Salmon Farming and Noxious Phytoplankton

Summary of a Workshop
February 22-23, 1990

Sponsored by Washington Sea Grant and University of Washington

Frieda B. Taub, Chairman
Terry Nosho, Editor

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PREFACE

Information on ways to reduce the loss of fish resulting from noxious phytoplankton blooms has been identified as the top research need of the net-pen salmon farming industry. The Washington Sea Grant Program committed funds to research the problem beginning in 1990. However, before the research effort began, industry took devastating losses during the summer of 1989. The mortalities resulted from an uncommon bloom of the dinoflagellate *Heterosigma akashiwo*. Previous losses of salmon to phytoplankton blooms in Washington were caused primarily by the diatom *Chaetoceros convolutus* or *c. concavicornis*. With a sense of urgency, Washington Sea Grant Marine Advisory Services and University of Washington experts decided to put on a workshop that would provide salmon farmers essential background information regarding blooms, species, and mitigation methods on an international level. At the same time, it was desirable to discuss the Washington Sea Grant Project with growers in order to cement a cooperative and standardized field effort. This report outlines the proceedings of the workshop, and is intended to serve as a reference source for the attendees.

ACKNOWLEDGMENTS

Our special thanks go to each of the speakers and respective organizations for taking time to participate in this workshop. We also greatly appreciated the input provided in the planning process by industry members Sandy Bill and Chris Gibson. Finally, we are grateful to Trish Peyton for distribution of the program, to Carol Ovens for editorial review, to Suzie Higert and Robyn Bowman for word processing of this manuscript, and to Pat Thomas for compilation of the registration list.

Terry Nosho and Frieda B. Taub
Seattle, WA

PROGRAM

SALMON FARMING AND NOXIOUS PHYTOPLANKTON

Thursday, February 22 South Campus Center, University of Washington

8:45 a.m. **Workshop Introduction and Objectives**
Frieda B. Taub, School of Fisheries, University of Washington

SESSION I

9:00 **Background on Noxious Phytoplankton**
Rapporteur: Rose Ann Cattolico, Department of Botany, University of Washington

Ecological Relationships of Noxious Algae in Northwest Waters
F.J.R. (Max) Taylor, University of British Columbia

Evolution and Design of Monitoring Programs
Edward A. Black, Ministry of Agriculture and Fisheries, British Columbia

10:30 Coffee Break

Washington Sea Grant Project Briefing
Jack Rensel, School of Fisheries, University of Washington

Noon Lunch on your own

SESSION II

1:00 p.m. **Mitigation Discussion**
Rapporteur: Walton W. Dickhoff, School of Fisheries, University of Washington

Insurance Company Perspectives
Craig A. Pankow, Stanley T. Scott & Co., Seattle

What is Being Done to Save Fish?
- British Columbia: Edward A. Black, Ministry of Agriculture and Fisheries, British Columbia
- Norway: Per O. Heggelund, AquaSeed Co., Seattle
- Chile: Jon M. Lindbergh, Aquaculture Consultant, North Bend

Early Warning Possibilities
- Satellites: Mary Jane Perry, School of Oceanography, University of Washington
- Spectrographic Imaging: Gary A. Borstad, Borstad Associates, Sidney, British Columbia

Routine Monitoring: Advantages and Disadvantages
James R. Postel, School of Oceanography, University of Washington
Regulatory Comments, William Moore, Washington Department of Ecology

3:00 Coffee Break and Growers' Meeting (concurrent)

3:45 **Summary of Sessions By Rapporteurs**

4:15 **Growers' Session: Comments and Questions**
Leader: Therese Wells, Scan Am Fish Farms

5:00 Adjourn

Friday, February 23 Oceanography Teaching Building, Room 306

8:30 a.m. **Training Session**
Leader: James R. Postel, School of Oceanography, University of Washington
Rita Horner, School of Oceanography, University of Washington
Jack Rensel, School of Fisheries, University of Washington

Introduction
Videotape on Noxious Species
Laboratory Work
- Microscopic Demonstrations of Problem Algae
- Phytoplankton Sampling Gear
- Microscope Calibration and Count Standardization
- Sample Analysis

12:30 p.m. Adjournment

SESSION I—SUMMARY

Background On Noxious Phytoplankton

Rapporteur: Dr. Rose Ann Cattolico, Department of Botany,
University of Washington

Ecological Relationships of Noxious Algae in Northwest Waters

The presentations made in this session were concerned with the biology of noxious phytoplankton blooms and monitoring. Max Taylor explained that: (a) blooms of photosynthetic algae are naturally occurring, usually in the spring, with a small recurrence in fall; (b) given the reproductive capacity of these organisms, it takes approximately two weeks to progress from very low to very high numbers of cells; (c) bloom organisms are basically cosmopolitan and their geographic location is usually temperature-dependent. Most importantly, some of these algae have resting spores or cysts that allow them to "tough out hard times," and these cysts then serve as seeds for future blooms. Only a few algal types are harmful. It appears that natural populations of fish can avoid "cloud-like" phytoplankton formations, and may also have a natural immunity to toxic algal blooms. Having fish in pens makes a difference; these fish may be physically unable or intrinsically less capable of an avoidance response.

Noxious organisms kill marine fauna by (a) physically damaging gills, (b) altering oxygen levels, or (c) releasing toxins. These noxious algae affect filter feeders by making them toxic. Paralytic shellfish poisoning (PSP), diarrheic shellfish poisoning (DSP), and amnesic shellfish poisoning (ASP) represent three health hazards that result from shellfish feeding on specific algae. Two examples of anthropomorphic impact on algal bloom formation were presented. It was suggested that the dumping of huge volumes of water used as ship ballast most likely has no impact on algal growth in a particular region. However, in confined areas where population density is high, growth of algae in local waters may be affected. Changes from a dominant diatom to a flagellated algal population have been documented.

