Overview of Maine Department of Marine Resources Finfish Aquaculture Monitoring Program: Eight Years of Monitoring, 1992-99

Prepared for
Maine Department of Marine Resources

Prepared by

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Executive Summary

This report has been prepared to facilitate the review and evaluation of the Maine Department of Marine Resources' Finfish Aquaculture Monitoring Program (FAMP) by the State agencies involved with the Program, as well as the Joint Standing Subcommittee on Marine Resources of the 119th Legislature and the public.

The Finfish Aquaculture Monitoring Program (FAMP) consists of five principal components:

- Monthly confidential production reporting by lease-holders,
- Annual dissolved oxygen water column profiles in September
- Spring video monitoring beneath and adjacent to the cages in May/June,
- Fall video monitoring beneath and adjacent to the cages in September/October,
- Biennial Fall benthic macrofauna community analyses.

The report present detailed descriptions of each of the monitoring program's environmental assessment components with a brief summary of the results obtained to-date.

Dissolved oxygen monitoring is carried out each year in the Fall using a Sea-Bird Electronics, Inc. model SBE 19 SEACAT Profiler, equipped with a pump, a pressure sensor, a temperature-conductivity sensor, a pH probe, and a dissolved oxygen sensor. Replicate casts are made at three locations in the vicinity of salmon aquaculture net pens: 100 meters upcurrent, 5 meters downcurrent, and 100 meters downcurrent. A total of 1085 profiles have been taken since the initiation of the FAMP in 1992. The results of these casts indicate that a slight depression in dissolved oxygen does occur immediately downcurrent of the cages, but saturation levels recover quickly to near upcurrent levels within 100 meters downcurrent of the cages. Of the 1085 profiles, only 47 include dissolved oxygen saturation values below the 85% saturation threshold for class SB waters in the State of Maine, and nearly all of these occur within 5 meters of cages. In the vast majority of these cases, however, the actual amount of oxygen dissolved in the water is still well within the biological requirements of marine organisms. This raises questions regarding the appropriateness of using percent saturation as a true representation of impacts on dissolved oxygen by net pen operations. It is therefore recommended that, at least in the case of percent dissolved oxygen saturation values below 85%, the actual amount of oxygen present in the water be reported in milligrams per liter (mg/l).

Video recordings are made at nearly every net pen site in Maine twice each year, once in the Spring and again in the Fall. The purpose of the underwater video recording is to provide those unable to dive beneath the cages with visual images of conditions adjacent to and beneath cages systems, as well as provide an objective, rapid, albeit superficial, means of documenting and evaluating changes in conditions beneath and adjacent to cage systems. Since the initiation of the FAMP in 1992 a total of 707 video recordings have been made representing approximately 220-250 hours of footage. Initially the FAMP required the development of narratives of the video recordings but, beginning in the Spring of 1995, the video narratives were replaced by graphic representations of key video observations recorded along the transects. These graphics allow the presentation of considerable information in a clear and concise way and allow easy comparison observed conditions from one monitoring period to another. As a monitoring tool, video recording has proven to be a relatively inexpensive and rapid, yet highly effective means of documenting and visually representing conditions beneath and adjacent to cage systems.

Generally speaking, with the exception of a few selected sites, conditions adjacent to and directly beneath finfish cage systems, as evidenced by the visual observations, appear to have improved since video monitoring began in 1992. Despite the overall improvement in benthic conditions as measured by the amount of feed, accumulation of organic matter and the extent of occurrence of the sulphur-reducing bacterial *Beggiatoa* sp., in 1997 the numbers of both predator and grower nets found beneath cage systems was identified as a matter of increasing concern. Recognizing the actual and potential problems posed by these nets, beginning in the Spring of 1998, the scope of work for the FAMP was expanded to include a task specifically focused on locating and tagging aquaculture-related nets found on bottom to facilitate their removal. Since 1998 a total of 74 nets have been located and tagged, the majority of which have been removed. However, numerous nets remain on bottom and tagging of nets will continue until all nets identified on video have been removed.

Recent advances in video technology and digital imaging have now made digital video (DV) highly reliable and affordable, offering better resolution, improved storage security and reproducibility, and increased versatility in the review process. Furthermore, the combination of DV with Internet technology offers the new possibilities for providing rapid feedback to operators, presumably reducing response time to any identified problems. It is therefore recommended that the Department investigate the cost/benefits of moving to DV format.

Benthic monitoring focuses on benthic impacts to the bottom directly beneath and adjacent to the cages. Sampling is carried out immediately adjacent to and at various distances from selected cage systems on a schedule such that each cage system is monitored in alternating years. The purpose of the benthic monitoring is to detect and document any changes that take place in the macrofaunal community structure on the sites as a result of the cage system operations. This component previously included analysis of sediment composition, or granulometry, but this component was dropped in the Fall of 1996 after little correlation could be found between sediment granulometry and environmental effect. The mesh size used for sieving samples was increased in 1995 from 0.5 mm to 1.0 mm and the level to which organisms are identified and reported was reduced from species to family. Beginning in 1998, benthic sampling was focused on sites having potentially greater impacts on the benthos and greater emphasis was placed on near-cage sampling.

As of 1998, 389 benthic samples have been analyzed, with an additional 87 having been taken in 1999 that are currently in process. Four indices are used to determine the condition of the benthic environment based on the condition benthic community: abundance, species richness, relative diversity, and dominance of *Capitella capitata*, a recognized indicator of organic loading. Comparison of individual site indices values over successive sampling periods shows that, with only a few exceptions, conditions around cage sites remain acceptable, although fluctuations do occur, likely in response to production cycles.

Spatial analysis of the indices values for all samples indicates that impacts to the benthos are confined to the immediate area of the cage systems, rarely extending more than 60 meters from the cages. Analysis of the indices values over time indicates, in most cases, a trend toward improvement in benthic conditions. The exception is species richness which has steadily declined over time. Much of this decline may simply be *apparent* and related to the changes in sampling and identification and reporting procedures mentioned above. Nevertheless, species richness bears watching to ensure the decline does not continue once sampling procedures and protocols are standardized. The Department may also wish to revisit the possibility of including ambient control stations to assist in the interpretation of near-cage benthic community changes.

Recent applications for aquaculture lease sites in more confined areas, removed from the open ocean and having lower rates of flushing, have rekindled concerns over the potential impacts of nutrients released from net-pen operations.

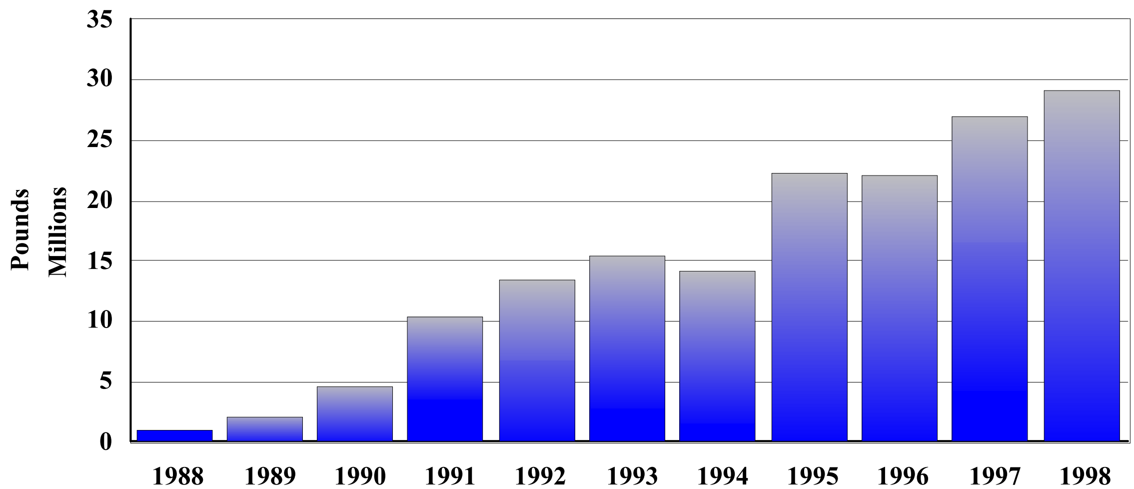
Testing for nutrients was formerly part of the U.S. Army Corps of Engineers/National Marine Fisheries Service's aquaculture site environmental monitoring requirements. After several years of testing, however, no specific effects were observed and the requirement was dropped. At the time nutrient testing was being conducted most sites were located in Cobscook Bay or in proximity to open ocean. In view of the possible westward expansion of net-pen operations, the Department may wish to consider incorporation of nutrient testing into the FAMP. Individual site monitoring is probably not warranted since the concern is on impacts on water bodies as a whole rather than site-specific effects. Consideration might therefore be given to the establishment of "ambient" monitoring stations for nutrient testing, perhaps the same stations used as control stations for the dissolved oxygen monitoring portion of the FAMP.

Finally, as the industry seeks to move onto increasingly deeper sites, new monitoring techniques will need to be developed to deal with the depths. MER and the DMR have investigated the possible use of a sled developed by others at DMR for deep video monitoring. Although satisfactory videos have been obtained, the system would require substantial improvement to be sufficiently useful and reliable for use in monitoring. Therefore, if it appears that deep site monitoring will be required in the future, additional work will need to be done to perfect the sled technique, possibly including the addition of realtime video capability.

1. Introduction and background

Farm production of Atlantic salmon, *Salmo salar,* began in Maine in the early to mid 70's at a single site in Blue Hill. After several years of trials, however, the site was eventually abandoned. Another site was established in 1983, but production remained low and development of the finfish culture industry remained static through 1985. In 1986 a second site was added, tripling the number of cages in operation, and rainbow trout, *Onchorynchus mykiss*, was added as a cultured species. Production of salmon reached the 1 million pound level in 1988 and continued to double annually through 1991. In 1992 and 1993 production increased only slightly, and actually declined in 1994. However, in 1995 production surged by 8 million pounds and total whole fish production exceeded 22 million pounds. Production remained relatively unchanged between 1995 and 1996, but again increased substantially in 1997, followed by yet another, although smaller, increase in 1998. Figure 1.1. below shows the increase in production over time.

Figure 1.1.
Maine Salmonid Aquaculture Production
1988-1998



During the 1970s and most of the 1980s no monitoring was required of finfish culture operations. Beginning in 1988, in response to the sudden expansion of production and associated concerns over the potential environmental impacts of the industry, certain growers were required to conduct environmental monitoring and provide the results to several different agencies, including the U.S. Environmental Protection Agency (EPA), Army Corps of Engineers (ACOE), and the Maine Department of Environmental Protection (DEP). Initially, the monitoring requirements were poorly coordinated and differed from site to site. The rapid growth of the industry during the 1987-1989 period caused some to question the adequacy of both the lease application and environmental monitoring processes. In response to this, legislation was submitted in 1990 to address these concerns. As written, however, the bill called for such stringent monitoring requirements that, had it passed in its original form, the industry would almost certainly have been crippled. After extensive study on the part of the legislature and considerable public input, a compromise was struck in 1991 which resulted in Public Law 381 and what is now termed the "unified" application and monitoring program.

The new application/monitoring process went into effect in the Spring of 1992. Accordingly, the Aquaculture Coordinator at the Maine Department of Marine Resources serves as the point of contact for submission of all application and monitoring information. The Aquaculture Coordinator then assumes responsibility for disseminating relevant information to the other state and federal agencies involved, as well as the public.

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- Biennial Fall benthic macrofauna community analyses.

The confidential monthly production reports are submitted directly to the Maine DMR and all records are handled and maintained solely by the Department. The following sections, therefore, present detailed descriptions only of each of the monitoring program's environmental assessment components with a brief summary of the results obtained for each component to-date. Due to the volume of data collected since the implementation of the Program in 1992, only summaries of the data are presented here to support the conclusions pertaining to the relevance of each component to the program. It also provides a synopsis of the modifications that have been made to the program since its inception, and offers suggestions for future expansion and modification of the Program. A copy of the Finfish Aquaculture Monitoring Program (FAMP) guidelines is included as Appendix I.

Finally, this report has been prepared to facilitate the review and evaluation of the Maine Department of Marine Resources' Finfish Aquaculture Monitoring Program (FAMP) by the State agencies involved with the Program, as well as the Joint Standing Subcommittee on Marine Resources of the 119th Legislature and the public. Thus, the report has been written for an audience of varying level of technical expertise. Consequently, some readers may find certain sections of this report overly technical, while others may find certain sections oversimplified. Therefore, for clarification or additional information the reader is directed to contact either of the following:

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2.0. Water quality survey

2.1. Sampling procedures and protocols

According to the originally sampling protocol, dissolved oxygen was to be analyzed by the operators of each aquaculture site every two weeks between July 1 and September 30 of each year. In addition, an annual dissolved oxygen profile was to be done at three specified locations around each site during the month of August using the same techniques used for the semi-monthly analyses (Appendix I, FAMP 3. Dissolved Oxygen). The semi-monthly monitoring was intended to evaluate short-term effects on dissolved oxygen while the annual profiling during the month of anticipated peak production was intended to describe the broader, longer-term water column effects.

Data collected during 1992, the first year of the program's implementation, was both sporadic and of questionable quality. Compliance with the program requirements improved in 1993 as did the quality of the data. Analysis of the results from individual sites showed that, in general, effects on dissolved oxygen were negligible. However, due to the large numbers of individuals collecting the information and the differences in techniques employed at different sites, the data were of limited value in comparing results between sites.

As a result of the high variability of results and the consequent inability to compare data between sites, the DEP and DMR chose to adopt a standard protocol and incorporate dissolved oxygen profiling into the scope of work of the Fall portion of the FAMP beginning with the 1994-95 season. These modifications to the Program have allowed the DMR to achieve two objectives: 1) the standardization of the sampling protocols, and 2) standardization of field procedures and observations by having a single entity apply the protocol at all sites. Accordingly, a dissolved oxygen survey has been conducted as part of the FAMP in every year since 1994 with the exception of 1997 when the task was omitted due to time constraints imposed by factors beyond the control of either the Maine DMR or its contractor (Heinig, 1994, 1995, 1996, 1999).

2.1.1. Location of sampling stations

According to the amended FAMP, dissolved oxygen profiles are to be taken at three specific distances from the finfish cage structures: 1) at 100 meters, or ~300 feet, upcurrent of the structure, 2) within 5 meters, or ~15 feet, downcurrent of the structure, and 3) within 100 meters, or ~300 feet downcurrent of the structure (see Appendix I, FAMP 3. Dissolved Oxygen).

Due to the strong, often unpredictable currents at the finfish culture sites, the 100 meter upcurrent and downcurrent station distances usually cannot be measured by metered line but must be estimated based on known distances of physical structures on the site, such as mooring balls, "tag" line buoys, transfer pens, etc. Where physical structures are not present, distances are estimated based on experience and are conservatively biased to ensure that profiling is done within the 100 meter distance. If obstructions, such as a pen system, vessel, feed barge, ledge, etc., preclude reaching the full 100 meter distance from the cage structure, the actual distance is recorded on the data sheet. In any case, the downcurrent sample is never taken further than 100 meters from the cage system.

At certain sites, the location of stations may appear contradictory, as in a case where the 100 meter upcurrent and 100 meter downcurrent stations are located on the same side of the cage system, only a short distance apart. These apparent contradictions are the result of rapidly shifting currents or eddy effects often found at sites removed from main channel influences, particularly those sheltered by projections of land, islands, or ledges. Where these conditions are encountered, every effort is made to accurately represent conditions at the site and the current directions at the time of sampling are shown on the individual site maps accompanying each site's profiles.

2.1.2. Equipment

All sampling has been, and continues to be, carried out using the DMR's Sea-Bird Electronics, Inc. model SBE 19 SEACAT Profiler, Serial No. SBE 192369-254. The SBE 19 is equipped with a pump, a Senso-Metrics Sp 91FFS pressure sensor (S/N 8M187), a temperature-conductivity sensor (S/N 254), a Beckman dissolved oxygen sensor (S/N 0-10-13), and an Innovative pH sensor.

A Hach Company Dissolved Oxygen Digital Titrator Kit was used in the field to perform Azide Modified "Winkler" dissolved oxygen titrations on control samples used to verify the reliability of the CTD collected data. A 2.0 N Sodium Thiosulfate syringe was used for the expected oxygen saturation range.

2.1.3. Profiler deployment procedure

The pump on the Maine DMR's SBE 19 Profiler has an adjusted start delay function that is set to start the pump and data collection 45 seconds after the switch is turned on. In addition, the unit is set to start only when the conductivity probe enters seawater. Furthermore, Sea-Bird recommends that the dissolved oxygen sensor be allowed to polarize for at least three minutes after power-up to insure accurate readings. To accommodate for the delayed start of the pump and full polarization of the D.O. sensor, the standard operation procedure is to allow the profiler to rest approximately 1 meter below the surface for 3 minutes before initiating each cast. This delay accounts for the initial 300-350 scans in each cast data file. Following the 3 minute surface "rest" interval, the profiler is allowed to descend through the water column at an average *free-fall* rate of approximately 1.0-1.5 m/sec. Once on the bottom, the profiler is hauled back to the surface at approximately the same rate as the descent.

2.1.4. Quality assurance/Quality control (QA/QC)

The FAMP specifies two QA/QC requirements: 1) calibration of electronic meters, and 2) verification of measurement consistency.

Factory Calibration

Calibration of the DMR's SBE 19 profiler sensors is done by Sea-Bird Electronics, Inc. each year prior to conducting the annual dissolved oxygen survey and this calibration serves as the pre-sampling calibration. Based on this calibration, Sea-Bird Electronics, Inc. develops a configuration file identified as SS(mmddyy).CON which is used to analyze and display profile results using SEASOFT software. Prior to December, 1999 SEASOFT ver. 4.203 was used to analyze data. The software was updated to SEASOFT ver. 4.236 on 8 September 1999 and is the version currently used. After completion of the dissolved oxygen survey, a post-sampling calibration of the SBE 19 SEACAT Profiler is performed by

Sea-Bird Electronics, Inc., usually in December or January. Based on the post-sampling calibration, a new configuration is developed by Sea-Bird. The post-sampling calibration serves as the pre-sampling calibration for the next survey unless subsequent calibrations are performed. To-date, comparison of dissolved oxygen saturation values using both pre- and post-sampling calibration configurations have consistently shown only insignificant, if any, discrepancies indicating that the profiler has performed accurately throughout all of the sampling surveys conducted thus far.

