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Biological Rate Measurements Working Group Report to the NOAA Quality Assurance Program

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ABSTRACT

As part of the U. S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA) Quality Assurance Program, a Biological Rate Measurements Working Group was formed to review the status of NOAA's research with regard to the quality assurance of biological rate measurements and make recommendations for improving and maintaining the quality assurance level of that research. The working group met 5-7 December 1983 in Miami, Florida to develop a report. That report which was submitted to NOAA on 30 April 1984, is presented here in its entirety.

TABLE OF CONTENTS

1.0 INTRODUCTION

The Working Group on Quality Assurance of Biological Rate Measurements met at the NOAA Atlantic Oceanographic and Meteorological Laboratories, Miami, Florida from December 5-7, 1983, in response to the charge to the working group.

1.1 Charge to the Working Group:

A. Review material submitted by NOAA scientists and NOAA contractors and determine deficiencies and positive aspects of current quality assurance practices with regard to biological rate measurements.

B. Prepare a report

1. Document the current status of quality assurance for biological rate measurements made by NOAA scientists and NOAA contractors.
2. Recommend actions to correct identified deficiencies and provide a continuing mechanism for promoting intercomparability of NOAA's environmental data and enhancing confidence in NOAA's biological rate measurements.

1.2 Background:

The Group had previously received for their individual review copies of the entire submissions developed by NOAA scientists and NOAA contractors in response to a request from NOAA's Quality Assurance Program (See NOAA's Quality Assurance Survey for Biological Rate Measurements, Vols. I-IV plus Supplement). Thirty-three separate reports from 11 laboratories were received and examined by the working group (See Appendix I, Laboratories and Types of Biological Rate Measurements Submitted for Review). Of the 33 reports, four lacked sufficient documentation for review and evaluation, and five were deemed beyond the feasible scope of the working group.

1.3 Functioning of Working Group:

The working group was divided into two subgroups (water column and benthic rate measurements) and the remaining 24 reports were individually reviewed by the appropriate subgroup with regard to quality assurance practices for the various biological rate measurements. These subgroup reviews and evaluations of individual reports are on file with Dr. John Calder. Following extensive discussion each subgroup: 1) wrote a report which describes the current status of quality assurance for NOAA's biological rate measurements based on all of the submissions reviewed and 2) made recommendations to correct deficiencies and improve and maintain quality assurance on a continuing basis (See Section 4). These subgroup reports are summarized in Section 2 (Overall Status) and Section 3 (Recommendations). The subgroup reports in their entirety are presented in Section 4.

1.3.1 Consensus:

This report reflects a collaborative effort and for the most part represents a consensus. Indeed, the Subgroup Reports and Recommendations were written and reviewed by the group during the meeting in Miami in order to achieve agreement.

2.0 OVERALL STATUS OF NOAA'S BIOLOGICAL RATE MEASUREMENTS

2.1 Limitations:

The working group was concerned that the submissions reviewed in response to the request by NOAA's Quality Assurance Program may not be fully representative of NOAA's involvement in biological rate measurements, particularly in regard to biological effects. However, the working group had no information to indicate the completeness of the response. Therefore, the working group determined the status of NOAA's biological rate measurements with regard to quality assurance based solely on the submissions received.

2.2 Positive Aspects:

With few exceptions the working group was generally impressed with the overall attention to detail and state-of-the-art protocol found with regard to NOAA's biological rate measurements. The working group felt that the quality of NOAA's biological rate measurements was comparable to the general spectrum and similar methodological protocol found in the general scientific community. Individual subgroup comments include, "It is obvious that the majority of the research considered here is comparable to the highest quality of research being carried on outside of NOAA;" "For the most part, these methods measure real-world conditions, though few could be characterized as being rapid, uncomplicated or inexpensive;" "Methods are continually being improved to deal with newly recognized problems and both NOAA scientists and NOAA contractors appear to be actively involved in the development of new (and better) techniques."