Evolution and Design of Monitoring Programs

Ed Black reminded us that not only marine, but also freshwater organisms are affected by phytoplankton kills. He stressed that the following factors are critical in the management of phytoplankton blooms by salmon farmers:

A) Site location of a farm is critical. Areas that have a higher probability of bloom formation can be identified. Remember that there is a correlation between water flush time vs. bloom potential. Knowing the local oceanography is also important. The growth of different algal species will depend on whether the water column is stratified or well mixed.

B) Criteria for a monitoring or warning program must be established. Questions that must be addressed include:

1. What should the distribution of sampling sites be?
2. Where should sampling be done? (in shore, off shore)
3. How frequently should sampling be done?
   (i.e. given plankton growth rate, or current flow)
4. How must monitoring be done?
   (composition of the warm water column, number of algae per volume of water, what algae are involved) Consistency must be the rule.

C) Communication among farmers must be enhanced. A program used in Canada was outlined. The components of this program include education (e.g. workshops on sampling techniques or fish physiology), an insurance incentive (monitoring algal blooms considered critical), and networking (e.g. no charge telephone line) among farmers, research scientists, consultants, processors, and insurance companies.

Lastly, Jack Rensel outlined a program that could be used for monitoring/mitigating noxious phytoplankton blooms. The key points of this program are:

A) Organize a cohesive monitoring effort that will serve for early bloom detection and crises management.

B) Provide training, field support, and technical advice including calibration of equipment and instruction on counting techniques so that interfarm data are consistent.

C) Provide field testing of mitigation systems.

D) Coordinate an assessment of environmental parameters as well as algal profiles at each farm site to serve as baseline data for the analysis of bloom potential and bloom development.

E) Develop and test more rapid monitoring techniques for observing noxious algal species.

SESSION II—SUMMARY

Mitigation Discussion

Rapporteur: Dr. Walton W. Dickhoff, School of Fisheries,
University of Washington

Summarizing the session on mitigation of noxious phytoplankton reminds me of an analogy that Dr. Sandy Bill once made about the salmon culture industry in general: "Running a net-pen salmon business is like assembling an airplane while in flight." The technology must be developed to deal with fundamental problems while the business is trying to operate at a profit. The task of mitigating effects of noxious phytoplankton is complicated because many of the problems need basic study to be defined. In the first session of this workshop, the overview of the field pointed out many basic questions that need to be addressed before a truly rational approach to the noxious phytoplankton problem can be made. Such fundamental questions as: What specific organisms are of concern? Are there particular life stages when they are most threatening? What factors control their abundance? Are they localized or distributed throughout the water column? Answers to these questions would narrow the approach to mitigation. The most economical approach would be to do the basic research first and then deal with solutions to the noxious phytoplankton problem. Yet the catastrophic rate of fish mortality apparently due to noxious phytoplankton is so great that it demands mitigative effort now. Clearly it is one of the major concerns of marine salmon farmers in the Pacific Northwest.

It is imperative that both basic research and mitigation evaluation on noxious phytoplankton be pursued simultaneously. Furthermore, progress can be maximized if there is widespread participation and cooperation among both farmers and researchers. The noxious phytoplankton problem is industry-wide, and everyone will benefit if all involved participate in helping to find a solution.

The discussion on mitigation covered a wide range of concerns and perspectives:

International efforts to save fish were discussed by several speakers. Ed Black, of the Ministry of Agriculture and Fisheries in British Columbia, covered the situation there. The experience in Norway was described by Per Heggelund of AquaSeed, Seattle; and Jon Lindbergh, Aquaculture Consultant, North Bend, discussed the concerns of salmon farmers in Chile.

Early warning possibilities using satellites were addressed by Dr. Mary Jane Perry of the School of Oceanography, University of Washington. Spectrographic imaging, an alternative that is closer to the ground, was described by Gary Borstad of Borstad Associates, Sidney, British Columbia.

The advantages and disadvantages of routine monitoring were discussed by Dr. James Postel of the School of Oceanography, University of Washington.

Here is a brief summary of what was said about these various topics. Further details may be found in the section entitled "Papers and Outlines."

Insurance Company Perspectives

Craig Pankow discussed actions that growers should take, and he also gave a philosophical approach to insurance. He pointed out that insuring fish farms is an international concern, covering farms in at least seven countries. However, there are not very many viable markets; in fact, there has been a 150 percent loss-ratio in insuring fish farms. In order to keep premium rates and deductibles low, it would be wise not to call in claims for minor losses, but wait in case there is a catastrophic loss. Fish losses due to phytoplankton blooms have accounted for a large percentage of claims, and if such claims continue or increase, it may be necessary to penalize such sites by increasing rates or deductibles.

Fish farmers may do several things to enhance their relationship with their insurer. If more information is provided to demonstrate scientifically sound site selection and fish-rearing technology, a better policy can be developed. Farmers should also take measures to reduce or prevent losses. If the farmer has defended the site, this may help the situation from the underwriter's perspective. Farmers are encouraged to develop a personal relationship with their broker or underwriter. Finally, it is important to share information with neighbors, and to show that the industry is working together to solve problems for everyone's benefit. The 1990-1991 period is a critical time in the industry, and actions should be undertaken now.

What Is Being Done to Save Fish?

British Columbia

Ed Black pointed out that site selection is the single most important factor to reduce or eliminate phytoplankton problems. Nutrient versus light limitation and locations of farms near boundaries of water are among important elements to consider in selecting a site. Farm design may facilitate mitigation procedures. Multiple water intakes for land-based systems, cages that can be raised or lowered, and cages that can be easily detached from their moorings are examples of advantageous design factors. Incorporating cages in towing structures would facilitate moving the farm to alternative locations. If the location already has been selected and the cages have been constructed, there are a number of mitigation measures to consider.