Unit verification and calibration curves

In addition to the Sea-Bird Electronics, Inc. factory calibration, pre-sampling calibration curves are developed each Fall by DMR and its contractor prior to initiating the dissolved oxygen survey. The calibration curves are developed by comparing CTD and Winkler titration dissolved oxygen (mg/l) results for each of three or four temperature baths at or near full (100%) saturation. Titrations are carried out using a Hach Company Azide Modified "Winkler" Dissolved Oxygen Digital Titrator Kit (Model No. OX-DT, Cat. No. 20631-00).

In-field consistency verification

In-field measurement consistency is verified by replicate casts at each station. Replicate casts of several randomly-selected stations are reviewed at mid-day and/or nightly to ensure "reasonable" consistency between profiles. If significant, unexplainable discrepancies between replicate profiles are detected, sampling is discontinued until the problem is corrected. Normally, no such unreasonable, unexplainable discrepancies are detected during the sampling period. However, unacceptable discrepancies were detected at the beginning of sampling in September 1999 and sampling was suspended.

Dissolved oxygen measurement accuracy is verified in the field by chemically measuring the dissolved oxygen (mg/l), using the Azide Modified Winkler titration method, of duplicate samples of water taken with a 3-liter sampling bottle at a depth of ten meters at random stations toward the beginning, middle and/or end of each sampling day. These values are then compared to those collected by the Sea-Bird SBE 19 profiler to determine any discrepancy between the values obtained using the two methods. Difficulties with the field titration equipment precluded field verification.

2.2. Protocol modifications

Since the initiation of the FAMP in 1992, few modifications have been made to the procedures and protocols described above. The only change of significance has been the increase in the surface delay time for each cast from the original one minute period to three minutes. Although an additional two minutes may seem trivial, over an average of 250 casts made per year, this change has added a extra full day to the annual effort.

2.3. Results

Table 2.3.1 through 2.3.4., below, summarize the dissolved oxygen minimum value for the three sampling distances at each site for each year of sampling and provide a comparison of the mean 100-meter upcurrent, 5-meter downcurrent and 100-meter downcurrent values with 95% confidence level error (±), (refer to Appendix II for additional statistical analysis results).

Table 2.3.1.
Comparison of mean D.O. saturation minima observed at the three distances from the cage systems at each of the active sites in 1994

	100m UP*	5m DN*	100m DN*	Diff. 100U-5D	Diff. 100U-100D
ECFF SB	106.0	103.5	104.0	2.5	2.0
BPFI BE	103.0	100.3	102.0	2.7	1.0
NESC GN	104.0	102.5	101.5	1.5	2.5
HARS JK	96.5	95.7	99.0	0.8	-2.5
AAQF JK2	99.5	99.0	99.5	0.5	0.0
NBFI JC	99.5	100.0	99.5	-0.5	0.0
ISSI PC	98.5	99.3	99.5	-0.8	-1.0
TIFI TW	100.0	95.3	98.3	4.7	1.7
CONA DC	102.5	96.8	98.0	5.7	4.5
MESI SH	104.5	98.0	99.0	6.5	5.5
HANK CL	103.0	100.0	99.5	3.0	3.5
CONA BC	100.3	93.9	99.8	6.4	0.5
CONA CP	103.0	97.0	98.5	6.0	4.5
RISC RN	101.3	97.8	97.5	3.5	3.8
ECFF TE	99.5	**80.5**	96.0	19.0	3.5
SFML JB2	97.3	**84.7**	95.5	12.6	1.8
STEV LU	98.5	98.5	99.0	0.0	-0.5
ASMI II Steel	101.0	97.0	103.0	4.0	-2.0
ASMI II Polar	108.0	105.0	106.0	3.0	2.0
MCNB CH	104.0	**82.0**	100.0	22.0	4.0
ASMI LI	103.0	103.5	107.0	-0.5	-4.0
RLLT SI	102.0	99.0	102.0	3.0	0.0
IACO TC	102.5	98.5	105.5	4.0	-3.0
TISF HI	105.3	104.0	104.5	1.3	0.8
ASMI CI	105.0	97.1	99.0	7.9	6.0
MCNC CH	93.0	86.5	92.5	6.5	0.5
Mean	**101.6 ± 1.3**	**96.7 ± 2.6**	**100.2 ± 1.4**	**4.8 ± 2.2**	**1.4 ± 1.1**
Max	**108.0**	**105.0**	**107.0**	**22.0**	**6.0**
Min	**93.0**	**80.5**	**92.5**	**-0.8**	**-4.0**

*** Where more than one value exists for a sampling distance, all values are averaged to provide a mean value for that distance**

Table 2.3.2.
Comparison of mean D.O. saturation minima observed at the three distances from the cage systems at each of the active sites in 1995

Site	100m UP*	5m DN*	100m DN*	Diff. 100U-5D	Diff. 100U-100D
CONA SB	88.0	85.7	87.0	2.3	1.0
BPFI BE	89.3	87.8	88.5	1.5	0.8
DESC GN	89.0	87.0	86.0	2.0	3.0
HANK CL	87.0	88.5	89.0	-1.5	-2.0
TIFI CC	89.5	88.0	88.0	1.5	1.5
HARS JK	92.0	89.5	91.5	2.5	0.5
AAQF JK2 1	88.0	88.0	86.0	0.0	2.0
AAQF JK2 2	89.5	88.0	88.0	1.5	1.5
MAFI PC	89.0	88.0	88.5	1.0	0.5
TIFI TW	88.0	85.5	88.3	2.5	-0.3
CONA DC	92.0	87.3	89.8	4.7	2.2
MESI SH	87.5	86.0	88.5	1.5	-1.0
CONA BC	88.3	85.2	88.0	3.1	0.3
CONA CP	92.0	88.0	91.0	4.0	1.0
SFML RN	89.0	**84.8**	87.5	4.3	1.5
ECFF TE	90.0	85.5	88.5	4.5	1.5
SFML JB3	92.5	87.5	92.5	5.0	0.0
STEV LU	90.0	90.5	91.0	-0.5	-1.0
ASMI II Steel	94.0	92.0	89.5	2.0	4.5
ASMI II Polar	92.5	87.5	89.5	5.0	3.0
MCNI CW	92.0	90.0	89.0	2.0	3.0
ASMI LI	89.0	87.5	89.0	1.5	0.0
RLLT SI	94.0	91.0	90.0	3.0	4.0
ASMI FI	91.5	89.0	89.5	2.5	2.0
IACO HS	92.5	**84.0**	92.0	8.5	0.5
IACO TC	90.5	**84.5**	90.5	6.0	0.0
TISF HT	91.0	86.8	90.0	4.2	1.0
ASMI CI	91.3	**84.6**	86.5	6.7	4.8
MCNC CN	88.0	88.0	89.5	0.0	-1.5
MCNC CH	84.0	85.5	87.5	-1.5	-3.5
Mean	**90.0 ± 0.8**	**87.4 ± 0.7**	**89.0 ± 0.6**	**2.7 ± 0.9**	**1.0 ± 0.7**
Max	**94.0**	**92.0**	**92.5**	**8.5**	**4.8**
Min	**84.0**	**84.0**	**86.0**	**-1.5**	**-3.5**
CONTROL 1	88.0	-----	-----	-----	-----
CONTROL 2	87.0	-----	-----	-----	-----

*** Where more than one value exists for a sampling distance, all values are averaged to provide a mean value for that distance**

Table 2.3.3.
Comparison of mean D.O. saturation minima observed at the three distances from the cage systems at each of the active sites in 1996

Site	100m UP*	5m DN*	100m DN*	Diff. 100U-5D	Diff. 100U-100D
CONA SB	91.8	89.8	91.5	2.0	0.3
BPFI BE	94.0	91.5	91.3	2.5	2.7
DESC GN	91.5	91.0	90.5	0.5	1.0
TIFI CC	89.5	91.0	92.0	-1.5	-2.5
HARS JK	98.0	96.5	95.5	1.5	2.5
AAQF JK2 1	94.5	94.5	92.5	0.0	2.0
AAQF JK2 2	93.0	92.0	94.0	1.0	-1.0
MAFI PC	95.0	88.8	90.5	6.2	4.5
TIFI TW	92.5	87.8	90.0	4.7	2.5
CONA DC	91.0	91.3	91.5	-0.3	-0.5
MESI SH	91.5	93.0	92.5	-1.5	-1.0
CONA BC	91.6	88.0	89.8	3.6	1.8
CONA CP	92.5	91.0	92.0	1.5	0.5
SFML RN	94.0	89.8	91.0	4.2	3.0
COOK TE	94.0	90.0	90.0	4.0	4.0
SFML JB3	92.2	87.0	90.7	5.2	1.5
STEV LU	95.5	92.0	93.0	3.5	2.5
ASMI II Steel	101.5	97.0	98.0	4.5	3.5
ASMI II Polar	96.5	93.3	95.3	3.2	1.2
MCNI CW	97.5	98.0	96.5	-0.5	1.0
ASMI FI	98.5	99.3	98.0	-0.8	0.5
ASMI DI	98.5	89.5	94.5	9.0	4.0
RLLT SI	101.5	97.5	98.0	4.0	3.5
IACO HS	104.5	103.0	103.0	1.5	1.5
IACO TC	101.3	93.8	96.0	7.5	5.3
TISF HT	98.9	99.8	97.8	-0.9	1.1
ASMI CI	94.8	90.0	93.3	4.8	1.5
MCNC CN	95.5	86.0	93.0	9.5	2.5
MCNC CH	98.5	95.0	95.5	3.5	3.0
Mean	**95.5 ± 1.4**	**92.7 ± 1.6**	**93.7 ± 1.2**	**2.8 ± 1.1**	**1.8 ± 0.7**
Max	**104.5**	**103.0**	**103.0**	**9.5**	**5.3**
Min	**89.5**	**86.0**	**89.8**	**-1.5**	**-2.5**

*** Where more than one value exists for a sampling distance, all values are averaged to provide a mean value for that distance**

Table 2.3.4.
Comparison of mean D.O. saturation minima observed at the three distances from the cage systems at each of the active sites in 1998

Site	100m UP*	5m DN*	100m DN*	Diff. 100U-5D	Diff. 100U-100D
CONA SB	99.0	95.3	96.8	3.7	2.2
BPFI BE	98.3	97.3	99.3	1.0	-1.0
DESC GN 1	101.0	98.0	100.0	3.0	1.0
DESC GN 2	100.0	99.0	99.0	1.0	1.0
TIFI CC	99.0	92.3	97.0	6.7	2.0
MAFI JK2 1	100.0	94.0	97.5	6.0	2.5
MAFI JK2 2	99.0	93.0	97.0	6.0	2.0
MAFI PC	98.0	96.3	99.0	1.7	-1.0
TIFI TW	100.0	97.4	99.0	2.6	1.0
CONA DC	101.8	99.0	101.0	2.8	0.8
MESI SH	99.0	98.5	98.5	0.5	0.5
CONA BC	100.0	90.9	97.1	9.1	2.9
CONA CP	97.5	91.0	96.3	6.5	1.2
SFML RN	99.5	96.5	97.5	3.0	2.0
SFML RS	99.0	97.5	99.5	1.5	-0.5
COOK TE	99.5	93.8	98.0	5.7	1.5
SFML JB3	100.8	95.2	97.3	5.6	3.5
DESC LU	99.5	96.3	99.0	3.2	0.5
ASMI II	103.3	93.8	*91.5*	9.5	*11.8*
ASMI FI	116.0	113.5	115.5	2.5	0.5
ASMI DI	118.0	110.0	112.5	8.0	5.5
RLLT SI	110.0	94.0	102.5	16.0	7.5
IACO HS	109.0	109.0	114.0	0.0	-5.0
IACO TC	110.0	109.5	109.5	0.5	0.5
TISF HT	106.0	103.0	102.5	3.0	3.5
ASMI CI	102.8	94.1	*88.4*	8.7	*14.4*
ASMI CI2	96.5	85.5	92.5	11.0	4.0
MCNC CN	103.0	99.0	100.5	4.0	2.5
MCNC CH	100.0	98.5	100.0	1.5	0.0
Mean	**102.3 ± 2.0**	**97.6 ± 2.4**	**99.9 ± 2.3**	**4.6 ± 1.4**	**2.3 ± 1.4**
Max	**118.0**	**113.5**	**115.5**	**16.0**	**14.4**
Min	**96.5**	**85.5**	**88.4**	**0.0**	**-5.0**

*** Where more than one value exists for a sampling distance, all values are averaged to provide a mean value for that distance**

It is important to note that the values reported for each cast in the Annual Fall Water Quality Survey report for each year represent the ***minimum*** percent saturation value recorded during each cast and, consequently, that the values reported in the above tables represent the average of the ***lowest*** percent saturation value(s) obtained in the two (or more) replicate casts conducted at each distance at each site. Furthermore, the SeaBird SBE 19 SEACAT Profiler collects sensor data every 0.5 seconds and, therefore, during an average descending cast, from surface to bottom in 50-60 feet of water, between 20 to 40 scans are recorded, each containing a data point for each parameter measured. Thus, the values shown in Tables 2.3.1. through 2.3.4. represent not only the worst situation, they may also represent only one or two of the total number of scans recorded during a given cast. Therefore, in many cases, these values describe conditions at a specific point within a profile and are not necessarily representative of an entire profile or the water column at the station (see Section 2.6.1., below).

Table 2.3.5., below, summarizes and compares the detailed data presented in Tables 2.3.1 through 2.3.4.

Table 2.3.5.
Summary of mean, maximum, and minimum D. O. percent saturation for all distances across all sites for each year of sampling

Year		100m UP*	5m DN*	100m DN*	Diff. 100U-5D	Diff. 100U-100D
1994	**Mean**	**101.6 ± 1.3**	**96.7 ± 2.6**	**100.2 ± 1.4**	**4.8 ± 2.2**	**1.4 ± 1.1**
	Max	108.0	105.0	107.0	22.0	6.0
	Min	93.0	80.5	92.5	-0.8	-4.0
1995	**Mean**	**90.0 ± 0.8**	**87.4 ± 0.7**	**89.0 ± 0.6**	**2.7 ± 0.9**	**1.0 ± 0.7**
	Max	94.0	92.0	92.5	8.5	4.8
	Min	84.0	84.0	86.0	-1.5	-3.5
1996	**Mean**	**95.5 ± 1.4**	**92.7 ± 1.6**	**93.7 ± 1.2**	**2.8 ± 1.1**	**1.8 ± 0.7**
	Max	104.5	103.0	103.0	9.5	5.3
	Min	89.5	86.0	89.8	-1.5	-2.5
1997		**No dissolved oxygen sampling conducted**				
1998	**Mean**	**102.3 ± 2.0**	**97.6 ± 2.4**	**99.9 ± 2.3**	**4.6 ± 1.4**	**2.3 ± 1.4**
	Max	118.0	113.5	115.5	16.0	14.4
	Min	96.5	85.5	88.4	0.0	-5.0

Over the period D.O. sampling has been carried out, the mean difference between the 100m upcurrent saturation minima and the 5m downcurrent saturation minima, or mean dissolved oxygen saturation depression (highlighted), across all sites ranges between 2.7 and 4.8 percentage points, with individual cast readings ranging between a saturation depression of 22.0 percentage points and a saturation increase of 1.5 percentage points. The mean difference between the 100m upcurrent and 100m downcurrent saturation minima, again across all sites and all years of sampling, ranges between 1.0 and 2.3 percentage points. The upper and lower individual cast values for the 100m upcurrent versus 100m downcurrent range from a saturation depression of 14.4 percentage points and a saturation increase of 5.0 percentage points.

The composite data for all sites, for ***each*** year of sampling, are presented graphically in the XY-scatter plots below. The Y-axis represents percent saturation of dissolved oxygen. The X-axis represents the distance in meters from the cage at which samples were taken, where -100 meters represents the *upcurrent* sampling stations, 0 meters the *cage* system, and +100 meters the *downcurrent* sampling stations. Although sampling normally takes place at 100 upcurrent, 5 meters downcurrent and 100 meters downcurrent, at times geographic or cage configuration require samples to be taken at other distances, thus accounting for the points that are out of alignment from the three main distances.