2.3 Deficiencies:

The most apparent deficiency is that NOAA scientists, with notable exceptions, do not pursue publication of their research in peer-reviewed journals as aggressively as they might. Such airing of the data would impose a natural and continuing quality control on methodology and the interpretation of results. Second, it was thought that NOAA could provide a more conducive environment for conducting quality science. A third deficiency and one more immediate to the task of the committee involves the broader use of ultra-clean techniques when measuring biological rates in the water column as well as additional methodological considerations for either the water column or the benthos. Investigators measuring biological rates in the water column or the benthos need to question and test all steps in their methodology in order to elucidate which are the most critical in terms of affecting the outcome (accuracy and precision) of the particular measurement and understand the causes that make these steps critical. Many rate measurements are time dependent; time course experiments need to be run in order to understand the effects of duration of the time period of measurement on the outcome of an experiment. Finally effects of temporal and spatial variability and partitioning of total rates into individual processes that contribute to the total should be examined to eliminate ambiguity. Our recommendations respond to these issues.

3.Ø RECOMMENDATIONS

It was the consensus of the working group that quality assurance for researchers measuring biological rates ultimately means having quality scientists who are conducting research comparable to the best in the scientific community as a whole. Therefore, to maintain and improve quality assurance, we believe that NOAA should encourage and foster high quality research and monitoring activities at the scientist and the organizational level. Our recommendations are made to that end and apply to all biological rate measurements, regardless of whether they are performed for biological effects monitoring or any other purpose.

3.1 Quality Assurance For The Individual Scientist:

Peer review and communication are the most effective means of providing quality assurance in NOAA research.

3.1.1 Research plans should be formalized and where possible peer-reviewed by the scientific community. We recognize that NOAA research plans frequently result from legislative mandate. Nevertheless, these plans should be scientifically sound.

3.1.2 Researchers should publish, whenever appropriate, in the open peer-reviewed literature, and interpret and air other data in the best and most public form possible. This should promote data quality.

3.1.3 NOAA scientists should be more active members of the scientific community. Workshops, for example, are a proven, effective means of communication among scientists; however, they are of limited success if they are exclusively "in-house". NOAA should co-sponsor workshops to discuss specific areas of research (e.g., benthic rates, biological effects, secondary production, etc.). Participants should include a mixture of investigators from various disciplines to insure diversity of input. For example, a biological effects workshop should include contaminant chemists.

3.1.4 NOAA scientists should present papers at scientific meetings. Such exposure enhances communication with the scientific community at large and serves as an effective means of maintaining quality of research.

3.1.5 Where appropriate NOAA scientists should collaborate with other scientists both inside and outside NOAA. This would both improve communication and encourage intercomparison of methods.

3.2 Policy Changes to Encourage and Sustain High Quality Research:

As conducive an environment as possible is desirable for conducting quality science.

3.2.1 NOAA administrators should consider additional ways to foster an intellectual climate in which there is an expectation of excellence.

3.2.2 Researchers need to be given the flexibility and time to do basic research and, where necessary, to develop new methods. This flexiblility, however, must obligate the researcher to conduct appropriate experiments, interpret the results and publish the findings in peer-reviewed scientific journals.

3.2.3 NOAA should encourage its active researchers to participate in methods meetings, to give seminars at governmental laboratories and universities, and where possible to join the academic community as adjunct professors or work with academia on joint research, NSF panels, editorial boards, etc. This will significantly improve the scientific community's perception of NOAA, and will help assure quality science by improving communication among NOAA investigators and between NOAA personnel and the scientific community at large.

3.2.4 Impartial panels or visiting committees should be selected to critically review NOAA research programs and laboratories periodically. These panels would not only assist in assuring quality during the execution of NOAA research efforts, but also would help to define and formulate new research programs.

3.2.5 Resources for mission-oriented and basic research should be allocated in light of the performance and responsiveness of specific laboratories and programs. This would provide a positive feedback mechanism for responsive, productive, quality research.

3.2.6 Due to the nature of the structure of academic funding, NOAA has a particularly important and unique role in conducting complex and long term ecological studies. Environmental monitoring activities must incorporate basic research to provide the most effective feedback mechanism for self correction and continuing quality control. As methods evolve during these studies, improvements in methodology must be incorporated, documented, and evaluated so that the continuity of data is maintained while improving its quality. This approach to monitoring will allow sufficient documentation to enable researchers to backtrack and evaluate long-term data sets.

3.2.7 NOAA must recognize that it is difficult to perform quality science in an unstable environment. Frequent changes of direction resulting in rapid overturn and reprogramming of personnel are detrimental to the quality of both basic research and monitoring programs.

