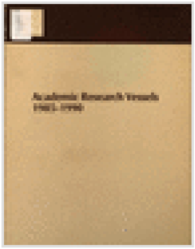

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Academic Research Vessels 1985-1990

Steering Committee for Academic Research Fleet Study
Ocean Sciences Board
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National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

Oceanography is an intersection of a wide range of scientific disciplines and technologies focused on a major part of earth. Future developments depend on advances in all these facets but especially on improvements in our technical capabilities. The Ocean Sciences Board has recently carried out studies on computer needs and on satellite systems, technical areas in which new methods and facilities can add greatly to our competence in investigating the ocean. However, research ships remain central to all our studies, and the maintenance of adequate sea-going facilities is crucial.

Any attempt to define what an adequate research fleet would be at some future date must, in part, be based on a projection of the way in which other technical capabilities -- such as numerical simulation and remote sensing -- will develop. To attempt to link all of these elements together would be to try to predict the whole future of our science. Neither the OSB nor the study committee presumed sufficient wisdom to make such a comprehensive prediction. Instead, the committee proceeded by holding one factor constant--the funding in real dollars--while examining the influence of other factors on the outcome. This highlights the effect of varying other factors such as the fleet's composition.

Much of this study was concerned with the need to put information about the academic research fleet in a coherent and quantitative form that could be used for projections rather than predictions. The data on past changes in fleet structure and funding have been scattered and sometimes contradictory. This report provides a necessary, agreed-upon data base. The information base and methodology developed here can be used to indicate the consequences of different policy alternatives. The authors have not attempted to select from these alternatives since, as is stressed in the report, such decisions must be made jointly by the scientific community and the funding sources. Instead of suggesting solutions that might abrogate the responsibilities of either, the report provides an input to a process whereby various aspects of the decisions can be analyzed.

This report, together with reports on computers, satellites, and manpower, will form a basis for the assessment of scientific strategies in oceanography during the 1980's.

John H. Steele
Chairman

SUMMARY OF FINDINGS AND RECOMMENDATIONS

In June 1980, the Ocean Sciences Board was asked by the National Science Foundation (NSF) and the Office of Naval Research (ONR) to conduct a study of academic research vessels. This study was begun because in recent years funds to operate the academic fleet have been insufficient despite the continuing scientific importance and practical value of work in academic oceanography. Many of the vessels, especially the larger ones, have been laid up for various periods as a result of financial constraints. There is no immediate prospect for improvement in this situation; and unless new sources of funds are found, indications are that funding for oceanographic research and for ship operations will be inadequate throughout the 1980's. If that is to be the situation, steps must be taken now to alter the academic research fleet so as to preserve the greatest possible measure of sea-going capability within the likely funding constraints.

A cardinal belief of the Ocean Sciences Board and the committee preparing this report is that the U.S. style of doing deep-water oceanography primarily through the academically operated research fleet is unquestionably the best in the world. This premier position results largely because the management of the fleet has been put in the hands of major academic and research institutions which places the responsibility for planning and conduct of marine science research with the key oceanographers in the country. In the words of one reviewer (John A. Knauss) "The ability of graduate students to go on cruises, the availability of a ship at the dock, even the urgings of laboratory directors to their scientists to think about problems that require ship-time, are among the various incentives that have made United States sea-going oceanography the leader in the world."

Thus it remains of prime importance that we continue the type of operation that does not separate the sea-going oceanographers from the responsibility for management of research vessels. This should be maintained regardless of budget levels.

The findings and recommendations of this committee are presented here in seven subject categories: scientific needs, cost projections, agency support, general-purpose ships, special-purpose ships, use of non-academic ships, and information base. Relevant sections of the report are indicated in parentheses.

1. Scientific Needs

Findings

Planning documents dealing with academic research were surveyed, and a questionnaire taking inventory of research plans was distributed to leaders in the academic oceanographic community. The resulting projections call for an academic research fleet larger than the present one, including particularly special-purpose vessels and additional general-purpose vessels less than 150 ft. in length. According to present funding projections, this larger fleet would be underfunded by almost 50 percent in the late 1980's (III.E, IV.A, Appendix III).

Review of four proposed programs that are national in scope--Antarctic marine ecosystems, physical oceanographic aspects of high-level radioactive waste disposal, global ocean climate dynamics, and ocean crustal dynamics--indicates that they would require almost half of the total operating funds now projected to be available for UNOLS ships in 1986 and most of the time of general-purpose academic vessels larger than 150 ft. It is important to realize that these four programs by no means exhaust current planning by academic oceanographers; nor will these programs, if conducted, absorb all the energies and creativity of oceanographic researchers. It is also apparent that these programs cannot all be conducted with the projected funding without dramatically perturbing the ship support for many other segments of oceanographic science (III.F).

Oceanographers currently use less ship-time per capita than in the past. However, the recent major increase in the total number of doctoral scientists employed in oceanography suggests that demands on the academic research fleet are likely to increase (III.B, D).

Recommendation

It is recommended that the United States maintain an academic research fleet capable of performing the sea-going tasks required by the continuing need for academic oceanographic research (I, II.A, III.D).

2. Cost Projections

Findings

If the projections that we have assembled for future funding of UNOLS ship operations hold true, the amount of funding available in 1985-1990 will be approximately 15 percent less than what would be required for full operation of a UNOLS fleet of the present size and composition. (Some measure of utilization relative to capacity is necessary, and we have adopted NSF's definition of full utilization, which depends on size class. The number of operating days per year equated with full utilization is, however, somewhat arbitrary and depends on the specific vessel and work being done, rather than on vessel size class alone). Even now there is inadequate funding to fully utilize all elements of the UNOLS fleet. For 1981, only the 150-199 ft. vessel class will be fully utilized, the 100-149 ft. class will be 47 percent utilized, and an 18 percent excess capacity will exist in the fleet as a whole. Therefore, if additional funding is not forthcoming, the UNOLS fleet of general-purpose vessels must be reduced through layups, retiring of vessels, or diverting vessels to special purposes for which funds from other sources will be available. Conversions are already underway to accommodate users in the field of geophysics, which may attract additional operating funds (III.C, IV.A,C).

Based on the multiple regression analysis performed on four years of UNOLS data (1977-1980), the economic savings of consolidation of the academic fleet into fewer operating centers appear to be modest. (It should be noted that the functional form used in the MRA analysis focuses on the savings realized by increasing the number of vessels at a particular institution relative to operation at separate institutions, not on system-wide savings incurred by redistribution of the fleet). Though there is a reduction of approximately 13 percent in operating costs associated with consolidating the operation of two vessels operated at single-ship institutions, this could be offset in the short term by the potential costs of additional facilities, e.g, dock or warehouse space. Moreover, consolidation of the academic fleet into fewer operating centers would have the deleterious effect of further decoupling the scientific users from the vessel operations (II.D, V.C., Appendix II.D,F).

Because of fluctuations in funding and ship requirements, the need for temporary ship layups is projected to continue. Calculations from the recent history of the UNOLS fleet using multiple regression analysis indicate that for short-term layups (10-30 percent of a year) an average 1 percent reduction of ship-days at sea for a vessel resulted in 0.3-0.5 percent reduction in total operating costs, depending upon the size of the vessel. Example calculations based on actual cost components indicate that a full-year layup saves 83 percent of the total operating cost for vessels > 200 ft. and 65 percent of the total operating costs for vessels 150-199 ft. (II.D, V.B).

Recommendation

It is recommended that predictive models of layup savings for all vessel classes be formulated and used by the funding agencies and UNOLS as guidelines for allocating funds and ship-time during periods of funding shortfall or decreased usage (V.B).

3. Agency Support

Findings

The use of ships can be reduced by insufficient funding for research just as surely as by insufficient funding for ship operations per se. The balance between funding for research and that for ships must continually be readjusted as the state of the science and national needs evolve. The ratio of funds for ship operations to funds for research is much higher in NSF/OCE than in ONR, both in the recent past and as projected for the near future (I, II.D, III.C).

In recent years NSF funds have consistently supported the operation of the UNOLS fleet--including some reprogramming of institutional ship support to provide for unforeseen emergencies and at least minimal replacement of shipboard scientific equipment--to such an extent that other agencies have been able to use these vessels relatively inexpensively and selectively to the degree required by their scientific programs. NSF funding is no longer adequate to provide this level of support (II.C).

Owing to a lack of adequate operating support, maintenance and improvements of academic research vessels have been deferred to the point of jeopardizing scientific missions through loss of operating days or diminished capability for data collection (II.A, C).

Recommendations

In order to maintain a healthy oceanographic research program, it is desirable that academic institutions and scientists share with sponsoring agencies the responsibility for broadening the base of financial support for a jointly planned academic research fleet. To this end, it is recommended that NSF and ONR, with the assistance of appropriate advisory bodies and institutions, develop a long-term plan that will guarantee the continuation of an effective and balanced academic research fleet. The plan should include schedules for maintenance and refit, as well as for orderly replacement and retirement within the fleet. Recommendations specific to these areas follow (II.C., IV.D, V.D).

Major mid-life refits and measures to correct design deficiencies and problems caused by deferred maintenance of UNOLS ships have been begun with financial support from ONR and NSF. It is imperative that expenditures adequate to the completion of these tasks be forthcoming (V.D).

Once the refit of older vessels is completed, NSF may have funds available to begin construction for the replacement of some vessels of smaller classes. However, it is recommended that NSF and ONR begin now to prepare requests for new construction funds needed for replacement and special-purpose vessels, especially those of size classes 150-199 and > 200 ft (V.D).

Criteria for retirement or conversion of academic oceanographic research vessels should include research capability, economy, scientific productivity, benefits to society, geographical considerations, and education, as these terms are discussed in section IV.D. A panel should be established (perhaps by UNOLS with advice from the National Academy of Sciences) to further develop these criteria and to recommend to the funding agencies and the owners of vessels how these criteria should be used in their evaluation of vessels being considered for retirement or conversion. The panel should be balanced to represent the interests of the agencies that fund oceangoing research, the institutions that own and/or operate the vessels, and the sea-going oceanographer. Funds saved as a result of vessel retirement or conversion should be devoted to upgrading the capabilities of the remaining vessels and to oceanographic research (IV.D).

It is recommended that funds for ship operations continue to be granted directly to operating institutions. This results in proposal review and funding commitments and ship schedules being made well in advance of ship operations. An effort must be made to conserve some measure of flexibility that allows operators to respond rapidly to changes and to targets of opportunity (V.F).

4. General-Purpose Ships

Findings

The present academic fleet composition, as it is evolved over years of use, is believed to be adequate for research requiring general-purpose vessels during the latter part of this decade. When discussing various compositions of the future oceanographic research fleet, it is important to remember that the smallest ships cannot conduct open ocean research, but that the large ships not only can conduct most coastal research but are required to conduct such research in the case of large-scale, cooperative programs (III.D, E, IV.B).

Recommendation

The academic research fleet of the future should be based on the present configuration of general-purpose vessels, with additional flexibility provided by special-purpose vessels and judicious use of leasing. Given constant funding in current dollars, a future fleet mix similar to that described in Chapter IV as scenario C.3 seems the most likely outcome.

Given that some retirements of general-purpose ships are likely, there should be a mechanism for deciding which specific ships should be retired or modified for some special use.

5. Special-Purpose Ships

Findings

Good use can be made within the academic fleet of one or more vessels dedicated primarily to underway seismic profiling and to studies of the benthic boundary layer requiring deep towing and deployment/recovery of large bottom instruments (III.D.2.b).

The U.S. oceanographic community could well utilize approximately 1000-2000 scientist-days per year on ice-strengthened ships in each polar ocean. Considering our present ship capability, such a program of polar oceanography would require that the United States lease or otherwise procure the use of ice-strengthened ships from other nations (III.D.2.d).

Academic researchers need the capability for using large nets and trawls at sea. However, the level of scientific interest appears insufficient at present to warrant a dedicated ship. If a trawl system could be available for temporary installation on selected UNOLS vessels, the use of dedicated or leased ships would not be necessary. (III.D.2.e).

Recommendations

The specific requirements and specifications of capabilities for special sea-going work in marine geology and geophysics should be considered by the community of such scientists and recommended to NSF and ONR (III.D.2.b).

The United States should begin at once the construction of a new, ice-strengthened vessel for polar research (III.D.2.d).

Immediate steps should be taken to provide a suitable tender for the submersible ALVIN, either by the design and construction of a new ship or by modifying an existing ship for this purpose (III.D.2.a).

The U.S. Navy should make sufficient diving time available to academic scientists on the 6000-m depth SEA CLIFF so that the need for an academic submersible of this capacity can be assessed by potential users. This may require the establishment of a technical support group to assist scientific users and coordinate with the Navy operators (III.D.2.a).

6. Use of Non-Academic Ships

Findings

Based on a sample from a small number of institutions, the academic use of non-academic ships (including federal agency, private, and foreign flag vessels) is increasing. This issue requires further study (V.A).

There are circumstances when chartering of private vessels is desirable, e.g., for reasons of economy or urgency. The leasing price usually includes amortization of construction costs, but the daily rate of existing academic vessels does not. Thus, leasing may not be economically favorable when compared with the use of existing academic vessels (V.A).

Federal operation of the academic fleet is undesirable, because federal regulations and practices result in federal research ships having higher operating costs than comparable UNOLS vessels, and because federal operation would further separate users of academic vessels from the management of them (V.C).

Recommendations

Complete reliance of the academic community on non-academic vessels should be avoided, since such vessels are not under the control of the academic community, and their availability to the community may be curtailed because of economic or policy reasons (V.A).

In order to make it more widely recognized that it is possible for academic oceanographers to conduct cooperative programs from federal research vessels operated by NOAA, the U.S. Navy, U.S. Coast Guard, and others, these agencies should alert academic oceanographers to such opportunities when federal vessels are scheduled to work in areas of common interest. We expect that this could benefit particularly individual scientists with small research projects, though it is unlikely to contribute much to large programs in most branches of oceanography (II.B).

When new construction of academic vessels is considered, the total vessel costs (amortization of construction as well as operating costs) should be compared to the cost of leasing. However, it should be realized that monies provided for construction and operation are not generally interchangeable (V.A).

7. Information Base

Findings

Our study of the academic research fleet has revealed that improved management of that resource requires the systematic collection and analysis of data necessary for making critical decisions.

UNOLS group scheduling seems to be an effective way of enhancing the efficiency of ship use. But it is important to note that retention within the operating institutions of a sense of responsibility for the academic vessels depends in part on retention of a degree of control over schedules.

Recommendations

To implement the recommendations of this report (and for future management studies), procedures should be initiated to ensure better record keeping and central data archiving. Vessel operating data (such as costs, days, or scientific use) should be broadened to include not only the UNOLS fleet but also the entire U.S. academic research fleet. Existing information should be gathered, and continuing records should be maintained on the following: (a) special costs (of new construction, conversion, refitting, and major scientific equipment), (b) savings due to layups, (c) use of UNOLS and other academic research vessels, and (d) use of non-academic vessels (such as federal agency vessels, charter vessels, or foreign vessels) by academic investigators. UNOLS should take the lead in this task, with the full and timely cooperation of vessel operators, sponsors, and users (II.D, III.C, IV.A,C,D., V.A,B,C,D,F).

An improved communication system and information pool (computer based and frequently updated) should be developed to permit rapid matching of the needs of academic and non-academic oceanographers with suitable UNOLS vessels. Such a system must be easily accessible by vessel users, sponsors, and operators and should be able to accommodate long-range plans (often tentative and as yet unfunded), medium-range plans (as decisions concerning the funding of specific projects are made), and short-range modification of plans (to replace or fill in portions of schedules or to take advantage of unique opportunities). This system should be operated by UNOLS and financially supported by NSF and ONR (V.E).

The requirements for and costs of requested ship operations should be explicit in research proposals in order to give investigators and reviewers additional incentive to arrive at the most economical combination of equipment, personnel, and ship-time. This should be implemented in a manner that will not lengthen the proposal review procedure (V.F).

I. INTRODUCTION

Oceanography is primarily a field science, dependent for its progress on the ability of its practitioners to observe, to measure, and to obtain samples from the ocean. Much of this work is conducted from vessels of various kinds. This study concerns those research vessels that are operated by academic institutions. Other major oceanographic fleets are operated by the U.S. Navy and the National Oceanic and Atmospheric Administration (NOAA). A few research vessels are also operated by other federal and state agencies, and several vessels (especially in geophysical exploration) are run by private industry.

Academic research vessels fall into two categories in terms of management and financial support. The University National Oceanographic Laboratory System (UNOLS) fleet is a well-defined unit, currently consisting of 26 vessels. These are mainly the larger vessels whose operation is primarily supported by federal funds and for which there is national cooperation (or at least communication) concerning schedules, operations, and facilities. Because of this, there is some uniformity in the nature of the available information concerning the utilization and cost of this fleet. The rest of the academic vessels are smaller (generally less than 100 ft.) and usually more dependent on a state or an institution for operating funds. Because these vessels are not usually centrally managed and funded, less information about them is available.

In June of 1980, the Ocean Sciences Board was asked by the National Science Foundation (NSF) and the Office of Naval Research (ONR) to conduct a study of academic research vessels. The request was accompanied by clear expressions of concern that sufficient funds would not be available in the near future to operate the existing academic vessels at full capacity. In fact, the fleet had been operating at partial capacity for the past six years because of insufficient funding for both ship operations and seagoing research.

The terms of reference for the study were as follows:

1. Review the present composition, condition, capability, funding, management, usage, and coordination of the academic research fleet and its evolution by collecting and summarizing data from federal agencies and other sources.

2. Characterize the nature and magnitude of the ocean science performed during the 1970's with this fleet by a set of case histories that describes the relationships between science and facilities.

3. Review the potential development of academic ocean science projected for the 1980's and consider the requirements for the kinds and magnitude of oceanographic research ships imposed thereby by reviewing, summarizing, and placing in perspective existing reports on future ocean science facilities needs and by selected inquiries to the ocean science community.

4. Review the projections for support of academic research fleet facilities, during the 1980's, keeping in mind the distinct nature of both "core" support and "special opportunity" support.

5. Examine the financial and management constraints on the operation of the academic research fleet, including methods for matching facilities with scientific needs.

6. Develop and evaluate scenarios for the evolution and operation of the academic oceanographic research fleet required in the future within alternative and realistic budgetary constraints and under alternative modes of operation and define criteria to serve as the basis for decisions that must be made to carry out such plans.

The federal sponsors were primarily and understandably concerned about the future of the larger vessels in the UNOLS fleet, but the Ocean Sciences Board and the steering committee it established for this study have tried to represent the academic oceanographic community at large. The intent of the steering committee was to provide a critical background, and where possible, quantitative analyses, on which to base future managerial decisions concerning research vessels in a period of likely financial stress for seagoing scientists and for other scientists dependent upon expensive facilities.

The committee met seven times. Additional meetings were held between individuals from the committee and the Ocean Sciences Board, officials of federal agencies, and representatives of academic institutions. The primary work of the committee was the collection, organization, analysis, and interpretation of data and of projections, policy statements, recommendations, and the like, from UNOLS, NSF, ONR, and other sources. The committee also distributed to a large number of scientists, whose titles indicated responsibilities for oversight and planning of research at institutions engaged in marine science, a questionnaire intended to determine plans for scientific activities and usage of vessels. In addition, various individuals were requested to contribute position papers or data on scientific or managerial issues.

In responding to term of reference 1, the committee reviewed primarily the management of the academic fleet at the national level. The committee did not examine the managerial practices of individual institutions except as reflected in the annual operating costs of vessels. This does not imply that institutional practices are unimportant, only that they are difficult to assess. Nor are the mechanisms by which decisions have been made concerning changes in the size and composition of the fleet discussed in this report, though criteria for future changes are presented.

In responding to term of reference 2, the committee examined eight case histories illustrating various aspects of the relation between research ships and the scientific work done from them. This information, summarized in Appendix IV, demonstrates among other things that the academic fleet is deployed in a great variety of configurations. These range from single investigators employing a single ship in a limited area over a limited time, to complex configurations involving 50 oceanographers on 6 major research vessels.

The committee reviewed many reports on scientific trends in academic oceanography in response to term of reference 3. The committee chose to concentrate upon the requirements for vessels stated or implied in existing reports and upon the responses to the committee's questionnaire, instead of presenting extensive justifications for the scientific efforts recommended in the reports.

Although the focus of this report is on the academic vessels themselves, and particularly those vessels from which research may be conducted in the open ocean, readers should be aware that the use of such vessels also requires expensive shore facilities, such as harbors, docks, and maintenance facilities. But these requirements and costs are not considered in this report, because the committee had neither the time nor the expertise to do so.

The most difficult task for the steering committee was to obtain complete and realistic projections for the future, both for the state of marine science and its financial support. Consistent and complete data from the past were also difficult to obtain. The committee has attempted in this report to distribute attention fairly among the enthusiasm for marine science on the part of the committee members and their academic colleagues, national needs for information regarding the ocean, and the likely financial situation for science in the late 1980's.

II. PRESENT STATUS OF ACADEMIC RESEARCH VESSELS

A. Composition and Condition of the Fleet

In order to facilitate scheduling, funding, and efficient use, most academic research vessels greater than 100 ft. in length, as well as seven vessels less than 100 ft. long, are grouped into the University National Oceanographic Laboratory Systems (UNOLS). The UNOLS fleet presently consists of 26 vessels operated by 17 different institutions (Table II.1). This number includes the deletion through retirement of Duke University's R/V EASTWARD and the addition of the two new coastal zone research vessels R/V CAPE FLORIDA and R/V CAPE HATTERAS during 1981. The University of Hawaii's MOANA WAVE is excluded from this list, as it has not been available for academic research for several years because of a long-term contract with the U.S. Naval Electronics Systems Command (NAVALEX) program.

Table II.1 also shows the year each vessel was built and its predicted date of retirement, as projected for a 30-year expected lifetime based on data collected by the Center for Naval Analysis.[7] It is expected that these liftimes can be extended 5 years by refit at mid-life. During the period 1985-1990, only three of these vessels will reach their retirement age. Even so, there is need to make provision for major replacements within the fleet during 1985-1990, because an additional five vessels will reach retirement during 1990-1995. Since five to seven years are presently required to obtain the funds, design, build, and outfit a new research vessel, plans must be ongoing during the 1980's for replacement and renovation of the fleet. Thus, approximately one-third of the UNOLS fleet will reach retirement age during the decade 1985-95. This will provide an opportunity to alter the composition of the fleet should that be desirable. The evolving objectives of academic oceanography and national needs for information may well conflict with shorter-term fiscal constraints.

The ownership of UNOLS vessels (Table II.1) is diverse. The Navy owns 7 vessels, including 5 of the 6 vessels that make up the 200 + ft. class; 11 of the UNOLS vessels are owned or were constructed by NSF; and the remaining 9 vessels are owned by the institutions that operate them.

TABLE II.1 Size and Age Distribution of the UNOLS Fleet (Surface Vessels). MOANA WAVE excluded.

Ship Class	Length	Name	Operator	"Full Utilization" days at sea per year[1]	Year Built	Desired*** Retirement
200 ft. (6)	245	MELVILLE*	Univ. Calif., (Scripps Inst.)	270	1970	2000
	245	KNORR*	Woods Hole Oceanogr. Inst.	270	1969	1999
	210	ATLANTIS II**	Woods Hole Oceanogr. Inst.	270	1963	1998****
	209	CONRAD*	Columbia Univ.(Lamont-Doherty)	270	1962	1997****
	209	T.G. THOMPSON*	Univ. of Washington	270	1965	1995
	209	T. WASHINGTON*	Univ. Calif., (Scripps Inst.)	270	1965	1995
150-199 ft. (7)	177	ENDEAVOR**	Univ. of Rhode Island	250	1976	2006
	177	OCEANUS**	Woods Hole Oceanogr. Inst.	250	1975	2005
	177	WECOMA**	Oregon State University	250	1975	2005
	174	GYRE*	Texas A&M University	250	1973	2003
	170	COLUMBUS ISELIN**	University of Miami	250	1972	2002
	170	NEW HORIZON	Univ. Calif., (Scripps Inst.)	250	1978	2008
	156	KANA KEOKI	University of Hawaii	250	1967	1992
100-149 ft. (6)	135	CAPE FLORIDA**	University of Miami	230	1981	2011
	135	CAPE HATTERAS**	Duke University (Univ. North Carolina)	230	1981	2011
	133	ALPHA HELIX**	University of Alaska	230	1965	1995
	120	CAPE HENLOPEN	University of Delaware	230	1975	2005
	110	VELERO IV	Univ. of South. Calif. (Inst. for Marine & Coastal Studies)	230	1948	1983***
	106	RIDGELY WARFIELD**	Johns Hopkins Univ. (Chesapeake Bay Institute)	230	1967	1997
100 ft. (7)	95	E.B. SCRIPPS	Univ. Calif., (Scripps Inst.)	210	1965	1995
	80	CAYUSE**	Cal. St. Univ. (Moss Landing Marine Laboratory)	210	1968	1998
	80	LONGHORN	University of Texas	210	1971	2001
	72	BLUE FIN	University of Georgia (Skidaway Inst. of Oceanogr.)	210	1972	2002
	65	HOH	University of Washington	210	1943	1973
	65	ONAR	University of Washington	210	1954	1984
	64	CALANUS**	University of Miami	210	1970	2000

[1]As defined by NSF in 1979, but under reconsideration.

*Ships owned by the U.S. Navy and on long-term charter to academic institution.
**NSF-owned or constructed ships.
***Based on 30-year expected lifetime based on data collected by Center for Naval Analysis.(7)
****5 years added because of mid-life refit.

As can be seen from Table II.2, the composition of the UNOLS fleet has not been static during the period 1974-1981; modest reductions have occurred in the largest and smallest size categories, and the number of vessels in the 100-149 ft. class has increased. Specific ships entering and leaving the UNOLS fleet are shown in Table II.7. As a result of these changes, the scientific capacity (measured as scientific bunks multiplied by full utilization days at sea) has decreased about 15 percent over the period.

Ships of this fleet have been used to carry out marine studies on behalf of many sponsoring agencies, which have borne most of the costs of operation. However, the cost of operating, maintaining, and modernizing the academic fleet has increased faster than federal agencies have been able to increase financial support. This has been a major cause for the temporary layup of several large ships for some periods of time (see Table II.7). Even more important in the long-range view is that major maintenance, modernization, and equipping has been deferred so that a substantial backlog of necessary work has accumulated. Deferred maintenance of equipment, both that basic to the efficient operation of a vessel and that which supports shipboard scientific activities, has also contributed to loss of fruitful research time at sea because of breakdowns.[1]

TABLE II.2 Size Composition of the UNOLS Fleet*

	Year							
Ship size	74	75	76	77	78	79	80	81
200 ft.	8	8	7	7	7	7	6	6
150-199 ft.**	8	8	8	7	7	8	8	7
100-149 ft.	4	4	4	5	5	5	5	6
100 ft.	10	9	9	8	8	8	7	7
Total	30	29	28	27	27	28	26	26

*Data from UNOLS Ship Reports (March 27, 1981)

**MOANA WAVE not included after 1976

Information on non-UNOLS academic vessels is much less complete, and there appears to be no coordinated plan for the maintenance and improvement of these vessels, nor for the UNOLS vessels owned by individual institutions (Table II.1). Table II.3 and Figure II.1 show research vessels outside UNOLS operated by the academic community during 1980. They were derived from the questionnaires returned as part of the present study and from other information. Although this information is incomplete, it is considered to be representative. These vessels are operated by a large number of academic institutions, as contrasted with the larger, deep-sea vessels which are centered at a few major oceanographic institutions. The number of vessels operated by any given institution is small, with no obvious dominance by any institution. Class size shows a prominence of vessels in the range of 30-70 ft.; undoubtedly there are many additional vessels smaller than 30 ft. not shown in the table. Investigators at recently established oceanographic institutions often emphasize coastal work, which can be accomplished with locally available facilities, increasing the apparent demand for small vessels.

Another important component of the academic research fleet is the submersibles. The deep (4000 m) submersible ALVIN and its tender R/V LULU are currently operated as a national facility by the Woods Hole Oceanographic Institution and funded by NSF/OFS, ONR, and NOAA. Support for ALVIN's operations is approximately $2.0 million per year; this figure does not include research funds, nor does it take into account the fact that it is often necessary for a larger vessel to be assigned to ALVIN operations. This has resulted in a review of the program by UNOLS and in the suggestion to decommission LULU and to modify an existing UNOLS vessel as a full-time ALVIN support-tender. This is discussed further in Chapter III.D.2.a.

In addition to ALVIN, other submersibles are available to academic users, such as DIAPHUS of Texas A&M University and JOHNSON-SEA-LINKs I and II of the Harbor Branch Foundation. These submersibles, and existing underwater habitats such as the Western Regional Undersea Laboratory operated by the University of Southern California, are not treated in detail in this report, although general recommendations are made concerning submersible capability required by the academic community.

B. Other Research Fleets

Academic researchers also make some use of research vessels operated by the federal government, including 25 National Oceanic and Atmospheric Administration (NOAA) ships, 13 Navy ships, 3 Environmental Protection Agency (EPA) ships, and one each for the Coast Guard and the United States Geological Survey (USGS). All of these ships are dedicated to study of the ocean and collection of data for a wide variety of disciplines, and each agency offers opportunities for cooperative effort between academic and governmental scientists. It must be recognized, however, that all of these ships exist to meet direct responsibilities of the various agencies. The vessels are generally scheduled one to two years in advance in support of the agency's missions. Schedules

TABLE II.3 Partial Lists of Non-UNOLS Ships Operated by Academic Institutions, 1980

Academic institution	Ship length-feet	Ship name
Bermuda Biological Station for Research	65	PANULIRUS II
Virginia Institute of Marine Science	80	LANGLEY
	57	PATHFINDER
Cornell University, Shoals Marine Laboratory	34	WRACK
Dauphin Island Sea Laboratory	65	G.A ROUNSEFELL
Duke University, Marine Laboratory	62	JOHN DE WOLF II
Florida Institute of Oceanography	65	BELLOWS
Florida Institute of Technology	65	TURSIOPS
Gulf Coast Research Laboratory	65	GULF RESEARCHER
Harbor Branch Foundation	125	JOHNSON SEA DIVER
Hobart and William Smith College	65	HOBART AND WILLIAM SMITH EXPLORER
Louisiana State University, Center for Wetland Resources	36	C'MON NESSIE II
Marine Science Consortium	90	ANNANDALE
Wallops Island, Virginia	50	DELAWARE BAY
Massachusetts Institute of Technology	65	EDGERTON
Mississippi-Alabama Sea Grant	90	TOMMY MONROE
Consortium	75	--
Naval Postgraduate School, Monterey	126	ACANIA
New Jersey Marine Consortium,	50	FOLEY
Sandy Hook & Seaville Field Stations	34	KOENEKE
	35	KIRKEBERG
	28	ALOPSIA
Northeastern University, Marine Science Institute	38	BARRON IV
Nova University	62	YOUNGSTER III
Occidental College	85	VANTUNA
Old Dominion University	65	LINWOOD HOLTON
Rutgers University	63	RUTGERS
Sea Education Association	100	WESTWARD
Southeastern Massachusetts University	65	CORSAIR
Southern Maine Vocational Technical Inst.	144	AQUALAB III
State University of New York, Stony Brook, Marine Sciences Research Center	55	ONRUST
Texas A&M University,	65	EXCELLENCE II
Department of Oceanography	48	QUEST
	35	LA MER
Tudor Hill Laboratory	105	ERLINE
University of California, Scripps Institute of Oceanography	38	AMIGO

TABLE II.3 (continued)

Academic institution	Ship length-feet	Ship name
University of Connecticut, Marine Sciences Institute	65	T-441
University of Delaware,	47	WOLVERINE
College of Marine Studies	42	SKIMMER
University of Hawaii	65	NOII
University of Maryland,	65	AQUARIUS
Center for Environmental and	52	ORION
Estuarine Studies	46	VENUS
	35	ANOMIA
	30	BLUEFISH
University of Miami, Rosenstiel School of Marine and Atmospheric Science	38	ORCA
University of North Carolina, Marine Sciences Program	47	MACHAPUNGA
University of Puerto Rico	125	CRAWFORD
	55	MEDUSA
University of Rhode Island,	65	SCHOCK
Graduate School of Oceanography	42	DULCINEA
University of Southern California	65	SEA WATCH
	43	GOLDEN WEST
	34	ESPOIR
University of Texas,	165	FRED H. MOORE
Geophysics Laboratory	130	IDA GREEN
University of Texas,	57	KEVO
Marine Sciences Institute, Port Aransas	32	BEVO
University of Washington,	70	J.E. HENDERSON
Applied Physics Laboratory	50	C.E. MILLER
University of Washington,	100	ALASKA
Department of Fisheries	35	MALKA
	35	TENAS
Woods Hole Oceanographic Institution	46	ASTERIAS
Operating in the Great Lakes		
State Univ. College at Buffalo	65	C.A. DAMBACH
University of Michigan	80	LAURENTIAN
	50	MYSIS
University of Wisconsin, Milwaukee	65	NEESKAY

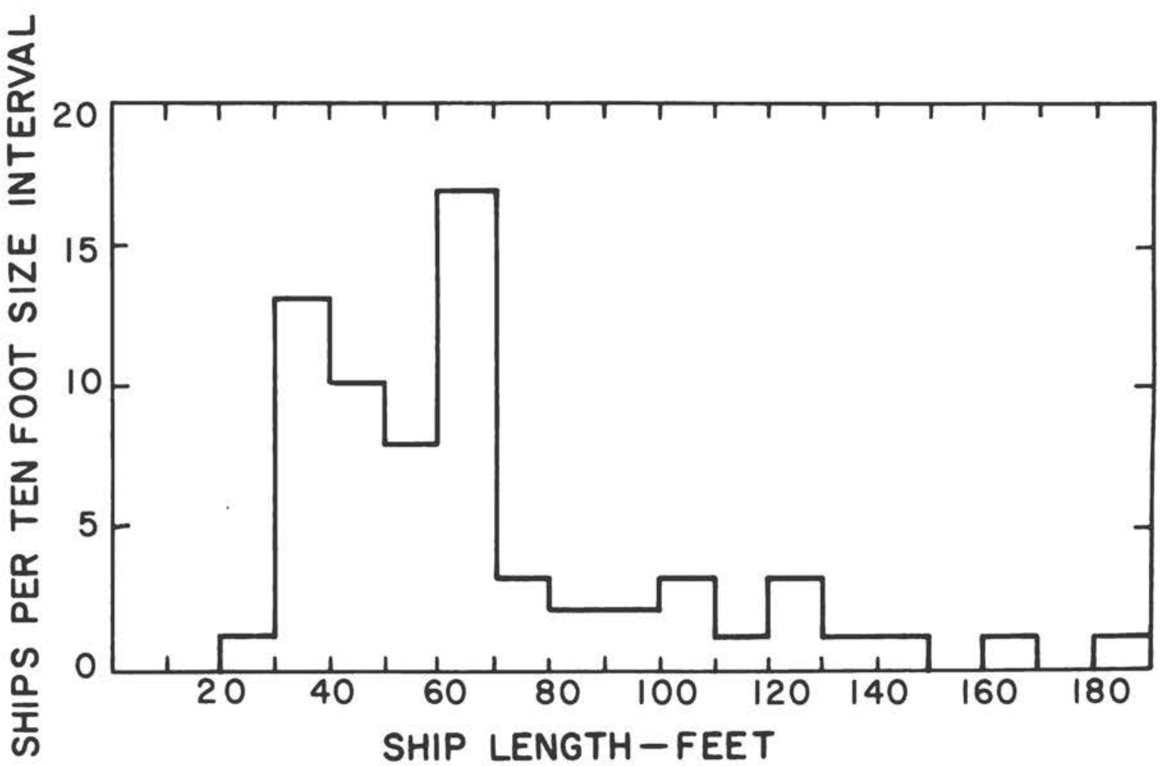

FIGURE II.1 Size distribution of non-UNOLS, academic, marine research vessels (from Table II.3) often change, and occasionally afford an opportunity for academic researchers to participate on a "not to interfere" basis, but the agency's missions for which the ships exist must always take precedence.