Monitoring for phytoplankton type and abundance will provide a baseline of information to determine whether phytoplankton blooms are occurring, and whether they may be of concern. If toxic blooms are present, then preemptive harvests or stock transportation may be in order. Other mitigative efforts may be directed toward reducing oxygen demand or shielding the stock. For example, nonporous barriers could be constructed, bubble curtains could be installed, or clean water could be injected into the pens.

An important caveat with these mitigative procedures is that they may make the situation worse. Examples were shown of farmers towing their pens into regions of higher phytoplankton abundance. Attempts to provide clean water may backfire by causing a concentration of phytoplankton within the pens or forcing fish into regions of high phytoplankton concentration. Two major points were emphasized: 1) Not all procedures may be effective in dealing with noxious blooms at all times; the farmer should have a tool-kit of mitigative procedures to use depending on specific circumstances. 2) It is important to monitor during mitigation in order to determine if the procedure was effective, and to establish a database of conditions in which a particular procedure was or was not effective.

Norway

Per Heggelund described the three phytoplankton blooms that were of significance in the 1980s in Norway. One striking aspect of these blooms is that they originated in different locations apparently because of different conditions. The first originated in the north, a second originated from the south, and the last one originated from inside a fjord. Since most of the farms are located on the southwest coast of Norway, the bloom originating in the south was of major concern. The major mitigation effort was focused on moving the farms to areas of low phytoplankton abundance. Approximately 119 farms were moved in a period of 3 weeks at a cost of $4-5 million. In spite of this effort, more than $4 million worth of fish were lost. During the last five years, a monitoring and communication system was set up to keep farmers informed of problems with phytoplankton.

Chile

Jon Lindbergh described the salmon pen-farming industry in Chile, where the first and only recognized phytoplankton bloom (*Heterosigma* and other species) occurred in 1988. Reactions of the farmers varied. Some panicked and dropped the nets of their cages only to lose fish as a result of the mitigation effort. Since the farming industry is relatively new in Chile, it is not clear how much of a long-term threat will be posed by phytoplankton. It is clear, however, that some sites may be more at risk than others.

Early Warning Possibilities

Satellites

Mary Jane Perry discussed remote sensing using satellites. Information from available satellites can be used to determine biomass, sea surface temperature and currents, among other parameters. Limitations to using satellite information include the requirement for no cloud cover, poor resolution of specific areas and repeat coverage of a particular area of interest. Furthermore, only the top 5 meters of ocean surface can be interrogated, and specific phytoplankton species cannot be identified. Water turbidity may interfere with estimates of biomass. It is anticipated that during the 1990s more satellites will be in place that have greater resolution and repeat coverage.

Dr. Perry also discussed the use of immunological techniques that could be used to quickly identify phytoplankton species on-site. Once the noxious species is (are) identified, specific antisera to these species could be generated and used in fluorescent or immunoprecipitin reactions. Such techniques could be valuable in a monitoring program.

Spectrographic Imaging

Gary Borstad described some advantages of using spectral measurement techniques from aircraft flying over the areas of concern: data are available almost immediately, visual verification can be obtained using photographs, cloud cover is not as problematic, and on-site sampling can be done for additional verification. Sea temperature and chlorophyll fluorescent data can be collected with high resolution. Although spectrographic imaging is relatively expensive, nonimaging techniques can be used at much reduced costs. It appears that this may be a useful tool to identify the extent and progress of blooms, but it may not be the best method for routine monitoring.

Routine Monitoring; Advantages and Disadvantages

James Postel discussed routine monitoring, and pointed out that it is not an end in itself. Routine monitoring provides data for other functions, such as making policy or management decisions, identifying or defining problems, evaluating progress, and developing a historical record. Routine monitoring is limited by the fact that it cannot in itself eliminate the problem. However, it is essential to determine the abundance of particular phytoplankton species and their temporal and geographic relationships.

It was emphasized that what is needed in a monitoring program is quality data that can be used. Data must be sufficiently frequent so that blooms can be detected early enough to do something about them. Gaps in data collection create problems. The more complete the data set, the easier it will be to develop and evaluate mitigation techniques. Broad participation in the monitoring program will reduce geographic gaps in the data. Training of personnel participating in a monitoring program is needed to ensure consistency from site to site. Uniform procedures in data collection will validate comparison of data from site to site. Finally, it is important to realize that collection and analysis of data need coordination and communication.

The Sea Grant-sponsored monitoring program for noxious phytoplankton will be most successful if it has broad industry support and participation. The industry is the ultimate beneficiary. This is a perfect opportunity for researchers and industry to get together to define problems and develop mitigation techniques.

William Moore, of the Washington Department of Ecology, was present to answer questions and make comments on regulations governing the industry.

Growers' Session

Leader: Therese Wells, Scan Am Fish Farms

Salmon farmers submitted the following list of needs. This list essentially refers to Washington Sea Grant's project on noxious phytoplankton.

1. Assistance, guidance, and training in development and implementation of the monitoring program.

2. Additional details of the monitoring program.

3. Assistance in analyzing effectiveness of mitigation measures.

4. Analysis and compilation of raw data collected by growers.

5. Timely feedback of analyzed data.

6. Rapid response in crisis situation.
   - test area farms
   - 24-hour access to key personnel

7. Toxicity of *Heterosigma* and its effect on marketability of salmon

APPENDIX I—PAPERS AND OUTLINES

SESSION I—BACKGROUND ON NOXIOUS PHYTOPLANKTON

A number of speakers at the workshop spoke from written texts. Others used outlines only. This section contains both, and for the sake of continuity, we have left them in the order in which they appeared on the program. It is obvious that outlines will have little meaning except to those who attended the workshop; however, further details on the various topics can be gained by contacting the speakers at the addresses shown in Appendix III.