3.3 A Future Quality Assurance Program for Biological Rate Measurements:

Quality assurance questions have been raised because accumulating data on quantitative chemical determinations have led to the suspicion that some techniques or procedures, or lack of attention to certain methodological protocols give erroneous results. For chemical analyses, it is possible to determine in advance what the true values for a sample are. Deviations of analytical results from the known true values reveal the errors in the determination. Intercalibrations with known standard samples reveal the relative errors of different analytical methods.

In contrast to chemical determinations, there are no "standard samples" by which different methods for measuring biological rates, especially of community - or ecosystem - level processes like primary production, community metabolism, nutrient regeneration, can be compared for assessment of their relative errors. There are problems of spatial and

temporal variability in the samples. If these sources of variability lead to coefficients of variation of 25% or more in the final results (not uncommon in benthic rate measurements), and different methods give results of overlapping ranges, who can tell for sure whether statistically significant differences between the results of different methods are due to methodological differences or to chance real differences between sets of samples?

There are indeed steps in biological rate measurements that may be subject to quality assurance questions, e.g. all associated quantitative chemical determinations. Every scientist should be aware of the need to use the latest techniques and modifications for accurate chemical measurements. Regarding benthic processes there has not been a perception among the workers involved that quality of chemical determinations is of concern.

The time will come when intercomparison of certain rate measurements will be deemed necessary, as it has for primary productivity. This group activity should be viewed not as a means of finding out which is the right method and which are wrong, but to determine what the agreements and disagreements among the different methods can tell us about biological processes taking place in the ecosystem.

At this time, the only judgment that should be made of a method for measuring biological rate, especially of community - or ecosystem - level processes, is whether it will answer the question or hypothesis posed by the scientist. Whether it is accurate or not, better than another method or not, these are impertinent absolute questions that cannot be asked where the truth is unknown and variable.

Based on these concerns our specific recommendations follow:

3.3.1 At this time, with regard to biological rate measurements, we are not in favor of establishing an elaborate, highly structured, quality assurance program or the writing of standard methods manuals. Instead scientists should be encouraged to modify existing methods, develop and publish new methods advancing the state-of-the-art.

3.3.2 Intercalibration exercises for biological rate measurements should be conducted when a need is perceived by active, well informed researchers in the specific area of interest and then only after the individual steps of a method have been investigated. The group felt that it was more important to find out which were the critical steps in any method and why, then to undertake wholesale intercalibration exercises without understanding the underlying mechanisms involved. NOAA should encourage and support individual investigators who wish to compare their different methods in ongoing, well-defined studies where such efforts will increase our understanding of the underlying mechanisms controlling biological rates. With regard to planktonic environments, intercomparison of diverse methods is already the focus of a major research effort (NSF-PRPOOS). For the benthos, however, the group felt that it would be unproductive to engage NOAA scientists or contractors in complex intercalibration exercises because of high coefficients of variation and no generally accepted methodological criteria.

3.3.3 We recommend no further followup questionaires or continuation of the Biological Rate Measurements Working Group as presently Charged. Members of the group, however, believed that a new quality assurance working group should be constituted for research on biological rates not adequately included in this survey (e.g., biological effects, secondary production). We realize that these two particular areas are complex and fundamentally interdisciplinary; however, more NOAA effort probably is expended here than in the rate measurements reviewed.

4.0 SUBGROUP REPORTS

4.1 Water Column Rate Measurements:

Water column rate measurements were divided into carbon-14 primary productivity and other microbial processes. Although several responses were submitted on macrobiological activity, we deferred discussion of these to possible other later panels on secondary production and biological effects.

The working group charged with evaluating biological rate processes relative to NOAA's Quality Assurance Program perceived that the small number of responses limited an overall evaluation of the varied rate process techniques employed by NOAA and its contractors. It became apparent to the group, however, that of the responses submitted for review one particular and very important rate measurement, the C-14 primary productivity technique, was sufficiently represented to allow for a reasonably rigorous evaluation.

In our initial discussion, we agreed that in the context of biological rate measurements, quality is assured only by applying the criteria of scientific quality as used by the general scientific community.

A. Would the overall planned research stand up to critical peer review?
B. Were the experimental and sampling designs appropriate to the research in question?
C. Was the particular method chosen appropriate, etc?