A review by NOAA of cooperative use of NOAA vessels indicated that in 1979-1980, the NOAA ships at sea hosted more than 500 people from 86 universities, 135 from 30 federal and state agencies, 110 from private activities, and 96 foreigners. These numbers are impressive, but they include significant numbers of students, trainees, and observers. A coherent analysis of the science accomplished by these "guest researchers" is not available. The fact that such cooperative voyages are possible should be more widely recognized, and academic researchers should be alerted by operating agencies to such opportunities when federal vessels are operating in their areas of interest.

Of the 25 NOAA ships listed in the NACOA report[4]), 9 are dedicated to fishery and biological investigations to support the National Marine Fisheries Service, 5 are designated for oceanography, and the balance are dedicated to navigation and charting tasks. A recent analysis of the fleet mix for the coming years[5] indicated that NOAA's fleet as it now stands is capable of meeting only about two-thirds of the agency's projected needs. Even allowing for a considerable reduction on the basis of disagreement concerning what is a real need, this projection suggests very tight scheduling and continued pressure for more days at sea. Also, current budgetary reductions are forcing a layup of three of the larger ships. Therefore, the prospect for accommodating significant amounts of academic research is decreasing.

The Navy (NAVOCEANO) operates 13 ships dedicated to ocean data programs. All are dedicated to meeting the Navy's needs in areas of military significance, including a number of classified projects which only occasionally coincide with broader scientific interests. The Navy has expressed interest in increasing academic participation in their research cruises.

The U.S. Coast Guard has a large number of ships operating in U.S. waters, a few of which collect oceanographic data. Particularly important to academic researchers has been the use of Coast Guard ice-breakers in polar regions. The Coast Guard's missions, however, are clearly law enforcement, search and rescue, and safety of sea lanes. These missions almost preclude the type of commitment which is required to complete a planned program of scientific data collection.

In summary, while it is clearly possible to conduct academic research from the federal vessels discussed above, and these vessels are used frequently by university researchers (Chapter V.A.), it is difficult to organize and plan a systematic and extensive research program using these platforms. Most of the ships are scheduled two years in advance, and most of the time there are backup missions which fill in the schedule. It is indeed serendipitous if availability of space on a NOAA or Navy ship happens to coincide with academic schedules and needs. There has recently been formed a Federal Oceanographic Fleet Coordination Council, to which UNOLS has been invited to send an observer. This Council may aid in coordinating the usage and management of the academic fleet with that of other fleets, although the Council's primary concern will be the federally operated fleets.

C. Present and Planned Methods for Funding, Scheduling, and Maintaining Vessels of the UNOLS Fleet

Federal agencies currently employ two different methods of funding the UNOLS fleet. These are, in simplest terms, "institutional funding" and "project funding." In recent years, NSF has funded approximately 70 percent of the usage of UNOLS ships through institutional funding from the Office of Oceanographic Facilities and Support (OFS) within the Division of Ocean Sciences (OCE). Institutional funding, as currently practiced, does not mean that each institution is given a fixed sum of money to operate its ships, independent of the projected amount of scientific use. Rather, this procedure consists of submission of proposals by the various operating institutions to NSF/OFS, requesting a certain number of ship days in order to carry out the research described in proposals that have been submitted by prospective investigators to the National Science Foundation. To receive such support for its ships, an operating institution must demonstrate that it has a substantial oceanographic research program of its own (though its own scientists need not be the major users of the ship), that it has the logistic capacity to operate the ship efficiently, that the ship is available to researchers from other institutions, and that the ship is in demand by investigators (especially those whose research is funded by NSF) and is capable of meeting the requirements of the proposed research. Institutions whose ships are supported in this way are almost always members of UNOLS, though not all members of UNOLS are thus supported.

As a part of its request, the operating institution submits a tentative schedule (which has been formulated with the advice of the UNOLS Scheduling Committee) showing how the various scientific programs will be accommodated. For those scientific proposals which are eventually funded by OCE, OFS has made every effort to supply the money needed to operate the ship. An advantage of institutional funding as used by NSF/OFS is the flexibility it permits the operating institution. If the cost of a particular research project or item (e.g., fuel) is higher than anticipated or if equipment failures occur, the operating institution can draw upon the entire funding granted by NSF, provided that the overrun can be covered by savings in other ship operating costs.

An important point is that the cost of operating a ship to conduct a research project does not appear in the budget of the research proposal; when the proposal is submitted, the investigator simply requests a period of time on a particular ship, plus acceptable alternatives. Since NSF/OCE defines ocean sciences very broadly (including the Great Lakes, for example), and we are in an era of intense competition for research funds, this method of funding has considerable appeal for a seagoing investigator whose research and budget are to be judged in comparison with many non-seagoing projects. One problem with this procedure as currently practiced by NSF is that the scientists who review OCE proposals by mail are not required to review the amount and kind of ship-time requested for a specific program. More effective utilization of NSF funds to support the fleet might result if the authors of NSF proposals were convinced that proposal reviewers as well as OCE scientific program managers had a strong incentive to evaluate the amount of ship-time needed to carry out the proposed research program. The scheduling of reviews of scientific proposals and of proposals for ship operations has recently been altered to improve this aspect, but even when such review occurs, it is likely that many researchers do not equate their requirements for ships with other items in their proposed NSF budgets (see Chapter III.F.).

ONR funded approximately 20 percent of the UNOLS ship-time during 1970-1980. This contribution steadily decreased during this period from 34 percent in 1970 to 12 percent in 1980. One reason for this decrease could be the method of funding used by ONR (and by other federal agencies except NSF). The funds for ship-time are requested as a specific item in the budget of each research proposal, and are supplied directly from research funds. Since ONR does not divide its funds between research and ship support, the program managers negotiate ship support, just as any other item in the budget, directly with the investigator and ship-operating institution, and only support the minimal number of ship days necessary to complete the proposed science. It is to the advantage of both the investigator and ONR that the investigator use the smallest ship available that will meet the requirements of the research. The savings made by using a vessel in the 150-199 ft. class instead of the 200 + ft. class can be considerable for a long cruise. Therefore, unlike NSF, one of whose goals has been to maintain a capability for U.S. seagoing research, ONR's goal usually has been to support only the specific amount of time needed for completion of specific research. The approach taken by ONR might not have been feasible without the commitment to "basic" support of the fleet by NSF.

Although NSF and ONR have different modes of funding, these agencies have jointly funded considerable research over the years; this has been especially true in large scale ocean programs (e.g., the Mid-Ocean Dynamics Experiment discussed in Appendix IV, section H). However, a marked difference between NSF and ONR in the ratio of ship support to total funds for ocean research has resulted from these diverse methods of funding. Table II.4 shows that for the period 1974-1982 NSF's Division of Ocean Sciences has spent approximately 31 percent of its funds on ship operations. Table II.5 shows that over the same period ONR has spent approximately 14 percent of its funds for ship support even though the Navy's mission would appear to depend directly upon seagoing research. The recent funding for operation of the UNOLS fleet by other agencies supporting marine science is shown in Table II.6. There does not appear to exist a current summary of funding for non-UNOLS vessels which would permit precise determination of the relative importance of federal and non-federal sources. The overall funding for the UNOLS fleet, and the funding which would have been required for full utilization, are shown in Table II.7, which also provides data on specific changes in this fleet.

TABLE II.4 Research and Ship Operations Expenditures (all ships except ALVIN), NSF Division of Ocean Sciences, 1974-1982 ($M, not adjusted for inflation)

	Year								
	1974	1975	1976	1977	1978	1979	1980	1981*	1982**
Research	27.6	31.2	31.3	34.7	37.3	39.3	41.6	45.7	49.3
Ship Ops.	12.5	13.4	13.6	15.0	15.8	16.5	18.1	21.0	23.4
Total	40.1	44.6	44.9	49.7	53.1	55.8	59.7	66.7	72.7
Ship Ops./Total	.312	.300	.303	.302	.298	.296	.303	.315	.322

* Estimated
**Projected

TABLE II.5 Research and Ship Operations Expenditures (all ships except ALVIN), Office of Naval Research ($M, not adjusted for inflation)

	Year						
	1974	1975	1976	1977	1978	1979	1980
Research	13.4	13.7	15.7	19.6	21.5	22.9	26.7
Ship Ops.	3.6	3.5	3.2	2.6	2.3	2.2	3.3
Total	17.0	17.2	18.9	22.2	23.8	25.1	30.0
Ship Ops/Total	.212	.203	.169	.117	.097	.088	.110

TABLE II.6 UNOLS Fleet Funding (millions of dollars) FY 77-80 and 81 Estimate (as of March 1981)

	1977	1978	1979	1980	1981
NSF/OFS	15.0	15.8	16.5	17.5	21.0
DPP				0.6	
ONR	2.6	2.3	2.2	3.3	3.4
Other Federal					
NAVELEX*	0.8	0.8	0.4**	0.4**	
BLM/USGS	2.1	1.3	0.9	1.1	1.2
DOE	0.6	1.0	0.6	1.0	1.8
NOAA	0.1	0.18	0.2	0.05	0.1
EPA	0.1	0.1	0.01	0.1	0.01
NASA		0.08	0.2		
ARPA					0.4
State & Private	0.6	1.2	0.9	1.5	1.5
Totals*	21.9	22.8	21.9	25.6	29.4

* Cost of operating MOANA WAVE by NAVELEX after 1978 not included in totals

**Provided to operate KANA KEOKI in lieu of access to MOANA WAVE

TABLE II.7 Funding for UNOLS Fleet Operation, 1970-79 ($M, not adjusted for inflation)
Source: NSF/OCE

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
NSF	7.4	8.2	10.1	11.6	12.5	13.4	13.6	15.0	15.8	16.5	18.1*
ONR	4.7	4.4	4.0	3.8	3.6	3.5	3.2	2.6	2.3	2.2	3.3
OTHER	1.6	1.9	1.8	1.5	2.1	2.8	4.1	4.3	4.7	3.2	4.2
TOTAL FUNDS AVAILABLE	13.7	14.5	15.9	16.9	18.2	19.7	20.9	21.9	22.8	21.9	25.6
SHORTFALL				0	0.3	0.7	0.4	0.5	1.7	2.7	2.0
TOTAL NEEDED FOR ALL SHIPS				16.9	18.5	20.4	21.3	22.4	24.5	24.6	27.6
NO. OF SHIPS OPERATING	35	35	34	34	29	29	28	28	28	27	25
FLEET CHANGES				PROTEUS (out)	GOSNOLD OCONOSTOTA INLAND SEAS MYSIS TURSIOPS (out)	GULFSTREAM (out) LONGHORN (in)	CHAIN (out) OCEANUS (in) YAQUINA (out) WECOMA (in) TRIDENT (out)	ENDEAVOR (in) AGASSIZ (out) MOANA WAVE (out)		NEW HORIZON (in) MAURY (out)	ACONA (out) GILLISS (out)
SHIPS LAID UP**/days operated				MELVILLE/223	WASH'TON/249 KNORR/250 A 11/252 THOMPSON/253	GILLISS/201 MELVILLE/144 WASH'TON/201 AGASSIZ/137 YAQUINA/186	THOMPSON/224 MELVILLE/203 WASH'TON/226 GILLISS/253 AGASSIZ/166 WECOMA/163 OCEANUS/188	THOMPSON/204 WASH'TON/253 GILLISS/150 ENDEAVOR/220	THOMPSON/249 WASH'TON/254 A 11/244 GILLISS/157 VEMA/161	MELVILLE/126 KNORR/213 A 11/118 WASH'TON/173 NEW HORIZON/213 VEMA/165	MELVILLE/181 CONRAD/23 ISELIN/171 NEW HORIZON/215

*0.4 for layup and termination costs (CONRAD and GILLISS).

**Based on full utilization as defined in Table II.1. "Layups" may be either for unanticipated repairs or because of lack of funds. Vessels of less than 150 ft which were underutilized are not listed.

The management of the UNOLS research fleet essentially lies with the 17 operating institutions which are voting members of UNOLS. The chief ingredient of UNOLS since its inception in 1972 has been cooperation and uniformity of purpose in order to facilitate access to all ships by qualified investigators, including those outside the operating institutions. Institutions which do not operate vessels but have significant instructional and research programs which require ships may become associate members of UNOLS by election. Nevertheless, control and scheduling of the ships remains with the operating institutions. As funding problems have become more acute during the late 1970's and early 1980's, the importance of UNOLS has increased.

In order to facilitate scheduling, a UNOLS Scheduling Group was established by the academic institutions. The operating procedures of this group have continuously undergone evaluation and refinement by the group itself and the UNOLS Advisory Council. In 1979 the following procedures were recommended to enable ship operators to reduce costs, increase available funding, and accomplish more science per dollar:[6]

1) NSF and other agencies should encourage the early submission and timely processing of proposals involving scientific work at sea.

2) OFS should provide the earliest possible information regarding funded ship days to the operating institutions, to permit them to revise schedules, plan economical operations and/or layups, and to seek other sources of funding.

3) Operating institutions should adopt accounting methods that reflect costs as they are incurred.

4) Institutions and/or UNOLS should provide open disclosure of daily and annual operating costs of UNOLS ships, and should institute "workshops" in which, experience on cost-reduction methods can be exchanged.

5) Each governmental agency supporting marine research should be urged to consider support of academic research ships as an integral part of its research budget, in an appropriate percentage of its total requirements for ships.

The UNOLS membership has recently formed, on a trial basis, an Eastern Region Ship Coordinating Group and a Western Region Ship Coordinating Group. Each group includes representatives from all major operating institutions within its region. Makeup of the groups is as follows:

Western	Eastern
U. of Alaska	Texas A&M (also participates in Western
U. of Hawaii	Rosenstiel School (U. of Miami)
U. of Washington	Duke U.
Oregon State U.	U. of Delaware
Moss Landing Lab.	U. of Rhode Island
U. of Southern California	Lamont-Doherty (Columbia U.)
Scripps Institutions (U. of CA)	Woods Hole
Member, Advisory Council	Member, Advisory Council
Observers: NSF, ONR	Observers, NSF, ONR

The makeup of the "fleets" with which each scheduling group works are as follows:

Western	Eastern
MELVILLE	KNORR
T. WASHINGTON	ATLANTIS II
T.G. THOMPSON	CONRAD
ALPHA HELIX	GYRE
KANA KEOKI	ISELIN
NEW HORIZON	CAPE FLORIDA
WECOMA	CAPE HATTERAS
CAYUSE	CAPE HENLOPEN
VELERO IV	ENDEAVOR
E.G. SCRIPPS	OCEANUS
ONAR	R. WARFIELD
HOH	LONGHORN
	BLUE FIN
	CALANUS

The Eastern Region Scheduling Group held its first meeting on 15 December 1980 and the Western Region Scheduling Group held its first meeting on 6 January 1981. The terms of reference under which these scheduling groups operate are given in Appendix I.

As noted above, shortages in operating funds have led to the laying up of some of the UNOLS vessels for parts of some years (Table II. 7) and to the deferment of major maintenance, modernization, and equipping, which has in turn led to other layups for repairs. Temporary layup is often a rapid solution to a problem of scheduling or funding, and permits maintenance and repairs. However, such layup, particularly on short notice, has many undesirable features including financial inefficiency, dislocation of people and facilities, and counter-productive competition for operating funds among UNOLS member institutions.

In part, because of the problems created by deferred maintenance of ships, the Navy is developing a management plan designed to provide the Navy with more positive control of its large UNOLS ships, to insure their availability when needed for Navy research, to improve their efficiency, and to protect the Navy's substantial investment in them. Responsibilities for management of Navy-owned oceanographic ships operated by academic institutions were transferred from the Oceanographer of the Navy to the Chief of Naval Research (CNR) on 1 October 1980. This establishes a clear responsibility within the Navy for the material condition, major maintenance, and rehabilitation for these ships by the same command which is responsible for Navy-supported academic research.

The CNR has instituted an ONR program which provides for the maintenance and upgrading of the Navy's academic ships, using Special Focus Program funds. This program specifically provides for the designation of a manager to cooperate with the academic institutions and other sponsors, development of a continuing inspection system, implementation of a maintenance and modernization program, and more active participation by Navy in the oversight of research operations of these ships. The management of the Navy's academic ships has been assigned to the ONR Environmental Division (Code 420), and a ship management office has been established to execute the program under the auspices of the Naval Ocean Research and Development Activity.

The Navy/ONR plan for maintenance and improvement can be divided into three categories: correction of accumulated deficiencies, improvements and upgrading of scientific capabilities, and replacements and major overhauls. In preparing their plan, the Navy has attempted to distinguish the ship and its basic equipment from the scientific gear associated with specific programs. This recognizes the fact that needs for specialized scientific equipment and instruments should be addressed in the plans for the research projects requiring this gear. The cost of routine maintenance, including periodic drydocking, is presumed to be covered by the daily rates charged to users of the vessels.

The Navy/ONR plan calls for the expenditure of on the order of $10.4 million (1979 dollars) on corrections, upgrading, and capital replacements during the period 1981-1986 to bring their ships to full operational capability. Plans are to accomplish a major refit on one ship each year and, as funding allows, to proceed with one or more areas of scientific upgrading for all the ships, such as replacement of satellite navigation receivers and improvement of oceanographic winches.

The NSF also has recognized that the growing difference between funds available to support operations of the existing UNOLS fleet and the funds needed to support full operation of this fleet has led to deferral of maintenance. Partly in an effort to counteract the problems caused by this, NSF has instituted (during the later part of 1980) a fleet-wide inspection procedure for the 11 NSF-owned or constructed vesels (Table II.1). This inspection procedure is being carried out under contract through the Maritime Administration by the American Bureau of Shipping Worldwide Technical Services, Inc. As of 1 September 1981, all 11 vessels have had their initial inspections to establish baselines for subsequent annual inspections and to identify the most urgent requirements for repair and upgrading. As in the Navy's new managerial program, NSF has attempted to distinguish the vessel and its basic outfit from scientific equipment associated with special programs. NSF may be aided in this matter by studies of the UNOLS.

D. Recent Cost of Operating Academic Research Vessels

Research vessels differ in several ways, but in terms of operating costs the most significant difference is in vessel size. This is not surprising, nor is it surprising that recent changes in the price of fuel have had marked effects on the cost of going to sea. For example, fuel was 12-13 percent of the total operating cost of the UNOLS fleet in 1974-79, but has risen to approximatly 25 percent in 1980-81. In order to understand more exactly the factors contributing to operating costs, we have examined two sets of data in some detail.

A measure of size of the academic fleet which incorporates the number of vessels, their scientific capacities (related to the vessels' sizes - Figure II.2), and the degree to which they are actually used is the scientist-days at sea per year on vessels operated by academic institutions. Costs can be evaluated against this measure of size. The number of scientist-days at sea is not necessarily correlated with scientific quality, but the former can be evaluated objectively and a priori, while the latter cannot.

1. Comparative Costs, 1973

The first data set, which is summarized in Table II.8A and B, is relatively old but was chosen because: 1) it was the most complete and thoroughly analyzed set of data available, and included the smaller categories of research ships which form only a minor part of the more recent UNOLS summaries; and 2) one of our interests was in the comparative cost for various sizes of ships for any given year, rather than in cost increases for a given size of ship through the years.

The last column in Table II.8 was derived from the relation, cost per potential scientist-day at sea = (total ship costs) / (actual days utilized at sea multiplied by potential scientific complement). It is of interest to note that this cost is relatively constant by class size except for the smallest ships; specifically, the average cost per potential scientist-day at sea for the 60-65 and 50-75 ft. categories in the two tables is $75 (1973 dollars) as compared with $165 for all other size classes. These figures are based on potential scientific ship complement and not on the actual scientists at sea for each class size for FY 1973. As discussed elsewhere in this report, the larger ships do not always go to sea with a full scientific complement, which would elevate the cost per actual scientist-day for the larger ships. It should also be pointed out, however, that the larger ships typically spend more days at sea per year than do small ships (see Table II.1).

The derived data in the last column of Table II.8A and B provide a convenient index but are not definitive in themselves. The more difficult question, which possibly can only be approached in a subjective manner, has to do with the type and quality of science obtained. The results do indicate why there has been a preference for the less expensive, smaller vessels for coastal and estuarine research; such a conclusion, however, should be tempered by the fact that there are many interesting coastal and estuarine problems that cannot be approached with the smaller vessels.

The numbers for a ship's scientific complement used in the above calculations were obtained from Figure II.2, which is based on data from UNOLS(8) and the National Oceanographic Data Center Volume(9). Although there is a fair amount of scatter to the data points, they do define a relatively linear relation; on average, adding 10 ft. of length adds one potential scientist.

Of somewhat more interest is Figure II.3, which was derived from the same source as Table II.8. The data produce a rather well-defined, distribution curve which might be helpful in determining the costs and benefits for alternative mixtures of ships.

There are significant differences between the results of this study and of that presented in the next section. These differences may be due in part to the distinct nature of the data sets. The 1973 data were collected from a variety of sources which employed different methods of accounting and record keeping. Moreover, these data reflect the situation during only one year, 1973. The conditions for funding and operation of the academic research fleet changed considerably between 1973 and 1980; as have the relative costs of vessel operation components (e.g., fuel vs. crew costs) and the general economic climate.

2. Costs of UNOLS Vessels, 1976-1980

The second set of data examined concerns the UNOLS fleet from 1976 to 1980, and was supplied by the UNOLS office. These data were subjected to a multivariate regression analysis (MRA) in order to examine the effects on the annual operating cost of a vessel of its size, the number of days per year at sea, the number of other vessels also operated by the home institution, and other factors. One advantage of this this approach is that the MRA summarizes data for the entire UNOLS fleet, and the mean trends identified thus pertain to a "typical" vessel, rather than to any particular existing vessel or institutional practice. Another advantage is that the form of the multiple regression equation is such that it can be used to evaluate the typical or average economic consequences of such policy decisions as layups of various durations for ships of various sizes, or of consolidating the fleet such that only a few institutions operate ships. What the MRA cannot do is to evaluate the scientific consequences of such actions.

Because of its length, the development and discussion of the MRA model for the UNOLS fleet is presented as Appendix II. The statistical significance of various results, and the assumptions underlying the analysis, are given there. It is important to note that the form of

TABLE II.8A Summary of Ship Cost Data for FY 1973 for Federally Funded Ships

Operated by	Ship length (feet)	Number in summary	Average length (feet)	Average Total ship costs, thousand dollars	Average utilization days at sea	Average scientific complement	Potential scientist cost per-day at sea (dollars)
Academic Institutions*	240	1	245	1,111	266	25	167
	201-240	6	210	993	266	21	178
	151-200	6	176	652	234	17	164
	101-150	4	117	404	234	11	157
	66-100	5	89	228	165	8	173
	60-65	8	62	64	165	5	78

TABLE II.8B Summary of Ship Cost Data for FY 1973 for Non-Federally Funded Ships

Operated by	Ship length (feet)	Number in summary	Average length (feet)	Average Total ship costs, thousand dollars	Average utilization days at sea	Average scientific complement	Potential scientist cost per-day at sea (dollars)
Academic Institutions*	76-100	5	88	140	112	8	156
	50-75	8	58	45	102	5	88
State Agencies	76-100	5	96	173	123	9	156
	50-75	10	60	35	116	5	60

*Questionnaires sent to 26 schools with largest dollar amounts of 1973 federal grants for ocean research from ONR, NSF, and NOAA.
**Questionnaires sent to 30 states with ocean or Great Lake ccoastlines.

Note: Columns 1, 2, 3, 4, 5 and 6 were taken from The capital structure for ocean science: Final report of the ocean science and technology resources study.(7) Column 7 for the scientific complement available for each class of ship was derived from Preliminary report UNOLS long-range planning meeting,(8) and Oceannographic vessels of the world.(9)

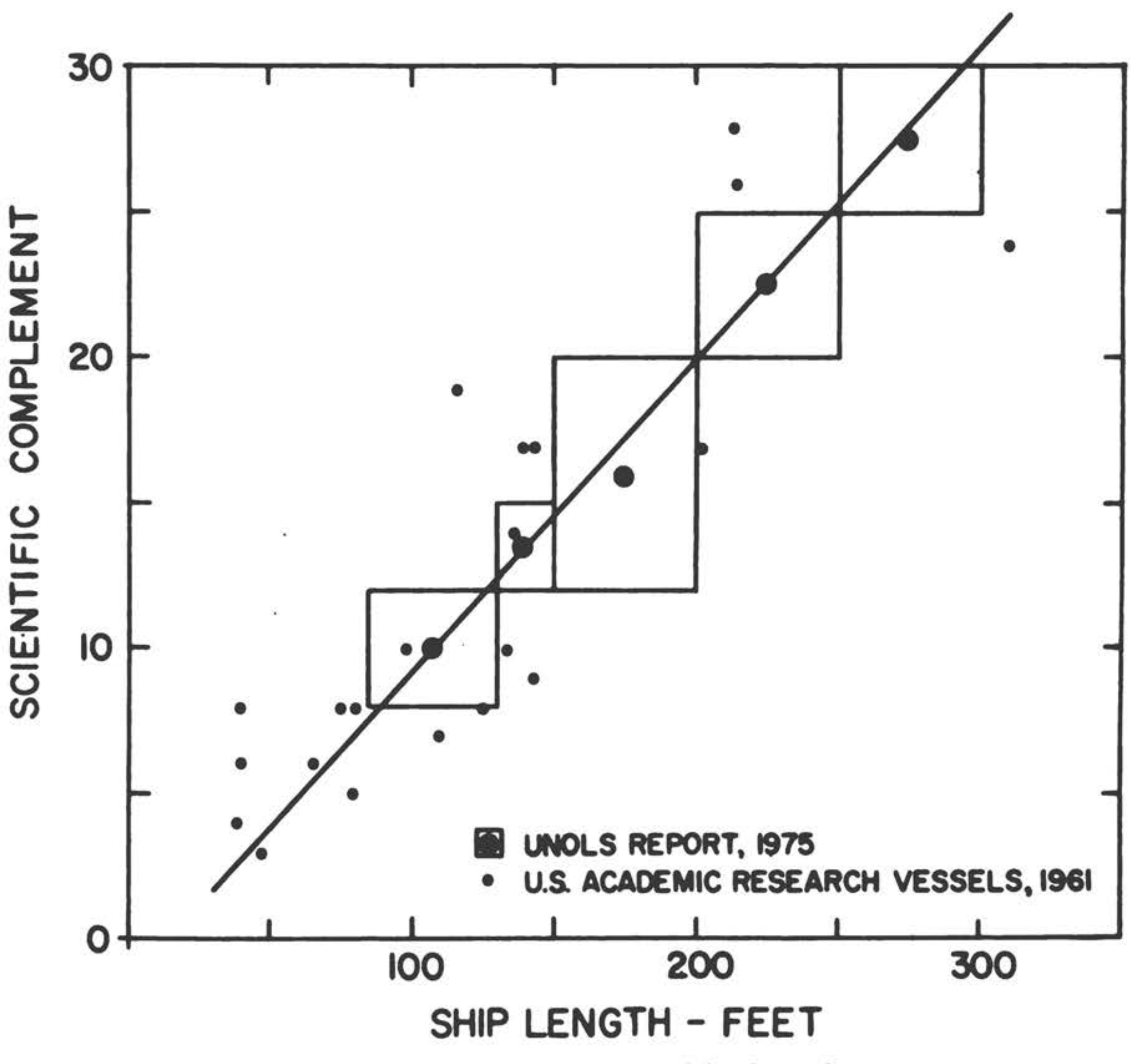

FIGURE II.2 Scientific complement versus ship length

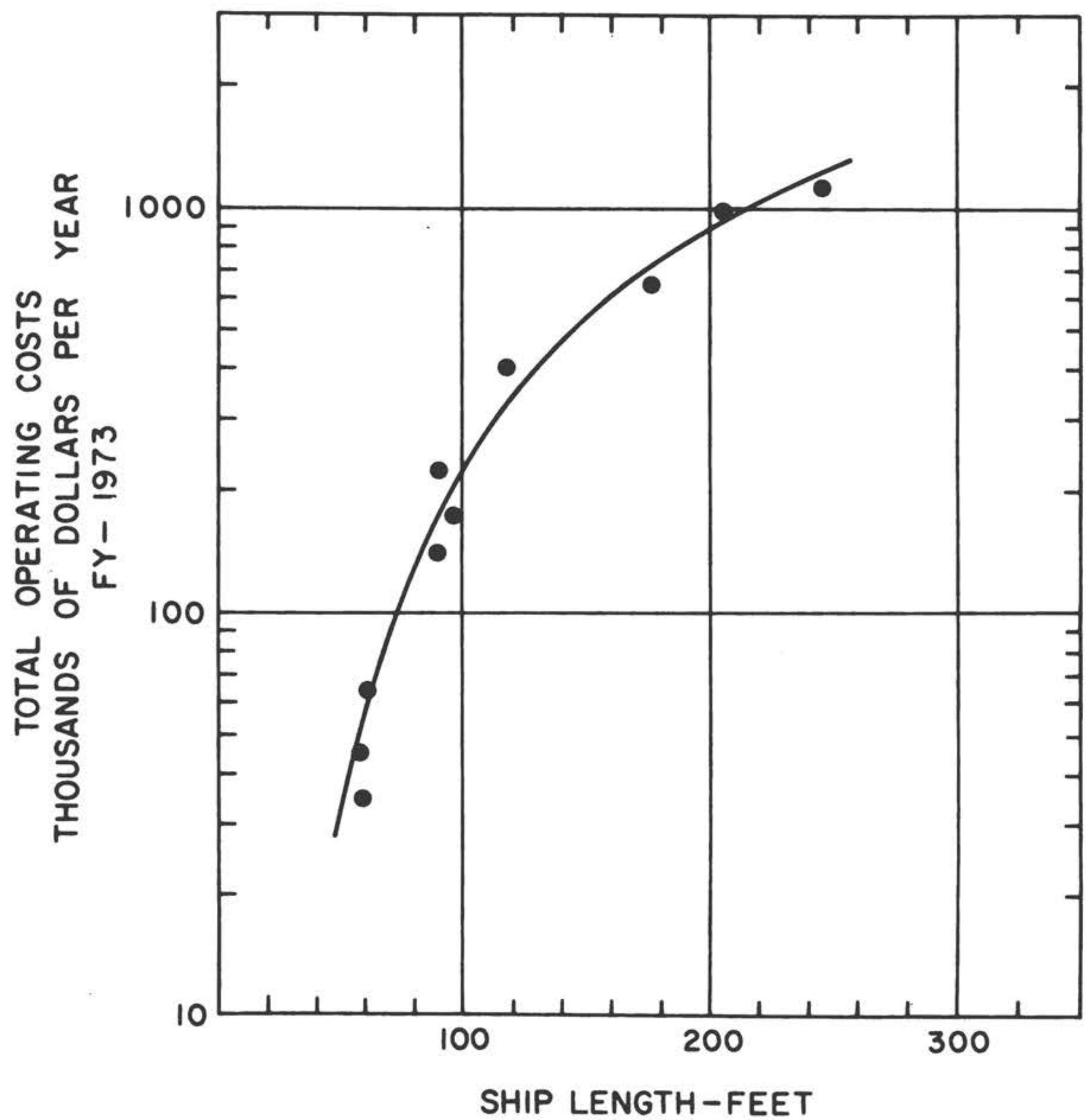

FIGURE II.3 Total annual operating costs, FY 1973, versus ship length (semilogarithmic). Points represent classes of vessels as summarized in Table II.8A and B, not individual ships.

the equation selected to relate vessel operating cost to operating days, vessel length, and vessel numbers will greatly condition the conclusions drawn from the regression analysis. The form of the relationship is not unique: another form might better fit a somewhat longer data set; modifications would be required if the data set included additional independent variables. Moreover, alternative formulations may be equally valid in describing the data set used.

