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Polar Research Board

Committee to Review the Gulf of Alaska Ecosystem Monitoring Program

Second Meeting

October 5-7, 2000

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POLAR RESEARCH BOARD
COMMITTEE TO REVIEW THE GULF OF ALASKA ECOSYSTEM MONITORING PROGRAM
OCTOBER 5-7, ANCHORAGE, ALASKA

MEETING BOOK CONTENTS

Ocean Drilling Research An Arctic Perspective

Polar Research Board

Commission on Geosciences, Environment, and Resources

National Research Council

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OCEAN DRILLING RESEARCH   AN ARCTIC PERSPECTIVE

The Polar Research Board, a unit of the National Research Council charged to promote excellence in polar science and enhance understanding of polar regions, is aware that cooperative international scientific efforts for deep-earth sampling in the marine environment conducted under the auspices of the Ocean Drilling Program (ODP) are scheduled to end in October 2003 In spring 1999, there will be a major international conference (Conference on the Scientific Objectives of Ocean Drilling in the 21st Century, to be held in Vancouver, Canada) to examine whether ocean drilling should be continued and, if so, define the scientific objectives that might be accomplished should the program be extended or another program begun   The conference will target the scientific goals for non-riser drilling and will complement a recent conference focused on ocean riser drilling, which defined the scientific initiatives for use of a riser-equipped drilling vessel

Conference organizers have requested input from the scientific community about the possible objectives, importance, and necessity of a continued drilling program   This report contains comments from the Polar Research Board to provide conference organizers and participants with an arctic perspective   Like the planned conference itself, we address the possible scientific goals of a continued drilling program, we do not address funding or priority-setting, issues that are beyond the scope of this short report   We do recognize that the cost implications of factors such as high operating costs and technology development needs would have to be considered in making a decision to include arctic ocean drilling in any future program

CONTEXT [1]

The Ocean Drilling Program is the direct successor to the Deep Sea Drilling Project (DSDP), which ran from 1968 to 1983   DSDP was the first broad scientific effort to sample the seafloor around the globe by coring and downhole logging, and the research was critical in supporting the then-new hypotheses of seafloor spreading and plate tectonics   Although DSDP began as a U S effort, it evolved into an international activity with five partners [2] By 1981, when the

[1] All National Research Council reports are intended as self-standing documents, so this report contains some background information to inform general readers of its context

[2] France West Germany, Japan, the United Kingdon, and the USSR

DSDP drillship GLOMAR *Challenger* was reaching the end of its useful life, many of the world's leading earth scientists met to plan the future of ocean drilling and recommended that a new program be formed—the Ocean Drilling Program (ODP) The ODP began in 1985 when the larger and more capable ship JOIDES *Resolution* was modified to meet the special requirements of scientific ocean drilling With this capacity, scientists could then drill deeper and into more difficult rock formations and use more sophisticated measuring tools

Since 1985, the Ocean Drilling Program (ODP) has continued as an international partnership of scientists and research institutions organized to explore the evolution and structure of Earth Funding for the program is provided by eight international partners representing 21 countries [3] ODP provides researchers around the world access to a vast repository of geological and environmental information recorded far below the ocean surface in seafloor sediments and rocks This information yields insights that improve our understanding of Earth's past, present, and future (NRC, 1998) As a result of DSDP and ODP activities, thousands of seafloor sites have been occupied and drilled and thousands of kilometers of ocean sediment and crustal samples have been obtained from every major ocean basin except the Arctic Ocean Interpretation of these samples has provided a record of ocean crustal spreading as well as insights into the origin and history of different ocean basins In addition, our knowledge of seawater chemistry, marine biology, marine geology, and the origin of submarine structures grew dramatically because of Ocean Drilling Program activities, making this one of the most important oceanographic research projects of the 20th century

Although it has long been recognized as potentially valuable[4], technical and logistical difficulties associated with drilling in an ice covered ocean forced the ODP, and the DSDP before it, to exclude the Arctic Ocean In addition, lack of sound geophysical surveys, crustal maps, and seismic understanding of the Arctic Ocean have made it difficult to select sites for drilling in the north This exclusion has left a significant gap in our understanding of the world's seafloors and leaves an important reservoir of information about global change untapped If we wish to understand the character and evolution of the Arctic Ocean[5], it is

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[3] Partners include the Australia/Canada/Korea/Chinese Taipei Consortium for Ocean Drilling, the European Science Foundation Consortium for Ocean Drilling (which includes Belgium, Denmark, Finland, Iceland, Italy, Norway, Portugal, Spain, Sweden, Switzerland, the Netherlands, and Turkey), France, Germany, Japan, the People's Republic of China, the United Kingdom, and the United States of America

[4] In 1987, the Second Conference on Scientific Ocean Drilling (COSOD II) was held to set goals that were then incorporated into the program's long-range plan At that time, sampling of the Arctic Ocean Basin was identified as a major objective of future exploratory drilling (NRC, 1992)

[5] This brief report, by necessity, addresses ocean drilling only in the Arctic and does not address similar questions in the Antarctic The limitations of the ships GLOMAR *Challenger* and GLOMAR *Resolution* for drilling in ice-covered seas also have limited drilling efforts in the Antarctic region Although several legs have drilled the deep sea floor around Antarctica, only two have successfully sampled the Antarctic continental shelf where a direct stratigraphic record of glaciation on the continent exists The results of these two legs have significantly altered our

essential to recover a complete sedimentary sequence As discussed in the next section, drilling in the Arctic could contribute to geophysics, structural geology, and our understanding of plate tectonics, including spreading rates and the onset of spreading at various locations In addition, biogeochemical based studies of organisms and their products preserved in the sediment can provide proxies for past climate change Understanding current ecosystem processes influencing the state of biological and biogeochemical proxies in the sediment coincident with analyses of sediment from deep cores from the Arctic Ocean will enable interpretation of past climatic systems that have influenced down core sediment records

THE IMPORTANCE OF DRILLING IN THE ARCTIC

Any justification for the perpetuation of scientific ocean drilling in general should be based at least in part on the need for drilling in the Arctic Ocean The Arctic Ocean is the last frontier for scientific ocean drilling It alone of Earth's oceans has never been drilled, and as a consequence has a largely unknown climatologic and geologic history or record In addition, it contains the largest essentially unexplored geologic feature on Earth, the Alpha-Mendeleyev Ridge system (Weber and Sweeney, 1990) Because of these factors, the relationship of the Arctic Ocean to other Earth structures has never been more than partially understood, and the Arctic Ocean's precise role in Earth's climate and geologic development remains enigmatic

What we do know about Earth's crust and paleoclimate in the Arctic is limited Short sediment cores taken from floating ice-islands and, more recently, multi-national ice-breakers, have provided a partial view of Arctic Ocean history (Clark et al , 1980, Jackson et al , 1985, Poore et al , 1994, Phillips and Grantz, 1997, Bischof and Darby, 1997) The only information on the older Arctic Ocean is based on four piston cores taken from ice-islands over the Alpha Ridge Three of these cores recovered Late Cretaceous (Maastrichtian) sediment, while the fourth is Early Cenozoic (middle Eocene) The Cretaceous cores are the oldest indigenous deep Arctic Ocean sediment known and in the absence of any other data, alone define the minimum age of the ocean These Cretaceous cores consist of biosiliceous as well as organic rich palynomorph-bearing sediment, indicating that the Arctic Ocean of approximately 70 million years ago had no ice-cover and thus was relatively warmer than today (Dell'Agnese and Clark, 1994, Firth and Clark, 1998) In addition, the fossils of these cores indicate that vigorous upwelling conditions existed in at least one part of the Arctic Ocean during the Late Cretaceous (Kitchell and Clark, 1982) The Early Cenozoic core contains a rich biosiliceous sediment and this suggests that the same climate

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knowledge of Antarctica's glacial history by extending the initiation of ice sheet evolution back many millions of years (Abru and Anderson, 1998) Many scientists believe there is still a great need for additional drilling on the Antarctic continental shelf using ice-strengthened platforms and upwelling conditions as that of the Late Cretaceous existed during the middle Eocene. From these four cores we can conclude that from at least 73 million years ago to approximately 45 million years ago, the Arctic Ocean was ice-free with high production of algae and other protists nurtured by upwelling, and must have been a major factor in Earth climate.

