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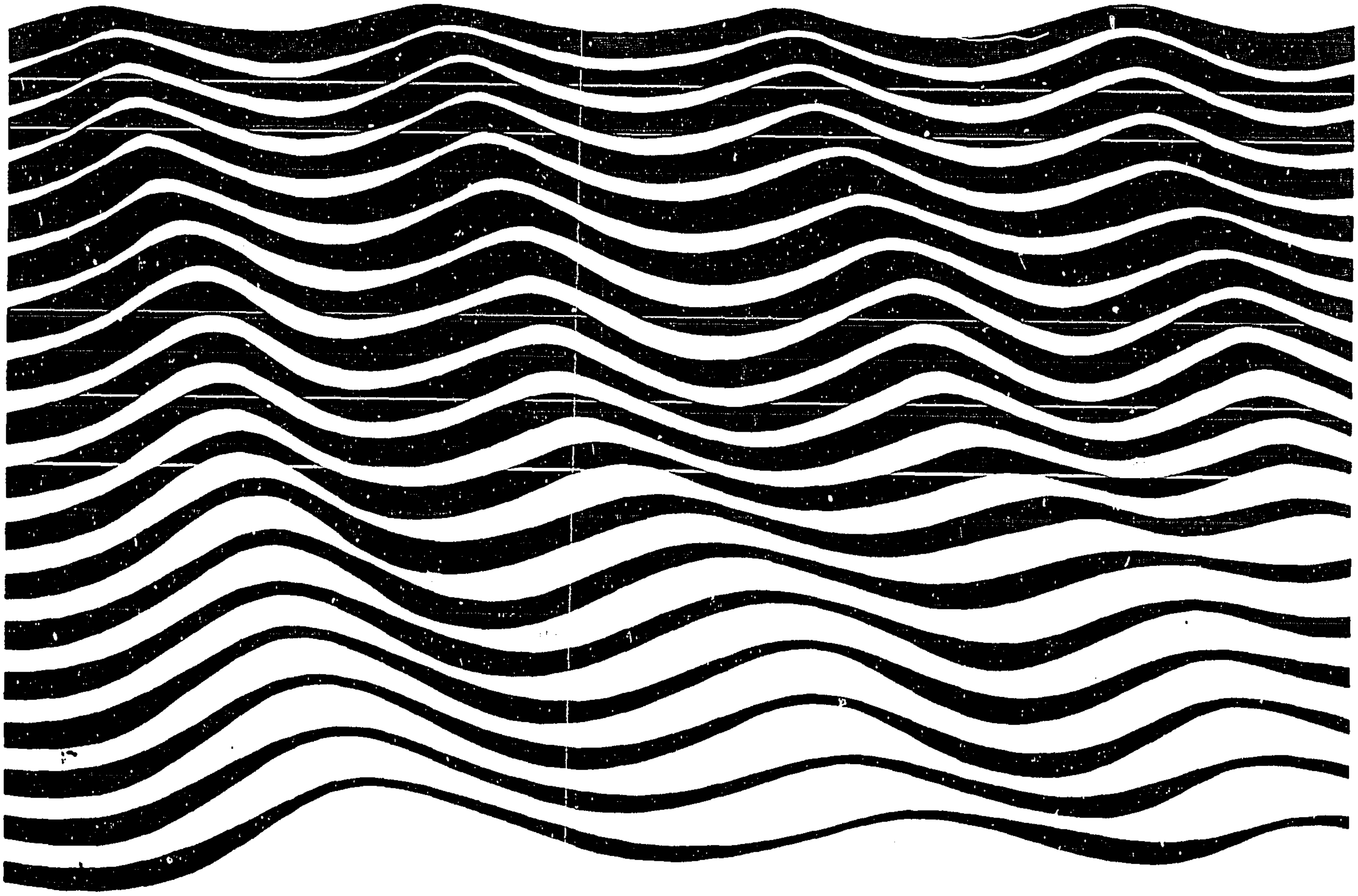
Marine Science Teaching at the University Level

Report of the Unesco Workshop on
University Curricula



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UNESCO TECHNICAL PAPERS IN MARINE SCIENCE

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No.		Year	SCOR WG
9	Report on intercalibration measurements, Leningrad, 24-28 May 1966 and Copenhagen, September 1966; organized by ICES	1969	
13	Technical report of sea trials conducted by the working group on photosynthetic radiant energy, Gulf of California, May 1968; sponsored by SCOR, IAPSO, Unesco	1969	WG 15
15	Monitoring life in the ocean; sponsored by SCOR, ACMRR, Unesco, IBP/PM	1973	WG 29
16	Sixth report of the joint panel on oceanographic tables and standards, Kiel, 24-26 January 1973; sponsored by Unesco, ICES, SCOR, IAPSO	1974	WG 10
17	An intercomparison of some current meters,report on an experiment of Research Vessel Akademic Kurchatov, March-April 1970, by the working group on Current Velocity Measurements; sponsored by SCOR, IAPSO, Unesco	1974	WG 21
18	A review of methods used for quantitative phytoplankton studies; sponsored by SCOR, Unesco	1974	WG 33
19	Marine Science Teaching at the University Level. Report of the Unesco Workshop on University Curricula - *Also published in French and Spanish*	1974	

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Marine Science Teaching at the University Level

Report of the Unesco Workshop on University Curricula

Paris, 17-20 December 1973

Unesco 1974

PREFACE

This series, the Unesco Technical Papers in Marine Science, is produced by the Unesco Division of Marine Sciences as a means of informing the scientific community of recent developments in oceanographic research and marine science affairs.

Many of the texts published within the series result from research activities of the Scientific Committee on Oceanic Research (SCOR) and are submitted to Unesco for printing following final approval by SCOR of the relevant working group report.

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The oceans are an important part of the global environment. They cover more than 70 per cent of the earth's surface and in volume are about 12 times that of the land masses over sea level. This great body of water influences the living and non-living processes of the land while concomitantly providing for a wealth of organisms and a reservoir of water and minerals from which man derives much of his substance.

To understand the world in which we live and to wisely use the oceans for man's benefit, intensive scientific studies of the ocean environment on a local, regional and world-wide basis should be undertaken systematically by all peoples of the world but especially those bordering the sea. Application of research and training aspects should be available to all. Ocean studies in the past have largely been done by the highly developed countries. However, as man continues to place ever increasing demands on the ocean environment for his uses, a greater understanding of his effects, particularly in the local regions, must be obtained. Neglecting the acquisition and application of such knowledge can only lead to a diminishing capacity of the ocean to provide those items desired or essential to man's existence.

The application of relevant ocean knowledge to a local situation can best be accomplished by the people of the local country or region and will require the availability of properly trained ocean scientists to do research, give advice and train others. It is with this explicit purpose that the Unesco Workshop on Marine Science University Curricula has prepared the following report as a document of encouragement and advice for establishing or improving marine science training programmes, particularly in the smaller and developing countries or regions of the world. However, any country or region which desires to enter into a training and research programme in marine science should further seek the advice of consultants familiar with the detailed problems encountered in such an undertaking.

At its seventh session in November 1971 the Intergovernmental Oceanographic Commission adopted Resolution VII-31, one part of which instructs the IOC Secretariat to compile representative plans and programmes for the teaching of marine science at different levels (including recommended curricula). In compliance with this resolution a questionnaire was sent to selected training institutes in several countries requesting information on their current training programmes in marine science. The results of this survey were summarized in a document (IOC/TEMA - 1/12) entitled "A Preliminary Survey of University Curricula in Marine Science", submitted at the first session of the IOC Working Group on Training, education and mutual assistance held in Paris 7-13 March 1973. At the suggestion of the Group, the Unesco Division of Marine Sciences contacted a number of leading marine scientists and marine science educators, requesting their co-operation in drawing up a list of selected textbooks and reference material useful for marine science training. On the basis of the replies received, such a list of books was prepared.

As a follow-up to these surveys the Division of Marine Sciences decided to invite a small group of well-known marine science educators to provide guidelines for the education and training of marine scientists and formulate recommended curricula in the following disciplines: marine biology (including fisheries biology), physical oceanography, chemical oceanography and marine geology.

The members of the workshop, which met at Unesco Headquarters in Paris, 17-20 December 1973, were:

Prof. Gotthilf Hempel
Institut für Meereskunde an der Universität
Kiel, Federal Republic of Germany

Prof. Donald W. Hood
Director, Institute of Marine Science
University of Alaska, U.S.A.

Dr. Ulf Lie (Rapporteur)
Biologisk stasjon
Universitetet i Bergen, Norway

Prof. George L. Pickard
Director, Institute of Oceanography
University of British Columbia, Canada

Prof. Adrian F. Richards
Marine Geotechnical Laboratory
Lehigh University, Pennsylvania, U.S.A.

Prof. Artem S. Sarkissian
Institute of Oceanology of the USSR
Academy of Science
Moscow, USSR

Prof. Eugen Seibold
Geologisch-Paläontologisches Institut der Universität
Kiel
Federal Republic of Germany

Dr. Unnsteinn Stefánsson (Chairman)
Hafrannsóknastofnunin
Reykjavík, Iceland

Dr. Marta Vannucci
Unesco Curator
Centro de Preclasificacion oceanica de Mexico
Mexico

The following agenda was adopted:

1. What should be the main objectives of marine science training, taking into account needs and priorities of different levels of development?

2. Organizational and interdisciplinary aspects.

   2.1. Depending upon the financial resources available, should marine science training be organized through the establishment of a marine science department, or should the various marine science disciplines be affiliated with separate science departments (e.g. physical oceanography as an option in geophysics, marine biology as an option in a biology department, etc.)?

   2.2. To which extent should multidisciplinary and interdisciplinary aspects of marine science be emphasized? Through an introductory course on the marine environment or through substantial training in major oceanographic disciplines prior to specialization?

3. Level at which marine science training in various disciplines should start in the university.

   3.1. What should be the minimum requirements of students in relevant basic science subjects (mathematics, physics, chemistry and related subjects such as biology, geology or geophysics) for starting training in the various marine science disciplines?

   3.2. Should marine science training be offered only to students who have completed their first degrees (B.Sc., or equivalent) in a basic science subject?