Here we present only a brief summary of the results and conclusions of the MRA presented in Appendix II:

i) The regression equation is:

Total annual cost =

$$35.7 + 202.4\,(\text{length})^2 - 112.9\,(\text{length})^2\,\frac{(\text{number of vessels} - 1)}{(\text{number of vessels})}$$

$$+0.85\,(\text{days at sea per year})\,(\text{length})^2$$

where cost is thousands of 1979 dollars, length is hundreds of feet, and number of vessels are those operated by the same institution. The use of square of length results in a good description of the data, but the mechanistic explanation of this particular power law (as distinct from some other power of length greater than 1.0) is unclear. In the simplest case where each vessel is operated by a different institution, this relation translates into daily rates of $980 for a 60-ft. vessel operated for 161 days per year (the UNOLS mean for this size) to $10,400 for a 250-ft. vessel operated for 256 days per year. Whereas the data from 1973 (Figure II.3) result in a ratio of annual costs of 15:1 for a 200 ft. vessel relative to a 60 ft. one, the regression equation implies a ratio of about 10:1 in 1979.

ii) In these same units, the marginal or incremental cost of an additional day at sea is $0.86(\text{length})^2$ and the fixed operating cost is $35.7 + 202.4(\text{length})^2$.

iii) Savings resulting from a layup range from 3 percent of the full operating cost for a 60-ft. vessel laid up for 16 days (10 percent of its full operating year) to 15 percent for a 250-ft. vessel laid up for 77 days (30 percent of its full year). Extrapolation to longer layups is unjustified because additional reductions in fixed costs then become possible.

iv) Cost per potential scientist-day-at-sea increases faster than does the daily rate with increasing length of vessel, because scientific capacity increases approximately linearly with length, while cost increases as a higher power. This conclusion differs from the calculations summarized in Table II.8A, which indicated that in 1973 the cost per potential scientist-day-at-sea was relatively constant for vessels longer than 65 ft.

v) Small savings could be realized by consolidating the fleet so that fewer institutions operate the vessels; the savings per ship increase in absolute amount with increasing size of ship, but the savings relative to the operating cost of a given size of vessel are independent of the vessel's size. The savings are real, but may be economically trivial. The greatest savings result from the first consolidation which eliminates operation of single vessels by institutions. This results as a consequence of the form in which the variable, number of vessels, appears in the regression equation chosen for the multiple regression analysis. Many alternate specifications are possible for the functional form of the term in the MRA equation used to examine economies of scale. As pointed out by Fred Spiess (personal communication), the form chosen in this analysis has the undesired property that the total cost of fleet operation is independent of how the fleet is divided up among the institutions. However, Gates and Vieira Appendix II) have used the MRA to estimate the costs (by vessel class) for the operations by one institution of one, two, three, etc. vessels. Then, the cost for two institutions each operating one vessel were compared with the cost of one institution operating two vessels. Other similar comparisons were also made.

Analysis of data supplied by UNOLS also revealed an extension of conclusion (iv), namely that the operating cost per actual scientist-day-at-sea increases with increasing length of vessel even faster than does cost per potential scientist-day-at sea because large UNOLS ships more often go to sea with some empty scientific bunks than do small ships. From UNOLS data, the mean ratio of usage of scientific capacity (fraction of scientific bunks occupied) is 71 percent in the period 1976-80. Though there is a large amount of unexplained variation, there is a statistically significant regression (based on 83 observations) as follows:

$$\text{actual/potential usage} = 80.6 - 7.25(\text{length})$$

where length is in hundreds of feet, and the usage ratio is a percentage. Thus, the "statistically typical" range in the UNOLS fleet is from 76 percent for a 60 ft. vessel to 63 percent for a 240 ft. one.

This does not mean that large ships are generally scientifically inefficient; their size is often required because of the associated cruising range, ability to launch and recover heavy gear or to contain bulky analytical or recording equipment, or for safety in bad weather, rather than because of the number of scientists required to conduct the research.

If additional, productive scientists can be accommodated on a cruise and accomplish additional research without interfering with or greatly prolonging the main program, this research usually has rather low incremental cost. This fact bears on the recommendations presented in Chapter V for funding and scheduling of the academic fleet.

All of these conclusions are subject to the limitations of the data themselves and of the factors considered in the analysis. For example, result (v) does not take into account new shoreside construction costs which might be incurred if ships were actually transferred to a few institutions, nor the transportation costs for seagoing scientists at institutions without ships. Result (iii) does not include remobilization costs following a prolonged layup. More important is that the MRA model is a purely economic analysis, and does not address costs or benefits other than those reflected in the annual operating cost of ships.

Implications of this analysis for the future size of the academic fleet and its management are elaborated upon in Chapters IV and V. The MRA suggests some possible benefits of managerial policies in terms of annual operating costs of the fleet, but there may be other economic costs to be weighed against these benefits. Even if overall economic benefits exceed costs, the more difficult question is that of how to evaluate scientific costs and benefits.

III. THE SIZE AND COMPOSITION OF THE ACADEMIC FLEET, 1985-1990

A. Introduction

In this section of the report, we discuss various trends (manpower, funding, and the plans of academic oceanographers) which may affect the use of academic vessels in 1985-1990. These different trends suggest different conclusions as to the desirable or likely size and composition of the fleet. Given these different conclusions, the goal is to bring the scientifically desirable and the economically possible situations as close together as is feasible. Chapters IV and V contain economic comparisons between possible options, based on recent history, and suggestions for the management and operation of the fleet which might make more funds available for the conduct of research.

We believe that we have reviewed all of the recent major documents and sources of information (see references) that provide credible clues as to future ocean science needs for research ships.

The committee has also attempted to determine plans of specific institutions by sending a questionnaire to 82 leaders of academic, oceanographic, research groups in the United States. Addressees were usually directors of small institutions or divisional or departmental heads in large institutions. The intent of the questionnaire (reproduced as Appendix III) was to determine realistic plans for future oceanographic research, and the implications of these plans for the use of ships.

It is useful to consider trends in manpower, in financial support for the operation of ships, and in marine science in attempting to predict changes in the size of the fleet, though these factors are surely interrelated. We have not attempted to evaluate in detail future financial support for seagoing research, though this is clearly a limiting factor as well for the use of ships can be (and has been) reduced by insufficient funding for research just as surely as by insufficient funding for the ships themselves.

B. Trends in Manpower

The annual rate of production of doctoral (Ph.D.) scientists who became employed in oceanography increased steadily from 1958 through 1978, and there is no indication that this trend has changed in the recent period, 1975-78 (10, Figure 1), though many expect that the rate of increase will soon be lessened.* Because careers are much longer than Ph.D. programs, the number of doctoral scientists employed in oceanography has continued to accelerate (ibid, Figure 2). Of course, not all these scientists are researchers, and not all researchers require ships, as discussed below. Further, the rates of growth differ between disciplines (ibid. Figure 19), and different disciplines apparently require somewhat different types of ships and amounts of ship-time per capita to be healthy. For example, in 1978 approximately half of the working oceanographers were biologists (ibid, Figure 20), yet the biologists used only 30 percent of the total ship-days at sea that year on the UNOLS fleet, and these days were primarily on the smaller ships (data from UNOLS ship reports).

Oceanographers employed outside academia would be expected to place fewer demands on the academic fleet than do academic oceanographers, but as of 1977 there was little indication of a major shift to non-academic employment (ibid, Figure 13). Therefore, judging only from the growth through 1978 in the total population of doctoral scientists employed in oceanography, the "size" of the academic fleet needed in 1985 to accommmodate them should be about 1.8 times the size in 1975. This is certainly not going to be the case; the comparison simply indicates that the need for the academic fleet is very unlikely to be limited by manpower per se, although certain disciplines may well grow more slowly than others because of a lack of current graduate students (notably, physical oceanography).

C. Trends in Financial Support for Vessels

The current status of funding for the UNOLS fleet, for which the best data are available, was outlined in Chapter II.C. This fleet has gradually become increasingly dependent on the NSF, which in 1979-80 supplied 74 percent of its operating funds, as contrasted with 55 percent

*After this report was prepared, data became avilable that suggest that the number of non-oceanography trained Ph.D.'s entering oceanography began to decrease in the early 1970's (1980 U.S. Directory of Marine Scientists Questionnaires) and that the number of oceanography trained Ph.D. oceanographers began to decline in 1979 (annual NRC Survey of U.S. Doctorates)." However, the 1980 U.S. directory survey data show that the high number of Ph.D. oceanographers estimated to be employed in 1978 by the NAS report "Doctoral Scientists in Oceanography" (2600) was very close (128 less) to the number actually counted by the 1980 survey. Furthermore, the 1980 survey probably under-sampled Ph.D. oceanographers in industry. Thus the primary conclusion of this section that academic research ship use will not be manpower-limited is still warranted.

in 1971-72. The total budget available for operation of the UNOLS Fleet is currently about 90 percent of that required for its full operation (Table II.7). In addition, maintenance has been deferred and eventually will have to be accomplished. A most serious contributing factor has been the increasing cost of fuel.

We do not have adequate data to examine the degree of utilization of non-UNOLS academic vessels, or whether operating funds for these vessels have been adequate.

Projections of future support for academic research and for the academic vessels by the Division of Ocean Sciences of NSF and by ONR are given in Tables III.1 and III.2, as supplied by these agencies. The projection for NSF is based on the assumptions that the rate of increase will match inflation. The category labeled "ship construction and upgrading" in Table III.1 is an estimate of funds to be used for

TABLE III.1 NSF Division of Ocean Sciences Projection of Support for Research Vessels ($M)

	1981	1982	1983*	1984*	1985*	1986*	1987*
OCE Research	45.7	49.3	54.2	59.6	65.6	72.2	79.4
OFS Ship Operations	22.9	25.9	28.5	31.3	34.5	37.9	41.7
Ship Construction & Upgrading	2.0	2.5	2.7	3.0	3.3	3.6	4.0
Shipboard Equipment & Shared Facilities	1.8	2.0	2.2	2.1	2.1	2.1	2.3
OFS Total	26.7	30.4	33.4	36.4	39.9	43.6	48.0
TOTAL OCEAN SCIENCE DIVISION	72.4	79.7	87.6	96.0	105.5	115.8	127.4

1981 Revised Budget (March 1981)

1982 Revised Budget (March 1981)

*1983-87 estimates (March 1981) based on the following assumptions: Level funding in 1982 dollars, and ten percent inflation. Decrease in shipboard equipment and shared facilities to allow for smaller growth for technicians and for ALVIN support.

TABLE III.2 ONR Projections of Support for Ocean Science Contract Research Programs ($M). Does not include ship refit program.

	1981		1982		1983		1984		1985		1986	
	a	b	a	b	a	b	a	b	a	b	a	b
Research	26.6	25.2	33.0	31.2	32.9	31.0	37.6	35.5	41.6	39.3	44.4	41.9
Ship Support	3.0	4.4	3.7	5.5	3.6	5.5	4.2	6.3	4.6	6.9	4.9	7.4
Total Support	29.6		36.7		36.5		41.8		46.2		49.3	

Assumptions: - Total support figures at projections within ±10% as of 17 March 1981.

a) 10% of total support goes to ship time
b) 15% of total support goes to ship time

needed deferred maintenance (Chapter II.A.) and for mid-life refits and construction of smaller vessels (Chapter III.D.). The funds labeled "shipboard equipment and shared facilities" will be used to improve basic ship operations, permanent shipboard scientific equipment, and oceanographic instrumentation.[25] Projected support for vessels from ONR depends on the fraction of the projected ONR research budget which is used to support the fleet directly. ONR does not expect to approach the ratio of ship support to research support in practice for many years and projected by NSF. In addition to the funds projected for the support of research and ship operations, ONR plans to spend during the period 1981-1986 approximately $10.4 million (1979 dollars) on corrections, upgrading, and capital equipment replacement in order to bring the Navy-owned ships of the oceanographic fleet to full operational capability (see II.C., V.D., and reference 2).

Use of academic vessels by researchers funded by other federal or state agencies, or by private industry, is difficult to anticipate. State and private usage might increase from the present $1.5 million to reach $2 million per year, in spite of the fact that the federal government is currently attempting to shift more of the responsibility for coastal research to the states. We know of no significant trends in use of ships by the Department of Energy, U.S. Geological Survey, Environmental Protection Agency, or Bureau of Land Management which will increase needs for academic vessels; the total usage of academic vessels by these agencies might continue at an amount of about $3 million per year. NOAA officials believe there are more mandated field programs for the near future than funds to operate the NOAA vessels will permit (see Chapter II.B). This could, in principle, result in some shift of NOAA research to academic vessels. However, it seems unlikely that NOAA will become a significant source of funds for research originated by academic scientists and requiring academic vessels, though some leasing of academic vessels to conduct NOAA research is perhaps desirable.

Within NSF, the most significant factors which will potentially affect the fleet are the development of the Ocean Margin Drilling Program (OMDP), possible continuation of the Deep Sea Drilling Program (DSDP), the recommended changes in the oceanographic programs of the Division of Polar Programs (DPP)[11] (see section III.F.2. below), and a developing research program dealing with world climate and the influence on it of variations in oceanic circulation (section III.F.5. below). The OMDP and DSDP might provide $4 million per year for surveys of potential drilling sites by conventional ships with multichannel seismic equipment. The contribution from Polar Programs depends in part on the question of ice-strengthened research vessels, as discussed below (D.2.d.). A reasonable expectation is $1.5 million per year if the large UNOLS vessels are employed for research in open water in the Antarctic.

As an indicator of the future, the likely range of financial support available for the operation of academic vessels in 1986 is $50 million (10 percent of ONR's total academic funds going to ships; no OMDP) to $56 million (ONR 15 percent to ships, $4 million OMDP). This is equivalent to an annual increase of 8-11 percent. These estimates do not include NSF and ONR funds earmarked for maintenance and upgrading of capabilities. Major upgrading reduces the requirement for operating funds somewhat, since a ship which is undergoing extensive refitting is thereby unavailable for operation for several months[3] and Chapter III.D.). Some additional funds will likely be needed to replace the submersible tender LULU (discussed in III.D.2.a. below) and to initiate the major replacements which will be needed in the early 1990's (see expected retirement dates, Table II.1).

It will be shown in Chapter IV that the level of vessel support currently projected for 1986 will be about 15 percent less than the amount necessary for full operation of the general-purpose vessels in a fleet of current size. This situation forces consideration of alternative actions. One possibility is to increase the projected future funding of vessels by agencies presently supporting the academic fleet. A second alternative is to increase the use and therefore the funding base of the academic research fleet through provision of vessel time for other agencies, e.g., many ship needs of the oceanographic laboratories of NOAA could be well served by academic research vessels. Another possibility is reduction in the costs of operating the fleet through reducing the size of the fleet. Measured in scientists-days at sea per year, this reduction could be accomplished by temporary layups for various periods; by retiring vessels from the fleet, possibly replacing them by smaller vessels; or by converting vessels to special purposes so as to make new sources of funds available.

D. Trends in Marine Science

In this section we are concerned with marine science and the academic researchers and institutions which conduct it.

1. Needs for General-Purpose Vessels

At present, the average oceanographer requires, or at least is able to obtain, less ship-time than did the statistical equivalent in earlier years. This conclusion is indicated by several observations: 1) Data from the NSF indicate a decrease from 1975 through 1979 for most disciplines in the fraction of projects funded by the Division of Ocean Sciences which were "field" as contrasted to "laboratory" in character;[12] 2) In spite of increases in fuel costs which exceeded the general inflation rate, the ratio of expenditures by the Division of Ocean Sciences of NSF on ship operations to those on research is slightly less than in 1974-75 (Table II.4); 3) The number of working oceanographers increased by 30-45 percent in the period, while the total number of ship-days at sea per year of the UNOLS fleet did not increase, and the usage of the largest (greater than 200 ft.) ships decreased. We believe the decrease in usage of the largest ships may be at least in part a response to their high cost.

Each of these points may be interpreted in several ways. For example, the fact that the initial phases of the IDOE, requiring extensive field work, came during the early 1970's might explain point 1. Point 2 may have resulted either from a decrease in demand for ship-time or from an administrative decision changing the allocation of funds. A shift in usage to non-UNOLS (i.e., NOAA, Navy, private, or state-owned) vessels would account for point 3; we have some evidence of a shift of this sort (Table V.1).

We believe that the decrease in per capita ship utilization is both real and comprehensible. In the late 1970's, many field researchers had accumulated a backlog of samples or data from IDOE projects, resulting in a temporary decrease (see sections H, I of Appendix IV). Over a longer time period, there has continued to be a shift from long cruises designed to explore and map the oceans' properties to cruises directed to answering specific questions. This shift is illustrated by studies of Cold Core Rings in the North Atlantic and of the North Pacific Gyre (see sections B and C of Appendix IV). Such investigations were often discipline-oriented, though some IDOE projects were notable exceptions. The role of theoretical studies, calculations, and models not requiring new field data has increased, as is natural for a maturing science. Most important has been the rapid development and increased use of long-lived, untended sensors of all sorts, and of electronic sensors deployed from ships. These have enormously increased the rate of accumulation of data per scientist-day at sea, and this augmentation is only partly offset by the simultaneous increase in computing power to reduce and analyze those data. All these factors have decreased the per capita use of ship-time, though the total need may still be increasing.

The responses by research leaders (listed in Appendix III) to our questionnaire indicate likely continuation of the trend noted above - namely, that research staffs will increase faster than will the size and use of the fleet (though there was one reported trend in the opposite direction). Nevertheless, there is a clear consensus that there will be an increased total need for research time on general-purpose ships, and that the size of the academic fleet should, if present plans are to be realized, increase somewhat by 1990.

Several research groups whose activities are now entirely estuarine plan expansion of research onto the continental shelf and slope, though some of these groups will rely on vessels operated by other institutions. Fewer than 10 percent of the respondents believed that increased use of remote sensing and unmanned devices would decrease the need for ship-time; the opinion of the large majority was that remote sensing would supplement ship operations, alter the tasks and equipment required on vessels, provide additional or new kinds of information, etc., but would leave unchanged or increase the need for general-purpose research vessels.

Only four respondents reported plans for retirement of existing vessels without replacement, and only one of these vessels was larger than 100 ft. In addition to the recently completed replacements of the EASTWARD and the GILLISS by CAPE FLORIDA and CAPE HATTERAS, five respondents reported plans (probably somewhere between firm plans and hopes) to replace existing vessels operated by their institutions with slightly larger vessels, and no respondents reported a reverse change. Plans (or hopes) for entirely new vessels included six of less than 100 ft., four in the 100-150 ft. class, and one ice-strengthened vessel of 200-250 ft. length.

Judging from the responses to the committee's questionnaire, use of federally or privately operated vessels is quite variable at present, and there are no clear projections for change in the future. Except that institutions with inland locations or very small marine programs tend to rely on leasing, there is no obvious correlation between extent of use of non-academic ships and size of institution; institutional personality, history, and geography seem to be the primary influences on such use.

The use of scientist-days at sea as a measure of the size of the academic fleet obscures the obvious fact that certain sizes of individual vessels are essential to conduct certain kinds of research, since cruising range, draft, ability to handle gear, and safety are all related to a vessel's size. A quantitative assessment of cost and utilization as functions of length of vessel is presented in Chapter II.D. and Appendix II of this report. Scientific trends and national needs give some indication as to future requirements for specific sizes of ships. Particularly critical is the role of large (> 200 ft.) ships which have high cost, both absolutely and per scientist-day at sea (see II.D.), and high political visibility.

The two newest UNOLS ships are 135-ft. coastal vessels. Several federal mission-oriented agencies have been primarily concerned with estuaries and coastal zones where moderate-sized vessels are generally satisfactory, at least in terms of safety. (However, this federal concern has not been matched by significant increase in operating funds for ships from the mission-oriented agencies). Institutional and regional pride have tended to encourage the proliferation of small vessels.

There are several arguments for maintaining some number of large vessels readily available to academic oceanographers. To the extent that IDOE projects (such as the GEOSECS program discussed in section I of Appendix IV) temporarily saturated seagoing oceanographers, need for large ships will eventually increase again. The U.S. Navy still has a worldwide, open-ocean mission which requires research, and there are several large areas of the world ocean in which research cannot be conducted without the cruising range of a large vessel. The Circum-Antarctic Survey discussed in section F of Appendix IV is a clear example of this need. Some kinds of mineral exploitation, power generation, and waste disposal, whose economic feasibilities and environmental impacts must be assessed, are moving offshore. Much scientific equipment, especially that going onto or into the bottom, has increased in weight, bulk, and complexity, and therefore must be deployed from large, stable ships, even if the equipment is a substitute for ship-days at sea and requires only a few people for deployment. Increasing scientific and national interest in interactions between the ocean and the atmosphere continues to require observations made under conditions where those interactions are hazardous for small vessels. Electronic sensors and computers have often resulted in a change in the kind, or even increase in number, of technicians who must go to sea, rather than a reduction in the number of technicians needed to conduct research. Partly as a result of the IDOE, academic scientists now frequently work together in large, interdisciplinary projects which require enough space that researchers from several disciplines be able to work on the same ship at the same time. This is true even if the ship is operating close to shore.

The extent to which federally operated, large vessels can meet academic needs is discussed further in Chapters II.B. and V.A, as is the leasing of vessels from the private sector. It is worth noting, however, that private operators are offering to provide moderate-sized vessels without major scientific equipment, rather than providing the capabilities now available on the UNOLS vessels.(13) Exceptions to this generalization are special-purpose vessels which private industry can provide, such as those equipped for geophysical exploration, as discussed in III.D.2.

A related issue is the use of ships of opportunity - that is, installation of scientific equipment on ships whose function is commercial and whose cruise tracks and speeds are dictated accordingly. Though there are obvious attractions of economics and frequency of coverage in the commercial sea-lanes, there does not seem to be a developing trend which might decrease the need for academic research vessels. This is probably because scientific instrumentation has become sufficiently complex that technically skilled operators are required for maintenance and calibration. Also, many areas of the ocean cannot be studied in this way because no major sea-lanes pass through them.

Another proven source of systematically collected oceanographic data has been naval vessels. As part of various defense related programs, naval vessels have been systematically collecting data in the areas of physical oceanography and marine geophysics since World War I. Most of these data have eventually been archived for general use by the scientific community. We anticipate that this data source will continue, but do not believe that it will decrease the need for academic research vessels.

2. Needs for Special-Purpose Vessels

For certain types of research, special vessels or vessel configurations are required which exclude other research either permanently (because of the vessel's basic design) or for long periods (because of special equipment which fully occupies the vessel). Here we consider a variety of such special-purpose vessels.

a. Research Submersibles and Underwater Habitats

The scientific investigations which can be pursued by direct observation or manipulation have recently been reviewed in a National Research

Council report.[14] This report was directed to NOAA, but the discussion and recommendations are broadly applicable and, in the committee's opinion, sound. No cost estimates were provided.

Estimated need for manned submersibles and habitats by federally funded programs (NOAA, Navy, NSF and AEC) in 1975-79 was approximately 600 dive-days per year.[7] However, the use by the academic community during the years 1975-80 of the submersible ALVIN averaged only 164 dive-days per year (250 operating days per year including transit time). This use rate may be lower than future needs however, since the increase in scientific interest in hydrothermal vents is not adequately reflected in the 1975-80 use period.

Submersibles are a particularly interesting case, since at one time there were more U.S. submersibles (including those operated by private industry) than could be operated profitably in either an economic or intellectual sense. After the spectacular discoveries at the hydrothermal vents, the scientific interest in the deep submersible ALVIN increased dramatically. This illustrates the unforeseable changes in utilization of such facilities. In future years, ALVIN should probably be used increasingly in conjunction with precise navigation and thorough preliminary surveys by unmanned camera (e.g., ANGUS) and/or acoustic (e.g., Deeptow, Seabeam) systems so that the manipulative and observational capabilities of ALVIN can be used most efficiently.[15]

A NACOA committee report[4] specifically recommended provision for two submersibles with 6000 m depth capability. That committee noted that the U.S. Navy would soon upgrade the SEA CLIFF to achieve this capacity, and suggested that the academic research submersible ALVIN could be upgraded to similar capability. We question the implementation of this recommendation until experience is gained with the SEA CLIFF (see below) and until financial support is programmed for the science programs requiring them. Perhaps more important is their recommendation for the replacement of ALVIN's tender, LULU, with a vessel of greater range, capacity, and ability to operate in rough seas.

An improved tender for ALVIN, will need to be designed and built (or converted) in order to utilize fully even the existing depth capacity. With proper design such a tender should be suitable for a modified ALVIN with greater depth capability. The ALVIN should probably be converted to a single-point lifting system for launch and recovery (UNOLS submersible report). The experience of the Navy in operating the SEA CLIFF (with 6000 m capability) should be examined for a few years before increasing the academic submersible capacity to this depth. This experience would be most instructive if the Navy can make a significant amount of diving time of the SEA CLIFF readily available to qualified academic scientists to pursue their own research projects. Scientific utilization of SEA CLIFF would be enhanced if a technical support group were established to assist scientific users and coordinate with the Navy operators. The recommendation to make SEA CLIFF time available to the academic community is consistent with that of the UNOLS Submersible Science Study[15] which also pointed out that by the mid-1980's, more data on the characteristics of fiber composite materials for the pressure hull would be available. These materials have the potential for savings in cost and weight compared to a titanium hull.

b. Dedicated Geology/Geophysics Ships

Marine geology and geophysics has seen rapid change in the past two decades. In the 1960's, the emphasis was on the reconnaissance of the seafloor worldwide, with many ships equipped with rudimentary instruments. In the 1970's, with scientific targets on the seafloor more clearly defined, thanks in large part to the plate tectonic model, studies were directed toward smaller areas and more incisive tools were applied. This trend will obviously continue into the 1980's. Reconnaissance surveying will only be needed in remote areas that have escaped earlier study, such as the Arctic and Circum-Antarctic Ocean. Future marine geology and geophysics research will be directed toward fundamental problems, such as the deep structure of rifted margins and their evolution, the structure and tectonics of collisional plate boundaries, deep-sea sedimentary processes (especially on the slope and rise), and hydrothermal phenomena on the deep seafloor.

These studies will require advanced technologies that are expensive to acquire and to operate. Because of the large cost of some of these facilities, the academic research community will be able to afford a limited number. Consequently, research programs will often require interdisciplinary and multiinstitutional cooperation to be effectively addressed. The Middle America Trench Study, discussed in section G of Appendix IV, is an example of such an investigation.

The needs of marine geoscience have already led to much interinstitutional cooperation in programs, e.g., the Deep Sea Drilling Project, and the sharing of national facilities, e.g., the deep submersible ALVIN. Cooperative arrangements have been formulated for the use of the Scripps Deep Tow and the multibeam echosounding capability. The need for sophisticated underway geophysical capability has given rise to the concept of a 'dedicated' research vessel to be equipped with 'state-of-the-art' instrumentation for studying the seafloor and the underlying structure. The term 'dedicated' implies that the vessel is configured and equipment on board is specialized so as to allow marine geologists and geophysists to do work not capable of being done from other vessels in the academic fleet and that the use of the vessel for such work will take precedence over other oceanographic uses. It is also recognized that the cost and uniqueness of dedicated ships require that they be a shared facility among the academic research community.

Marine geologists and geophysists in the United States currently use a major fraction of the available academic ship-time. It is a field that supports a growing number of researchers, and certain aspects of the research are of profound economic importance. The level of field activity anticipated during the 1980's can well support two types of special facilities:

1. vessels dedicated to long seismic array experiments, and
2. the seagoing capabilities to carry out studies of the

benthic boundary layer requiring deep towing and the deployment/recovery of large bottom instruments.

Of the ships in the U.S. Academic Fleet, those over 200 ft. are best suited for use as specially equipped geology and geophysics vessels in the deep sea. They have the range to work in remote areas of the ocean for weeks at a time; they have the stability to operate in high latitudes and heavy weather, the power to tow large vehicles or arrays, the hull size appropriate for multibeam sounding systems, and the space to accommodate large, heavy and cumbersome sampling equipment and the gear necessary to handle it. They must be equipped with a suite of instruments for basic surveying, including the capabilities for absolute and relative positioning, magnetic field determination, digital data logging, digital data synthesis, subbottom profiling, and perhaps others.

A research vessel dedicated to handling the long seismic arrays would probably require: large capacity, high pressure air compressors; a capacity for storing very long seismic streamers (either on reels or in coiling wells), and special booms, davits, and outriggers to tow airgun arrays. This vessel should also be equipped with a good sea gravimeter and would require rather powerful computer capability. The receiving and recording equipment required could vary considerably (in numbers of streamers and channels) depending on the scientific objectives.

The capability needed to carry out modern benthic boundary studies may be achieved through the acquisition of a suite of dedicated equipment which could be deployed on various research vessels. The capability to operate deep-towed instrument packages dictates a system for routinely and reliably handling a several-km long conductor or coaxial cable and deck equipment for handling the towed "fish" and requires that the ship be maneuverable at slow speeds. It is desirable that the vessel be acoustically quiet in order to use bottom navigation nets. Equipment should include a multiple narrow-beam swath mapping system and 3.5 khz sounder, and perhaps large and deep-sea piston coring or handling special ocean-bottom samplers or submersibles.

These stated capabilities of the two types of geological/geophysical facilities are meant only to be suggestive. The specific requirements and specifications of capabilities for special seagoing work in marine geology and geophysics should be considered by the community of such scientists and recommended to NSF and ONR.

c. Drilling Ships

The GLOMAR CHALLENGER, operated by Global Marine Inc., is the ship around which the highly successful Deep Sea Drilling Project (DSDP) has been centered since 1968. This project has made remarkable contributions to our understanding of plate tectonics, paleoclimatology, and geochemistry by verifying the predictions of the sea-floor spreading hypothesis; documenting the history of great horizontal movements and the vertical subsidence of the crust beneath the sea; establishing the major features of oceanic circulation patterns over the past 100 millions years, and some of the relations between these patterns and the evolution of earth's climates, including glaciation; providing samples to calibrate geophysical measurements and access for *in situ* geophysical and geochemical experiments; and, where sediments are thin enough to permit CHALLENGER drilling, documenting the tectonic and sedimentary history of typical continental margins. Technical achievements included dynamic positioning of the drilling ship, development of sonar techniques for reentering a drill hole, and improvement in coring techniques.

Funding for operating the CHALLENGER, now running at about $22 million per year, comes from U.S. agencies ($\sim$ 60 percent) and participating foreign governments ($\sim$ 40 percent).

The drilling system deployed from the CHALLENGER has, however, no positive control over the drill hole, and the drilling fluid (sea water) flows in an open system. For drilling on the outer continental slopes where oil and/or gas under pressure may be encountered, it is necessary for safety and environmental protection to have a closed circulation system in order to use drilling mud and for positive blowout prevention. The necessary riser pipe and blowout preventers require a much larger ship than the CHALLENGER for their deployment. The scientific and industrial interests in an exploratory Ocean Margin Drilling Program (OMDP) are strong. Thus a proposal to modify the GLOMAR EXPLORER, which is owned by the U.S. Government, to accomplish the goals of OMDP is being discussed. The conversion of the EXPLORER is estimated to cost $60-80 million, and the OMDP itself about $560 million over 10 years; this cost would be borne jointly by federal agencies and major U.S. petroleum industries. The converted EXPLORER could drill into sediments on the ocean's margins which are too thick for the CHALLENGER, and thus reveal more clearly the structure of active margins (where two crustal plates, one continental, collide to form a trench or subduction zone) and passive margins (the trailing edge of a moving continental plate), and permit the assessment of hydrocarbon resources, especially along the passive margins. Because of its thicker hull, the EXPLORER is also more suitable for drilling in Antarctic waters than is the CHALLENGER.

