Biological Observations of the Global Ocean: Requirements and how to meet them

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Organised by

***The Partnership for Observation of the Global Oceans* (POGO)**

and

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1. *Introduction*

The ocean carbon cycle cannot be understood without information on the biologically-mediated transformations and transport of carbon within the ocean. In addition to carbon dioxide, biological processes also affect the cycles of other green-house gases such as methane. We have much to learn of the role of the ocean biota in climate change. We also have very little understanding of how marine life will be affected by, and respond to, global change.

The signatories to the UN convention on biodiversity have an obligation to monitor the biodiversity of various environments. However, the commitment to record marine diversity lags far behind the required level.

Collapsing fisheries and disappearing stocks of living resources from the ocean have highlighted the need for sustained, scientific management of fisheries and other living resources. Reports of coral reefs under threat have highlighted the fragility of marine ecosystems, and the need to understand them better, to serve the needs of conservation.

All these concerns argue for improved monitoring of marine life and their interactions with their physical and chemical environment. Yet, no system for sustained, long-term, monitoring of marine biota and biological processes is in place at the global scale. POGO therefore convened a Biology Meeting to explore the requirements of such an observing system, and to recommend step-wise and organised implementation of elements of such a system, through the POGO institutions.

The meeting was held in Dartington, Devon, England from 28-30 June 2001. Some seventeen scientific experts attended the meeting. They were invited for their leadership and active involvement in various international projects, as well as for their experience and expertise in techniques of biological observations in the ocean.

Members of the group were actively involved in programmes such as The Census of Marine Life (CoML), Surface Ocean – Lower Atmosphere Studies (SOLAS), Global Ocean Ecosystem Dynamics (GLOBEC) and Joint Global Ocean Flux Study (JGOFS). Some members of the Ocean Futures Committee set up by IGBP and SCOR to look at the future of ocean biogeochemical studies were also present at the table. Furthermore, operational programmes such as the Global Ocean Observation System (GOOS) and its Coastal Ocean Observation Panel (COOP) were also represented, as was the SCOR panel on Emerging Technologies. There were also representatives of POGO and the International Ocean Colour Co-ordinating Group (IOCCG). The above thus represent both widespread non-governmental organisations and programmes and inter-governmental ones linked to the UN system. The participants are listed in Appendix 1.

The experts were asked to identify what POGO can do to enhance the biological and biochemical complements to emerging and existing elements of a global oceanic observation system. In promoting and developing a biological complement to these elements, the participants were asked to give due consideration to several questions:

- Can the observational plans build on lessons learned from major international research programmes with a global perspective such as JGOFS and GLOBEC, and serve the needs of emerging programmes such as SOLAS and Census of Marine Life?

- From the plethora of measurements that are of interest to biological oceanographers, what elements can be selected reasonably to form the basis of a biological observational scheme implemented at the global scale?

- How can we reconcile the sometimes-conflicting demands of programmes interested in climate change and the carbon cycle, with those that are interested in issues related to biodiversity or fisheries management?

- Achieving global oceanic coverage of these observations requires the full participation of all coastal nations, including the developing countries. How can we address the limitations on observing systems imposed by the limited capacity in laboratories of developing countries?

- Any scheme for global observations must, of necessity, rely to some extent on remote and autonomous platforms. Yet, calibration of biological sensors is notoriously difficult. How can we ensure that biological and chemical sensors on remote platforms are calibrated to rigorous standards?

- How can we take advantage of new and emerging technologies for biological observations in the oceans?

- How can we ensure that *in situ* observations are tied in with remote observations of ocean colour from satellites, in a way that enhances and complements interpretations of the data and their applications?

- Interpretations of biological observations often require background information on the physical environment, and yet the time and space scales of interest to physical and biological oceanographers are not always the same. How can we reconcile these conflicts?

- What are the implications of the UN convention on biodiversity, for observations and study of marine life?

- How can we build the elements of a biological observation scheme on the recommendations of GOOS panels that have studied these issues?

During the three days of the meeting, the participants discussed what POGO could contribute towards achieving the requirements and goals of existing emerging biological programmes. Traditional and conventional observational techniques, as well as new and promising methods were discussed. The philosophy followed was that the proposed observations must serve the scientific and societal needs for large-scale ocean observations.

The observational requirements were discussed in the context of the vast size spectrum of marine organisms, which ranges from microbial organisms to fish and mammals. The need to record marine biodiversity and the functional diversity in marine organisms was examined. Various types of sensors designed for biological observations, and observation platforms were discussed, ranging from satellites, research vessels, autonomous underwater vehicles, drifting and moored buoys and underwater observatories. Methods that are ready for immediate implementation, and those that merit further development towards implementation in the short to medium term were also treated. Methods that provide low-cost measurements at large scales were given high priority in the discussions.

The need to have data management and distribution systems that are suitable to address the requirements of biological observations was also dealt with. In view of the POGO commitment to enhancing observations in the Southern Hemisphere, the special issues and requirements pertaining to the Southern Hemisphere were also examined.

A list of web sites that contain material related to the report is provided in Appendix 2.

2. Why should POGO take an active interest in this area?

Ocean sciences are now poised at a very important point in their evolution, when considerable attention and effort are being focused on establishing global-scale networks of monitoring systems. In this context, the emphasis is not on achieving short-term research goals: observational programmes to serve the needs of research goals are well left in the hands of individual research teams. However, it would be highly desirable that the observations made as part of long-term monitoring systems serve the needs of the research community. Nor is the goal here to monitor small parcels of the oceans to meet the local demands for management and conservation of the coastal environment: such monitoring programmes have been handled ably by individual institutions or by consortia of institutions with regional interests. The topic under discussion here is the creation of a global network of observations. This can only be achieved through world-wide collaboration among oceanographic institutions, with the capability to contribute to large-scale observations, and POGO provides just the right forum for such collaboration. It is of course recognised that the realisation of the goal of a global network of observations would also require that suitable links be made with other user groups and data providers as well.

The GOOS (Global Ocean Observation System) panels set up by IOC (the Intergovernmental Oceanographic Commission) provide expert advice on such matters, but the implementation of the panel recommendations must rely on the efforts of operating institutions of the world, and it is desirable that the efforts of these institutions be co-ordinated from the outset. POGO provides an opportunity for such co-ordination.

It is also worth adding, especially in the context of biological observations, that co-ordination must also include standardisation of methods, to facilitate integration and comparison. Again, POGO provides an avenue for such discussions on standardisation of protocols among leading oceanographic institutions. Thus, there is much that POGO can do to help with the implementation of GOOS.

Global-scale monitoring programmes of the type discussed here aim to achieve multi-decadal data, capable of discerning long-term trends and regime shifts. Such schemes must outlive the working lives of individual scientists. They must, therefore, of necessity, rely on the collective memory and effort of institutions. POGO provides the opportunity for institutions to work together towards this goal.

Attaining the global coverage envisaged here cannot ignore the practical difficulties imposed by the fact that two-thirds of the ocean is in the Southern Hemisphere and most of the institutions with major oceanographic capabilities are in the Northern Hemisphere. The plans to reach this goal must therefore include increased dialogue between the Northern and Southern Hemisphere, and capacity building in the South. Again, POGO provides an informal venue for promoting interactions between oceanographic institutions of the North and South, and for facilitating capacity building in operational oceanography.

3. Scientific and Societal Concerns

Any scheme to monitor the ocean biota and their environment must strive to address the major scientific and societal concerns of the day pertaining to marine life. This section summarises some major concerns that emerged during discussions at the meeting. Many other concerns could have been included, but space precludes a complete listing of concerns.

3.1. Biodiversity and Conservation

Marine biodiversity is not easy to assess and is generally poorly known. There are many complicating factors, including a three-dimensional, fluid, mobile environment, its vastness, and its challenging depths. Away from shore, primary producers and primary grazers are usually small, drifting forms that undergo spatial variability and seasonal changes. The larger invertebrate grazers have a range of life history stages, often with planktonic and benthic phases. Many large animals are migratory. Ocean habitats can be linked by the dispersal of planktonic larvae, and in this way, the systems can be interconnected even at a distance. Finally, the higher-order diversity of life is much greater in the oceans than in terrestrial systems—there are 13 unique phyla in the oceans and only one on land. Marine biodiversity is essentially the evolutionary history of life.