Ecological Relationships of Noxious Algae in Northwest Waters.

F.J.R. "Max" Taylor, University of British Columbia

General

- A. Theory vs. actual blooms
- B. Phases of blooms
- C. Species requirements differ, e.g. diatoms vs. flagellates
- D. Locations differ
    - a. Stability
    - b. Sources and rates of nutrients supply
    - c. Which species?
- E. Situational ecology
    - a. Multiyear regional study
    - b. Monitoring

Ecology

- A. Prediction (indices, models)
    - a. Regular background on seasonal blooms
        - 1. Spring bloom—diatoms
        - 2. Summer bloom—flagellates
        - 3. Fall bloom—diatoms
    - b. Timing
    - c. Water Stability—the two strategies
        - l. Stratification
            - Nutricline at about 10 meters
            - High light, low nutrients above nutricline
            - Low light, high nutrients below nutricline
        - 2. Migration—one meter per hour maximum
    - e. Elsewhere
        - 1. *Chattonella* (chloromonad)
        - 2. *Gymnodinium (dinoflagellate)*
            - *G. breve*
            - *G. nagasakiense (=Gyrodinium aureolum)*
- B. Noxious Organisms
    - a. Kill marine fauna
        - 1. Fish, other
        - 2. Damage, oxygen and toxins
    - b. Makes filter feeders toxic
        - 1. Paralytic Shellfish Poison—PSP
        - 2. Diarrheic Shellfish Poison—DSP
        - 3. Amnesic Shellfish Poison—ASP

c. Examples

1. Diatom fish kills—*Chaetoceros concavicorne (-is), c. convolutum (-us)*
2. Flagellate fish kills—*Heterosigma akashiwo* (Chloromonad)
3. PSP—*Protogonyaulax (Alexandrium)*

C. Nutrition

a. Energy—solar

b. Raw materials—C H O N S P...iron, vitamins

D. Reproduction

a. Division—rate

b. Resting Stages

1. Diatoms resting spores
2. Flagellate resting cysts

E. Distribution—latitudinal cosmopolitans

F. Beneficial/harmful?

a. Natural exposure

b. Adaption

c. Vulnerability

Noxious Phytoplankton Blooms

A. Plankton

a. Phytoplankton

b. Zooplankton

B. Algae

a. Simple plants

b. Microscopic to seaweeds

C. Blooms

a. Millions per liter

b. Natural—occur in spring, summer and fall

c. Unnatural blooms—pollution

D. Organisms

a. Diatoms—wall of silica

b. Flagellates—swim by flagella

c. Dinoflagellates, chloromonads, prymnesiomonad

Evolution and Design of Monitoring Programs

Ed Black, Ministry of Agriculture and Fisheries, British Columbia

Design Criteria for a Warning Program

A. Source of the problem

a. *In situ*

b. Longshore transport

c. Offshore transport

B. Sampling frequency

a. Plankton doubling rates

b. Current time to next station

C. Distribution of sampling sites

a. Distribution of algal sources

b. Distribution of industry

c. Historical records of blooms

d. Currents
e. Boundaries of water masses
f. Water mass structure and persistence
g. Residence time of water

Structure of the British Columbia Phytoplankton Monitoring Program

- A. Communication
  - a. Recorded Information—no charge telephone service
  - b. Interactions:
    Researcher—Farmer—Farmer—Support System
  - c. Support system includes consultants, processors, and insurance companies.
- B. Quality Control
  - a. Species composition of vertically integrated qualitative samples
  - b. Species of isolated algae
  - c. Concentration of problem algae in discrete quantitative samples
- C. Motivation
  - a. Loss of insurance coverage
  - b. Loss of ability to effectively employ some mitigation measures
- D. Education
  - a. Purpose of sampling—mechanism of fish mortalities
  - b. Familiarization with sampling techniques
    - 1. Parameters measured:
      - Dissolved oxygen
      - Temperature
      - Salinity
      - Species occurrence
      - Weather conditions
      - Water color
    - 2. Sampling:
      - When to sample phytoplankton and DO
      - Use of standardized data recording sheets
      - Sample preservation and storage
  - c. Equipment use and maintenance
    - 1. Phytoplankton nets
    - 2. Sampling bottles
    - 3. Oxygen meters and titrations
  - d. Phytoplankton identification
  - e. Lessening the effects of harmful algae

Washington Sea Grant Project Briefing
Noxious Phytoplankton and Marine Salmon Culture

Jack Rensel, School of Fisheries, University of Washington

In order to characterize potential net-pen sites more carefully, some of us began limited studies of fish-killing algae in Puget Sound about 3 years ago. To help explain the Sea Grant project goals, I would like to begin by describing the Sea Grant-sponsored staff, and what they contribute to the team.

Leadership and oversight are provided by Drs. Frieda Taub and Karl Banse. Dr. Taub is an algal culture expert and toxicologist. Dr. Banse is a biological oceanographer with extensive knowledge and familiarity with marine phytoplankton dynamics. Identification, enumeration, and ecology of phytoplankton species are provided by Dr. Rita Horner. Oceanography tasks and coordination with growers are provided by Dr. James Postel, Senior Oceanographer in the School of Oceanography. Dr. Ralph Elston, Battelle Marine Laboratory at Sequim, is in charge of fish pathology services. I will be involved in field work and laboratory studies on the effects of noxious algae on fish, although much of my recent background involves descriptive biological, chemical, and physical oceanographic studies. The project goals are described as follows.

The first goal is to organize a cohesive monitoring effort for early detection and management of noxious phytoplankton blooms. I believe that routine monitoring of phytoplankton and hydrographic parameters at the farm sites is the most cost-efficient and most effective means possible to detect the onset of a bloom. Once either the hydrographic parameters or the phytoplankton monitoring shows some unusual changes, other means of monitoring, such as collection of samples from remote areas or visual observation from airplanes, may be warranted.