Because of their ownership and operation, neither the CHALLENGER nor the EXPLORER are part of the academic fleet in the strict sense, but they clearly require a major investment of effort by academic oceanographers, both as individuals and through the scientific advisory bodies of JOI Inc., and have yielded (or may yield) great scientific benefits. It is beyond the scope of this report to assess the merits of the OMDP in detail, or to resolve the relative merits of starting the OMDP versus continuing the DSDP. The two programs may be brought into closer harmony as a result of a Conference on Scientific Ocean Drilling held in November of 1981. The OMDP in particular will be very expensive (the annual cost of the total program will be approximately equivalent to the annual operating costs of the entire UNOLS fleet). This high cost and the cost sharing by industry have caused OMDP to be managed as a separate program within NSF, so that it will not compete initially for funds with the general-purpose ships of the academic fleet. In fact, as noted in III.C. above, the necessity for pre-drilling site surveys by more conventional geological and geophysical techniques may result in some new operating funds for several academic ships.

d. Polar Vessels

There is presently little commercial interest in the U.S. in the exploitation of Antarctic fisheries. There is, however, considerable concern with the food chains which affect the whales and seals, and with the effects on these food chains of exploitation by other nations.[11] This concern stems from an interest in fundamental scientific problems as well as from the need for such information to meet for U.S. responsibilities under the Convention on the Conservation of Antarctic Living Marine Resources. Also there is mounting pressure to conduct geophysical exploration around Antarctica, and there is the need to assess the potential biological impacts of possible future exploration and exploitation of offshore hydrocarbons.[16,17] Many of the biologically important processes are associated directly with the edge of the pack ice, where an ice-strengthened vessel is essential to carry out research.

In the Arctic, major exploitation of oil and gas resources is already underway, and pragmatic needs for research are continually increasing. Commercial traffic in the seas around Alaska is very likely to increase in association with exploitation of minerals and hydrocarbons, and environmental research is needed for safety of both the ships and the environment. The U.S. has become responsible for management of a major fishery on the Bering Sea shelf. This area is covered by ice much of the year. With the spring melting of the ice is associated unusually high primary productivity, and upon this base rests an abundant and conspicuous food chain. Soviet vessels, because of their ice-worthiness, have dominated the fishing and oceanographic activities.

Even in the unlikely event that U.S. interests in Antarctic resources do not increase, there is a need for polar research in order to improve our understanding of world climate. In both polar regions, the ice cover has a significant effect on climate by affecting reflectivity of solar energy (albedo), insulating the sea from the atmosphere so modifying exchanges, and affecting the oceans' salinity through freezing and melting. The polar oceans thus provide the major source of intermediate and bottom waters and a major heat sink for the deep waters of the ocean.

The UNOLS fleet now has no fully ice-strengthened vessels (except ALPHA HELIX which is Class C), though some vessels (such as MELVILLE, KNORR, and OCEANUS) have some ice protection, and potential for work in ice pack is severely limited. In the vicinity of the Antarctic Peninsula, some work can be conducted from the 125-ft. R/V HERO, a wooden-hulled trawler owned and operated by NSF. Past work has been conducted from the USNS ELTANIN, (later operated as the ISLAS ORCADAS by Argentina), which is not now operating and would require expensive refitting prior to further work, and from large foreign vessels or from Coast Guard ice-breakers (see Appendix IV, section F). These latter vessels have never been generally satisfactory, because their other missions received first priority. In addition to the need for ice-strenthening, long endurance is required of vessels working in the Antarctic. No UNOLS vessel currently has the necessary endurance.

In principle, a single ice-strengthened research vessel of 200-250 ft. would probably accommodate the scientific needs of academic oceanographers, but the fuel costs of moving a very heavy ship from pole to pole perhaps twice a year would be considerable, and critical portions of transition seasons would be missed at both poles. If the U.S. is to have an active research program in the ice, the NSF should immediately implement a policy to provide for the order of 1000-2000 scientist-days at sea every year on an ice-strengthened vessel in each polar ocean. Research needs are likely to continue well beyond 1990, and therefore construction of a new vessel or vessels would be economically preferable to reconditioning the ELTANIN/ISLAS ORCADAS. Also, an effective program of research in the Arctic Ocean requires a vessel which meets different conditions (including limited ice-breaking capability) than those in the Antarctic. A suitably designed vessel could be kept in continual operation in Arctic seas. If a new vessel is not constructed, a combination of leasing of ice-strengthened vessels and use of one of the largest UNOLS vessels for open-water work may be adequate for U.S. research, but will make this research dependent on the activities of other nations.

The U.S. must either begin construction of a new ice-strengthened vessel at once, or accept the fact that oceanography in pack ice will depend on the ships of other nations. In the latter case, agencies must provide assistance with legal and logistic problems arising from use arrangements. One use arrangement may take the form of cooperative programs with other nations in which U.S. scientists and equipment are placed on foreign vessels in order to accomplish mutually interesting research. Alternatively, there might be a cooperative program involving a UNOLS vessel working in open water and a foreign vessel. This arrangement would perhaps be more feasible in the Antarctic than in the Arctic, because of the international nature of the former.

Because of the intensity of biological processes at the edge of the ice, consideration should be given to improvement of under-ice submersible and habitat capabilities.(15) The difficulties are more those of launch and recovery than of submerged operation.

e. Deployment of Large Nets and Trawls

Some studies, particularly certain kinds of fisheries investigations (of interest to NOAA) and studies of sound scatters (of interest to Navy), are seriously handicapped by the inability to sample quantitatively the large, mobile, rare nekton (fish and squid), especially in deep water.(20) Acoustic devices have provided a partial solution, but do not permit determination of species, sexual maturity, gut contents, chemical constituents (both natural and pollutant), etc. Hence, there is interest in developing an ability to deploy very large trawls for academic research use. The need for such a capability is illustrated by experience during the Cold Core Ring Study, in the North Atlantic (see Section B of Appendix IV).

There are several approaches available to obtain this capability. The Glosten Associates Report[18] estimates that the necessary winches, towing warp, and related equipment needed to adapt the larger UNOLS vessels for deployment of large nets and trawls would cost $400-440,000, excluding the trawl nets. Another approach would be through commercial leasing, which would require provision of considerable financial support for leasing, since the few suitable U.S. commercial vessels are very expensive and would probably have to be leased for several months at a time to assure availability. Finally, it might be possible to work in cooperation with NOAA or various foreign governments, such as Japan, USSR, West Germany, or Norway, which already have this capability.

We recommend that the capability for using large nets and trawls be made available to academic researchers as required. If a trawl system could be available for temporary installation on selected UNOLS vessels, leasing would not be necessary. However, the level of scientific interest appears insufficient at present to warrant a dedicated ship.

f. Research Barges and FLIP

Because of interests in repetitive sampling to establish time series, and in having immediate access to modern laboratory facilities in the open ocean, biological and chemical oceanograhers have urged consideration of research "barges."[8] A "barge" in this context simply means a large, stable platform with very limited self-mobility. Chemical and biological "clean rooms," enhanced physical stability for sensitive instruments, and a large suite of analytical equipment might be incorporated in such a design.

This suggestion has not been pursued, though in the past floating ice stations have been used in an analogous way in the Arctic Ocean and very useful time series are obtained from weather ships. If site-specific questions about the open ocean must be answered, such as environmental effects of waste disposal or the generation of electrical power from oceanic thermal gradients, detailed long-term studies at a few potential sites might be more economically conducted from moored barges than from conventional research ships. Whether a barge would be cost-effective depends on the specific circumstances.

A special case of a barge is the stable platform, FLIP. This platform lacks the capacious laboratory space discussed above, but has great stability and is ideal for suspending equipment without sea-induced motion, densely instrumenting the upper 100 m, etc. Though it has not been used for very long moorings in the past, it can be refueled and reprovisioned at sea. With adequate maintenance, it will still be in service by 1990. It has recently been used for deployment of Doppler sonar systems to study surface and internal movements of water in the upper few hundred meters and for environmental acoustic research concerning sound propagation and ambient noise. FLIP operations are presently subsidized by ONR.

E. Composition of a Research Fleet Based on Institutional Plans

Several distinct approaches to projecting an academic fleet which would be adequate to the research demands of the oceanographic community during the period 1985-1990 are possible. In this section, we describe the fleet which we have projected based on one such approach.

This approach began with the study of planning documents dealing with oceanographic research and the distribution of a questionnaire to leaders in the academic research community (Appendix III). Based on plans as reported in answers to our questionnaire and on information from the planning documents, the composition of an academic fleet for the late 1980's was formulated. Since we included representatives from the spectrum of institutions concerned with ocean science, the vessel requirements being projected are those now met by the total academic research fleet, not only the UNOLS fleet.

Predictably, the projection is for a fleet comprised principally of the present UNOLS fleet (Table II.1) plus existing non-UNOLS academic vessels (Table II.3). This core would be supplemented by the addition of a number of general-purpose vessels, principally of small size (Class III and IV). In addition, a number of special-purpose vessels needed to cover the projected science plans for the period 1985-1990 have been included in this projected fleet. We refer to this as the academically planned fleet, the composition of which is presented in Table III.3. (One might argue that academically planned is not the correct description for this fleet, since the views expressed by the individual group leaders contacted do not always coincide with those of the institutional management, since there is probably redundancy in the requested expansion in numbers of smaller sized vessels, and perhaps for other reasons. Nevertheless, academically planned is the term used in this report, and the reader should bear these caveats in mind.)

TABLE III.3. Composition of the Academically Planned Fleet, and Change from Current Fleet

General - purpose number	size	Change from current level
6	200 + ft.	0
9	150-200 ft.	+1
17	100-150 ft.	+5
33-38	50-100 ft.	+6
Special-purpose		
1 new tender for ALVIN		additional funds
existing submersibles and underwater habitats		0
2 drilling ships (GLOMAR EXPLORER, GLOMAR CHALLENGER)		+1
1 200 + ft., ice-strengthened polar vessel		+1
leasing commercial vessels		additional funds
FLIP		0

For the most part the scientific community believes that the present fleet composition, as evolved over the years, is adequate for the research planned during the latter part of this decade. The increased numbers of small, general-purpose ships reflect an increased interest at the local levels in capabilities for near-shore reserch (III.D.1). Most of these vessels are desired at institutions whose current capabilities are quite limited. It should be noted that an excess capacity on ships of length less than 150 ft. seems already to exist (IV.C).

The rationale for the increase in special-purpose vessels was discussed in section III.D.2. a-f. In addition to the vessels listed in Table III.3, the scientific community wishes improved capabilities in the field of marine geophysics and the capability of handling in the field of marine geophysics and the capability of handling large nets and trawls. Our opinion is that these capabilties would best be attained by adaptation of large general-purpose vessels or by commercial leasing, and not through the construction of special-purpose vessels.

The fleet composition indicated in Table III.3 should accommodate the academic research projected for the late 1980's, and for a considerable period thereafter. Whether funds will be available for the construction and operation of this fleet, or for the research needed to keep this fleet occupied, remains to be seen. It is clear that the current trends in financial support summarized in section III.C are not adequate for operation of such an expanded fleet. These trends must be modified, if we expect to accommodate the research needs foreseen by representatives of the academic community.

F. Trends in Some National and International Plans

1. Introduction

Another way of assessing future needs for research vessels is to examine recently planned or evolving scientific programs which are national (or international) in character, and might not therefore be fully subsumed in the institutional plans reported in response to the questionnaire (Appendix III). Such planning, usually presented in reports of study groups of various sorts, provides both advance notice and advice to governmental agencies (and, though usually not by design, to working scientists and research leaders) on the changing nature of oceanographic research. Often absent in such reports, however, is a philosophy of limited financial resources, and explicit statements as to those activities which should be stopped or reduced in magnitude so as to finance proposed new activities. Also absent, in most cases, are analyses of the ship-time required to complete the programs.

As examples, five proposed research programs were examined for their implications with respect to research ships. The programs involve both important scientific questions and the national interests of the United States.

2. Antarctic Marine Ecosystems

A committee to evaluate marine ecosystems research in the Antarctic was established by the Polar Research Board and the Ocean Sciences Board of the National Research Council in response: to international interest in assessing the stocks of krill (Euphausia superba) in the Antarctic (Southern) Ocean; to interests in the preservation of marine mammals; and to United States commitments under the Convention of the Conservation of Antarctic Marine Living Resources. This committee recommended specific research programs on the ice edge ecosystem and aggregations of krill, and estimated (by comparison with existing projects) that the additional cost of these new programs, for ship operations alone, would be about $3 million in 1980.(11) The report also summarizes the foreign vessels involved in Antarctic research, and concludes that, "...the USNS ELTANIN should be modernized or, depending on cost-benefit studies, an ice-worthy replacement ship should be provided as soon as possible."

The committee recommended use of a combination of research ships and remote or untended sensing devices (satellites, drifting buoys, free-vehicle acoustic systems, etc.) for the two research programs. If both programs are to be conducted simultaneously, approximately 250 ship-days at sea per year, involving at times three ships operating simultaneously, will be required. If ships of suitable sizes, ranges, and ice-strengthening will be obtainable in 1985 for an average cost of $12,000 (1980 dollars) per day - and this is reasonable since one of the ships could be fairly small - the total estimate of $3 million for ship operations will suffice.

Two points deserve reemphasis: 1) the sea time is viewed by the committee as required in addition to existing Antarctic programs of a more general nature; and 2) the sea time is to be supplemented and extended by expensive, remote sensing devices and special sampling equipment, some of which are not yet developed. For comparison, it is important to recognize that the current projection of funds for operation of research vessels in the Antarctic is only $1.5 million.

3. The Ocean as a Repository for General Wastes

A report entitled, "The Role of the Ocean in a Waste Management Strategy"(19) presents a comprehensive summary of recent views of the ability of the ocean to absorb sewage sludge, municipal wastes, dredge spoils, and industrial waste, and presents a summary of the legal framework governing land, air, and water pollution. The report concludes that disposal of wastes at sea should continue to be an option for the United States (with reasonable safeguards), and that such disposal is preferable in many instances to disposal in air (through incineration) or in fresh water or on land.

The report recommends, "...research and monitoring relevant to the disposal of wastes of all kinds in various oceanic environments." However, the report does not include an estimate of the requirements for ships which this research and monitoring will presumably entail, and the acting chairman of the NACOA committee does not believe that a reliable estimate of this sort exists (Knauss, personal communication). It is likely that the monitoring of waste disposal will be at geographically dispersed sites. It probably will be accomplished with on-site, unmanned devices on the bottom; requiring large ships which can work in any weather and deploy large, cumbersome seafloor systems.

4. Physical Oceanographic Research Related to Subseabed Disposal of High-Level Radioactive Waste

A possible means of disposal of high-level radioactive waste containing thousands of curies per cubic meter (mainly as spent fuel rods and solidified waste of reprocessed reactor fuels) by the United States and/or by other nations is to bury them in or place them upon the abyssal sea floor. Some low-level wastes are already disposed of by dumping on the sea floor, but burial has not been attempted.

A group of American, Canadian, and English physical oceanographers considered the research which is needed to assess the modes and magnitudes of possible transport of radionuclides.(20) This report was part of a continuing planning effort. The basic problem is the estimation of transport of water, and hence (potentially) radionuclides, from a small area of the abyssal sea floor to surface waters, where contact with humans is possible. It was recognized that research in geology and geophysics, chemistry, and biology would also be needed.

The group recommended a combination of analysis of historical data; measurements at sea with present equipment (e.g., deep dye dispersion experiments); development of new methods (e.g., detection of deep salt fingers) or improvment of existing techniques (e.g., sofar and pop-up floats, faster deep-sea winches); and modeling on several scales of physical processes (e.g., regional and general eddy-resolving models). Research at sea was required for studies ranging from measuring the escapement and reentrainment of parcels of water from the benthic boundary layer, and the microstructure of abyssal temperature, to measuring the volume flux of the abyssal water of the Pacific Ocean.

Practical decisions will be required by the United States within a decade; even if the United States decides not to dispose of high-level waste at sea, it must be prepared to evaluate disposal plans of nations which do decide to dispose of such waste in this way.

If the projects which were considered essential by this group of scientists are to be completed, approximately $4.5 million (1980 dollars) of ship-time per year will be required for approximately five years. Most of these projects deal with fundamental problems in physical oceanography, and therefore could be funded by any one of several federal agencies, or a combination. However, this requirement for ship-time to assess the physical oceanographic aspects of abyssal waste disposal can be compared to the annual expenditures by the Department of Energy of $1 - 1.8 million for UNOLS ship operations for all projects in 1980-81 (Table II.6). During these same years, the total expenditures by DOE, EPA, and BLM together were only $2 - 3 million per year.

5. Global Oceanic Circulation and Climate

The large-scale movement of water in the world ocean affects the global distributions of natural and anthropogenic substances introduced into its waters; controls to a large degree the earth's climate through transports of heat and substances, e.g., CO_2; causes coastal fisheries to wax and wane; affects the routes used by maritime commerce; and contributes to the operational problems of the U.S. Navy's sea-based deterent. A general, though incomplete, picture of the oceanic circulation has been built up from conventional shipboard measurements made in different places at different times. Further understanding, especially of the variability in the general circulation, requires measurements which cannot realistically be obtained using ships alone, principally because time series of synoptic, worldwide observations are needed.

Since meso- and macro-scale oceanic currents have associated cross-current changes in the elevation of the sea surface which are proportional to the current's surface speed, the locations and strengths of the major surface currents can be mapped if the global distribution of sea surface elevation can be determined relative to some known level. If this determination can be repeated frequently, the variability of such surface currents can be assessed.

Combining these directly measured patterns of surface currents with subsurface distributions of relative pressure gradients and directly measured subsurface currents will yield a picture of subsurface flow patterns also. The subsurface distributions can be obtained from density measured at hydrographic stations and from measurements using moored arrays.

These possibilities have led to a plan for a long term program to study the general ocean circulation.[21] This plan calls for measurements of the topography of the sea surface using altimetric-and geoid-measuring satellites, supplemented by selected measurements from instrument arrays moored in the ocean and by hydrographic and chemical measurements from ships in the North and South Atlantic, North Pacific, and Indian Oceans. Including plans for measurements of transient isotopic tracers, these large-scale shipboard surveys will require approximately two ship-years per year on large (Class I, > 200 ft.) ships for about five years, and the United States will probably perform half of this work. Study of relations between forcing by wind and the response of the ocean's circulation will be possible using satellite measurements of surface wind stress, which are included in the TOPEX (Ocean Topography Experiment) plan.

Several other programs dealing with ocean dynamics and climate are closely related to the TOPEX study of general circulation. Studies of the heat budgets and heat fluxes in the Atlantic and Southern (Antarctic) Oceans, and Greenland-Iceland-Norwegian Seas are expected to use annually one large NOAA vessel, 0.3 ship-year of a Class I academic vessel, and one full Class II vessel,, as well as ships-of-opportunity and Scandanavian vessels. Pacific sea-air interaction studies will require one Class II academic vessel per year for the next few years, together with the continued use of a large NOAA ship. In addition, about 0.3 ship-year of both a Class I and a Class II academic vessel annually will be needed for associated studies of micro- and meso-scale processes.

This large, complex program can be considered as the United States component of the oceanographic portion of the World Climate Research Program, which is of interest to several federal agencies. It is presently still in the planning stage, though some components are already underway. The annual requirement for academic ship-time to carry out the ocean climate dynamics program, which is proposed for the mid and late 1980's, is 2 full ship-years on 200 + ft. vessels and 2.3 full ship-years on 150-200 ft. vessels (D.J. Baker and C. Wunsch, personal communication). The annual operating cost would be $6.3 million in 1985 (from Table IV.1). The ship-time required in the late 1980's for this U.S. ocean climate dynamics program would completely utilize one-third to one-half of the Class I and II (> 150 ft.) vessels which will be available at that time based on the present projections of ship operating funds.

6. Ocean Crustal Dynamics

The Joint Oceanographic Institutions Incorporated (JOI Inc.) sponsored a series of workshops on various aspects of marine geology and geophysics to develop research plans for the 1980's. These workshops resulted in a report[23] defining the Ocean Crustal Dynamics Program, which is intended as a complement to oceanic drilling programs (section D.2.c. above). Specific recommendations relating to research ships are to:

1) Acquire and install two multibeam bathymetric charting (Seabeam) systems immediately, and four more by 1990;
2) Increase support for near-bottom towed acoustic systems;
3) Develop a long-range, side-scanning sonar;
4) Study the use of unmanned, cable-controlled vehicles in deep water;
5) Evaluate the possibility of converting a 200-300 ft. commercial ship for deep piston coring; and
6) Begin development of long-term ocean bottom observatories.

An important element in the program is the development and acquisition of high-resolution instruments and technological capabilities which can be installed on existing academic vessels (except perhaps for the deep piston coring). The report recommends that such systems be deployed on a few ships which, though operated by individual academic institutions, would then become national facilities scheduled through UNOLS.

The report recommends that a set of corridors (transects) extending from land across the continental shelf into the oceanic regions be studied. Recommended transects include one each in the northeastern United States, the southeastern United States, the Gulf of Mexico, Southern California, and the Cascades of Washington; two extending south from Alaska; and one in the Mariana Island Arc. The ship-time required to carry out these transects and other recommended studies is estimated at a mean of 77 ship-months (6.4 ship-years) per year from 1985 through 1990. Much of the work would be a necessary adjunct to drilling. The ships required would be in the largest classes, because of the equipment to be used; an estimated cost in 1985 is $10 million for ship-time (from Table IV.1, assuming an average annual cost per ship of $1.6 million).

7. Conclusion

The purpose of this section is to illustrate, through examples, the discrepancy between the seagoing research which United States scientists believe to be necessary to solve some of the important scientific problems which are also significant for United States national interests, and the projected ship operating funds which we have been able to identify. Four programs - Antarctic marine ecosystems, physical oceanographic aspects of high-level radioactive waste disposal, global ocean climate dynamics, and ocean crustal dynamics - would require almost half of the total operating funds projected to be available from all sources for all UNOLS ships in 1986 (section C. above), if conducted simultaneously. If only academic vessels were used, these programs would also occupy the total time of United States academic vessels larger than 150 ft. It is important to realize that these programs by no means exhaust current planning by academic oceanographers and governmental officials; nor will these programs, if conducted, absorb all the energies and creativity of oceanographic researchers, many of whom wish to conduct small-scale, individual projects. And, it is apparent that these programs cannot all be conducted with the projected funding without dramatically perturbing the ship support for many other segments of oceanographic science.

IV. COSTS AND SCIENTIFIC IMPLICATIONS OF ALTERNATIVE COMPOSITIONS OF THE ACADEMIC FLEET, AND CRITERIA FOR RETIREMENT OF SHIPS

A. Present, Academically Planned, and Possible Compositions in 1985-1990, and Their Operating Costs

Trends in seagoing research and in financial support for research ships were discussed in the preceding chapter. Based on these trends, four basic models or scenarios of the composition of the academic fleet (defined as all research vessels operated by academic institutions) have been developed. They probably represent the range of likely situations; each model fleet has associated with it a financial cost and several important consequences for the magnitudes and types of oceanographic research which can be conducted.

The scenarios were constructed so as to illustrate economic causes and consequences rather than scientific needs, although one scenario is the academically planned model described in Chapter III. The focus is on the cost of operation of the general-purpose vessels, because these costs are the best known. The distinction between UNOLS and non-UNOLS vessels becomes unimportant, since the purpose is to evaluate national capabilities and costs. However, separate models for both the UNOLS and the total fleet are presented, since the economic analysis is based on data only from the UNOLS fleet (Table II.7 and Appendix II) and extrapolation to non-UNOLS vessels requires further assumptions. There is no inclusion in the analysis of the construction costs which would be incurred by increasing the fleet, nor of the funds recovered by sale of vessels eliminated from the fleet. Also excluded is the fact that vessels undergoing refit are unavailable for use at sea.

Assumptions included in the calculations are as follows:

1) Constant funding for ship operations in real (1979) dollars was assumed. This means that actual funding is assumed to grow at the rate of inflation, which has been the case for NSF in recent years.

2) Fuel prices are assumed to increase at a <u>real</u> rate (i.e., in excess of inflation) of 3 percent per year. This assumption is consistent with recent judgments made by the oil industry and the Department of Energy.

3) Non-fuel costs (see Appendix II, Table A II.1) remain constant in real terms. We note that, based on the recent past, this assumption will result in a <u>considerable</u> underestimation of vessel operating

costs, because the costs of marine operations have increased at a much greater rate than the general rate of inflation.

4) The annual cost for vessels in each class from 1985-1990 is based on the mean predicted value for each class from equation 3 (Appendix II, Table A II.3) rather than using data for each vessel. In using the regression equation, it is assumed that vessels operate the number of days during 1985-1990 that they did, on average, over the period 1975-79. The resulting annual costs are shown in Table IV.1.

5) The current funding shortfall is about 10 percent of full annual operating costs for the UNOLS fleet (see Table II.7). This is assumed to be also true for the academic fleet as a whole, though we have no data with which to confirm this speculation.

6) As noted in Chapter III.C, when major upgrading and maintenance are performed on a ship, the requirement for operating funds is somewhat reduced because that ship is not available for operation during the refitting. Such cost savings are <u>not</u> reflected in the calculation.

Obvious implications of these assumptions are (1) energy price increases will worsen the present real funding shortfall in the future and, (2) given the relative fuel consumption rates, real costs will increase faster for larger vessels than for small vessels.

It is important to realize that the costs in Table IV.1 are in 1979 dollars. If inflation continues at 10 percent through 1990, then the nominal cost of Class I vessel (> 200 ft.) in 1990 will be $5124 thousand per vessel per year instead of the indicated $1796 thousand per vessel per year. Under the assumption of level real funding, it is simpler to work with costs expressed in real or constant 1979 dollars.

Using the projected cost equation for the multiple regression analysis (Equation 3, Appendix II), the 1985-1990 costs of four scenarios were evaluated for two separate fleet compositions: the UNOLS fleet (Table IV.2.a.) and the total academic fleet (Table IV.2. b.). For these fleets scenario A consists of the existing UNOLS fleet or the total academic fleet, respectively. Scenario B consists of the academically planned fleet discussed in section III.G. and is only applicable when discussing the total academic fleet. Scenario C was constructed under the assumption that there will be level funding for the fleet in 1979 dollars, except for a gradual increase (above the inflation rate) due to rising fuel costs (Table IV.1). Scenario D was constructed under the assumption that the standing fleet would be reduced in size because of the increasing desirability to lease special-purpose vessels to conduct academic research. In this case, an arbitrary 15 percent of the total operating budget for the fleet was set aside for such leasing. In addition, Scenarios C and D are each broken into 3 subscenarios or variants (e.g., C1, C2, and C3). These variants correspond to the placement of emphasis on particular vessel classes: a I-II variant emphasizes retention of vessel Classes I and II; a III-IV variant emphasizes retention of Class III and IV vessel; and an "equal sacrifice" variant allows for adjustments to eliminate budget shortfalls to be made as equatably as possible across all vessel classes.

TABLE IV.1 Projections of Annual Vessel Cost for UNOLS Fleet, in Thousands of 1979 Dollars

Increases are due to the fact that the cost of fuel exceeds the general inflation rate.

		Year						
Vessel Class	(length in ft.)	1979[1]	1985	1986	1987	1988	1989	1990
		Total Annual Operating Costs in Thousands of Dollars per Vessel per Year (RTOTAL(t))[2]						
I	(200+)	1,677	1,737	1,748	1,760	1,772	1,784	1,796
II	(150-200)	1,190	1,233	1,241	1,249	1,257	1,266	1,275
III	(100-150)	548	568	571	575	579	583	587
IV	(50-100)	179	182	182	183	184	184	185

[1]RTOTAL (1979) = mean projected cost by vessel class from Appendix II, Table A II.4.

[2]Projection formula (see Appendix II for definitions). Formulae and parameter values used were as follows:

RTOTAL(t) = ESTCOST(1979)*RPINDEX(t)
$RPINDEX(t) = PINDEX(t)*(1+i)^{-(t-1979)}$
PINDEX(t) = *FUEL(t) + (1-)*(NFUEL(t))
Assumptions: (i) $\frac{FUEL(t)}{(1+i)^t}$ (ii) $\frac{NFUEL(t)}{(1+i)^t}$

Implications: $RPINDEX(t) = (1.03)^t + (1-) = 1.0 + (1.03)^t$

(iii) = 0.185 for vessel classes I - III
= 0.077 for vessel class IV
See Appendix Table A II.1

These particular scenarios were selected to illustrate a range of possibilities which might exist within the budget restrictions imposed by currently projected funding levels for vessel operations. These budgetary projections are not desirable or recommended, but are considered as possible.

For each fleet and scenario (where applicable) Tables IV.2 a and b contain the number of vessels by size class, the mean percentage layups by vessel class, and the projected budgetary shortfall (-) or surplus (+). No vessel layups or retirements are allowed in scenarios A and B; hence, the budgetary shortfalls represent the full deficit without remedial action. In scenarios C and D retirements or layups are used to minimize budget shortfalls. Here, a layup simply means a rate of utilization less than the planned number of operational days for that size of ship, not necessarily a situation where savings such as laying off crew can be realized (see section V.B.). If budgetary shortfalls could be met by laying up vessels, then this strategy was chosen. Calculation of layup period involves the ratio of percentage cost savings to cost elasticity coefficients in Table A.II.5. The numerator in this ratio is the budgetary shortfall expressed as a percentage of mean cost for a vessel of that size class (Table IV.1). The actual distribution of layup time is arbitrary (in reality this distribution would reflect the demands for ship-time among vessel classes). Assignment of layup to a particular class merely reflects the fact that a vessel of that class was being considered for retirement in order to meet a budgetary short-fall. Within a vessel class, the necessary layup was evenly distributed among all the vessels in that class for that year. If the total layup days required to eliminate the projected budgetary shortfall exceeded 75 percent of the mean operating days required for full utilization of a vessel of that class, a vessel was retired. In size classes and years when vessels are retired, a modest budgetary surplus (+) usually appears because retirement generally reduces cost in excess of the budgetary shortfall for a short period of time.

When vessel retirements were invoked under the 75 percent maximum layup rule, certain judgmental criteria were applied. The first criterion corresponded to the variant: for I-II variants, vessels of Classes III and IV were retired, and for III-IV variants, vessels of Classes I and II were retired. Second priority was given to retiring vessels where savings were greatest, subject to preserving some semblance of balance between Classes I and II and between Classes III and IV. For example, in academic fleet scenario C.I, one Class I and two Class II ships have already been retired by 1985 to balance the budget. Layups occur increasingly through 1989, when the aggregate layup of the five Class I ships, each at 15 percent, equals 75 percent of one ship, and therefore a ship is to be retired. In this case a Class II vessel was retired to balance the budget, leaving five vessels each in Classes I and II.

