosystem." He concluded his remarks by advising the group that: (1) management options will continue to be attended by uncertainty, and (2) levels of uncertainty can be reduced through a better understanding of the recruitment process in marine fish populations.

CORE STRATEGY

The discussions on monitoring were open and probing. The importance of monitoring LMEs with a core strategy of linked components, including productivity at different trophic levels as well as associated physical and pollutant-related parameters, was underscored by several participants. This strategy is based on the need for providing a key suite of multiple parameters to allow for the identification of the effects of human interventions and natural processes on variability and perturbations in productivity, biomass yield, biodiversity, and health of LMEs.

PRODUCTIVITY CORE

The use of the CPR sampling strategy for monitoring changes in the plankton component of LMEs was shown to be effective, even for certain species of dinoflagellates, and to have enough spatial resolution to focus on the location of such changes, and thus to aid their interpretations.

The sensor options and sampling profile configurations for CPR systems now available for deployment in long-term monitoring programs have increased during the past decade to augment the standard 10-m instrument with sensors for chlorophyll, conductivity, temperature, irradiance, hydrocarbons, and nitrate-nitrite. This sensor package is also available for deployment in an undulating towed body which covers the upper 70 m of the water column in a continuous undulating pattern.

Interest has been expressed for continued deployment of the standard 10-m plankton recorder as part of the GOOS strategy. The deployment of an instrumented CPR has shown promise for advancing the understanding of biological and physical linkages important to fisheries, pollution, and coastal zone habitat studies. Notably, the extensive use of the CPR provides the potential to add an estimate of zooplankton grazing to current satellite-derived estimates of net primary production, so that the large-scale assessment of apparent phytoplankton growth rate seems possible.

Some concern was expressed in relation to the difference in cost between the instrumented, fixed-depth CPR and the undulating CPR. Greater costs are associated with operating the undulating instrument because it requires more attention during sampling. The advantages of simultaneous measurements of plankton and environmental variables were considered cost effective.

The question of importance of nutrient monitoring in relation to growing interest in eutrophication and its causes and extent in LMEs was addressed. It was pointed out that information on eutrophication could be monitored effectively with a "pump and probe" fluorometer system developed by the Ocean Sciences Division of the Brookhaven National Laboratory. The present pump and probe system, designed for buoy deployment, is being reconfigured to be carried in a UOR, providing the possibility for obtaining direct measurements of chlorophyll and primary productivity at depth. This development represents the potential for a major breakthrough in biological oceanography, allowing for the bypassing of calibration difficulties with other primary productivity methods. The UOR deployment, augmented by instrumented buoys for productivity and nutrients at the offings of major land-based inflows to LMEs, appeared to be a useful monitoring strategy for plankton and eutrophication.

FISH SURVEY CORE

At the upper trophic levels, the case was made very well by J. Pope and others to include a fish survey component module for monitoring fish populations and their environments. For developing countries, it was recommended that small vessel operations were likely cost effective in nearshore waters. The FAO experience in Uruguay, where the fish survey was augmented by a commercial operation that placed the activity on a profit or break-even economic base, is a case worthy of further examination.

The fish survey would provide, among the sampling suite, information on length frequencies which appear to hold promise as a means for comparing the changing states of fish communities among LMEs (*e.g.*, Northeast U.S. Shelf Ecosystem). Other important measurements to be made on the fish monitoring survey would include observations on fish pathology and stomach contents to extend the information base on pollution effects and multispecies trophic interactions within the LME.

Monitoring of fish biomass is an obvious and essential component of any adequate measurement of the health of LMEs. Fishing surveys (usually trawl surveys) are often the most straightforward, simple way of providing such a monitoring of both commercially important and noncommercial fish species. They have a proven track record in the North Atlantic and have also been used successfully in tropical areas, notably in the Gulf of Thailand. We would, therefore, see such surveys as a rational component of a core monitoring program.

In Third World countries, such surveys would provide information on changes in fish communities and their environments which is of local as well as global value. They would, however, probably need to be supported by suitable funding packages to cover running cost, gear cost, and data archiving, plus training and data analysis. Suitable vessels for conducting such surveys are usually similar to local fishing vessel types rather than large, expensive, general-purpose research vessels. Long-term chartering of fishing vessels may provide a possible alternative to dedicated research vessels.