In general, long-term environmental stability seems to increase biodiversity and, conversely, global climate change can be expected to decrease it. Thus, changes in sensitive species maybe the first indicators of impact on ecosystems such as those in the deep sea. Human activities, such as fisheries, have reduced the biodiversity of marine systems in which they occur, especially in tropical waters. There is a global move towards marine protected areas to protect rare and endangered species as well as for general conservation of diversity. Marine protected areas also provide breeding reserves to improve fish stocks and aid the sustainable management of fisheries. Choosing and managing marine protected areas requires fine-scale biogeographic information. Oceanographic research with increased biological and spatial resolution is essential to serve this important need, and it would have a lasting and beneficial impact on society.

The Census of Marine Life, an international programme, has emerged to address this need to improve our understanding of marine biodiversity.

3.2. Sustainable Management of Marine Living Resources

In many places around the globe, governments and communities have had to deal with the consequences of collapsing fisheries and their socio-economic consequences. Renewed efforts have been made to improve our understanding of the factors that control the variability of fisheries resources and to arrive at better fisheries management strategies. The merits of alternative hypotheses ranging from overfishing to regime shifts are being re-evaluated. There has been increasing awareness that fisheries management has to be based on the structure and function of the entire ecosystem, rather than on just a single species or a few exploitable species. There is a strong call for responsible fisheries, managed in a way to preserve the integrity and functioning of the ecosystems that sustain them, but much work is needed to develop theory and techniques for managing fisheries in an ecosystem context.

3.3. Response of Oceanic Biota to Global Change

The structure and functions of the marine food web are intricately related to their environment: temperature, vertical stability, nutrient supply and light, for example. We know very little of how marine life will be influenced by, and adapt to, changes in their environment. These changes may be minor adjustments in some cases, and major regime shifts involving changes in species composition and foodwebs in others. The human dimension of these changes cannot be ignored, since they may easily impact on living resources from the sea.

3.4. Bio-invasion

This is an issue of global concern to all. Bio-invasion occurs when an alien organism is introduced into a new environment, and the ecosystem is modified significantly by the new species. The invading organisms in their native environment are usually in balance with their predators and are controlled by ecosystem interaction. However, in a new environment they can increase in numbers rapidly and can become pests out of control. One of the major pathways for marine bio-invasion is from ballast water discharge from ships and from hull fouling organisms. The advent of faster and larger ships has increased the chances of bio-invasion on a global scale. Two examples of bio-invasion are the black stripped mussel *Mytilopsis sallei* and the green crab *Carcinus meanas*. *Mytilopsis sallei* is a native of tropical and sub-tropical Atlantic waters, and invaded Indian waters in the 1960's. In addition to Mumbai and Visakhapatnam in India, it has also been reported in Hong Kong and Australia. The green crab, a native of Europe has been reported in Sri Lankan waters. There is currently no viable tool for the treatment of ballast water, or to avoid introductions by hull fouling organisms. Observations for invasive species must be at the species level to allow clear identification of the species involved and to allow differentiation from potentially similar native species in the region of the invasion.

3.5. Ocean Fertilisation

Since the 1990's, the increasing pressure from the public to consider the fertilization of the oceans as a viable possibility to increase the productivity of fisheries and for CO_2 mitigation has prompted the scientific community to consider the implications of such actions. In recent meetings between groups of scientists and entrepreneurs, it has become clear that the pressure to perform such fertilization by commercial enterprise is very high and that an objective scientific assessment of the possible consequences is urgently needed. At present we know very little of the long-term effects that could result from continuous or episodic fertilization of the ocean, although we have consistently observed short-term increases in primary productivity. However, recent studies have begun to throw light on what may happen on the long-term. It has been suggested that the system would reach a new steady state in which primary production is much lower than the magnitude of the initial increase in production, through a more rapid recycling of the particulate material. It is the responsibility of scientists to provide guidance to the best of their knowledge on issues such as this, which can have a major and lasting impact on life on this planet. The quality of the advice that scientists can provide in such situations would of course be compromised in the absence of sufficient appropriate data collected over long duration.

3.6. Threatened Habitats

Habitats in the marine environment are being lost and modified as a result of the direct and indirect impacts of human activity. The loss of habitats can result in significant losses of biodiversity and is of serious concern worldwide. For example, ecosystems of coral reefs are considered to be "biodiversity hot-spots', and are of concern to over a hundred countries around the globe. It is estimated that 60% of coral reef ecosystems have been seriously damaged due to increased sedimentation and nutrients from land-based sources, algal overgrowth and the exploitation of coral-reef species, for example finfish catches. There is a need to monitor coral reef and other endangered habitats such as mangroves. There are programmes for several key habitats that have been developed to form global monitoring programmes. For example, the Global Coral Reef Monitoring

Network programme (GCRM) for coral reefs and the sea grass monitoring network (SEAGNET) for monitoring sea grass beds globally are designed to monitor two types of threatened marine habitats.

4. Scientific Issues and Rationale

Monitoring programmes are largely driven by practical issues and applications, rather than by scientific questions. However, given the tight financial constraints in which oceanographers operate, observations garnered through monitoring programmes must also serve the research community. Long-term monitoring would provide a two-fold service to the research community: (i) establishment of a skeleton of basic observations, on which individual research teams can add additional detailed observations to serve the research objectives; and (ii) provision of long-term observations with a longer life-span than those of individual research programmes. Therefore, some major scientific issues of the day were also discussed at the Dartington Meeting. These could be broadly classified into three categories. Each of these major issues is briefly outlined below.

4.1. Global Change and Carbon Cycle

The scientific community is well aware of the importance of the oceanic biota in the global carbon cycle. Biota play a central role in three of the four mechanisms involved in carbon fluxes in the ocean: the "biological pump", involving photosynthetic uptake of carbon and its transfer to deep water, the "carbonate pump" involving coral reefs and coccolithophores in the plankton, the "continental shelf pump" on continental shelf margins, and finally the physical "solubility pump". Recognition of the importance of biota in the global carbon cycle gave impetus to major international initiatives such as the Joint Global Ocean Flux Study (JGOFS). The need to understand how various marine ecosystems respond to global change has led to other international programmes such as Global Ocean Ecosystem Dynamics (GLOBEC). A new programme, the Surface Ocean – Lower Atmosphere Studies (SOLAS) is just emerging, focussing on understanding the air-sea exchange of green-house gases, and the role of ocean biota in modifying and modulating these exchanges. A theme paper prepared by the Integrated Global Observation Strategy (IGOS) Partners recognises the need to establish a global network to monitor the global carbon cycle, including its oceanic component.

A joint SCOR-IGBP committee is now discussing the future of ocean bio-geochemical research, and this panel has identified three major issues in this area:

1. Transport and transformation of carbon in the ocean.
2. Carbon sequestration in the ocean.
3. The marine food web

The scientific community recognises interconnectedness of the three major issues identified. It is understood that the response of marine biota to global change and its possible impact on the carbon cycle will depend on the functional diversity of life in the oceans and the roles played by the entire food web, rather than just the microbial component. The importance of processes at depths in the ocean ("the twilight zone"), rather than just those in the near-surface layers is also recognised now.

4.2. Constraints on primary production and remineralisation

A major challenge in biological oceanography is to understand the constraints on primary production and on remineralisation in our oceans. These two processes are fundamental to understanding the role of the ocean on carbon cycling (see Section 5.1) as shown in Figure 4.2.1.