But how did this "warm" Arctic Ocean form? Was it ice-free throughout the Mesozoic? How was its origin related to that of the modern Pacific and Atlantic oceans? How did the temperature of the Arctic Ocean influence Earth climate during this warm geologic interval? And what were the climatic and oceanographic conditions that have resulted in the present permanent ice-cover? No deep Arctic Ocean sediment older than the Maastrichtian or for the interval of approximately 45 million years to 5 million years has been recovered. From the sedimentary record, we only know that the Arctic Ocean must have formed sometime prior to the Maastrichtian. Geophysical evidence suggests an earlier, perhaps Jurassic age for the Arctic Ocean origin (see geophysical reviews by Grantz et al., 1990, and Lawver and Scotese, 1990). In addition, it was during the Eocene that Earth's warm climate began a dramatic change that has led to the modern climate. What was the Arctic Ocean's role in this important transition? Was the Arctic Ocean involved in the development of Earth's present climate or did it only respond to the change (Alley, 1997)? A sedimentary record of relationship of Earth's climatic and oceanographic history in the Arctic would be invaluable for comparisons and understanding of similar research in the North Atlantic and elsewhere.

Regardless of past interactions between the Arctic Ocean and the World Ocean, modern thermohaline circulation in the North Atlantic is directly affected by Arctic Ocean water and its circulation, and may be the immediate control for major shifts in Earth's modern climate (Broecker and Peng, 1982, Broecker, 1998). Arctic drilling should provide important new insights into the origin and development of modern arctic circulation with its major variations in fresh versus saline-rich water discharge, and the control it has exerted on the "conveyor belt" thermohaline circulation of the World Ocean. Recent studies that indicate dramatic changes in the Arctic's salinity and ice-content (Levi, 1998) can best be understood in the context of the developmental history of the present condition, and this information is available only in the Arctic Ocean sediments.

The origin and evolution of the Arctic Ocean and its contribution to, or control of, Earth's modern climate can be interpreted from the results of Arctic Ocean drilling. For example:

- Knowledge of how and when the Arctic Ocean formed may be determined from a study of systems such as the Alpha-Mendeleyev Ridge system.
- Knowledge of Arctic Ocean circulation, venting, and other oceanographic factors may be gained from study of the Lomonosov Ridge, a high standing barrier to oceanic circulation in the Arctic.

Drilling of broad arctic ridges at moderate depth should provide very high-resolution stratigraphic records of arctic oceanographic and climatic history that will address the most fundamental issues of paleoceanographic development of the Arctic Ocean and Earth climate. Such sites would be isolated from the strong turbidite deposition found in all basinal areas in the Arctic, and would be isolated from strong currents that truncate the stratigraphic record on shallower ridge crests, and above the CCD. It is clear that the Arctic, the least studied of Earth's oceans, is key to understanding fundamental aspects of the geologic, oceanographic, and climatic conditions of the modern Earth. Without scientific drilling, an enormous gap in our knowledge of Earth will remain unfilled.

Additional objectives of Arctic Ocean drilling are discussed in *the Nansen Arctic Drilling Implementation Plan* (1997) and the NSF strategy document, *Marine Science in the Arctic* (Aagaard, 1999). Any inclusion of Arctic Ocean drilling as part of future scientific ocean drilling should be coordinated with the plans of these projects.

TECHNICAL CHALLENGES

The main obstacles preventing deep ocean drilling at sites in the Arctic have been technical. As noted in a 1991 PRB report (NRC, 1991), even with ice-breaker support, existing drill ships (including the ODP's JOIDES *Resolution*) are not sufficiently ice strengthened to maneuver safely within the main polar ice pack. In addition, many potentially important arctic drilling sites are in water greater than 4 km deep. In addition to expense, the semi-continuous movement of the mainly wind-driven ice pack limits drilling in deep water, because it requires continuous coring and with that the necessity of holding position against the drift of the ice pack for significant periods of time. Such methods have been developed for shallow areas of arctic shelves, but are lacking for the deep-water areas of the basin (NRC, 1991).

Now, however, arctic experience suggests that an ice-strengthened ship with a dynamic positioning system to maximize drilling time, in the company of an icebreaker, probably could maintain position in 2-3 m ice for drilling operations, at least in shallower depths. The sites of the oldest known Arctic Ocean sediment on the Alpha Ridge include some in water of less than 1500m. In addition, submersible drilling rigs similar to the Russian GNPP *Sevmorgeo* might be usable in the Arctic Ocean (Nansen Arctic Drilling Implementation Plan, 1997). Also, new technology is being developed by some of our Scandinavian colleagues which could be available sometime early in the 21st Century, in time for a new scientific ocean drilling program. This includes drilling in maximum water depth with anticipated sub-bottom penetration. If there is a commitment to Arctic Ocean drilling as part of any new scientific ocean drilling program, the technology should be available to accomplish many important objectives. For example, the new USCGC *Healy* will be available for support of deep Arctic Ocean drilling after 2001. Also, it has an announced potential to recover 30m pıston cores, whıch, ıf true, ıs a good example of developıng technology that wıll benefit deep Arctıc Ocean drıllıng

Another problem ıs related to the fact that deep ocean drıllıng commonly ıs preceded by sıte surveys that ıdentıfy the optımum locatıons for meetıng the drıllıng objectıves Such surveys stıll are lackıng ın the Arctıc Ocean basın, although some recent bathymetrıc data may be avaılable from the Navy Whıle tradıtıonal methods of sıte surveys would be dıfficult ın an ıce-covered ocean, alternatıves are now avaılable For example, the geophysıcal capabılıtıes of the Submarıne Ice Experıment (SCICEX) provıde a novel but effectıve means of survey, ıf the program ıs contınued More ımportant, seabed corıng performed durıng the past 20 years from the varıous ıce-platforms (T-3, CESAR, LOREX ıcebreakers) has recovered sedıment cores that can provıde much of the ınformatıon necessary for sıte selectıon From the prevıous pıston corıng, we know four sıtes where there ıs lıttle Cenozoıc sedıment cover and would be ıdeal for corıng Cretaceous and older sedıment to the crust From the short 3-4 m sedıment cores (more than 500 of whıch are avaılable from the T-3 project alone and at least 150 more from U S ıcebreakers), we also have learned the general sedımentary facıes that wıll be encountered ın Arctıc Ocean drıllıng These ınclude the basınal turbıdıte facıes, generally at depths ın excess of 3000m, the Cenozoıc glacıal-marıne sedıment facıes, common at depths of 1000 to 3000 m on most of the Arctıc Ocean rıdges, and the mıxed facıes, common ın the Eurasıan Basın but also ıncludıng some of the Chukchı Cap sedıment Thıs ınformatıon could be consıdered as prelımınary sıte surveys The scıentıfic case for Arctıc Ocean drıllıng ıs so compellıng that ıt should proceed ın spıte of less than perfect sıte survey ınformatıon

CONCLUSION

The Polar Research Board belıeves that the contınuatıon of an organızed ınternatıonal program of scıentıfic drıllıng ıs valuable because ıt wıll contınue to provıde ımportant ınsıghts about Earth's past, present, and future If such a program ıs contınued, we recommend that ıt ınclude drıll sıtes ın the Arctıc Ocean These would help us understand the orıgın, age, and hıstory of the only ocean not ıncluded ın prevıous drıllıng programs and fill sıgnıficant gaps ın our knowledge of Earth's ocean basıns Thıs knowledge ıs crıtıcal to understandıng the role of the Arctıc Ocean ın Earth's tectonıc evolutıon, especıally ıts ınvolvement ın the structural evolutıon of the North Atlantıc and North Pacıfic Oceans In addıtıon, the role of the Arctıc Ocean ın the evolutıon of Earth's clımate needs better definıtıon ın relatıonshıp to both thermohalıne cırculatıon ın the North Atlantıc-Arctıc Ocean transıtıon area and the clımatıc ımpact of an alternately ıce-free and ıce-covered Arctıc Ocean

