Drilling Program cores, also from the eastern equatorial Pacific, revealed the presence of vast ancient deposits of the diatom *Thalassiothrix longissima*, a needle-shaped diatom that grows up to 4 mm in length and also forms tangled masses or mats (**Figure 1**). These layers that extend along the equator for >2000 km record ancient surface concentrations of giant diatoms that settled to the seafloor between 4 and 15 Ma.

The 'Fall Dump'

As a result of sediment trap studies and work on ancient laminated marine sediments (the tree-rings of the oceans) a further explanation for mass flux for large and mat-forming diatoms has recently emerged (**Figure 2**). Most diatom production and flux was previously thought to be generated by small, rapidly growing diatoms in a spring bloom or upwelling pulse. However, a review of sediment trap studies and evidence from laminated sediments shows that large or mat-forming diatoms that grow in stratified waters in the summer and sediment massively when autumn or winter storms disrupt the water column may contribute as much or greater flux to the seafloor than the spring bloom. Ancient examples of this process are the Mediterranean sapropels, black layers whose high organic carbon content may be explained by the contribution from diatom flux.

See also

Carbon Cycle. Primary Production Distribution. Primary Production Methods. Primary Production Processes.

Further Reading

Alldredge AL and Gotschalk CC (1989) Direct observations of the mass flocculation of diatom blooms: characteristics, settling velocities and formation of diatom aggregates. *Deep-Sea Research* 36: 159–171.

Goldman JC (1993) Potential role of large oceanic diatoms in new primary production. *Deep-Sea Research I* 40: 159–168.

Grimm KA, Lange CB and Gill AS (1997) Self-sedimentation of phytoplankton blooms in the geologic record. *Sedimentary Geology* 110: 151–161.

Kemp AES and Baldauf JG (1993) Vast Neogene laminated diatom mat deposits from the eastern equatorial Pacific Ocean. *Nature* 362: 141–143.

Kemp AES, Pearce RB, Koizumi I, Pike J and Rance SJ (1999) The role of mat forming diatoms in formation of Mediterranean sapropels. *Nature* 398: 57–61.

Kemp AES, Pike J, Pearce R and Lange C (2000) The 'fall dump': a new perspective on the role of a shade flora in the annual cycle of diatom production and export flux. *Deep-Sea Research* II 47: 2129–2154.

Sancetta C, Villareal T and Falkowski P (1991) Massive fluxes of Rhizosolenid diatoms: a common occurrence? *Limnology and Oceanography* 36: 1452–1457.

Smith CR, Hoover DJ, Doan SE *et al*. (1996) Phytodetritus at the abyssal seafloor across 10° of latitude in the central equatorial Pacific. *Deep-Sea Research II* 43: 1309–1338.

Smetacek V (2000) The giant diatom dump. *Nature* 406: 574–575.

Villareal TA, Altabet MA and Culver-Rymsza K (1993) Nitrogen transport by vertically migrating diatom mats in the North Pacific Ocean. *Nature* 363: 709–712.

Yoder JA, Ackleson S, Barber RT, Flamant P and Balch WA (1994) A line in the sea. *Nature* 371: 689–692.

MARINE MESOCOSMS

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Controlled experiments are the basis of the scientific method. There are obvious difficulties in using this technique when dealing with natural communities or ecosystems, given the great spatial and temporal variability of their environment. On land the standard method is to divide an area of ground, say a field, into a large number of equal plots. Then with a randomized treatment, such as nutrient addition, it is possible to replicate growth of plants and animals over a season.

It is apparent that this approach is not possible in the open sea because of continuous advection and dispersion of water and the organisms in it. Bottom-living organisms are an exception, especially these living near shore, so there have been a wide range of experiments on rocky shores, salt marshes, and sea grasses. But even there, the critical reproductive period for most animals involves dispersion of the larvae in a pelagic phase. Also these experiments require continuous exchange of sea water.

For the completely pelagic plants and animals, short-term experiments – usually a few days – on single species are used to study physiological responses. There can be 24-hour experimental measurements of the rates of grazing of copepods on phytoplankton in liter bottles. But for studies of longer-term interactions, much larger volumes of water are necessary, to contain whole communities and to minimize wall effects of the containers.