An arbitrary constraint was also invoked that no class should be left with fewer than two vessels under any scenario. This constraint was important in scenario D.2. In that scenario, the UNOLS vessels retired after 1985 are in Classes I and II, despite the fact that D.2

TABLE IV.2.a. Summary of Fleet Composition (General-Purpose Vessels), Layups, and Budgets for Alternative Scenarios

UNOLS FLEET												
			Fleet Composition by size class				Mean Percent Layups by size class				Budgetary Shortfall (-) or Surplus (+)	
Scenario	Description of fleet	Year	I	II	III	IV	I	II	III	IV		
			-number of vessels-				-percent of operating days-				-thousands $ -	percent-
A	Present Composition											
		1985	6	7	6	7					(-)3,094	13
	(including WASHINGTON,	1986	6	7	6	7					(-)3,234	14
	excluding MOANA WAVE)	1987	6	7	6	7	not applicable				(-)3,393	14
		1988	6	7	6	7					(-)3,552	15
		1989	6	7	6	7					(-)3,711	15
		1990	6	7	6	7					(-)3,877	16
B	Academically Planned											
		1985										
		1986										
		1987	not applicable									
		1988										
		1989										
		1990										
C.1	Present Shortfall, III-IV variant											
		1985	5	6	6	7					(+) 103	1
		1986	5	6	6	7	5					
		1987	5	6	6	7	9					
		1988	5	6	6	7	12					
		1989	5	6	6	7	15					
		1990	5	5	6	7					(+) 469	2
C.2	Present Shortfall, I-II variant											
		1985	6	7	2	2					(+) 94	1
		1986	6	7	2	2			1			
		1987	6	7	2	2			4			
		1988	6	7	2	2			8			
		1989	6	7	2	2			11			
		1990	6	7	2	2			14			
C.3	Present Shortfall, 'equal' sacrifice											
		1985	5	6	6	6					(+) 58	
		1986	5	6	6	6			4			
		1987	5	6	5	6					(+) 374	2
		1988	5	6	5	6					(+) 240	1
		1989	5	6	5	6					(+) 106	1
		1990	5	6	5	6					(+) 34	
D.1	Increased Leasing, III-IV variant											
		1985	4	5	6	7	17					
		1986	4	4	6	7					(+) 544	3
		1987	4	4	6	7					(+) 433	3
		1988	4	4	6	7					(+) 322	2
		1989	4	4	6	7					(+) 214	1
		1990	4	4	6	7					(+) 99	
D.2	Increased Leasing, I-II variant											
		1985	5	6	2	2		11				
		1986	5	6	2	2	11					
		1987	5	6	2	2	14					
		1988	5	5	2	2					(+) 527	3
		1989	5	5	2	2					(+) 416	2
		1990	5	5	2	2					(+) 301	2
D.3	Increased Leasing, 'equal' sacrifice											
		1985	4	5	5	5					(+) 337	2
		1986	4	5	5	5					(+) 238	1
		1987	4	5	5	5					(+) 125	1
		1988	4	5	5	5					(+) 12	
		1989	4	5	5	5						
		1990	4	5	5	5		1	8			

TABLE IV.2.b (continued)

TOTAL ACADEMIC FLEET												
Scenario	Description of fleet	Year	Fleet Composition by size class I	II	III	IV	Mean Percent Layups by size class I	II	III	IV	Budgetary Shortfall (-) or Surplus (+)	
			-number of vessels-				-percent of operating days-				-thousands $ -	percent-
A	Present Composition											
		1985	6	8	12	27-32	not applicable				(-)3,319-4,229	12-15
		1986	6	8	12	27-32					(-)3,485-4,395	12-15
		1987	6	8	12	27-32					(-)3,696-4,611	13-16
		1988	6	8	12	27-32					(-)3,907-4,827	14-17
		1989	6	8	12	27-32					(-)4,099-5,019	14-18
		1990	6	8	12	27-32					(-)4,318-5,243	15-18
B	Academically Planned											
		1985	7	9	17	33-38	not applicable				(-)18,277-19,181	45-46
	(including one Class I	1986	7	9	17	33-38					(-)18,477-19,387	47-48
	vessel for polar	1987	7	9	17	33-38					(-)18,734-19,649	47-48
	research, but operated	1988	7	9	17	33-38					(-)18,991-19,111	48-49
	for the same cost as a	1989	7	9	17	33-38					(-)19,224-20,144	48-49
	general-purpose vessel)	1990	7	9	17	33-38					(-)19,490-20,415	49-50
C.1	Present Shortfall, III-IV variant											
		1985	5	6	12	32	1					
	III-IV	1986	5	6	12	32	4					
		1987	5	6	12	32	8					
		1988	5	6	12	32	12					
		1989	5	5	12	32					(+) 563	2
		1990	5	5	12	32					(+) 378	1
C.2	Present Shortfall, I-II variant											
		1985	6	8	8	22			7			
	I-II	1986	6	8	9	21			6			
		1987	6	8	7	21					(+) 277	1
		1988	6	8	7	21					(+) 92	
		1989	6	8	7	21			5			
		1990	6	8	7	21			6			
C.3	Present Shortfall, 'equal' sacrifice											
		1985	5	7	11	28					(+) 37	
		1986	5	7	11	28			4			
		1987	5	7	10	28					(+) 280	1
		1988	5	7	10	28					(+) 96	
		1989	5	7	10	28			3			
		1990	5	7	10	27			3			
D.1	Increased Leasing, III-IV variant											
		1985	3	5	12	32		3				
	III-IV	1986	3	5	12	32		7				
		1987	3	5	12	32		12				
		1988	3	4	12	32					(+) 735	3
		1989	3	4	12	32					(+) 615	3
		1990	3	4	12	32					(+) 463	2
D.2	Increased Leasing, I-II variant											
		1985	6	8	5	5			10			
	I-II	1986	6	8	5	4			7			
		1987	6	8	4	4					(+) 331	1
		1988	6	8	4	4					(+) 175	1
		1989	6	8	4	4					(+) 15	
		1990	6	8	4	4			15			
D.3	Increased Leasing, 'equal' sacrifice											
		1985	4	6	10	22			5			
		1986	4	6	9	22					(+) 334	1
		1987	4	6	9	22					(+) 180	1
		1988	4	6	9	22					(+) 26	
		1989	4	6	9	22		3				
		1990	4	6	9	22		7				

is a I-II variant of scenario D, simply because Classes III and IV cannot be reduced below two, the reduction to this level having been accomplished (in the scenario) before 1985.

B. Scientific Implications of Alternative Compositions

The models of composition of the fleet were based on a distinction between general-purpose vessels and those vessels which, because of unique capabilities or configurations, are unsuitable (or at least highly inefficient) for a large variety of research. There is, of course, some existing and potential overlap between these categories. For example, the R/V WASHINGTON is basically configured as a general-purpose vessel, but because of the Seabeam acoustic system will probably act as a vessel partially dedicated to geology and geophysics (see III.D.2.b.). The KNORR or MELVILLE could, with provision for extended range, operate throughout the open waters of polar seas (see III.D.2.d.) although their cycloidal propulsion system is poorly suited for work around floating ice. All Class I and II UNOLS vessels are being considered as possible tenders for a modified ALVIN (see III.D. 2.a.); such use would (except in the case of MOANA WAVE which is currently operated by the Navy) reduce the existing availability of large vessels for other academic research. Since a large vessel presently must accompany LULU/ALVIN on most long expeditions, the most serious issue is the degree to which installation of deck equipment to handle ALVIN would interfere with other kinds of work. If MOANA WAVE were returned to the UNOLS fleet for use as an ALVIN tender, capacity would actually be increased, but MOANA WAVE does not carry many more scientists than LULU.

These examples illustrate a point obscured in Table IV.2; namely, that the size of the academic fleet, and the balance between general and special capabilities, will depend to some extent on decisions involving specific, existing ships. We have emphasized leasing and conversion as ways of providing some special capabilities for the reasons given in Chapter III.D.2. Reduction from the present fleet to scenario C.1, for example, is in one sense already underway by increasing the geophysical capabilities of the WASHINGTON and the CONRAD, making them more nearly dedicated, special-purpose vessels. Such conversions, however, must result in new or augmented funds for ship operations if they are to alter the projections in Table IV.2.

Another issue to be kept in mind is the meaning of "efficiency" when applied to academic research. Academic scientists like to believe that great ideas and opportunities for research are just around the corner, and they are occasionally correct in this belief. It is generally acknowledged that some seagoing capacity to respond quickly to unexpected events (e.g., Krakatoa; major petroleum spill) should be retained by the nation. Also, time or money spent on refining logistics cannot be spent on contemplation or solution of scientific problems. These arguments suggest that some level of excess or reserve capacity for field research, and therefore some degree of short-term inefficiency, is necessary for the health of academic oceanography.

The academically planned composition (Scenario B) provides sufficient capacity to meet needs for general-purpose ships. This model would permit research in the near future to be carried out more or less as it is conceived, with minimal deferral of projects for lack of ships or to adjust annual schedules. In addition to the assumptions involved in the computation of operating funds, such a fleet would require not only additional funds for operating the vessels, but also additional funds for seagoing research, if the vessels were to be fully utilized. There would probably be some years in which layups would be necessary (see Chapter V). This scenario would become much more attractive economically if a decision were made to shift a significant fraction of NOAA's work to academic vessels (see Chapters II.B., III.C.).

The existing fleet, (Scenario A) is generally adequate in terms of general-purpose vessels, but is inadequate to meet the needs for special facilities. In a choice between III-IV and I-II variants of Scenarios C or D, the former variant would be likely if BLM, EPA, DOE, or state agencies provided greater funding for near-shore research. There would, however, be loss of capabilities for work under adverse weather conditions, in situations where long cruising range is essential, or by large groups of mutually dependent researchers. The last point touches on an asymmetry; the smallest ships cannot conduct truly oceanic research, while the large ships not only can conduct most coastal research (as illustrated by the case history discussed in section D of Appendix IV), but must do so for large-scale, cooperative programs.

Scenario D meets the needs for special capabilities provided through leasing, but at the cost of considerable reduction in the general-purpose fleet. Either the D.1 or the D.2 extreme would reduce some capabilities to a level we believe to be unacceptable in terms of the progress of marine science in the U.S. and the national needs for oceanographic information.

We believe scenario C.3 to be the most likely outcome of the continuing interplay between the state of oceanography in the United States as a science, the nation's needs for information (and understanding), the nation's financial situation, and the multiplicity of governmental agencies and academic institutions involved in oceanographic research. This is because the existing fleet seems appropriate in relative composition, and because we cannot predict adequately the future course of "small" science. Tendencies towards increased coastal work, which might suggest a composition as in scenario C.1, are counteracted by recent efforts of the federal government to shift responsibility for coastal work to the states, many of whom are financially unable to assume this responsibility.

As a result of overall decrease in the size of the fleet, there will be greater difficulty in conducting some kinds of multidisciplinary research, work involving massive equipment, and work in foul-weather seasons. There will also be a premium on the development and deployment of remote or untended sensing systems in all disciplines--activities which are, of course, desirable in their own right. Some disciplines (notably biology) will be particularly affected because remote sensing of some important properties (e.g., identity of species) is currently primitive.

C. Utilization of Present UNOLS Vessels

The mean annual utilization of UNOLS vessels from 1975 through 1979 (Appendix Table A.II.4) was less than the "full utilization days at sea" as defined by NSF in 1979 (Table II.1): 91 percent, 102 percent, 93 percent and 70 percent for Class I, II, III and IV vessels, respectively. Assuming for the moment that operating days are identical with days at sea plus days in foreign ports necessary to resupply and exchange personnel and equipment, then the discrepancies are indicative of underutilized capacity. We examine here the degree of utilization by year and vessel class using data and best estimates taken from UNOLS ship reports for the period 1974 through 1981.

We note that the numbers of operating days per year which are equated with the full utilization of a vessel are somewhat arbitrary. Realistic numbers are difficult or impossible to set on the basis of size class alone. Reasonable full utilization of a vessel depends on many additional factors, e.g., vessel condition, configuration, type of work carried out, area of operation, etc. Even now, the NSF is considering reducing the number of days set (see Table II.1) to represent a nominal full utilization rate for each vessel class.

The causes of less than full utilization of a UNOLS ship may include: (1) lack of funding for operation; (2) unavailability of the vessel during periods of major repair, maintenance, overhaul, or refitting; (3) alternative usage by academic researchers of non-UNOLS vessels, vessels of other classes, or special purpose vessels because of their greater availability or lower cost; (4) lack of demand by scientists, either because proposals for research at sea are not funded or because scientists shift to types of research which do not require as much time at sea; and (5) unreasonably large definitions of full utilization.

Because definitions of full utilization are arbitrary, we examined secular trends in vessel utilization. Table IV.3 contains information on UNOLS vessel utilization for the period 1974-1981. This includes not only percentage utilization of the fleet (number of operating days relative to NSF's definition of full utilization, see Table II.1) but the actual number of operating days by vessel class for the fleet for this period. These data are quite interesting--pointing to a higher utilization of Class I-II vessels than of Class III-IV vessels in recent years. Most notable is the evidence that even though the fleet has become smaller (decreased from 30 to 26 vessels), the average utilization has not increased. In fact there appears to be a general decrease in utilization of Class III (100-149 ft.) vessels, although NSF added two new vessels in this class during 1981. If the projected number of operating days for 1981 are correct, only the 150-199 ft. vessel class will be fully utilized, and an 18 percent excess capacity will exist in the fleet as a whole.

TABLE IV.3 UNOLS Vessel Utilization; 1974-1981

Year	Fleet	Vessel Class I > 200 ft.	II 150-199 ft.	III 100-149 ft.	IV > 100 ft.
		Total Operating Days* (Number of Vessels) Utilization**			
1974	6283 (30) 88%	2209 (8) 106%	2003 (8) 100%	840 (4) 91%	1231 (10) 59%
1975	6043 (29) 87%	1941 (8) 90%	1844 (8) 92%	943 (4) 103%	1351 (9) 70%
1976	6012 (28) 90%	1852 (7) 98%	1906 (8) 95%	916 (4) 100%	1388 (9) 71%
1977	5953 (27) 92%	1744 (7) 92%	1852 (7) 106%	1007 (5) 88%	1350 (8) 80%
1978	5728 (27) 89%	1938 (7) 103%	1619 (7) 93%	995 (5) 87%	1176 (8) 70%
1979	5336 (28) 79%	1427 (7) 76%	1990 (8) 100%	865 (5) 75%	1054 (8) 63%
1980***	5420 (26) 87%	1539 (6) 95%	1988 (8) 99%	734 (5) 64%	1141 (7) 78%
1981***	5079 (26) 82%	1461 (6) 90%	1818 (7) 104%	647 (6) 47%	1153 (7) 78%
Average % Utilization	87%	94%	99%	82%	71%

* Data taken from UNOLS ship reports (March 27, 1981)
** Based on "full utilization" as defined in Table II.1.
***Data are estimates from UNOLS ship reports (March 27, 1981)

D. Criteria for Determining Retirements

The preceding analyses, even if incorrect in detail, indicate that there must be: (1) more financial support for seagoing research and the operation of academic research vessels from sources other than NSF/OCE and ONR, (2) more funding from NSF/OCE and ONR for the operation of academic research vessels, or (3) retirement of vessels from the academic fleet without replacement in kind. The savings which can be generated by greater economic efficiency in operating the fleet (Chapter V) will not alter this situation significantly, though these savings are worth achieving so that additional funds can be devoted to science.

Given the fact that some retirements of general-purpose ships are likely, there should be a mechanism for deciding which specific ships should be retired or modified for some special function. The problem is complicated by diverse ownership of vessels, even within the UNOLS fleet; for example, it is not clear how a rational decision to retire a vessel owned by an institution can be enforced except by that institution, though financial incentives can be provided by federal agencies.

There are several criteria which should be weighed in considering specific retirements or conversions.

1) Research capability - To qualify for continued support a vessel must have the capability to conduct the kinds of research anticipated in the future. Therefore, for general-purpose work, ships would be judged in terms of overall condition, general capabilities, habitability, etc.

In addition, scientific uniqueness of the vessel should be taken into account. Certain vessels have scientific capabilities which are unique within the fleet. To the extent that these capabilities are thought to be scientifically valuable (e.g., are needed by productive scientists), it would be wise to preserve such vessels even though they may be more expensive to operate or less fully utilized than other vessels of comparable size.

2) Economy - Large ships are more expensive to operate than are small ones, even on the basis of scientist-days-at-sea per year, and some reduction in cost of the fleet could probably be achieved through converting a large ship to a special purpose which would match a source of operating funds other than the present plans of NSF/OCE or ONR. Alternatively, one large ship (200 ft.) could probably be retired, with or without replacement by a smaller ship (150 ft.; 35-40 percent as expensive to operate), though not without reducing the needed capability of the fleet as evidenced by the utilization of Class I vessels (Table IV.3). Further "downsizing" of the fleet, as in scenario D.1 of Table IV.2, would significantly reduce the quantity and affect the character of the research performed.

Within size categories, a ship which is usually expensive to operate, or which requires costly refitting, is an potential candidate for retirement. That there is relatively little variation around the mean relation between a vessel's length and its operating cost (Appendix II

Figure A.II.1) suggests that there are not perennially inefficient vessels in the UNOLS fleet. Since federally-owned vessels may be transferred from one operating institution to another, thus potentially affecting operating costs, the cost of refitting these vessels may be the most significant factor in choosing between those in a particular size class. However, if funds allocated for refitting cannot be redirected to other aspects of seagoing science, then (at least from the scientists' point of view) the relative costs of refitting are not a significant criterion for determining retirements.

3) Scientific productivity - In theory, some ships may be associated with the production of more high-quality science than are others. Unfortunately, scientific quality is difficult to measure, and the productivity associated with a ship is ultimately dependent on the productivity of the specific scientists using her. "Low" productivity for a ship, however measured, might simply mean that it should be transferred to another institution, rather than retired. To the extent that awards of funding for research constitute an assessment by the scientific community (through peer review) of a researcher's productivity and potential, one could base a decision upon recent history of success of scientific proposals for the use of particular ships. Even by this standard, there are subtilties of negotiated scheduling and the degree to which an investigator has free choice of ships which would have to be taken into account.

4) Benefit to society - This is another form of productivity, but is distinct because certain kinds of research - and certain forms of reporting the results - may be viewed as unexciting or trivial by most academic scientists because they add little to the conceptual understanding of nature, and yet are of considerable value to society in providing evidence upon which pragmatic decisions can be based. Measuring these benefits, and attributing them to specific ships, have the inherent problems noted above.

5) Geography and politics - A ship which the above criteria indicate should be retired may be retained because its removal (or transfer) is perceived as crippling a region or institution in terms of future contributions to oceanographic knowledge and training. This factor operates to maintain at least one ship in each locale, against the minor economies of scale identified in Appendix II. D. The criterion rests partly on the potent opinion that an institution must operate its own ship in order to engage in oceanography. The criterion is, however, related also to the distinction between criteria 2 and 3. The advancement of oceanography as an academic discipline depends on the study of natural processes, and particular locations or regions are chosen for study because a specific process may be clearly identified there. In contrast, the decisions of most importance to society relate to the interactions between humans and nature, and such decisions must often be based on the detailed description of specific sites which are not of particular scientific interest. The need for information about such sites provides an argument for preserving a broad geographical distribution of ships, though some of this need could be met through leasing of non-academic vessels.

Figure A.II.1) suggests that there are not perennially inefficient vessels in the UNOLS fleet. Since federally-owned vessels may be transferred from one operating institution to another, thus potentially affecting operating costs, the cost of refitting these vessels may be the most significant factor in choosing between those in a particular size class. However, if funds allocated for refitting cannot be redirected to other aspects of seagoing science, then (at least from the scientists' point of view) the relative costs of refitting are not a significant criterion for determining retirements.

3) Scientific productivity - In theory, some ships may be associated with the production of more high-quality science than are others. Unfortunately, scientific quality is difficult to measure, and the productivity associated with a ship is ultimately dependent on the productivity of the specific scientists using her. "Low productivity for a ship, however measured, might simply mean that it should be transferred to another institution, rather than retired. To the extent that awards of funding for research constitute an assessment by the scientific community (through peer review) of a researcher's productivity and potential, one could base a decision upon recent history of success of scientific proposals for the use of particular ships. Even by this standard, there are subtilties of negotiated scheduling and the degree to which an investigator has free choice of ships which would have to be taken into account.

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6) Education - The practical education of oceanographers requires some experience on ships, a point illustrated in section E of Appendix IV. This might be an argument for preserving a distribution of vessels accessible from the major oceanographic teaching institutions. These criteria need to be further developed, and sharpened through the consideration of additional cost data, before they can be applied to selection of vessels for retirement or conversion.

We recommend that these criteria be further developed by an ad hoc panel in which the interests of the institutions which own and/or operate vessels, the agencies which fund seagoing research, and the seagoing oceanographers themselves are balanced. This panel, which could be appointed by UNOLS with advice from the National Academy of Sciences, should recommend how these criteria should be used by agencies/owners of vessels in their evaluation of vessels being considered for retirement or conversion.

Because budgetary decisions concerning refits and replacements must be made in the near future in order to avoid decision by crisis, and because the evaluation process outlined above must be done thoroughly (and widely perceived to be so) to be of use, the initial decisions concerning the forms of evidence which will be most valuable, and the weights to be given to various criteria should be made and promulgated at once.

V. SOME ASPECTS OF FUTURE MANAGEMENT OF THE ACADEMIC FLEET

In this chapter we address various functions which together constitute the management of the academic fleet. Included are discussions of: funding, scheduling; replacement, refitting, and maintenance; modes of operation; temporary layups; and leasing or other use of non-academic vessels. These discussions are not meant to be exhaustive; rather, they are meant to be suggestive of the types of considerations and studies which should take place on an ongoing basis in order to maximize the research obtained from the funds available for ship-time to support academic research.

A. Use of Non-Academic Ships for Academic Research

The possibility that scientific needs, particularly for special types of vessels, might be met by increased chartering of ship-time from non-academic sources was discussed in Chapter III. If in the future the academic fleet is reduced in size but funding for field research remains available (as might result from the funding of research by agencies which traditionally have not supported the academic fleet except on an "as needed" basis), leasing of general-purpose vessels is also likely to increase.

There is evidence that the utilization of non-academic vessels (including those in federal fleets - see Chapter II.B) by academic researchers has indeed increased rapidly in recent years. Researchers at the University of Washington (Applied Physics Laboratory), Scripps Institution of Oceanography, Texas A&M University (Department of Oceanography), the Mississippi-Alabama Sea Grant Consortium, and the New Jersey Marine Science Consortium reported their usage of non-academic vessels over the period 1975-79. The numbers reported in Table V.1 a. are somewhat inaccurate because of two counteracting effects - first, not all researchers reported their usage, and second, there is the potential for duplication since more than one investigator may have reported the same, shared cruise. The trend is, however, very clear.

Researchers from Texas A&M and Scripps reported their use of academic ships, as well as non-academic ones (Table V.1 b.), which allows their use of non-academic ships to be scaled to total time at sea. It appears that the relative as well as the absolute use of non-academic ships has increased, and that such use in an important fraction of the total seagoing effort of academic oceanographers - even those at institutions which operate their own vessels. Usage of non-academic vessels is not entirely leasing, of course; judging from the responses of Texas A&M researchers, more than half of the non-academic ship-time is on federally-operated vessels. Foreign vessels are also being used by U.S. academicians, particularly in high latitudes where U.S. vessel capability is restricted.

If more specific data on types of vessels used, joint usage, and sponsorship over a longer period of time were available, it might be possible to decide whether the use of non-academic ships complimented the use of academic ships (the two kinds of usage, when corrected for long-term trends, would be positively correlated year by year), or substituted and compensated for fluctuations in availability (negative correlation of detrended data). A more complete study of this pheonmena is desirable.

TABLE V.1 Use of Non-Academic Ships by Academic Oceanographers, in Ship-Days Per Year

a. University of Washington, Scripps Institution of Oceanography, Texas A&M University, Mississippi-Alabama Sea Grant Consortium, and New Jersey Marine Science Consortium

Year	1975	'76	'77	'78	'79
Ship-days	583	864	917	1226	1472

b. Scripps Institution of Oceanography and Texas A&M University

Year	1975	'76	'77	'78	'79
A. Academic vessels	640	1088	990	1006	1253
B. Non-academic vessels	315	486	533	664	900
Ratio, $\frac{B}{A + B}$	0.33	0.31	0.35	0.40	0.42

Chartering is desirable in a variety of situations, even with the present academic fleet, and some of the use by academic scientists of non-academic vessels may reflect these:

1. A vessel may be needed for a relatively short period to operate from a distant port, and it is uneconomical to move an academic vessel there because of inadequate time for planning or insufficient interest to conduct meaningful research in transit.

2. An accident to, or unanticipated layup for maintenance of, an academic ship creates a need for a vessel to accomplish planned, funded research. For example, when the ATLANTIS II was laid up longer for engine refitting than had been expected, the 158-ft. G.W. PIERCE was chartered for a scheduled biological cruise between Woods Hole and Bermuda. Of course, the replacement with short lead time of an academic research vessel with a charter vessel may result in substantial loss of scientific productivity, as appears to have been the case when the G.W. PIERCE was substituted for the ATLANTIS II.

3. A particular private vessel has capabilities which are not available on an academic vessel which is as economical to use. These capabilities may be in the deployment of special gear (e.g., multichannel seismic streamers or large trawls, as suggested in Chapter IV. D.2.) or aspects of the ship itself, such as power or stability.

4. An unanticipated, rare opportunity for important research may arise through a natural event (e.g., eruption of a submarine volcano) and the need for rapid exploitation of the opportunity precludes the use of an academic vessel.

Situation 1 is directly economic while situation 2 involves the indirect financial (and psychological) cost of postponing a scheduled program, especially one in which equipment and people are standing by. Situation 3 results from comparison of the costs of charter with the costs of providing a comparably equipped academic vessel. In situation 4, urgency is a more important consideration than is minimizing the cost.

These situations, which presently exist, may well be more frequent if the number of academic vessels is reduced (Models C and D of Table IV.2). There will continue to be occasional need for short-term chartering of private vessels in situations 1 and 2, even though such charters will generally be more expensive than would a comparable UNOLS vessel (if one could be provided at the same time and place), since the private operator will attempt to make a profit as well as amortizing the cost of the vessel. Cost comparisons must be made carefully, since expendables (fuel and food) must sometimes be added to a charter's basic cost (this is also true for some academic vessels.) Also, general-purpose, private vessels generally lack (or charge separately for) suitable winches and booms or A-frames, on-board computers, echo-sounding equipment for use in great depths, and other facilities which are provided as part of the daily use cost of most academic vessels.

Long-term charters (annual or longer) often result in marked reductions in cost per day at sea (since charter rates are set in part on the basis of the operator's degree of certainty that the vessel will operate a set number of days per year) and a greater willingness on the part of the operator to equip the ship in a particular way for the investigator and to schedule a vessel well in advance. Use of a special-purpose vessel that is equipped by its private operator with gear which coincidentally is essential for certain kinds of academic research (e.g., multichannel seismic equipment) is an extension of this approach. The academic community should, however, avoid complete reliance on non-academic vessels, since such vessels may be effectively removed for considerable time from academic availability for reasons of economy (greatly increased demand in the private sector) or policy (mission-oriented needs of an operating federal agency).

Charters of a few months' duration usually offer neither the advantages of rapid responsiveness nor those of lower cost and modification of equipment to meet the exact needs of the researcher. Scheduling of academic vessels which includes both thoughtful planning well in advance and a degree of flexibility (V.E. below) should minimize the need for such charters.

Chartering foreign vessels may be desirable to obtain certain capabilities (e.g., polar research vessels - see Chapter III.D.2.d.) or meet temporary needs in distant locations, but involves flow of currency out of the U.S. and runs counter to a stated policy of NSF that the U.S. academic research fleet should be used wherever possible (Lou Brown, personal communication). A charter paid for by providing access for foreign scientists to U.S. equipment or knowledge might circumvent these difficulties.

Another factor affecting the extent of chartering is the process of proposal review and funding described in Chapter II.C and discussed further below (V.F.). Scientists proposing to NSF to use a UNOLS vessel (except the CAPE HENLOPEN) do not include the operational cost of the ship in the budget for research, while costs of charter would be included in the budget and therefore subject to peer review. This may place a psychological burden on a potential investigator when soliciting funds from NSF because any proposed leasing greatly increases the reviewable cost of the research in an intensely competitive setting. An analogous situation, resulting in a disincentive to consider chartering, exists in NOAA.(5)

A final consideration relevant for long-range planning is the degree to which increased leasing of private vessels could decrease the expense of new construction or major refitting of academic vessels.(13) That is, the daily rate of an existing academic ship does not reflect amortization (or recovery) of past construction costs, while a private operator normally attempts to do this except for very short charters in unscheduled periods, where the only consideration may be to charge a rate which exceeds the incremental cost to the operator of the few additional days at sea.

When expenditures for new vessel construction are considered, the projected operating and maintenance costs and the capital outlay for a proposed academic vessel must be compared to the charter rates (which reflect recovery of capital costs by the operator) projected for the same period in the private sector. Thus, the basis for comparison of costs of chartering against costs of using an academic vessel may be quite different when a new academic vessel is envisioned than when an existing academic vessel is suitable. This is an important consideration for the special-purpose vessels discussed in Chapter III.D.2. It should be realized that most vessels of the present academic research fleet were built using one-time appropriations which would not have been available to pay for operations or leasing. Thus, as in the question of criteria for retirements (Chapter IV.D.), the degree to which scientists will be willing to charter vessels instead of arguing for new academic vessels depends in part on their perception that any new construction funds thus saved could be used for operation and charter costs.

B. Savings Resulting from Layups

Even if the size of the academic fleet is reduced, as in Models C and D of Table IV.2, fluctuations in funding for research, and in the nature of research itself, are likely to create the necessity for temporary layups of some vessels. It is therefore of some importance to determine the savings which might result from this action. As fuel costs become an increasingly larger component of the operating costs of the fleet, the attractiveness of layups as a short-term economy measure increases. We have used three types of information to investigate the likely savings--these are: 1) recent experience in the UNOLS fleet with actual layups, 2) implications of the multiple regression analysis of costs of the UNOLS fleet (Appendix II), and 3) a layup model formulated by WHOI.

1. Recent Layups in the UNOLS Fleet

As discussed in Chapter II and elsewhere, layups of large ships have been used to lower the annual cost of the UNOLS fleet to match available funding over the past several years. Examination of specific cases can lead to inconsistencies unless the bookkeeping practices and particular situations of the institutions which operate each vessel are taken into account. For example, if the cost of vacation time accumulated by a vessel's crew is charged to a period of layup (when the vacation may be taken) instead of to the period at sea when the vacation was earned, the apparent savings resulting from the layup will be much reduced. Institutions differ in their willingness to lay off crew during layup, and in their ability to incorporate the crew of a laid-up vessel into the crew rotation schedules for other vessels operated by the institution. Obviously, the degree of forewarning and the length of a layup affect the options open to an institution.

An approximation of savings may be obtained by comparing the reported total layups of UNOLS ships in a given year to the reported funding shortfall in that year--that is, the difference between the actual cost of operation of the fleet and the funds which would have been required to operate at full capacity. This approach thus uses aggregate data for the fleet and institutional practices. The days lost to layups are estimated as the difference between the number of days at sea per year for "full utilization" (given for each class of ship in Table II.1) and the actual days the ships were utilized during the year (Table IV.3). Ships being retired or just coming on line are not considered as contributing to layup time.

During the years 1975-1980, the mean total number of vessel-days laid up was 843 per year. The average number of vessel days laid up for the years 1975-1977 was 697 per year which resulted in a mean savings of about 4 percent of the cost of operating the fleet at full capacity (costs from Table II.7); while in 1978-1980, the savings was approximately 8 percent of the full capacity cost for an average of 989 ship-days of layup per year.

Because ships entered and left the UNOLS fleet, its capacity changed through time. In order to evaluate the loss of seagoing capacity due to layups, relative to the costs saved, it is convenient to examine two relatively stable years, 1977 and 1978. During these years the full capacity was approximately 6440 ship-days at sea per year (from Tables II.1 and II.2), or about 90,000 scientist-days-at-sea (from data on scientific berths summarized in Figure II.2). For these two years the total layup of 9.3 percent of the ship-day capacity (1199 layup days for the two years/2/6440) and resulted in a saving of 4.9 percent of the full capacity cost. The layup of 9.3 percent of the ship-day capacity resulted in a loss of 4.8 percent of the potential scientist-days-at-sea in 1977-78.

2. Implications of the Multiple Regression Analysis

The cost analysis of the UNOLS fleet given in Appendix II provides another method of considering the cost of layups based on aggregated data from recent years. In Table A.II.5 of this Appendix are presented savings which would accrue for each class of ship assuming operation for 70-90 percent of the mean number of operating days for the vessel class. This is roughly equivalent to layups ranging from 10 to 30 percent, but is expressed relative to the mean number of actual days at sea, rather than the "full utilization" standard given in Table II.1. The indicated savings range from 3 percent of the annual cost for a 60-ft. vessel laid up 10 percent of the 161 days of typical operation (UNOLS average) to 15 percent of the annual cost for a 250-ft. vessel laid up for 30 percent of its 256 operating days. Each 1 percent layup generates a 0.3 percent saving in cost for a 60-ft. vessel, or a 0.5 percent saving for a 250-ft. vessel, with layups of vessels of intermediate sizes resulting in intermediate savings.

This result can be compared to the more direct examination of the UNOLS fleet given in V.B.1. above, which indicated that in 1977-78 a layup of 9.3 percent of the ship-day capacity resulted in a saving of 4.9 percent of the full capacity cost. If equation 6 from Appendix II is applied to the actual operating days given in Table IV.3 for a "model" fleet consisting of 7 250-ft., 7 150-ft., 5 100-ft., and 8 60-ft. vessels (cf. Table II.2), a saving of 2.6 percent of the operating cost of the fleet is realized. Thus, this calculation from the multiple regression analysis suggests less of a "magnifier" (2.6 percent saving for 9.3 percent loss of ship-day capacity) than did the approach taken in V.B.1 (4.9 percent for 9.3 percent loss of capacity).

3. The WHOI Model

In the two calculations presented above, there was no attempt to identify the components of the annual operating cost of a research vessel, nor how these components might change with layups of various durations. By contrast, the Facilities and Marine Operations Department of the Woods Hole Oceanographic Institution (WHOI) is developing a model to predict the savings which might be realized from short-term layups (1 month to 1 year) of their vessels > 200-ft. in length, the R/V KNORR and R/V ATLANTIS II (Robert Dinsmore, personal communication). The preliminary results of their analysis are that in 1981 dollars a full year of operation of this class of vessel (defined as 300 operating days, including 276 days actually at sea, and 65 days in home port) costs approximately $3.05 million. By comparison, maintaining the vessel during total layup for a year costs $590,000, or 19 percent of the full operating cost. Annual costs during a total layup include: salaries and fringe benefits for six persons (a full crew for these vessels is about 25 persons); food for those six persons; $80,000 for marine staff costs at the shore facility; $175,000 for maintenance; $12,000 for dockside insurance; $20,000 for shore facilities support; and $50,000 for miscellaneous. While these costs may be slightly high, the only way that they could be substantially lowered would be to decommission or sell the ship. Therefore, the savings incurred by fully laying up a > 200-ft. vessel would be on the order of $2.5 million or 83 percent of the cost of full utilization.