Researchers drıllıng at Arctıc Ocean sıtes wıll face challengıng condıtıons, but recent technologıcal developments, the consıderable experıence gaıned ın shallow corıng ın the Arctıc, and advances that are lıkely ın the next few years can provide solutions to many of these problems if there is an international commitment to the task Much has changed in the past few decades since the GLOMAR *Challenger*, with icebreaker support, ventured into the high southern latitudes to drill on Antarctica's continental shelf There is more knowledge of the pack ice because of satellite photography, new technologies and drilling platforms, and even evidence of thinning of the pack ice The geopolitical and national security climate has changed as well, with great relevance to the Arctic This combination of factors strengthens the case for incorporating some Arctic Ocean drilling into any new program that might evolve

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Executive Summary

REVIEW OF THE GLEN CANYON ENVIRONMENTAL STUDIES

Since the turn of the century, water issues in the Southwest have centered on the use of irrigation to reclaim land for agriculture and, more recently, the generation of hydroelectric power The Bureau of Reclamation has a major responsibility for federal government involvement in water resource development and, by most measures of progress, their activities have been successful.

In recent years, however, water quality issues have assumed greater attention As the limits of the quantity of water are reached and as the population of the Southwest grows and changes, water users other than agriculture and power generation (e g , recreation and urban water supply) have gained more legal and political standing As a result, the laws are changing and the Bureau of Reclamation is adjusting to major changes in responsibility, i e , from irrigation development and power generation to operations planning and environmental management.

The Bureau of Reclamation's performance of the Glen Canyon Environmental Studies (GCES), in the period from 1982 to 1987, is one manifestation of the change The GCES were initiated in 1982 as a response to some of these new pressures, but now (1987) the Department of Interior would like to use the GCES results to help make decisions about (1) long-term operational criteria for the dam, (2) opportunities for managing the Colorado River, and, finally, (3) legal requirements for environmental protection

In 1986, the Department of Interior requested the Water Science and Technology Board (WSTB) of the National Research Council to review the Glen Canyon Environmental Studies (GCES) for the Bureau of Reclamation The WSTB agreed to provide advice to the bureau as it sought to evaluate the effects of the operation of Glen Canyon Dam on downstream resources

This review of the GCES is focused on the July 1987 Glen Canyon Environmental Studies Draft Report prepared by Bureau of Reclamation scientists and the planning and work leading to it The NRC's committee was involved with the GCES scientists throughout the period when the July GCES Draft Report was being prepared The committee had the opportunity to discuss various issues with them and to review the individual research reports that underpin their integrated draft (see Appendix D) **Although the committee does not believe that the Bureau of Reclamation can make long term decisions concerning the management of Glen Canyon Dam based on the GCES, the studies have yielded some excellent information in the areas of geomorphology, aquatic and terrestrial biology, and recreation**

Many of the individual studies in the GCES resulted in publishable scientific products useful to the bureau The shortfalls of the GCES program can be placed in four general categories

- **Insufficient attention to early planning and careful articulation of objectives This lack of planning has led to an appearance that the bureau is not fully open to changes that might be suggested as a result of the research done by the GCES investigations, or, that by limiting the scope, unwanted options would not be examined**
- **Inadequate consideration of management options For example, questions to consider include what are the costs of operational changes in terms of lost power revenues and what are the gains from meeting management goals in regard to downstream resources?**
- **Uncertain conversion of the research results into management options**
- **Failure to identify the rationale for assigning values to downstream resources so management goals could be set Thus, the GCES researchers have not reached (could not reach) firm conclusions about the operation of the dam**

Although the final draft GCES report recommends several options, this committee believes that, only those calling for additional work are justified Therefore, the GCES effort was a mix of success and failure The committee believes that, despite the obvious inadequacies of the GCES, useful new

knowledge has been gained which can serve as the basis for future work by the Department of the Interior The committee believes that management of resources is feasible but it demands ecological understanding Such understanding in this case will require sustained research because (1) management of the Colorado River will make use of the control afforded by the dam, (2) the river ecosystem is in disequilibrium because of the dam construction itself, and thus (3) operational decisions will require continuous checking to confirm that the desired effects are being achieved

To achieve this level of understanding, managers must make new commitments to involve scientists in the development of management strategies Scientists have been willing to be involved, but unfortunately are often seen by managers as "gadflies " The margin for error is shrinking as management goals become more complex and the effects of mistakes extend further and last longer Management, approached as if the plans were merely reform actions to solve specific problems, with no subsequent interest in whether management goals were achieved, is unacceptable Careful planning that incorporates ecosystem principles accompanied by follow up monitoring effort is essential

If the Bureau of Reclamation seeks to alter its mission from development to resource management, a major revision in perspective and skill will be required A possible approach might include establishing, among Department of Interior agencies and leading scientists, an oversight group with the necessary breadth of perspective to meld science with natural resource management

FINDINGS AND RECOMMENDATIONS

The committee's findings and recommendations provide advice to the Department of the Interior not only on the specific components of the GCES but also for the design and conduct of future environmental studies of a similar nature These brief abstracts of the major findings are followed by recommendations in bold print

Valuable New Information

The results of the GCES represent a substantial increase in knowledge of the Colorado River ecosystem as it exists in the Glen Canyon and the Grand Canyon Unfortunately, few data were available to describe the character of the river system prior to the closure of Glen Canyon Dam This will remain a major impediment to our full understanding of the changes that have occurred as a result of the construction of the dam, although studying reaches of the Colorado not affected by impoundment may give important clues Thus, the uncertainty about how the river continues to change and how it might be managed will be higher than if pre-dam information had been available Nevertheless, the GCES provides the beginning of useful documentation at a time when the Bureau of Reclamation is considering improved management of the Colorado River as part of its responsibility

Although the committee does not believe that the Bureau of Reclamation can make any long-term decisions concerning the management of Glen Canyon Dam based on the GCES, the studies have yielded some excellent information GCES scientists should be encouraged to submit their work for publication Clearly, not all reports will yield publishable manuscripts In some cases the production of unpublishable results is testimony to the inadequacy of the work and of the planning that led to it Many results, however, represent new knowledge and will contribute to the information base about the Colorado River

Future work by the Department of the Interior should seek to

- **encourage publication of study results to gain credibility in the scientific community and to assure accessibility of information**
- **establish a data management, storage, and retrieval system to provide easy access and quality assurance**
- **consider investigations of southwestern rivers in other places where impoundment has not altered system interaction**

Aquatic Resources

The studies of aquatic resources have good breadth and touch on most of the subjects that could have been considered of potential significance when the studies began Program components that were particularly outstanding include extensive documentation of the abundance and distribution of fishes, documentation of physical habitat characteristics, growth and condition factors in fishes, and determination of fish feeding habits The interpretation of these data provides numerous useful insights concerning the mechanisms that regulate the fish resources of the Colorado River

The new information improves our understanding of the physical limitations on individual fish species in the Colorado River However, the data base and data analysis need to be expanded to support predictive modeling of critical habitat space for fish species in both adult and larval stages This requires integration of research efforts with studies focused on sediment deposition, particle size distribution, and invertebrate and algal productivity in the river downstream from Glen Canyon

The Department of the Interior should

- **support a monitoring program to evaluate future operations in the context of a Colorado River ecosystem model with priority on sediments and aquatic biota components**
- **evaluate the quality of the water that is released or could be released at different levels from Lake Powell, e g , temperature, nutrients, particulate organic materials, and zooplankton**
- **include algal and invertebrate productivity in future aquatic study**
- **perform focused studies on sediment movement and deposition in reaches between the dam and Lake Mead**
- **develop predictive, process oriented models to understand sediments, water temperature, nutrient concentrations, and economics of power production**