Figure 2.3.1. Dissolved oxygen saturation as a function of distance in 1994

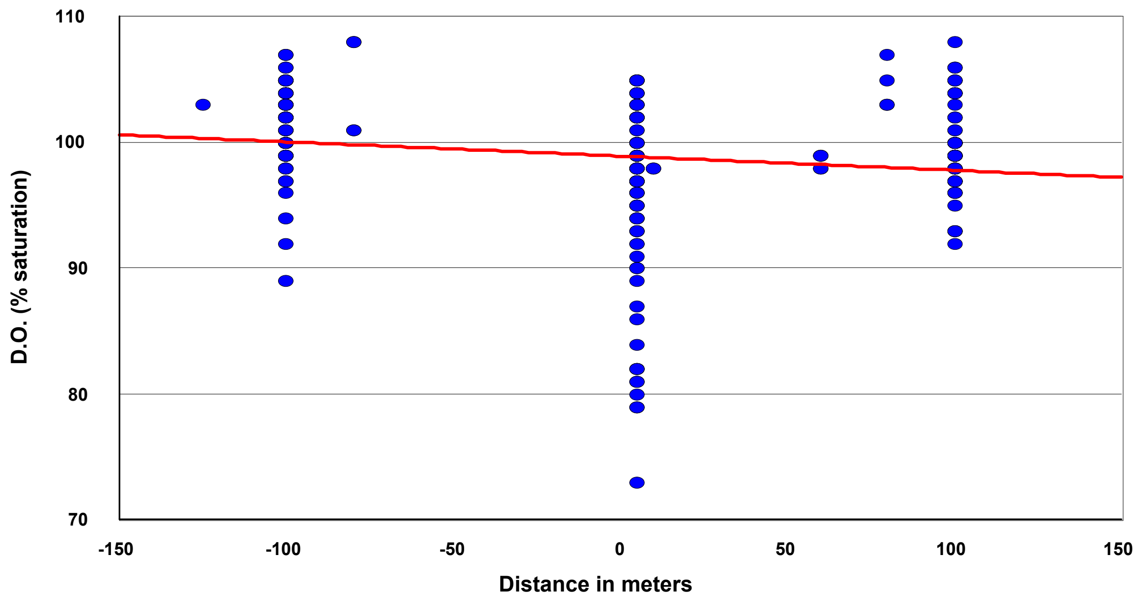


Figure 2.3.2. Dissolved oxygen saturation as a function of distance in 1995

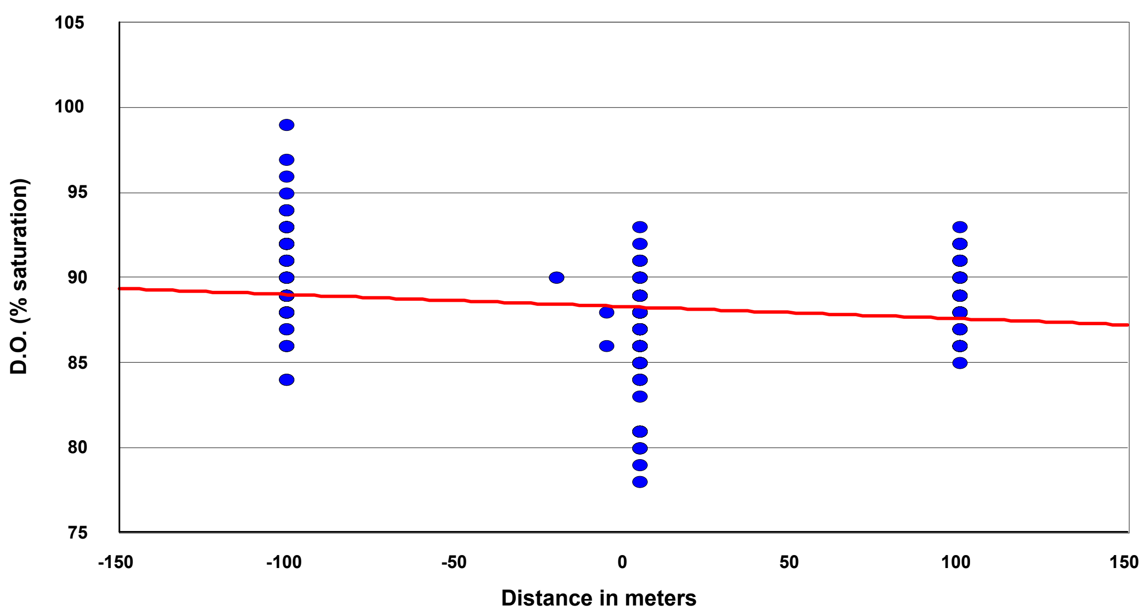


Figure 2.3.3. Dissolved oxygen saturation as a function of distance in 1996

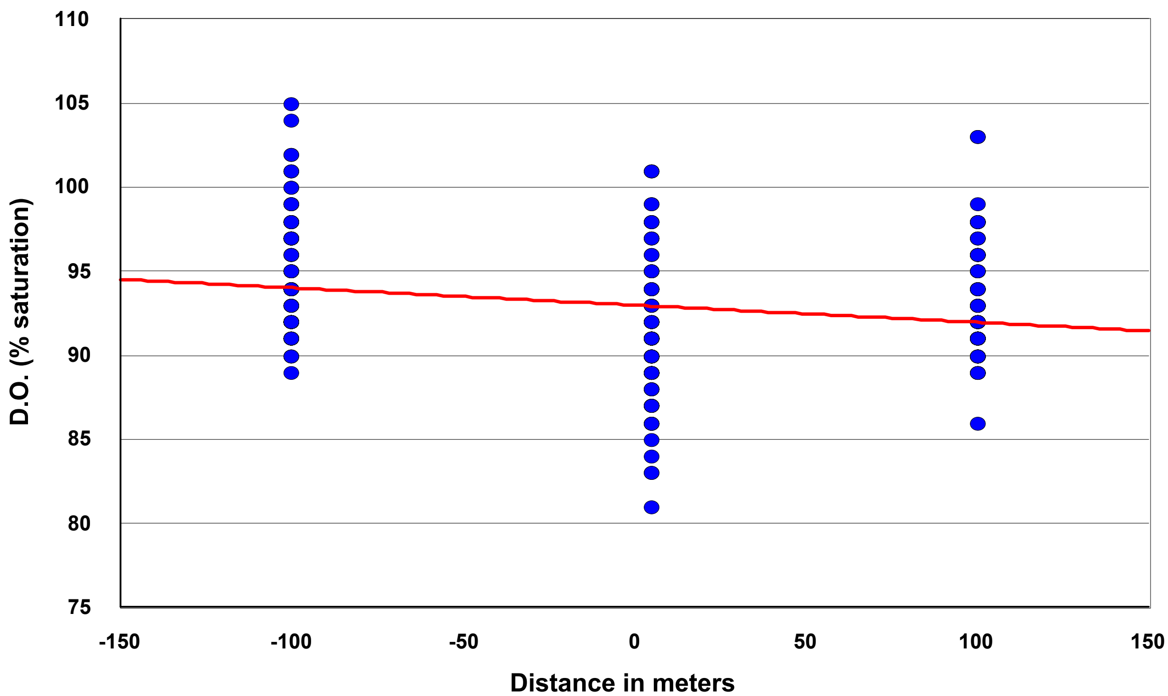
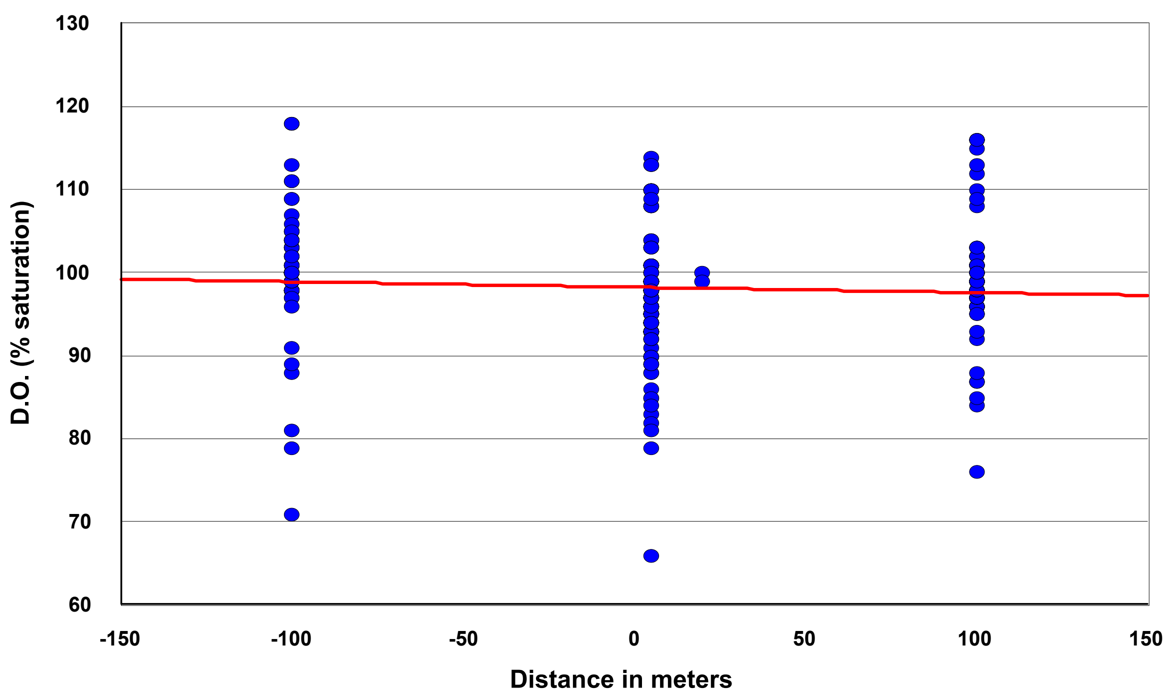


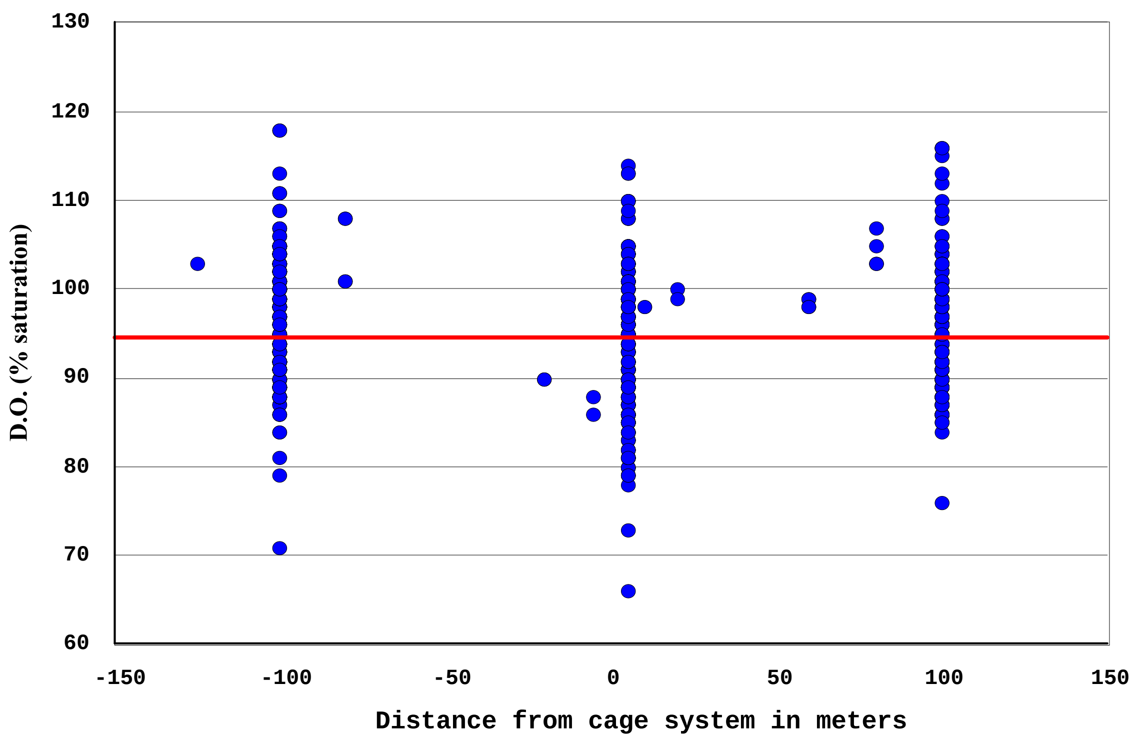
Figure 2.3.4. Dissolved oxygen saturation as a function of distance in 1998



In each year there is a discernable decline in D.O. saturation in the immediate vicinity of the cages. The cage stations also show the greatest range in D.O. saturation readings. The linear trend lines also show this decline from upcurrent to cage stations. However, the D.O. saturation downcurrent of the cages increases rather rapidly and the range of readings decreases.

The composite data for all sites over ***all*** years of sampling, are presented graphically in the XY-scatter plots in Figure 2.3.5, below.

Figure 2.3.5. Dissolved oxygen saturation as a function of distance for all sampling years



Based on the summary data for upcurrent and downcurrent differences in D.O. saturation presented in Table 2.3.5., these differences are generally small, thus the higher upcurrent values shown in Figure 2.3.5. correspond to the higher cage-side values and similarly to the higher downcurrent values. Seen graphically, then, the impact on ambient dissolved oxygen levels is relatively small, with the vast majority of readings being well above the 85% saturation threshold and a "straight line" trend at ~95%.

Table 2.3.6. on the following page summarizes the number of stations by percent dissolved oxygen saturation range for each survey year and Table 2.3.7. presents a summary for all years combined.

Table 2.3.6.
Categorization of number of stations by percent dissolved oxygen saturation range by year

1994

No. of Stations	D.O. Saturation	Percent of Total
90	>100%	37.0
121	95-100%	49.8
18	90-94%	7.4
4	85-89%	1.6
7	80-84%	2.9
3	<80%	1.2
247		**100.0**

1995

No. of Stations*	D.O. Saturation	Percent of Total*
0	>100%	0.0
4	95-100%	1.5
82	90-94%	30.6
163	85-89%	60.8
17	80-84%	6.3
2	<80%	0.7
268		**100.0**

***Number corrected from that reported in 1995 - in 1995 No. of Stations Day 95-3 was inadvertently counted twice.**

1996

No. of Stations	D.O. Saturation	Percent of Total
12	>100%	4.6
67	95-100%	25.9
145	90-94%	56.0
31	85-89%	12.0
4	80-84%	1.5
3	<80%	1.0
262		**100.0**

1998

No. of Stations	D.O. Saturation	Percent of Total
82	>100%	26.3
175	95-100%	56.1
31	90-94%	9.9
13	85-89%	4.2
6**	80-84%	1.9
5	<80%	1.6
312		**100.0**

**** Three readings in 80-84% range are highly anomalous and inconsistent with replicate casts**

Table 2.3.7
Categorization of number of stations by percent dissolved oxygen saturation range for all years

1994-98

No. of Stations	D.O. Saturation	Percent of Total
184	>100%	17.0
367	95-100%	33.8
276	90-94%	25.4
211	85-89%	19.4
34	80-84%	3.1
13	<80%	1.2
1085		**100.0**

Over the 1085 profiles taken since 1994, only 47 included saturation values below the 85% regulatory threshold. Three of these, however, are anomalies where the replicate casts taken at the same stations within 4-5 minutes of the "violation profile", showed saturation levels at 95%. An additional two were recorded at control stations well beyond the influence of finfish operations. Adjusting for these anomalies, the remaining 42 profiles represent only 3.9% of the total number of profiles taken.

2.4. Discussion of results

All of the data collected to-date suggests that, with only a few exceptions, finfish culture operations have limited impact on ambient dissolved oxygen levels, and even where near-cage D.O. depression does occur, D.O. levels recover rapidly to near upcurrent, or ambient, levels within a short distance of the cages. It should be noted that D.O. saturation levels below the 85% threshold are essentially confined to the areas immediately adjacent to cages. Only 2 of 307 profiles taken 100 meters downcurrent of cages showed D.O. saturation levels below the 85% threshold. Furthermore, one of these is an anomalous profile showing a minimum of 79% while its replicate shows a minimum of 88%; the second shows a minimum saturation of 84%, just one percentage point below the threshold. It should also be noted that, where near-pen D.O. saturations are below the 85% regulatory threshold, the level of depression is rarely more than five percentage points and, as is discussed in Section 2.6.2. , usually occurs within a specific area or fraction of the water column coinciding with the net-pen depth and area of highest biomass.

No single site has shown consistently poor dissolved oxygen levels through over the sampling years. Some sites do, however, show more frequent depressions. The Sea Farm Maine (SFML) sites in Johnson's Bay, Lubec (JB2 in 1994 and JB3 thereafter) frequently show depressed D.O. saturations within 5 meters of the systems, however, recovery to upcurrent levels occurs quickly within 100 meters downcurrent of the cages. Johnson's Bay is relatively shallow and circulation in the Bay is not as great as in other areas of the Cobscook Bay region. Atlantic Salmon of Maine's (ASMI) Cross Island (CI) site has shown occasional D.O. depressions both within the immediate vicinity of cages and 100 meters downcurrent, although the latter are above the 85% threshold. ASMI's Cross Island site is the largest salmon biomass production site in Maine and it is therefore not particularly surprising to see D.O. saturation depression occurring downcurrent of the cages, as well as the site as a whole. Although other sites have shown depressed D.O. saturations, the D.O. depressions have been confined to a single year of occurrence.

The colder waters and more dynamic hydrographic conditions in Cobscook Bay would appear to make it reasonable to assume that D.O. saturation levels in Cobscook would be higher than elsewhere along the coast. Table 2.4.1., below, presents a comparison of D.O. saturation levels in the vicinity of cage sites both inside and outside of Cobscook Bay.

Table 2.4.1.
Comparison of mean Percent D.O. saturation as a function of distance from cage systems in different coastal regions of the State of Maine

		100m UP	5m DN	100m DN	Δ 100U-5D	Δ 100U-100D
1994	**Cobscook Bay**	101.0	96.6	99.2	4.4	1.8
	Outside Cobscook Bay	102.6	97.0	102.2	5.7	0.5
1995	**Cobscook Bay**	89.5	87.3	88.8	2.2	0.7
	Outside Cobscook Bay	97.6	94.0	95.6	3.6	2.0
1996	**Cobscook Bay**	93.1	90.9	91.7	2.2	1.4
	Outside Cobscook Bay	99.0	95.2	96.6	3.8	2.4
1998	**Cobscook Bay**	99.5	95.6	98.3	3.9	1.2
	Outside Cobscook Bay	106.8	100.9	102.7	5.9	4.1

It is somewhat surprising that D.O. levels outside of Cobscook Bay are consistently higher than those within Cobscook Bay. On the other hand, it is not at all surprising that, with the sole exception of the Δ 100U-100D distance in 1994, the effects on D.O. persist at a higher level at a greater distance from the cages outside of Cobscook Bay. This is consistent with the greater hydrodynamic conditions prevalent in Cobscook Bay that would tend to cause greater mixing within a short distance from the cages.

2.5. Identified problems

The calibration curves developed in 1994, 1995 and 1996 showed close correspondence between the CTD and Winkler titration results. However, poor correspondence was found between the two methods in 1998 and again in 1999. In 1998 the titration results did not coincide with either the profiler or handheld oxygen meter results while the latter two coincided closely (data not recorded; personal observation, C. Heinig). These results suggested that the CTD was reading correctly while the titrator results were inaccurate. The inaccuracy was attributed to either mechanical problems with the digital titrator, the reagents, or both. Nevertheless, due to time constraints, sampling was allowed to proceed despite the calibration curve discrepancies. Subsequent post-sampling calibration of the CTD by Sea-Bird Electronics, Inc. in January 1999 confirmed that the CTD had been operating correctly and accurately.

In 1999 the CTD and Winkler titration results again showed poor correspondence, however, in this case the discrepancy appeared linear, *i.e.* consistently increasing with decreasing temperature, suggesting an algorithmic basis for the problem. After extensive investigation and several calibrations and re-calibrations, the problem was finally identified as incompatibility between different software versions, one being used by the unit to encode data and a second to decode and analyze those data. The problem was corrected once the same, most recently updated software was used to decode and analyzed the data.

Unfortunately, the need for repeated calibrations caused sampling to be delayed from what was hoped to be an early start in late August/early September to late September/early October. The early start was prompted by reports of low dissolved oxygen levels in August, apparently the result of algal blooms caused by heavy rainfall in August following an unusually dry summer. Algal blooms were reported all along the Maine coast. A particularly heavy bloom of *Prorocentrum micans* occurred in Casco Bay and persisted for several weeks.