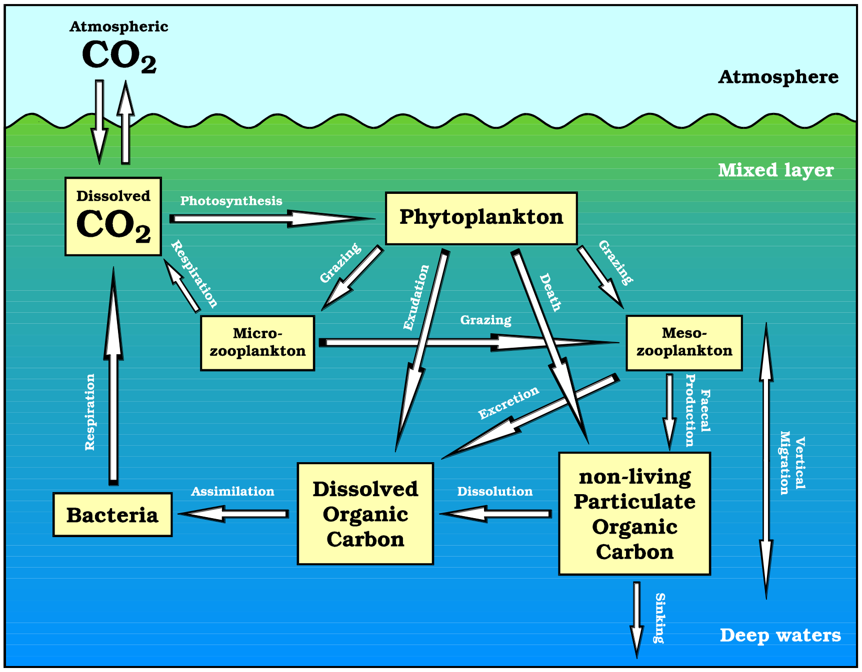

Fig 4.2.1 The relationship of phytoplankton growth and respiration to the carbon cycle

Primary production driven by photosynthesis results in the reduction in the ambient pool of dissolved CO_2 in the surface mixed layer (Fig 4.2.1). This pool is in equilibrium with that in the atmosphere and so is able to draw down CO_2 from the atmosphere. This results in the reduction in the atmospheric CO_2 concentration, with consequent effects on the Earth's "greenhouse activity". The constraints on the level of primary production involve factors that influence the specific growth and mortality rates of phytoplankton.

The factors that influence the specific growth rate of phytoplankton include the light fields, wind driven mixing rates and nutrient concentration. The factors that influence the mortality rates include grazing by protists and by larger zooplankton, and attack by viruses.

Remineralisation processes, including respiration, are influenced by the biomass concentrations of the plankton (bacteria, algae, protists and zooplankton), temperature, oxygen and organic substrate (DOC). Respiration processes will fuel the ambient CO_2 concentration with downstream potential to influence the “greenhouse Earth”.

In additional to the above is the increasing concern of whether the oceans are a net autotrophic or heterotrophic system. While there are many measurements of primary production on a global scale, the number of comparable measurements of respiration is significantly much lower. In the context Earth System Science, it is now important to have measurements of primary production and respiration that match synoptically.

The downstream issue passed on to POGO is the degree to which this can be achieved by “operational oceanography”.

4.3. Biodiversity and Ecological Function

As noted above, the functions of the marine biota are inextricably linked to the structure of the ecosystem. There is a need to improve our understanding of marine biodiversity and ecosystem structure and function, not just to satisfy our scientific curiosity, but also address pressing issues in other fields such as ocean biogeochemistry.

Such studies call for a return to traditional approaches for recording life, but we also need to cultivate new and emerging techniques. Studies of marine organisms are currently poised for a major change in approach. Traditional studies of marine organisms have involved their collection, preservation, and microscopic or taxonomic enumeration. The recent development of molecular technologies allows us to alter the focus and examine ecological functional groups within an ecosystem, particularly when examining planktonic species. The foci of the two approaches are fundamentally different. Traditional plankton studies tend to include a wide consideration of biodiversity and complexity whereas the requirements for biochemistry allow us to focus more closely on the function or functions of an organism. For example, we can use molecular probes to study organisms which are autotrophic, heterotrophic, produce dimethyl sulphide (DMS), assimilate DMSP, or fix nitrogen. We need to take advantage of the new techniques and undertake to develop these techniques so that they become routine and operational in the future.

It is important to note that there are also new molecular techniques that can be used in investigating biodiversity. These also need to be developed to make them useful in routine and operational measurements. These new methods have to be developed, but not at the expense of conventional and traditional methods which also have their place in science today.

5. Identification of Key Variables

The biological variables of interest in addressing the major scientific issues were listed and prioritised according to their impact; their ease of measurement; adaptability to different platforms; their cost; the time required for sampling and analysis; and whether they can be monitored in discrete or continuous mode. When different techniques could be used to measure the same or similar biological variables, an attempt was made to distinguish between techniques. All the variables that were considered by the group are tabulated in Appendix 3. Only variables that have the capability or the potential to be measured in operational mode were considered. In this context, the term “operational” is used in the sense of being implemented widely and easily, using simple, inexpensive, standardised techniques operated automatically or by technicians rather than by scientists. The variables that emerged as being high priority are listed in Table 5.1.

Remote sensing of ocean colour from satellites was identified as one of the highest priorities in all three categories considered. Measurement of chlorophyll-a concentration *in situ* was recognised as being highest priority under two categories (Carbon Cycle and Primary Production). It is recommended that *in situ* fluorescence technique be used for estimating chlorophyll in continuous mode, with laboratory techniques (Turner fluorometer and HPLC) being used as frequently as possible to calibrate the fluorescence measurements. In addition, measurement of pCO_2 was recognised as being highest priority for carbon cycle studies, and estimates of the plankton populations by Continuous Plankton Recorder (CPR) was recognised as highest priority for studies of biodiversity and ecosystem function.

There was general consensus that all biological measurements must be placed in their physical context. Hence it is recommended that all biological measurements be accompanied by measurements of conductivity, temperature and depth (CTD), and this is considered to be of the highest priority.

Optical measurements were considered to be high priority in general, for both climate change and primary production studies. Whereas measurements of the total photosynthetically-active radiation (PAR) has often been considered to be the quantity to be measured in the past, the present group was of the opinion that it would be more useful to have measurements of underwater light in three or more discrete wavebands within the PAR range. It was argued that such measurements, in combination with spectral models of light transmission, are more likely to yield a complete picture of the underwater light field than measurements of PAR. Measurement of the beam attenuation coefficient (or beam attenuation) was recommended as an indirect method to estimate particulate carbon in the water.

In general, there was recognition that many aspects of studies of biodiversity and functional diversity require developmental work before they could be considered operational. This implies that efforts must be made to render techniques for biodiversity studies operational, and capacity building efforts have to be redoubled. A combination of traditional (e.g., microscopy) and modern (e.g., DNA probes) techniques is required to yield the best results for biodiversity studies.

Elements of observational schemes in support of carbon cycle and primary production studies are ready for implementation at the operational level. But there are emerging techniques that appear to be extremely promising for expanding the range of measurements at the operational level, and these include laser imaging techniques, automated flow-cytometers that can be operated from stand-alone buoys (cytobuoys), and fast-repetition-rate fluorometers (FRRF) that can be used to derive information on photosynthetic rates.

Table 5.1. Recommended Variables and Measurements

Priority	**Global Change & Carbon Cycle**	**Primary Production & Remineralisation**	**Biodiversity & Ecosystem Function**
Highest			
	Ocean Colour	Ocean Colour	Ocean Colour
	Chlorophyll (*in situ*)	Chlorophyll	CPR
	pCO_2	CTD	CTD
	CTD	Light	
	Beam attenuation		
High			
	Chlorophyll (lab)	Nutrients	DNA Probes
	3-channel light	ADCP	
	NO_3		
	P and SiO_4		
	Dissolved Oxygen		
	ADCP		
Recommended for Development to Operational Level			
	FRRF	FRRF	DNA Probes
	Flow Cytometry	Zooplankton Grazing	Functional Groups (DNA)
		Bacteria (Flow Cytometry)	DNA Chips
		Respiration	Image Analysis
			Molecular Data Bank
			Microscopy
Capacity Building			
	Microscopy		
	Ocean Colour (emphasis on extracting information on Phytoplankton community)		
	Molecular Techniques		

6. Sensors and Platforms

Military interests provided early impetus to physical-oceanographic observations at large scales. Furthermore, in the field of physical oceanography, there seems to be general agreement about what variables and parameters are the appropriate ones to measure. As a result of this, sensors (e.g., C, T, D) are available at low cost for physical oceanographic measurements. For biological and biogeochemical systems there is still an active debate on the measurements that are required to describe adequately the structure and function of the system. These measurements are also, to a large extent, more complex. Partly as a result of this, biological sensors are only now becoming available which address appropriate variables and have the characteristics of high accuracy and reliability. The specifications for the sensors clearly depend on the platform on which they are to be deployed with the most extreme demands being made on optical sensors deployed at near-surface depths in long-term Eulerian observatories. In these situations biofouling is a major factor compromising such endeavours, although significant progress has been made over the past few years to overcome this.