Terrestrial Biology

The terrestrial researchers were faced with the difficult task of collecting enough data in a short period of time, and under conditions for which they had not planned, to be able to offer suggestions for river management This component of the GCES report suffers from a failure to link riverine phenomena (e g , sediment erosion and deposition) to terrestrial phenomena (e g , food of terrestrial vertebrates from the river) and from a confusing mixture of science and value judgment Although it is often useful to remove references and lengthy explanations from the body of the report, in this instance the text became more confusing because assumptions, values, and facts were not documented, differentiated, and/or explained Even so, the recommendation made by the researchers to continue the monitoring is significant Willingness to adjust the flow pattern in response to resource changes is the key to managing the system

The majority of the individual GCES terrestrial biology research projects were carefully executed The results contribute valuable information Analysis, however, was limited because some data were missing, numbers were few, and replication was minimal Many of these problems resulted from unexpected flood conditions during the study period

Future work by the Department of the Interior should seek to

- **establish links to river productivity in future terrestrial studies**
- **plan for heterogeneity and match methods to the temporal and spatial scales of the phenomena**
- **prepare for the unexpected in schedule and budget preparation, think probabilistically**
- **document the process by which resource values are judged**

Sediments and Hydrology

The sediment and hydrology research effort has produced some excellent new understanding of certain critical components of the complex system of water and sediment movement through the Grand Canyon The information about mechanisms of sand erosion and deposition in recirculation zones, observations of changes in sediment storage in the river channel, observation of the deposition resulting from debris flows, and the physical analysis of flow dynamics in rapids are examples of this good work. Integrating these elements into a fuller understanding of sedimentary phenomena was hindered, however, because the modeling study of the sediment and water flow was conducted separately Also, insufficient attention was paid to sediment source, sinks, and sediment movement to beaches and riparian zones These elements are now realized to be of central importance because they were the focus of other portions of GCES

Future work by the Department of the Interior should seek to

- **look for connections between research disciplines in the planning phases of the study**
- **initiate studies of tributary processes because they are the main source of sediment in the Colorado River mainstem**
- **include in future hydrologic research empirical approaches as well as modeling approaches**
- **link sediment studies to biological and hydrological monitoring and research**
- **institute geomorphic studies to supplement the hydraulic studies of the Colorado River system in the Grand Canyon**

Recreation

The committee was well satisfied that the relevant questions in the recreation study were approached given the constraints in the scope of analysis embedded in the design of the GCES research program The change in recreation value in response to changes in dam operations and in terms of appropriate monetary units of measure was evaluated successfully The study is notable first for the care that was taken to design a survey research instrument for each of the relevant recreation populations and second for the care with which the statistical inferences were drawn A great deal of relevant information for management was obtained from these results The recreation reports provided a new dimension to planning for dam operations and an opportunity for further exploration and testing of the contingency valuation study

Future work by the Department of the Interior should seek to

- **clarify the costs, benefits, and tradeoffs between power generation and recreation opportunities**
- **broaden the definition of constituencies to include not only those who enjoy the Grand Canyon's recreational opportunities, but all those who care about the future of the resource**
- **avoid reliance on the use of hypothetical flows as the basis for predicting user behavior**

Operations

The material presented in the operations section of the final July 1987 draft GCES report is a major improvement over earlier drafts seen by the committee This type of information would have been useful in the planning phases of the GCES However, much of the material presented in the operations section of the final July draft GCES report is more relevant to revenue, customers, and the operation of the entire Western Area Power Administration (WAPA) service area than it is to the operation of the dam itself The hydropower capacity of Glen Canyon Dam is about 78 percent of the total Colorado River Storage Project (CRSP) capacity, but CRSP is but a small percentage of WAPA. The operations section would have been more useful to the analysis of Glen Canyon Dam operations if it had focused on Lake Powell (or at least on CRSP) to develop economic information useful to decisions on changes in dam operations Furthermore, a comparison of lost revenues from power production and potential gains from management operation of the dam will be necessary at some time

The Department of the Interior should

- **accept options 1 and 2 of the final draft GCES report (1) Initiate a feasibility study of possible changes in dam operations and non-operations alternatives for protecting downstream resources Such studies comply with National Environmental Policy Act (NEPA) requirements for informing and involving interested and affected publics and agencies (2) Continue with research and monitoring of resources**
- **consider all management options (e g , base load hydroelectric operations, discharge and timing of releases, installation and operation of multiple outlet structures, and strategies for conservation that use less than maximum storage in Lake Powell)**

The Integrated Final Report

The integrated final GCES report that was given to the committee in July 1987 is a readable document for the general public The committee suspects that this type of document was produced to achieve policy objectives The GCES scientists, however, have sacrificed scholarly rigor to achieve this brevity and readability By doing so, they have risked confusing readers who do not take the time to read the supporting reports The combination of sacrificed scholarly rigor and apparent value judgments increases the risk of misleading managers This inappropriate use of science could lead to poor policy

The integration of the results from the biological, sediment, and recreational studies is incomplete There is little direct cross-referencing, between study components and many policy statements do not consider interactions and indirect effects In short, it is not clear how the authors arrived at their bold, box-enclosed statements even after inspection of the supporting appendixes

Unclear Objectives

The goals and objectives presented in the GCES were articulated vaguely, they were inconsistent across individual studies, and they often confused science and policy They seemed to be more strongly related to the missions of the participating agencies than to understanding how the controlled hydrologic regime of the river influenced downstream resources For example, the National Park Service emphasized "naturalness," and the Arizona Game and Fish Department emphasized a sport fishery based on trout. The GCES did not carefully identify the resource uses and the boundaries of the study, especially as related to the missions of the agencies responsible for management. Potential management strategies (called operational scenarios) were limited in the original research design and were stated in such a way that the GCES scientists assumed that only one management strategy could be employed without adjustments through time (i e , management strategy is assumed immutable)

These shortcomings in the early planning stages precluded orderly progress toward integration of information The problems they caused grew until the GCES scientists experienced great difficulty producing an integrated report at the end of the study

Future work by the Department of the Interior should seek to

- **establish specific objectives, establish the geographic zone of potential effects, and identify resource uses and values**
- **set proper boundaries for the study**

Existing Information Not Used In Planning

One feature of early planning that seemed to be missing was the recognition and use of existing research on the Colorado River system For example, information was available from parallel studies at the impoundment in Flaming Gorge and its tailwater fishery that might have led to early insight about the conceptual scheme for the river below Lake Powell An early review of this and other information about the river in the Grand Canyon might have led researchers to recognize the need for early planning and the need to understand the interaction of ecosystem components This might have preempted what turned out to be an over-reliance on the missions of participating agencies, their budgets, their available "pool" of researchers, and so on, as the mechanism of planning that was apparently used by default.