We felt that evaluation of the quality of specific biological rate measurements is best approached in the total research context. Since we had neither detailed research proposals nor the request to evaluate such, we limited our evaluation to methodology.

4.1.1 Carbon-14 Primary Productivity:

4.1.1.1 Criteria:

The following paragraphs were constructed in order to aid the working group in its evaluations of quality assurance. The paragraphs were based on the expertise of our group and the considerations/recommendations of similar groups (e.g., ICES, 1981/L:46). It should be emphasized that the items listed in these paragraphs are not exhaustive but do reflect a sufficient set of criteria for evaluating the C-14 rate process technique.

Clean sampling equipment: The necessity of clean sampling is of particular importance in oligotrophic waters, but also may be important in coastal, estuarine and fresh water. Therefore it is necessary to use established "trace-metal clean" techniques or to verify that the procedure used (metal hydrowire, PVC water bottles, etc.) in the particular environment does not cause artifacts.

Manipulations: Since the usual intent of biological rate measurements is to measure natural processes, departure from in situ conditions should be minimized. When in situ incubations cannot be used, light and temperature conditions should be maintained as close to ambient as possible, and light and temperature shocks should be avoided.

Incubation bottles: Probably it is desirable to avoid glass. If plastics such as polycarbonate are used, caution in cleaning is necessary (e.g., improper cleaning can cause activation of binding sites on container walls).

Isotope used: The carbon-14 solution of high specific activity should be made up by the individual investigator. It should be a highly concentrated single stock solution for use as a small injection volume for an entire set of samples and be stored in a Teflon bottle.

Incubation time: Multiple, short-term, in situ incubations are preferred and should be checked with time course measurements. If 24 hour incubations are used, they should be checked with time course experiments. Avoid use of formalin to stop incubation.

Sampling depths: Incubation levels should be chosen to be consistent with hydrographic features as well as light extinction.

Photoassimilated release of dissolved organic carbon: Dissolved organic carbon (carbon-14 labeled) production should be assessed to determine the relative contribution of dissolved vs. particulate primary production.

Separation of labeled phytoplankton from inorganic C-14: Vacuum must be minimal (50-60 mm Hg) and the filter should not go dry. Inorganic C-14 should be removed from filters by acidification within the scintillation vial. An acceptable alternative procedure is fuming of the filter above concentrated hydrochloric acid. If rinsing with filtered seawater is done, verification is necessary to show that inorganic C-14 has been removed. Filters should not be rinsed with acid.

Dark Bottles and time zero blanks: Controversy exists and interpretation is ambigious. They are desirable to measure, but values should be reported separately.

Counting and efficiency determinations: Liquid scintillation counting is the method of choice. Internal spiking should be used to determine whether or not quench correction curves accurately correct for counting efficiency of all types of productivity samples (filters, filtrates, high color quench from pigments, etc.).

Calculating total inorganic carbon: If pH is above 7.5, then salinity alone should be sufficient to use for calculating total inorganic carbon in oceanic and estuarine waters. At lower pH's, total inorganic carbon should be determined. This is especially true in freshwater systems (regardless of pH) where calculations based upon pH and alkalinity are inaccurate.

4.1.1.2 Status:

Except for a few deficiencies, the group was impressed with the overall attention to detail and state-of-the-art protocol found in the C-14 primary production method sections of the quality assurance survey responses examined. The group felt that their quality was comparable to the general spectrum and similar methodological protocol found in the overall scientific community. However, it was not clear that all NOAA activity (especially bioassay work) was represented in the submissions made to us.

4.1.2 Other Microbial Processes:

This discussion deals with water column respiration, nutrient regeneration, nutrient uptake, and other chemical estimates of heterotrophic potential. The rate measurements discussed below are different from those using carbon-14 productivity in that some of these methods are used in few laboratories or are fairly new.

4.1.2.1 Inorganic Nutrient Utilization and Remineralization:

Under the general category of nutrient recycling, the elements nitrogen, phosphorus, and silicon can be considered. We received responses on nitrogen uptake and remineralization and on phosphorus uptake. Nitrogen measurements use the heavy isotope, N-15, and mass spectrometry; phosphorus measurements use radioactive tracer techniques. In general, the documentation provided indicated that analytical state-of-the-art procedures were used with both isotope approaches. As stated in our carbon-14 writeup, however, ultraclean sampling and incubation may be important, and the documentation provided did not demonstrate that clean techniques had been verified.