6.1. Eulerian Sites (Time Series Stations and Ocean Observatories)

Temporal variability is a prominent feature of all biogeochemical systems and in the open ocean such variability often confounds attempts to understand system function and structure. The reason for this is that sampling is almost always too infrequent.

Eulerian Observatories can be defined as observation systems that remain at one geographic location for prolonged periods of time (months to years). Although fixed to the seabed, the focus of such systems can be on any part of the water column, the air-sea interface or the seabed. These have been very widely used for many years to provide an understanding of meteorological, geophysical and physical oceanographic processes.

Apart from an urgent need to develop appropriate sensors, critical factors in implementation of such observatories are power requirements and data managements (storage and transmission). These have been extensively discussed elsewhere ("Illuminating the hidden planet" National Academy Press 2000).

There are a number of Eulerian observatories, which address issues of biology and biogeochemistry in shallow coastal waters (e.g. LEO15 off New Jersey, USA). However, in the open ocean only one can be considered as fully functional with a range of sensors. This is based off Bermuda.

Traditionally, sensors have been deployed at fixed depths, but over the past decade several profiling instrument carriers have been developed. These have several advantages:

1. Reduction of biofouling if they spend significant periods of time deep in the water column.
2. Vertical gradients are less sensitive to instrument drift and calibration as a single sensor characterises the entire vertical range.
3. Vertical resolution is much higher than for fixed-depth sensors.

The rates of horizontal change of biological systems across the oceans are not constant and areas of rapid change may be considered as boundaries. Using a range of properties of the oceans, Longhurst has defined the oceans in terms of 57 biogeographical provinces. The locations of the boundaries of these are not fixed in time and the characterisation and definition of these provinces is still under debate. Nevertheless they provide a strong framework in which the locations of Eulerian observatories can be considered. Observatories sited at the boundaries of such provinces may provide data which are difficult to interpret and to compare with observatories elsewhere. It is suggested that the criteria used to determine and characterise provinces continue to be developed and that observatories be located far from the (dynamic) boundaries of provinces.

Since the mid-70s, manned and unmanned submersible vehicles have supported highly successful multidisciplinary research programs at intensive water column and seafloor study sites called observatories. Examples include long-term deep-sea stations serviced by combinations of landers and submersibles in both open ocean sediment environments and hydrothermal vents. These technologies have allowed relatively comprehensive observations of biota and in situ experiments to be conducted on the sea floor. The expense of submersibles and the platforms from which they are deployed severely limits the operational capabilities of this kind of bottom observatory.

A report commissioned by the U.S. National Academy of Sciences Ocean Studies Board recommends seafloor observatories whose primary infrastructure is a series of seafloor junction boxes connected by undersea cables capable of providing power and broad-band fibre-optic communications. This network of ocean observatories will facilitate collection of time-series data streams from a broad range of instrumentation including robotic vehicles that operate from docking stations on the sea floor. Such a system of observatories would facilitate the temporal exploration of the ocean and address issues in the following areas:

- Ecological characterisation of water column and sediment
- Sub-bottom biosphere characteristics and ecological characterisation of life at sites of hydrothermal vent and seep flows
- Fluid, chemical, and particle flux at the sediment-water interface and in the bottom boundary layer
- Deployment of water column observing networks using instruments of unprecedented volume coverage (4-D sampling of a large cylinder or block of ocean) and variety (including instruments with heavy power and communication requirements)
- Seismic, subduction, and intra-plate processes using simultaneous measurements at the scale of an entire plate boundary at the sea floor and in existing drill holes

Because of the communications capabilities, real-time regional forecasting and modelling of a broad range of processes can be achieved. The telecommunications industry has considerable experience with deep-sea cable systems and the usage of such systems is increasing. Cable-based observatories are expected to have at least a 30-year life expectancy. POGO Directors are urged to support strongly the needs of these new facilities. Another issue linked to this that has emerged recently is the problem associated with using ARGOS for data transfer. The limited bandwidth causes major problems in the transfer of data from Argo buoys and other instruments. There is an urgent need to have this facility upgraded. Support from POGO in this matter is recommended.

6.2. Autonomous Underwater Vehicles

There are compelling reasons for considering low-cost, portable autonomous underwater vehicles (AUV's) as routine observational platforms used in conjunction with research vessels at sea, or deployed as stand-alone platforms from the shore.

The justifications for the extensive use of AUV's are many:

- To optimise the use of expensive ship time;
- To collect uncontaminated, unperturbed data away from the ship; and
- As stand-alone platforms to study estuaries, lakes and the coastal zone, launched from mobile trailers.

The AUV's can be configured with sensor payloads for specific missions, for example:

- Calibration and validation of satellite sensors;
- Studies of the sea surface and the water column at high resolution; and
- Inspection of coral reef systems, the deep scattering layer and blooms.

Many sensors are now available for biological and related observations from AUV's:

- CTD
- ADCP for acoustic biomass estimates
- Optical radiometers
- Echosounder
- Dissolved oxygen
- Back-scatter meter
- Beam attenuation meter
- Fluorometer
- Nutrients
- Specialised payloads such as flow cytometers.

It is recommended that AUV's should be adopted to enhance oceanographic studies. But it is important to incorporate the highest safety standards at sea for AUV's.

6.3. Volunteer Observing Ships

Observations of the surface ocean from space have revolutionized biological oceanography. Ocean-colour satellites give an unprecedented global view of the variability (space and time) of biological production in the oceans. The potential is developing for satellite-colour retrievals to extend further towards characterisation of key functional groups (e.g. Coccolithophores, N-fixers, etc).

Such observations have some obvious limitations and requirements, however, including lack of data in highly-productive, cloud (or fog) -covered areas (e.g., productive fronts), problems of ground truthing, detection limit problems (especially with respect to functional group separation) etc.

The ocean climate and meteorological community has the benefit of extensive climatologies of sea-surface temperature, air-sea fluxes, winds, waves etc. based on data collected from volunteer observing ships which traverse wide regions of the ocean surface year round. Volunteer observing ships therefore represent an alternative means of sampling large regions of the ocean surface year round. In Table 6.1 we compare 4 available sampling platforms.

Table 6.1. Characteristics of different observation platforms

	Satellite	Mooring	VOS	Research Vessel
Spatial coverage	Global. Surface ocean	Limited.	Regional-global.	Regional.
Vertical coverage	Surface only	Depth profiles.	Surface few metres only	Depth profiles.
Temporal coverage	Daily(?) constant	High frequency/ constant/(hourly)	Low-frequency/ constant/monthly	Low Frequency/Intermittent
Sources of data biases	Clouds, fog, coastal	Location-specific	limited to shipping routes	Summer bias; location specific
Data accuracy	Low. Requires ground truth	Medium. Drift and fouling are problems.	High to medium.	High
Platform cost	High	Medium	Low	High
Cost per observation	Very low	Medium	low	Very high
Variety of measurements possible	Low	Medium	High (but space-limited?)	High

Despite their extensive use by the climate community, long-term use of VOS by the biological and chemical oceanographic community has been limited largely to the CPR Survey of the Sir Alister Hardy Foundation. In recent years, an extensive VOS measurement programme for surface pCO_2 and related properties has been established by Japanese investigators in co-operation with US and Canadian groups.

Advantages of VOS: Major advantages of VOS for biogeochemical measurements include:

A. Extensive geographical coverage of surface waters can be obtained with daily (coastal) to monthly (ocean basin) frequency. This coverage is compatible with remote sensing, and is unaffected by fog, cloud cover, etc. Hence VOS offer excellent possibilities for ground truthing of satellite sensors (e.g. by data assimilation), as well as tools to assess sampling bias in satellite observations.

B. Sophisticated measurement technologies can be deployed. Issues such as power requirements, instrument size, fouling, etc. are less demanding problems for VOS than for unattended, mooring-based instrumentation. Many of the analytical technologies regularly used on specialized research vessels could be adapted for use on VOS.

C. The possibility exists to send scientific personnel on vessels to perform more complex measurements.

Limitations of VOS: VOS operations have several logistical limitations. These include:

- Shipping companies receive no benefit for accommodating science operations, which depend purely on good will. Personal relations with the officers and crew are critically important for maintaining long-term data collection. The company or captain can terminate operations at any time, for any reason.

- Commercial vessels are presently not designed for science operation. As a result, installation of equipment or sampling of waters requires an often difficult, sub-optimal and costly retrofit.