Future investigations should be preceded by

- **a review of existing knowledge in the planning phase, and preparation of a written report of the review as documentation**

Confusion Between Administrative and Scientific Oversight

There was no clear separation of administrative and scientific oversight for the GCES project. Both functions suffered as a result. For example, the GCES project manager was also one of the researchers, the contracts manager, and the report integrator, and was looked to for general oversight by many of the participant researchers Although the GCES project manager was energetic and enthusiastic about the tasks, the committee believes that no one person should have been assigned such diverse responsibilities for research and management in such a large environmental study

Furthermore, no senior scientist or group of experienced science advisors were involved in the early planning or in helping the researchers in analysis and integration during the study Had experienced scientists been involved, the results almost certainly would have been more satisfactory and useful Such an advisory group could have aided the researchers as their work progressed and might have been able to make smooth mid-course corrections as opportunities arose The committee was especially aware of this need because of the difficulty it encountered in its advisory capacity at the end of the GCES study period

Future work by the Department of the Interior should seek to

- **bring senior scientists in at the beginning of environmental studies**
- **establish a scientific oversight group**
- **separate agency administration from scientific oversight**
- **establish a report integration team at the beginning of such a project rather than at the end**

Lack of Contingency Planning

In any environmental study of a river, unexpected events may occur and should be considered in the planning phase of the study During the 20 year period preceding the study, the flow in the river was controlled, usually with low flows so Lake Powell would fill Variations in flows reflected variations in demand for hydroelectric power With the reservoir at full storage capacity, however, the probability of uncontrolled flow (spill or flood) increased dramatically

Extraordinarily high runoff from spring thaw combined with late snows and rains in 1983 produced an unexpected inflow to an already full Lake Powell Release of the water required the use of the bypass tubes and the spillways and produced higher flows in the river than had been experienced for at least two decades

With few exceptions the individual GCES reports refer to the effects of the flooding, and so it is clear that some analyses were conducted as the opportunity forced itself on the project The flooding was seen by most researchers, however, as a major interference with the stated tasks Bureau of Reclamation administrators considered the flood to be a potential reason for discontinuing the studies

The lesson from this experience is that uncertainty characterizes ecosystem processes and the unexpected should be considered in planning What are the most likely major events that would influence the conduct of the research? What should be done if such an event occurred?

Future work by the Department of the Interior should

- **assume complexity, interactions, and indirect effects in future studies**
- **treat operations as manipulative experiments and, thus, monitoring as experimental data collection**

Need for Peer Review in Project Selection

The individual projects in the GCES were identified at the beginning of the study in the absence of a careful design, specific goals, and well-stated objectives Project funds were committed early, and planning was added as the project grew A conceptual scheme to guide the selection of critical research questions and clear identification of the required research skills was needed

The lead agency for the GCES—the Bureau of Reclamation—apparently did not solicit the talent to conduct the needed research through a peer-reviewed request for proposals The committee believes that such talent exists outside the agencies directly involved in the project, e g, U S Geological Survey, National Park Service, Arizona Fish and Game Department, U S Fish and Wildlife Service A broad search for the best and most experienced researchers is a necessary effort for such a large-scale environmental study This applies to scientists that are supported to conduct the work and to the appointment of any scientific oversight group

Future government research should

- **solicit scientific talent for the work based on a research plan**
- **use merit competition to select researchers, including a peer review system outside the agency or agencies conducting the study**

Review of EPA's Environmental Monitoring and Assessment Program Overall Evaluation

Committee to Review the EPA's Environmental Monitoring and Assessment Program

Board on Environmental Studies and Toxicology

Water Science and Technology Board

Commission on Life Sciences

Commission on Geosciences, Environment, and Resources

National Research Council
Washington, D C 1995

NOTICE The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine The members of the board responsible for the report were chosen for their special competences and with regard for appropriate balance

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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Executive Summary

EPA's Environmental Monitoring and Assessment Program (EMAP) was established to provide a comprehensive report card on the condition of the nation's ecological resources and to detect trends in the condition of those resources At EPA's request, the National Research Council's Board on Environmental Studies and Toxicology and Water Science and Technology Board established the Committee to Review EPA's Environmental Monitoring and Assessment Program This fourth and final report is the committee's overall evaluation of the program

In 1988, the Science Advisory Board of the U S Environmental Protection Agency recommended that EPA "undertake research on techniques that can be used to help anticipate environmental problems," and that "an office be created within EPA for the purpose of evaluating environmental trends and assessing other predictors of potential environmental problems before they become acute"

Following the Science Advisory Board's advice, EPA established the Environmental Monitoring and Assessment Program (EMAP) "to monitor ecological status and trends, as well as to develop innovative methods to anticipate emerging environmental problems before they reach crisis proportions" In 1993 EMAP's stated goals were to

1 Estimate the current status, trends, and changes in selected indicators of condition of the nation's ecological resources on a regional basis with known confidence
2 Estimate the geographic coverage and extent of the nation's ecological resources with known confidence
3 Seek associations between selected indicators of natural and human stresses and indicators of the condition of ecological resources
4 Provide annual statistical summaries and periodic assessments of the nation's ecological resources

As described by EPA, EMAP is unified by its approach to landscape characterization, the application of a coherent strategy for the choice and the development of indicators, and the use of a probability-based sampling approach that uses a hexagonal grid for identifying sampling sites There are eight resource groups identified by the program agroecosystems, and (now rangeland) ecosystems, forests, the Great Lakes, estuaries, inland surface waters, wetlands (recently subsumed under surface waters and the Great Lakes), and landscape ecology These resource groups are intended to represent ecosystem types or resources of national interest, and to provide a basis for incorporating ecological knowledge into the design of indicators and sampling programs

The committee's reviews of other EMAP components such as forests and estuaries and surface waters were published as separate reports The executive summaries of these reports are in Chapter 4

After four years of review, the committee retains its belief that EMAP's goals are laudable However, because achieving the goals of this ambitious program will require that EMAP successfully meet many difficult scientific, practical, and management challenges, the committee continues to question whether and how well all these goals can be achieved This final report reiterates that general assessment

As first conceived and presented to the committee in 1991, EMAP was significantly different than it is today Several of its central features and components seem to have less importance in mid-1994 than they did in 1991 The reverse is also true the resource groups have become much more important and are leading the program One of the major strengths of EMAP as initially presented was that it planned to integrate information across regions and across resource types, but the nature and extent of that integration is still not clear

Given the need for 10 years or more of data to sample regions and distinguish trends, nobody—including the members of this committee—can be certain whether, or how fully, EMAP will achieve its stated goals This is to be expected for a large, ambitious, and novel program like EMAP However, the program-wide concerns expressed in the committee's previous reports, in Chapter 2 of this report, and summarized below, are so important that EMAP will have little chance of achieving its goals if they are not addressed Concerns revolve around the following issues

- The EMAP sampling program may operate at too coarse a scale in space and time to detect meaningful changes in the condition of ecological resources
- EMAP's success will be diminished if it does not develop reliable, scientifically defensible indicators for measuring change The development of indicators of ecological health or integrity and of aesthetic quality appear to be particularly challenging
- EMAP's success will be diminished if it does not select the right assessment end points (i e , the end effect that is the goal of the monitoring program), something it has not done so far
- EMAP's success will be diminished if the retrospective or prospective monitoring approach does not match the assessment needs and the needs of policymakers
- EMAP needs to incorporate the best scientific advice in the design, implementation, and review of its program
- EMAP has not yet fulfilled its promise of innovation and national comprehensiveness because the programs to integrate

information across space, time and resource types have not been developed The most important of these are an indicator-development strategy, information management, and landscape characterization

• EMAP's information management system must support efficient access to a large, distributed database and application of an appropriate range of information processing tools

• Lack of continuity in staffing at EMAP has inhibited development of the program EMAP cannot succeed unless the government (i e , the administration and the Congress) makes a sufficient financial commitment to EMAP to support administrative and technical excellence, continuity, and efficiency in program management That commitment is necessary for EMAP to succeed, but is not sufficient by itself

A September 1994 letter from EMAP director Edward Martinko (Appendix A) describes EMAP's recent responses to earlier NRC reports and provides additional updates about the program Many of the changes described appear to be in line with the earlier committee recommendations EMAP has not provided more detailed documentation of these encouraging changes, so this report has not been substantially altered However, recommendations in this report that deal with matters directly addressed by Dr Martinko's letter are indicated with an asterisk

RECOMMENDATIONS

Statistics, Sampling, and Design

• **EMAP should consider design changes that would increase the probability of detecting smaller-scale ecological changes** Some possibilities include increasing revisitation rates at a subset of sample sites, inclusion of a set of nonrandomly selected sentinel sites with intensive data-collection, such as the Long

Term Ecological Research (LTER)/Land Margin Ecosystems Research (LMER) networks, and stratified random sampling by ecoregion with data-quality objectives specified for strata If EMAP does not adopt these design changes itself, then it should become extremely closely and explicitly coordinated with a program that has these features