   3.3. Should an introductory course in general marine science be offered at a lower level as an elective?

4. Curriculum programmes.

   4.1. Description of courses needed in a marine science discipline selected as a speciality.

   4.2. Description of courses needed or recommended in marine science disciplines other than the major one.

   4.3. Courses needed or recommended in supporting subjects.

   4.4. Marine science training in relation to other multidisciplinary environmental science fields.

   4.5. Shipboard training.

   4.6. Research requirements.

   4.7. Language requirements.

   4.8. Suggested course schedules.

5. Estimation of minimum duration of oceanographic training to achieve.

   5.1. A first degree (if offered).

   5.2. Higher degrees.

6. Minimum facilities required to organize oceanographic university training of an accepted standard.

   6.1. Facilities for training in relevant basic and supporting science subjects (mathematics, physics, chemistry, biology, geology, etc.).

   6.2. Teachers and their qualifications.

   6.3. Laboratory equipment facilities. Problems of servicing.

   6.4. Library.

   6.5. Recommended texts for students.

   6.6. Shipboard training facilities.

The main items of the workshop report are summarized in the recommendations listed in Annex I.

In the present context, the term "marine science" is taken to include the application of the basic sciences (physics, chemistry, biology and geology) to the study of the oceans but to exclude the technological aspects of ocean engineering. The term "curriculum" describes the aggregate of courses offered in the subject.

The basic objectives of university education in marine science are to prepare scientists (1) to carry out research, (2) to offer expert advice and (3) to train others. Research includes the development of theories and new methods; designing observational programmes; making observations in the field; and presenting and interpreting them for use by scientists and by others. The research programmes and advice might, for example, be concerned with providing the scientific information needed for rational utilization of the sea and its resources and for proper design of coastal and offshore structures. The advice might be of a technical nature as required by a government or industry or be of a more general nature to educate the public. Training would be primarily academic instruction in a university but might also include programmes within a research institute.

The marine science field is both multidisciplinary (involving several basic sciences) and interdisciplinary (involving problems on the boundaries between the basic sciences). Therefore the individuals trained must be highly qualified in at least one basic science field; they should have an acquaintance with other fields, and if possible, they should also have a good knowledge of a second scientific field.

The priorities within the scientific fields will depend on the needs of the particular country or region. From the scientific point of view some of the major applications of marine science expertise are (1) in relation to living resources, (2) for the assessment of mineral resources, including petroleum (3) in relation to forecasting weather and sea conditions and (4) for the disposal of pollutants.

Many other applications of results from oceanographic studies could be suggested. It is emphasized that the order of priority may be different from one country or region to another, although it is probable that the production of food from the sea (either by fishing or by aquaculture) is likely to be a high priority item in most cases.

A further need is to inform the public about the significance of the marine field to their well-being and to the country's economy. It is suggested that this information process could well be started in primary school and consideration should be given to offering interdisciplinary training and refresher courses for school teachers.

ORGANIZATION

The establishment of a full department or an institute of marine science in a university is considered the best way to create an organizational structure for oceanographic research, teaching and to encourage communication among scholars and students majoring in the different marine disciplines. This undertaking will be expensive because the department or institute preferably will consist of a critical nucleus of persons representing at least the four basic disciplines of marine science, a suitable library, adequately equipped laboratories, and a research vessel. The critical nucleus in all probability will include at least two professionals in each field.

If financial or other constraints do not permit the initial formation of a full department or institute, several alternatives are suggested.

1. A marine science department or institute can consist of a critical nucleus of scholars representing only one or two fields of marine science, and at least one scientist in each of the other basic fields. It is strongly recommended that positions be foreseen for the disciplines not initially established and that these positions be filled as soon as practicable. In many cases, particularly in developing countries, biological oceanography or fisheries biology will be the first curriculum to be established. The early addition of physical and chemical oceanography is especially desirable.

2. A department of science can provide graduate training in marine science and encourage scholars from other departments of the university to participate in the instructional programme. In this case, one qualified marine scientist should be responsible for the existing marine science curriculum within the department and the development of a broader marine science curriculum within the university.

3. An interdisciplinary committee, consisting of scholars teaching or concerned with marine science from various departments of the university, can co-ordinate the academic programme in marine science. It is desirable that the chairman of the committee, being a recognized marine scientist, be responsible for the development of the marine science curriculum and related facilities.

Undergraduate Studies

Undergraduate students desiring to become professional marine scientists should be encouraged to concentrate on the fundamentals of science and mathematics and to delay their formal instruction in marine science until graduate school.

However, an introductory undergraduate course in marine science offered as an elective will serve to demonstrate the interdisciplinary aspects of marine science to both science and non-science students. Such a course will help to create an awareness of marine science and its relevancy to global environmental problems, as well as a vocation.

Graduate Studies

It is recognized that modern oceanography requires specialists in the various disciplines who are familiar with the basic facts and trends of the other marine disciplines. Therefore, graduate studies in marine science should be initiated by a comprehensive instructional programme in general oceanography. This programme should comprise 100-150 lecture hours covering the four basic disciplines of marine science.

Full-scale training in marine science, including its broad requisites in basic science, is expensive. It is only economical if there is a definite demand for graduates in a major discipline of oceanography. Therefore, a department or an institute should be established only within a country or a region that has the potential of employing and effectively utilizing students graduating in marine science.

It is of paramount importance that within each country a strong liaison be established between governmental or other institutions in marine science and universities providing such education. Furthermore, student research projects might often be selected in consultation with an outside marine science institute or partly supervised by senior scientists of such institutes. It would also be of advantage if such scientists could to some extent contribute to university teaching on a part-time basis, by giving occasional lectures and participating in seminars. Similarly, research institutions should be encouraged to provide research facilities to university teachers. This co-operation between universities and institutions would be of mutual benefit. It would serve as an intellectual stimulus to scientists at the institutions, assure that the most pressing research needs be given appropriate priority when selecting projects for students, and prevent the universities from becoming ivory towers having little or no contact with practical problems.

1. General Requirements

It is recognized that a well-educated scientist in a relevant discipline may contribute to the study of the oceans, but there are strong arguments in favour of organized and integrated marine science education. Among these is the vast accumulation of knowledge concerning the ocean and its phenomena, the special nature of marine research, and the unusual requirement for interdisciplinary communication. Therefore, it is clearly an advantage both from the point of view of economy and effectiveness that marine scientists be educated by systematic training through organized courses, seminars and laboratory exercises in addition to field experience and selected research projects.

It is the opinion of the workshop that the need for a high standard of marine science university training is even greater in developing countries than in the highly industrialized countries where junior scientists may receive further and more specialized training at research institutions under the guidance of senior specialists. In the smaller and less advanced countries where each scientist may have to cope with research assignments of varied nature within his field, education in marine science needs to be as broad as possible.

The marine science curricula presented here are for graduate studies only. It is the consensus of this workshop that students entering this field should have a B. Sc. degree(1) in one of the natural sciences, with about 800 lecture hours in a basic subject (i.e. physics, biology, chemistry or geology). The background in mathematics for all students should include calculus; statistics, differential equations and computer programming are strongly recommended. It is highly desirable that all students have one university level course in physics, geology, biology and chemistry, including physical chemistry. Additional requirements are outlined in the prerequisites for each subject. This implies that a university entering into the marine sciences should have strong programmes in the natural sciences and mathematics. Language requirements should include a good knowledge of English, if this is not the language of instruction. Reading proficiency in one or more additional languages, in which significant oceanographic literature exists, is highly desirable.

Ideally, the individual who can best carry out research in the oceans has an indepth understanding of a broad spectrum of basic disciplines of science, at least a working knowledge of those areas in which he does not specialize, and the scientific tools necessary to formulate interactions within this system. In general, however, it is impractical for a single individual to competently cover the necessary areas of science which are related to the problems of the ocean. As a result, most of the research carried out in this field involves an interdisciplinary approach by a team of specialists who combine the results of their special talents in solving both simple and complex problems. As we continue to learn more about the ocean, its dynamics and the interactions between processes, a continuing trend toward large experiments in oceanography appears to be inevitable. The preparation of individuals to work in those teams is the major objective of the proposed curricula.

(1) B. Sc. is here understood to be that typical of the North American system.

In addition to the general prerequisites of a suitable background in a basic subject and courses in marine science disciplines, a knowledge of other related environmental sciences, such as limnology, may be desirable or essential, in particular for those preparing themselves for work in estuaries and inshore environments. Other special subjects (e.g. meteorology, geophysics and geochemistry) will be referred to under the separate marine science curricula.

The training should be sufficiently fundamental, even in the initial stages, so that the matriculating students can continue to develop their research programmes to lead to long-range meaningful understanding of the sea.

2. Introductory Course in Marine Science

2.1. General considerations

It is recommended that the first graduate instruction in marine science be a multidisciplinary course including physical, chemical, biological and geological oceanography. It should emphasize the close interrelation and mutual dependance of these disciplines. Although introductory, it should be comprehensive and of sufficient substance to provide basic knowledge of these fields. This is essential, since any marine scientist should be familiar with the research techniques and terminology of his fellow investigators. He should also be able to recognize results within his own field which might be useful to others, as well as to recognize when data obtained by workers in other fields may have a bearing on his own research.

This course should be taken by all students of marine science. However, that portion of the course which deals with their own major discipline may not be required (in the case of biological and chemical oceanographers), since it will be covered in more detail by special courses in their own field. Students majoring in physical oceanography will take introductory physical synoptic oceanography, and all students of marine geology will take the introduction to geological oceanography.

2.2. Course description

Synoptic Physical Oceanography (25 hours)

Dimensions of oceans; physical properties of sea water; including optical and acoustic properties; typical distributions of density, temperature, salinity and oxygen in the vertical and horizontal and in time; conservation of volume and salt; heat budget. General descriptions of the Southern, Atlantic, Pacific and Indian Ocean water properties and currents; detailed descriptions of regions near the particular country.

Dynamic Physical Oceanography (25 hours)

Classification of forces and types of motion in the sea. Kinematics of fluid flow, equation of continuity and applications. Equations of motion on a rotating earth, typical solutions including geostrophic flow, wind-driven currents (Ekman, Stommel, Munk). Wind waves, generation and character in relation to wind speed, duration and fetch, behaviour at the shore. Internal waves. Tsunami waves. Tides, general character of sea level rise and fall and of tidal currents, generating forces, analysis and prediction. Turbulent diffusion. Coastal and estuarine circulations.