To this end ‘mesocosms’ – containers much larger than can fit into the normal laboratory – have been used in a variety of designs and for a diversity of purposes. The first choice is whether to construct these on land, at the sea’s edge, or to immerse them in the sea. The former has advantages in durability, ease of access, and re-use. There are constraints on the volumes that can be contained, difficulties in temperature control, and, especially, problems in transferring representative marine communities from the sea to the tanks. This approach was used originally in tall relatively narrow tanks to study populations of copepods and fish larvae; in particular to experiment on factors such as light that control vertical migration. Another use of such large tanks is to study the effect of pollutants on communities of pelagic and benthic organisms.

These shore-based tanks are limited by the weight of water, usually to volumes of 10–30 m^3. Enclosures immersed in the sea do not have this constraint. Instead the problems concern the strength of the flexible materials used for the walls in relation to currents and, especially, wind-induced waves. For this reason, such enclosures are placed in sheltered semienclosed places such as fiords. Nylon-reinforced polythene or vinyl reinforced with fabric have been used for these large ‘test-tubes’ containing 300–3000 m^3 (**Figure 1**). A column of water containing the natural plankton is captured by drawing up the bag from the bottom and fastening it in a rigid frame. The water and plankton can then be sampled by normal oceanographic methods.

It is possible to maintain at least three trophic levels – phytoplankton, copepods, and fish larvae – for 100 days or more. The only necessary treatment is addition of nutrients to replace those in the organic matter that sinks out. Such mesocosms can also be used for study of the fates and effects of pollutants.

These mesocosms have the obvious advantages associated with their large volumes – numerous