- Commercial vessels are regularly sold, decommissioned, or re-routed. Long-term data collection in a region may require frequent de-installation and re-installation of equipment.

Medium-term Issues and Suggestions: To maximize the use of commercial vessels, custom VOS packages of standard size, a common suite of basic measurements (e.g. temperature and salinity) and with standardized physical and data connections should be developed for biological/chemical measurements. Data transmission and data storage and archival must also be planned.

There are already several groups interested in VOS observations. Scientists interested in VOS operations must co-ordinate across disciplines and carefully regulate their contacts with shipping companies.

Un-coordinated requests and demands from diverse scientific groups to the shipping industry will put long-term cooperation at risk for the entire community. Recently, JCOMM (Joint Technical Commission for meteorology and oceanography of IOC and WMO) has formed a Ship Observations Team to co-ordinate VOS measurements. This group will meet in India (Goa) in February 2002. The Integrated Carbon Observation Theme of IGOS, which under preparation, also pays attention to the need to co-ordinate VOS observations. IOC is at the moment collecting information on existing VOS observations.

The oceanographic community should initiate a dialogue with the shipping industry with the goal of building basic science capability into the design of the next generation of commercial ships. A standardised “science compartment” with provision for clean seawater intakes, and through-the-hull sensors should be proposed for future vessels. The VOS instrumentation could be designed for rapid installation and removal in such standardized compartments.

Financial incentives. Contacts to date have suggested that provision of some financial incentive would greatly increase the likelihood of long-term co-operation between scientists and the shipping industry. Such incentive could be in two forms:

1. Tax incentives for companies that support science.
2. Partial payments of salaries for crew members that help maintain science operations during transit.

In order to improve overall VOS utility for marine science, POGO might consider initiating an informal information exchange between the scientific community and the shipping industry. Shipping companies are increasingly aware of, and sensitive to, the environmental consequences of their operations in terms of atmospheric pollution, environmental accidents, ballast-water issues, etc. The possibility to support environmental science in the public good may therefore be of interest to such companies. POGO could consider hosting an “information weekend” for the owners of large shipping companies in order to initiate a dialogue. Continuous underway displays of scientific data being collected on ferries and other passenger-carrying vessels can be used to enhance the public exposure and the good image of all parties concerned.

6.4. Autonomous floats

Specification of the 4-D distribution of photosynthetic biomass, light and photosynthetic efficiency could significantly improve global and regional estimates of ocean primary production with implications for improved understanding of carbon cycling and the fate of CO_2. A similar need has been broadly discussed and accepted by the physical oceanographic and climate community. In the past decade, physical, meteorological and optical sensors have been integrated to autonomous systems (surface and profiling floats, gliders). Initial efforts focused on the feasibility of retrieving temperature, salinity and surface winds and these systems are now considered operational. The international Argo program has been initiated and will deploy thousands of Lagrangian drift profilers to measure salinity and temperature in the top 2 km of the ocean at unprecedented spatial and temporal scales. The data from Argo are considered essential for the Global Ocean Data Assimilation Experiment (GODAE) and related modelling efforts. Similar goals for both observing and modeling should be specified for ocean productivity, and the instrumentation to accomplish the observations should be developed.

In the past 5 years there have been efforts to develop and deploy optical instruments that can provide important biological information including estimates of chlorophyll, particulate organic carbon, light and photosynthetic yields. Oxygen sensors with low power and duration of months are feasible now, while longer duration oxygen sensors and low-power pCO_2 may be feasible within several years. Continued development of advanced sensors of this type, and demonstration of the feasibility of their long-term performance is strongly encouraged to allow observations of key biological variables at the time- and space-scales needed to advance models of photosynthesis. In particular, low-cost autonomous systems are envisioned as an essential complement to surface-observing satellite ocean color sensors whose data is limited by cloud cover, especially at high latitudes.

There have been several successful projects that demonstrate the feasibility and scientific value of integrating optical sensors onto Lagrangian surface or profiling floats. Recently, a 3-wavelength irradiance sensor was incorporated onto a SOLO (Sounding Oceanographic Lagrangian Observer) system to estimate the spectral diffuse attenuation coefficient (K). SOLO is one of several designs that will be used routinely in the Argo program. The K-SOLO system was deployed during late winter in a deeply mixed (>800 m) region of the Sea of Japan and resolved the spring bloom by transmitting temperature and optical data every second day for 5 months. The data provide estimates of depth distribution of chlorophyll and light for use in productivity models. A transmissometer has also been deployed on SOLO near Station PAPA in the northeast Pacific. The transmissometer allows direct estimates of particulate carbon. Sensors for measuring light backscattering (which correlates well with particulate organic carbon) could be deployed at potentially lower cost than transmissometers.

The most significant global impact of these new technologies will be achieved through integration of systems to estimate light, chlorophyll, photosynthetic quantum yields, particulate carbon (inorganic and organic), and the physical-chemical structure of the ocean. Sensors for salinity and temperature are already operational, and viewed as essential for specifying the density structure that must be known for accurate models of productivity. Optical sensors for determining irradiance, solar-stimulated fluorescence, beam attenuation and backscatter can all be deployed immediately at low cost. However, there remain issues with respect to the long-term performance of the sensors due to potential bio-fouling or calibration drift. Simple irradiance sensors for estimation of the diffuse attenuation coefficient (K) are not subject to fouling or calibration issues since K is the depth derivative of irradiance and thus can be determined independently of absolute calibration as long as the sensor is stable for short periods (e.g. seconds). Recent research using copper shutters indicates that optical systems can be deployed in the environment for long periods with negligible degradation of their calibration from bio-fouling. Augmenting the optical and physical sensors with simple chemical sensors would enhance the significance of an autonomous photosynthesis float. At this time oxygen sensors are consider the most feasible.

Development of small, low cost and low power versions of variable fluorescence, nutrient, oxygen and pCO2 sensors is encouraged. Variable fluorescence has advantages over solar-stimulated fluorescence in the assessment of physiological status of phytoplankton. Since nutrients (together with light and temperature) govern photosynthetic physiology, a sensor that could specify the depth of the nutricline would be of great value, even if only the gradient were defined, rather than absolute nutrient concentrations. By making a compromise on accuracy, with a goal only of defining the depth of the nutrient gradient, power, size and cost might be dramatically lowered, making it feasible to acquire minimum information on nutrient structure on a wider scale to improve productivity models.

The ideal observational missions for photosynthetic floats would be different from those for physical missions. For example, since phytoplankton blooms during spring can develop on rather short time scales (e.g. 4-10 days), temporal resolution should be rather short. Also, the maximum depth for a float designed for improving photosynthetic models need not be nearly as deep as that required for circulation models. The biological community should move quickly to specify low-cost systems with proven feasibility and build upon the plans to deploy floats within the context of larger basin-scale experiments such as the Argo plan for the north Atlantic. Whereas it is unrealistic to envision augmenting Argo floats that will be deployed immediately, consideration should be given to specifying a minimum optical augmentation of Argo floats that will be deployed in the 2-5 year time frame. Such consideration must take into account the reasonable expectation from the Argo program that any such augmentation would not compromise the mission of the floats to be modified. This undoubtedly would require a separate sensor, power and communication module with negligible buoyancy impact. If such a system could be specified, designed, tested and funded, the benefit to global ocean carbon cycle understanding would be advanced significantly. Benefits are also noted for the understanding of upper ocean thermal stratification that depends in part on the concentration and vertical distribution of phytoplankton absorption. Thus, inclusion of a sensor to provide information on light attenuation coefficients could be of importance for physical models in some regions of the world's ocean by improving the parameterization of depth distribution of solar radiation storage.

Sensors available for immediate deployment on Argo-type floats, or in the near future, following new funding for development are listed below.

Immediate feasibility:
Basic Argo CTD float (Mixed layer depth, T, stratification)
Underwater Light field (Irradiance at three or more narrow wavebands)
Diffuse vertical attenuation coefficient, PAR, chl, absorption coefficient, back-scattering coefficient
Beam attenuation or backscattering as proxies for c, POC and perhaps PIC
Fluorometer for estimating Chlorophyll (artificial light) and photosynthetic yield and photosynthetic yield (solar stimulated)
Oxygen

Feasible after 1-3 year of development and testing
Fast repetition rate fluorescence (Fv/ Fm) for photosynthetic quantum yield
Depth of the photic zone
Nutricline sensor (dN/dz)

It is recommended that a few experimental Bio-Argo floats, which are designed to sample over depth ranges and time intervals of relevance to biological processes, be developed and deployed, to test their viability and utility, as a complement to the existing physical Argo programme.