2.6. Considerations/recommendations for future

2.6.1. Calibration/survey schedule

Given the difficulties encountered with the calibration of the CTD in both 1996 and 1998 and the resultant delays, it may be advisable to conduct the multiple bath/Winkler calibration and calibration curve preparation as early as June or July. By carrying out the calibration earlier any difficulties encountered can be corrected before the scheduled start of sampling, thus avoiding delays.

The water quality survey, or dissolved oxygen survey, has previously been scheduled for the end of September or beginning of October to coincide with the period of maximum feeding rate during the year and, at least in September, the period of highest seawater temperatures, thus presumably the period of lowest natural, ambient dissolved oxygen. According to industry observers, however, over the past several years it appears that the annual D.O. minima occur in late August rather than in early September.

In both 1996 and 1998 the dissolved oxygen survey was scheduled to be carried out independently of the video and benthic monitoring to allow the entire coast to be monitored within a relatively brief period, *i.e.* a single week, rather than over the extended period over which video and benthic surveys are conducted. Unfortunately, the delays caused by the calibration problems, combined with the time constraints on carrying out the video monitoring in Cobscook Bay as a result of the October 1 start to the dragging season for urchins, precluded the separation of these tasks.

Also as a result of these delays, in 1996 and 1998 the D.O. survey of sites outside of Cobscook Bay were not carried out until mid- to late-October, perhaps missing the period of D.O. minima in these areas. This may explain, at least in part, the surprisingly higher D.O. saturation values found outside of Cobscook Bay in these years as shown in Table 2.4.1. The near-consistently higher D.O. saturations found at sites outside of Cobscook Bay may be partly the result of the lower seawater temperatures and/or increased wind-driven mixing often experienced later in the Fall. In 1995, when sampling was done over a relatively short period between 10/14/95 (Day 1) and 10/19/95 (Day 6), the seawater temperature was the same throughout at ~12^{O} C. Despite the similar temperatures at the Cobscook Bay sites and the western sites, the D.O. values outside Cobscook Bay were still higher. In 1996, when the survey was conducted over a longer period of time, the seawater temperature varied from 12.0^{O} C. in Cobscook Bay on 09/24/96 (Day 1) down to 9.8^{O} C. on 11/01/96 (Day 8) at Swans Island and D.O. was again higher in the western region. In 1998 the survey was conducted over a one-month period between 09/28/98 (Day 1) and 10/29/98 (Day 10). Seawater temperature over the period ranged from 11.1-10.8^{O} C. in Cobscook Bay at the start of the survey down t 9.5^{O} C. at Cutler on the last day, and again, D.O. levels outside of Cobscook Bay were generally substantially higher than in Cobscook Bay.

Based on the fact that the maximum annual seawater temperature and/or the minimum ambient D.O. saturation appear to occur in late-August, and to avoid the possible influence of temperature or wind-driven mixing on D.O. levels over time and space during the survey, it is recommended that the survey be started in mid- to late-August and carried out over as abbreviated a period as practicable. To prevent delays related to CTD performance, the CTD should be calibrated and calibration curves prepared as early in the Summer as possible.

2.6.2. Individual scan vs. profile average percent D.O. saturation

The CTD Profiler deployment procedure has been described in Section 2.1.3. Following is a brief description of the data recording and review processes:

> Each time the CTD is switched on to begin a cast, a file is created in which the cast data is recorded. The CTD scans the sensor once every 0.5 seconds and records data on all parameters as a "scan". Thus each cast file consists of numerous scans, and each scan contains data on each parameter. The SeaBird SEASOFT software used to reviewed the data collected by the CTD allows selective display of the data. In addition, the software allows selection of data collected only during descent through the water column, only during ascent, or both. For the purposes of the FAMP, depth, salinity, temperature, dissolved oxygen concentration and percent saturation are displayed, and only data collected during descent is used. Data collected by the CTD during the 3-minute surface polarization period are omitted. The data review process of each cast file, therefore, only considers those data collected once the CTD begins its descent through the water column, *i.e.* increasing depth, and ends once the CTD reaches the bottom, *i.e.* maximum depth. The reason for using only descending data is that soft sediment often enters the pump intake upon impact on the bottom blocking the intake, causing an immediate and continued decline in D.O. saturation values.

As the individual scans of the cast file scroll across the display, each scan of the descent is reviewed to determine if the 85% D.O. saturation minimum threshold is exceeded. If the threshold is exceeded, the minimum value observed for all scans reviewed is recorded for the appropriate cast on the spreadsheet for the date of sampling. Therefore, as mentioned earlier in Section 2.3., the minimum percent saturation value reported for each cast in the Annual Fall Water Quality Survey reports represents the *minimum value* observed during the descent of the CTD through the water column during the cast.

Since dissolved oxygen surveys began in 1994, very few profiles have shown dissolved oxygen saturation levels below the 85% saturation threshold throughout the water column. When values below 85% are found, the zone of D.O. depression tends to be confined to a specific depth range that usually coincides with either the depth of the net pen or the depth at which the fish happen to be at the time the profile cast is done. Table 2.6.2.1. on the following page shows the profile data for such a cast. In this case, the D.O. depression begins close to the surface at ~84%, decreases slightly over 0.5 meters, then increases above 85%. At ~7.5 meters the D.O. saturation begins to drop and continues to drop until the 10.5 meter depth, then climbs back above the 85% level through the maximum depth of 13.5 meters. This profile suggests that the fish in the net pen were holding within a depth band of 7-10 meters.

Table 2.6.2.1.
Profile of cast 0342 on 10/04/95 at CONA BC 5m Downcurrent (5) Trial 1, Unit 5500

Scan	Depth (m)	Salinity (‰)	Temp. ^{O}C.	D.O. mg/l	% sat.
365	1.2	32.3	11.9	7.5	84.5
366	**1.2**	**32.3**	**11.9**	**7.4**	**84.0**
367	**1.3**	**32.3**	**11.9**	**7.4**	**83.5**
368	**1.7**	**32.3**	**11.9**	**7.4**	**83.7**
369	2.4	32.2	11.9	7.5	84.5
370	3.3	32.3	11.9	7.5	85.5
371	3.9	32.3	11.9	7.6	86.0
372	4.6	32.3	11.9	7.6	86.2
373	5.2	32.3	11.9	7.6	86.2
374	5.8	32.3	11.9	7.6	86.1
375	6.4	32.3	11.9	7.6	85.8
376	7.0	32.3	11.9	7.5	85.1
377	**7.5**	**32.3**	**11.9**	**7.4**	**83.9**
378	**8.1**	**32.3**	**11.9**	**7.3**	**82.8**
379	**8.7**	**32.3**	**11.9**	**7.2**	**82.1**
380	**9.4**	**32.2**	**11.9**	**7.2**	**81.5**
381	**10.0**	**32.2**	**11.8**	**7.2**	**81.2**
382	**10.6**	**32.3**	**11.8**	**7.2**	**81.6**
383	**11.2**	**32.3**	**11.8**	**7.3**	**83.0**
384	11.7	32.3	11.8	7.5	84.7
385	12.3	32.3	11.8	7.6	86.5
386	12.6	32.3	11.8	7.8	88.1
387	12.8	32.3	11.8	7.8	88.8
23					
	Mean	**32.3**	**11.8**	**7.5**	**84.6**

The minimum D.O. saturation reported for this profile is 81.2% recorded in scan 381at 10.0 meters and the profile would be considered a violation of the 85% minimum threshold. The mean D.O. saturation for the entire cast is 84.6%, just below the minimum threshold, but nevertheless, technically a violation.

Table 2.6.2.2. on the following page shows data for a similar cast at the same site, but in a different year. In this case, the D.O. depression again begins close to the surface at ~83% but remains at that level through the first 6.0 to 6.5 meters. Between 6 and 8 meters the D.O. begins to increase slowly, but then increases rapidly below 9 meters to a maximum of 96.2% at the bottom.

Table 2.6.2.2
Profile of cast 1319 on 09/23/98 at CONA BC 5m Downcurrent (1) Trial 1

Scan	Depth (m)	Salinity (‰)	Temp. ^{O}C.	D.O. mg/l	% sat.
338	2.0	32.1	11.3	7.4	**82.9**
339	2.7	32.1	11.3	7.4	**82.9**
340	**3.4**	**32.1**	**11.3**	**7.4**	**82.8**
341	**4.2**	**32.1**	**11.3**	**7.4**	**82.8**
342	5.0	32.1	11.3	7.4	**82.9**
343	5.7	32.1	11.3	7.4	**83.2**
344	6.4	32.1	11.3	7.5	**83.8**
345	7.0	32.1	11.3	7.5	**84.2**
346	7.7	32.1	11.2	7.6	**84.3**
347	8.3	32.1	11.2	7.6	**84.4**
348	9.1	32.1	11.1	7.6	84.9
349	9.7	32.1	11.1	7.7	85.4
350	10.3	32.1	11.1	7.8	86.3
351	10.9	32.1	11.1	7.9	87.5
352	11.5	32.1	11.1	8.0	88.7
353	12.1	32.1	11.0	8.1	90.0
354	12.7	32.2	11.0	8.2	91.4
355	13.2	32.2	11.0	8.3	92.6
356	13.8	32.2	11.0	8.4	93.7
357	14.4	32.2	11.0	8.5	94.6
358	15.0	32.2	11.0	8.6	95.3
359	15.6	32.1	11.0	8.6	95.8
360	16.1	32.2	11.0	8.7	96.2
23					
	Mean	**32.1**	**11.1**	**7.9**	**87.7**

The minimum D.O. saturation reported for this profile is 82.8% recorded in scans 340 and 341 at 3.4 and 4.2 meters. Accordingly, this profile would be considered a violation of the 85% minimum threshold. The average D.O. saturation for the entire cast, however, is 87.7%, above the 85% minimum threshold.

In the case illustrated above the range of violation extends from the surface to a depth of ~9 meters. In many cases, however, the range of violation is very limited, in certain cases limited to a single scan. Table 2.6.2.3. on the following page presents the profile data for a cast which contains a single 85% minimum threshold violation.

Table 2.6.2.3.
Profile of cast 0819 on 10/18/958 at IACO TC 5m Downcurrent (2) Trial 2

Scan	Depth (m)	Salinity (‰)	Temp. ^{O}C.	D.O. mg/l	% sat.
355	1.1	32.3	12.0	7.6	86.2
356	1.2	32.3	12.0	7.6	86.9
357	1.6	32.3	12.0	7.6	86.9
358	2.3	32.3	12.0	7.6	86.8
359	2.8	32.3	11.9	7.6	86.6
360	3.4	32.3	11.9	7.6	86.6
361	4.1	32.4	11.9	7.6	86.8
362	4.8	32.3	11.9	7.6	86.5
363	5.6	32.3	11.9	7.6	85.8
364	6.2	32.3	11.9	7.5	85.2
365	6.9	32.3	11.9	7.4	84.6
366	7.5	32.4	11.9	7.4	84.5
367	**8.1**	**32.4**	**11.9**	**7.4**	***84.4***
368	8.7	32.4	11.9	7.5	85.3
369	9.2	32.4	11.9	7.6	86.4
370	9.8	32.4	11.9	7.8	88.4
371	10.3	32.4	11.9	7.9	89.6
372	10.9	32.4	11.9	8.0	90.5
373	11.4	32.4	11.9	8.0	91.0
374	11.9	32.4	11.9	8.0	90.7
375	12.5	32.4	11.9	8.0	90.9
376	13.1	32.4	11.8	8.0	90.8
377	13.6	32.4	11.8	8.0	90.7
378	14.1	32.4	11.8	8.0	90.5
379	14.7	32.4	11.8	8.0	90.2
380	15.2	32.4	11.8	8.0	90.6
381	15.7	32.4	11.8	8.1	91.6
382	16.1	32.4	11.8	8.1	91.5
383	16.2	32.4	11.8	8.0	91.0
29					
	Mean	**32.4**	**11.9**	**7.8**	**88.6**

Rounding individual readings to the nearest whole percentage point, the minimum D.O. saturation reported for this profile is 84.4% recorded in scans 367 at 8.1 meters. As a result of the single value 0.1 percentage points below the 85% minimum threshold, this profile, too, would be considered a violation. As in the previous case, however, the average D.O. saturation for the entire cast is well above the 85% minimum threshold. Although this profile technically constitutes a violation of the dissolved oxygen saturation regulations, and is reported as such, a valid argument could probably be made that a single value taken in 0.5 seconds is not justifiable reason for considering this a violation. Although the profile presented above is the best example of the problem, it is not unique, for many of the 47 violations shown in Table 2.3.7. are classified as violations based on a limited number of low D.O. values in an otherwise acceptable profile.

To put the significance of any given percent saturation into proper context, it is recommended that the *mean* percent saturation for the profile of the descending portion of each cast be reported along with the minimum percent D.O. observed. Inclusion of the mean percent saturation will facilitate interpretation of a specific minimum value by allowing the value to be compared to the mean. It should be noted that the simple fact that the minimum value, particularly one below the 85% threshold, is substantially lower than the mean does not necessarily indicate that the minimum value is insignificant and not a matter of concern. It simply suggests that the profile data for the cast deserves further scrutiny.

As simple as the inclusion of the mean saturation value for a profile may sound, the fact is, the inclusion may require significantly more work during the data analysis phase. According to SeaBird, Inc., the Seasoft software package does have the capability of calculating means although the process of scan interval selection is cumbersome. Given the substantial additional effort that would be required to perform expanded analyses on all profiles, it is recommended that such expanded analyses be confined to those profiles that include violations, i.e. <85% D.O. saturation.

2.6.3. Percent saturation vs. D.O. concentration

Due to recent decisions on aquaculture lease applications where percent D.O. saturation played a significant role in the decision, combined with the low dissolved oxygen events of late-summer 1999 apparently associated with algal blooms, considerable attention has been focused on D.O. One question of particular importance to the FAMP regards the relationship between percent D.O. saturation and the actual concentration of oxygen in the water.

The solubility of oxygen in water is directly dependent on the temperature and salinity of the water. The relationship is inverse, that is, the higher the temperature and/or salinity, the lower the D.O. In other words, the actual amount of oxygen dissolved in water, when speaking of percent saturation, depends directly on the waters temperature and salinity. At a salinity of 32 ‰, the normal salinity of Maine's coastal waters, the concentration of oxygen in the water at 100% saturation is 9.20 mg/l at 10^{O} C, 8.81 mg/l at 12^{O} C, and 8.29 mg/l and at 15^{O} C. Applying the 85% threshold to these values, the concentration of oxygen in the water at 85% saturation would be 7.82 mg/l at 10^{O} C, 7.49 mg/l at 12^{O} C, and 7.05 mg/l and at 15^{O} C.

Table 2.6.3.1. on the following page presents the minimum percent dissolved oxygen saturation values and corresponding dissolved oxygen concentration for all 44 non-anomalous violations of the 85% threshold. As the table shows, the lowest D.O. concentration recorded is 6.1 mg/l; the mean concentration for all violations is 7.2 ± 0.73 mg/l (@ 95% conf.).

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Table 2.6.3.1
Summary of 85% D.O. saturation violations from 1994 to 1998
with corresponding D.O. concentration as mg/l

Year	Cast	Date	Site	Min. % D.O.	D.O. mg/l
1994	cast 0311	09/19	ECFF TE	**81**	7.0
	cast 0312			**80**	6.8
	cast 0202	09/20	SFML JB2	**84**	7.3
	cast 0203			**81**	7.0
	cast 0208			**73**	6.3
	cast 0209			**82**	7.1
	cast 0106	10/13	ASMI CI	**79**	6.9
	cast 0107			**79**	6.9
	cast 0114	10/26	MCNB HC	**82**	7.2
	cast0115			**82**	7.3
1995	cast0328	10/04	CONA BC	**78**	6.9
	cast0342			**81**	7.2
	cast0343			**81**	7.2
	cast0429		TIF TW	**84**	7.4
	cast0611	10/05	SFML RN	**81**	7.1
	cast0606	10/13	ASMI CI	**84**	7.5
	cast0612			**80**	7.1
	cast0613			**80**	7.1
	cast0614			**80**	7.1
	cast0615			**83**	7.3
	cast0619			**79**	7.0
	cast0620			**81**	7.1
	cast0621			**81**	7.1
	cast0623			**81**	7.2
	cast0636		MCNC CH	**84**	7.5
	cast0637			**84**	7.5
	cast0819	10/18	IACO TC	**84**	7.4
	cast0828		TISF HI	**84**	7.3
	cast0829			**84**	7.3
1996	cast1220	09/24	TIFI TW	**83**	7.4
	cast1311	09/25	SFML JB3	**84**	7.5
	cast1416		CONA BC	**81**	7.2
	cast1417			**83**	7.4
1998	cast1319	09/23	CONA BC	**83**	7.4
	cast1825	10/06	ASMI CI	**84**	7.8
	cast1826			**84**	7.6
	cast1913	10/07	ASMI CI2	**82**	7.6
	cast1914			**81**	7.5
	cast1933		ASMI II	**79**	7.3
	cast1934			**66**	6.1
	cast1936			**76**	7.0
	cast1938		**CONTROL 5**	**79**	6.7
	cast1939		**CONTROL 6**	**71**	6.5
	cast1940			**81**	7.5
			Mean	**80.8±1.1**	**7.2±0.10**

According to the U.S. Fish and Wildlife Service (Piper *et al.*, 1982), the desirable level of dissolved oxygen for warm freshwater pond fish is 5.0 mg/l or greater, and percent saturation should not drop below 80% in intensive culture systems such as raceways. Between 5.0 and 1.0 mg/l fish will survive, but growth will be slowed and deformities may occur if the exposure time is long. Different species of fish differ in their oxygen requirements, but the minimum safe level for most species is 5.0 mg/l. Research by the U.S. Environmental Protection Agency's Research Laboratory in Narragansett, Rhode Island and the Connecticut Department of Environmental Protection Marine Fisheries Division also suggests that dissolved oxygen concentrations of 5.0 mg/l or greater result in few adverse effects on marine organisms (EPA, 1999). According to the Federal Register of January 19, 2000, "Pursuant to section 304(a)(1) of the Clean Water Act (CWA), the Environmental Protection Agency announced on January 19, 2000 the availability of a draft document titled, Draft *Ambient Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras*. The EPA is considering using the values presented in this document as its recommended national 304(a) criteria for dissolved oxygen in saltwater." This draft document states that dissolved oxygen concentrations above 4.8 mg/l are considered to be acceptable. D.O. concentration #2.0 mg/l are considered critical and concentrations between 4.8 mg/l and 2.0 mg/l are considered to be of concern.