Chemical Oceanography (40 hours)

Chemistry of water. Composition of sea water; constancy of composition concept; distribution of gases and minor constituents. Nutrient distribution and cycles; pH and carbon dioxide system; reduction-oxidation considerations; carbon cycle.

Selected radioactive and stable isotopes. Elements of marine pollution and eutrophication.

Chemical Oceanography Laboratory (20 hours)

A laboratory to teach especially important standard marine chemical techniques. The course will be offered to students to whom it may be applicable.

Biological Oceanography (30 hours)

Terminology; major taxonomic groups of marine organisms including examples of life history of plankton and benthos; vertical zonation including vertical migration; major water masses and their biological communities; the concept of food webs and ecological systems; production, food transfer and decomposition in relation to biotic and abiotic factors; effect of abiotic factors on species and communities; chemical and physical effect of the communities on their environment; pollution, exploitation.

Geological Oceanography (30 hours + 50 hours laboratory and field work)

Size, shape and origin of the ocean basins. Classification, composition, distribution, and source of sediments, with emphasis on coastal areas and the continental shelf. Near-shore and oceanic geological processes, including erosion, transportation, and deposition. Stratigraphy and structure of the continental margins and the deep-sea floor. Geological history and plate tectonics. Bathymetric surveying; sampling and laboratory techniques; analysis of geological data; and the application of marine geological knowledge to practical problems.

3. Curriculum in Physical Oceanography

3.1. Introduction

Physical oceanography is essentially the study of the movements of the ocean waters, with the object of understanding them well enough to predict them into the future. It is generally divided into two aspects, synoptic and dynamic. Synoptic oceanography involves observing the distribution of certain characteristics of the ocean waters, in both horizontal and vertical directions and also in time. From the distributions of properties it is possible to deduce the direction of flow of ocean currents; but to determine the speed of flow it is necessary either to make direct observations with current meters or to refer to techniques of dynamic oceanography. This aspect involves applying some of the basic principles of physics to the oceans. These principles include the Newtonian equations of motion and the principles of conservation of energy and of momentum. In their general form the resulting equations involve non-linear differential equations which have no general solutions. In addition, the complicated topography of the real oceans makes it difficult to obtain solutions. The classical approach has been to simplify these equations to a linear form and to solve them by stages for simple shapes of ocean basins. One result of this is the geostrophic method for calculating the velocity from the distribution of density (which is determined by the distribution of temperature and salinity) and from certain assumptions about locations of zero flow. To obtain more useful results, one must use modern numerical techniques for solution to the equations.

In practice, the dynamic method uses information from the synoptic approach and vice-versa, and the two progress together.

From the practical point of view, a knowledge of the circulation is essential if waste products are to be disposed of efficiently. It is also necessary for studies in connexion with fish behaviour and with the distribution of nutrients in relation to primary and secondary productivity. A knowledge of the relations between wind and waves can be useful to small boat operations or to offshore mining operations, and surges in harbours may need investigation. These are just a few examples of the applications of physical oceanographic studies.

3.2. Prerequisites

For graduate work in physical oceanography, a necessary prerequisite is a B. Sc. degree in physics and mathematics or the equivalent. The physics should include mechanics, properties of matter, thermodynamics, fluid dynamics, electricity and magnetism through Maxwell's equations, optics, atomic and nuclear physics and statistics. The mathematics should include algebra, analysis, differential and integral calculus, vector analysis, real and complex variables, numerical methods and computer programming. The other science subjects should include physical chemistry and electives from biology and geology.

3.3. Physical Oceanography - Course Description

Introductory Course in Marine Science (125 hours + laboratory)

Chemical, biological and geological oceanography and introductory synoptic physical oceanography. See 2.2.

Dynamic Oceanography I (50 hours)

Basic fluid mechanics including stream functions, vorticity, stress tensor, Navier-Stokes equations, Reynolds' Number, Bernoulli, Reynolds' stresses, non-inertial co-ordinate systems. General equation of motion for the ocean; special cases such as geostrophic flow, wind driven currents (Ekman, Stommel, Munk). Thermohaline circulation, equatorial currents, micro-structure, estuarine flow, numerical modelling.

Dynamic Oceanography II (seminar, 25 hours)

A review of selected journal papers on the dynamics of ocean currents.

Waves (25 hours)

Surface gravity waves of small amplitude, dispersion, group and phase velocity, energy and flux, refraction, radiation stress and sea level, edge waves, internal waves. Large amplitude waves, solitary and cnoidal waves, bores.

Turbulence (50 hours)

Reynolds' stresses, energy flow, inhomogeneous fluids, conservation of scalar properties, Richardson number. Locally isotropic turbulence, Kolmogoroff hypothesis and universal spectra. Measurement and instruments. Covariance, spectral theory and E (k). Turbulent boundary layers, similarity theory and statistics, experimental results.

Oceanographic Methods (25 hours)

Design of surveys, cruise procedures, measurement of temperature, salinity, oxygen, sampling bottles, winches and wire, research ship characteristics, echo sounding, position determination, current measurements. Electronic devices, pressure housings, tide and wave gauges. Plankton collection, bottom sampling by corer and dredge, seismic scunding.

Desirable additional courses include:

Advanced Synoptic Oceanography (seminar, 25 hours)

A review of selected journal papers.

Tides and Waves and Rotating Fluids (25 hours)

Description of tides, tide generating potential, equilibrium theory. Long waves in a rotating fluid (inertial, Kelvin, Poincaré), tides in open and closed basins and in estuaries; planetary (Rossby) waves; non-astronomical tides, tsunamis. Tidal observations, harmonic analysis, prediction, power from tides.

Air-Sea Transfer Processes (25 hours)

Physical processes at the air-ocean interface (micro-scale), wave generation, Phillips' and Miles' theories. Transfer of momentum and of sensible and latent heat. Radiation transfer.

Dynamic Meteorology (25 hours)

Basic principles with special reference to processes over the sea on micro- and meso-scale.

Applied Mathematics (50 hours)

Asymptotic methods, perturbation methods (WKB), Wiener-Hopf method, similarity methods, stochastic equations, transform techniques.

Numerical Methods (50 hours)

Numerical methods for solving differential equations with special application to the equations of dynamic oceanography.

4. Curriculum in Chemical Oceanography

4.1. Introduction

Chemical oceanography may be defined as follows: a broad account of the chemical composition of sea water, its constituents, species and processes; the effect of physical, geological and biological properties and processes and man's activities on the chemistry of the ocean in space and time; the chemical interaction between the ocean and its interfaces, the atmosphere and the lithosphere; application of chemical methods to all phases of marine science; the development of new chemical technology in response to problems of various disciplines of marine science.

This definition emphasizes the central rôle of chemical oceanography in the study of the sea, and it implies that the prospective chemical oceanographer needs not only a rigorous training in chemistry, but also education in various natural science disciplines which are concerned with the marine environment. The marine chemist will thus contribute to the understanding of problems concerning the fertility of the ocean; behaviour pattern of fishes; exchange of materials and properties between the ocean and the atmosphere; the interaction of waste disposal practices with other ocean uses; development and identification of non-renewable resources in the sea; advance technology in obtaining oceanographic data; and will provide necessary data for construction of numerical and physical models.

In regions initiating training in marine science where environmental information is lacking, it will be necessary to begin research programmes of a more descriptive nature. As countries develop their marine science background information a greater sophistication will be required, leading to a quantitative understanding of ocean processes.

The curriculum recommended below has in mind the training of chemical oceanographers who will during their careers contribute to the development of marine resources in their respective countries and to the understanding of the effects on the sea of man's activities.

4.2. Prerequisites

It is recommended that students of chemical oceanography should have a B.Sc. or equivalent in chemistry to include courses leading to specialization in physical, organic, analytical, inorganic and bio-chemistry. Bringing them to this level of training will obviously require the standard teaching facilities for these chemistry courses.

They should have mathematics through differential equations. Statistics and computer programming are highly desirable. The physics required for a B.Sc. or equivalent in chemistry would provide sufficient background in this area. Some courses in descriptive geology and elementary biology should be required.

4.3. Chemical Oceanography - Course Description

Introductory Course in Marine Science (110 hours + laboratory)

Physical, biological and geological oceanography. See 2.2.

Chemical Oceanography (50 hours)

Physico-chemical properties and processes of sea water; major and minor inorganic constituents and their distribution; chemical speciation; chemical equilibrium; chemical cycles; dissolved gases, distribution and processes; pH, alkalinity and the carbon dioxide system; organic carbon cycles; introduction to chemical technology as applied to exploitation of marine resources.

Chemical Techniques in Oceanography (60 laboratory hours)

Sampling techniques; chemical methods of analysis in routine use in oceanography; use of modern instruments; processing and interpretation of data.

Advanced Chemical Oceanography II (50 hours)

Advanced physical chemistry of sea water; dynamic equilibria in the chemical systems in the ocean, including trace metals, organic materials, stable and radioactive isotopes and suspended matter; chemistry of interstitial waters; formation and geo-chemistry of sediments. Processes involved in marine contamination including mode of entry, pathways and fate. Chemical models of the ocean.

General Multidisciplinary Seminar (30 hours)

Jointly for all disciplines of marine science.

Chemical Oceanography Seminar (30 hours)

For specialists in chemical oceanography and interested scientists in other disciplines.

Dynamic Physical Oceanography (50 hours)

See 3.3.

A choice of one of the following (50 hours)

1. An advanced physical oceanography course (see 3.3.);
2. Marine sedimentology and/or advanced geochemistry (see 6.3.);
3. Marine biology (see 5.3.) and/or marine biochemistry.

Optional Courses

Depending upon the student's area of interest, he should take enough additional special courses in chemistry, biology, geology or physics to gain depth in his speciality.

5. Curriculum in Biological Oceanography and Fisheries Biology

5.1. Introduction

Three major biological lines are related to the sea: marine biology, biological oceanography and fisheries biology. Marine biology may be defined as the description of the marine fauna and flora, the physiology and life history of marine organisms. Marine biology has a long tradition in several parts of the world, particularly in shallow waters of the temperate zone.