6.5. Remote Sensing

Remote sensing of ocean colour was recognised as being a high priority by the group, from all perspectives. Given that ocean colour provides the only window into marine ecosystems at synoptic scales, it would be unthinkable to develop any plans for monitoring oceanic biota at the global scale, without using ocean-colour data. Recommendations with respect to ocean-colour data are the following:

- There is a need for **operational** ocean-colour data. That is to stay, the community has to be able to rely on a consistent, compatible, long-term data stream with global coverage over time scales of a day. The data must be freely available in a timely fashion. Planned redundancy is essential, to allow for loss of data due to cloud cover, as well as for unplanned breakdowns in satellites or sensors.

- The operational data stream must complement research developments in ocean colour. The full potential of ocean colour is yet to be realised and the launch of experimental satellites designed to push the applications further must continue, in parallel with the operational stream.

- The applications of ocean-colour data can be improved, enhanced and extended, when the satellite data can be complemented by data for calibration and validation. POGO member institutions must participate actively in these efforts.

- The development of algorithms for interpretation of ocean-colour data in coastal waters must be encouraged.

- The retrieval of other variables in addition to chlorophyll-a is to be encouraged.

- Regional differences in performance of algorithms may be related to phytoplankton community structure and hence to biodiversity. *In situ* observations that can help understand these regional differences and their link to biodiversity are to be encouraged.

- The concept of biogeographical provinces advanced by Alan Longhurst and colleagues can be used as a template on which to base regional studies. POGO member institutions are encouraged to adopt one or two provinces. This would imply that they accept prime responsibility for *in situ* observations in support of satellite data, and test and validate the performance of the algorithms for the province. The IOCCG has recommended a series of *in situ* observations (see Appendix 4) that would best serve the needs of validating the algorithms and enhancing the applications. These measurements are recommended as minimum observations from research cruises in support of remote sensing of ocean colour.

- Ocean-colour data provide information only on the near-surface waters of the ocean. Extrapolating the information to derive what happens deeper in the water column must rely heavily on both complementary *in situ* observations and on modelling.

- The IOCCG is an international body that attempts to co-ordinate research and applications of ocean-colour data. POGO should work with IOCCG to get the message of the user community to members of CEOS.

6.6. BioProbes

The Census of Marine Life is developing a program to allow mobile marine animals to report their responses to environmental changes directly. Animals as small as 25g can carry individually coded (up to 256,000 codes) acoustic telemetry tags that will be recorded as they pass fixed monitoring lines extending the full width of continental shelves. When these monitoring lines are in place they could also have the capacity to record physical data spatially complementary to Argo floats. Larger animals (initially elephant seals, turtles, albatrosses and tuna) will carry archival tags that store, and can transfer via satellites, data on time, geo-location, physiology and physics. As they dive they will provide near real-time physical temperature/depth profiles comparable to Argo floats in locations of highbiological relevance. Different behaviours among these ‘bioprobes’ will identify different biological zones indicative of particular biota. Interaction between bioprobes and their relative locations will give additional biodiversity information.

Hot spots identified by bioprobe convergences are prime areas for direct biological sampling, which will provide calibration for bioprobes. It would be valuable if research vessels in these areas could be encouraged to increase sampling effort to this end. The time and space scales and data availability for bioprobes are consistent with and can be cross-correlated with satellite imagery making them especially useful. Discussions at the meeting led to the recommendation that miniature 490 nm irradiance be added to some bioprobe packages to provide direct estimate of local light attenuation to improve global primary production estimates.

6.7. Research Vessels

In the context of POGO, the major uses of the research vessels as observation platforms will be three-fold:

1). *Carrying out the basic minimum measurements that are identified as high priority and are currently measurable from all platforms.*
An effort should be made to incorporate the basic package of high-priority variables, recommended for all platforms, on all ships belonging to POGO member institutions. At the very least, research vessels should make the same observations recommended for VOS. These basic core biological measurements derived mainly from low-maintenance, automated instruments should be made on all voyages of a research vessel, assuming that there is no hindrance to the major focus of the mission. Semi-autonomous sampling of pCO_2, ferrybox, and cytobuoy-modules in containers are suitable tools for biological measurements during the steaming time on research vessels. Information on ship scheduling can be rendered easier of access, to promote better utilisation of cruise time. POGO can help enhance information on ship track and scheduling available on the Internet via the University of Delaware.

2) Conduct process studies specific to research topics as recommended by POGO.
These could be made in reference to the more automated moored instruments and drifters, and would allow for the basic set of biological observations that are carried out on a continuous basis to be complemented periodically.

3) *Serve as test platform for the deployment and validation of emerging technologies.*
To that effect, an effort should be made to outfit existing vessels with equipment that will allow the use of these new technologies. The increasing requirement to freeze samples at very low temperature could be easily met by outfitting research vessels with liquid nitrogen generators. Adequate power supply, and trace metal clean containers and sampling gears should also be considered. Research vessels can be used to collect DNA samples and to set up an archived set of DNA samples that can be analysed by interested groups and referred to again in the future.

7. Data Management and Distribution

Operational oceanography cannot be discussed without emphasising the need for adequate facilities for making the data available to the user community in a timely basis. Data archival, management and distribution are issues that merit special attention, and POGO should not underestimate the effort that is required here. Archival and management of data related to biological observations have always lagged behind the physical fields, partially because of the complex nature of biological observations. Biological observations encompass a vast variety of variables; many types of measurements exist for measuring the same variables; and many observations are of a descriptive nature. All of these factors make storage and retrieval of biological data a challenging task.

When initiating operational observations, one must also emphasise the need to establish free access to data on a global basis, in a timely fashion. These are issues that preoccupy other agencies and programmes as well, for example GOOS, IOC, IODE, JCOMM, PICES, and CoML. JGOFS adopted a policy of free and open access to data from the very outset of the programme, and also made great efforts to promote the concepts of distributed databases, and also worked on common standards and protocols for data archives. The lessons learned from such efforts must be exploited. Furthermore, in operational oceanography, the usefulness of the data acquired will diminish rapidly with delay in availability. Our attempts to increase biological observations at the global scale must move hand in hand with efforts to enhance availability of, and access to, the data acquired.

Initiatives by programmes such as JGOFS and GLOBEC on data management focused on observations that are made in the context of research into the marine ecosystems, carbon cycle and climate change. GOOS has also developed extensive documents on data management that merit attention in this context. Recent efforts initiated by CoML to co-ordinate and enhance biodiversity studies have also led to a new initiative in data management in a biodiversity context. This new effort is described in some detail below.

The Ocean Biogeographical Information System: Present data systems make retrieval of taxonomically-accurate, quality-controlled, geo-referenced biological data extremely difficult. The Ocean Biogeographical Information System (OBIS), part of the Census of Marine Life, is an effort to create and maintain a dynamic global data system for marine biological and environmental data. OBIS is growing as an international system dedicated to advancing a world wide, distributed network of interoperating, ocean biogeographic databases. The initial vision and strategy of OBIS was developed at the first international OBIS workshop in Washington, D.C. in November 1999. Participants defined OBIS as "an on-line, world wide marine atlas infrastructure providing scientists with the capability of operating in a four-dimensional environment so that analyses, modelling, and mapping can be accomplished in response to user demand through accessing and providing relevant data." It was agreed that OBIS would be managed as a federation of database sources that reaches agreement on the means to achieve interoperability, yet allows a high degree of autonomy with respect to both existing and developing data systems.

Further information on OBIS is provided as Appendix 5.

We recommend that the POGO Directors strongly support the principle of interoperability of national and international ocean databases and, in particular, the development of OBIS for biodiversity data. We also recommend that POGO work with other organisations such as IODE, PICES, ICES and JCOMM in developing common protocols and data management systems that are suitable for biological observations of the oceans. It is worth pointing out here that many of the existing initiatives have not yet begun to grapple with the issue of biological data. This is clearly a lacuna that needs to be addressed.