Monitoring means many things, and has many benefits. It is something that each farm needs to do because the conditions are often site-specific. It means becoming familiar with the water column at a net-pen farm, knowing its physical properties like temperature, water clarity, and water motion patterns and becoming familiar with the dissolved oxygen concentrations and salinity and how they change over various time periods.

A practical example of the value of routine monitoring can be drawn from the recent *Heterosigma* blooms in North Puget Sound. Minor fish mortality was first detected at one of the sites in early August. Thanks to Scan Am Fish Farms, I was able to collect some samples shortly thereafter that suggested *Heterosigma* cells were diminished with depth, but there was no depth trend for *Chaetoceros convolutus,* also present in the water column. That initial mortality may have been due to *Chaetoceros,* as it is known to kill at relatively low concentrations, but the observation of *Heterosigma* was certainly of interest at that early date. What this experience shows is that there was possibly a three-week early warning last summer, before the main bloom. When the major *Heterosigma* bloom took place, three weeks later on Labor Day weekend, the bloom was highly concentrated and caused considerable damage.

The second goal is to provide training, field support, and technical advice to growers in their routine monitoring efforts. This includes calibration of equipment and counting techniques essential to interfarm communication, and standardization of monitoring and reporting efforts to some degree. For example, at present there is no universally accepted method to count *Heterosigma* cells using a microscope. For *Chaetoceros,* some individuals may use filtered samples; others may use regular microscope slides; and still others use counting chambers.

Goal number three is to assess the effectiveness of airlift pumps, and skirting or aeration at participating farms, prior to bloom events. We will use a computerized probe (CTD) that gives a continuous measure of salinity and temperature in and around the pens. We should be able to use these properties as tracers to assess how well the pumps are able to dilute the warmer, less saline surface water. This CTD probe will connect to a portable computer to provide fast data reduction and display and allow us to make dozens of casts per day, compared to a few that would be possible using non-computerized probes, such as the YSI equipment that many farms presently use. (YSI is a brand name.) Again, I should stress that there is likely no universal solution that can be applied to every farm.

The fourth goal of this project is to characterize conditions that precede and accompany problem blooms in order to seek indicators of bloom development. This may be a practical way of gauging the increased probability of noxious blooms and providing a longer lead time for growers. Several factors control the occurrence of phytoplankton in Puget Sound, but it has been shown that sunlight is a dominant one in terms of limiting the growth of phytoplankton populations. We plan to place recording light meters at each of the participating farms to help sort out the effect of this factor from other factors such as water temperature, tidal amplitude, and nutrient concentrations.

While growers will be inspecting samples for noxious species, we will periodically inspect samples collected by them to count all species present. It may well be that the presence or absence of some species prior to a noxious bloom may give another form of early warning.

The fifth goal of the project is to develop and test new rapid-monitoring methods for noxious species to be used by the growers and to develop and publish a guide that contains methods for monitoring and bloom mitigation. We need a way to shorten the time required for concentration of water and counting of samples. Having to wait even a couple of hours may be too long for farms that do not have any means to estimate phytoplankton abundance, other than counting. We need to standardize methods for the collection of environmental data (e.g., temperature, salinity, dissolved oxygen, and nutrient samples) and phytoplankton (e.g., collection, preservation, and identification techniques).

In conclusion, this is still relatively new ground that we are treading on, and the solutions to problems may come rapidly if we apply ourselves intently to the problem. The fish grower's primary job is to grow fish. That definition now demands that the grower know what is going on in the water column and how to keep his fish alive. We hope that our project will significantly aid in that process.

SESSION II—MITIGATION DISCUSSION

Insurance Company Perspective On Noxious Phytoplankton

Craig A. Pankow, Stanley T. Scott & Co., Seattle, WA

This is a short synopsis of the insurance industrie's view of noxious phytoplankton in Canada and the United States, as well as aquaculture operations around the world. The main points to emphasize are as follows:

Mortality Insurance Overview

It is important to recognize that the viable insurance firms that write mortality insurance can easily be counted on two hands (more accurately on one). From an overall perspective, insurance companies have not found this line of coverage immensely profitable. In fact, many markets have loss ratios that run 200-300 percent. Algae blooms caused severe losses in 1989, and the insurance industry is keeping a close watch on farms that are threatened by this peril.

Given the fact that many insurance carriers have lost money and that the reinsurance market is now paying close attention, one can expect rate and deductible increases, especially if there has been a large claim.

Research and Insurance Carrier Perspective

Since this is a tough coverage to obtain, it is important to prevent a claim by taking every possible measure to protect the operation. Insurance companies do not take a long-term perspective on the coverage, thinking that some day in the future they will make their profits. If an underwriter loses money today, you can be certain he will have to answer to top management, and it could cost him his job.

In addition, it is not a coverage where there are millions of policyholders. It is a coverage where one or two bad claims can literally ruin an entire year's loss ratio.

Scientific research is greatly needed and appreciated by the aquaculture community. In the long run, it will be what makes this industry survive. Unfortunately, farms cannot wait for the full benefits of scientific research. They must take action today to protect themselves from blooms. If a farmer waits, chances are he could lose the ability to obtain insurance, or rates and deductibles could become so high that the farm is unable to continue operations.

Farmers' Response

Today's salmon/aquaculture operation needs to consider every viable defense system on the market. It is important to communicate with all farmers in the region and around the world. Of course, a bloom watch program should be established. (I know this is being done by local farmers.)

With the large deductibles in force today, even if a defense system saves only a small percentage of inventory, one can be many dollars ahead. Each farmer should try to know in advance just what his defense system can and cannot do. A plan of action must be made in advance, and this plan should change depending on the severity of the bloom and how much advance warning is given. Considering what is at stake, an overprotective approach should be taken whenever in doubt.