Biological oceanography is the description of biological systems and processes in the sea. The structure of marine ecosystems and the biological flow of energy and matter under various natural and man-made environmental factors are central questions of biological oceanography. The ultimate aim of biological oceanography is to understand the major biological processes as applied to the study of marine ecosystems. Therefore, in the teaching of biological oceanography the major emphasis must be on ecology, and the curriculum must include all major ecological branches such as systems ecology, synecology, population ecology and physiological ecology.

Fisheries biology is the study of the living resources of the sea, and of man's interaction with them, i.e. rational exploitation, aquaculture, marine pollution.

Obviously there are no well-defined border lines between marine biology, biological oceanography and fisheries biology. A good knowledge of marine fauna and flora, of marine communities, and of the life history of the dominant groups of organisms is a prerequisite for most approaches in biological oceanography. Fisheries biology can be considered as applied biological oceanography.

Because of the similarity between biological oceanography and marine biology, the workshop suggests identical training for the two lines of biological marine science. The distinction will be determined by the choice of thesis subject.

Any marine teaching programme has to take into account the close connexion between the three lines. Emphasis might change from place to place according to the needs and the teaching potential of each individual university. In many tropical regions, descriptive marine biology still needs to be strengthened. It should however be stressed that those adjustments should not result in the abolishment of other aspects of marine biology or biological oceanography. Furthermore, some information on the principles of marine pollution as well as of fisheries is an essential part of the training in biological oceanography.

5.2. Prerequisites

Students specializing in biological aspects of marine science must have a general background in the sciences as must other graduates in the various biological specialities. It is felt that the undergraduate curriculum must include a relatively high level of chemistry and mathematics. One of the major fields in present-day biological oceanography is marine productivity which is partly based on mathematics (statistics, population dynamics) and partly on chemistry (environmental physiology, energy transfer). The undergraduate mathematics curriculum must therefore include statistics, calculus and matrix algebra. Some knowledge of computer programming is a definite advantage. Undergraduate chemistry must include qualitative and quantitative analytical inorganic and organic chemistry, and good laboratory courses in chemistry are essential. For a proper understanding of biological processes, such as primary production, the rôle of biological pigments, energy transfer, etc. a good knowledge of physical chemistry must be emphasized.

5.3. Biological Oceanography - Course Description

Introductory course in marine science (120 hours + laboratory)

Physical, chemical and geological oceanography. See 2.2.

Introductory course in Biological Oceanography (25 hours)

A review of biological processes such as primary and secondary production, annual and seasonal cycles, and the relationships among these processes and environmental conditions.

Floristics and Faunistics (45-75 hours + laboratory)

Suggested breakdown: regional phytoplankton and zooplankton: 15-25 hours + laboratory; regional phytobenthos and zoobenthos: 15-25 hours + laboratory; regional marine vertebrates: 15-25 hours + laboratory.

Systems ecology and synecology (30 hours)

Includes the discussion of marine ecosystem models, description of communities, community structure and function. Thorough treatment of plankton, benthos, nekton, etc., with emphasis on local fauna.

Population ecology (25 hours)

Includes growth, reproduction and mortality of unexploited (invertebrate) populations, with examples if possible from local marine populations.

Physiological ecology (15 hours)

Includes the interaction between organisms and environmental parameters, experimental design, energy budget.

In all the ecology classes there must be laboratory classes, but the emphasis must be on calculations based on case studies and not on sorting, identification, etc.

Marine Microbiology (10 hours)

Includes major microbiological processes in connexion with decomposition of organic matter and regeneration of nutrients.

Basic Fisheries Biology (15 hours)

Includes biology of fishes, principles of theory of optimum fishing, and review of local fisheries.

World Fisheries Resources (20 hours)

The resources of the major ocean regions. Predictions of fishing potentials for single species and for multi-species assemblages. Estimating potential from biological oceanography such as primary production, food chain efficiencies, etc. Predictions based on echo-surveying, surveys of eggs and larvae, exploratory fishing.

General Multidisciplinary Seminar (30 hours)

Jointly for all disciplines of marine science.

5.4. Fisheries Biology - Course Description

Introductory course in marine science (120 hours + laboratory)

As for biological oceanography. See 2.2.

Introductory course in Biological Oceanography (25 hours + laboratory)

As for biological oceanography.

Floristics and Faunistics (15 hours)

As for biological oceanography but reduced (15 hours).

General Marine Ecology (40 hours)

As for biological oceanography but reduced (40 hours).

General Biology of Fishes (35 hours)

Includes age determination, growth, fecundity, reproduction and life history of fishes, with examples preferably, but not exclusively, from local populations. Migrations and feeding ecology. Fish diseases and parasitology.

Regional Fish Resources (25 hours)

Review of major local fisheries ranked by economic and social importance. Emphasis on biology of the species, the relationship between the developments of techniques and the history of the fisheries, and protective measures.

Exploited Non-Fish Resources of the World (25 hours)

Review of major fisheries for molluscs, crustaceans and mammals, including local potentials.

Aquaculture (25 hours)

Review of the culturing of molluscs, crustaceans and fishes with emphasis on techniques, diseases and economic aspects. Should include excursions to aquaculture installations, if available.

Dynamics of exploited populations (20 hours)

Estimation of population parameters such as recruitment and gear selection, growth and mortality. Application of yield equations. Extensive use of laboratory courses.

World Fisheries Resources (20 hours)

Same as for biological oceanographers.

General Multidisciplinary Seminar (30 hours)

Jointly for all disciplines of marine science.

6. Curriculum in Geological Oceanography

6.1. Introduction

Marine geology or geological oceanography may be defined as the geological study of that part of the solid earth covered by sea water, or oceanic islands, and of the coastal zone. It is concerned with: the origin of the continental margins and the ocean basins and their associated features; the composition, structure, stratigraphy, and history of the sediments and rocks underneath the oceans; the processes of erosion, transportation and deposition of geological materials under different morphological and climatological conditions and the comparison of recent and ancient marine sediments and environments.

The practical application of this knowledge may be directed towards the exploration and exploitation of non-living resources, particularly oil, gas and minerals of economic importance; siltation in harbours and bays; and erosion, deposition and movement of sediments along the shore. Marine geology is an integral part of coastal and seafloor engineering.

The curriculum presented is predicated on the assumption that a good geological oceanographer must first be a good geologist. Graduate-level preparation has been designed to strengthen the students' knowledge of the geological sciences and to introduce them to the marine environment. Students having undergraduate preparation in geophysics and geochemistry would be encouraged to take advanced seminars or elective courses in the marine geosciences.

Geological oceanography is considered to include not only marine geology, in the strict sense, but also marine geophysics and marine geochemistry, since many aspects of the science lead naturally into these latter disciplines.

The degree of specialization to be achieved in an institute will depend upon the environment to be studied and the purpose of the institute or department. An institute devoted to coastal processes will have a strong emphasis on sedimentological techniques; one devoted to exploration or exploitation of oil and gas will have a strong emphasis on marine geophysics; while one devoted to pollution or to carbonate studies (such as on coral reefs) will have a strong emphasis on marine geochemistry. A broadly based institute or department may have to have a broad curriculum of specialized courses. However, if the students have adequate backgrounds, a common core of graduate courses can serve to prepare the students for research. This requires that the incoming students are trained geologists, geophysicists or geochemists.

In the courses listed below, a student would be expected to take up to 300 lecture hours, in addition to the Introductory Course in Marine Science, in those courses necessary for his specialization. The variety of courses allows for several different specializations. Advanced courses can be added or deleted depending on local facilities and priorities and the regional geological environment.

Preparation of students for computer processing of data should be made as soon as local conditions permit.

6.2. Prerequisites

Students specializing in the geological aspects of marine science must have a general background equivalent to a B.Sc. degree in geology. In mathematics this curriculum should include algebra, geometry, trigonometry, and calculus (differential and integral); some knowledge of statistics and computer programming is desirable. In physics, a course should include elementary mechanics, electricity and magnetism, optics, and introductory atomic and nuclear physics. In chemistry, courses are required in inorganic chemistry, quantitative analysis, and introductory physical chemistry. Because sediments containing biogenous particles and organic remains have a stratigraphic record in the past geological environment, undergraduate biology must include elementary zoology and botany with some knowledge of systematics.

Fundamental courses in geology include lectures and laboratory work in general geology (physical and historical geology); structural geology; mineralogy, crystallography and petrology; and paleontology and/or stratigraphy. Field geology, consisting of field trips and mapping (about four weeks), is an essential part of geological education.

Students specializing in geophysics should have a firm background in mathematics and physics like that presented for the Curriculum in Physical Oceanography but without atomic and nuclear physics. It should include courses in geophysical techniques (seismic reflection and refraction, heat flow, geomagnetism, gravity) with field experience as well as basic geologic courses such as physical geology, historical geology, structural geology and sedimentology.

Students specializing in geochemistry should have a background similar to that required for the Curriculum in Chemical Oceanography with additional courses such as physical geology, historical geology, mineralogy and sedimentology.

6.3. Marine Geology - Course Description

Introductory Course in Marine Science (150 hours + laboratory)

Physical, chemical, biological and geological oceanography. See 2.2.

Tectonics (50 hours)

The solid earth crust-mantle system and its movements. Structure, origin and evolution of the ocean basins and continental margins. Plate tectonics hypothesis. Relationships of terrestrial and oceanic features.

Marine Sedimentology (50 hours + 50 hours laboratory)

Marine processes or erosion, transportation and deposition; composition, single-grain, texture and structural relationships of sediments; consolidation of the water-sediment-gas system; diagenesis; sedimentary environments; examples of sedimentological problems relevant to coastal and seafloor engineering.

Paleontology (50 hours + 50 hours laboratory)

Description of the geologically significant plants and animals comprising the marine micropaleontological record; representative groups of marine invertebrate and vertebrate fossils; principles of fossilization, taxonomy, paleoecology and evolution.

Geology of Continental Margins (50 hours)

Comparison of types of continental margins; deep and shallow geologic structure; processes of formation and evolution of continental margins; petroleum and mineral deposits; comparison to continental analogues.

Marine Volcanology (50 hours)

Petrology and chemistry of volcanic rocks; magmatic evolution; volcanic processes; relationship of volcanism to plate tectonics; contrast of island arc and rift volcanism; alteration of volcanic rocks; structural and erosional alteration of volcanic forms.