• **EMAP should consider further combining effects-oriented and stressor-oriented monitoring approaches** Predictive, or stressor-oriented, monitoring seeks to detect the cause of an undesirable effect (a stressor) before the effect occurs or becomes serious Retrospective, or effects-oriented, monitoring seeks to detect the effect after it has occurred EMAP has relied mostly on the latter Stressor-oriented monitoring will increase the probability of detecting meaningful ecological changes As in the above point, if EMAP does not adopt these changes, it should become closely coordinated with a program that monitors in this way

• **EMAP should undertake power analyses regarding the effectiveness of the sampling design for each resource group** * A power analysis is an analysis of the statistical strength of an approach to detect change if a change exists Different resource groups have adopted different sampling approaches All the resource groups should adopt the practice of the EMAP lakes component, which has assigned teams of statisticians to assess the effectiveness of EMAP for that particular resource

• **EMAP should reconsider its detection criterion of a 20 percent change over 10 years** In some systems, such a large change is unlikely to occur in nature, while in other systems, a much smaller change would elicit concern EMAP should also consider systems or indicators for which a change in the *variance*, rather than mean or median, is important

*Recommendations marked with an asterisk are addressed in Dr Martinko's 9/20/94 letter describing recent changes in EMAP

Indicators

• **EMAP should initiate a major, focused research program on indicator development** * Indicator development is at the heart of the EMAP program Without a well-considered set of indicators for each resource group, EMAP will not fulfill its goal of presenting an evaluation of the nation's ecological resources The difficulty and importance of indicator development requires EPA to attract the highest quality researchers in the environmental sciences to this program The program should include a combination of internal research (by EMAP scientists) and external research involving open announcements of funding availability with peer-reviewed grants

• **Each EMAP resource group should develop one or more *mechanistic* conceptual models of its resource, based on current scientific knowledge** * These models should serve as explicit hypotheses about those aspects of ecosystem structure and functioning relevant to the assessment end points the group has chosen The models must be detailed enough to include potential indicators, assessment end points, and key variables

• **EMAP should provide program-wide guidance for numerous evaluation issues if the indicator-selection strategy is going to yield the nationally applicable set of indicators EMAP envisions** The committee recommends as a high priority the explicit and early evaluation of the statistical properties of all potential indicators Such evaluations should include analyses of the properties of the mean, variance, and behavior of the index in power tests If this cannot be done analytically, then simulation analyses should be performed

• **EMAP should carefully evaluate each potential indicator at incrementally larger spatial scales** EMAP needs to make sure that it has information on the domains of usefulness of its indicators—at what spatial and temporal scales are they reliable, and at what scales are they less reliable? The ways in which the various resource groups deal with this problem will have important consequences for the selection of nationally implemented indicator metrics Program-wide strategies for dealing with this issue should be developed now, in time to be applied with some uniformity across the resource groups

Integration

• **EMAP should develop key integration and assessment questions that cross resources** This would help focus the program and significantly extend its value nationwide

• **EMAP should designate resources for integration** As EMAP now stands, there are relatively few financial or other resources directed specifically at integration Such resources could be directed in various ways, but several important needs must be met Individual resource programs directed at integration must have access to the information management system, and must have computer and software resources to generate and test generalizations One approach would support a team of individuals who focus on developing and addressing the integration and assessment questions, and who either work together at one physical location or were coordinated among resource groups by a central office Key members of this group must be participants of the Landscape Characterization, Landscape Ecology, and Indicator Development groups The new Integration and Assessment Program is a positive step in this direction, but we do not have a good description of the activities of this program

• **EMAP should develop coordinated sampling between terrestrial, aquatic, and atmospheric resources** [1] Resources

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[1] One committee member has been deeply concerned about the apparent lack of communication between senior administrators and possibly senior scientists, in the Air and Deposition Section of EMAP and those in major federal, state, and international agencies (e g , Canada and Mexico) who are also heavily involved in ecological risk assessments and environmental protection This

(continued on p 8)

appearing to have very important ecological connections due to hydrologic linkages are now being sampled in separate locations The design would be enhanced by a cooperative sampling scheme between resource groups in which lakes and streams were sampled in watersheds whose terrestrial systems (forests, agroecosystems, arid systems) also were being sampled A stratified random system such as this would not compromise EMAP's ability to make regional-scale generalizations based on probability-based samples The data sets would be considerably stronger because the spatial covariance of the data sets could be used to test hypotheses related to cause and effect relationships

Possible examples include indicators reflecting net primary productivity, biological diversity, and aesthetic value At present, it is unclear whether or not the assessment questions in each resource group are similar enough to lead to parallel sets of indicators Such symmetry among resource groups, while not essential to basic EMAP objectives, would greatly enhance the scientific and analytical value of the data collected

Appropriate Scale and Boundaries Of Regions

• **EMAP should choose ecologically meaningful units as the primary scale for summarizing and reporting data** Ecologically meaningful units, such as Bailey's or Omernik's ecoregions, should be the primary objects of statistical analysis and data reporting rather than political units or EPA regions In general,

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member feels strongly that such inter- and indeed intra-agency interactions are essential for effective coordination of monitoring and assessment efforts involving the atmospheric transport, transformations, and deposition (as well as associated intermedia transport) of a wide range of hazardous gaseous and particulate air pollutants

EMAP should reconsider the scale and boundaries of units for which the national program summarizes and reports data

Coordination And Management

• **EMAP is unlikely to succeed unless EPA commits permanent, senior-level positions to the program, and recruits qualified people to fill them** Commitment and continuity are crucial for the implementation of such an innovative national program Too many important responsibilities in EMAP have been assigned to people on temporary Interagency Personnel Agreements (IPAs) or to contractors

• **The committee recommends that EPA senior administrators facilitate close working relationships between EMAP and appropriate offices and divisions of EPA, including other research programs in the Office of Research and Development** In particular, EMAP should continue in its efforts to develop close working relationships with the EPA Office of Water to capture the benefits of EPA's past experience in collecting data on surface waters Continued reliance on the experience of such programs leverages EMAP's resources and brings complementary expertise to the program

• **EMAP should develop and maintain an administrative structure that demands close communication and interaction among EMAP-LC (Landscape Characterization), EMAP-IM (Information Management), and each of the resource groups** This structure could take several forms, such as locating lead personnel of each of these groups at a central office or some other mechanism that requires regular communication among these groups

• **The committee recommends that EMAP continue its efforts to coordinate its activities with those of other agencies** The Memorandum of Understanding, signed by National Biological Service director H Ron Pulliam and EPA Office of Research and Development director Robert Huggett (MOU, September 30,

1994) is an excellent example of such coordination The committee encourages further efforts with programs like the National Water Quality Assessment of the U S Geological Survey

External Scientific Review

- **The current external review structure of EMAP should be modified so that its core is a permanent panel, with rotating membership, to provide continuity** A permanent board of accomplished scientists may provide more expertise and consistency of viewpoint than EMAP has had access to heretofore The panel should advise both at the level of resource groups, such as the forests or estuary resource level, and at the level of the entire EMAP program

Information Management

- **While top-down planning for EMAP's information system is important, EMAP should base such planning on the viewpoint that the information system is a scientific database system, rather than an information system focused on the needs of management if the Information Management System is to function and facilitate integration among research groups as envisioned by EMAP** In particular, the planning should focus on the design of an environment that is sensitive to user requirements and that provides excellent hardware, software, and support personnel

IMPROVING FISH STOCK ASSESSMENTS

Committee on Fish Stock Assessment Methods
Ocean Studies Board
Commission on Geosciences, Environment, and Resources
National Research Council

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Executive Summary

Marine fisheries provide a vital contribution to food supplies, employment, and culture worldwide. Therefore, matching fishing activities with natural fluctuations so as to avoid unsustainable harvests and population crashes is an important goal. In an ideal world, accurate and precise estimates of the abundance of fish stocks and their dynamics (how and why population levels change) would be available to set sustainable harvest levels to accommodate commercial and recreational demand. In reality, fishery management is based on imperfect estimation of the number, biomass, productivity, and age structure of fish populations and incomplete knowledge of population dynamics. The ocean is relatively opaque to light, and acoustic techniques of remote sensing are not yet sufficiently developed for general use in estimating fish populations. Thus, it is difficult to count fish through nondestructive means and fish usually must be caught to be counted, weighed, and measured. Standardized techniques have been developed to sample a relatively small proportion of fish from a population and to combine such data with commercial and recreational catch information to estimate population characteristics. These techniques yield *stock assessments* used by managers at state, regional, national, and international levels.