The documentation provided to us for two studies using nitrogen-15 indicated knowledge and implementation of the most up to date procedures and interpretations.

Although phosphorus isotope research has been practiced for a number of years, recent research has demonstrated

that traditional chemical analyses may overestimate the ambient orthophosphate pool. This bias results in consistent overestimates of uptake rates. Inability to measure correct othophosphate concentrations also complicates interpretations of nutrient cycling. Documentation provided to us indicates that NOAA-sponsored research is contributing to changes in our understanding of phosphorus dynamics by directly addressing determination of bioavailable phosphorus.

4.1.2.2 Water Column Respiration:

Early experimental efforts to estimate primary productivity and respiraton used changes of dissolved oxygen in water samples contained in bottles. This approach has been limited in application due to the fact that changes in dissolved oxygen are relatively slow in most circumstances. Enclosed systems, such as the University of Rhode Island's Marine Exosystems Research Laboratory (MERL) Tanks, lend themselves to estimates of net community primary production and respiration from diel oxygen measurements.

We received documentation of research measuring water column respiration using the enclosed system method and the more conventional water sample (bottles) method. The enclosed system (the MERL mesocosm) research was straightforward using methodology appropriate for the questions being addressed. Further, these studies complement other aspects of MERL research.

The contained water sample approach is inherently more complicated, involving sampling, analytical, and experimental problems. Many of the same considerations discussed in the carbon-14 productivity writeup apply here. Application of recently developed high precision techniques for oxygen analyses (Williams and Jenkinson, Limnol, and Oceanogr. 27, 576 (1982)) might improve detection limits. In any case, interpretation is hindered by several co-occurring microbial and chemical processes as is the case with most gross community rate measurements.

4.1.2.3 Bacterial Secondary Productivity:

The changing paradigm of carbon flow in the oceanic foodchain indicates the substantial role of bacterioplankton as secondary producers. As a result, a number of alternative methods are being developed to estimate bacterial productivity. The response received by us in this area employs two of these techniques with tritiated tracers. The first involves amino acid uptake to estimate protein growth, while the second uses thymidine uptake for DNA growth. For this work, ultraclean sampling and incubation techniques were demonstrated to be necessary and were used. In addition to metal-clean requirements, this work suggests the need for precautions

against organic contamination (specifically in regard to the substrate being measured). This research may change our appreciation of the role of bacteria in planktonic systems.

4.1.2.4 Status:

Overall the panel was impressed with the quality of research considered here. It is obvious that the majority of research is comparable to the highest quality of research being carried on outside of NOAA. This not only applies to analytical capability but also to conceptual development and interpretation. Deficiencies as pointed out in previous paragraphs concerned specific techniques, procedures, or data interpretation. In part these were due to the incomplete nature of the responses submitted or to the outline provided. For a more representative evaluation of NOAA-sponsored research, a more complete survey of NOAA activities would be required.

4.1.3 Recommendations:

There is the perception within NOAA and outside the agency that much of the data generated in NOAA pursuits is of inferior quality. This perception occurs, in large part, because a number of monitoring and experimental efforts in NOAA collect data that are not interpreted and seen by the general scientific community. These data are often relegated to the voluminous and poorly documented "grey literature".

The approach taken by some agencies to create quality assurance has been to create rigid methods handbooks and calibration standards. It is the opinion of this panel that such an approach is wrong and definitely should not be pursued by NOAA. It is generally viewed that rigidly promulgated and out-dated methodology does not guarantee quality assurance.

The NOAA administration must urge NOAA scientists and contractors to bring their "light out from under the bushel". Rather than endorsing and publishing methodology guidelines, NOAA must urge publicaton and open study of results and interpretation of collected data. While this is not always practical, every effort should be made on an administrative level to encourage publication of results (i.e., commitment of necessary funding, facilities and personnel). NOAA must encourage, at the administrative level, open examination and review of research plans. Only when it is perceived that NOAA data collection is done in a manner similar to the scientific community at large and not behind the protective door of the "NOAA mandated mission" will NOAA data be perceived to have quality assurance.