In Norway, communication has been of great benefit to the farmers, as was demonstrated during the terrible blooms that took place during 1988. During that time, blooms were tracked and many systems were towed to safety when it was thought it was too risky to stay and fight. In our region, it appears that decisions will have to be made more quickly, but if plans are made in advance, hopefully the results will be as good.

Summary

The aquaculture industry needs to be prepared today, not in five years, for a severe bloom. Farmers must consider all viable options to protect themselves, and must invest in protection equipment and bloom strategies. No viable defense system or action should be overlooked, as insurance companies will penalize those who do not take appropriate risk management procedures.

Mitigation Efforts in British Columbia

Ed Black, Ministry of Agriculture and Fisheries, Sidney, B.C.

Integrated Management for Plankton Problems
- Site Selection
- Farm Design
- Monitoring: environment
  - product

Site Selection
- Nutrient vs. light limitation
- Boundaries of water masses
- Water residence time
- Local or imported sources of seed
- Currents
- Historical records

Farm Design
- Multiple intakes for land-based plants
- Cages or rafts that permit cultured organisms to be raised or lowered
- Easily detached moorings
- Physical structures that are designed to be towed during culture

Mitigation
- Role of monitoring in mitigation

- Techniques of mitigation
  - Preemptive harvest
  - Transport of stock
  - Reduction of metabolic oxygen demand
  - *In situ* shielding of stock
    - nonporous barriers
    - bubble curtains
    - injection of clean water

Recent Algae Blooms in Norway Affecting Salmon Farms

Per Heggelund, AquaSeed, Seattle, WA

The following table summarizes recent blooms in Norway.

ITEMS	1988 BLOOM	1989 BLOOM
Time Period	9 May-3 June	3-19 August
Algae Species	*Chrysochromulina polylepis*	*Prymnesium parvum*
Geographic Distribution	Lysikil (Sweden)— Bomlo (Norway)	West of Sauda and Hylen-Inside Karmøy
Algae Concentration	10-30 (max 90) mil cells/l	0.5-10 mil cells/l
Algae Depth	14-25 (max 30) meter	N/A
Toxicity	Breakdown of membrane osmoregulation	N/A
Salinity in Algae Front	20-22 ppt	5-25 ppt
Algal Front Propagation	20-30 km/day	N/A
Number of Farms Towed	119	N/A
Loss of Farmed Salmon (tons)	670	750

The Impact of Noxious Phytoplankton on Marine Salmonid Farms in Chile

Jon M. Lindbergh, Aquaculture Consultant, North Bend, WA

Background

Chilean marine salmon farming activities are carried out from Puerto Montt at 41 degrees south latitude to Punta Arenas at 53 degrees south latitude. The salmon industry in Chile in general has very low capital and operating costs, but high transportation costs.

The Chilean coast from Puerto Montt south is characterized by deep fjords and extensive islands. Salinity, temperature, and water depth in the Tenth Region near Puerto Montt and the island of Chiloe are similar to those in Puget Sound and the Strait of Georgia. The tidal range in the Tenth Region is somewhat larger.

Most production takes place in the Tenth Region, but significant harvesting is done near Puerto Aysen 400 km to the south. During the 1989/90 harvesting season, about 60 percent of production was coho, 30 percent was Atlantic salmon, and about 10 percent was rainbow trout. Small numbers of Chinook and Masou salmon were also raised. Total production is estimated to have been about 12,000 metric tons.

Noxious Phytoplankton Blooms

The Chilean salmon industry has faced one major bloom of noxious phytoplankton, which occurred in the southern hemisphere spring in September 1988. The primary organism was *Heterosigma*, but other noxious plankton were reported, particularly towards the end of the bloom. Total countrywide mortality over a period of about ten days was estimated to be between 20 and 30 percent. Smaller blooms have been reported subsequently, but without serious fish mortality.

A substantial bloom was reported in the outer islands west of the Strait of Magellan in December 1989, which impacted the wild catch fishery. No salmon farming exists in the areas affected.

The 1988 bloom was first identified in the waters near Puerto Montt (see Figure l) and moved towards the south and east over a period of several days. It was highly visible from the air. The concentration of organisms was quite high at some times and places, but was patchy and uneven. Water masses with high concentrations of phytoplankton seemed to stagnate in certain bays with low circulation. The bloom extended down to at least ten-meter depth.

Marine salmonid farms in the Tenth Region were affected differently. Two or three farms located in bays with shallow water and low circulation had almost 100 percent mortality. One of these reported heavy plankton concentrations all the way to the bottom at ten meters and the bloom stayed for days. Other farms in more open water with strong currents were not affected at all. Quite a number of farms incurred mortalities of between 20 and 50 percent, with chance appearing to be a large factor. Atlantic salmon and rainbow trout were affected more quickly than coho.

Short-Term Responses to the 1988 Bloom

The 1988 bloom caught Chilean salmon farms unprepared and there was no coordinated response. Some of the short-term actions taken were as follows:

- Most growers stopped feeding to reduce metabolic activity.

- Several sewed netting on top of their nets and lowered the fish into deeper water. The fish were seriously stressed by this procedure, but it is believed to have saved fish at some farms.

- A few attempted to tow net-pen facilities to safer waters with varying success.

- Quite a number of farms preemptively harvested fish that were threatened with the bloom. Preemptive harvesting in September in Chile involves several serious capable of handling the huge volume of fish all at once, so many were frozen in the round. Nevertheless, preemptive harvesting did help cut financial losses.

- Some growers panicked. One farm near Puerto Aysen heard about the bloom to the north, sewed up the top of its nets, and dropped the fish into deep water and currents. Fish were trapped in folds of netting and losses were high. The bloom did not come within 300 kilometers of that farm.