Geochemistry (25 hours)

Principal geochemical cycles and processes in the hydrosphere and lithosphere; radiometric dating.

Advanced Marine Geochemistry (50 hours + 50 hours laboratory)

Geochemical and biochemical processes in sediments and their interaction with the overlying water and organisms; evaluation of geochemical balances; geochemical paths of heavy metals and pollutants; geochemical processes of coastal areas and the deep ocean. Application of techniques to the marine environment. Individual research required.

Geophysical Acoustics (50 hours)

Sound transmission in water and sediments. Principles of the acoustic properties of water, sediments and other rocks. Introduction to the techniques of echo-sounding, sound ranging and backscatter, side-scan sonar, seismic refraction, seismic reflection and information transmission.

Geophysics (75 hours + 50 hours laboratory)

Elementary principles and practices of seismology, geomagnetism, gravimetry, and thermal properties leading to the elucidation of the structure of the earth, with particular emphasis on marine problems.

General Multidisciplinary Seminar (30 hours)

Jointly for all phases of marine science.

Advanced Seminars in Marine Geology and/or electives (variable)

7. Shipboard Training

Shipboard training is an essential part of the education of a marine scientist. The student should have sufficient shiptime, either through the facilities provided by his own university or a co-operating agency, to become familiar with the basic oceanographic techniques used at sea. A minimum of two weeks at sea appears essential for this training; however, longer periods are recommended. Initially the student should go to sea with an experienced group to become used to living and working on a ship. For the theoretician, this experience with other groups would be sufficient; for the experimentalist, it is necessary that he then plan and execute his own research project on cruises, under the supervision of a professor.

8. Research Requirements

For a student who is preparing himself to carry out research, it is essential that he plan, execute, analyse and write up a research project, besides undertaking course work. This would culminate in a thesis or dissertation which would have to be accepted by his responsible supervisor and/or supervising committee. The research topic should be selected in consultation with his supervisor or supervising committee. The topic should preferably be one which is relevant to the marine environment of his region, but at the same time involve both application of theory and training in methodology. It would be desirable that the material be suitable for publication in a recognized journal, although this would not be required. The research project would constitute about one-half of the student's effort towards his degree.

9. Duration of Marine Science Training

The marine science programme here envisaged is aimed at providing an M.Sc. degree or equivalent, and its duration will be about two years or more of graduate studies. Fellowships should be made available to enable the best M.Sc. candidates to continue abroad their studies towards a Ph.D. degree or equivalent at a well-known institute of advanced studies.

A Ph.D. programme in marine science of suitable standard requires sophisticated facilities and highly competent research and teaching staff. Therefore it is recommended that such a programme should not be attempted initially, and only at such universities which have reached a high level of development in marine science teaching and research.

1. Teachers and Their Qualifications

Minimum manpower requirements for a full curriculum as here described in the four basic disciplines are estimated as follows:

for biological oceanography, two or three full-time employed professors; for fisheries biology two additional teachers are needed;

for chemical oceanography, two professors;

for marine geology, three professors;

for physical oceanography, two professors.

University professors in marine science should hold a Ph.D. degree or equivalent, have research experience and teaching proficiency. It is the concensus of the workshop that only those who are themselves active in research are likely to be effective and stimulating teachers and research supervisors. Therefore, the professors should not be overloaded with teaching, and they should be provided with facilities to participate in cruises and carry out research in their respective fields.

2. Laboratory and Ship Facilities

To efficiently train students in the programme envisioned, it will be necessary to provide shore laboratory and ship support facilities.

The laboratory must be sufficiently large and be suitably equipped to carry out marine biological, chemical, geological and physical oceanographic work. The size and facilities needed will of course depend on the research requirements and the number of students, and must be worked out for each specific situation.

If the university is located far from the coast, provisions must be made for docking of ships and storage of sampling gear at a convenient seaside location. Such facilities should also have some laboratory for running certain chemical analyses and for the initial treatment of biological samples.

Without access to a ship or boat, marine science training is hardly conceivable. For certain types of investigations in harbours or nearshore regions a small boat may possibly be used, but for training purposes, even in the coastal zone or estuarine environments, a larger vessel is generally essential. It is strongly recommended that any university planning to initiate marine science training should acquire at least a 15 to 17 metres research vessel for its own use. Although a specifically built research vessel is desirable, local boats or ships can often be satisfactorily converted for this purpose. The ship should have living quarters for six to eight persons in addition to the crew. The research vessel must have good navigational equipment suitable for local conditions and may include sextants used for positioning by horizontal angles, radar, electronic devices, etc. Other shipboard equipment will consist of an echosounder (for geological work a good quality precision-type echosounder is particularly recommended), a powered winch, a hydrowinch and sampling gear. A modest laboratory for wet and dry work is essential.

For research and training cruises in offshore or deep water regions, a larger ship with more sophisticated equipment and facilities is needed. Shiptime for students, professors and research staff on such research vessels must be ensured either through ownership or through arrangements with other agencies (local, national or foreign).

3. Equipment

Certain shipboard equipment, essential for any marine science training, such as navigational devices, winches, and echosounders, have already been mentioned. In conjunction with biological, chemical, as well as physical oceanographic studies, water sampling bottles (non-metallic, e.g. NIO or Niskin type) sample bottles and jars, and temperature measuring devices are needed. Special minimum requirements by disciplines are as follows:

Physical Oceanography

Minimum laboratory and shipboard equipment needed are as follows (assuming that the ship has a hydrowinch and wire): water sampling bottles, reversing thermometers of good quality (protected and unprotected), bathythermographs and auxiliaries, salinometers (inductive), transparency meters, current meters (both for ship use and for anchorage buoys), meteorological equipment (air temperature and humidity, wind speed and direction, pyranometer), desk computer. A self-contained S.T.D. (salinity-temperature-depth) recorder is desirable.

Chemical Oceanography

Laboratory equipment consisting of instruments for precise measurement of salinity and temperature, pH, oxygen, transparency and chlorophyll, refrigerators, spectrophotometers, autoclaves, balances, calculators, temperature controlled water baths, sampling bottles, laboratory glassware and chemicals will be needed. Much valuable work can be done in the oceans by competent individuals without sophisticated equipment. However, as the programme develops, the need for sophistication will also increase and it will be necessary to have access to computer facilities, atomic absorption spectrophotometers, mass spectrophotometers, gas chromatographs, radioactive counting systems, X-ray diffraction apparatus, and other equipment common to a modern university.

Biological Oceanography

Shipboard sampling equipment including standard plankton nets, high speed nets, neuston nets, micronecton nets, dredges, grabs, corers, trawls, beach seines, flow-meters, field salinometers, oxymeter, pH-meter, bathythermographs, teflon coated water bottles. For subsequent treatment of biological material in the laboratory, refrigerators and deep freezers, drying ovens, muffle furnaces, balances, microscopes (compound, stereo and Utermöhl), aquaria, laboratory pumps, constant temperature rooms, surgical and photographic equipment, calculating machines, and assorted glassware are necessary. For more advanced studies at least some of the following instruments are required: spectrophotometers, bomb calorimeters, potentiometer recorders, radioactivity counters, centrifuges and equipment for particle size analyses. Chemicals for preservation and for neutralization of preservatives, and for analyses of organic matter, carbon, nitrogen, oxygen, etc. are essential in the laboratory.

Fisheries Biology

The sampling for fish eggs and larvae and for planktonic and benthic food requires the same shipboard equipment as listed for biological oceanography. For the catching of larger fish, echosounding devices and fishing gear are required of the same kind as used in the commercial fishery or the region. Most of the laboratory equipment for biological oceanography is also needed in fisheries biology. For standard methods of fishery biology, a projection microscope, fish egg counter and equipment for determination of basic compounds (water, lipids, protein) are required in addition. Emphasis should be laid on calculating devices, preferably with access to a computer, and on good aquarium facilities. Studies in the biochemistry of fish and in accumulation of pollutants require the sophisticated apparatus listed for advanced biological studies. However, acquisition of most of such apparatus should be deferred until specific research projects are formulated that require such equipment.

Geological Oceanography

The laboratory tools and equipment of the geological oceanographer involved in the sedimentary environment consist of: a binocular and a petrographic microscope, with such accessories as heavy liquids; wet chemicals with glassware or standardized instruments for routine chemical analysis of organic matter and calcium carbonate; sediment sieves and water sediment column for size analysis, balances, etc. The laboratory equipment for a geochemist will be similar to that of a chemical oceanographer. The laboratory equipment of a geophysicist will vary with his speciality but must include test equipment such as voltmeters and oscilloscopes.

Shipboard equipment for a beginning research and training programme will consist of as good a quality echosounder as can be afforded and sampling gear such as grabs, dredges and short corers. For the next stage in training and research, equipment such as vibrocorers for sand and long-piston corers for mud will be needed in sedimentology and geochemistry, while geophysical equipment, such as seismic profilers magnetometers and side-scan sonars will be needed.

For advanced studies, more sophisticated equipment is required, using modern techniques in marine geology and geophysics. The choice of this equipment will depend on local conditions and on the long-term objectives of the studies.

4. Servicing

Although some items may be manufactured locally (e.g. net frames, dredges, corers), the greater part of the specialized oceanographic equipment will have to be purchased from suppliers in other countries. The mechanical items, such as water sampling bottles or plankton nets, can be maintained locally with a small mechanical workshop and a metal-working technician. Electrical and electronic equipment, however, will need well-trained technicians in this field with test equipment and supplies of spare parts and materials. For the periodic calibration of instruments, such as thermometers and bathythermographs, it will probably be necessary to use established calibration facilities. Overall, it is estimated that maintenance of laboratory and shipboard equipment might require at least ten per cent of the annual budget of the institute.

5. Library

A technical library is of fundamental importance in marine science.

The library should have as strong a collection as possible in the basic biological, chemical, geological and physical sciences. Moreover, the acquisition of basic reference works in their fields is of utmost importance for libraries with limited resources and must precede the acquisition of marine science literature.

Three selective bibliographies of books have been compiled (see Annex II); none of these lists is intended to be exhaustive or exclusive. The first of the three selective bibliographies indicates some of the typical books considered suitable for an introductory, interdisciplinary marine science course taught at the undergraduate level. The second list includes a selection of books considered suitable for beginning graduate students taking each of the four basic marine science courses that have been recommended. The third bibliography contains a short list of advanced-level or reference books considered desirable for marine science graduate students beyond the beginning level.