In addition to monitoring the abundance and productivity of exploited fish populations, stock assessments can provide a quantitative prediction of the consequences of possible alternative management actions. The mechanisms that cause fish populations to change are poorly understood but include environmental and ecosystem effects, interactions among multiple species, and effects of humans through harvesting, pollution, habitat disruption, and other factors. Without accurate stock assessments and their proper use in management, exploited fish populations can collapse, creating severe economic, social, and ecological problems. Therefore, ensuring that stock assessment research progresses and that operational stock assessments use the best techniques for a given stock are fundamental for ensuring the sustainability of commercial and recreational marine fisheries.

Stock assessment is a multistage process. Steps include (1) definition of the geographic and biological extent of the stock, (2) choice of data collection procedures and collection of data, (3) choice of an assessment model and its parameters and conduct of assessments, (4) specification of performance indicators and evaluation of alternative actions, and (5) presentation of results. This report concentrates on evaluating assessment models, with less extensive treatment of the other steps. Chapter 1 discusses these steps in greater detail. Techniques of stock assessment range from informal estimates to more sophisticated modeling approaches used to combine data of various types. Assessment models predict rates of change in biomass and productivity based on information about yield from fisheries and the rates at which fish enter the harvestable population (*recruitment*), grow in size, and exit the population (*natural* and *fishing mortality*).

Stock assessments for fish living in the U S exclusive economic zone (3 to 200 nautical miles from shore) and for some highly migratory species are conducted by scientists from the National Oceanic and Atmospheric Administration's (NOAA's) National Marine Fisheries Service (NMFS) and independent species group commissions (e g , the International Pacific Halibut Commission and the Inter-American Tropical Tuna Commission) In addition, interstate fishery management commissions were created to facilitate the coordination of state assessment scientists in working with each other and with federal scientists to assess and manage stocks shared among states in their coastal waters (within 3 nautical miles from shore on open coasts, as well as bays and estuaries) These organizations include the Atlantic States, Gulf States, and Pacific States Marine Fisheries Commissions Some states (e g , Alaska, Oregon, and Florida) also perform assessments for fisheries conducted in their own state waters

Fishery management organizations use the results of stock assessments to design and implement various controls for the total catch that can be removed from fish populations under their jurisdictions Commercial catch can be managed by specifying the amount of harvesting allowed, the areas of fishing and times of the year that fishing can take place, the gear that can be used, minimum fish size limits, and in some cases, the amount of fish that any single fisher, community, company, or other entity can catch Recreational fisheries more often impose minimum size limits, daily catch limits, seasons, and sometimes gear restrictions and requirements to release fish that are caught

STUDY PROCESS

The National Research Council (NRC) Committee on Fish Stock Assessment Methods was formed in early 1996 to review existing stock assessment methods and to consider alternative approaches for the future The committee's statement of task was two-fold

1 Conduct a scientific review of stock assessment methods and models for marine fisheries management
2 Compare models using actual and simulated data having a variety of characteristics, to test the sensitivity and robustness of the models to data quality and type

As part of this study, the committee asked selected stock assessment scientists to conduct blind runs of simulated data sets using five different models Models tested included a production model, a delay-difference model, and three age-structured methods (described in detail in Chapter 3) The goal of the simulation study was to evaluate the performance of stock assessment methods for simulated fish populations for which the true population parameters were known (to the committee, but not to the analysts) and some of the assumptions usually made in stock assessments were violated One type of data set was typical of the catch biomass, age composition of the catch, and catch per unit effort (CPUE) that are obtained from commercial and recreational fisheries The other type of data set was typical of that collected by fishery-independent surveys

Each analyst was asked to evaluate five 30-year sets of simulated commercial and survey data, alone and in combination The five data sets provided different combinations of parameters in terms of the following

- Increasing or decreasing stock size over time (*population trend*)
- Constant versus changing age of fish caught (*fishery selectivity*) over time
- Accuracy of catch reported by fishers
- Ability of fishery and survey vessels to catch fish (*fishery* and *survey catchability*)

The analysts were given essential information about fish growth and maturity, the probability of mis-estimating fish ages, and selected information about the structure of the populations and the data Analysts were not provided information about natural mortality, catchability, selectivity, recruitment, or the amount of underreporting (although they were warned that underreporting might have occurred)

In addition to the results of these basic analyses, (1) some analysts repeated their model runs with the true average natural mortality (provided by the committee), (2) key management variables were calculated by analysts and the committee, and (3) retrospective analyses were conducted by the committee to determine the persistence of over- or underestimation of population parameters over time by the different models Greater detail about the study process is given in Chapter 5 and Appendix E

FINDINGS AND RECOMMENDATIONS

The committee focused its examination on the data that are used in assessments, model performance, use of harvest strategies, new assessment techniques, periodic review and quality control of assessments and assessment methods, and education and training of stock assessment scientists The committee based its recommendations on the results of the simulations and on its collective experience Caveats about how the analyses conducted for this study compare to actual stock assessments are given in Chapter 5 Accomplishing the recommendations of this report will require concerted and cooperative action by all interested parties (academic and government scientists, fishery managers, user groups, and environmental nongovernmental organizations) to improve the stock assessment process and products

Data Collection and Assessment Methods

The committee concludes that stock assessments do not always provide enough information to evaluate data quality and to estimate model parameters, and it recommends a checklist that would promote more complete data collection for use in stock assessments The results of the committee's simulations demonstrated that the availability of continuous sets of data collected by using standardized and calibrated methods is important for the use of existing stock assessment models The best index of fish abundance is one for which extraneous influences (e g , changes in gear and seasonal coverage, changes in fishers' behavior) can be controlled The committee recommends that at least one reliable abundance index should be available for each significant stock CPUE data from commercial fisheries, if not properly standardized, do not usually provide the most appropriate index Likewise, CPUE data from recreational fisheries require standardization to serve as a good index of abundance

Fishery-independent surveys offer the best opportunity for controlling sampling conditions over time and the best choice for achieving a reliable index if they are designed well with respect to location, timing, sampling gear, and other considerations of statistically valid survey design NMFS should support the long-term collection of fishery-independent data, using either the NOAA fleet or calibrated independent vessels Diminishing the quality of fishery-independent data by failing to modernize NOAA fishery research vessels or by changing sampling methods and gear without proper calibration could reduce the usefulness of existing and future data sets

The simulation study demonstrated that assessments are sensitive to underlying structural features of fish stocks and fishery practices, such as natural mortality, age selectivity, catch reporting, and variations in these or other quantities Auxiliary information in the form of indices or survey estimates of abundance, population structure information, and accurate estimates of other population parameters (e g , natural or fishing mortality, growth, catchability) improves the accuracy of assessments

Formally reviewed sampling protocols for collection of commercial fisheries statistics have not been implemented in many geographic regions The lack of formalized, peer-reviewed data collection methods in commercial fisheries is problematic because bias and improper survey conduct may exist, with unknown impact on data reliability Greater attention should be devoted to sampling design based on an understanding of the statistical properties of the estimators for catch at age and other factors Sampling and subsequent analysis should also consider the issue of systematic biases that emerge with factors such as misreporting Formalized sampling protocols have been developed for recreational fisheries in the form of the Marine Recreational Fisheries Statistics Survey (MRFSS) MRFSS data and methods, albeit imperfect, have undergone independent peer review, are readily available, and could serve as a model for commercial fisheries The committee recommends that a standardized and formalized data collection protocol be established for commercial fisheries nationwide