8. Recommendations for Capacity Building

At POGO 2, it was recognised that training, education and capacity building will be major priorities for POGO members. POGO has also recognised that enhancing observations in the Southern Hemisphere has to be an integral part of the strategy, if we are to achieve our goal of global observations of the oceans. These general POGO priorities are very relevant and true in the particular case of biological observations.

It is recommended that POGO link its capacity-building efforts with those of other organisations such as SCOR's Regional Centres to enhance graduate education in Marine Science, and GOOS capacity building (see SCOR and GOOS web pages for details). It is recommended that training be linked to specific ongoing projects, so that any experience gained by people being trained is put into use immediately. Thus training must go hand in hand with infrastructure and with appropriate employment after training, with backup to assist new practitioners if they encounter difficulties with new instruments and techniques. GOOS has a policy of pilot projects in capacity building. POGO may wish to emulate this. It is essential to have partners in developing countries to take responsibility for projects at the regional and local levels. They can be the best advocates for POGO projects and can take the lead in defining local and regional needs, and in finding ways to meet those needs.

The following aspects of capacity building are particularly recommended:

Development of biotechnology: These tools have the potential to be made operational, both for studying the functionality of marine ecosystem as well as for recording marine biotechnology. Both training and capacity building must be encouraged to exploit this tool better for biological observations of the ocean.

Sensors and Platforms: Several new platforms and sensors are now emerging that would greatly facilitate making biological observations operational. These include in situ, self-contained, flow cytometers for classification of phytoplankton and bacteria (the "cytobuoys") and underwater laser imaging techniques that can be used for recording marine life underwater. These and similar emerging technologies have to be taken forward and made available to a larger community.

Data management and Communication: New technology being advocated for operational use is likely to result in large streams of biological data being collected. It is vital that adequate data storage and communication facilities be installed at all sites where such data are gathered, and that people be trained to operate the appropriate hardware and software to gather, archive and analyse large bodies of data. In the absence of such ability, it is likely that faulty, biased and inappropriate data will be stored without any quality control, reducing the utility of such data.

Issues relevant to the Southern Hemisphere and other undersampled regions: An effective and easy way of augmenting the capacity of the Southern Hemisphere and other undersampled regions would be to ensure that berths are available to scientists from developing countries on research vessels that operate in their regions of interest. Furthermore, scientists should be encouraged to make contact with counterparts in those countries that they visit for professional reasons. Often scientists come in and out of a country to join a research vessel. These visits could easily be used to make and build contacts with local scientists. Just taking the time to visit and give a seminar can make a significant impact on a small group of scientists working in relative isolation.

9. *Action Plans*

We recommend a two pronged action plan to POGO. The first one is aimed at a regional level, and has the goal to help develop regional capacity for biodiversity monitoring. The second is aimed at the global level, and aims at contributing to the study of the carbon cycle.

Action 1: A workshop on Biodiversity in S. America

The goal of this workshop will be to provide a forum where scientists can discuss organisation and co-ordination of studies of marine diversity off S. American waters. A secondary goal will be to identify the common grounds between biodiversity and other issues in biological oceanography with a view to enhancing the benefits from the observations. An example is to identify the links between biodiversity and functional diversity in marine organisms. Dr. Victor Ariel Gallardo from the University of Chile has agreed to take the leadership in organising the workshop. A detailed proposal for the workshop will be presented at POGO 3 for consideration of the members. Once approved, the proposal will be submitted to the Sloan Foundation for financial support.

Action 2: A Long-term Observational Programme in Support of Phytoplankton Dynamics, Primary Production and Carbon Cycle.

POGO can make a significant contribution to the study of the ocean carbon cycle by co-ordinating an effort to collect global, in situ data on a few key variables. These would be:

Chlorophyll-a concentration
pCO_2
NO_3

These should be measured along with the following physical variables:

Wind
CTD

This would allow a number of applications, at the global scale:

1. Global calibration of ocean-colour data
2. Improve Global Computations of Primary Production
3. Study the relationship between primary production and pCO_2
4. Study the relationship between primary production, nutrient supply and vertical stratification

The development in the sensor technology has advanced to the stage where the proposed measurements can be made from all the types of platforms discussed here. In particular, POGO members can:

1. Make a commitment to making these measurements at all possible stations during research cruises.
2. Participate in the development and deployment of a few free-floating, Argo-type biological floats with a minimum of the sensors proposed here.
3. Extend VOS contributions to these measurements whenever and where ever possible.
4. Approach other international programmes such as CLIVAR to include these measurements in all their cruises.
5. Approach space agencies (jointly with the IOCCG) to ensure continued, reliable, stable, long-term, steady, stream of ocean-colour data.
6. Establish a POGO team, consisting of a representative from each of the participating POGO institutions, that will oversee maintenance of standards, co-ordination of efforts and data management and distribution.
7. Establish links with other relevant organisations to avoid duplication of efforts and promote effective co-ordination.

These measurements can be supplemented, whenever possible with CPR measurements on VOS and Research Vessels. This would serve the need to understand the food web structure in the marine community, as well as the need to record the biodiversity in mesozooplankton.

10. Summary and Conclusions

There was remarkable consensus among the participants of the meeting on the useful role that POGO can play in enhancing biological observations of the oceans. There was also agreement that sensor developments have brought biological oceanography to the stage where certain key variables can be measured in operational mode, at the global scale. Biodiversity studies, on the other hand, are best addressed as a series of regional initiatives. The action plans proposed here address both these aspects of biological oceanographic studies. Given the diversity of scientific issues and societal concerns discussed, and the variety of biological measurements that were considered, it is remarkable that it was possible to identify a small number of variables as being the most important ones. This makes it well within the reach of POGO to initiate a viable programme of biological observations. There are two proposals here that are complementary in nature and which are ready for immediate implementation: the first one is a workshop to enhance biodiversity studies in S. America, and the second is a global initiative to study phytoplankton dynamics.

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Appendix 1

Participants at the POGO Biology Meeting

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Dr. Satsuki Matsumura (Japan)
Dr. Ron O’Dor (CoML)
Dr. Shubha Sathyendranath (POGO)

Appendix 2

Web Sites of Interest:

- Argo
  http://www.argo.ucsd.edu/

- Census of Marine Life (CoML)
  http://core.cast.msstate.edu/censhome.html

- CLImate VARiability and Predictability (CLIVAR)
  http://www.clivar.org/

- Coastal Ocean Observations Panel (COOP)
  http://ioc.unesco.org/goos/COOP.htm

- Continuous Plankton Recorder Survey (Sir Alister Hardy Foundation)
  http://www.npm.ac.uk/sahfos/sahfos2/html

- Convention on Biological Diversity
  http://www.biodiv.org/

- Ecological Determinants of Ocean Carbon Cycling (EDOCC)
  http://picasso.oce.orst.edu/ORSOO/EDOCC/EDOCC.html

- Global Ocean Data Assimilation Experiment (GODAE)
  http://www.bom.gov.au/bmrc/ocean/GODAE/

- GLOBal ocean ECosystem dynamics (GLOBEC)
  http://www.pml.ac.uk.globec/

- Global Ocean Observation System
  http://ioc.unesco.org/goos/

- Joint Global Ocean Flux Study (JGOFS)
  http://ads.smr.uib.no/jgofs/jgofs.htm

- Integrated Global Observation Strategy (IGOS)
  http://www.igospartners.org/

- International Ocean Colour Co-ordinating Group (IOCCG)
  http://www.ioccg.org/

- Ocean Carbon Transport, Exchanges and Transformations (OCTET)
  http://www.msrc.sunysb.edu/octet/

- Scientific Committee on Oceanic Research (SCOR)
  http://www.jhu.edu/~scor

- SCOR Working Group 118 on New Technologies for Observing Marine Life
  http://pulson.seos.uvic.ca/meeting/scor2000/scor2000.html

- Surface Ocean – Lower Atmosphere Studies (SOLAS)
  http://www.ifm.uni-kiel.de/ch/solas/main.html

- SYMBIOS Ocean Optics Protocols
  http://symbios.gsfc.nasa.gov/Documents/Protocol.pdf

- World Ocean Circulation Experiment (WOCE)
  http://www.soc.soton.ac.uk/OTHERS/woceipo/ipo.html