Fish surveys often have an added advantage of providing a platform for other environmental monitoring. The global value of such surveys could be enhanced by intercomparisons between systems. The development of a suitable coordinating group for such comparisons would serve to further this work.

FISHING SURVEY TIME SERIES

J. Pope kindly provided the participants with the design requirements of a fish monitoring survey for LMEs. The remainder of this section provides background on these requirements.

Repetitive fishing surveys provide a straightforward way of monitoring the changing biomass of fish in areas of the scale of LMEs. The essence of all such surveys is the link between survey catch rate [U(y)] and fish biomass [B(y)] in a year:

$$U(y) = qB(y)$$

where q is the catchability coefficient. The essential requirements are that q is nonzero and is not biased between years (and--preferably--through space), and that its variance is appropriate to the purposes of the monitoring process. These requirements are most simply achieved through research-vessel-based groundfish surveys using standard trawls in a standard sampling design, which is repeated over a number of years. For example, the North Sea survey is standardized using the same research vessel and a standard Granton trawl fished at the same fishing positions in the same month each year.

Where the surveys are to be used for short-term management advice, such as in catch quota estimation, the requirement for precision of q is exacting and the needs for standardization correspondingly stringent. Where the requirement is for a more general monitoring of biomass, the precision requirement may be less exacting, and, for example, the strict requirement of the same research vessel might be relaxed. Major sources of bias, however, still need to be strenuously avoided if the results of the monitoring are not to be confused by systematic changes in method through time.

Given that these design requirements are met, fishing surveys prove to be a powerful means of monitoring fish biomass in a number of areas. The surveys of Georges Bank, the Gulf of Thailand, the North Sea, and surveys of the Canadian Atlantic Shelf, for example, have provided valuable trend monitoring of these systems through natural and fishery-induced changes. Their particular value is in monitoring trends in space and time of noncommercial fish species as well as commercial species, thus providing information of the development of much of the fish biomass of an area.

These surveys have an as-yet-unrealized potential for providing comparisons between LMEs. Most imply this may be done by comparing properties such as size distributions, but a more thorough intercomparison would almost certainly yield additional insights. For example, different demersal catch rates (and presumably biomass per unit of area) between the North Sea on the one hand, and the Irish Sea, Celtic Sea, and Bay of Biscay on the other hand, indicate important differences between the systems in these areas. A widening of these comparisons would certainly be interesting and illuminating.

SEMI-ENCLOSED LMEs

A discussion on the importance of comparative studies among semi-enclosed LMEs was led by J. Caddy who kindly provided a summary of the discussion on this topic.

The LME concept, as it has developed, has acquired a broad inclusive content, including large marine systems with different characteristics, particularly with respect to the predominant source of nutrients. To a significant extent, however, developing a monitoring strategy depends on proper classification of the LME. Among these categories may be included river-driven shelf systems (*e.g.*, Bay of Bengal, South China Sea) and semi-enclosed seas. Both of these systems are particularly vulnerable to anthropogenic effects, and it would be misleading to consider "terrestrial" effects such as nutrient, silt, and toxic chemical runoffs to be extrinsic to the marine system being studied or modeled.

There has been a tendency to refer to the semi-enclosed seas as "marine catchment basins," reflecting the reality that factors such as land-use practices, human population density, industry, *etc.*, distant from the semi-enclosed sea, are having a profound influence on events in the "marine" system. Many of these issues were addressed in the report of the EMELS '90 symposium held in Kobe, Japan (see recent special issue of *Marine Pollution Bulletin*).

Events in semi-enclosed seas such as the Mediterranean, Seto Inland, Yellow, and Baltic Seas indicate that such areas are moving, or have already moved, into heavily stressed conditions which may be anticipatory to harmful impacts on coastal water masses subject to river and land inputs. Other systems, such as the Black Sea, have apparently reached a state where their capacity to provide sustainable yield of living marine resources is already in doubt, and the priority of monitoring programs is to measure movements along the gradient "oligotrophic and eutrophic," and hopefully, in the future, to measure the positive effects of system rehabilitation.