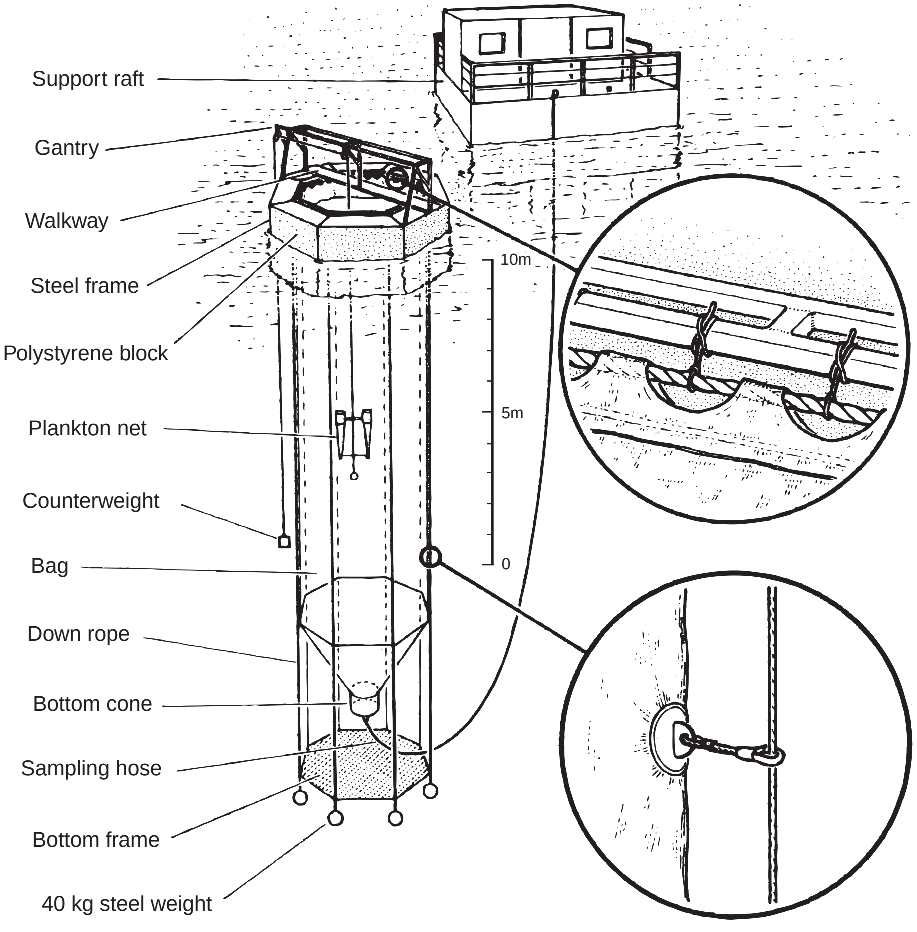

Figure 1 The design of a mesocosm used in Loch Ewe, Scotland for studies of the dynamics of plankton communities and of fish larval growth and mortality (adapted from Davies and Gamble, 1979).

animals for sampling, minimal wall effects. Temperature is regulated by exchange of heat through the walls. But they have various drawbacks. Not only is advection suppressed but vertical mixing decreases so that the outside physical conditions are not reproduced. The greatest disadvantage, however, is lack of adequate replication. There have been only three to six of these mesocosms available for any experiment and pairs did not often agree closely. Thus each tube represents an ecosystem on its own rather than a replicate of a larger community.

The need for experimental results at the community level represents an unresolved problem in biological oceanography. There are smaller-scale experiments continuing. Open mesh containers through which water and plankton pass can be a compromise for the study of small fish and fish larvae. It is now possible to mark a body of water with very sensitive tracers and follow the effects on plankton of the addition of nutrients, specifically iron, for several weeks. The concatenation of these results may have to depend on computer simulations.

See also

Copepods. Fish Larvae. Iron Fertilization. Population Dynamics Models.

Further Reading

Cowan JH and Houde ED (1990). Growth and survival of bay anchovy in mesocosm enclosures. *Marine Ecology Progress Series* 68: 47–57.

Davies JM and Gamble JC (1979) Experiments with large enclosed ecosystems. *Philosophical Transactions of the Royal Society, B. Biological Sciences* 286: 523–544.

Gardner RH, Kemp WM, Kennedy VS and Peterson JS (eds) (2001), *Scaling Relations in Experimental Ecology*. New York: Columbia University Press.

Grice GD and Reeve MR (eds) (1982). *Marine Mesocosms*. New York: Springer-Verlag.

Lalli CM (ed.) (1990). *Enclosed Experimental Marine Ecosystems: A Review and Recommendations*. Coastal and Estuarine Studies 37. New York: Springer-Verlag.

Underwood AJ (1997). *Experiments in Ecology*. Cambridge: Cambridge University Press.

MARINE POLICY OVERVIEW

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Introduction

Marine policy is an academic field in which approaches from social science disciplines are applied to problems arising out of the human use of the oceans. Usually, human actions affecting ocean resources take place within an institutional context: laws establish a system of enforceable property rights, and goods and services are exchanged through markets. Most marine policy problems involve institutional imperfections or 'failures.' Governance failures include ill-defined property rights, the incomplete integration of the actions of public agencies operating under separate authorities, and wasteful 'rent seeking' on the part of stakeholders. Market imperfections include oil spills, nutrient runoffs leading to eutrophication in coastal seas, and overexploitation of commercial fish stocks, among others. Even in the absence of technically defined institutional failures, problems may arise when decisions allocating marine resources are perceived to be unfair.

Most marine policy issues are subsets of broader policy areas. Some examples are presented in **Table 1**. Marine policy can be distinguished from these more general policy areas because legal property rights in the ocean often differ from those found on land. One reason for this difference is the relatively high cost of monitoring and enforcing private property rights in a remote and sometimes hostile environment. Other reasons include the fugitive nature of biological resources and the ease with which nutrients and pollutants are dispersed by currents and other physical processes.

The existence of these characteristics argues for collective action (i.e., the exercise of public authority) as a means of optimizing human uses and managing conflicts among users. The nature of collective action covers a spectrum from a centralized system of government 'command and control' to the implementation of decentralized 'market-based approaches.' The goal of marine policy analysis is to identify alternative courses of action for addressing a problem of ocean resource use and to inform public and private decision makers about the likely consequences. Consequences include physical, ecological, economic, and distributional (equity) effects. In any particular situation, the universe of policy