Appendix 3

Matrices of Variables

Table A3.1. Global Change and Carbon Cycle

Variable	Impact	Difficulty	Cost	Time		Platform	Cost per measurement	Continuous/Discrete
Optical Measurements								
3-5 channel light	H	M	L	I		2-6	L	C
PAR	M	L	L	I		2-6	L	C
Multispectral sun photometer	M	L	M	I		3	L	C
Backscatter	M	M	M	I		3-6	L	C
Optical Particle Counter	M	M	M	I		3-6	L	D
In situ fluorometer	V	L	L	I		2-6	L	C
FRRF	H	M	H	M		3(-6)	L	C
Flow Cytometer	H	M	H	M		3-6	L	D
Beam attenuation	V	L	L	I		2-6	L	C
Chemical Measurements								
Dissolved Oxygen	H	L	L	I		2-6	L	C
Nitrate	H	M	M	I		2-6	L	C
Nitrite	L	M	M	I		2-6	L	C

Phosphorus	H	M	M	I		2-6	L	C
Silicate	H	M	M	I		2-6	L	C
Methane	L	M	M	I		2,3	M	C-D
Nitrous Oxide + Isotopes	M	H	M	I		3	M	C-D
Carbon monoxide	M	H	M	I		3	M	C-D
DMS	H	H	M	I		3	M	C-D
COS	M	H	M	I		3	M	C-D
PCO_2	V	M	M	I		2-6	L	C
DIC	H	M	M	I		3	M	D(C)
Alkalinity	H	M	M	I		3	M	D
Iron	H	H	H	I		3 (5)	V	D(C)
Particle Flux (Th)	H	H	H	I		3	H	D
Biological Variables								
Chlorophyll-a								
By HPLC	H	M	M	I		3	M	D
By Fluorometer	H	L	L	I		2	L	D
Phytoplankton Pigments (HPLC)	H	M	M	I		3	M	D
POC/PON	H	M	M	I		3	M	D
Bacterial Abundance (DNA)	H	H	H	M		3(2)	H(M)	D
Mesozooplankton (CPR)	M	M	M	I		2	H	C
DON/DOC	H	H	M	I		3(2)		
Particulate Organic P	H	M	L	I		3	M	D
Physical Variables								
CTD	V	L	M	I		4-5	H	D
Particle Flux (Sediment trap)	H	H	H	I		4-5	H	D
Acoustic Biomass (ADCP)	M	M	M	I		2-6	L	C

Code: V = Very high; H = High M = Medium L = Low
Code for Platforms: 1: remote sensing; 2: VOS; 3: Research vessel; 4: AUVs; 5: Buoys/observatories; 6: Bio-probes

Table A3.2. Controls on Production & Remineralisation

a) JGOFS Level 1 variables

Variable	Impact	Difficulty	Cost	Time	Platform	Comments
Light	V	L	L	I	1-6	
T & S	V	L	L	I	1-6	
DO	V	L	L	I	3	Available by electrode or wet chemistry with issues of sensitivity
TIC	H	H	H	I	3	
Nutrients	V	L	M	I	2-6	Ditto
Chl- HPLC	V	M	M	I	2-3	
Chl-fluro	V	L	L	I	2-3	
POC/N	H	L	L	I	2-3	
DOC/N	V	M	M	I	3	Labile DOC may be more useful
Bact	M	L	L	I	2-3	
Bprod	V	L	L	I	2-3	
Micropl	H	M	M	I	2-3	
MicroGraz	V	H	M	I	2-3	
ParFlux Trap	V	L	M	I	5	
PF Th	V	M	L	I	3,5	
Mesozooplan	H	L	L	I	2-3	
MesoGraz	H	H	M	I	3I	

b) Other new variables

Variable	Impact	Difficulty	Cost	Time	Platform	Comments
BioAcoustics	M	H	M	I	2-3, 5	
Chl optics	V	L	L	I	All`	
POC optics	H	M	L	I	All	
Coulter	M	M	M	I	3	
OPC	M	L	M	I	2-6	
AFC	V	M	H	I	3	
Trace metals*	H	M	h	I	3	Many elements incl. Fe
Phycobilins*	V	M	L	I	3	Fluorometric sensor not yet available but we chemistry analysis available
Wind	H	L	L	I	1-3, 5	
Respiration*	V	H	M	I	3	Major goal for remineralisation
DNA*	V	M	V	I	2-3	Covers many topics; yet to be developed
FRRF	V	L	H	I	2-6	

Table A3.3. Biodiversity and Functional Diversity

Variable	Impact Biod	Impact Ecol Funct	Difficulty	Time	Costs Equip ment	Costs Per sample	Level Diversity
Zoopankton OPC	M	H	M	L/M	M	L	Groups
Zooplankton OPC Video	M	H	M	L/M	M	L	Species
Zooplankton CPR	H	H	M	L	L	M	Species
Zooplankton MFA	M	H	M	L/M	M	M	Groups
Zooplankton Micro Optics	M	M	L	L	M	M	Species
Fish Optical	H	M	L	M/L	M	L/M	Species
Fish MFA	M	H	M	L	M	M	Groups
Underway eggs/larvae	M	M	L	L	M	M	Species
GPS data fishing ves	M	H	H	L	L		Groups
Image analyses fishing Ves	H	M	M	L	L/M	L	Species
Bioprobes		H	H	L	H	H	Species
Monitor lines		H	VH	M	VH	M	Species
Satellite colour	L	M	M	L	H	L	Groups
Flow Cytometry	M	M	M	L/M	H	L	Groups/Species
16/18S ribosomes	H	M	M	L/M		L	Groups
HPLC pigments	M	M	M	L	M	M	Groups
DNA Probes	H	H	L	L	H/L	L	Species
Functional genes	H	H	H	L	L	M/H	Groups/species
DNA chips	M	M	H	M	H	L	Groups/species
Nitrogenase	L	M	M	L	M	L	Groups
Biomarker compounds	M	H	M	L	M	M/L	Groups
LIDAR/SOSUS							
Microscope	H	H	M	L	M	M	Species

Note: In this table, variables are only categorised as high, medium or low.

Appendix 4

Recommended *in situ* measurements in support of satellite ocean colour for global ocean carbon studies

Submitted by the IOCCG

1) ***In situ* Water-Column Measurements**

   Samples to be collected through the water-column down to the 1% light level

   a) Minimum required measurements
      - Chlorophyll-a (Fluorometric method)
      - Phytoplankton pigment composition (HPLC method)
      - Yellow substance absorption coefficient (CDOM)
      - Total suspended particulate material (coastal waters)
      - *In situ* photosynthetic rates and parameters

   b) Highly desired measurements
      - Total particle, phytoplankton and non-pigmented particle absorption spectra
      - DOC
      - Optical measurements (ocean colour, spectral light transmission etc.)

2) **Semi-automated, in-transit measurements**
   - *In vivo* fluorescence (note: requires frequent calibration)
   - Partial pressure of CO_2
   - Nutrients (N, P, Si)
   - Incoming solar radiation (PAR)
   - Wind speed and direction
   - Temperature
   - Fast repetition rate fluorometry (FRRF) (ideally calibrated frequently against ^{14}C uptake measurements)

Appendix 5

Details of Ocean Biogeographical Information System

The following mission and goals statement was part of the OBIS application that enabled OBIS to recently become an Associate Member of the Global Biodiversity Information Facility (GBIF):

> The Ocean Biogeographic Information System (OBIS) will be a dynamic, world-wide, inter-networked, inter-operating biogeographic information system for the marine environment. OBIS will provide a global information portal where systematic, genetic, ecological, and environmental information on marine species can be cross-searched, and where these interconnected sources of information can be integrated into value-added products such as derived data, maps, and models.
>
> OBIS will:

- Energize regional, national, and international scale development of ocean biogeographic and systematic databases
- Foster collaboration and interoperability by promoting standards and protocols
- Advance integrated biological and oceanographic research by supporting a multidisciplinary ocean information portal
- Speed up the dissemination of and public access to ocean biogeographic information while appropriately addressing the issue of intellectual property rights.

OBIS would be open to any interested individual, country, or organisation. OBIS might be managed through integrated operations offices around the world with overall guidance from the OBIS International Committee. The International Office is needed to:

- Form coalitions with existing regional and international systems and research programs
- Form alliances with national and international funding agencies to foster the worldwide development of OBIS
- Coordinate the development of national/regional data centers and promote the adoption of technology standards under the OBIS umbrella
- Oversee the development of an OBIS information portal and ensure the interoperability of databases within OBIS
- Establish an OBIS education and outreach strategy