It was the consensus of the workshop that there is a need for an introductory multidisciplinary textbook in marine science suitable at the graduate level. It is recommended that Unesco in consultation with SCOR investigate the possibility of arranging for the publication of such a textbook, which should be written by recognized marine scientists in the four basic disciplines.

A list of the abstracting journals, periodicals, annual reviews and other serials essential to a graduate-level marine science curriculum is also presented (Annex III). This should by no means be considered an exhaustive list of journals, but rather as examples of the most important international publications particularly useful for training and education. In addition to this basic list of international journals, regional marine science journals suitable for a graduate curriculum should also be acquired by the library.

The establishment of such a core collection is costly. At 1974 prices it is estimated conservatively that the price of average marine science books is $20, and the average price of marine science journals is $40 per year. (These figures do not include the price of abstracting journals and expensive reference sets, nor the cost of ordering and cataloguing).

At universities where graduate students do not customarily purchase their own textbooks, libraries should acquire multiple copies of texts required for each course in the approximate ratio of one copy for every 5-10 students.

SUMMARY OF RECOMMENDATIONS

1. The increasing demands by man on the marine environment require intensive and systematic studies as a prerequisite for a rational utilization. The acquisition of relevant knowledge in any local situation requires the availability of properly trained marine scientists, preferably of the local country or region. Training in marine sciences, including its broad requisites in basic sciences, is costly, since it necessitates not only competent teaching personnel, but also expensive equipment and facilities. Therefore, it is recommended that full-scale training only be established within countries or regions that have the potential of employing and effectively utilizing students graduating in marine sciences.

2. Where marine science training is conducted, a full department or institution should be established wherever possible, to provide identity and undertake the training of marine scientists in the four basic disciplines, i.e. physical oceanography, chemical oceanography, biological oceanography (including fisheries biology), and geological oceanography. If financial or other constraints do not make this possible initially, several alternatives are suggested:

(a) formation of a marine science department or institute consisting of a critical nucleus of scholars representing one or more fields of marine science, and at least one scientist in each of the other fields;

(b) provision of marine science education at an existing science department within the university, with participation in the teaching by scholars of other departments. In this case, one qualified marine scientist should be charged with the responsibility for the marine science curriculum within the department and the development of a broader marine science curriculum within the university;

(c) co-ordination of the academic programme in marine science through an interdisciplinary committee, consisting of scholars teaching or concerned with marine science in the various departments.

A close liaison by means of frequent communication, consultation, and provision of facilities between governmental or other institutions in marine sciences and universities providing such education should be established wherever possible.

3. Training of professional marine scientists should begin in graduate schools and be given to students holding at least a B.Sc. degree or equivalent in one of the natural sciences. An elementary undergraduate course in marine science might be offered as an elective to both science and non-science students to demonstrate the interdisciplinary aspects of oceanography and help to create awareness of marine science and its relevancy to global environmental problems. The first graduate instruction in marine sciences should be a multidisciplinary course including physical, chemical, biological and geological oceanography. Although introductory it should be comprehensive and of sufficient substance to provide basic knowledge of these fields and emphasize interdisciplinary aspects. Specific curricula for the four basic marine science fields leading to an M.Sc. degree or equivalent are recommended and proposals are given in the report.

4. Only well educated and experienced marine scientists are qualified to undertake training in the marine sciences, and only those who are themselves active in research are likely to be effective and stimulating teachers and research supervisors. The workshop therefore recommends that scientists employed as professors

in marine sciences should hold a Ph.D. degree or equivalent, have research experience and teaching proficiency. The professors must not be overloaded with teaching, and facilities should be provided to enable them to participate in research cruises and to carry out research in their respective fields.

5. Marine science training of an appropriate standard requires a basic library, laboratory, equipment and ship facilities. The workshop therefore recommends that at any university conducting marine science training, provision should be made for:

(a) access to a research ship or boat equipped for training and research;

(b) laboratory space and standard equipment for conducting research in the basic oceanographic disciplines as well as means for maintenance of laboratory and shipboard equipment;

(c) a technical marine science library containing basic reference works in physical, chemical, biological and geological oceanography, and a core collection of international oceanographic journals, annual reviews, as well as abstracting and information sources.

6. The workshop found that there is a need for an introductory textbook in general oceanography stressing the interdisciplinary aspects and aimed at an appreciation of the importance of oceanography for the better use of the oceans by man. A textbook of this kind would find particularly wide acceptance as an introductory text for graduate students, if its editor and authors are recognized scientists of different countries and if it be published by Unesco. The workshop therefore recommends that Unesco, possibly in consultation with SCOR, investigates the possibility to publish such a textbook containing the following major subject matters:

(a) physical oceanography, including synoptic and dynamic oceanography and air-sea interaction;

(b) chemical oceanography, including pollution and chemical processes at the sea-bed;

(c) biological oceanography, including fisheries biology;

(d) geological and geophysical oceanography, including practical applications.

Although introductory, the textbook should be comprehensive and of sufficient substance to provide a basic knowledge of the major fields of marine science. Particular attention should be given to the selection of an outstanding editor who would ensure conformity and appropriate coverage. Furthermore, publication in other languages than English should be envisaged.

ANNEX II

LIST OF RECOMMENDED TEXTBOOKS AND REFERENCE MATERIALS IN MARINE SCIENCE

I. Books recommended for elementary interdisciplinary course offered at the undergraduate level

Coker, R.E. This great and wide sea. Univ. of North Carolina Press, Chapel Hill, N.C., 1974. (Also available in German).

Davis, A.R. Principles of oceanography. Addison-Wesley Publ. Co., Reading, Mass., 1972, 435 pp.

Duxbury, A.D. The earth and its oceans. Addison-Wesley Publ. Co., Reading, Mass., 1971, 381 pp.

Gross, G. Oceanography - a view of the earth. Prentice-Hall, Englewood Cliffs, N.J., 1972, 581 pp.

Moore, J.R. (ed.) Oceanography - readings from Scientific American. W. H. Freeman and Co., San Francisco, 1971, 417 pp.

Ross, D.A. Introduction to oceanography. Appelton-Century-Crofts, New York, 1970, 384 pp.

Schuleikin, V.V. Ockerki po fizike morya. Izd. Akad. Nauk. USSR, 1962, 471 pp. (In Russian).

Thorson, G. Life in the sea. McGraw-Hill, New York, 1971, 256 pp.

Turekian, K.K. Oceans. Prentice-Hall, Englewood Cliffs, N.J., 1968, 120 pp.

Vetter, R.C. (ed.) Oceanography: the last frontier. Basic Books, New York, 1973, 399 pp.

Weyl, P.P. Oceanography. An introduction to the marine environment. John Wiley and Sons, Inc., New York, 1970, 535 pp. (Instruction manual also available, 110 pp.).

II. Books recommended for introductory graduate courses in the four basic marine science disciplines

1. Physical Oceanography

1.1. Textbooks

Arx, W. von An introduction to physical oceanography. Addison-Wesley Publ. Co., Reading, Mass., 1962, 422 pp.

Dietrich, G. and Kalle, K. Allgemeine Meereskunde. Bornträger, Berlin, 1957, 492 pp. (English translation: General oceanography. Interscience, New York, 1963, 588 pp. Also available in Russian).

Egorov, N.I. Fiziceskaja Okeanografia. Gidromet. Izdatel'stvo, Leningrad, 1966, 394 pp. (In Russian).

Groen, P. Waters of the sea. Van Nostrand Co., London, 1967, 323 pp. (Also available in Dutch).

McLellan, H.J. Elements of physical oceanography. Pergamon, Oxford, 1965, 150 pp.

Pickard, G.L. Descriptive physical oceanography. Pergamon Press, Oxford, 1963, 200 pp.

Tchernia, P. Cours d'océanographie régionale. Service Hydrographique de la Marine, Paris, Vol. I, 1969, 132 pp.; Vol. II, 1969, 103 pp.; Vol. III

1.2. Physical Oceanography Techniques

Anon. Instruction manual for obtaining oceanographic data. (U.S. N.O.O. Publ. 607), U.S. Naval Oceanographic Office, Washington, D.C., 3rd ed., 1970, 226 pp.

Cox, R.A. (ed.) International oceanographic tables. Unesco and National Institute of Oceanography, U.K., Vol. 1, 1971, 128 pp.

Lafond, E.C. Processing oceanographic data. (U.S. N.O.O. Publ. 614), U.S. Naval Oceanographic Office, Washington, D.C., 195+, 114 pp.

1.3. Additional reading material

Defant, A. Ebb and flow. University of Michigan Press, 1958, 121 pp. (Also available in German).

Ivanoff, A. Océanographie. Propriétés physique et chimique des eaux de mer. Vuibert Editeur, Paris, 1972, 208 pp.

2. Chemical Oceanography

2.1. Textbooks

Lange, R. (ed.) Chemical oceanography. Universitetsforlaget, Oslo, 1969, 152 pp.

Riley, J.P. and Chester, R. Introduction to marine chemistry. Academic Press, New York, 1971, 465 pp.

2.2. Laboratory manuals

Carlberg, S.R. (ed.) New Baltic Manual. Co-operative Research Report, ICES, Series A, ICES Charlottenlund, Denmark, 1972, 145 pp.

Strickland, J.D.H. and Parson, T.R. A practical handbook of seawater analysis. Fisheries Research Board of Canada, Bull. 167, Ottawa, 1968, 311 pp.

Unesco (ed.) International oceanographic tables. Vol. 2, 1973.

2.3. Additional reading

Dyrssen, D. and Jagner, D. The changing chemistry of the oceans. (A Nobel Symposium). Almquist & Wiksell, Stockholm, and Wiley Interscience Division, New York, London, 1972, 365 pp.

Goldberg, E. Guide to marine pollution. Gordon and Breach Science Publishers, Ltd., London, New York, Paris, 1968, 168 pp.

Ketchum, B.H. (ed.) The water's edge. (Proceedings of a workshop on coastal zone management). M.I.T. Press, Cambridge, Mass., 1972, 393 pp.

3. Marine Biology

3.1. Textbooks

Castellvi, H. Ecología marina. Fundación La Salle, Caracas, 1967, 703 pp.