Long-Term Responses

In the period since the 1988 bloom, Chilean marine salmonid producers have had time to evaluate the bloom and plan measures to mitigate the effects of future blooms. Some actions taken have been:

- The establishment of a warning network that includes individual farms, govern ment agencies, universities, and private laboratories.

• Consideration of reducing the number of farms in shallow, closed-end bays and educing the biomass in such bays.

• Planning strategies for towing threatened facilities to safer waters. This is an option for only a limited number of farms.

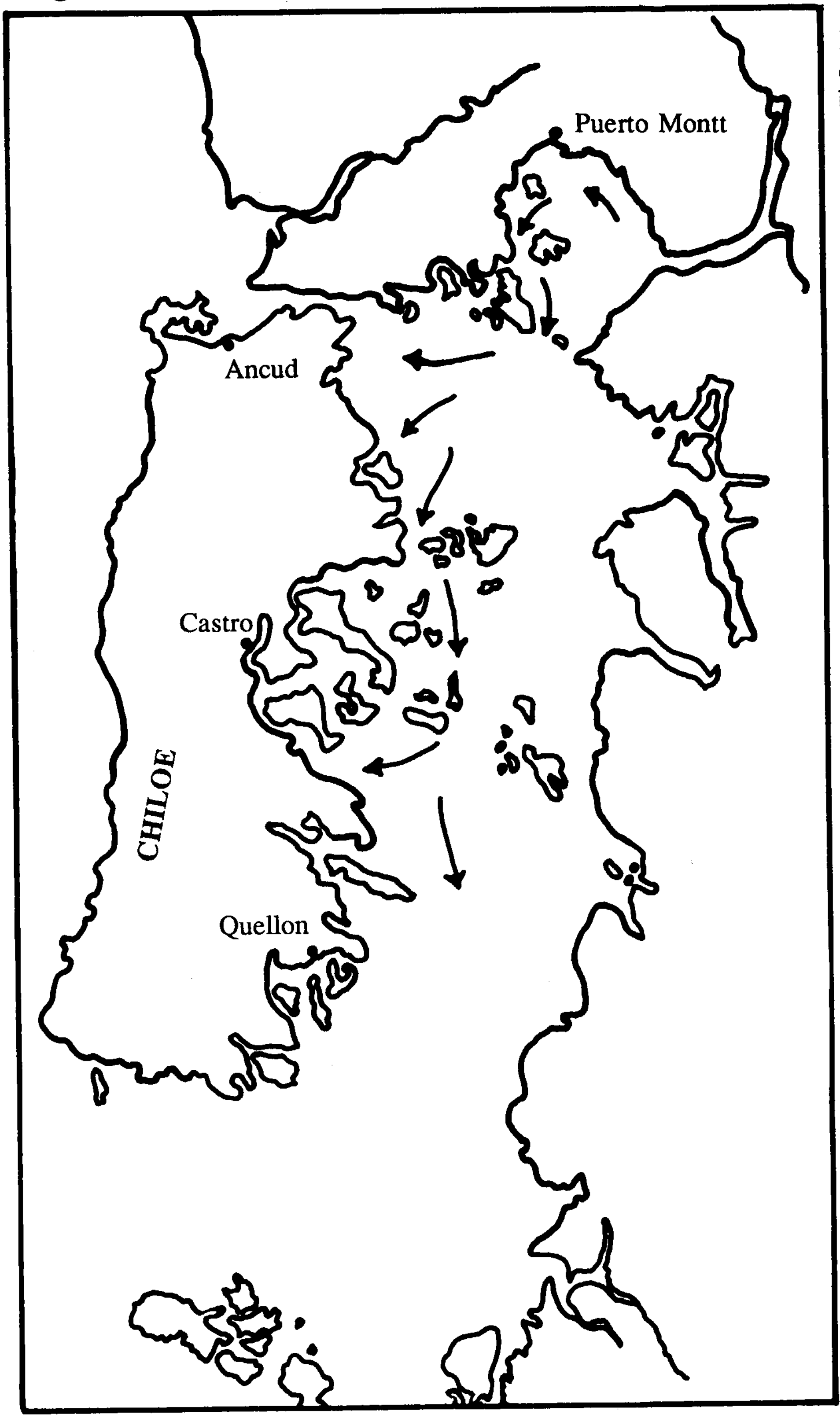
• Consideration of airlift systems.

Summary

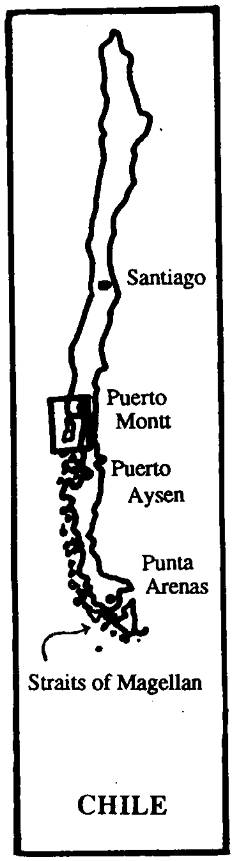
Chile is definitely vulnerable to serious blooms of noxious phytoplankton. The incidence of damaging blooms has not yet been as high as in some marine salmonid growing areas. Chilean salmon growers have organized a warning network and are considering various defensive measures in the event of future blooms.

The warning network has already demonstrated its reliability. Small blooms have been detected in specific areas and the threat became known to most farms quite quickly. The effectiveness of direct defensive measures has not yet been tested; that must wait until the next major bloom strikes.

Figure 1



Map depicting the progress of a noxious phytoplankton bloom in September, 1988



Early Warning Possibilities—Satellites

Mary Jane Perry, School of Oceanography, University of Washington

Remote Sensing
- What is it?

Ocean Color
- Why does it vary?
- How can we use it?
- What can't it do?