The USEPA has not previously used specific criteria for dissolved oxygen in sea water due an insufficiency of data. However, sufficient data now appear to exist for the region between Cape Cod and Cape Hatteras to allow such criteria to be established. Unfortunately, similar data for the Gulf of Maine appear to remain insufficient and similar criteria for the region north of Cape Cod have not yet been developed. Given the naturally higher levels of dissolved oxygen found in colder water, it is reasonable to assume that cold water organisms would likely require higher levels of dissolved oxygen. Nevertheless, the Cape Cod to Cape Hatteras region criteria can be used as guidelines.

If the 4.8 mg/l criterion is applied to the violations listed in Table 2.6.3.1., it is clear that none of violations constitute a biological threat to the environment. Even if the Cape Cod to Cape Hatteras minimum "safe" criterion is increased by an arbitrary 20% (0.96 mg/l) to 5.76 mg/l, all of the violations still exceed this level, most by a significant amount. Again, it should be emphasized that all of the violations, with the exception of only two, were recorded immediately adjacent to the cages. Unfortunately, in the absence of qualifying data on actual D.O. concentration, any violation of the 85% saturation threshold is currently being interpreted as posing a biological threat to the environment.

In view of the potential for misinterpretation of the significance of a violation of the 85% threshold, it is recommended that, at least in the case of a violation, the actual concentration of dissolved oxygen in mg/l be reported along with the percent saturation. Within the context of this report, this recommendation clearly applies specifically to the FAMP. However, since the 85% D.O. saturation threshold applies broadly across all environmental monitoring efforts in the State, both the DMR and DEP may wish to revisit percent saturation as the appropriate criterion for use in determining acceptable and unacceptable impacts on dissolved oxygen. Should the State determine that absolute concentration of dissolved oxygen is a more appropriate criterion for determining, reporting, and interpreting dissolved oxygen levels, it may also wish to consider determining what information would be required to develop criteria similar to those being proposed for the Cape Cod to Cape Hatteras region. This may be a matter for the Gulf of Maine Council to consider.

3.0. Video monitoring

Video monitoring is carried out semi-annually in the Spring and Fall of each year. The purpose of the underwater video recording is to provide those unable to dive beneath the cages with visual images of conditions adjacent to and beneath cages systems, as well as provide an objective, rapid, albeit superficial, means of documenting and evaluating changes in conditions beneath and adjacent to cage systems. Therefore, this component of the monitoring program allows an instantaneous view of shorter-term effects as well as a comparison of visible changes over time.

3.1. Procedure and protocols

The procedures and protocols used to make the video recordings has not changed significantly since the beginning of the Program, although some slight modifications have been made.

Transect lines, consisting of 60 meter (~200 ft) ropes, are marked in 10m alternating black and white sections, with the exception of the first and last 10m which are marked as two 5m sections, the last five of which are marked in alternating 1m black and white increments. One 60m transect line is deployed at each end of the cage system to allow measurement of distance from the cage edge along the bottom. The line is weighted at each end with yellow window weights to provide highly visible starting and ending points. The line is deployed by allowing one end-weight to drop to the bottom immediately adjacent to the cage edge. The remaining line is payed out from a boat running parallel to the predominant current direction until the line becomes taught, at which point the end-weight is allowed to drop to the bottom. Certain Polar Circle systems, where grid mooring systems are used, preclude deployment of the line immediately adjacent to the cages. In these cases, the end-weight is dropped to a depth of ~10 meters some distance from the outer grid line and is slowly moved forward until the weight tag line strikes the grid. The weight is then dropped to the bottom and the remainder of the transect line deployed as described above. This effectively moves the near-end of the transect line approximately 5-10 meters away from the actual edge of the first cage.

The diver survey and video recording are begun at the distant end of the 60m transect on the upcurrent side of the cage(s) to allow the diver to swim with the current. Once the diver reaches the end of the transect line at the pen edge, the survey continues either adjacent to or directly beneath the cage(s) until the second transect line is found at the opposite end of the system where the survey continues along the transect line to a distance 60m downcurrent of the cage(s). The video recording is taken with an underwater video camera package using Hi8 format. Lighting is provided by at least one 50 watt video light during the dive. The video recording is started at the end-weight and usually runs continuously throughout the dive, with the exception of certain instances when the diver becomes disoriented and considerable time is required to relocate the transect lines. In such cases the camera is turned off to conserve both video tape and battery power for completion of pertinent video recording of the bottom. Current velocity permitting, the swim rate during a video recording is ~0.3 meters/sec, or ~20 meters/minute. At this rate video recording time for cage systems ranges from 10-25 minutes, depending on the length of the system, and averages between 15-16 minutes.

When the diver observations and video recording indicate significant or substantial impact to the bottom the site operator is immediately made aware of the problem(s) and, when possible, an effort is made to review the video recording with the site operator on-site. If no specific problems are identified, the Hi8 video tapes are transferred to the Maine Department of Marine Resources as soon after recording as possible for review and copying onto standard VHS tapes. The original video recordings are then returned to the contractor for detailed review and development of the “hard copy” graphic representations and reporting. Individual reports that compare the recent video monitoring results with those of the previous monitoring are prepared for each site and sent to the respective site operator.

3.2. Procedure modifications

3.2.1. Video format

Initially, compact VHS, or C-VHS format was used for recording video images of the bottom. The required format was changed in 1994 to Hi8 in order to benefit from the higher level of image resolution afforded by this format.

3.2.2. Lighting

In the first year or two of the Program, artificial lighting was used only when filming directly beneath the cage systems; available, natural light was used beyond the cage edge. As video became an increasingly important monitoring tool, proper lighting was required to ensure optimal use of the enhanced resolution Hi8 format. Filming is now carried out using artificial light throughout the entire dive. Furthermore, single light sources are used on the approach to and departure from the cage systems, but dual lights are used during filming beneath or adjacent to the cages. Increasing the illuminated area has increased spatial coverage as well as resolution during filming.

3.2.3. "Drop" video technique

The currently acceptable maximum-safe depth for SCUBA-diver recorded videos is 85 feet. At least one existing, active finfish aquaculture site, and several proposed sites, exceed this limit. To allow video recording at depths in excess of 85 feet a "drop" video technique has been developed whereby the camera, housed in a 100+ meter rated housing shielded by a stainless steel frame, is started at the surface and dropped to the bottom with a tether line along the edge of the net pen. Once on bottom, the frame is raised off of the bottom ~1 meter and the line and housing walked along the cage until impeded by mooring lines. While still on bottom, the line and housing are moved away from the cage by a boat connected to the cage by a measured line. The measured line is payed out to a distance of 60 meters, or until an obstruction is encountered, i.e., another cage or a subsurface grid line. If a grid line is encountered before the 60 meters is reached, the camera is hoisted to the surface and redeployed on the opposite side of the grid line and the video recording continued. Realtime imaging is not currently used, therefore, to insure the camera is maintained at a proper viewing distance off of the bottom, the camera is periodically allowed to drop back to the bottom, then again raised ~1 meter off the bottom. Although laborious and time-consuming, this technique has yielded remarkably good results in depths approaching 200 feet. However, due to the darkness at these depths, considerable lighting is required at substantial energy consumption. This, combined with the "dead" or "blank" video recording time during the descent and ascent through the water column, rapidly depleted both the camera and lighting package batteries, seriously constrains actual bottom filming time.

3.2.4. Incorporation of wireless surface-to-diver communications

Wireless communication between the surface and divers is currently being used for safety reasons and to guide divers while inspecting beneath and adjacent to cages. The communications between the surface and the diver offer the opportunity to more clearly identify observations on the bottom with their location relative to the cage structures on the surface. The surface-to-diver communications are recorded directly on the audio portion of the video recording. This addition has vastly improved the capability of relating specific observations, such as severe impacts, excessive feed, and nets, to nearly exact location the bottom and relative locations on the cage system. This has proven particularly effective in relocating nets on the bottom for tagging and subsequent removal.

3.2.5. Video monitoring reporting

3.2.5.1. Written reports

Initially, the video survey reporting format required the development of a written narrative to accompany each video. As brief text summaries of the visual images, these narratives were intended primarily to assist viewers in properly identifying organisms and objects on the videos recordings. However, the narrative was of very limited use without the video recording itself. Furthermore, a comparison with previously recorded information required either a replay of the previous video itself or a recollection of the video images while reviewing the narrative. Although marginally adequate, this approach proved cumbersome and of limited value given the wealth of information contained in the video recordings.

Beginning in the Spring of 1995, the video narratives were replaced by graphic representations of key video observations recorded along the transects. These graphics allow the presentation of considerable information in a clear and concise way. First, the location of cages or cage systems and the direction and course of dive transects are clearly indicated. Second, times taken from the time stamp on the video recording are used as time-distance markers along the dive path. Third, specific observations are located along the transect based on the surface-to-diver communication audio embedded on the tape. Fourth, particularly important observations, such as gassing, nets on bottom, etc., are highlighted, thus immediately focusing attention on the most critical observations.

Individual iconic symbols have been developed using CorelDRAW 3® /CorelDRAW 9® graphic software to represent the most commonly observed organisms, benthic conditions, and pen operation-related debris. Figure 3.2.5.1., on the following page, shows the legend developed to assist the reader in identifying the individual iconic symbols. Figures 3.2.5.2. and 3.2.5.3., on the subsequent, following pages, show example graphic representations of the Fall 1998 and Spring 1999 dives along one of the cage systems in Cobscook Bay. This side-by-side presentation of sequential video graphic representations demonstrates the ease with which comparisons can be made between current and previous observations.

3.2.5.2. Targeted video recording and increased personal contact

Over time it has been demonstrated that certain sites show negligible, at times nearly undetectable, impact to the bottom and few changes occur between video monitoring visits to these sites. Consequently, in the interest of focusing monitoring efforts on those sites of greater concern, these minimal-impact sites were omitted and the video monitoring effort of Spring 1999 was targeted on those sites having shown either moderate or significant degradation of the bottom, or where nets had been observed on the bottom during the Fall 1998 monitoring. Furthermore, reporting was limited strictly to development of the video graphic representations.

The time savings resulting from the reduction in the number of videos recorded and the reduced reporting effort was intended to allowed the contractor to personally meet with individual site operators to review and discuss the results of 8 years of monitoring. These meetings focused attention on any areas of concern, specifically areas of significant degradation or presence of nets on the bottom and, where appropriate, requested the development of a 6-month correction/mitigation plan to be submitted to the Aquaculture Environmental Coordinator at the Maine DMR.

Figure 3.2.5.1.
Video monitoring graphic representation legend

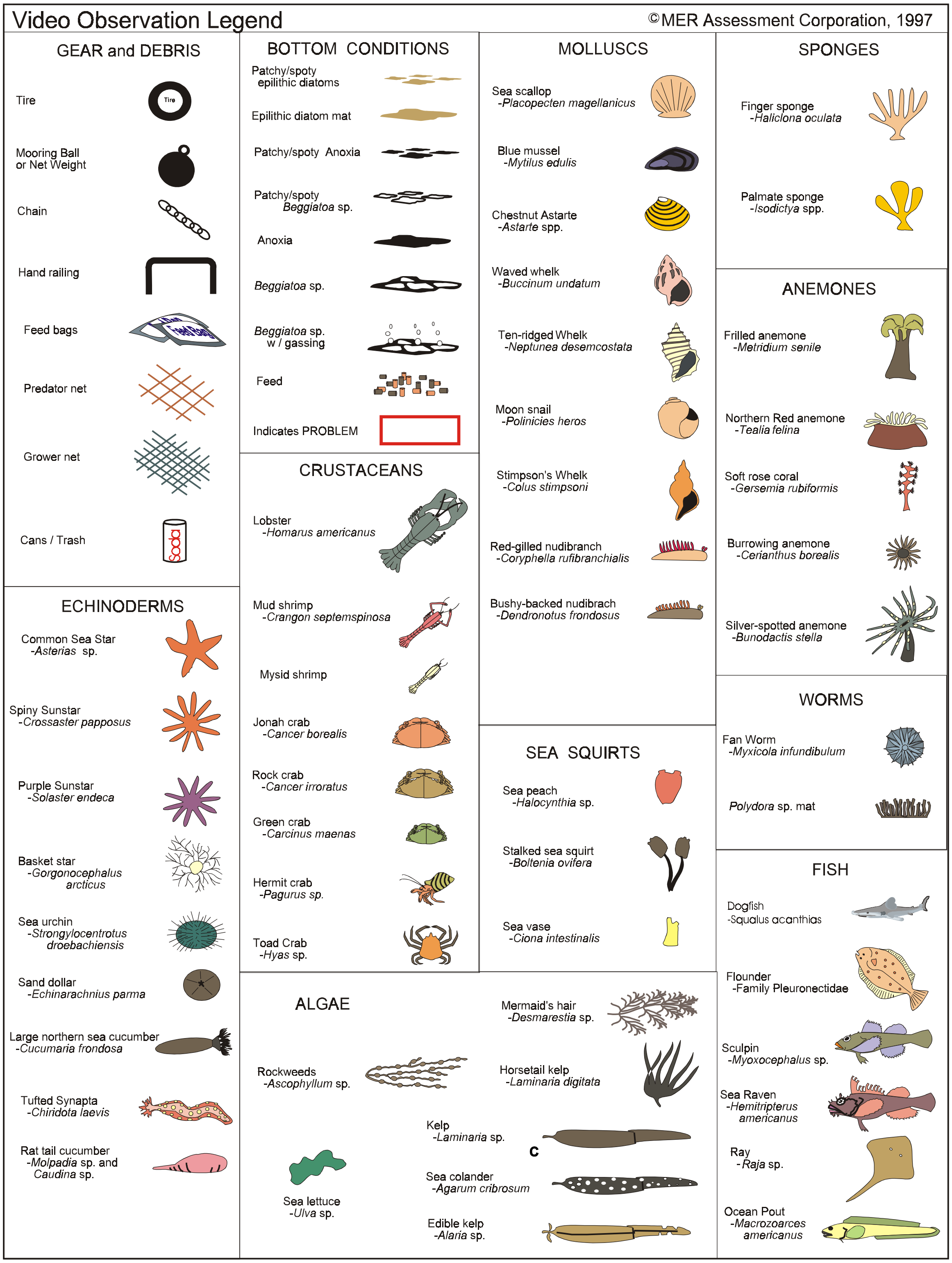


Figure 3.2.5.2.
Video monitoring graphic - SFML RN - Fall 1998

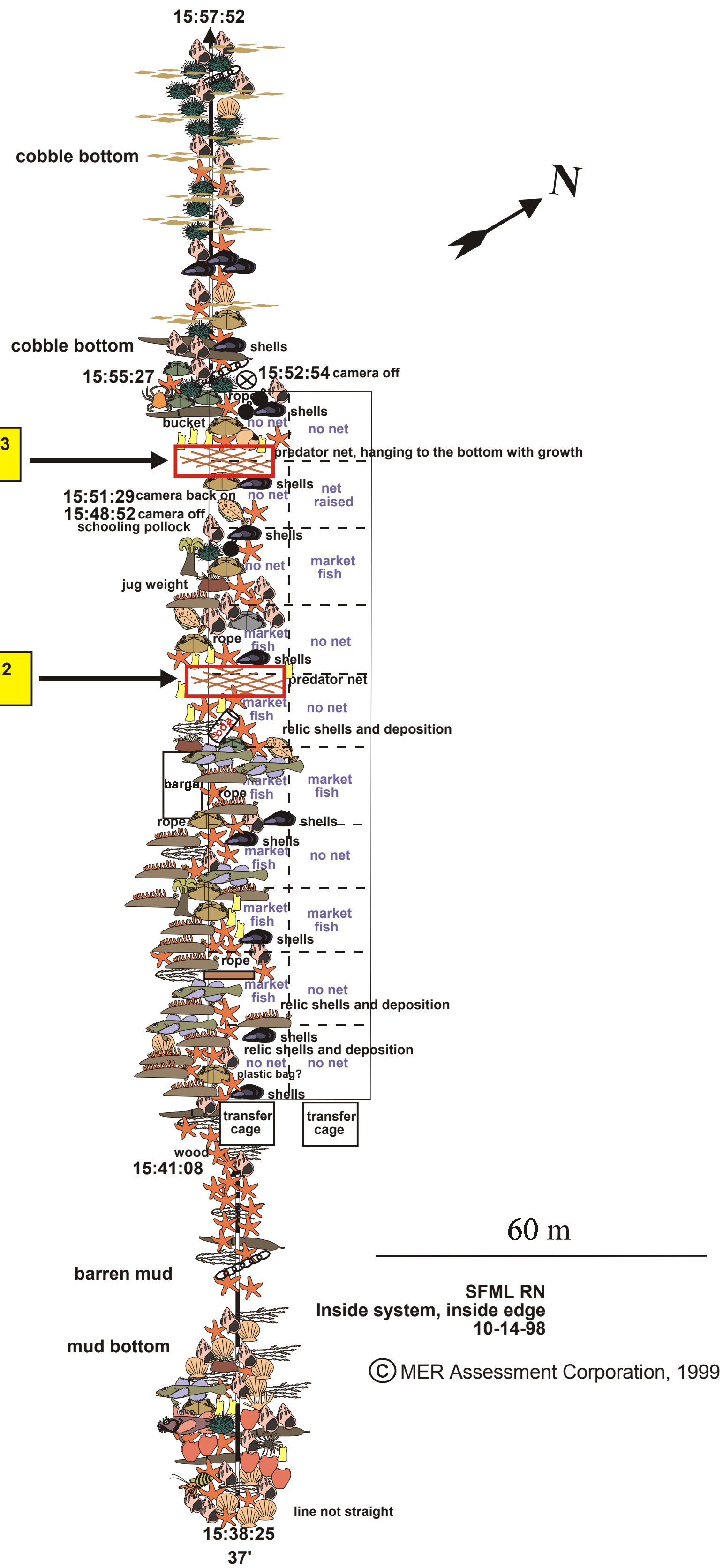
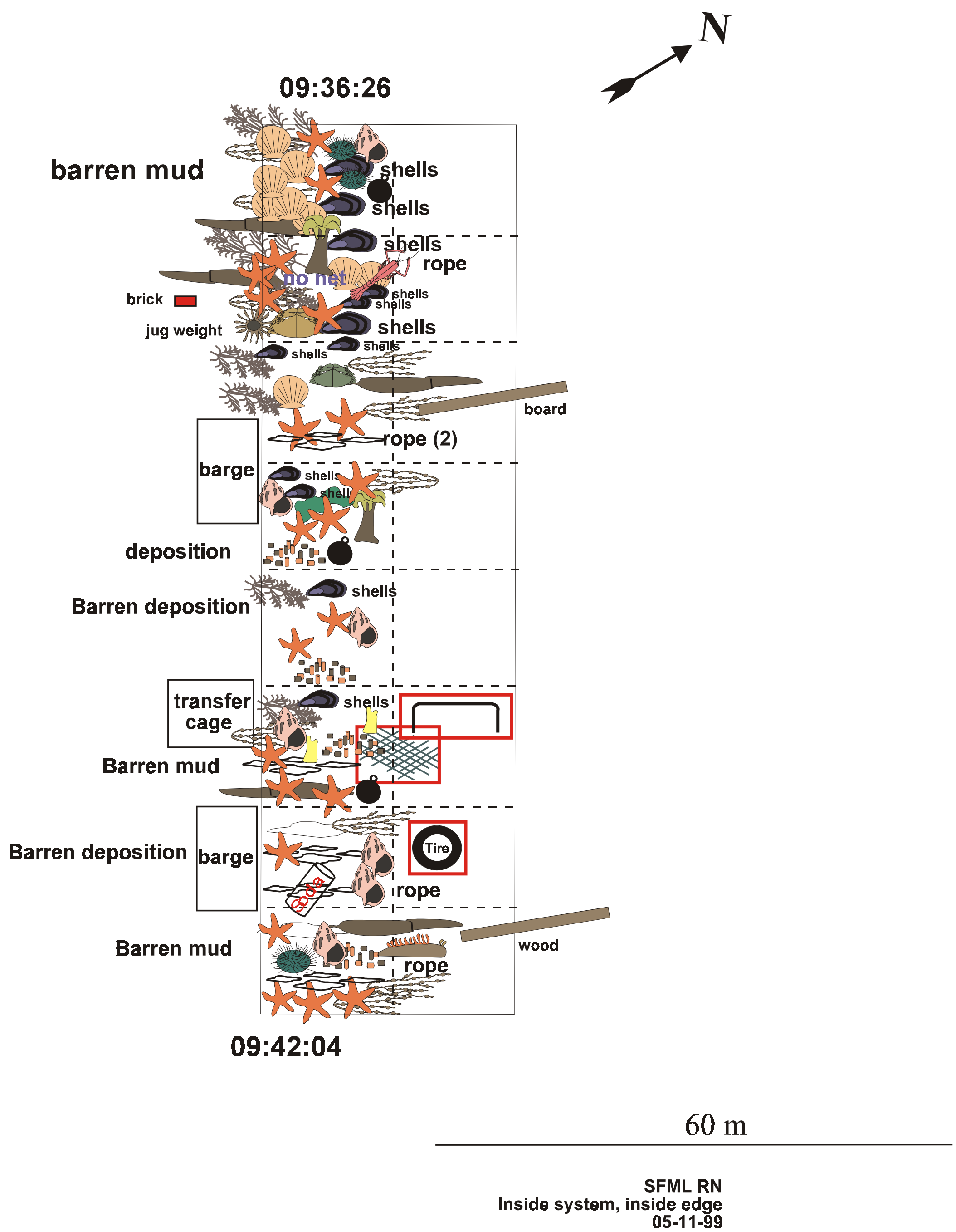