Gines and Margaleff, R. (eds.) Ecología marina. Fundación La Salle, Caracas, 1972, 712 pp.

Parsons, T. and Takahashi, M. Biological oceanographic processes. Pergamon Press, Oxford, 1973, 178 pp.

Peres, J.M. Océanographie biologique et biologie marine. Presses Universitaires de France, Paris, 1963, Tome I, 552 pp.; Tome II, 550 pp.

Tait, R.V. Elements of marine ecology. Butterworths, London, 1972, 314 pp.

3.2. Additional reading

(Included in the list of additional reading for specialists in biological oceanography. The biologists in the working group did not distinguish between the two lists of additional reading).

4. Marine Geology

4.1. Textbooks

Guilcher, A. Morphologie sous-marine et littorale. Presses Universitaires de France, 1954, 216 pp. (English translation: Coastal and submarine morphology, Wiley, New York, 274 pp. Also Methuen, London).

Shepard, F.P. Submarine geology. Harper and Row, New York, 3rd. ed. 1972, 517 pp.

4.2. Additional reading

Emery, K.O. The sea off southern California. John Wiley & Sons, New York, London, 1960, 366 pp.

Emery, K.O. and Uchupi, E. Western North Atlantic Ocean: topography, rocks, structure, water, life and sediments. Amer. Assoc. Petroleum Geologists, Memoir 17, Tulsa, Oklahoma, 1972, 532 pp.

Mero, J.L. Mineral resources of the sea. Elsevier, Amsterdam, 1969, 312 pp.

Seibold, E. Meeresgeologie. In Brinkman (ed.): Lehrbuch der Allgeminen Geologie I, F. Enke Verlag, Stuttgart, 1972, 2nd edition.

5. Multidisciplinary Reference Books

Fairbridge, R.W. (ed.) Encyclopedia of oceanography. Reinhold, New York, 1966, 1033 pp.

Hedgepeth, J.W. and Ladd, H.S. (eds.) Treatise on marine ecology and paleoecology. Mem. 67, Geol. Soc. of America, 1957, Vol. 1, Ecology, repr. 1963, 1296 pp.; Vol. 2, Paleoecology, repr. 1963, 1077 pp.

Hill, M.N. (ed.) The sea: ideas and observations. Vols. 1, 2 & 3. Interscience, New York, 1962 & 1963, 864 pp., 570 pp., and 963 pp.

Maxwell, A.E. (ed.) The sea: ideas and observations. Vol. 4(1 & 2), Interscience, New York, 1970, 802 pp. and 676 pp.

Pirie, R.G. (ed.) Oceanography, contemporary readings in ocean sciences. Oxford University Press, New York, 1973, 530 pp.

Sverdrup, H.O., Johnson, M.W. and Fleming, R.H. The oceans - their physics, chemistry and general biology. Prentice-Hall, New York, 1946, 1087 pp.

III. Books recommended for advanced or special studies in marine science in graduate school

1. Physical Oceanography

1.1. Textbooks

Defant, A. Physical oceanography. Vol. I-II. Pergamon Press, Oxford, 1961, 729 pp. and 598 pp.

Eckart, C. Hydrodynamics of oceans and atmosphere. Pergamon Press, Oxford, 1960, 290 pp.

Godin, G. The analysis of tides. University of Toronto Press, Toronto, 1972, 264 pp.

Jerlov, N.G. Optical oceanography. Elsevier Publ. Co., Amsterdam, 1964, 194 pp. (Also available in Russian).

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Philips, O.M. The dynamics of the upper ocean. Cambridge Univ. Press, 1966, 258 pp.

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1.2. Reference books

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Barnes, H. (ed.) Oceanography and marine biology. Vol. II, George Allen & Unwin, London, 1972, 360 pp., and Hafner, New York.

Greenspan, H.P. The theory of rotating fluids. Cambridge Univ. Press, London, 1968, 327 pp.

Hill, M.N. (ed.) The sea - ideas and observations. Interscience Publ., New York, Vol. 1-2, 1963, 864 pp. and 544 pp.

Kraus, E.G. Atmosphere-ocean interaction. Clarendon Press, Oxford, 1972, 275 pp.

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2. Chemical Oceanography

2.1. Textbooks

Berner, R.A. Principles of chemical sedimentology. McGraw-Hill, New York, 1971. 240 p.

Degens, E.T. Geochemistry of sediments. Prentice-Hall, New York, 1965, 342 pp.

Riley, J.P. and Skirrow, G. Chemical oceanography. Vol. I-II. Academic Press, London, New York, 1965, 712 pp. and 508 pp.

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2.2. Reference books

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Myake, Y. Elements of geochemistry. Muruzen, Tokyo, 1965, 475 pp.

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Vinogradov, A.P. Introduction to the geochemistry of the ocean. Nauka Press, Moscow, 1967, 214 pp. (In Russian).

3. Marine Biology (including fisheries biology)

3.1. Textbooks

Barrington, E.J.W. Invertebrate structure and function. Houghton Mifflin Co., Boston, 1967, 549 pp.

Belyaev, G.M. Bottom fauna of the Ultraabyssal depth of the world ocean. Izdat., Nauka Press, Moscow, 1966, 247 pp. (In Russian).

Beverton, R.J.H. and Holt, S.J. On the dynamics of exploited fish populations. Fishery Investigations, Series II, No. 19, Her Majesty's Stationary Office, 1957, 533 pp.

Cushing, D.H. Fisheries biology: a study in population dynamics. University of Wisconsin Press, Madison, Wisconsin, London, 1968, 200 pp.

Dawson, E.Y. Marine botany: an introduction. Holt, Rinehart & Winston, New York, 1966, 371 pp.

Fogg, G.E. Algal cultures and phytoplankton ecology. University of Wisconsin Press, Madison, Wisconsin, 1965, 126 pp.

Friedrich, H. Marine biology. Sidgwick & Jackson, Ltd., London, 1969, 474 pp. (originally in German: Meeresbiologie, Gebrüder Borntrager).

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Jöregensen, C.B. Biology of suspension feeding. Pergamon Press, Oxford, 1966, 357 pp.

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Margalef, R. Comunidades naturales. Universidad de Puerto Rico, 1962, 469 pp.

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Wimpenny, R.S. The plankton of the sea. Faber and Faber, London, 1966, 426 pp.

3.2. Handbooks

Edmondson, W.T. and Winberg, G.G. A manual on methods for the assessment of secondary productivity in fresh waters. IBP Handbook No. 17, Blackwell Scientific Publications, Oxford, 1971, 358 pp.

Forbes, S.T. and Nakken, O. (eds.) Manual of methods for fisheries resource surveys and appraisal. Part II: The use of acoustic instruments for fish detection and abundance estimation. FAO, Rome, 1972, 139 pp.

Gulland, J.A. (ed.) Manual of methods for fish stock assessment. Part I: Fish population analysis. FAO, Rome, 1969, 54 pp.

Holme, N.A. and McIntyre, A.D. (eds.) Methods for the study of marine benthos. IBP Handbook No. 16, Blackwell Scientific Publications, Oxford, 1971, 334 pp.

Hulings, N.C. and Gray, J.S. A manual for the study of meiofauna. Smithsonian Institution Press, Washington, 1971, 84 pp.

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Vollenweider, R.A. A manual on methods for measuring primary production in aquatic environments. IBP Handbook No. 12, Blackwell Scientific Publications, Oxford, and F.A. Davis Co., Philadelphia, 1969, 213 pp.

Winberg, G.G. (ed.) Methods of estimation of production of aquatic animals. (Translated from Russian), Academic Press, New York, 1971, 175 pp.

3.3. Reference books for additional reading

Bardach, J.E., Ryther, J.H. and McLarney The forming and husbandry of freshwater and marine organisms. Wiley-Interscience, New York, 1972, 868 pp.

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Schaperclaus, W. Lehrbuch der Teichwirtschaft. P. Parey, Hamburg, 1961, 289 pp.

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Waterman, T.H. (ed.) The physiology of crustacea. Academic Press, New York. Vol. 1: metabolism and growth, 1960, 670 pp. Vol. 2: sense organs, integration and behaviour, 1961, 681 pp.

Wilbur, K.M. and Yonge, C.M. (eds.) Physiology of mollusca. Academic Press, New York, Vol. 1, 1964, 473 pp.; Vol. 2, 1966, 658 pp.

4. Marine Geology

A revolution in marine geology is occurring because of recent discoveries leading to the formulation of the new global tectonics concept. Graduate-level instruction in marine geology is supplemented by very heavy reliance on papers appearing in professional journals, the Initial Reports of the Deep-Sea Drilling Project, and elsewhere.

Furthermore, advanced studies in marine geology often deal with problems within regions where the institutions promoting graduate students are situated. Therefore they need many regional publications in different languages.

Consequently, the selected list of post-1969 recommended advanced-level textbooks is very limited. Books representing closely ancillary fields, such as sedimentology, geochemistry, and geophysics, have not been included.

4.1. Advanced level geology references

Belderson, P.H., Kenyon, N.H., Stride, A.H., and Stubbs, A.R. Sonographs of the sea floor. Elsevier Publishing Co., Amsterdam, 1972, 185 pp.

Bird, E.C.G. Coasts. M.I.T. Press, Cambridge, Mass., 1969, 246 pp.

Cohen, P.M. Bathymetric navigation and charting. United States Naval Institute, Annapolis, Maryland, 1970, 138 pp.

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Donovan, D.T. (ed.) Geology of shelf seas. Oliver & Boyd, Edinburgh, 1968, 160 pp.

Emery, K.O. The sea off southern California, a modern habitat of petroleum. John Wiley & Sons, New York, 1960, 366 pp.

Funnell, B.M. and Riedel, W.R. (eds.) The micropaleontology of oceans. Cambridge Univ. Press, Cambridge, 1971, 828 pp.

Heezen, B.C. and Hollister, C.D. The face of the deep. Oxford Univ. Press, New York, 1971, 659 pp.

Kukal, Z. Geology of recent sediments. Academia Publishing House of the Czechoslovak Academy of Science, Prague and Academic Press, London, 1971, 490 pp.

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Moore, D.G. Reflection profiling studies of the California continental borderland: structure and quarternary turbidite basins. Geological Society of America, Boulder, Colo., Special Paper 107, 1969, 142 pp.