In practice, it seems that four main effects need to be considered for the semi-enclosed seas:

- removal of apex predators;
- accumulation of nutrients and other materials, especially where input is not exceeded by flushing and

anoxic effects;

- fishing intensity; and
- introduction of exotics and the replacement of "native" species as new niches are created.

Measuring fishery-related parameters in semi-enclosed seas will continue to be essential, but should be aimed also at monitoring biodiversity and recording appearance of "exotics" that indicate qualitative changes in the benthic, demersal, and pelagic subsystems. The importance, however, of combining fishery data with environmental parameters in a common monitoring and modeling framework seems essential and will require interdisciplinary work between a wide range of scientific specialists. This should be done in a comparative way, for example, between institutes studying different semi-enclosed large marine systems.

CORE MONITORING STRATEGY

The workshop participants reached consensus on a long-term (decadal), large-area, core monitoring effort for LMEs:

- A CPR/UOR sampling strategy should be employed to measure variability in LME health. Such a program will provide useful knowledge on marine pollution, fisheries, and coastal zone management.
- The CPR/UOR sensor package should include components for measuring: zooplankton in terms of species composition, biomass, biodiversity, and size; phytoplankton in terms of species composition, biomass (as chlorophyll), productivity (using a pump and probe sensor), diatom/flagellate ratios, and size; salinity; temperature; hydrocarbons; light; and oxygen.
- A small-coastal-vessel sampling program, using nets, acoustics, and other appropriate gear, should be employed to: measure species abundance, biodiversity, and stock levels; gather data on fish age, size, and growth; gather data on predator-prey interactions from stomach sampling; make observations on gross pathologic conditions; obtain simultaneous measurements of temperature and salinity; and sample for pollutants and photograph macrobenthics on an opportunistic basis.
- Satellite images should be used for characterizing water mass movements. Sea-sampled chlorophyll and temperature data should be used for satellite cross-calibrations.
- For monitoring inshore-offshore extensions of nutrients and eutrophication, a system of towed CPRs and--where possible--moored buoys should be employed for collecting chlorophyll and productivity data.

ESTABLISHING THE CONCEPT

Outreach and education should be pursued by:

- establishing regional CPR/UOR plankton identification and data processing centers, including facilities for training;
- convening regional workshops, based on initial development of relevant background papers, for developing-country scientists, managers, and students; and
- encouraging support for institutional development.

LME AND OPEN OCEAN/GLOBAL OCEAN OBSERVING SYSTEM

The linkage between LMEs and global-scale oceanwide processes could be accomplished by using the CPR sampling strategy to support inter- and intra-LME ocean variability observations to be collected by GOOS as now under consideration by the IOC.

RECOMMENDATIONS

The participants agreed that much-needed, long-term monitoring studies should be organized at three levels of activity; certain efforts should begin without further delay. Reliable instruments presently exist for this purpose. Continuous plankton recorders instrumented to collect zooplankton, phytoplankton, and other major ecosystem components, and fitted with sensors to measure temperature, salinity, chlorophyll, depth, and--perhaps soon--primary productivity and light, can be purchased at relatively modest expense. These instruments have a history of reliability in numerous deployments. They will be particularly appropriate for describing individual events (*e.g.*, productivity trends, biomass yield trends) and summary statistics such as spectra or empirical orthogonal functions.

Second, within a matter of years, everyday monitoring with "today's" research gear can become a reality. The participants recommended that development of this capability--with a target deadline of 2-3 years--be initiated at the same time, and further, that these instruments (*e.g.*, acoustic sensors, moored instruments such as fluorometers and acoustic doppler current profilers), which will soon be readily available for any user, be deployed as soon as possible in selected LMEs. The use of coupled circulation-biological models that update their predictions and interpolations by assimilation of both physical and biological data will soon be a reality for many parts of the world ocean. Before such techniques can be incorporated into a stand-alone monitoring system, extensive tests will be necessary.