Figure 3.2.5.3.
Video monitoring graphic - SFML RN - Spring 1999



3.3. Results

As a monitoring tool, video recording has proven to be a relatively inexpensive and rapid, yet highly effective means of documenting and visually representing conditions beneath and adjacent to cage systems. Furthermore, the video recordings, combined with the graphic representations of those images have proven to be an effective way of comparing sequential observations as shown in Figures 3.2.5.2. and 3.2.5.3. on the previous pages.

Since the initiation of the FAMP in 1992 a total of 707 video recordings have been made representing approximately 220-250 hours of footage. The results of the video monitoring have been reported in individual site reports for each Spring and Fall video monitoring period between Spring 1992 and Fall 999, the latter of which are currently in preparation. Given the number of video recording and the extensive information contained in them, presentation of individual site video monitoring results is well beyond the scope of this report. Copies of all video recordings and site monitoring reports are archived at the Maine DMR, West Boothbay Harbor, Maine facility and can be obtained by contacting Jon Lew at 207-633-9594 or Jon.Lewis@state.me.us.

3.4. Interpretation of results

Generally speaking, with the exception of a few selected sites, conditions adjacent to and directly beneath finfish cage systems, as evidenced by the visual observations, appear to have improved since the initiation of the FAMP in 1992. The trend toward improvement, or at least stabilization, of conditions beneath and adjacent to cage systems in Maine was initially reported in 1995 and appears to be continuing at most sites. As suggested in previous reports, this trend toward improvement may be attributable to several factors. Two factors stand out as most important: 1) the continued use of dry feed over moist feed and 2) increased competition on the national and world markets that has depressed the price of salmon, consequently increasing the need for cost-efficiency.

Regarding the first, the increased structural integrity of the dry feed pellets appears to have significantly reduced the amount of non-intercepted feed reaching the bottom, thus reducing the carbon load to the bottom. With respect to the second, the increased competition in the marketplace, principally from Norway and Chile, has significantly depressed the price of salmon over the past several years. This, in turn, has significantly impacted the profit margin for salmon growers, necessitating cost reductions, particularly in the areas of labor and feed. Consequently, considerable attention has been focused on the automation, control and efficiency of feeding. The increased use of sophisticated computer-assisted feeding systems, combined with increased attention to efficiency on the part of feeding teams, has also resulted in less feed reaching the bottom.

Significant deterioration of the bottom beneath cages has been observed at certain sites, particularly at Atlantic Salmon of Maine's Cross Island sites (CI and CI2) and the Maine Coast Nordic-operated sites of Robert Liberty at Spectacle Island, Eastern Bay, Jonesport (RLLT SI) and Robert Cates in Cutler Harbor, Cutler (MCNC CH and CN).

At three of these sites (CI, CI2, and SI) the deterioration has been associated with an increase in production in anticipation of expansion onto additional, new lease sites. At the Jonesport site, the recent transfer of part of the RLLT SI production to a new site established in nearby Sand Cove appears to have reduced the organic load to the bottom at SI and conditions beneath the cages now appear to be improving. Atlantic Salmon of Maine, however, continues to have difficulty acquiring new sites and consequently the deterioration of the bottom at Cross Island continues. The Maine DMR and Atlantic Salmon of Maine are currently developing a plan to address the situation. Conditions at the MCNC sites in Cutler do not appear related to increased production, but are instead related to the relatively shallow depths of the sites combined with relatively slow currents. Although deterioration of the bottom immediately beneath the cages has been shown to be very significant at times, the impact zone is restricted to the immediate area of the cages ±2-3 meters. Slight changes can be detected between seasons at these sites, but the overall conditions do not appear to have changed substantially since monitoring began. These cage systems are periodically shifted within the lease boundaries to allow the bottom a fallowing period between production cycles.

3.5. Identified problems

Despite the overall improvement in benthic conditions as measured by the amount of feed, accumulation of organic matter and the extent of occurrence of the sulphur-reducing bacterial *Beggiatoa* sp., in 1997 the numbers of both predator and grower nets found beneath cage systems was identified as a matter of increasing concern.

The temporary lowering of nets to the bottom for "biological" cleaning is a common practice, for there are times when fouling on the nets is great enough to preclude their being raised out of the water. At certain sites, however, nets were repeatedly seen in the same location indicating that the nets were being left on bottom for prolonged periods of time. Mussels, *Mytilus edulis*, fouling these nets seem to migrate to the surface of the net and appear to thrive on the bottom rather than being preyed upon, thus significantly altering the benthic community beneath the cage systems. Whether the replacement of a polychaete-based infaunal community by an epibenthic bivalve-based community is beneficial or detrimental may be debatable, but it certainly constitutes a significant change.

Perhaps of greater concern, however, was the fact that many of the nets slowly becoming buried in the bottom. Once buried and out-of-sight, detection of these nets is difficult, if not impossible. Since these nets are made of synthetic materials they will likely persist in the bottom for a considerable period of time and could eventually pose an obstruction and hazard to mobile fishing gear if and when the aquaculture operations temporarily or permanently cease. According to the industry, part of the problem of removing these nets was the difficulty of locating a net on the bottom, even when a video was available that identified its general location.

Recognizing the actual and potential problems posed by these nets, beginning in the Spring of 1998, the scope of work for the FAMP was expanded to include a task specifically focused on the location and tagging of aquaculture-related nets found on bottom. Implementation of this task began in the summer of 1998 during which 47 nets were located and tagged based on reviews of the Fall 1997 and Spring 1998 video recordings. Following tagging, the Maine DMR sent letters to each site operator where nets had been tagged requesting that the nets be removed as soon as possible. Recognizing that in certain cases, due to operational constraints, the nets would not be able to be immediately removed, the Department requested that a plan be submitted within six months detailing a plan and schedule for removal. The Department also requested that proof of disposal be furnished for nets removed and taken out of service.

It is difficult to estimate the total number of nets removed in response to this request, however, DMR records indicated that approximately 10-15 nets were removed in this first effort. This number should be considered a minimum value since many net removals have gone unreported, particularly nets that were returned to service.

A second net location and tagging effort was carried out in the Spring/Summer of 1999 resulting in the identification and tagging of an additional 27 nets. Response by the industry to this second effort improved during the Summer and Fall of 1999 when 39 nets were reported removed.

As stated, forty-seven nets were observed on the bottom in the Fall of 1998. In Spring 1999, 42 nets were observed when sites that had previously shown nets on bottom were specifically targeted. A review of the Fall 1999 video summaries shows 63 nets identified on bottom, some of which may have been counted twice. This indicates that, while the problem is being addressed as net management becomes an integral part of overall site management, a substantial number of nets remains on bottom. The removal process is being facilitated and expedited by the recent acquisition of large net hauling equipment in the Cobscook Bay area. Nevertheless, due to the continued presence of these nets, it is anticipated that the net tagging program will continue for the foreseeable future until all nets are removed.

Summaries of the net tagging efforts of 1998 and 1999 are included here as Appendix III. No separate report was prepared for the Summer 1998 tagging effort. In 1999 a the results of the net tagging effort were submitted to the Maine DMR in a separate report (Heinig and Cowperthwaite, 1999)

3.6. Considerations/recommendations for future

As stated in Section 3.2.1., the video format used for recording was changed from VHS-C to Hi8 in 1994. Since then considerable advances have been made in video technology, particularly with the introduction of digital video, commonly referred to as DV. Although DV has been around for several years, it has now become readily available and affordable, more so than in 1998 when consideration of a shift to DV was first suggested.

The Hi8 video format has served the needs of the FAMP very well, with excellent resolution, reliability, and tape durability over time. However, due to the versatility of the DV format, this format is rapidly replacing Hi8 as the format of choice in professional applications.

Currently, the Hi8 video recordings are played back for review and analysis either on the cameras themselves or 8mm video cassette recorders. The 8mm video cassette recorders are expensive and the alternative use of cameras for both recording and review subject the cameras to multiple and repeated, perhaps excessive, play-rewind-play cycles, substantially reducing the life-expectancy of the units. Furthermore, copies are inevitably subject to loss of resolution which becomes magnified with each subsequent generation.

DV technology, on the other hand, allows digitally recorded images to be downloaded directly onto other media, such as a high capacity computer hard drive, for subsequent review and analysis. DV software packages offer a wide variety of playback and review modes, including slow motion, “freeze frame”, frame-by-frame, and frame specification/selection. The “frame capture” feature offers additional versatility allowing individual frames to be captured and subsequently copied into documents or exported as separate files for individual analysis or transmitted electronically as attachments to electronic mail.

The ease of electronic transmission of the DV format may prove to be of greatest benefit. Under the current procedures and protocols, unless the site operator and video reviewing equipment are available on-site, site operators usually must wait until they receive the VHS copies from the Maine DMR, often several weeks after recordings are actually made, to review recordings. A shift to DV could substantially reduce this delay by allowing site operators to review recordings made at their respective sites over the Internet within days, if not hours, of filming, vastly improving the rate of information exchange and consequently response time to any identified problems, *e.g.* over-feeding.

This suggestion is clearly preliminary, but a future move towards web-based information transfer is virtually inevitable. Such a move presumes, of course, availability of a server, site operator access to the Internet, and adequate security measures to prevent unauthorized tampering with files and/or data. The requisite servers, storage capacity, and security measures are likely already available to the Department through the State's Intranet system. Regarding site operator access to the Internet, in most cases, if not all, cases such access already exists. Furthermore, a shift towards web-based reporting would unlikely completely replace the current reporting system and traditional methods of reporting could be continued in cases where Internet access was not available.

A shift towards DV format and an associated web-based reporting system would undoubtedly carry some costs, perhaps even significant. Much of the cost, however, could eventually be recuperated through savings on labor associated with video review and traditional reporting, and could be distributed over other aspects of the FAMP, for example by offering web-based production reporting by the industry. Moreover, a reduction of time spent on these tasks would allow more time to be focused on data analysis and problem identification and correction.

4.0. Benthic monitoring

Benthic monitoring focuses on benthic impacts to the bottom directly beneath and adjacent to the cages. Since the FAMP began in 1992, 389 samples have been processed, with an additional 87 having been taken in 1999, (Heinig, 1995, 1996, 1997, 1998, 1999). Sampling is carried out immediately adjacent to and at various distances from selected cage systems on a schedule such that each cage system is monitored in alternating years. The purpose of the benthic monitoring is to detect and document any changes that take place in the macrofaunal community structure on the sites as a result of the cage system operations. This component previously included analysis of sediment composition, or granulometry, but this component was dropped in the Fall of 1996 after little correlation could be found between sediment granulometry and environmental effect. The benthic monitoring portion of the monitoring program seeks to track the longer-term effects and changes related to cage culture operations.

4.1. Procedure and protocols

4.1.1. Macrofauna

Single sediment cores for benthic macrofauna analysis are taken at pre-selected stations around and under the cage systems using 4 in. diameter PVC pipe coring devices. These are inserted to a depth of 10 cm or to resistance, whichever is reached first. The contents of the cores are washed through a U.S. Standard No. 50 sieve (1.0 mm mesh). All material retained on the sieve is transferred into sample containers, and the containers filled with 10% buffered formalin. Several drops of a 1% Rose Bengal staining solution are added to each sample to assist in highlighting the organisms for sorting. After 5 days of fixing in 10% Formalin, the formalin solution is decanted from the sample containers through a 500F mesh sieve and the formalin volume replaced with 70% ethanol to insure preservation of the organisms' integrity, particularly the bivalves and other calcareous forms.

The benthic macrofaunal community analysis is the most time-consuming and expensive part of the monitoring program. In addition to being highly labor-intensive, the identification of the organisms requires specific expertise in taxonomy. Although costly, these analyses yield a great deal of information and provide a clearer understanding of the subtle, yet complex changes which take place beneath the cage systems once the systems are installed and operations begin.

Several computer spreadsheets have been developed in Lotus SmartSuite97 1-2-3® to tabulate all of the data and facilitate comparisons between individual samples as well as between sites. The spreadsheet lists all species found to-date in the rows and provides column space for entering the number of individuals of each species found at each station. The spreadsheets also carry out several calculations of indices used to understanding and interpreting these data.

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Four values continue to be used to evaluate the benthic condition. First is *abundance*, a derivative of the total number of organisms, reported as number of organisms per $0.1m^2$, or

$$\textit{Abundance} = \text{total no. organisms} \bullet 12.345$$

where 12.345 is the coefficient to convert the surface area sampled by the 4-inch diameter corer to $0.1m^2$.

Second, *species richness* is simply the number of individual species represented in the sample. Species richness serves as an index of diversity indicating either a heterogeneous community where numerous species are represented, or a homogeneous community where only a few species are present.

Third is *relative diversity*, also referred to as *evenness*, an index that relates the number of species represented to the number of individuals of each species. Thus, while a large number of species may be represented, most may be represented by a small number of individuals, while two or three may be represented by the majority of the individuals found. Consequently, while the species richness may be high, the representation of the species, *relative to one another*, may be far from evenly split. The diversity index *H* used here (Shannon, 1948) is expressed as

$$H = \frac{n \log n - \sum_{i=1}^{k} f_i \log f_i}{n}$$

where *n* is the total number of organisms in the sample, *k* is the number of species in the sample, and f_i is the number of individuals in each species *i*.

The theoretical maximum diversity is given as

$$H_{max} = \log k$$

and the following proportion can be used to compare the actual and theoretical maximum diversity, thus yielding a relative diversity *J*

$$J = H/H_{max}$$

Theoretically, under "normal", unaffected conditions the actual diversity should approach the theoretical maximum diversity and *J* should approach 1. In reality "normal", unaffected conditions are virtually impossible to find due to the extent of fishing activity along the bottom. Where environmental degradation favors certain tolerant species, the *actual* diversity can be considerably less than the theoretical maximum and *J* may approach 0. Theoretically then, the smaller *J* becomes, the more affected the environment is assumed to be. However, as explained later, this is not always necessarily the case.

The fourth value is the percent of the total population represented by the indicator species *Capitella capitata*. *C. capitata* is ubiquitous, is very tolerant of hypoxic, or oxygen depleted, conditions and is therefore often used as an indicator of environmental degradation, particularly degradation associated with organic loading. A determination of % *C. capitata* therefore allows a comparison of this species' relative abundance from one sample to another and provides some indication of the bottom conditions.

Each of these values or indices provides a means of interpreting the mass of numbers generated through the benthic analyses. However, no single value or index, taken by itself, can be relied upon to reflect the complete and complex nature of the benthic community. For example, consider a case where two samples have similar *J* values of, say, 0.335 and 0.314, and % *C. capitata* of 69% and 79%, respectively, but species richness values of 64 and 10, respectively. On the basis of *J* and % *C. capitata* the two samples may appear rather similar, but the fact that the first sample comes from an area supporting 64 species and the second from conditions supporting only 10 species suggests that the latter represents a more degraded environment that the former.

To avoid relying on any one of these values and to better reflect the relationship between relative diversity and species richness we have simply multiplied the relative diversity value *J* by the species richness (RD*SR). Thus, as a general rule, the larger the product, the better the environmental condition.

4.2. Procedure modifications

4.2.1. Sediment analyses

The original monitoring program included a suite of sediment analyses, specifically, 1) determination of the depth of the overlying *unconsolidated sediment* layer, 2) measurement of the *reduction-oxidation (redox) discontinuity (RPD) level*, and 3) sediment grain size, or *granulometry*.