Purser, B.H. The Persian Gulf, Holocene carbonate sedimentation and diagenesis in a shallow epicontinental sea. Springer-Verlag, Heidelberg, 1973, 471 pp.

Seibold, E. Meeresgeologie. In Brinkman (ed.), Lehrbuch der Allgemeinen Geologie I, Verlag ENKE, Stuttgart, 1974, 220 pp.

Shepard, F.P. and Dill, R.F. Submarine canyons and other sea valleys. Rand McNally & Co., Chicago, 1966, 381 pp.

Shirley, M.F. (ed.) Deltas in the geologic framework. Houston Geological Society, Houston, Co., 1966, 251 pp.

Stanley, D.J. (convenor) The new concepts of continental margin sedimentation: application to the geological record. Am. Geol. Inst., Washington, 1969, v.p.

__________ (ed.) The Mediterranean Sea: a natural sedimentation laboratory. Hutchinson & Ross, Stroudsburg, Penn., Dowden, 1972, 765 pp.

Steers, J.A. (ed.) Applied coastal geomorphology. M.I.T. Press, Cambridge, Mass., 1971, 227 pp.

__________ (ed.) Introduction to coastline development. M.I.T. Press, Cambridge, Mass., 1971, 229 pp.

Swift, D.J.P., Duane, D.B. and Pilkey, O.H. (eds.) Shelf sediment transport: process and pattern. Hutchinson & Ross, Stroudsburg, Penn., Dowden, 1972, 656 pp.

Valentine, J.W. Evolutionary paleoecology of the marine biosphere. Prentice-Hall, Englewood Cliffs, N.J., 1973, 511 pp.

Zenkovich, V.P. Processes of coastal development. Oliver and Boyd, Edinburgh, 1967, 738 pp. (Edited by J.A. Steers).

ANNEX III

A LIST OF SELECTED MARINE SCIENCE JOURNALS, ANNUAL REVIEWS AND ABSTRACTS ON MARINE SCIENCE

1. Journals

Analytical Chimica Acta

Analytical Chemistry

Aquaculture, Elsevier

Berichte wissenschaftliche Kommission Meeresforschung, Hamburg

British Journal on Coastal and Estuarine Biology (one year old)

Bulletin de l'Institut Océanographique de Monaco

Deep Sea Research, Oxford

Fishery Bulletin, Washington

Geochimica & Cosmochimica Acta

Helgoländer wissenschaftliche Meeresuntersuchungen

Internationale Revue der Gesamten Hydrobiologie, Berlin

Izvestia Akademii nauk Physiza Atmospheri i Okeana (in Russian)

Journal du Conseil, ICES, Copenhagen

Journal of Environmental Science and Technology (ACS)

Journal of Federated Society of Water Pollution Research

Journal of the Fisheries Research Board of Canada

Journal of Fluid Mechanics

Journal of Geochemistry, Japan (in English)

Journal of Geophysics (AGU)

Journal of Geophysical Research

Journal of the Marine Biological Association of the United Kingdom

Journal of Marine Research

Journal of the Oceanographic Society of Japan (in English)

Journal of Physical Oceanography

Journal of Sedimentary Petrology

Kieler Meeresforschungen

Limnology and Oceanography

Marine Biology, Berlin

Marine Chemistry, Elsevier

Marine Geology, Elsevier

Meteorologia i Hydrologia (in Russian)

Nature

Netherlands Journal of Sea Research

Okeanologia (also available in English translation)

Ophelia, Helsingör, Denmark

Rapport et Procès-Verbaux des Rêunions, ICES

Records of Oceanographic Works in Japan (in English)

Science

Sedimentology, Elsevier up to and including 1972; 1973 onwards: Blackwell Scientific Publications.

Tellus, Stockholm

Vie et milieu

2. Annual Reviews

Barnes, H. (ed.) Oceanography and marine biology. An annual review, Vol. I-II, George Allen & Unwin Ltd., London, 1963-1973.

Chow, V.T. (ed.) Advances in hydroscience. Academic Press Inc., New York, 1964.

Droop, M. (ed.) Advances in microbiology of the sea. Academic Press, London, 1968.

Dyke, M. van, Vincenti, W.G. and Wehausen, J.V. (eds.) Annual review of fluid mechanics. Annual Reviews Inc., Palo Alto, Calif., Vol. 2, 1970.

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Russel, F.S. (ed.) Advances in marine biology. Academic Press, London, 1963.

Sears, W.R. and Dyke, M. van (eds.) Annual review of fluid mechanics. Annual Reviews Inc., Palo Alto, Calif., Vol. 1, 1969.

Sears, M. (ed.) Progress in oceanography. Pergamon Press, Oxford, 1963.

3. Abstracts and Information Sources

Aquatic Science Abstracts. Food and Agricultural Organization of the United Nations, Rome.

Deep-Sea Research and Oceanographic Abstracts, Pergamon Press Oxford.

Oceanic Abstracts with Indexes. Pollution Abstracts, La Jolla California.

Underwater Science and Technology Information Bulletin and Journal, Cliffe-NTP Inc., New York.

Marine Science Contents Tables. Food and Agriculture Organization of the United Nations, Rome.

Hydrospace Buyers Guide, 1972. Data Publications, Washington D.C.

Offshore Contractors and Equipment Directory. The Petroleum Publishing Company, Tulsa, Oklahoma. (annual)

Handbook/Directory. Sea Technology, Arlington, Virginia. (annual)

Ocean Master. Charles Kerr Enterprises, New Hope, Pennsylvania. (annual)

Vetter, R.C. (compiler), 1970, Oceanography information sources 70: National Academy of Science - National Research Council, Washington, D.C. 51 pp.

ANNEX IV

LIST OF QUOTED PUBLISHERS

Academic Press, Inc. (London) Limited
Publishers
24-28 Oval Road
London NW1 7DX
England

Academic Press, Inc.
Publishers
111 Fifth Avenue
New York, N.Y. 10003
U.S.A.

Academy of Sciences of the USSR
Leninsky Prospekt 14
Moscow V-71
USSR

Addison-Wesley Publishing Co., Inc.
Reading, Mass. 01867
U.S.A.

George Allen and Unwin Ltd.
40 Museum Street
London W.C.1
England

American Association of Petroleum
Geologists
P.O. Box 979
Tulsa, Okla. 74101
U.S.A.

American Chemical Society - Publication
1155 16th Street
Washington, D.C. 20036
U.S.A.

American Public Health Association
1740 Broadway
New York, N.Y. 10019
U.S.A.

Appleton-Century Crofts
An Affiliate of the Educational Div.
Meredith Corp.
440 Park Avenue South
New York, N.Y. 10016
U.S.A.

Edward Arnold (Publishers) Ltd.
41 Maddox Street
London W1R 0AN
England

Basic Books, Inc., Publishers
404 Park Avenue South
New York, New York 10016
U.S.A.

Blackwell Scientific Publications Ltd.
Osney Mead
Oxford OX2 0EL
England

Butterworths & Co., (Publishers) Ltd.
88 Kingsway
London WC2B 6AB
England

Borntraeger, Gebrüder
1000 Berlin 38
An der Rehwiese 14-Bv
Federal Republic of Germany

University of California Press
2223 Fulton Street
Berkeley, Calif. 94720
U.S.A.

Cambridge University Press
Bentley House
200 Euston Road
London N.W.1
England

Cambridge University Press
32 East 57th Street
New York, N.Y. 10022
U.S.A.

Centre National de la Recherche Scientifique
191, rue St. Jacques
75005 Paris
France

Clarendon Press
Walton Street
Oxford OZ2 6DP
U.K.

Collins, William, Sons & Co., Ltd.
144 Cathedral St.
Glasgow G4 0NB
U.K.

F.A. Davis, Co.
1915 Arch St.
Philadelphia, Pa. 19103
U.S.A.

Marcel Dekker, Inc.
95 Madison Avenue
New York, N.Y. 10016
U.S.A.

Dowden, Hutchinson & Ross
523 Sarah St.
Box 699
Stroudsburg , Pa. 18360
U.S.A.

Elsevier Publishing Company
P.O. Box 211
Jan van Calenstraat 335
Amsterdam
Netherlands

English Universities Press Ltd.
Saint Paul's House,
Warwick Lane,
London EC4P 4AH
U.K.

Enke, Ferdinand
D-7000 Stuttgart
Hasenbergsteige 3,
Postfach 1304
Federal Republic of Germany

Faber and Faber Ltd.
3 Queen Square,
London WC1N 3AU
England

Food and Agriculture Organization (FAO)
Rome,
Italy

Fishing News (Books) Ltd.
Ludgate House,
110 Fleet Street
London E.C.4,
England

Fisheries Research Board of Canada
Sir Charles Tupper Building
Riverside Drive
Ottawa, 8 - Ontario
Canada

Gustav Fisher Verlag
D-7000 Stuttgart 72 (Hohenheim)
Wollgrasweg 49, Postfach 53
Federal Republic of Germany

Foulis, G.T. & Co., Ltd.
50 A Bell Street,
Henley-on-Thames (Oxfordshire) RG9 2BJ
U.K.

W.H. Freeman and Co., Publishers
660 Market Street
San Francisco, Calif. 94104
U.S.A.

Gauthier-Villars et Cie (Editeurs)
55, Quai des Grands-Augustins
75006 Paris
France

Geological Society of America
231 East 46th Street
New York, N.Y. 10017
U.S.A.

G.M. Manufacturing Co.
12 East 12th Street
New York, N.Y.
U.S.A.

Gidrometeorologičeskoe izdatel'stvo
Vasil'evskij ostrov 3,
Leningrad V-53
USSR

Gordon & Breach, Science Publishers, Ltd.
12 Bloomsbury Way,
London W.C.1,
U.K.

Gordon and Breach, Science Publishers, Inc.
150 Fifth Avenue
New York, N.Y. 10011
U.S.A.

Gosudarstvennoe naučno - techničeskoe izdatel'stvo
Gruzinskij val 35,
Moscow
USSR

Hafner Publishing Co.,
Subs. of Crowell Collier & MacMillan, Inc.
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New York, N.Y. 10022
U.S.A.

Harper & Row, Publishers
49 East 33rd Street
New York, N.Y. 10016
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Holt, Reinhart & Winston, Inc.
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