New instrumentation may provide major breakthroughs in long-term monitoring of coupled biological and physical quantities. Sensors for such tasks are not now available, but planning for their development and deployment in monitoring efforts should begin immediately. Such new measurements might include molecular "tags" for taxonomic identification as well as physiological rates. New acoustic devices are also on the horizon. Finally, the collaboration with planned process studies, such as GLOBEC and the Joint Global Ocean Flux Study, should be explored in this "new measurement" initiative.

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APPENDIX A

LME MONITORING WORKSHOP AGENDA AND PARTICIPANTS

AGENDA

Topic	Speaker
SATURDAY, 13 JULY	
Morning Session	
Ecosystem Theory	Discussion Leaders
Options for Sustaining Biomass Yields in LMEs	S. Levin
Scale Selections for Biodynamics of Marine Ecosystems	J. Steele
Physical Dynamics of LMEs	J. Powell
Afternoon Session	
Ecosystem Monitoring	Discussion Leaders
CPR and Ocean Climatology	R. Dickson
CalCOFI Time Series	M. Mullin
MARMAP Time Series	K. Sherman
Lowestoft Time Series	J. Pope
Semi-enclosed LMEs	J. Caddy
Uncertainty and Risk in an Exploited Ecosystem	M. Fogarty
SUNDAY, 14 JULY	
Morning Session	
Review of Ecosystem Theory and Monitoring	
State-of-the-Art Theory	
State-of-the-Art Monitoring	
Brookhaven Pump-and-Probe System for Measuring Chlorophyll and Primary Productivity	P. Falkowski
NOAA's Status and Trends Program	A. Robertson
EPA's Environmental Monitoring and Assessment Program (EMAP)	J. Paul
Drafting of Core Monitoring Strategy Summary and Risk Assessment Recommendations	
Afternoon Session	
Review of Draft	
Adjourn	