An *unconsolidated layer* usually appears as a loosely compacted to flocculent layer on the surface of an otherwise relatively compacted sediment core. When the FAMP was initiated in 1993, based on reports from Europe and Canada, it was expected that the amount of unconsolidated material found beneath and adjacent to the cages would be substantial. However, after two years of sampling Maine sites, it became apparent that, given the heterogeneous nature of sediments across most sites, the depth of the unconsolidated organic material layer was usually difficult to establish. A discrete line of demarcation between the unconsolidated and consolidated portions of the sediment cores was usually difficult to find. Further, it was often difficult to distinguish between an unconsolidated layer of organic material and very fine, loosely compacted inorganic silt. Although the depth of this loosely compacted layer was generally deeper directly beneath the cages than at a distance from the cages, the difference between the "ambient" condition and "affected" condition was usually slight, and in many cases, undetectable.

Similarly, the *reduction-oxidation (redox) discontinuity (RPD) level*, which defines the boundary between oxic, or oxygenated sediments, and the anoxic, or oxygen depleted sediments, was often very difficult to distinguish. Streaking of the layers along the inner surface of the corer, as well as localized variations in the RPD level within the core, made detection of the RPD boundary difficult. This difficulty, however, was usually limited to the areas showing negligible effect; where significant effect was encountered, *i.e.* directly beneath the cages, a clear RPD boundary was usually definable, and where little or no effect was encountered, the entire core was oxic and no RPD boundary was seen. Despite the apparent correlation with "impact", however, the redox results appeared to be related more with sediment composition and current velocity than to husbandry practices or pen operations.

Total organic carbon, or *TOC*, analysis measures the amount of carbon present in the sediment originating from organic rather than inorganic sources. Since cage culture operations add significant amounts of organic carbon in the form of fish feed, it was initially expected that the TOC values beneath and adjacent to the cages would be significantly higher than those found some distance from the cages, the latter representing ambient conditions. However, the combined results from three years of sampling showed no clear trend towards elevated TOC content at near-cage stations. It was suggested that this was probably due to the varying carbon sources found at different distances from the cages. For example, directly beneath the cages, waste feed, feces, and bacteria contribute to the total carbon. At several meters from the cage, polychaetes may account for the majority of the carbon, while at a considerable distance from the cage, epilithic (bottom-covering) diatom mats may account for most of the carbon. Clearly, the source of the carbon can change from one sampling location to another and the total amount of carbon found can vary only slightly, all of which makes interpretation of the results rather difficult.

Granulometric analyses were carried out for two reasons: 1) to determine changes which might occur in bottom sediments as a result of changes in deposition rates associated with the cages and 2) to correlate levels of impact with sediment types. After three years of sampling, however, little change was detected in sediment composition around cage sites over the sampling period. In addition, no significant correlation could be found between the granulometry results and any of the environmental effect indices (see the 1996 Report to the Legislature).

Given the inability to relate these sediment analyses results to any observed effect, the redox, TOC, and granulometry components of the benthic sampling were dropped from the monitoring program in the Fall of 1996. These tests have been retained as part of the baseline field survey requirements for lease applications to provide baseline information should the Department wish to carry out pre- and post-development comparative studies in the future.

4.2.2. Benthic infauna analysis

Benthic infauna analysis yields a considerable amount of information and is a very effective tool for tracking subtle, long-term changes in benthic conditions. It is, however, very time-consuming, requires very specialized expertise, and is consequently very costly. Shortly after implementing the Program in 1992, ways were sought to reduce the cost of the Program.

Two studies were carried out in 1994 and 1995 to evaluate the effects on data quality resulting from an increase in the mesh size used to sieve samples and the taxonomic level to which organisms were identified. The first study compared the resulting indices values from samples screened on a U.S. Standard No. 35 sieve (0.5 mm mesh) and a U.S. Standard No. 50 sieve (1.0 mm mesh). The study showed a significant drop in abundance and a slight decrease in species richness when using the larger mesh, an expected result. However, despite these differences in input data, the values for the indices used to track environmental change did not differ sufficiently from one mesh size to the other to warrant the additional effort and cost associated with using the smaller mesh size. Thus, beginning with the sampling in the Fall of 1995, cores are now sieved on a U.S. Standard No. 50 sieve (1.0 mm mesh).

Similarly, in the second study the resulting indices values from samples where organisms were identified down to the species level were compared to those where organisms were identified only to the family level. The results of this study clearly showed no significant difference in the resulting indices values, particularly relative diversity. Consequently, in the interest of reducing costs while maintaining the quality of data produced, the taxonomic level to which identification is required was changed from species to family beginning with the Fall 1995 sampling period. These two changes, when combined, have allowed the unit cost of the infauna analysis component of the benthic monitoring to be cut in half.

A review of the data from five years of sampling also showed that over that period little change had occurred at certain sites, principally smaller sites carrying relatively small loads of fish and subjected to relatively strong currents. In view of the evidence that these sites posed little risk of environmental deterioration, the requirement for biennial benthic monitoring at these sites was changed to periodic sampling to be conducted based on observed changes in bottom conditions as evidenced by video monitoring. Furthermore, sampling at the remaining sites was reduced by concentrating on near-cage sampling and eliminating distant stations. These changes in the requirements went into effect in the Fall of 1997 and have allowed substantial reduction in the overall number of required samples, despite an increased intensity of sampling at certain larger sites where the risk of environmental degradation is considered higher.

4.3. Results

The first full round of sampling of all sites was first completed over the Falls of 1992 and 1993. A second round of sampling was completed in 1994 and 1995. The third round of benthic monitoring covering 1996 and 1997 was completed in Fall 1997; the 1998-99 sampling period represents the fourth complete round of sampling. As mentioned above, the Fall 1997 sampling did not represent a duplication of the Fall 1995 since certain sites sampled in 1995 were omitted in 1997. Repeated biennial sampling offers the opportunity to compare benthic infauna results over time and allows conclusions to be drawn on the effects of finfish aquaculture on benthic communities over time.

A detailed summary of the Fall 1992 through Fall 1998 benthic monitoring results are presented in *Maine Department of Marine Resources Fall 1992 and Fall 1993 Finfish Aquaculture Monitoring Survey: Benthic Infauna and Sediment Data Summary*, (Heinig, MER Assessment Corporation, 1995). *Maine Department of Marine Resources Fall 1994 and Fall 1995 Finfish Aquaculture Monitoring Survey: Benthic Infauna and Sediment Data Summary*, (Heinig, MER Assessment Corporation, 1996), *Maine Department of Marine Resources Fall 1996 Finfish Aquaculture Monitoring Survey: Benthic Infauna Data Summary*, (Heinig, MER Assessment Corporation, 1997), *Maine Department of Marine Resources Fall 1997 Finfish Aquaculture Monitoring Survey: Benthic Infauna Data Summary*, (Heinig, MER Assessment Corporation, 1998) and *Maine Department of Marine Resources Fall 1998 Finfish Aquaculture Monitoring Survey: Benthic Infauna Data Summary*, (Heinig, MER Assessment Corporation, 1999).

A detailed discussion of those results on a site-by-site basis is far beyond the scope of this report. However, the results of all benthic sampling conducted since the initiation of the FAMP is summarized on a site-by-site basis in Appendix IV of this report. In addition, the results of analysis for each of the five indices used to evaluate the benthic data have been plotted as a function of distance from the cages as well as a function of time. Each triangle in the graph represents the result for a single sample. Thus the vertical distribution of the triangles describes the range of results for either a certain distance from the cages, or in the case of time, for the year in which the sample was taken. The trend shown by the data is indicated by the line across the graphed plot and may represent an exponential, logarithmic, or linear trend, this being indicated in the title.

Tables 4.3.1. and 4.3.2. on the following pages present a summary comparison of benthic data, group by even and odd years, for the 1992,1994, 1996 and 1998, and 1993, 1995 and 1997 sampling periods, respectively, based on the values for certain indices. The values for each index are *means* for *all* samples taken at a site in the year of sampling, both within the immediate footprint of the cage(s) as well as beyond, and therefore provide an index for the *site* rather than any particular station or portion of the site. The difference, or change, between years is shown in the columns indicated by the **Δ**, immediately following index values; change is presented as a numerical value as well as percent change. Individual site data used in these comparisons are included in detailed summary reports mentioned earlier.

Table 4.3.1.
Comparison of benthic infauna analysis indices for 1992, 1994, 1996 and 1998

Comparison of benthic analysis results for all sites sampled in 1992 and 1994

Site	Mean Abundance '92	Mean Abundance '94	Mean Abundance Δ	Mean Abundance %	Mean Richness '92	Mean Richness '94	Mean Richness Δ	Mean Richness %	Mean Relative Diversity '92	Mean Relative Diversity '94	Mean Relative Diversity Δ	Mean Relative Diversity %	Mean % *C. capitata* '92	Mean % *C. capitata* '94	Mean % *C. capitata* Δ	Mean % *C. capitata* %
ASMI CI	3533	5481	1948	55.1	13	11	-2	-15.4	0.440	0.321	-0.119	-27.0	69	62	-7	-10.1
CONA BC 5300	12577	4601	-7976	-63.4	22	36	14	63.6	0.479	0.713	0.234	48.9	48	4	-44	-91.7
CONA BC 6000	74200	21102	-53098	-71.6	47	33	-14	-29.8	0.377	0.429	0.052	13.8	62	61	-1	-1.6
CONA CP	20902	9841	-11061	-52.9	34	34	0	0.0	0.374	0.712	0.338	90.4	74	29	-45	-60.8
CONA DC	40181	18456	-21725	-54.1	49	45	-4	-8.2	0.59	0.631	0.041	6.9	18	37	19	105.6
HARS JK	2649	2889	240	9.1	39	31	-8	-20.5	0.793	0.765	-0.028	-3.5	13	9	-4	-30.8
IACO TC*	1952	496	-1456	-74.6	15	9	-6	-40.0	0.642	0.729	0.087	13.6	6	3	-3	-50.0
NBFI JC	3620	3510	-110	-3.0	28	34	6	21.4	0.787	0.772	-0.015	-1.9	2	18	16	800.0
NESC GN	6804	15263	8459	124.3	22	38	16	72.7	0.513	0.551	0.038	7.4	39	44	5	12.8
SFML JB	3174	639	-2535	-79.9	13	16	3	23.1	0.342	0.718	0.376	109.9	63	28	-35	-55.6
Mean Change			**-8731**	**-21.1**			**0.5**	**6.7**			**0.100**	**25.8**			**-9.9**	**61.8**

Cages removed between 1992 and 1994 (CONA BC 5300 and SFML JB highlighted)

*** formerly MPLT TC**

Comparison of benthic analysis results for all sites sampled in 1994 and 1996

Site	Mean Abundance '94	Mean Abundance '96	Mean Abundance Δ	Mean Abundance %	Mean Richness '94	Mean Richness '96	Mean Richness Δ	Mean Richness %	Mean Relative Diversity '94	Mean Relative Diversity '96	Mean Relative Diversity Δ	Mean Relative Diversity %	Mean % *C. capitata* '94	Mean % *C. capitata* '96	Mean % *C. capitata* Δ	Mean % *C. capitata* %
ASMI CI	5481	281	-5200	-94.9	11	3	-8	-72.7	0.321	0.395	0.074	23.1	62	67	5	8.1
ASMI FI	----	630	----	----	----	9	----	----	----	0.671	----	----	----	22	----	----
ASMI II	997	148	-849	-85.2	11	7	-4	-36.4	0.621	0.924	0.303	48.8	17	5	-12	-70.6
CONA BC 5300	4601	1076	-3525	-76.6	36	11	-25	-69.4	0.713	0.513	-0.200	-28.1	4	39	35	875.0
CONA BC 6000	21102	2774	-18328	-86.9	33	16	-17	-51.5	0.429	0.673	0.244	56.9	61	73	12	19.7
CONA CP	9841	1885	-7956	-80.8	34	23	-11	-32.4	0.712	0.756	0.044	6.2	29	39	10	34.5
CONA DC	18456	2685	-15771	-85.5	45	22	-23	-51.1	0.631	0.715	0.084	13.3	37	17	-20	-54.1
DESC (NESC) GN	15263	2931	-12332	-80.8	38	23	-15	-39.5	0.551	0.671	0.120	21.8	44	45	1	2.3
HARS JK	2889	475	-2414	-83.6	31	16	-15	-48.4	0.765	0.912	0.147	19.2	9	4	-5	-55.6
IACO HS	----	1346	----	----	----	14	----	----	----	0.592	----	----	----	48	----	----
IACO TC	496	597	101	20.4	9	4	-5	-55.6	0.729	0.469	-0.260	-35.7	3	0	-3	300.0
MCNC CN	----	938	----	----	----	10	----	----	----	0.577	----	----	----	20	----	----
MCNI CW	----	663	----	----	----	15	----	----	----	0.832	----	----	----	3	----	----
TIFI CC	1152	1671	519	45.1	22	23	1	4.5	0.686	0.689	0.003	0.4	13	39	26	200.0
TISF HT	1630	1072	-558	-34.2	14	10	-4	-28.6	0.504	0.557	0.053	10.5	7	5	-2	-28.6
Mean Change			**-6028**	**-58.5**			**-11.5**	**-43.7**			**0.056**	**12.4**			**4.3**	**111.9**

Sites sampled for first time in 1996 (ASMI FI, IACO HS, MCNC CN and MCNI CW highlighted)

Table 4.3.1.
Comparison of benthic infauna analysis indices for 1992, 1994, 1996 and 1998
(Continued)

Comparison of benthic analysis results for all sites sampled in 1996 ('95) and 1998

Site	Mean Abundance '96	Mean Abundance '98	Mean Abundance Δ	Mean Abundance %	Mean Richness '96	Mean Richness '98	Mean Richness Δ	Mean Richness %	Mean Relative Diversity '96	Mean Relative Diversity '98	Mean Relative Diversity Δ	Mean Relative Diversity %	Mean % *C. capitata* '96	Mean % *C. capitata* '98	Mean % *C. capitata* Δ	Mean % *C. capitata* %
CONA BC 6200	----	564	----	----	----	14	----	----	----	0.767	----	----	----	42	----	----
DESC LU	2564	2003	-561	-21.9	38	18	-20	-52.6	0.784	0.651	-0.133	-17.0	20	39	19	95.0
ASMI CI	281	144	-137	-48.8	3	3	0	0.0	0.395	0.637	0.242	61.3	67	49	-18	-26.9
ASMI II	148	2327	2179	1472.3	7	8	1	14.3	0.924	0.739	-0.185	-20.0	5	39	34	680.0
CONA BC 6000*	2774	2535	-239	-8.6	16	17	1	6.3	0.673	0.571	-0.102	-15.2	73	66	-7	-9.6
CONA CP	1885	1475	-410	-21.8	23	8	-15	-65.2	0.756	0.544	-0.212	-28.0	39	60	21	53.8
CONA DC	2685	7123	4438	165.3	22	14	-8	-36.4	0.715	0.661	-0.054	-7.6	17	49	32	188.2
COOK TE	756	1722	966	127.8	15	12	-3	-20.0	0.785	0.763	-0.022	-2.8	28	32	4	14.3
MAFI PC	3543	3500	-43	-1.2	32	16	-16	-50.0	0.730	0.636	-0.094	-12.9	16	37	21	131.3
MCNC CN	938	1071	133	14.2	10	11	1	10.0	0.577	0.614	0.037	6.4	20	54	34	170.0
TIFI TW	1030	311	-719	-69.8	22	10	-12	-54.5	0.802	0.858	0.056	7.0	11	4	-7	-63.6
Mean Change			**561**	**160.8**			**-7.1**	**-24.8**			**-0.047**	**-2.9**			**13.3**	**123.3**

Sites sampled for first time in 1998 (shaded)

*** formerly CONA BC 5900**

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Table 4.3.2.
Comparison of benthic infauna analysis indices for 1993, 1995, and 1997

Comparison of benthic analysis results for all sites sampled in 1993 and 1995

Site	Mean Abundance '93	Mean Abundance '95	Mean Abundance Δ	Mean Abundance %	Mean Richness '93	Mean Richness '95	Mean Richness Δ	Mean Richness %	Mean Relative Diversity '93	Mean Relative Diversity '95	Mean Relative Diversity Δ	Mean Relative Diversity %	Mean % *C. capitata* '93	Mean % *C. capitata* '95	Mean % *C. capitata* Δ	Mean % *C. capitata* %
BPFI BE	3657	2862	-795	-21.7	42	30	-12	-28.6	0.744	0.776	0.032	4.3	69	62	-7	-10.1
ECFF TE	5315	756	-4559	-85.8	20	15	-5	-25.0	0.498	0.785	0.287	57.6	36	34	-2	-5.6
HANK CL	16950	4673	-12277	-72.4	36	13	-23	-63.9	0.632	0.624	-0.008	-1.3	27	55	28	103.7
MAFI PC	5117	3543	-1574	-30.8	28	33	5	17.9	0.661	0.730	0.069	10.4	34	20	-14	-41.2
MCNC CH	2900	226	-2674	-92.2	16	4	-12	-75.0	0.515	0.807	0.292	56.7	34	42	8	23.5
MESI SH	4298	4263	-35	-0.8	21	11	-10	-47.6	0.682	0.525	-0.157	-23.0	16	45	29	181.3
RLLT SI	1337	158	-1179	-88.2	**2**	**1**	**-1**	**-50.0**	0.367	**0.203**	-0.164	-44.7	75	50	-25	-33.3
SFML RN	8056	776	-7280	-90.4	26	18	-8	-30.8	0.660	0.704	0.044	6.7	32	16	-16	-50.5
TIFI TW	2544	1029	-1515	-59.6	32	22	-10	-31.3	0.750	0.802	0.052	6.9	13	11	-2	-15.4
Mean Change			**-3543**	**-60.2**			**-8.4**	**-37.1**			**0.050**	**8.2**			**-0.1**	**16.9**

Cages removed or partially removed between 1993 and 1995

Comparison of benthic analysis results for all sites sampled in 1995 and 1997

Site	Mean Abundance '95	Mean Abundance '97	Mean Abundance Δ	Mean Abundance %	Mean Richness '95	Mean Richness '97	Mean Richness Δ	Mean Richness %	Mean Relative Diversity '95	Mean Relative Diversity '97	Mean Relative Diversity Δ	Mean Relative Diversity %	Mean % *C. capitata* '95	Mean % *C. capitata* '97	Mean % *C. capitata* Δ	Mean % *C. capitata* %
ASMI DI	-----	543	-----	-----	-----	9	-----	-----	-----	0.651	-----	-----	-----	0	-----	-----
ASMI FI	-----	325	-----	-----	-----	7	-----	-----	-----	0.619	-----	-----	-----	28	-----	-----
CONA SB	3347	4879	1532	45.8	27	18	-9	-33.3	0.597	0.627	0.03	5.0	56	81	25	44.6
MCNC CH	226	451	225	99.6	4	5	1	25.0	0.807	0.496	-0.311	-38.5	42	46	4	9.5
RLLT SI	158	337	179	113.3	**1**	**2**	**1**	**100.0**	**0.203**	0.418	0.215	105.9	50	92	42	84.0
SFML JB3	639	2144	1505	235.5	16	16	0	0.0	0.718	0.710	-0.008	-1.1	28	42	14	50.0
SFML RN	776	539	-237	-30.5	18	13	-5	-27.8	0.704	0.723	0.019	2.7	16	23	7	43.8
Mean Change			**641**	**92.7**			**-2**	**12.8**			**-0.011**	**14.8**			**18**	**46.4**

Sites sampled for first time in 1997

4.4. Interpretation of results

4.4.1. Individual site results

Tables 4.31. and 4.3.2. can be overwhelming and consequently intimidating, however, a review of the information can be facilitated by focusing on significant changes. Since the relative diversity value is derived from the abundance and species richness, a small change in the relative diversity index often suggests a small change in either abundance, species richness, or both. Conversely, a significant change in the relative diversity, either up or down, suggests a significant change in one or both of these indices. This is clearly an oversimplification, but offers an easy, quick way of focusing attention on the those changes that may indicate potential problems. For the purposes of this review, a change of ±0.200 in the relative diversity is considered significant.