In research activities, data are collected to address questions posed on a hypothesis-oriented plan. In monitoring activities, data are often collected with a somewhat unclear long-term goal. The best way to assure high quality data from monitoring is to have a knowledgable scientist (preferably the same one or one working with the one who generated the data) examine and analyze the data during collection. Data collectors distant from data interpretors

and users of the data may not have a vested interest in data quality nor the opportunity to evaluate whether data are good or bad.

Maintenance of active research groups by NOAA at most facilities is, in our opinion, essential to any overall quality assurance program. The application and refinement of biological rate techniques is in a rapid state of flux (as is most of oceanography in general). Because of this, there is a long period between refinement of techniques and their implementation (often years). Thus, those agencies not actively involved in basic research run the real risk of having to always play "catch-up" relative to the state-of-art. Active researchers, on the other hand, maintain contact with on-going research through scientific meetings and publications and proposals in review procedures.

4.2 Benthic Rate Measurements:

The panel reviewed eight reports (four NOAA and four non-NOAA) dealing with sediments and interstitial water. The rationale for the work described was generally ecosystem understanding and basic research. A few studies were concerned with biological effects, long-term monitoring and ecological modeling. None were involved with enforcement.

The level of activity ranged from part-time efforts of single individuals to large-scale interdisciplinary efforts in different regions of the country, and dealt with lakes, marshes, lagoons, estuaries, and the continental shelf as well as experimental microcosms.

4.2.1 Status:

All of the studies reviewed appeared to use state-of-the-art methodology that was adequate to meet objectives. For the most part, these methods measure real-world conditions, though few could be characterized as being rapid, uncomplicated or inexpensive. This reflects the complex nature of the natural processes, the rates of which scientists try to measure. Methods are continually being improved to deal with newly recognized problems and both NOAA scientists and NOAA contractors appear to be actively involved in the development of new techniques. Scientists have addressed the problem of defining the precision and, where possible, accuracy of their chemical determinations.

There were two basic deficiencies. First, in some reports there was inadequate documentation of the impact of spatial and temporal variability on biological rate measurements. This problem is characteristic of ecology in general and clearly defines the need for future research. Oxygen uptake, heat and energy flow and nutrient regeneration studies measure the net result of many simultaneous processes within the benthic community. There is also a need to look at individual processes and quantify their contribution to the total benthic activity. This may increase our understanding of the factors contributing to the substantial spatial and temporal variability characterizing benthic environments. Second, few investigators reported any attempt to analyze errors in the overall methodology leading to a calculated rate.

At present there is also a variety of techniques used in the measurement of benthic metabolism. Unfortunately, it is difficult to intercalibrate these methods because of spatial heterogeneity and because no generally accepted criterion exists for accuracy in rate measurements. As a result we can not compare the errors associated with each of them.

4.2.2 Recommendations:

4.2.2.1 Better attempts should be made to assess spatial and temporal variability in benthic environments and its effects on rate processes because they contribute more to the variability of rate estimates than does analytical variability.

4.2.2.1 Investigators should attempt to determine how rates vary with the duration of the experiment.

4.2.2.3 Investigators should assess the overall error of their calculated rates by properly evaluating and combining the variance of component measurements in their rate estimates (e.g., initial and final concentrations, water volume measurement, surface area, etc.).

4.2.2.4 Efforts should continue to determine the influence of the conditions of measurements (e.g., design of metabolic chambers, quality of materials used, etc.) on the rates obtained.

4.2.2.5 Comparisons in terms of holistic measurements alone (e.g. oxygen uptake and heat flow) may be misleading in some cases because of variability in underlying processes. For example, two areas may show the same rates of total oxygen uptake but one area may have 10% chemical oxidation versus 90% in another. These possible underlying differences must be considered in light of the ultimate objectives of the study. When appropriate, further partitioning of total rates into individual processes that contribute to the total should be done to eliminate ambiguity.

4.2.2.6 Funds should be provided to prepare a state-of-the-art report reviewing methods and experimental designs used to measure benthic rate processes. The review should summarize the results of past work comparing core and in situ measurements, fluxes from pore water profiles versus direct measurements, various chamber designs, the importance of water circulation within chambers, the duration of experiments, and all other factors which are thought to affect benthic rate processes. A preliminary, first-cut report should be produced and evaluated by a workshop group consisting of NOAA scientists, contractors and other involved scientists working in this area (see below).