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APPENDIX B

LME MONITORING WORKSHOP BACKGROUND DOCUMENT: ENVIRONMENTAL MONITORING FROM MERCHANT VESSELS

LME MONITORING WORKSHOP
Cornell University

JULY 13-14, 1991

BACKGROUND DOCUMENT

ENVIRONMENTAL MONITORING FROM MERCHANT VESSELS

by

Robert Williams
Plymouth Marine Laboratory

July 10, 1991

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ENVIRONMENTAL MONITORING FROM MERCHANT VESSELS

1. INSTRUMENTED CONTINUOUS PLANKTON RECORDERS

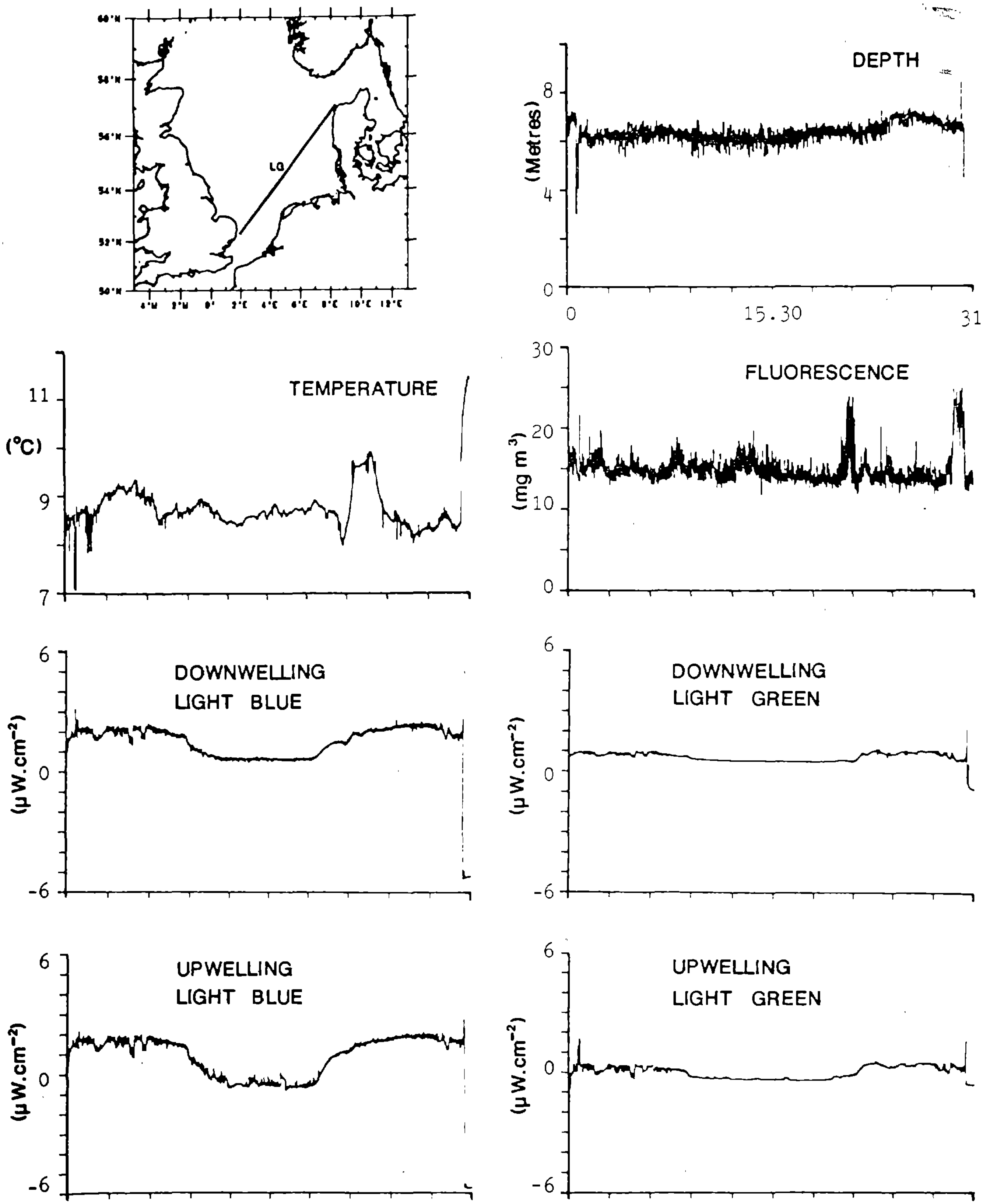
The Continuous Plankton Recorder (CPR) was designed as a plankton sampling instrument to be towed behind merchant ships at a constant depth of 10m on regular routes without the need for the presence of a scientist or techinician.The towed vehicle is about 1m long and weighs approximately 66kg. The CPR survey was started in 1931 by Professor (later Sir Alister) Hardy at the University College of Hull and was later transferred to Edinburgh before finally moving to Plymouth. The plankton survey is now run by the Sir Alister Hardy Foundation for Marine Science based at PML.

For many years no physical measurements were taken with the CPR and this has imposed limitations on the interpretation of the plankton data. Recording thermographs measured temperature on selected routes during the 1960s and early 1970s and these were superceded by electronic systems logging the data on a tape cassette. Now the development of a variety of sensors and the availability of solid state data loggers has made it possible to measure and record a variety of environmental variables simultaneously with the plankton sampling. The data are used to interpret the results of plankton sampling and as valuable basic data for monitoring the ever changing conditions in the sea.

At present the system can measure pressure (which gives depth), temperature, conductivity (from which salinity can be calculated), chlorophyll concentration, upwelling and downwelling light at 2 wavelengths (450nm and 550nm, i.e. blue and green) and turbidity. A total of 16 channels are available, so additional sensors could be added. The logger can accommodate 256,000 measurements which can be taken at predetermined intervals of 1, 2, 3, 4, 5, 6, 10, 12, 15, 20, 30 or 60 seconds and the battery life is about 30 hours. The sensors and data logger are automatically switched on and off by contact with the sea water.

The CPRs equipped with the solid state data logger and associated sensors have been deployed on a regular basis on routes from Grimsby to Aberdeen and from Aberdeen to Stavanger since 1988 and on routes from Aberdeen to Lerwick and from the southern North Sea to the Kattegat for part of this period. The deployment of the electronic data acquisition equipment with CPRs is part of the PML programme in co-operation with the Sir Alister Hardy Foundation for Marine Science. PML gratefully acknowledge the willing co-operation of the owners, agents, masters and crews of the ships which tow the CPRs which make this work possible.