WHOI has not repeated this exercise for the OCEANUS class vessels (177-ft.) chiefly because it has never been necessary for them to lay up the OCEANUS. The annual operating costs for the OCEANUS with no layups range from approximately $1.49 million for 240 operating days to $1.61 million for 280 operating days. Of these costs, $712,000 are fixed costs and the remainder are variable costs (such as overtime, shore leave, fuel, food and indirect costs) of going to sea. Using these numbers, we can see that the maximum cost for a total layup of the OCEANUS would be $712,000, assuming all variable costs are saved. This include no provision for crew layoff. The crew costs for an OCEANUS class vessel are approximately $310,000 for a crew of 12 persons. If one applies the same assumption used for the ATLANTIS class vessels, namely that six crew members are needed during a period of full layup, approximately another $150,000 can be saved by crew reduction during a period of full layup. Therefore, the layup cost would be on the order of $560,000, yielding a total savings by fully laying up the OCEANUS on the order of $1.05 million or 65 percent of the total operating cost.

Additional information may be obtained by comparing the cost computation figures supplied by R.P. Dinsmore (personal communication) for the R/V OCEANUS and the cost elasticity coefficients of Appendix II (Table A.II.5). Dinsmore's calculations for the OCEANUS indicate that a reduction in operating days from 280 to 260 days would result in a cost savings of 3.6 percent. For a reduction in operating days from 280 to 240 days, he projects savings of 7.3 percent. Using a cost elasticity coefficient of 0.5 (interpolated for a 177-ft. vessel from Table A. II.5), the corresponding estimates using the elasticity coefficients are 3.5 percent and 7.1 percent, which agree with Dinsmore's estimates within two-tenths of 1 percent.

We recommend that layup models similar to the WHOI model be constructed for all vessel classes. If reliable predictive models of layup savings can be constructed, the funding agencies and UNOLS will have some guidelines for how best to allocate funds and ship-time during years when funding shortfalls occur.

C. Operation of the Academic Fleet

Alternatives to the present mode of operation of the academic fleet include consolidating the fleet into one or a few regional centers with management by academic concerns, or turning all or a part of the fleet over to a federal agency or commercial concern for operation. With only limited available data, we have considered these options.

Academic fleets in Canada, France and England are each consolidated, and in principle some economies of scale could be achieved by consolidation of the U.S. research fleets. Indeed, a report by the Comptroller General of the United States[23] attributes a "relative decline in oceanographic vessel resources ..." in the U.S. to "... a lack of a coordinated and definitive national ocean policy..." and of central management. This comment is meant to apply to federal and UNOLS fleets, and the report recommends designation of a single manager or allocation council. The report notes that the quality of U.S. oceanographic research is still high, but that "... fragmented and decentralized use of oceanographic vessels has ... contributed to inefficient and uneconomical use of the nation's ocean research/survey fleet." The Federal Oceanographic Fleet Coordination Council (FOFCC) was established in response to this criticism, though it is too early to assess it's effectiveness. It should be noted that the academic fleet is not within the province of the FOFCC, athough a UNOLS observer has been invited to attend Council meetings.

Consideration has been, and is being given, to increasing the efficiency of the UNOLS portion of the academic fleet through such measures as scheduling, common purchasing, sharing of technology and equipment, etc. One form of consolidation which has been initiated by NSF/OFS is the establishment of regional supply centers for wire rope. Using wire sizes recommended by UNOLS/TAC, wire rope is to be purchased, inventoried at regional centers, and assigned to ships on the basis of need, thus reducing the financial impact of accidental loss of wire at sea. UNOLS/TAC is expected to make analogous recommendations concerning cranes, winches, and other wire-handling systems.

The analysis of operating costs of UNOLS ships (Appendix II) indicates that some saving might be realized by consolidating vessels into regional centers. For example, consolidating the two largest vessels, MELVILLE and KNORR, would apparently reduce their combined cost of operation by approximately 13 percent. Even in purely economic terms, however, the analysis should be interpreted with care, both because of the data on which it is based and because of factors not included in the calculation:

1) The data base for our economic analysis is quite limited, both in length of time and in total numbers of vessels and institutions.

2) The largest institutional fleet represented by the data includes five UNOLS ships, so extrapolation to larger fleets is questionable.

3) No existing institution actually operates several vessels of the same size and configuration, so the data may not be adequate to detect economies from interchangeable parts, common crew training and practices, etc.

4) The analysis does not include the costs of new shore facilities such as docks or storage warehouses which might be needed for consolidation.

5) The analysis focusses on sizes rather than kinds of ships and so cannot be used to estimate potential savings which might result from placing like ships together, e.g., placing the KNORR and MELVILLE at one institution and the WASHINGTON and THOMPSON at another. In such a transfer, the change in size distribution of ships is small, and there would be little effect on shoreside facilities, but vessels of similar design and propulsive system would be brought together, which might create efficiencies. The added costs of such changes would be in transportation of people and equipment, and perhaps in transit time between Atlantic and Pacific, for operations in which only the largest ships are suitable.

We sought advice from A. Longhurst, Canadian Director-General of Ocean Science and Surveys, Atlantic, because he has had experience with both the management of a single large vessel from a U.S. National Marine Fisheries Laboratory Service and the highly consolidated system in the United Kingdom. At the Bedford Institute of Oceanography, Canada, Dr. Longhurst is responsible for the four major research vessels in eastern Canada. He believes that, "... each system is capable of being efficient or disastrous depending entirely on the calibre of its managers." A centralized fleet is, "... specially susceptible to the danger of empire-building." He does not believe that single-ship installations are necessarily inefficient.

We do not believe that there is sufficient evidence to warrant consolidation of the academic fleet, though more intensive analyses should be undertaken. Further, if the fleet is reduced in size through retirement of ships, some consolidation will occur without the capital construction costs of expanded shoreside facilities.

We do not have sufficient data to evaluate commercial operation of the academic fleet. Information on the costs of federal research fleet suggests that academic vessels should not be transferred to a federal manager. Data from 1976 and 1977, supplied by Keith Kaulum (ONR), show that research vessels operated by the Navy and NOAA are at least as expensive as are academic vessels, and the larger federal ships are probably more expensive (Figure V.1). A statistical comparison of data from 1976-80 (Appendix II.E.) reinforces this conclusion. When the costs of research vessels operated by the U.S. Navy, Geological Survey, Coast Guard, and NOAA[23] were compared with those of the UNOLS fleet (after adjustment for differences in lengths of vessels and in the number of days at sea per year), the annual costs of the federal fleets were 58-118 percent higher per vessel than were those of academic vessels (Table A.II.10). Whatever the causes of these differences, the results indicate that unless the quality of federal management can be shown to be very high (that is, providing much better service to researchers than do academic operators), it would be undesirable to transfer the academic fleet to a federal operator.

D. Replacement, Refit, and Maintenance

Table II.1 shows the year each vessel of the UNOLS fleet was built and the predicted retirement date, for a 30-year life, assuming adequate maintenance. During the period 1985-1990, only three of these vessels will reach retirement age, and those are smaller vessels (65-110-ft. in length). However, there is the pressing need to make provision during the 1985-1990 time frame for major replacements within the fleet because five additional vessels will reach retirement age during the 1990-1995 period and three of these are of the larger classes (> 150-ft.). Since three to five years are presently required to obtain funds, design, build, and outfit a new research vessel, plans must be ongoing during the 1980's for replacement and renovation of the fleet. In summary, approximately one-third of the UNOLS fleet will reach retirement age during the decade 1985-1995, which will provide the opportunity to alter the composition of the fleet, if it should be desired.

1. Refit

The problem of major replacements within the academic fleet may be deferred somewhat by the use of major mid-life refits. Material and technological upgrading at or about a vessel's mid-life can provide for an extended lifetime. NOAA has adopted a conservative position in establishing 25 years as the expected material lifetime for its fleet, which they project may be extended by up to 10 years through mid-life refit.[24] Although age is used as a starting point in scheduling replacement, no operator schedules replacement on the basis of age alone. The expected lifetime must be adjusted based on evaluation of the material condition, availability of parts for basic vessel machinery, technical ability to meet mission requirements, and economy of running the vessel (as opposed to a new more efficient vessel). NOAA estimates that for each dollar allocated for rehabilitation of its existing fleet, over two dollars can be saved by deferring the average annual capital cost of new ship construction. Therefore, the decision to refit a ship to extend its lifetime or replace it at its normal lifetime must be considered very carefully.

Both NSF and ONR have recently initiated major refit programs for the vessels of the UNOLS fleet which they either own or built (see Table II.1). It is anticipated that these programs will complement each other.

The Navy's plan for maintenance and improvement can be divided into three categories: correction of accumulated deficiencies, improvements and upgrading of scientific capabilities, and replacements and major overhauls or equipment. In preparing their plan, the Navy has considered the ship and its basic equipment separate from the scientific gear associated with specific programs. This recognizes the fact that needs for specialized scientific equipment and instruments should be addressed in the plans for the research projects requiring this gear. The cost of routine maintenance, including periodic drydocking, is presumed to be covered by the daily rates charged to users of the vessels.

The Navy/ONR Ship Management Office will be guided in implementation of its plan by several ongoing inspection procedures as required by the Charter Party Agreements with operating institutions. These include the American Bureau of Shipping, U.S. Coast Guard and others. In addition, special INSURV inspections will be conducted by the Navy Board of Inspection Survey on a biennial schedule primarily to determine material condition of the vessels. Scientific readiness deficiencies of the ships will be determined from a reporting system newly initiated by UNOLS, whereby chief scientists file a brief report at the end of each cruise, and independent inspections as needed.

The Navy/ONR plan calls for an expenditure on the order of $10.4 million during the period 1981-1986 for corrections, upgrading, and capital replacements in order to bring their ships to full operational capability. Plans are to accomplish a major refit on one ship per year and, as funding allows, to proceed with one or more areas of scientific upgrading for all the ships, such as replacement of satellite navigation receivers or improvements to oceanographic winches.

NSF has instituted an inspection procedure for the 11 NSF-owned or constructed ships (see Table II.1) in order to establish baselines for subsequent annual inspections and to identify the most urgent requirements for repair and upgrading (see Chapter II.C.). Allocations of $2.0 million in 1981 and $2.5 million in 1982 are projected by NSF for ship construction and upgrading (see Table III.1). They project that funding for these items will remain at approximately this level, with provision for inflation, during the 1980's. Unlike ONR, which has created a new budget for inspection, maintenance, and upgrading, NSF intends to use its ship construction budget in the short-term to support ship upgrading work.[25] NSF has begun accepting proposals for this work during 1981.

The expenditure of the funds projected by ONR and NSF should be adequate to correct the accumulated deficiencies within the UNOLS fleet, as well as accomplish major mid-life refits. It is critical however that funds of at least these projected levels be provided as scheduled, if the fleet is to be sustained.

2. Construction

One of the major concerns of the oceanographic community is the lack of a long-term plan that will guarantee the coordination of an effective and balanced fleet. During 1980, an oversight review of NSF/OFS by the Division of Ocean Sciences Advisory Committee[1] recommended that, with the aid of appropriate advisory bodies, OFS should prepare a long-range plan for future fleet replacements and refits within the academic fleet. Our committee concurs with the need for the development of such a plan.

The UNOLS Advisory Council made a first cut at a long-range plan for the replacement of the UNOLS fleet in 1978.[3] Their plan estimated that the replacement costs of the various vessel classes in 1978 would be: $12 million for vessels > 200-ft.; $6 million for vessels 150-200 ft.; $3 million for vessels 100-149 ft.; and $1 million for vessels 65-100 ft. Using these costs, they estimated that a steady annual expenditure of $3 million (in 1978 dollars) over the next 15 years should be adequate to replace intermediate and smaller vessels. Additional funding of about $48 million (in 1978 dollars) would be required to replace four major vessels which should be retired during the late 1980's to early 1990's. These expenditures would maintain a fleet of about present size and with somewhat enhanced capabilities, especially in coastal waters. Additional funds would be required for specialized vessels. This plan for fleet replacement was never formally adopted, but some parts of it have been implemented, such as replacement of the R/V GILLISS and R/V EASTWARD by two new coastal vessels, the R/V CAPE FLORIDA and R/V CAPE HATTERAS.

These estimates for the cost of vessel replacement still appear to be reasonable, but as stated before, what is lacking is a coordinated long-range plan for vessel replacement. A long-range plan for the orderly replacement of vessels in order to continue the UNOLS fleet should be formulated by NSF and ONR, with assistance from appropriate advisory bodies and institutions. Once adopted and promulgated, this plan will allow the funding agencies to plan vessel refits and new construction in such a manner that an effective and balanced research fleet is maintained during any transition.

As already discussed (Chapter V.B.1.), NSF has earmarked about $2.5 million/year (constant value dollars) for construction and refit of the academic fleet during the 1980's. Once the major refits that are desperately needed by the fleet at the present time are completed, these funds should remain in the NSF budget and be used to maintain the fleet and for new construction of small vessels. These newly constructed vessels would be used to replace vessels that reach retirement age. Also, it might be possible to use refits later in the life of a vessel to extend its life to the time when its replacement would come on line. Provision should be made such that, during the years when all the money budgeted for refits and construction are not used, the excess funds be used to support research.

Replacement of the > 200-ft. vessels and construction of new special purpose vessels will not be possible using the projected funds available through NSF/OFS. At $12 million each, it would take the total budget for five years to construct a single vessel. It will still be necessary to get single-shot infusions of new money to NSF or ONR to construct these vessels.

E. Scheduling of Academic Research Vessels

In the early 1960's, funding for operation of ships was primarily from ONR, and expeditions were planned primarily within individual institutions, often based on the common need of scientists in several disciplines to map the distributions of properties in the ocean. This mode of operation was effective because there were only a few institutions involved, and because the Navy discharged its responsibility for maintaining a healthy oceanographic enterprise primarily by funding programs assembled within the individual institutions.

Since that time, NSF has become the principal source of support for seagoing science, and there are now differences in procedures and philosophies between NSF and ONR. Many more institutions, oceanographic departments, and ship-operating entities have come into being, and there are also many researchers outside of the major oceanographic departments who are interested in working at sea. At the same time, the range of technical capabilities which can be brought to bear on a particular problem has greatly increased.

Because of these trends, there have been national shifts both to a very large number of small research projects, each managed by an individual scientist, and to a few large projects, each oriented towards a specific discipline or problem, with participants drawn from many institutions. Further, operating costs of ships have increased faster than have overall oceanographic budgets, and consequently there is now more emphasis on economic "efficiency" and on centralized management. This has led in turn to pressure by funding agencies for long-term planning by researchers, and simultaneously to a decrease in the ability of these same agencies to make timely commitments of funds, much less long-term ones. For example, requests for proposals for surveys of areas of the Pacific where drilling operations were to be conducted in early 1982 were not sent out to the academic community until March of 1981, by which time the ships suitable for the site surveys had been completely scheduled. Similarly, proposals for use of the Seabeam system (see III.D.2.b.) in late 1981 and early 1982 were not slated for review by ONR until August of 1981, causing considerable uncertainty in ship scheduling.

As a result of these changes, the control of individual academic institutions over schedules of ships has been somewhat weakened. We cannot turn back the clock, but should attempt to preserve the advantages of the old approaches in the evolving, new system for scheduling ships (see Appendix I). First, the old system led to a sense of responsibility on the part of the users for the effective utilization of the ships and their capabilities. This sense came directly from the fact that the users had real control over the conditions, scheduling, and costs of the vessels operated by their institutions, which were the vessels they themselves used. Under current arrangements, there are users from non-operating institutions who have criticisms, but no obligation except future self-interest to devote their own energies to see that corrective measures are taken. At the same time, there are ships which are not principally used by scientists at the operating institution. Bearing on this situation is the fact that there are now many oceanographers at ship-operating institutions who rarely, if ever, need to go to sea themselves in order to obtain data (see Chapter III.D.)

The other advantage of institutionally controlled scheduling which should be preserved was the ease of communication, allowing the buildup through informal discussions of a list of cooperating users for a ship, starting from some initially tentative research plans, and facilitating the generation of programs on short notice to take advantage of cancellations or lightly scheduled or "dead-head" (no science, only transportation) legs of long cruises.

Scheduling is intimately related to both operating costs and income, and the number of potential sources of operating funds is large. Though centrally controlled scheduling would seem to promote economic efficiency and equitable decisions, it is doubtful that any single agency can negotiate effectively with all these potential sources of operating funds. No single agency can or should assume the scheduling function unless it also assumes itself the entire responsibility for funding. The role of NSF/OFS has recently approached this level of responsibility, but it has been repeatedly necessary for institutional operators to find augmenting sources of operating funds. In view of the recent and projected shortfalls in operating funds from NSF (Tables II.7 and III.1), it is desirable for a healthy oceanic research program that academic institutions and scientists share in the responsibility to broaden the base of support for the fleet. Retaining responsibility for scheduling at the operating institutions will provide some incentive for this.

Well-coordinated scheduling of the fleet, and access to ship-time by all qualified scientists, can be accomplished without centralized control by use of an improved system of communication. Such a system should be able to accommodate long-range plans for research which are often tentative and as yet unfunded; medium-range planning (monthly or quarterly) as decisions concerning the funding of specific research projects are made by agencies; and short-range modifications of plans to replace or fill in portions of a schedule or to take advantage of unique opportunities as they are presented by nature. The system should be sufficiently flexible to match supply and demand for large ships which often operate for long periods in waters distant from their home ports with some vacant scientific bunks, and small ships which normally carry a single scientific research team from home port to the area of work and back again.

A centrally-operated, telephone-linked computer system could act as a central repository for all information and requests. Each ship-operating institution should be able to enter into the system information for its ships on their sizes, scientific equipment and capabilities, costs, known and proposed geographical areas of work, sailing schedules, potential vacancies of space (scientific bunks on a scheduled cruise) or time (gaps in the schedule), and daily costs for use. A potential user - an individual, group, or federal agency - should be able to obtain current status reports on ships which would be appropriate for particular kinds of research, using several levels of detail in the search. The system should work in both directions - that is, a scientist or ship-operating institution planning a cruise should be able to search the system for requests which would be appropriate to the cruise (e.g., requiring the scientific equipment already planned to be on board, or utilizing the excess portions of planned samples), especially those which might provide desirable ancillary information or meet a share of the operating costs. This system would facilitate the generation of track-oriented programs to more efficiently use lightly scheduled or "dead-head" legs of long cruises. Also, it would enable potential users to respond on short notice to take advantage of cancellations or unique opportunities presented by nature. Requests between vessel operators for crew or equipment exchanges might even be effected through this system.

The UNOLS office should establish such a system, supported by federal agencies funding academic oceanography; the benefits of using the system should be such that operators of non-UNOLS ships larger than, say, 100 ft. would find it advantageous to join the system. Final responsibility for the scheduling of specific ships should, however, remain with the operating institution.

The ideal is to obtain the diversity of goals and the sense of responsibility which derive from having ships scheduled by those who also use them, with the completeness and speed of matching supply and demand which would result from a central pool of information.

F. The Modes of Funding of Ships and of Research

The introduction of market incentives into the preparation and review of proposals for seagoing research is discussed in this section. In particular, the possible effects of the use of increased economic incentives on scientists, on the peer review system, and on institutions operating ships are discussed.

Presently, UNOLS ship operators submit proposals to NSF/OFS requesting funding for a specific number of days of seagoing operations to carry out research that has been proposed to NSF/OCE by individual investigators. In preparing a proposal to NSF, the individual investigator must estimate the number of days needed and the vessels which will be suitable, but not the cost of the sea time required to carry out the proposed project, though the cost of the research itself is estimated. The request for vessel time is submitted with the research proposal, but separate from the proposed research budget. To the extent that investigators believe the request for vessel time is not given much weight in the peer review process, there is little incentive for an investigator to "shop around" for the lowest cost vessel which would be suitable for the project, even though NSF program managers in fact do evaluate the request for ship-time.

An alternative to the present system would be to include some details of the request for vessel research time and its costs as part of the research proposal, so as to indicate the full requirements and costs of the proposed research. Specifically, we recommend that each investigator be required to present in the proposal the vessel(s) appropriate for conducting the research, the days at sea required, and the estimated cost. Reviewers should be invited to comment on the reasonableness of the request for vessels, and should be informed that these costs of ship-time should be considered when evaluating the rest of the proposed budget. To the extent that budgetary constraints influence approval of the project, and that the investigators recognize that this is the case, the investigator will have an incentive to select the least-expensive combination of a vessel suitable for carrying out the research and the number of days actually required to do the research. Other possible substitutions within the budget can be considered on the same basis, such as hiring more technicians or purchasing new equipment to accomplish the research in fewer days at sea. This might require individual investigators to invest even more of their time in planning, but could create additional funding for other projects through more economical use of ships.

It should be clearly understood that funds for the operation of vessels would continue to go from NSF/OFS to the institutions operating the vessels, not to the individual investigators or their institutions (if different from the ship-operating institution). The purpose of our recommendation is to obtain better review of ship costs relative to other research costs, and through this to provide incentive for careful planning by investigators, not to alter the path of disbursal of funds for ship operations.

One potential objection to the suggested approach is its possible effect on timely scheduling of the use of vessels and on the flexibility available to the operators. Important scheduling economies can be realized within an institution and within the UNOLS fleet network if proposal funding decisions are known early. It is for this reason that funding agencies have been strongly urged to expedite the proposal review process.[6] If a new system causes delays on the part of agencies making funding decisions, then scheduling is made more difficult and operating costs may increase, as will the level of frustration experienced by scientists. Thus, it is clear that the review process should not be lengthened; a goal is to achieve reviewable reporting of the total costs of proposed research without lengthening the review process.

A second potential problem is related to the predictability of funding for the operating institutions. Under the current system of institutional funding as practiced by NSF, the principal funder, an institutional proposal for operating funds may be approved prior to final decisions concerning the funding of all the research which has been proposed for that institution's vessels. In this case, NSF/OFS attempts to estimate the requirements associated with those research proposals which have been or probably will be funded by NSF (as does the institution in preparing its proposal for operating funds) and provides the necessary operating funds as far as possible. For the operators of most UNOLS vessels, this system provides a degree of certainty at an early date. It therefore aids in establishing a daily rate for using the vessel which is relatively stable and lower than if the operator had to protect against loss of funds from unexpectedly low utilization. It is desirable that any revised review and funding procedure continue these beneficial policies.

A final potential objection is based on the fear that seagoing research will be "priced out of the market" by non-seagoing projects within NSF/OCE. This is, however, a question of definition and of value; OCE and its academic advisers must decide what the significant oceanographic problems are and will be in the coming decade or so, and how important seagoing work is to the solution of these problems. This establishes values for both immediate and future use of academic ships. The present report constitutes one such source of advice, with emphasis on the delineation of the options which appear to be available using resources already committed to academic oceanography.

APPENDIX I: TERMS OF REFERENCE FOR UNOLS SCHEDULING GROUPS
(Both groups have the same terms of reference)

1. The group shall be designated the Eastern (or Western) Region Ship Schedule Coordinating Group of UNOLS. (Short title: Eastern (or Western) Region Scheduling Group).
2. The purpose of the group is to serve as a mechanism within UNOLS for the development and coordination of ship schedules in order to assure the most effective, efficient and economic utilization of ships and associated resources.
3. Membership of the group shall comprise authorized representatives from each UNOLS Institution in the Eastern (Atlantic) Region plus a member appointed from the UNOLS Advisory Council drawn from the Eastern Region Associate Membership. Representatives of NSF and ONR shall be included regularly as observers.
4. Chairman of the group shall be elected annually by and from the members. Duties of the chairman include the convening and reporting of meetings, and adherence to the purposes of the group.
5. Meetings of the group shall normally be held four times yearly including spring and fall semi-annual UNOLS meetings, and at other times as may be necessary. In addition to meetings of the full group. meetings of smaller groups representing sub-regions and operating consortia are encouraged. Although meetings are intended to be working sessions between members, nothing precludes a potential investigator or user from attending a meeting for the purpose of discussing ship use requirements or problems.
6. Procedures of the group for the accomplishment of its purposes shall include, but not be limited to, the following:
    a) Close and continuing liaison between members of the group shall be maintained, and
    b) Requests for ship use shall be submitted to the intended operating lab and to the UNOLS Office. Regional group members shall circulate copies of ship use requests via the UNOLS Office as they are received. It is intended that all members be aware of all requests within the region.
    c) Initial ship operating schedules usually will be prepared by individual labs considering the UNOLS Fleet as a whole. Preliminary schedules and subsequent iterations will be circulated

to all members of the group. At this stage as well as later, care shall be exercised by place the proposed use on the most appropriate ship and to avoid duplications.

d) Meetings early in the scheduling cycle are for the purpose of developing the best possible ship schedules using the following criteria:
   Knowledge of funded scientific programs
   Appropriateness of ships assigned
   Combining compatible projects
   Minimizing unproductive transits

e) Later meetings will produce final schedules for the ensuing year assuming that both science and ships' operations funding are reasonably well known. At this stage all ship schedules will be reviewed using the above criteria and stressing both appropriateness and efficiency.

f) Throughout the scheduling cycle, anticipated costs of ship operations vis-a-vis projected agency funding shall be reviewed to determine potential funding shortfalls. In such cases recommendations shall be made regarding practicable alternatives. These include:
   Reduction of operating days
   Further combination of projects
   Deferment of projects
   Ship layups

g) Based on the criteria for effective scheduling, and on the needs and resources of science and facilities funding, the group has the authority and responsibility to recommend specific ships for temporary periods out of service. Such periods shall be included within the schedule and shall be transmitted to UNOLS and to the funding agencies, following appropriate discussions with the operating lab regarding the potentials of alternate use.

h) From time to time summarizes of available ship-time will be circulated by the group via the UNOLS Office.

i) The evolution of major expeditions and distant voyages should be the result of scientific meetings and discussions, but the planning and scheduling for such cruises should be a long-range effort through the group. This will ensure the widest participation possible as well as develop sound funding arrangements well in advance. Information should be communicated broadly to all potential participants.

j) In the event that a ship is proposed to operate as a "dedicated" facility, the group may assist in developing participation in the facility. Conversely, the group must ensure that investigators displaced by the dedicated operation are accorded opportunities on other vessels.

7. Recommendations of the group in the matters given above shall be transmitted concurrently to UNOLS members, the Advisory Council and to federal sponsoring agencies.
8. Operation of the group is on a temporary and trial basis and shall expire at any time at the direction of UNOLS.

APPENDIX II: A MULTIVARIATE REGRESSION ANALYSIS OF THE OPERATING COSTS OF OCEANOGRAPHIC RESEARCH VESSELS

A Report to the Steering Committee
for the
Ocean Sciences Board Academic Research Fleet Study

by

John M. Gates
Luis Vieira

Department of Resource Economics
University of Rhode Island
Kingston, RI 02881

November 1981

LIST OF EQUATIONS

TABLES

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A. INTRODUCTION

This appendix describes the results obtained in a statistical analysis of cost data for oceanographic research vessels. The focus of the analysis is on that segment of the academic research fleet designated as University National Oceanographic Laboratory System (UNOLS) vessels. The UNOLS fleet during 1975-1979 consisted of at most 29 vessels operated by 17 institutions. An exception to this focus is part D which consists of a comparative cost analysis of UNOLS vessels with those of federal agencies with substantial oceanographic research programs.

The objective of the statistical analysis was to measure factors contributing to the costs of vessels in the UNOLS fleet. As a prelude to the analysis it is appropriate to describe what are known or expected to be determinants of cost. The costs of operating a research vessel are known or expected to be influenced by various factors including the size and age of the vessel, intensity of use, geographic location(s) of the research (local vs. distant water operations) and the nature of demands which various types of research may place on a vessel's capabilities. Specifically, research conducted from a stationary vessel is (presumably) less costly than research which requires that the vessel travel. Also, some have hypothesized economies of scale associated with multi-ship vs. isolated (single) ship installations.

A multivariate regression analysis of UNOLS vessels data was conducted to measure and test statistically the validity of these expectations. This technique permits one to isolate the effects of the various determinants of costs and to test hypotheses regarding their statistical significance.[1]

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[1]Waiving extensive apologia and caveats, it should be noted that application of the technique is partially a matter of art and its results, as with any technique, must be used with discretion.

Data for all vessels were obtained through Dr. Thomas Stetson, Executive Secretary, UNOLS, Woods Hole Oceanographic Institution for the years 1977-1980. Although the 1980 data were projections only, the analyses included the 1980 data.[1] In the course of the study, some correspondence took place with individual institutions which led to pre-1977 data for some vessels in the UNOLS fleet.

There are several applications for which the regression results may be of interest. First of all, it provides an efficient means for decribing or summarizing the net effects of various determinants by means of an equation instead of extensive tabulations. Such an equation is also useful for analyzing certain policy alternatives. Secondly, the estimated equation enables one to compare actual costs with "expected" costs. The MRA technique estimates a functional relationship or equation which links the dependent variable (cost) with explanatory variables (the determinants of cost discussed earlier). Given values for the explanatory variables, the regression equation permits us to predict what we "expect" the dependent variable (cost) to be. In fact, the regression equation can be regarded as a conditional mean; it expresses the expectation (i.e., mean) of the dependent variable (cost) as a function of (and therefore conditional upon) values of the explanatory variables. If a vessel is atypical, we would expect it to show up as (more or less) consistent deviations from the expected value or conditional mean. The cause of deviations may be unusual events or unknown causal factors which might be determined by a more in-depth investigation. In this application, the estimated equation is used as a "screening device" to flag unusual observations or "outliers" for further investigation.[2]

A third application of the results is to provide some quantitative information relevant to policy issues such as decreased vessel utilization retirement and fleet consolidation in multi-vessel vs. isolated (single) vessel installations. In the latter policy issue the questions of economic fact are (1) whether or not there are economies of size and if so (2) what are the approximate magnitude of savings.

B. Statistical Analysis of Operating Costs of UNOLS Vessels

1. General

There are several measures of cost, each of which may be of interest depending on the context. The most basic measure is total annual operating costs; hereafter referred to as TOTAL. This measure is the most basic in that other measures can be derived from it by differentition or by division. For example, the daily rate (DAYRAT) is of some

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[1]The exclusion of 1980 data did not materially change results from those reported below.
[2]Robert E. Klitgaard, "Looking for the Best," Paper P-5598 RAND Corporation, Santa Monica, 1976.

interest but it can be derived from TOTAL by dividing through by the number of operating days.

The general expression for total cost is given by equation (1):

(1) TOTAL = F(LGTH, OPDAYS, N, F, AGE, PINDEX)

where: TOTAL = total annual operating costs in thousands of dollars. Note that costs of major overhauls or midlife refit are not included in this cost measure,

LGTH denotes vessel length measured in hundreds of feet,

OPDAYS denotes operating days, as defined by UNOLS,

N denotes number of vessels operated by the institution,

F denotes a vector of operating days by type of research conducted,

AGE denotes vessel age in years,

PINDEX denotes a price index used to adjust for cost inflation over time.

Data on TOTAL, LGTH, OPDAYS, N, F and vessel age were obtained for each UNOLS vessel from sources as described earlier. The PINDEX variable was developed as a weighted average of a fuel price index and a boat building and repair index. The weights used differed by vessel length class to reflect the 1979 UNOLS fuel costs as a fraction of total costs.[1] The weights, price indices and PINDEX values are indicated in Table A.II.1.

Data for the fuel price index were obtained from the producer price index for diesel fuel to commercial consumers from issues of Supplement to Producer Prices and Price Indexes. Data for the ship and boat building and repair index (SIC 373) were obtained from issues of Employment and Earnings Supplement: Revised Establishment Data. Both sources are publications of the U.S. Department of Labor, Bureau of Labor Statistics.

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[1]Vessel length classes were defined as follows:

Class I	200+ ft.
II	150-200 ft.
III	100-149 ft.
IV	60- 99 ft.

TABLE A.II.1 Price Indices and Weights Used to Derive PINDEX

Year	Fuel Price Index[1]	Ship and Boat Building and Repair Index[1]	Weighted Price Index (PINDEX) by vessel Class[2] I-III	IV
1980	1.4943	1.1050	1.1770	1.1350
1979	1.0000	1.0000	1.0000	1.0000
1978	0.7143	0.9075	0.8718	0.8926
1977	0.6852	0.8273	0.8010	0.8164
1976	0.6318	0.8025	0.7709	0.7894
1975	0.5612	0.7500	0.7151	0.7355
1974	0.5342	0.7182	0.6842	0.7040

[1]Sources: U.S. Department of Labor, Bureau of Labor Statistics Supplement to Product Prices and Price Indexes and Employment and Earnings Supplement: Revised Establishment Data (SIC 373).

[2]PINDEX = α(fuel price index) + (1-α) (Boat supply & repairs index). Values of α were fuel fraction of total expenses in 1979 for UNOLS vessels. Values of α were 0.185 for vessel classes I-III and 0.077 for vessel class IV.