4.2.2.7 We recommend that NOAA, in cooperation with other agencies, convene a workshop to evaluate the status of studies on benthic rate processes (and to review the preliminary report described above). This workshop would be focused sharply on benthic metabolic processes,

specifically oxygen uptake, heat flow, nutrient regeneration, denitrification and other specific metabolic processes.

4.2.2.8 We believe that the nature of natural biological rate measurement is such that it will NOT be productive to engage NOAA scientists or contractors in complex intercalibration exercises. Our reason is that no generally accepted criterion exists for accuracy in rate measurements. Intercalibration of biological rate measurement techniques is not like intercalibration of chemical analytical methods. The spatial and temporal variability of biological rate processes in benthic environments (and perhaps elsewhere) are so great that it is unlikely that meaningful comparisons can be made regarding the acceptability of one method over another. However, we do recommend that NOAA support individual investigators who wish to compare or intercalibrate their methods. Benthic environments are so varied that two different methods might prove to give the same result in one but not in another situation. A more productive use of funds would be to support periodic workshops, such as described above, that would result in modification of existing methods and development of new techniques.

5.0 ACKNOWLEDGEMENTS

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6.0 APPENDICES

6.1 Appendix I: Laboratories and Types of Biological Rate Measurements Submitted for Review:

6.1.1 C-14 Primary Productivity

NOAA, Atlantic Oceanographic & Meteorological Laboratories, Miami, FL.

NOAA, Great Lakes Environmental Research Laboratory, Ann Arbor, MI.

NOAA, National Marine Fisheries Service, NEFC, Sandy Hook Laboratory, NJ.

State University of New York, Stony Brook, NY.

University of Georgia Marine Institute, Sapelo Island, GA.

University of Rhode Island (MERL), Narragansett, RI.

6.1.2 N-15 Uptake by Plankton

State University of New York, Stony Brook, NY.

University of Georgia Marine Institute, Sapelo Island, GA.

University of Rhode Island (MERL), Narragansett, RI.

6.1.3 P-33 Uptake by Plankton

NOAA, Great Lakes Environmental Research Laboratory, Ann Arbor, MI.

6.1.4 Marine Bacterial Protein or DNA Growth

NOAA, National Marine Fisheries Service, SEFC, Beaufort Laboratory, NC.

6.1.5 Plankton Respiration

NOAA, National Marine Fisheries Service, NEFC, Sandy Hook Laboratory, NJ.

University of Georgia Marine Institute, Sapelo Island, GA.

University of Rhode Island (MERL), Narragansett, RI.

6.1.6 Benthic Nutrient Regeneration

NOAA, Great Lakes Environmental Researach Laboratory (4 reports).

NOAA, National Marine Fisheries Service, NEFC, Sandy Hook Laboratory, NJ.

University of Georgia Marine Institue, Sapelo Island, GA.

University of Rhode Island (MERL), Narragansett, RI.

6.1.7 Benthic Community Metabolism

NOAA, Great Lakes Environmental Research Laboratory (2 reports).

NOAA, National Marine Fisheries Service, NEFC, Sandy Hook Laboratory, NJ.

San Francisco State University, Tiburon Center for Environmental Studies, Tiburon, CA.

State University of New York, Stony Brook, NY.

University of Georgia Marine Institute, Sapelo Island, GA.

University of Rhode Island, (MERL), Narragansett, RI.

6.1.8 Macrofaunal Respiration under Laboratory Imposed Contaminant Stress

NOAA, National Marine Fisheries Service, NEFC, Milford Laboratory, Conn.

6.1.9 Responses Received, but not Critically Reviewed

Algal growth via cell counts and fluorescence, State University of New York, Stony Brook.

Zooplankton egg production and growth, University of Rhode Island (MERL).

Zooplankton grazing on natural seston, Great Lakes Environmental Research Laboratory.

Effect of lipophilic pollutants on marine zooplankton energetics, Woods Hole Oceanographic Instituiton.

Mixed function oxidase activity in fish and fish growth via otolith measurements.
Lawrence Livermore National Laboratory.