C.P.R. SURVEY MAY 1989 'LG' ROUTE



CPR TOWS

OCTOBER 1990

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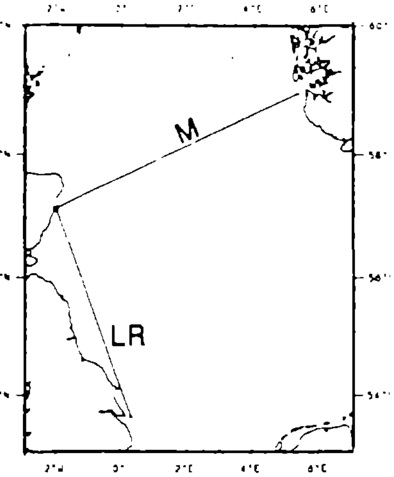
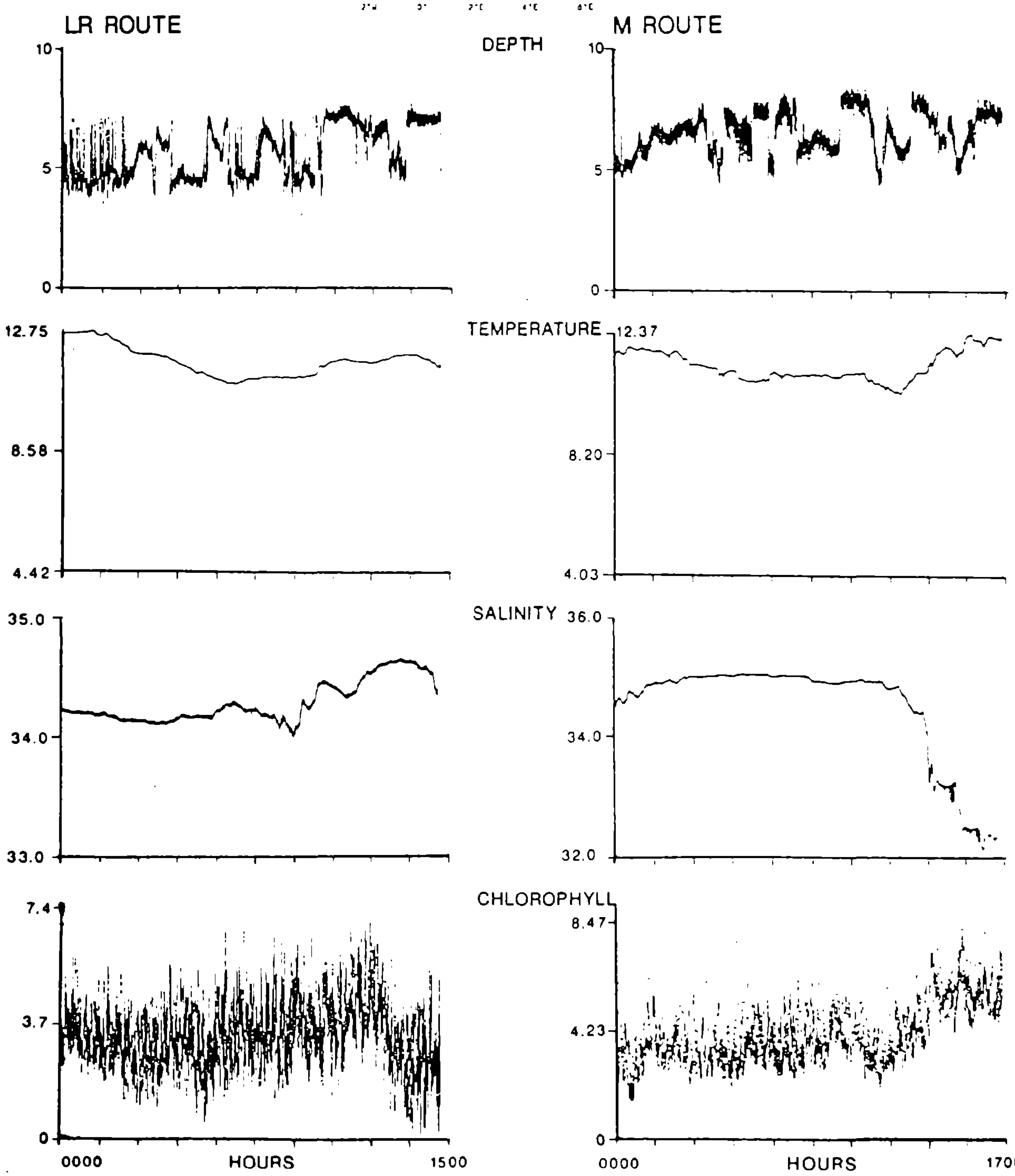
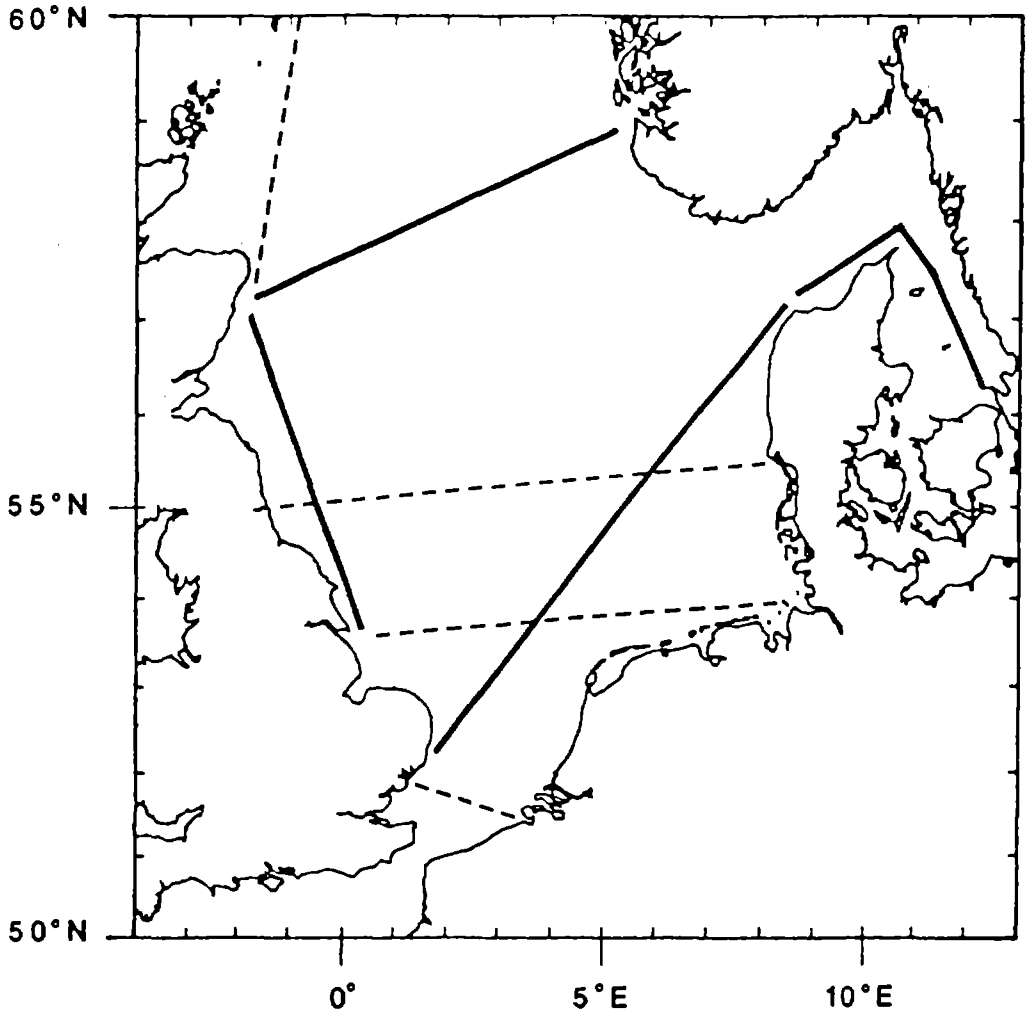
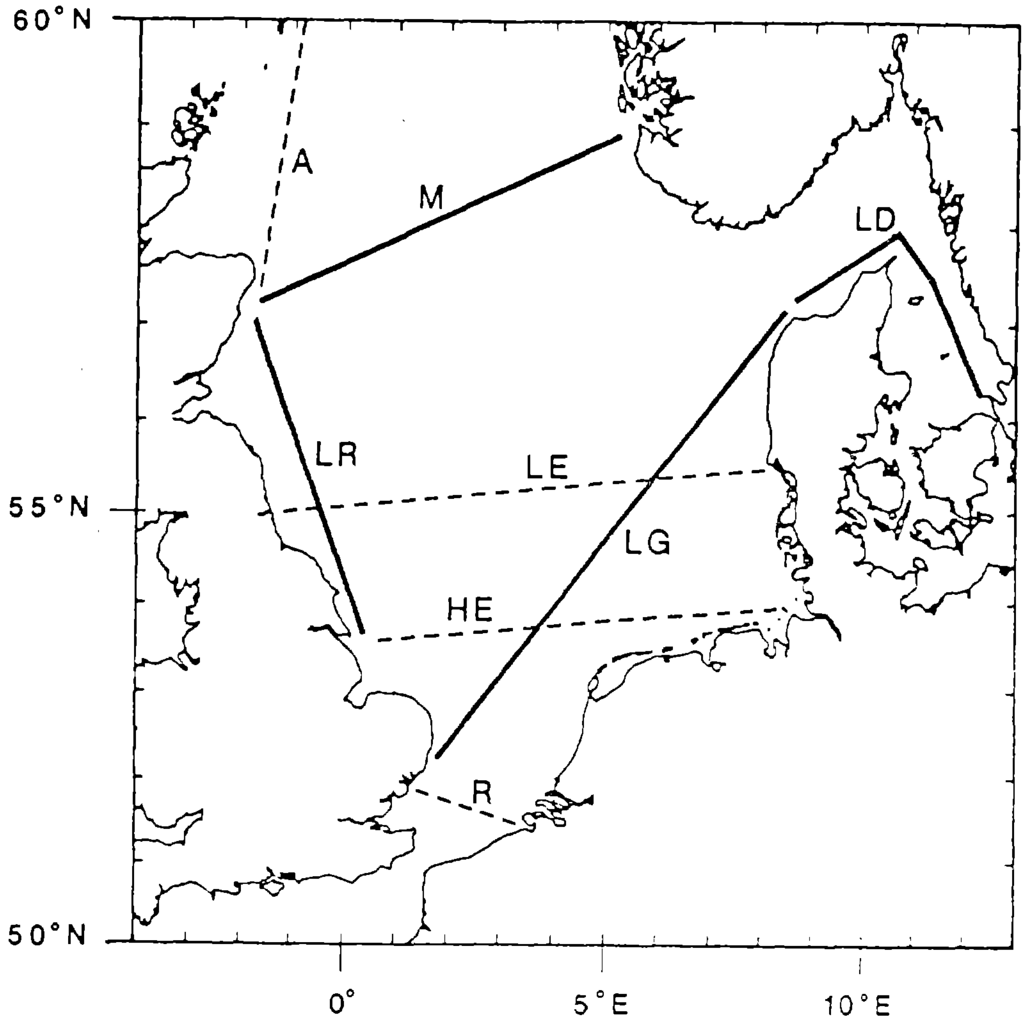






Continuous Plankton Recorder routes in the North Sea. CPRs with instrumentation are shown as a solid line, those without as dashed lines.



PLANKTON SAMPLING WITH THE CONTINUOUS PLANKTON RECORDER IN THE NORTH SEA DURING 1990. THE SOLID LINES ARE THE ROUTES WHICH CARRY INSTRUMENTATION... TEMPERATURE, DEPTH, CHLOROPHYLL, CONDUCTIVITY, TURBIDITY AND IRRADIANCE SENSORS FOR UPWELLING AND DOWNWELLING LIGHT.

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(continued from inside front cover)

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