Vessel length classes were defined as follows:

Class	I	200+ft.
	II	150-200 ft.
	III	100-149 ft.
	IV	60- 99 ft.

2. Plausible Properties of the Total Cost Function

Before stating equation (1) explicitly we indicate properties which we would expect it to possess and indicate the rationale of each property. These properties will influence the choice(s) of functional form of equation (1) which will be tested empirically:

(1) $\frac{\partial TOTAL}{\partial LGTH} > 0$

(2) $\frac{\partial^2 TOTAL}{\partial^2 LGTH} > 0$

(3) $\frac{\partial TOTAL}{\partial OPDAYS} > 0$

(4) $\frac{\partial^2 TOTAL}{\partial OPDAYS\ \partial LGTH} > 0$

(5) $\frac{\partial TOTAL}{\partial N} < 0$

(6) $\frac{\partial^2 TOTAL}{\partial^2 N} > 0$

(7) $\frac{\partial TOTAL}{\partial N} = 0 \quad \text{for } N = 1$

(8) $\frac{\partial TOTAL}{\partial F(i)} \gtreqless 0$

(9) $\frac{\partial TOTAL}{\partial AGE} \gtreqless 0$

(10) $\frac{\partial TOTAL}{\partial PINDEX} > 0$

(11) $F(LGTH,O,N,F,AGE,PINDEX)>0$

(12) $\frac{\partial F(LGTH,\ O,N,F,AGE,PINDEX)}{\partial LGTH}>0$

Property (1) indicates that total cost is expected to increase with vessel length. In cases where we have reasonable expectations on the signs of coefficients, a two tailed test is unnecessarily conservative. Given this expectation we can apply a one tailed t test of the null hypothesis.

A casual examination of mean total cost and mean vessel length by length class indicated that cost per foot of length is greater for large vessels than small. This suggests that the cost function should possess property (2) viz that total costs increase at an increasing rate with vessel length.

Property (3) indicates that the marginal or incremental costs of vessel operating days are positive. Property (4) indicates that these incremental costs increase with vessel length.

Property (5) indicates that total costs per vessel decrease with the number of vessels located at a given installation or institution; that there are economies of scale.

Property (6) indicates that the costs decrease at a decreasing absolute rate with number of vessels at a multiple vessel installation. This property is desirable to avoid possible nonsensical results. If the cost function does not possess property (6), then it would be possible to reduce costs to zero by adding enough ships at a central installation. Property (7) is a truism; economies of scale vanish for single vessel installations. However, if it is to be a truism, we must specify the cost equation appropriately to permit it.

Property (8) simply says that we have no a priori expectations for the sign or magnitude of cost effects associated with vessel days by type of scientific research conducted.

Property (9) indicates that we entertain no expectation for the magnitude or sign of operating cost effects associated with vessel age. It is important to realize that this expectation exists only because major overhaul costs and mid life refit costs are not included in our cost data.

Property (10) indicates that total operating costs are expected to increase with our cost index.

We expect to have some operating costs which are fixed in the sense that they do not vary continuously with OPDAYS. Property (11) allows for the existence of such costs by specifying positive operating costs even with zero operating days. Property (12) indicates that fixed operating costs increase with vessel size.

These properties summarize what we know or think we know a priori about the total cost function. They are useful in suggesting plausible model specifications and in hypothesis testing (one vs. two tailed t tests).

A simple model which admits (or in some cases, forces) most of these properties is given by equation (2).

$$(2)\quad \mathrm{RTOTAL} = \beta_0 + \beta_1\,\mathrm{LGTH}^2 + \beta_2\,\mathrm{LGTH}^2\,\frac{(N-1)}{N} + \beta_3\,\mathrm{OPLGTH}^2 + u$$

where: RTOTAL = TOTAL/PINDEX = costs in 1979 dollars,
the β_i are coefficients to be estimated from the data,
u = error term, and
$\mathrm{OPLGTH}^2 = \mathrm{OPDAYS}\,(\mathrm{LGTH})^2$.

The functional specification in equation (2) permits all properties except (8) and (9). The missing properties will be discussed below with the statistical results. Properties (2), (4), (6), (7), and (10) are forced to hold (barring nonsensical signs) by virtue of the model specification. We, therefore, cannot test them per se.

The error term in equation (2) exhibited unequal variance across vessel sizes[1]. Weighted least squares was used to obtain best linear unbiased estimates of the parameters in equation (2).

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[1]Glejser, H. 1969, "A New Test for Heteroskedasticity." Jour: Amer. Stat. Assoc., March 1969, pp. 316-323.

3. Results

The estimated parameters for equation (2) are given by equation (3). Standard errors and summary statistics for equation (3) appear in Table A.II.2.

$$(3)\quad RTOTAL = 35.7 + 202.4\ LGTH^2 - 112.9\ LGTH^2\ \frac{(N-1)}{N} + 0.85\ OPLGTH^2$$

The goodness of fit of this equation, as measured by the R^2 statistic in Table A.II.2 is 0.88. This statistic indicates that of the total variation about the mean value of RTOTAL, the estimated equation accounts for 88 percent. The F ratio of 312 permits us to test the possibility that all coefficients are simultaneously zero (null hypothesis) against the alternate hypothesis that at least one is non zero. The probability of obtaining the observed F ratio given that the null hypothesis is true is only 0.0001 or 0.01 percent. The number in parentheses beside each parameter estimate is the estimated standard error of that parameter estimate. With the exception of the intercept coefficient, (β_0) all parameter estimates are more than triple their standard errors. It is evident for each parameter estimate that the conditional probability of obtaining the estimate, given the null hypothesis, is low. For a 0.1 percent rejection level, and using one tailed t tests of significance, the null hypothesis is rejected for all but the intercept estimate[1]. For the intercept estimate, rejection of the null hypothesis is possible at the ten percent level of significance using a two tailed test of significance. The signs of the parameter estimates are in accord with a priori expectations as specified earlier in properties (1) through (12). Table A.II.3 lists predicted 1979 values for TOTAL and DAYRAT for selected vessel sizes. Table A. II.4 contains mean values actual and predicted for all variables in equation (3). Thus, Table A.II.3 illustrates predicted costs for arbitrarily selected vessel sizes. In Table A.II.4 however, the mean values for the UNOLS fleet are used. The numbers in Table A.II.4 were used in calculations of relative savings from centralization. They were also used in calculations for Tables IV.1 and IV.2 in part IV of the text. It is noteworthy that mean vessel utilization in Table A. II.4 is significantly less than the "full utilization" levels of text table II.1. If we assume, for the moment, that operating days and days were also used in calculations for Tables IV.1 and IV.2 in part IV of the text. It is noteworthy that mean vessel utilization in Table A.II.4 is significantly less than the "full utilization" levels of text table II.1. If we assume, for the moment, that operating days and days at sea are equivalent, then the discrepancies are indicative of underutilized vessel capacity. Due to non-uniform definitions, we are uncertain about the correspondences between operating days and days at

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[1]Technically we are justified, based on properties stated earlier for (2), in using one tailed tests of significance for β_1, β_2, and β_3.

TABLE A.II.2 Statistical Results for Equation (2)

Parameter	Estimated value	Standard error	t ratio
β_0	35.7	(18.4)	1.9
β_1	202.4	(36.3)	5.6
β_2	- 112.9	(33.1)	3.4
β_3	0.85	(0.1)	8.5

Summary Statistics:

$R^2 = 0.88$
MSE = 111.4; SE = $10.55 thousand/year
# observations = 132
F ratio = 312

TABLE A.II.3 Expected 1979 Costs for Selected Vessel Sizes

Length	NVESS[1]	Mean OPDAYS[2]	Expected Values TOTAL[3]	DAYRAT[4]
- feet x 10^{-2} -		-# days-	-\$ x 10^{-3}/year	-\$ x10^{-3}/day-
0.60	1	161	158	0.98
1.00	1	212	418	1.97
1.50	1	253	974	3.85
2.50	1	256	2660	10.39

[1]With N=1 there are no multiple vessel economies.

[2]Mean OPDAYS by vessel class; 1977-1979.

[3]Total annual operating costs predicted by equation (3) with values as indicated and PINDEX = 1.0 = 1979 value.

[4]Predicted TOTAL divided by mean OPDAYS.

TABLE A.II.4 Mean Values of Variables for Equation (3)

Variable	Units	Mean Values by Vessel Class I	II	III	IV
LGTH	feet x 10^{-2}	219	174	117	74
$LGTH^2$	$feet^2$ x 10^{-4}	4.83	3.04	1.39	.57
$LGTH^2$	$feet^2$ x 10^{-4}	3.21	1.25	0.13	0.19
OPDAYS	Days	246	255	213	148
$OPLGTH^2$	$feet^2$-days x 10^{-4}	1199	779	296	85
Daily Rate Estimated	\$/day x 10^{-3}	6.55	4.70	2.58	1.11
RTOTAL actual	\$ x 10^{-3}	1717	1048	659	223
predicted[1]	\$ x 10^{-3}	1678	1190	548	179
predicted[2]	\$ x 10^{-3}	1670	1174	554	202

[1]Calculated as mean of predicted values of RTOTAL. These values are repeated in Table IV.1 of Part IV of the text.

[2]Calculated by substituting mean values of explanatory variables in equation (3).

Vessel length classes were defined as follows:

Class I	200 ft.
II	150-200 ft.
III	100-149 ft.
IV	60- 99 ft.

sea. However, informed opinion holds that operating days (OPDAYS) as used in the regression analysis usually exceed days at sea. Therefore, it seems reasonable to regard the discrepancies between mean operating days in Table A.II.4 and potential days at sea in text table II.1, as underestimates of underutilized vessel capacity. Furthermore, since the discrepancies seem to have become chronic, it seems reasonable to conclude that some underutilized vessel capacity may be excess capacity which could be decommissioned with little consequence on the progress of science.

Figure A.II.1 contains a plot of the standardized residuals (prediction errors) for equation (3). In this figure, the horizontal axis is a vessel identification code (NEWID). This code has been randomized with respect to vessel size to disguise vessel identity. The vertical axis measures the standardized residual; i.e., the prediction error divided by the standard error. Perfect predictions fall on the 0.0 horizontal line. Additional horizontal lines are drawn at ± 1.0, ± 1.5, and ± 2.0 standard errors. Single observations are denoted by the plot symbol A; two observations by B etc.

Figure A.II.1 suggests that the UNOLS fleet is remarkably homogeneous. Vessel 22 had consistently higher costs than it "should have" based on the regression. Similarly, vessel 25 had consistently lower costs. Some vessels (e.g., vessel 5) were "outliers" in one year but in other years were within ± 1.5 standard errors in other years.

Several specifications were investigated for economies of scale. In the least restrictive specification it was hypothesized that scale economies would be non separable. If non separable, detection of scale economies would require that we specify a model dealing with aggregates (sum of observed values) of variables for all vessels at an institution. It was also hypothesized that economies of scale might affect variable operating costs as well as fixed operating costs. This proved not to be the case. It was then hypothesized that any economies of scale might be prorated among vessels in proportion to fixed operating costs. If this were true, it should be possible to otain similar coefficients using either aggregated variables for all vessels at a multi-vessel institution or using individual vessel data as specified in (2) and (3). This proved to be the case. Results were indistinguishable between the aggregated and individual vessel specifications so the individual vessel regression of (2) and (3) has been presented for simplicity. More extensive discussion of economies of scale appears in Section C of this Appendix.

Several determinants of cost, discussed in the Introduction, do not appear in equations (2) or (3). Among individuals interviewed there was some difference of opinion concerning the relevance of vessel age. Vessel age was included in several regressions but its coefficient was not significantly different from zero.

The geographic location of research may or may not be relevant. The data set at our disposal did not permit a test. It may be hypothesized however, that such effects would be difficult to unscramble statistically from vessel size measures such as LGTH.

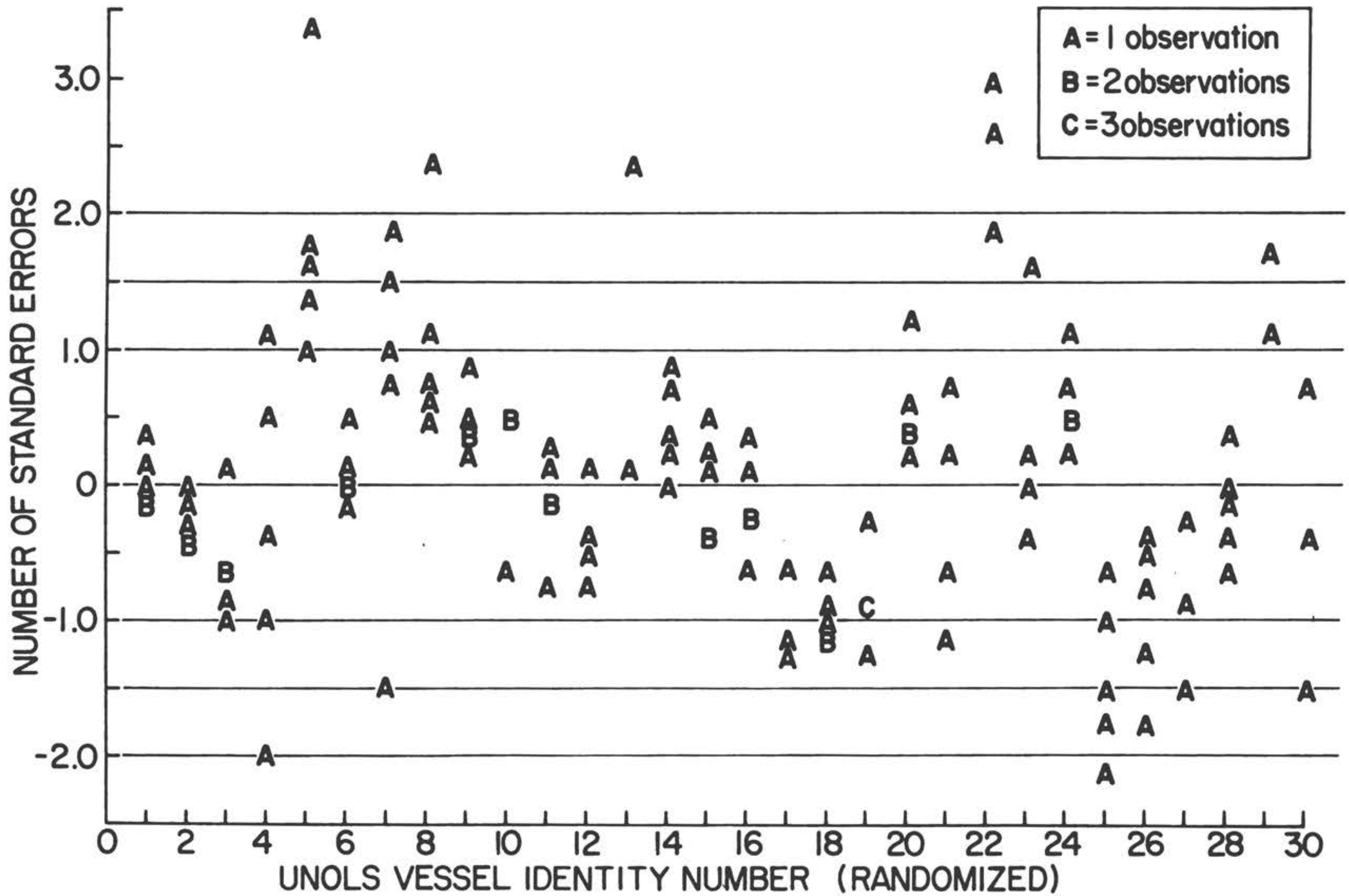

FIGURE A.II.1 Plot of Prediction Errors for Equation (3).

The effect of type of research (discipline) was explored by including vessel days by type of research in lieu of total operating days. The coefficients obtained proved to be very sensitive to model specification and unstable between years. It was concluded that the research discipline per se is not a relevant determinant of costs.

Inter year differences in cost were explored via a covariance analysis using an undeflated analogue of equation (2). The results indicated significant cost increases over time as expected. However, covariance analysis is cumbersome when making projections for future costs. It was decided therefore to deflate total costs by the price index PINDEX as indicated in the definition of RTOTAL.

A variety of alternative specifications were explored to refine equation (3). The rationales of some of the specifications explored derive from economic interpretations of equation (3). The use of $LGTH^2$ in equations is not entirely arbitrary. A graph of mean cost per foot against length appeared to be linear which is consistent with a quadratic effect in the total cost relationship. Inclusion of both linear and squared length effects was unsuccessful because of multicollinearity between length and squared length terms. Alternative specifications using LGTH and $LGTH^3$ proved inferior to $LGTH^2$ based on goodness of fit.

C. Economic Interpretation of Results

In analyzing costs it is customary to adopt certain distinctions between the production or technical unit (i.e., individual vessels or plants) versus the financial unit or firm (i.e., the institution) which operates one or more technical units. There will usually exist short-run economies of size (or diseconomies) within production units (at least over a range) as intensity of use is increased with a given plant size or, in the long-run, when plant size or scale is varied. There may also exist economies (or diseconomies) of scale for the firm as a whole as the number of technical units or plants (vessels) is varied. It is also customary to divide costs into "fixed" and variable costs. Fixed costs are usually considered to include such items as depreciation, interest, repairs, taxes and insurance. Since the data used in this analysis include only operating costs, it is convenient to use the terminology of fixed operating costs and variable operating costs. It will not be necessary to classify UNOLS operating cost items as uniquely fixed or variable. In fact, only total cost data are used. However, for illustrative purposes, an example of a variable operating cost would be fuel since, for a given vessel, it varies (more or less proportionally) with operating days. An example of an operating cost which is fixed (or nearly so) might be salaries of marine personnel. Due to the experience and human capital embodied in such personnel a vessel operator would choose to lay off marine personnel only if the associated vessel will be laid up for prolonged periods. Since accumulative leave and sick pay may be drawn on during such periods, the layup period must be very prolonged before any cost reductions are realized. Fuel and salary costs are offered as examples only. In practice many costs do not fit neatly into mutually exclusive categories.

Fortunately, when using regression analysis the allocation of total costs is done implicitly by the estimation procedure. For discussion purposes, assume isolated vessels so that scale economies are zero. The term $OPLGTH^2$ in equations (B.2) and (B.3) represents variable operating costs. The marginal or incremental cost of another operating day is given by equation (4):

$$(4) \quad \frac{\partial RTOTAL}{\partial OPDAYS} = \beta_3\, LGTH^2 = 0.85 \; LGTH^2$$

Thus, for a 100 ft. vessel the marginal cost of an operating day would be $0.85 thousand in 1979 dollars. For a 200 ft. vessel this cost would be $3.4 thousand.[1] This rapid increase in marginal operating costs stems from the specification of $LGTH^2$ in equations (2) and (3).

Conversely, the fixed operating costs are given by the intercept and the terms associated with β_0 and β_1 in equations (2) and (3). Thus, for a 100 ft. vessel in 1979, the fixed operating costs were $35.7 + 202.4 or $238.1 thousand per year. For a 200 ft. vessel these costs would be $845.3 thousand per year.

If we measure the intensity of use of "output" of a vessel by OPDAYS then the unit operating costs are given by the daily rate (DAYRAT):

$$(5) \quad DAYRAT = \frac{\beta_0}{OPDAYS} + \beta_1 \frac{LGTH^2}{OPDAYS} + \beta_2 \frac{LGTH^2}{OPDAYS} \left(\frac{N-1}{N}\right) + \beta_3 LGTH^2$$

For a given vessel, LGTH is fixed and hence the numerators of all terms in (5) are fixed. However, as OPDAYS increase, terms containing OPDAYS as a denominator diminish so that unit operating costs decline continuously as OPDAYS increase. Thus, there are economies associated with fully utilizing vessels. This would suggest that the long-run way to reduce costs is not through layups but through reduction in fleet size. Consideration of the annualized salvage (market) value of vessels retired would reinforce this conclusion.

Based on comments received on a draft of this Appendix, it appears that vessel operators use the term "layups" to refer to a fairly lengthy period of vessel inactivity. The period of inactivity is long enough to warrant a series of managerial decisions to cut costs but not long enough to warrant retirement. Under layups, a variety of specific decisions are possible and cost savings from layups will depend on which decisions are implemented, when they are implemented, contractual obligations and accounting procedures. We wish to use our regression results to discuss probable savings associated with not fully utilizing

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[1] LGTH is measured in hundreds of ft. in the regression; hence $LGTH^2 = 4.0$ for a 200 ft. vessel.

vessels. To avoid confusion with the widely familiar but somewhat vague term "layups," we need a concept and terminology which corresponds to the measure derivable from the regression equation. However, in Chapter IV of the text, the term layups is used synonymously with decreases in vessel utilization.

In the discussion which follows, we define the utilization ratio as the ratio of actual or planned operating days to the observed mean operating days during 1977-1980. Our calculation and discussion of savings associated with decreases in the utilization ratio may underestimate the savings associated with prolonged layups for which more drastic cost cutting measures (such as laying off crews) may be involved. There are numerous cost cutting measures which might be taken and so actual cost savings depend on which actions are in fact adopted. For modest variations in operating days, our measure accurately describes savings realized in the past. This is a good guide to the future if vessel operators continue to react to modest variations in the utilization ratio as they have in the past. For drastic decreases in the utilization ratio, vessel operators would, at some interval, begin to adopt more aggressive cost cutting measures. For this reason we do not project cost reductions for utilization levels below 70 percent. The cutoff at 70 percent was arrived at judgementally in committee.

While decreased utilization is not a sensible solution to cost cutting in the long run, it is interesting to calculate the savings in total operating costs for various utilization percentages. To do this we can use equation (3). Let us define OPDAYS as the difference between actual or planned OPDAYS and mean OPDAYS observed during 1977-1979. Absolute cost savings through decreased utilization, denoted by Δ COST, are given by

$$(6)\ \Delta\ COST = \beta_3\ (LGTH^2)\ (\Delta\ OPDAYS).$$

Relative cost savings are obtained by expressing absolute savings as a percentage of total costs. Table A.II.5 contains absolute and relative cost savings for utilization ratios of 90, 80 and 70 percent for vessels of various lengths. The percentage savings range from 3.1 percent to 15.3 percent depending on vessel utilization and vessel size. The elasticity of costs with respect to utilization expresses the percent change in total costs for each percentage change (reduction) in OPDAYS. Clearly the elasticity increases with vessel size (0.31 for 60 ft. versus 0.51 for 250 ft. vessels). Somewhat surprisingly the elasticity measure was constant over the range from 90 to 70 percent vessel utilization. Analysis of equations (2) and (3) reveals that this result is to be expected given the functional form and parameter values. These elasticities are dimensionless and provide convenient rules of thumb for cost savings. For example, for 250 ft. vessels, each percentage reduction in OPDAYS will reduce total costs by 0.51 percent. A one percent reduction in OPDAYS for 60 ft. vessels will reduce total costs by only 0.3 percent.

TABLE A.II.5 Cost Savings from 90, 80 and 70 Percent Vessel Utilization

Vessel Size Feet x10^{-2}	Mean OPDAYS[1] #	Projected 1979 Cost[2] 10^3 $/year	Absolute Cost Savings — Percent Utilization 90	80	70	Relative Cost Savings — Percent Utilization 90	80	70	Cost Elasticity With Respect to % Utilization[3] 90	80	70
			10^3 $/year								
0.6	161	158	4.9	9.7	14.8	3.1	6.1	9.3	0.31	0.31	0.31
1.0	212	418	17.9	35.9	54.1	4.3	8.6	12.9	0.43	0.43	0.43
1.5	253	973	48.2	96.3	145.2	5.0	9.9	14.9	0.49	0.49	0.49
2.5	256	2660	135.3	270.7	407.8	5.1	10.2	15.3	0.51	0.51	0.51

[1]Mean values for UNOLS fleet 1972-1980.

[2]From TABLE A.II.2.

[3]Ratio of relative cost savings (percent) to percent reduction in OPDAYS.

D. Economies of Scale in Multiple Vessel Installations

The estimated regression equation (3) includes a term which measures economies of scale realized in multiple vessel installations.[1] In this section we elaborate on the economic significance of this result by calculating the absolute and relative magnitude of potential savings through consolidation of vessels.

1. Absolute Savings

Economies of scale are measured by the term $\beta_2 \text{ LGTH}^2 \left(\frac{N-1}{N}\right) = -112.8 \text{ LGTH}^2 \left(\frac{N-1}{N}\right)$ in equation (3).

If, as assumed earlier for discussion purposes, we have an isolated vessel then N-1 = 0 and there are no other vessels from which economies might derive. For $N > 1$ we have scale economies which increase at a decreasing rate with increases in N and asymptotically approaching $\beta_2 \text{ LGTH}^2 = -112.8 \text{ LGTH}^2$.

Suppose a situation in which an N^{th} homogeneous vessel is added to an N-1 vessel installation versus dispersing the same N homogeneous vessels; one per installation[2]. The expected cumulative savings due to economies of scale would be given by S(N) and the <u>incremental</u> savings would be given by s(N) = S(N) - S(N-1):

$$(7) \quad S(N) = \beta_2 \text{ LGTH}^2 \left(\frac{N-1}{N}\right), \quad N \geq 2$$

$$(8) \quad s(N) = \beta_2 \text{ LGTH}^2 \left(\frac{1}{N(N-1)}\right), \quad N \geq 2$$

Table A.II.6 contains the projected savings in thousands of dollars per year associated with homogeneous multiple vessel installations for N ranging from 1 to 6, and 4 vessel sizes; viz. 60 ft., 100 ft., 150 ft., and 250 ft. vessels. Thus, for 60 ft. vessels, total annual savings (S(N)) increase from zero (when N=1) to $33.7 thousand per year (when N=6). Note, however, that the savings increase at a decreasing rate. This is indicated by the marginal savings (s(N)) which decline rapidly with increases in N above 2.

These savings should be interpreted with care. They may be given either of two equivalent interpretations; viz.:

(i) the annual savings in total operating costs due to scale economies when the N^{th} vessel of a given size is added to an existing

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[1]See Section B for details.
[2]By homogeneous vessels we mean simply that all vessels are identical. As explained below, this is a simplifying assumption which can be relaxed.

TABLE A.II.6 Absolute Savings in Annual Operating Costs Due to Scale Economies in Multiple Vessel Installations

			Vessel Length							
		LGTH[1]	0.60		1.00		1.50		2.50	
		OPDAYS[2]	161		212		253		256	
		β_2 LGTH[2]	40.6		112.8		253.8		705	
N	$\frac{N-1}{N}$	$\frac{1}{N(N-1)}$	S(N)	s(N)	S(N)	s(N)	S(N)	s(N)	S(N)	s(N)[3]
			- $ x 10^{-3}/year -							
1	0	N.A.	0	0	0	0	0	0	0	0
2	0.5	0.5	20.3	20.3	56.4	56.4	126.9	126.9	352.5	352.5
3	0.67	0.17	27.1	6.8	75.2	18.8	169.2	42.3	470.0	117.5
4	0.75	0.08	30.5	3.4	84.6	9.4	189.7	21.2	529.0	58.7
5	0.80	0.05	32.5	2.0	90.2	5.6	203.0	12.7	564.0	35.3
6*	0.83	0.03	33.7	1.4	93.6	3.8	211.5	8.5	587.5	23.5

[1]LGTH = ship length in hundreds of ft.

[2]OPDAYS = mean OPDAYS for UNOLS vessels; 1972-1979.

[3]S(N) = cumulative savings equation (7).

s(N) = marginal or incremental savings equation (8).

*N=6 is an extrapolation beyond the range of observations.

N-1 identical vessel installation versus dispersing these same N vessels to N single vessel installations;

(ii) the savings in annual operating costs due to multiple vessel economies when N identical vessels are moved from single vessel installations to create a single multiple ship installation with N identical vessels.

The restriction to identical vessels (homogeneous fleet) is done for simplicity. Technically one can do the calculations for heterogeneous fleets. Practically, the problem with doing so is one of deciding which of the very large number of combinations to evaluate. With homogeneous fleets the calculations are simpler and calculations for heterogeneous fleets should yield results which can be approximated by interpolations from homogeneous fleets.

The restriction to single vessel donor installations maximizes the potential gains from consolidation transfers. If a vessel is transferred from a multiple vessel installation, there are diseconomies induced at the donor institution because $\frac{N-1}{N}$ declines at the donor institution. Thus, potential aggregate net savings are the net effect of economies realized at the receiving installation and diseconomies induced at the donor installation. Such transfers can be evaluated but the possible transfers are combinatorial and hence tedious to enumerate. The information in Table A.II.6 gives considerable insight into potential economies merely by enumerating polar cases which yield maximal potential savings.

The total potential savings range from $20.3 thousand per year, for adding a second 60 ft. vessel to an existing single 60 ft. vessel installation, to $587.5 thousand per year, for adding five 250 ft. vessels to an existing single, 250 ft. vessel installation.

The adjectives "potential" and "maximal" were used for several reasons. First, there are random differences in costs between vessels. If a transferred vessel is higher cost than average, and vessels at the receiving institution are lower cost, there may be no apparent economies realized at the receiving institution. Secondly, the nature of the data used is such that we measure only potential scale economies in operating costs. If a transfer requires capital investments to accommodate the vessel at its new home, the annualized cost of these investments must be deducted from the potential savings in annual operating costs. The cost savings from consolidation depend, other things being equal, on the square of vessel length. Thus, comparing consolidation involving a 150 ft. versus 60 ft. vessel, the savings with the larger vessel would be $(150/60)^2$ or 6.25 times as great as with the smaller vessel. This specific result stems from the specification of $LGTH^2$ in equations (2) and (3). Alternative specifications using LGTH and $LGTH^3$ were explored. Of these, the $LGTH^2$ gave the better fit. It should be recognized that the use of 2 as an exponent of LGTH has no known theoretical basis; perhaps the correct number is 1.5 or 2.5 (for example). The linear and cubic specifications tended to yield smaller estimates of economies of scale. Thus, for the several reasons discussed, we regard the calculated economies of scale as upper bound estimates on savings which might be realized through centralization.

2. Relative Savings

An alternative perspective of scale economies is obtained by expressing the absolute savings (S(N) and s(N)) of Table A.II.6 as percentages of projected costs in the absence of scale economies. This can be done by dividing the savings in Table A.II.6 by the total annual operating cost estimates of Table A.II.3 (multiplied by the appropriate number of vessels). Examination of the total percentage savings for a given fleet size (fixed N) in Table A.II.7 indicates that the percentage is almost constant across vessel sizes. Conversely, for a given vessel size the total percentage savings declines with fleet size from 6.5 to 6.7 percent with two vessels to 3.5 to 3.7 with six vessels. Clearly, the greatest absolute and percentage savings are associated with the first consolidation which creates two-vessel installations. It matters little, in percentage terms, whether the vessels consolidated are large or small. In absolute terms, savings are greatest for large vessels.

It seems reasonable to conclude that there may be cost savings through consolidation of vessels in multiple vessel installations. However, it must be emphasized that (1) these savings are not large in percentage terms, (2) they do not allow for any capital investments required to accommodate additional vessels at the receiving installation and (3) the estimates are averages or expected values. Actual savings will depend also on variability between vessels.

E. A Comparison of Costs for UNOLS and Non-UNOLS Vessels

A comparison was made of costs of oceanographic research vessels operated by different federal agencies. Agencies whose vessels were included were UNOLS, U.S. Navy, Military Sealift Command (USMSC), U.S. Geological Survey (USGS), and U.S. Coast Guard (USCG), and the National Oceanic and Atmospheric Administration (NOAA). For discussion purposes, numeric codes were assigned each fleet. Code 1 was assigned to the UNOLS fleet. Data for the non-UNOLS vessels were obtained from a report by the Comptroller General of the United States.[23]

The comparison of costs for different fleets is complicated by the existence of interfleet differences in vessel sizes and intensity of vessel usage. The desired comparison is one which adjusts costs for such interfleet differences. Residual differences will then be indicative of relative efficiencies of the various fleets.

To permit adjustments for interfleet differences we first refitted equation (2) to pooled data for the various fleets. The scale effect variable was deleted, however, because we did not have information on single versus multiple vessel installation for the non-UNOLS fleets. The equation to be estimated is given by (9):

$$(9)\quad RTOTAL = \beta_0 + \beta_1\, LGTH^2 + \beta_3\, OPLGTH^2$$

TABLE A.II.7 Relative Savings in Annual Operating Costs Due to Scale Economies in Multiple Vessel Installations

	Vessel Length[1]							
	0.60		1.00		1.50		2.50	
	Percent Savings[2]							
N	total	marginal	total	marginal	total	marginal	total	marginal
1	0	0	0	0	0	0	0	0
2	6.4	12.9	6.7	13.5	6.5	13.0	6.6	13.3
3	5.7	4.3	6.0	4.5	5.8	4.4	5.9	4.4
4	4.8	2.2	5.1	2.3	4.9	2.2	5.0	2.2
5	4.1	1.3	4.3	1.3	4.2	1.3	4.2	1.3
6	3.6	0.9	3.7	0.9	3.5	0.9	3.7	0.9

[1]LGTH = ship length in hundreds of ft.; N = number of vessels.