Models

Both harvesting strategies and decision rules for regulatory actions have to be evaluated simultaneously to determine their combined ability to sustain stocks Simulation models should be realistic and encompass a wide range of possible stock responses to management actions and natural fluctuations consistent with experience The committee recommends that fish stock assessments present realistic measures of the uncertainty in model outputs whenever feasible Although a simple model can be a useful management tool, more complex models are needed to better quantify the unknown aspects of the system and to address the long-term consequences of specific decision rules adequately Retrospective analyses performed by the committee showed that persistent over- or underestimation can occur over a number of years of assessment, regardless of which model is used The committee recommends the use of Bayesian methods both for creating distributions of input variables and for evaluating alternative management policies Other methods for including realistic levels of uncertainty in models also should be investigated

In the simulations, model performance became erratic as more variability or errors were introduced to data sets Newer modeling methods offer promise for reducing bias in key parameter estimates, although using mathematically sophisticated assessment models did not mitigate poor data quality Different assessment models should be used to analyze the same data to help recognize poor data and to improve the quality of assessment results Results from such comparisons can be used to direct survey programs to improve data quality and to assess the degree of improvement in data achieved over time Greater attention should also be devoted to including independent estimates of natural mortality and its variability in assessment models Further simulation work of this kind is also needed to determine whether the simulation results and the conclusions based on these results remain the same over multiple replications

The committee believes that single-species assessments provide the best approach at present for assessing population parameters and providing short-term forecasting and management advice Recent interest in bringing ecological and environmental considerations and multi-species interactions into stock assessments should be encouraged, but not at the expense of a reduction in the quality of stock assessments

Harvest Strategies

Although the committee did not evaluate alternative harvest strategies, it believes that assessment methods and harvest strategies should be evaluated together because harvest strategies can affect stock assessments and the uncertainty inherent in stock assessments should be reflected in harvest strategies Despite the uncertainty in stock assessments, fishery scientists may be able to identify robust management measures that can at least prevent overfishing, even if they cannot optimize performance Conservative management procedures include management tools specific to the species managed, such as minimum biomass levels, size limits, gear restrictions, and area closures (for sedentary species) Management procedures by which the allowable catch is set as a constant fraction of biomass (used for many U S fisheries) generally perform better than many alternative procedures However, errors in implementation due to assessment uncertainties could result in substantial reductions in long-term average harvests in some years if biomass estimates are highly uncertain Assessment methods and harvest strategies need to be evaluated simultaneously to determine their ability to achieve management goals Application of risk-adjusted reference points (based on fishing mortality or biomass) would immediately lead to reduced total allowable catch and thus create an economic incentive for investment in improved data gathering and assessment procedures to reduce the coefficient of variation of biomass estimates

There are at least four alternatives to harvesting a constant fraction of exploitable biomass that may result in levels of total mortality that are consistent with maintaining a fish stock First, target fishing mortality can be reduced as a stock decreases in size to reduce risks Second, a minimum biomass level can be established, below which fishing would be halted (this is done for some U S fisheries) Third, the size of fish captured can be increased by changing requirements for harvest gear This restriction might allow smaller fish to escape and spawn, but could be ineffective if harvesters apply more effort to the larger fish Finally, geographic areas can be closed to limit mortality for sedentary species if the distribution of organisms is well known and if the fishing mortality in other areas is not increased Area closures have been implemented or proposed for many fisheries worldwide in the form of marine reserves and sanctuaries

New Approaches

NMFS and other organizations responsible for fisheries management should support the development of new techniques that can better accommodate incomplete and variable data and can account for the effects of environmental fluctuations on fisheries Such techniques should allow the specification of uncertainty in key parameters (rather than assuming constant, known values), should be robust to measurement error, and should include the ability to show the risks associated with estimated uncertainty

A few prominent recommendations for new approaches emerged from the study Scientists that conduct stock assessments and organizations that depend on assessments should

- incorporate Bayesian methods and other techniques to include realistic uncertainty in stock assessment models,
- develop better assessment models for recreational fisheries and methods to evaluate the impacts of the quality of recreational data on stock assessments,
- account for effects of directional changes in environmental variables (e g , those that would accompany climate change) in new models, and
- develop new means to estimate changes in average catchability, selectivity, and mortality over time, rather than assuming that these parameters remain constant

The results from the simulation exercise should be sobering to scientists, managers, and the users of fishery resources The majority of the estimates of exploitable biomass exceeded true values by more than 25%, assessments that used accurate abundance indices performed roughly twice as well as those that use faulty indices A disturbing feature of the assessment methods is their tendency to lag in their detection of trends in the simulated population abundance over time For example, some methods with some types of data consistently overestimate exploitable biomass during periods of decreasing simulated abundance and underestimate exploitable biomass during periods of increasing simulated abundance

Although no stock assessment model was free from significant error in the simulations, it is also true that few of the models failed consistently Hence, the message of this report is not that stock assessment models should not be used, but rather that data collection, stock assessment techniques, and management procedures need to be improved in terms of their ability to detect and respond to population declines The simulation results and some actual fishery management examples suggest that overestimation of stock biomass and overfishing of a population can occur due to inaccurate stock assessments and that the overestimation can persist over time The committee believes that the two most important management actions to mitigate this problem are (1) to model and express uncertainty in stock assessments explicitly, and (2) to incorporate uncertainty explicitly into management actions such as harvesting strategies

The absence of adequate data is the primary factor constraining accurate stock assessments The differences between estimated and true values derived from the simulated data were most likely not introduced by any mistakes made by the analysts Rather, the large differences that occurred under some scenarios were primarily the result of poor data and model misspecification stemming from incomplete knowledge of the true situation by the analysts The surplus production and delay difference models did not include the ability to account for changes over time in key parameters for the simulated populations The simulated data sets were better structured for analysis by age-structured methods, hence, these kinds of models performed better When they did not perform well it was generally because the models used biased information (e g , the fishery CPUE index) or did not account for changes in selectivity and catchability over time Had the analysts been told about these data features, it is likely that they could have compensated for them and obtained better assessments Some of the newer models appear to be able to achieve such compensation through the introduction of process errors Nevertheless, modeling will never be able to provide estimates that are as accurate as direct knowledge obtained by measurement and experimentation Thus, if future stock assessments are to avoid some of the past problems, management agencies must devote the necessary resources to monitor and investigate fish populations in a stable research environment that fosters creative approaches

Peer Review

It is imperative that stock assessment procedures and results be understood better and trusted more by all stakeholders One means to achieve such trust is to conduct independent peer review of fishery management methods and results including (1) the survey sampling methods used in data collection, (2) stock assessment procedures, and (3) risk assessment and management strategies When applied properly to stock assessments, peer review yields an impartial evaluation of the quality of assessments as well as constructive suggestions for improvement. Such reviews are most beneficial when conducted periodically, for example, every 5 to 10 years, as new information and practices develop In addition, a complete review of methods for collection of data from commercial fisheries should be conducted in the near future by an independent panel of experts, which could lead to the adoption of formal protocols

Education and Training

Reduction in the supply of stock assessment scientists would endanger the conduct of fishery assessments by the federal government, interstate commissions, and international management organizations and would hinder progress in the development and implementation of new stock assessment methods NMFS and other bodies that conduct and depend on fish stock assessments should cooperate to ensure a steady supply of well-trained stock assessment scientists by using mechanisms such as personnel exchanges among universities, government laboratories, and industry and by funding stock assessment research activities The training of stock assessment scientists should endow them with skills in applied mathematics, fisheries biology, and oceanography Education of fisheries scientists should be organized and executed in such a way that it complements and augments the NMFS research mission and leads to improved management strategies for fisheries in the future

Improving the Collection, Management, and Use of Marine Fisheries Data

Committee on Improving the Collection and Use of Fisheries Data
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