Satellites

CZCS:	Phytoplankton biomass	
	Turbidity	
AVHRR:	Sea surface temperature	
	Surface currents	

Limitations
- No clouds
- Upper Ocean
  - CZCS: @ 5 meters in Puget Sound
  - AVHRR: @ surface
- Repeat coverage
  - CZCS: ________
  - AVHRR: 4 times per day
- No species specific information

Ocean Color:

Satellite	When	Pixel	Repeat
CZCS	78-86	1 km	5 day
Landsat MT	80's	20-80 m	17 day
SPOT	88+	20-80 m	17 day
C-Wifs	92?	1 km	1 day
ADEOS-2	95	Japanese	
EOS			
MODIS	95?	1 km	
HIRUS	99?	10-50	

Immunological Detection
1. Antibody to cell surface component
   - Inject mouse or rabbit
   - Screen antibodies
     - a. React with target species
     - b. No (or minimal) reaction with any other species
2. Immunological reaction is like lock and key
3. Detection: add X to antibody
   - X = fluorescent tag (flow cytometry)
   - X = iron particle (magnet)
   - X = ...

Routine Monitoring: Advantages and Disadvantages

James R. Postel, School of Oceanography, University of Washington

Environmental monitoring is a necessary component of most studies that attempt to quantify or solve a more or less defined problem that man encounters in his use of, or interaction with, the natural environment. When dealing with nature in general or with particular ecosystems, we just don't have all the information we need to fully understand causes and effects or sometimes even which variables are most important. Basically, environmental monitoring is a data-gathering step wherein we try to measure parameters that we believe have major effects or influence on the environmental processes or natural resources of interest.

We can use the definition of the Council of Environmental Quality as a starting point. The council defines environmental monitoring as the systematic and repetitive collection and analysis of data that can be used 1) to help determine the quality of the environment or condition of natural resources as they are or will be, and 2) to help relate environmental quality or natural resources to factors that cause them to change or to effects produced by such changes.

Monitoring is not an end in itself, but rather it is a means of providing data and analytical information for other functions, including:

1) policy and management decisions, such as defining objectives and priorities or selecting among alternative actions;
2) identification and definition of problems that are recognized now or that may arise in the future;
3) evaluation of "progress" as a result of specific policies, decisions, or actions;
4) development of a historical record.

In our present case, the problem we face is to understand the interaction of certain species of naturally occurring phytoplankton with finfish, such as Atlantic salmon, being raised commercially in net-pen farms throughout the Puget Sound region. Your presence here indicates that you have recognized this as a priority problem that has already affected your own farms or that could do so in the future and that you are trying to develop some alternatives to address the problem at your farms and as an industry.

We will not be able to eliminate the occurrence of blooming of the phytoplankton species, but we will try to characterize the seasonal and annual succession of the phytoplankton communities at several salmon farm sites in Puget Sound. We hope to relate this information to measurable hydrographic and environmental variables that precede and accompany noxious blooms. These kinds of data are needed to develop effective mitigation strategies and to decide when to implement these strategies at individual farm sites. The basic advantage of monitoring is the timely development of information that is pertinent to the problem at hand.

In Puget Sound we do not know much about the occurrence or distribution in time or space of some of the phytoplankton implicated in fish pen mortality, so we cannot pull that information off our bookshelves. We know in general that in the main basins and open channels of Puget Sound there are a series of blooms (each of which may be comprised of different species) that occur throughout the spring, summer, and fall. We know that water column stability and amount of sunlight are important factors that influence the timing of the blooms, and that nutrient levels, mixing rates, and seed stocks can determine the dominant species that bloom and the overall level that occurs. In our case, we will be looking for particular species and documenting their occurrence on time and geographic scales that have not been attempted here before. To do this well requires a committed effort by people from many different farm sites because we will be trying to collect area-wide data synoptically. The more complete the data are, the better we will be able to use them to recognize the development of noxious blooms early enough to institute effective mitigation measures.

Let's return to the definition of environmental monitoring and emphasize some key concepts that will make it useful.

1) Data that can be used: We do not want just to collect data to store on a shelf or file in a drawer. We want to look at the data and use them to answer questions and share them to solve the problems that arise at net pens where noxious phytoplankton species occur. The question is not so much "Will this kind of bloom occur?" as it is "Will we recognize this kind of bloom early enough to do something about it?" We need to know what our questions are when we begin the sampling effort in order to be efficient and to use our resources effectively. We need to decide what data will help us make necessary decisions, and how quickly those data must be available. Furthermore, we must realize that different people will be interested in different kinds of data or may have diverging priorities, and so we must be willing to cooperate with each other and try to address the concerns and priorities of all participants.

2) Collection and analysis: One of the main problems that we face is to try to collect synoptic data over a wide geographic area. We hope to do that through the cooperative efforts of on-site personnel from farms throughout Puget Sound. If everyone collects samples and just sends them to us for analyses, we would not be able to keep up. We know that this is a problem of concern to the individual farms, and we plan to help personnel at each participating site learn to collect and analyze some of the data themselves so that the information remains timely for their own sites. We must also look at the data regularly and critically to be sure it is useful for answering our questions.

3) Systematic and repetitive sampling: Common problems encountered in environmental monitoring efforts include gaps in the data record, changes in procedures or personnel, and natural variability in time and space. We hope to establish a schedule for sampling and a set of common variables that are quickly and easily measured by on-site personnel. We recognize that these people have more to do than collect samples for us, and that they have other duties in the day-to-day operations of the farms. However, we need to collect the data over time scales that will allow us to describe the seasonal and annual, and perhaps occasionally daily, patterns that occur at a given site and compare information among several different sites. By using comparable procedures at the various locations, by utilizing trained personnel, and by making this effort a priority of individual farm managements, we should all be able to obtain information that will be applicable, with appropriate interpretation, at more than the individual site where it was collected.

APPENDIX II

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