[2]Derived by expressing absolute savings from Table A.II.6 as a percentage of projected cost in the absence of economies of size. For total percent savings, the numerator is 100 S(N). For the marginal percent savings, the numerator is 100 s(N). For the marginal percent savings, the denominator is the total cost per vessel from Table A.II.3. For the total percent savings, this denominator is multiplied by the number of vessels.

The variables and units of measurement for this equation were defined in part B of this Appendix. Table A.II.8 contains estimated

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TABLE A.II.8 Parameter Estimates for Equation (9) for the UNOLS Fleet Using Pooled Data and General Linear Model: RTOTAL = FLT + β_1 LGTH^2 (FLT) + β_3 OPLGTH^2 (FLT)[1]

Parameter	Estimate	Standard error	t ratio
β_0	29.6	29.8	0.99
β_1	117.9	43.2	2.73
β_3	0.6213	0.172	3.61

obervations = 258
R^2 = 0.92
F statistic = 196

mean squared error = 295.7
standard deviation = 17.2

[1]In the general linear model a discrete variable, such as FLT acts as an argument of the term with which it appears. In the specification used it appears in all terms; including the intercept. Wherever it is used, FLT allows the associated regression coefficient to differ between fleets. If FLT had been excluded from a given term, its absence would have forced the associated regression coefficient to be the same for all fleets. The results indicated that coefficients differ between fleets.

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coefficients, standard errors, and t ratios for the UNOLS fleet. Analogous estimates were obtained for non-UNOLS fleets. However, since we will not be using them, they are not reported here. Table A.II.8 also contains summary statistics for the regression. Overall, the results for the general linear model were quite good. However, the estimated value of β_3 for fleet 3 was negative although not statistically significant.

Table A.II.9 contains observed mean values of explanatory variables for each fleet. These mean values will be used to adjust for interfleet differences. It also contains the mean values of RTOTAL; the total annual operating cost per vessel. ESTCOST is the predicted value of RTOTAL using the estimated general linear model. The mean value of ESTCOST also appears in Table A.II.9.

Using equation (9), the parameter estimates of Table A.II.8 and the mean values of explanatory variables from Table A.II.9, we calculated expected values for RTOTAL for non-UNOLS vessels using the UNOLS cost equation and non-UNOLS vessel characteristics. If there were no differences between fleets, such calculations (Table A.II.10) would yield identical cost estimates. In fact, the calculations indicate rather substantial differences. Specifically, the UNOLS fleet is substantially lower cost. The non-UNOLS fleets had mean costs which range from 30.5 to 117.9 percent higher than mean costs predicted using the UNOLS prediction equation. Such differences are attributable to unexplained factors or causes. Specification of those factors is not within the scope of this Appendix.

F. Summary and Conclusions

The first set of data examined concerned the UNOLS fleet from 1976 to 1980, and was supplied by the UNOLS office. These data were subjected to a multivariate regression analysis in order to determine effects on the annual operating cost of a vessel of its size, the number of days per year at sea, the number of other vessels also operated by the home institution, and other factors. One advantage of this approach is that the regression summarizes data for the entire UNOLS fleet, and the mean trends identified thus pertain to a "typical" vessel, rather than to any particular, existing ship or institutional practice. Another advantage is that the form of the multiple regression equation is such that it can be used to evaluate the typical or average economic consequences of such policy decisions as decreased vessel utilization for ships of various sizes, or of consolidating the fleet such that only a few institutions operate ships. What the regression cannot do, obviously, is to evaluate the scientific consequences of such actions.

1) The estimated regression equation for the UNOLS fleet is:

$$\text{Total annual cost} = 35.7 + 202.4\,(\text{length})^2 - 112.9\,(\text{length})^2 \frac{(\text{number of vessels} - 1)}{(\text{number of vessels})} + 0.85\,(\text{operating days per year})\,(\text{length})^2$$

where cost is measured in thousands of 1979 dollars, length is hundreds of feet, and number of vessels are those operated by the same institution. The use of the square of length results in a better description of the data, than either linear or cubic terms involving length. Several alternative specifications were fitted to the data. The model reported above described the data as well or better than others. In the simplest case where each vessel is operated by a different institution, this relation translates into daily rates of $980 for a 60-ft. vessel operated 161 days per year (the UNOLS mean for this size) to $10,400 for a 250-ft. vessel operated for 256 days per year.

TABLE A.II.9 Mean Values of Variables for Oceanographic Research Vessels; by Fleet, 1976-1980

Variable	Units	Fleet[1] 1	2	3	4	5
		- mean values -				
OPLGTH[2]	$Feet^2$ - days x 10^{-4}	589.1	746.3	1231.2	2429.3	451.3
LGTH[2]	$Feet^2$ x 10^{-4}	2.44	3.81	8.86	12.76	3.08
OPDAYS	# days	213.5	195.6	171.2	205.3	143.6
RTOTAL	$/vessel/year x 10^{-3}	683.2	1497.4	3025.6	3972.4	1186.5
ESTCOST1[2]	$/vessel/year x 10^{-3}	683.8	1497.4	3025.6	3972.4	1186.5

[1]Fleet 1 is the UNOLS fleet.

[2]Mean of predicted values for RTOTAL. Prediction equation used was equation (9) using fleet-specific parameter estimates.

TABLE A.II.10 Cost Comparisons for UNOLS and Non-UNOLS Research Vessels

	Fleet				
Variable	1	2	3	4	5
	- \$/vessel/year x 10^{-3}				
RTOTAL[1]	684	1497	3026	3972	1186
ESTCOST2[2]	631	943	1389	3043	673
Difference[3]	53[a]	554	1637	929	513
Percent Difference[4]	8.4	58.8	117.9	30.5	76.2

[1]RTOTAL = mean total cost from Table A.II.9.

[2]Estimated by substituting estimated coefficients for fleet 1 (UNOLS fleet)from Table A.II.8 and mean values of explanatory variables from Table A.II.9 in equation (9).

[3]RTOTAL minus ESTCOST2.

[4]Difference expressed as a percent of RTOTAL.

[a]Difference for the UNOLS fleet is associated with use of mean values for explanatory variables to estimate costs. The mean of predicted values (ESTCOST 1 in Table A.II.8) equals the observed mean of RTOTAL.

2) In these same units, the marginal or incremental cost of an additional day at sea is $0.85(\text{length})^2$; the annual fixed operating cost is $35.7 + 202.4(\text{length})^2$.

3) Savings resulting from decreased vessel utilization range from 3 percent of the full operating cost for a 60-ft. vessel with 90 percent utilization to 15 percent for a 250-ft. vessel with 70 percent utilization.

4) Cost per potential scientist-day-at-sea increases faster than does the daily rate with increasing length of vessel, because scientific capacity increases approximately linearly with length, while cost increases as a higher power. Cost per actual scientist-day-at-sea increases still faster with length; this is because large vessels more often go to sea with some empty scientific bunks than do small vessels[1].

5) Small savings could be realized by consolidating the fleet so that fewer institutions operate the vessels; the savings per ship increase in absolute amount with increasing size of ship, but the savings relative to the operating cost of a given size of vessel are independent of the vessel's size. The savings are statistically significant, but may be economically trivial. The greatest savings result from consolidations in which the donor is a single vessel institution. This result is a consequence of the form in which the variable (number of vessels) appears in the regression equation.

These conclusions are subject to the limitations of the data themselves and of the factors considered in the analysis. For example, the conclusion regarding fleet consolidation and cost savings does not take into account new shoreside construction costs which might be incurred if ships were actually transferred to a few institutions, nor the transportation costs for seagoing scientists at institutions without ships. More important is that calculated savings are purely a fleet cost analysis. Such savings do not address non-pecuniary costs or benefits, such as research flexibility and adaptability, associated with the centralization/decentralization question.

Implications of this analysis for the future size of the academic fleet and its management are elaborated upon in Chapters IV and V of the report. This appendix suggests some possible benefits of managerial policies in terms of annual operating costs of the fleet, but there may be other economic costs to be weighed against these benefits. Even if overall economic benefits exceed costs, the more difficult question is that of scientific costs and benefits. It is assumed that the objective of increased efficiency is not budget savings per se but the support of more and/or better scientific research. Much discussion is therefore required as to whether financial gains resulting from a fleet which is more economically efficient than is the present one can also be used to produce better ocean science.

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[1]The statistical comparisons leading to this conclusion were not presented in this Appendix. They were presented in committee meetings however.

A statistical comparison of UNOLS and non-UNOLS research vessels was made. In this comparison, data for the various fleets were pooled and subjected to a covariance analysis. The analysis indicated significant differences between fleets. These differences were partially due to interfleet differences in vessel characteristics, such as size, and partially due to differences in parameter estimates.

The comparison we wished to make was one adjusted for interfleet differences in vessel characteristics. To do this, we applied the estimated regression equation for the UNOLS fleet to the non-UNOLS fleets. The cost projections thereby obtained indicate what fleets of those compositions would have cost if their total cost equation had been the same as that of UNOLS. These projections are therefore purged of any differences due to measured vessel characteristics. A comparison of these projections with actual costs indicated substantial differences. After adjustment for measured differences in vessel characteristics, the non-UNOLS vessels have operating costs substantially greater than those of UNOLS vessels.

APPENDIX III: QUESTIONS ADDRESSED TO LEADERS OF OCEANOGRAPHIC OR MARINE RESEARCH GROUPS, AND LIST OF RESPONDENTS

31 December 1980

Dear

The Ocean Sciences Board of the National Research Council has been asked by the National Science Foundation and the Office of Naval Research to report on the needs of the U.S. academic research fleet for the period 1985-90, in view of the probable budgetary constraints and the probable sizes and condition of the ships in the fleet. The terms of reference for this study are attached. We will stress conventional ships operated U.S. academic institutions, but will also include manned submersibles, special platforms, and aircraft in the study.

We intend to base this projection on the likely development of oceanography (in its broadest sense) and are therefore asking you to write a brief overview of the future of research in 1985-90 at your institution or within the research group you lead, based on consultations with your colleagues. We are asking about 50 other directors and leaders or organized research groups (some large, some small) to prepare similar overviews and we will then try to synthesize these views in a main section of our report which will be a public document. We will not identify specific organizations with any research concept nor present the sort of detail that might prejudice future proposals.

We are much more interested in realistic plans than in idealized cases. In addition to whatever other comments you can make, please specifically comment on the following five topics.

1) What plans does your research group have for future scientific staff appointments, especially those which will represent new areas of research for your institution? What projects, especially those using seagoing facilities, will change in size or level of activity during the mid-1980's?

2) What is the present level of usage by your research unit of federal vessels (Navy, NOAA, etc.) and/or vessels chartered from the private sector?

3) How do you and your colleagues believe unmanned devices (satellites, buoys, benthic stations, etc.) will actually change the needs for manned platforms in 1985-90, and, if so, how much change do you believe to be desirable?

4) Will your work call for new capabilities, or new kinds of facilities? If so, please describe them.

5) We wish to make two judgemental projections for the number and sizes of ships in the fleet. The first is based on firm plans at your institution which there is good reason to believe (say, better than 75%) will actually be carried out. The second projection is based on your judgement of reasonable, desirable vessel changes you would like to see at your institution (though firm plans may not yet exist) in order to undertake important future projects that otherwise would not be done. Specifically, please answer the following two questions:

a) Does your institution have firm plans (75% likely to be carried out) to acquire or to replace or retire a research vessel? Yes ___ No ___. If yes, please complete the following.

	Date of expected acquisition, replacement, or retirement	Vessel length	Vessel name	Notes
vessel acquisitions(s)	____________	______	________	__________
	____________	______	________	__________
vessel(s) to be replaced or retired	____________	______	________	__________
	____________	______	________	__________
	____________	______	________	__________

b) What highly desirable, reasonable vessel changes would you like to see at your institution in order to conduct important future research which otherwise will not be done? Indicate the changes which are in addition to those given in a).

	Date of desired acquisition, replacement or retirement	Vessel length	Project for which this change is required	Notes
vessel acquistions	________	____	________	____
	________	____	________	____
vessel(s) to be replaced or retired	________	____	________	____
	________	____	________	____
	________	____	________	____

I stress that we will appreciate your efforts to consult with your colleagues, and to synthesize their views; though opinions which are yours alone (and are identified as such) are welcome. Please indicate the extent of disciplinary and interdisciplinary research you have covered within your research group or more broadly within your institution. I may write or call you again to ask you to expand upon the comments you make.

To be useful your reply must reach me at the address below on or before February 6, 1981. Call me (714) 452-2711) if you have any questions or cannot meet our deadline. Thank you for taking the time to consider this important issue.

Sincerely yours,

Michael M. Mullin
Chairman, Academic Research Fleet
Study Steering Committee
Scripps Institute of Oceanography
La Jolla, California 92037

Attachment

List of Respondents

(Inclusion on this list does not imply that these respondents agree with the summary given in Chapter IV.D.1. Some additional addresses did not respond to the questionnaire)

Name	Institution
Anderson, G.C.	Dept. of Oceanography, Univ. of Washington
Alexander, V.	Inst. Marine Science, Univ. of Alaska
Barber, R.J.	Duke Univ. Marine Lab.
Beeton, A.M.	Great Lakes Research Division, Univ. of Michigan
Clayton, W.H.	Texas A&M Univ. at Galveston
Colwell, R.R.	Center for Environmental & Estuarine Studies, Univ. of Maryland
Davis, C.O.	Tiburon Center for Environmental Studies, San Francisco State Univ.
Davis, R.	Oceanic Research Division, Scrippps Inst. of Oceanography, Univ. of California San Diego
Dowling, J.J.	Univ. of Connecticut
Ellis, R.H.	New Jersey Marine Sciences Consortium
Flandorfer, M.	Mississippi-Alabama Sea Grant Consortium
Frankenberg, D.	Marine Sciences Program, Univ. of North Carolina
Gaither, W.S.	College of Marine Studies, Univ. of Delaware
Harrison, C.	Rosenstiel Sch. of Marine & Atmospheric Science, Univ. of Miami
Helfrich, P.	Hawaii Inst. Marine Biology, Univ. of Hawaii
Helsley, C.E.	Hawaii Inst. Geophysics, Univ. of Hawaii
Jones, R.S.	Harbor Branch Foundation
Keller, G.H.	School of Oceanography, Oregon State Univ.
Knauss, J.A.	School of Oceanography, Univ. of Rhode Island
Knox, R.A.	Inst. Geophysics & Planetary Physics, Univ. of California
Margolis, S.V	Dept. of Oceanography, Univ. of Hawaii
Martin, J.H.	Moss Landing Marine Lab.
Middleton, F.H.	Ocean Engineering Dept., Univ. of Rhode Island
Murphy, S.R.	Applied Physics Lab., Univ. of Washington
Offen, H.W.	Marine Science Inst., Univ. of California, Santa Barbara

Name	Institution
Opdyke, N.D.	Lamont-Doherty Geological Observatory, Columbia University
Rhoads, D.C.	Dept. of Geology & geophysics, Yale University
Riedel, W.	Geological Research Division, Scripps Inst. of Oceanography, Univ. of California, San Diego
Roberts, F.G.	Marine Sciences Research Center, State Univ. New York, Stony Brook
Robins, C.R.	Rosenstiel Sch. of Marine & Atmospheric Science, Univ. of Miami
Schott, F.	Rosenstiel Sch. of Marine & Atmospheric Science, Univ. of Miami
Shepard, R.A.	Marine Science Inst., Northeastern University
Shleser, R.A.	The Oceanic Institute
Spiess, F.N.	Inst. of Marine Resources, Univ. of California
Sterrer, W.E.	Bermuda Biological Station
Taft, W.H.	Mote Marine Laboratory
Thompson, D.M., Jr.	Shoals Marine Lab., Cornell University, Univ. of New Hampshire
Van Lopik, J.R.	Center for Wetlands Resources, Louisiana State University
Treadwell, T.K.	College of Geosciences, Texas A&M University
Vernberg, F.J.	Baruch Inst. for Marine Biology & Coastal Research, Univ. of South Carolina
Walsh, D.	Institute of Marine & Coastal Studies, Univ. of Southern California
Wisby, W.J.	Rosenstiel Sch. of Marine & Atmospheric Science, Univ. of Miami

APPENDIX IV: SHIPS AND SCIENCE IN THE EARLY 1970's - SOME CASE HISTORIES

A. Introduction

The following case histories illustrate various aspects of the relation between research ships and the scientific work done from them during the period 1962-1979. Some of the difficulties encountered by seagoing scientists are also noted. These cases were chosen to reflect research in several disciplines; to include both "big" and "little" research projects; and to have ended (or at least paused) sufficiently long ago that the scientific results are generally available. The cases are, it is important to stress, only illustrations of the many classes of investigations which depend directly on ships. The information on each project was provided by one or more principal investigators and by the funding agencies or home institutions.

B. Cold Core Rings in the North Atlantic

Though the textbook maps of oceanic currents typically show these as relatively straight and well-defined, oceanographers have long realized that the currents meander considerably around their average positions. These meanders can be so pronounced as to pinch off closed rings of current of a few hundred kilometers in diameter. The Gulf Stream off North America flows north and east between cold, relatively fresh water on the landward (continental slope) side, and the warmer, saltier Sargasso Sea on the seaward side. Rings shed to seaward drift through the Sargasso Sea and enclose columns of cold water from the continental slope in their cores. These can be detected and tracked for many months from satellites by this anomalously cold temperature.

To the physical oceanographer, these mesoscale features are important because they are the most energetic processes in redistributing heat, momentum, and potential energy in the ocean. To the biologist, these events are natural experiments in which an assemblage of organisms from one environment (the slope water) is placed in another environment (the Sargasso Sea) in a large enough inocula that the interactions between the organisms and the changing surroundings can be followed through time.

A series of cruises from the Woods Hole Oceanographic Institution on the R/Vs CHAIN, ATLANTIS II, and KNORR visited various rings from 1972 through 1975; most of these cruises had other primary or official scientific objectives. During the same period, the spatial distribution and physics of ring decay were studied through a series of cruises on the University of Rhode Island's R/V TRIDENT and ships of opportunity; some of the cruises were specifically funded for this purpose by ONR, and others were "bootlegged." This led to the planning of a series of cruises, whose express purpose was to study the rings, by a group of nine physical, biological, and chemical oceanographers from Woods Hole, Texas A&M University, and the University of Rhode Island. These cruises on the R/Vs KNORR and ENDEAVOR II in 1976-77 were funded by ONR and NSF, as the earlier cruises had been.

The investigators' intent was to study the evolution of a ring and its biota with four or five cruises spaced at three-month intervals, tracking the ring via satellite infrared images and satellite-tracked buoys between cruises. There were, in fact, four cruises, one of which was officially designated for another project and another of which was on a relatively small ship (for financial reasons) which was inadequate for deploying the large biological trawl around which the biological part of the sampling plan had been designed.

A total of approximately 290 ship-days was used by this project between 1971 and 1978; the current cost would be approximately $2.8 million. Building in part upon this work, many of the same investigators have begun a study of the warm core rings which are spun off on the landward side of the Gulf Stream.

Interruption of some of the biological sampling by financial pressure to use a smaller-than-desired ship has already been mentioned. Other frustrations reported by investigators include difficulties in assured long-term support and in lack of flexibility of scheduling ships to investigate the transient and unpredictable rings; time consumed in negotiations while the two funding agencies passed the proposal back and forth; lack of adequate funds for work on phytoplankton at a level comparable to that on zooplankton and fish; and paucity of pre-cruise support for testing of gear and post-cruise support for the tedious workup of biological collections. In general, however, the eventual scientific work was not greatly reduced from that envisioned by the investigators.

C. The North Pacific Central Gyre

This is an example of a program - that is, a planned series of cruises and associated laboratory work - which was never officially recognized as such, but nonetheless took place. All the principal investigators were from Scripps Institution of Oceanography, as were leaders of related physical and benthic studies which shared ship time and funding; these latter projects will not be discussed further.

The plankton program began in 1964-66 with two 30-day transects from Kodiak, Alaska, to Honolulu, Hawaii, in which biogeographic interests were dominant. These cruises were led by J.A. McGowan, and funded by the Marine Life Research Program (State of California) and ONR. NSF-funded cruises in 1968 and 1969 were used to establish the vertical and horizontal structure of the water column, nutrients, and plankton in the Central Gyre in summer and winter, and another pair of cruises was funded in 1970-71 to collect material for analysis of pollutants (though it is not clear that the analyses were ever done).

In 1971, a number of investigators submitted a large proposal to NSF to investigate community structure and dynamics on a seasonal basis at 28°N, 155°W, based on existing evidence of physical stability, faunal diversity and constancy, and a two-layered system of nutrient flux. Physical stability and faunal diversity are important because the assemblage of species should be constant and determined by biological processes such as competition and predation. Study of the assemblage was proposed to provide a test of ecological hypotheses derived primarily from studies of birds or of sessile organisms. The physical stability also indicates that the fluxes of nutrients must be primarily vertical and biologically mediated. Both these aspects are in sharp contrast to the much studied coastal currents, where horizontal and vertical advection of water also supplies nutrients and mixes together organisms such that their relative abundances may be both variable and not determined entirely by biological interactions between them. Of practical significance is the fact that such Central Gyre areas are likely candidates for generation of electrical power using the stratified temperature regime.

The ships and technical assistants were scheduled, but the proposal was declined for funding. Nonetheless, between November, 1971 and May, 1974, nine cruises involving 344 ship-days were completed, using financial support from NSF to individual projects of these same investigators and through the R/V ALPHA HELIX program, ONR, the Atomic Energy Commission, and the University of California.

In the ten years considered here (1964-1974), this study used (or shared with other projects) a total of 617 days on medium to large research vessels operated by Scripps Institution of Oceanography. At 1980 rates, this amount of ship-time would cost approximately $3.5 million. As might be expected, the participants differ on the degree to which the "bootleg" nature of the program affected the quality of the research. One investigator has pointed out that although some coherent concepts have been formulated, seasonal coverage within any one year was poor; individual studies which should have supported each other had to be done on different cruises, and often in different years. This investigator states, "The mushiness of this extensive data set is in large part due to the fact that we were forced to scheme, beg, borrow, steal, and piggyback ship-time in order to accomplish our objectives."

Other investigators noted deficiencies such as insufficient winter coverage, limited large-scale spatial survey, and inadequate comparison with the South Pacific, plus lack of high-quality data on penetration of light. Several report, however, that lack of sufficient sensitivity of analytical methods or the time required for microscopic examination of the diverse flora were more serious handicaps than was lack of ship-time.

Work in the Central North Pacific is continuing under ONR sponsorship, and the results of the program continue to generate research ideas and financial support.

D. Studies of Sedimentation of Hydrocarbons and ^{210}Pb in Puget Sound and the Washington Coast

Though research projects involving many investigators at several institutions became increasingly important (and publicly visible) in the 1970's, in part because of the International Decade of Ocean Exploration, most academic marine scientists continue to work primarily in small groups--one or two principal investigators assisted by three to ten students, postdoctoral scientists, graduate students, and technicians. A case in point is the investigation of sedimentation rates in coastal and inland waters of Washington State by R. Carpenter of the University of Washington, from 1975 through 1979.

The work, funded by the U.S. Department of Energy and its predecessors, was directed primarily at determining the rate of accumulation of hydrocarbons and other materials. The radioisotope, lead-210, was used to determine the rates of sedimentation from the water column onto the bottom, and from this the measured concentrations of hydrocarbons in the sediments could be converted into the rates at which they accumulated over time.

Dr. Carpenter received the amount of ship-time he had requested. The primary constraint imposed by ships was their size and configuration. The larger and more expensive vessel (the R/V T.G. THOMPSON) had ample bunk space and was safe to use on the open coast, but the fact that the work deck was aft of smokestack, galley, and bilges created a potential for contamination of samples when the ship held station The smaller R/V ONAR had working space on a forward deck, but lacked sufficient accommodations and was hazardous to use outside of Puget Sound.

A total of 51 days at sea was spent on the 2 ships; at 1980 rates, the same ship-time would cost approximately $160,000.

E. Ecology of Dinoflagellates in Chesapeake Bay

As in any field of scholarship, graduate students in oceanography pass through an apprenticeship during which they contribute to scientific knowledge in the process of becoming fully professional colleagues. Ships are needed for training purposes - that is, simply to teach students, both undergraduate and graduate, the tools of the trade. However, this case history illustrates the contribution of research ships to an original Ph.D. thesis.

M. Tyler, advised by H. Seliger at The Johns Hopkins University, investigated the ecology of dinoflagellates (a group of planktonic, single-celled plants, some members of which contribute to toxic "red tides") in a large estuary, the Chesapeake Bay. Though dinoflagellates can swim weakly, they move primarily with the water which surrounds them. This project was designed to determine how populations maintained themselves in the estuary without being swept out to sea.

A detailed study of water movement at various locations, depths, and seasons, and of the growth and behavior of the dinoflagellates, revealed a pattern which allowed the plants to be periodically repopulated at the head of the estuary where they could then grow to form dense blooms.

The research was funded by the U.S. Department of Energy and the NSF. The investigators received the amount of ship-time they requested: 180 days distributed over two years and over 40 cruises. The primary research vessel as the R/V RIDGLEY WARFIELD, a 110 ft. catamaran operated by Johns Hopkins. In 1981, this amount of ship-time would cost approximately $500,000.

F. The Circum-Antarctic Survey

The primary objective of the Circum-Antarctic Survey program since its inception in the late 1950's was a thorough, systematic survey of the geology, geophysics, physical oceanography, meteorology, and biology of the Southern Ocean. The funding for the program came primarily from the Division of Polar Programs (DPP) of the NSF.

The Circum-Antarctic Survey program depended upon the special features of the USNS ELTANIN. This was the only ship available on a regular basis to the academic community from which significant station work could be carried out on cruises of very long duration; much of the Southern Ocean (mainly South Pacific, southern South Indian and Weddell regions) could not be studied without this capability. Its special characteristics included; 60-90 day duration between ports (the limiting factor tended to be the people on board, as ELTANIN was fully capable of making 90-day cruises); stability at sea, even in rough weather; ability to carry a scientific party of up to 30 people (necessary because of the interdisciplinary nature of most of the cruises); and an ice-strengthened hull. Therefore, the Circum-Antarctic Survey was essentially a facilities-limited program which depended upon the availability of the ELTANIN.

The scientific program was divided into two phases. From 1962-1972, NSF/DPP sponsored a total of 55 cruises aboard ELTANIN in the Southern Ocean totaling 410,000 nautical miles and 3,014 days at sea. In 1972, because of financial considerations, NSF was obliged to stop operating ELTANIN, thus placing completion of the Circum-Antarctic Survey program in jeopardy. Beginning in 1975, a five-year agreement of cooperation between the Argentine navy and NSF, resulting in the leasing of ELTANIN (renamed ISLAS ORCADAS) to the Argentine government, allowed 14 more cruises to be made. Eight of these cruises (totaling 420 days) were for U.S. scientific programs, and six (totaling 288 days) were for Argentine science. During this period an additional 111,000 nautical miles were surveyed. The four ELTANIN/ISLAS ORCADAS cruises in the South Atlantic Ocean were supplemented by a survey cruise in the southeast Indian Ocean during January-April 1974 using R/V CONRAD. This work was supported by the Division of Ocean Sciences of NSF (not specifically as part of the DPP-funded Circum-Antarctic Survey), and included marine geophysics and physical oceanography (A. Gordon, personal communication).

In addition to the work summarized above, there have been many cruises aboard U.S. icebreakers and various foreign vessels which were directly related to the circumpolar survey.

With the end of the U.S./Argentine agreement on the ISLAS ORCADAS in 1979, the first two phases of the circumpolar survey have ended and the vessel has been returned to the U.S. The ELTANIN is a special-purpose vessel which has seen much service and would require extensive refitting for further use. Many scientists hope that the U.S. will be able to replace this vessel with a suitable polar research vessel which can venture into the pack-ice regions (see Chapter III.D.2.d).

G. The Middle America Trench Study

As the Circum-Antarctic Survey was dependent upon a particular ship with the necessary cruising range and ice-strengthening, the Middle America Trench Study was dependent upon the R/V IDA Green of the University of Texas because of the multichannel seismic reflection equipment available only on this ship (see also Chapter III.D.2.b.).

The purpose of the work, which involved investigators from the University of Texas, the University of California, Santa Cruz, and the U.S. Geological Survey, was to conduct seismic and coring/dredging studies of a subduction zone - a trench where one crustal plate is overriding another - with the expectation that the Deep Sea Drilling Program would later drill in the area.

The cost of operating the ship was borne primarily by the University of Texas, with additional funding from NSF and the International Program of Ocean Drilling. The sea time in 1977-78 was 188 days, which would currently cost approximately $602,000. This ship-time was about 75 percent of that originally planned by the investigators.

The major results of the study included calculation of a reasonably satisfactory budget of sediment for the subduction zone; delineation of areas of accretion and subduction, and the possible controlling processes; confirmation of the existence of gas hydrates in the continental slopes; reconstruction of the geological history of a portion of the Trench; and acquisition of extensive data on geological structures in the area.

H. Mid-Ocean Dynamics Experiment

The Mid-Ocean Dynamics Experiment (MODE-I) was one of the first large-scale oceanography studies which absorbed the energies and talents of a large number of physical oceanographers, as well as a significant fraction of the equipment resources and ship-time of the United States and United Kingdom for a considerable period.

Recognition of the importance of low frequency (weeks to months) intermediate scale (hundreds of kilometers) motions for the dynamics of the open ocean was the driving force behind MODE-I. The overall objective of MODE was to develop a model of the open ocean which correctly portrayed dynamic processes. MODE-I contributed the preliminary steps toward such a model. It was designed to permit description of the kinematic processes of local eddy fields, to examine the local dynamics of eddies, and to begin to gather data on the statistical properties of eddy fields.

MODE-I was primarily a physical oceanographic program conducted in the North Atlantic in mid-1973. When the experiment went to sea in March 1973, its final complement involved an international group of more than 50 oceanographers, representing 15 institutions, several hundred support personnel, 6 major research vessels, and 2 aircraft. In all, the level of U.S. funding for MODE-I was approximately $8 million, divided between the NSF, ONR, and NOAA. A total of almost 500-ship days was used in this experiment; the current cost would be approximately $4.5 million dollars. This included, in addition to the U.S. academic vessels CHAIN, TRIDENT, and EASTWARD, approximately 140 days aboard TRACOR Marine's R/V HUNT which was chartered because of lack of available ship-time in the academic fleet (ample funds were available); work on NOAA's RESEARCHER; and participation of the RRS DISCOVERY from the National Institute of Oceanography, England.

The overall scientific program did not suffer from the lack of ship or other scientific resources because a rigorous and dedicated program office and executive committee worked hard to make sure that requirements were met (A.R. Robinson, personal communication). This included chartering and outfitting the R/V HUNT and solving frequent logistic problems. A special aspect of the MODE-I program was an overt attempt to exploit novel instrumentation and technology to investigate phenomena which initially were rather poorly defined (A.R. Robinson, personal communication). This resulted in measurements of the same property by a variety of methods, and was possible because of a particularly strong concern for the match of science and resources on the part of the participants.

The importance of MODE was to demonstrate clearly that eddies of a few hundred kilometers in size transport much of the energy in the ocean. This realization has led to increased interest in remote sensing, since the eddies often have surface manifestations detectable from satellites (as temperature or sea surface level anomalies) and to the development of new techniques, e.g., acoustic tomography, for detection of deeper manifestations.

I. GEOSECS

The Geochemical Ocean Sections Study (GEOSECS) was part of the International Decade of Ocean Exploration of the 1970s. Its objective was to perform long, north-south sections through the Atlantic, Pacific, and Indian Oceans in which a large number of chemical elements, compounds, and isotopes would be measured from the surface to the bottom with a high degree of precision. From these sections, maps could be constructed of the deep circulation of the world ocean, using those chemical species which had known sources as tracers, and conclusions could be drawn as to the processes and rates controlling the distributions of compounds in the water column.

Both sampling and analytical techniques had to be improved or developed to attain the necessary precision. This was accomplished in part by a series of relatively short cruises, starting in 1969, on WASHINGTON, KNORR, and MELVILLE. The three "main events" - the long sections - were conducted in 1972-73, 73-74, and 77-78 on KNORR and MELVILLE. The total time at sea (or at least away from home port) in the ten years of field studies was 783 ship-days; the current cost on the same ships would be about $7.5 million.

The sections did indeed provide detailed chemical data which will be the standard measurements for years to come. Much of the power of the results came from the corroboration of patterns from several different species. The turnover time of the Atlantic Ocean, which had been estimated from carbon-14, was made more credible by the data on barium and radium. Tritium, which is produced by cosmic ray reactions and by nuclear weapons, enters the ocean at the surface, and its distribution in the western Atlantic shows clearly the sinking of water at high northern latitudes. In the mid-North Pacific, tritium is essentially restricted to the upper 500 m. These data, together with the distributions of carbon-14, carbon dioxide, and radon have permitted an approximate calculation of the rate at which carbon dioxide enters the ocean from the atmosphere. Silicate proved to be a very useful tracer for the northward flow of deep water from the Antarctic into the Pacific and Indian Oceans, and of its mixing with the resident water.

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Massachusetts 02543.

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