Even after focusing on those sites where significant changes appear in the data, interpretation of the changes is difficult, but can be facilitated if the site's history is considered. The following is a brief review of each of the most significant changes shown in Tables 4.31. and 4.3.2. along with speculation as to the reasons for the changes in view of the site's history.

Beginning with Table 4.3.1. and using the ±0.200 criterion, the first significant change between 1992 and 1994 is at CONA BC 5300 where the relative diversity increases 0.234 from 0.479 in 1992 to 0.731 in 1994. A review of the other indices shows that a significant decrease in abundance occurred over the period, but more significantly, the number of species increased very significantly. Furthermore, during the same period the percent *C. capitata* decreased precipitously by nearly 92%. All of these results are consistent with the fact that Unit 5300 was removed in 1993, thus even though cages were reinstalled at the site, the benthic sampling results indicate substantial recovery of the bottom following removal of the cages. Indeed, these results are consistent with the results of a benthic recovery study carried out during 1993 and 1994 at this site. A very similar effect is seen at SFML JB where a very significant increase of 0.376 in relative diversity is seen following the removal of the cages. Again, this increase is the result of a significant decrease in abundance, particularly of *C. capitata* (-55.6%), coupled with a moderate increase in species richness from 13 to 16. This again shows the beneficial effect fallowing can have and the relatively rapid improvement in benthic conditions once the organic loading ceases.

The other very significant change in relative diversity is an increase of 0.338 observed at CONA CP. This increase is driven principally by the substantial decrease in abundance (-11,061) coupled with a decreased dominance of *C. capitata* (-60.8%) Species richness had no effect, remaining unchanged at 34. It is interesting to note that similar decreases in abundance were observed at the other CONA sites, BC 6000 (-53,098) and DC (-21,725). The relative diversity did not increase appreciably at either of the latter sites, at CONA BC 6000 due to an offsetting substantial decrease in species richness (-14) and at CONA DC by a slight decrease in species richness combined with an increase in dominance by *C. capitata*.

As reported several times in previous reports, the overall decrease in mean abundance combined with the relatively little change in mean species richness, moderate improvement in relative, and substantial decrease of 14% in the *C. capitata* population. These results suggest that the overall organic load to the bottom resulting from the cage culture operations has been reduced over time resulting in fewer organisms being supported in the area, particularly immediately adjacent to and beneath the cages. Indeed, a brief review of operational changes and market forces of the time may help explain the changes observed in the benthos.

Between 1992 and 1993 the industry made a switch from moist feed to dry feed. Dry feed has a longer persistence within the water column and has less "fines" or dust associated with it. Consequently, dry feed has an increased interception time within the cage, resulting in greater a consumption rate and therefore reduced export beyond the net pen, ultimately reducing the organic load to the bottom in the vicinity of the cage(s). The reduction in fines similarly reduces the amount of feed material too small to be intercepted by the fish (feed that would consequently not be consumed and would therefore be exported to the surrounding area), thus also contributing to a reduction in loading to the bottom.

Connors Aquaculture, which operates the sites where the greatest change in abundance was observed between 1992 and 1994 (CONA BC, CONA CP, CONA DC), switched from moist feed to dry feed for its market fish in the Spring of 1993. It seems reasonable to assume that much of this decrease can be attributed to the shift to dry feed and the associated reduction of the organic load reaching the bottom. Furthermore, the affects of global market pressures on the Maine salmon industry cannot be discounted. Competition between the U.S. and foreign producers increased dramatically in the early 1990s. The precipitous decline in salmon wholesale prices was allegedly due to illegal "dumping" on the U.S. market by foreign producers that eventually led to the imposition of duties by the Department of Commerce on foreign imports in 1998. The sudden and dramatic decline in wholesale price forced U.S. producers to increase efficiency and lower production costs. Since labor and feed represent the highest costs of finfish operations, the industry responded by reducing labor costs by installing high-efficiency automated or semi-automated feeding systems and improving feed-to-fish conversion rates, both of which imply improvement in feed consumption and reduced export from the cages.

Furthermore, during the early 1990s, the industry suffered losses to the "super chill" disease (Hitra), and infestation by parasites. Several operations responded to these problems by reducing densities within their cages in an effort to reduce stress on the fish and reduce the spread of disease and parasites. Since density reduction reduces the amount of feed required by individual pens and increases the likelihood of pellet interception, this, too, would reduce the organic load to the bottom.

Significant overall decreases in abundance (-6,028) and species richness (-11.5) are again seen between 1994 and 1996 at nearly every site sampled during the period. Both of these decreases are directly related to the change in mesh size, from 0.5 mm to 1.0 mm, of the sieves used in processing benthic samples and, in the latter, the reduced level of identification, as of the 1995 benthic sampling season (see Section 4.2.2. Procedure modifications, Benthic infauna analysis). The increase in mesh size represents a 4-fold increase in the mesh opening of the screens, thus allowing many of the organisms previously retained to pass through, thus resulting in significantly lower levels of abundance. Similarly, many of the smaller species previously retained by the 0.5 mm mesh passed through the larger 1.0 mm mesh, thus accounting for the concomitant decrease in species richness. Furthermore, the identification of organisms at the family rather than species level allowed certain organisms previously reported separately to be grouped, thus reducing the number of "species" reported. Despite these decreases, at most sites the mean relative diversity values changed only slightly compared to the 1994 values. Only four sites showed significant changes, two (ASMI II and CONA BC 6000) showing "improvement" and two (CONA BC 5300/5500 and IACO TC Pen 5) showing increased deterioration of the bottom. The "improvement" shown at ASMI II (0.303) is more mathematical than real; it is driven principally by a decline in dominance by *C. capitata*, coupled with the substantial decline in abundance. The apparent "improvement" is further tempered by the loss of four species. Similarly, the increase in relative diversity at CONA BC 6000 of 0.244 is artificial, apparently related to the decline in abundance caused by the mesh size change. With respect to the declines, it is important to note, however, that in these two cases, both sites started at relatively high values, thus the decrease in relative diversity still yields values in the moderate range.

Between 1996 and 1998 the change in overall abundance is negligible, some sites showing an increase, others a decrease. Species richness, however, declines at most site or remains essentially unchanged. This decline in species richness has been interpreted by some as a negative result of the use of cypermethrin in the treatment of sea lice. However, the increase in dominance of *C. capitata* in most cases where species have been lost suggests that the loss of species may actually be the result of increased intensity of production. It should be noted that while production increase substantially between 1996 and 1998, the number of production sites remained essentially unchanged. Thus, the increase in production was achieved through increased intensity of production on existing sites. This suggestion is supported by the fact that over the same period standard cage size increased dramatically from 12 to 15 meter sided cages to a 24 meter sided cages, thus nearly quadrupling the capacity of individual cages.

The increase in relative diversity of 0.242 seen at ASMI CI as a result of the 0.637 mean value for the 1998 sampling misrepresents actual conditions at the site. A review of the individual benthic samples shows very few organisms representing very few species. However, since in most samples each species is represented by just one individual, the even distribution of organisms yields a very high relative diversity value. Thus, despite the elevated relative diversity value reported, conditions at the site are in reality significantly deteriorated.

Moving to Table 4.3.2., the overall sharp decline in both abundance and species richness seen between 1993 and 1995 is directly related to the change in mesh size in 1995, discussed previously. The exceptionally large decrease in both abundance and species richness at the HANK CL site is likely due to a combination of the mesh size change and the intensive dragging for sea urchins that took place at the site following the removal of the cages from the site in 1994. Furthermore, sampling followed a fallowing period of 12-18 months, and this, too, likely contributed to the decline in these indices.

Similar to the situation with ASMI CI mentioned above, the increase in relative diversity of 0.292 seen at MCNC CH from 0.515 to 0.807 is misleading. This substantial increase in relative diversity is more like the result of the confounding effect of mesh size change than any actual improvement of conditions of the bottom. This site has been routinely monitored since 1988 and bottom condition has remained stable throughout the period.

The 1995 and 1997 comparison, much like the 1996 and 1998 comparison, shows little overall change in abundance. The declines in species richness at CONA SB and SFML JB3 are likely related to the aging of these sites. Both of these sites were put into production between 1994 and 1995, thus the 1995 results describe early production conditions, conditions which would be expected to decline until stabilizing in response to stable production levels.

Taken as a whole, these data indicate that, although fluctuations certainly occur at all sites between years, likely due to alternating production cycles, there is a general tendency towards stabilization. The exceptions, again, are ASMI CI and RLLT SI, both of which have shown a trend toward increased deterioration.

4.4.2. Industry-wide results

The data interpretation presented thus far focuses on specific changes at individual sites between sampling years. Another approach is to review the pooled data from all samples to determine the distribution and trend of the indices' values over space and time for the industry as a whole. Figures 4.4.2.1 through 4.4.2.8 show the distribution and trends of each of the four principal indices, first as a function of distance from the cages, and second as a function of time.

Figure 4.4.2.1.
Relative diversity as a function of distance from cages based on all data 1992-98
(Trend is exponential)

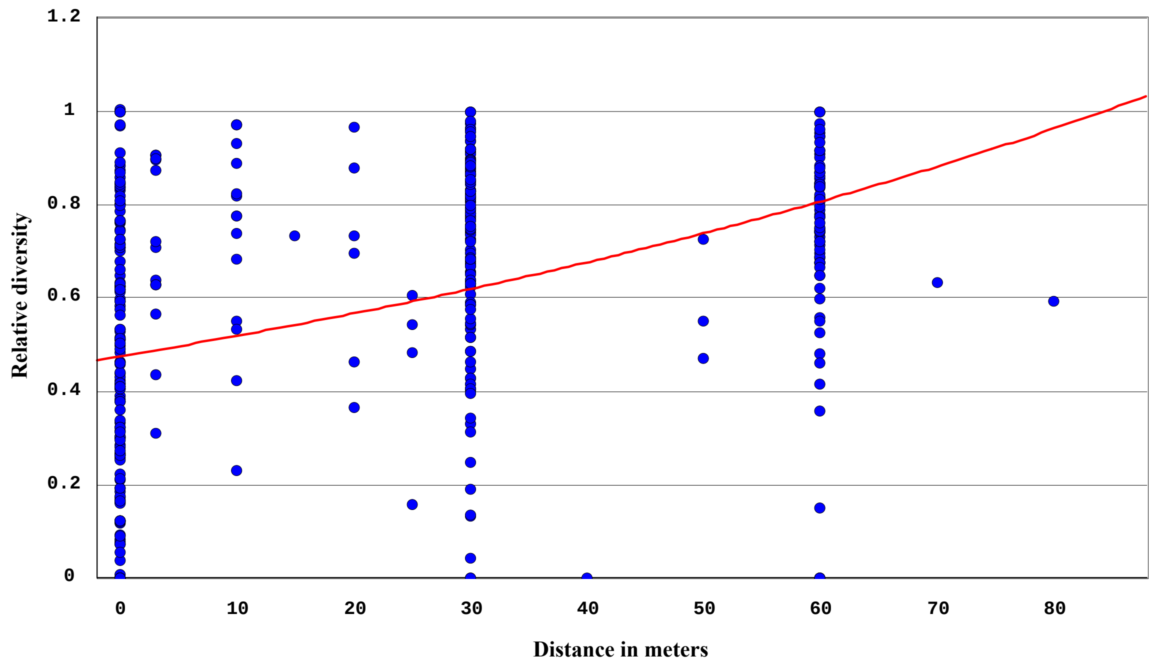


Figure 4.4.2.2.
Relative diversity as a function of time based on all data 1992-98
(Trend is linear)

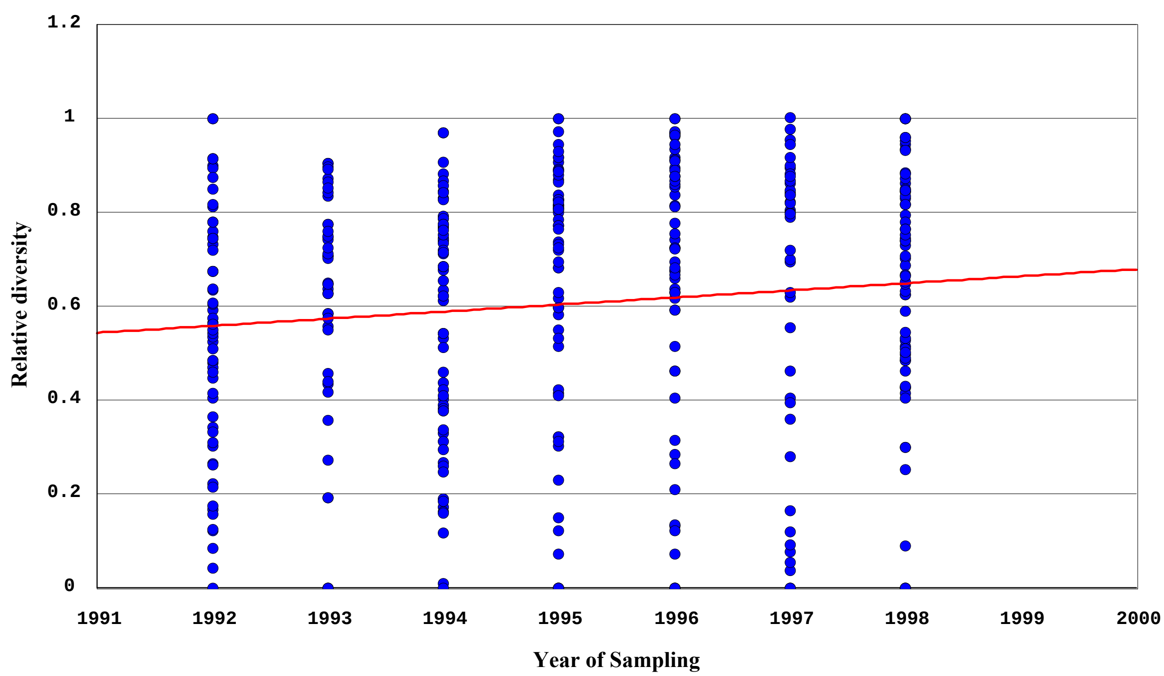


Figure 4.4.2.3.
Abundance as a function of distance from cages based on all data 1992-98
(Trend is logarithmic)

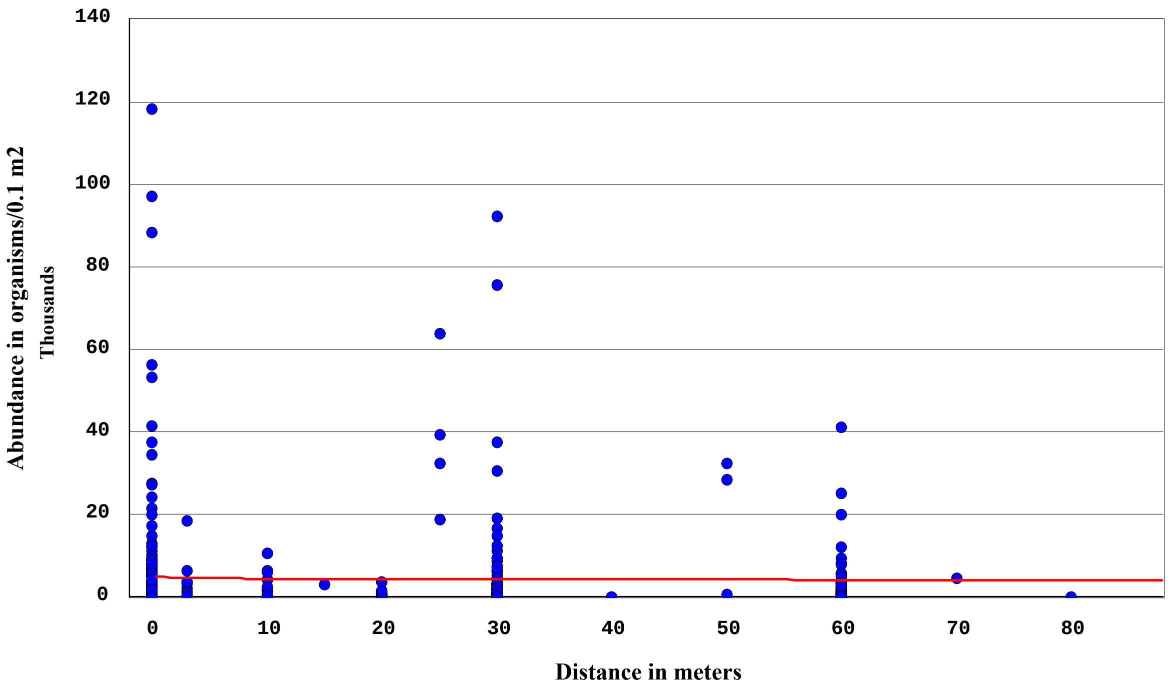


Figure 4.4.2.4.
Abundance as a function of time based on all data 1992-98
(Trend is logarithmic)

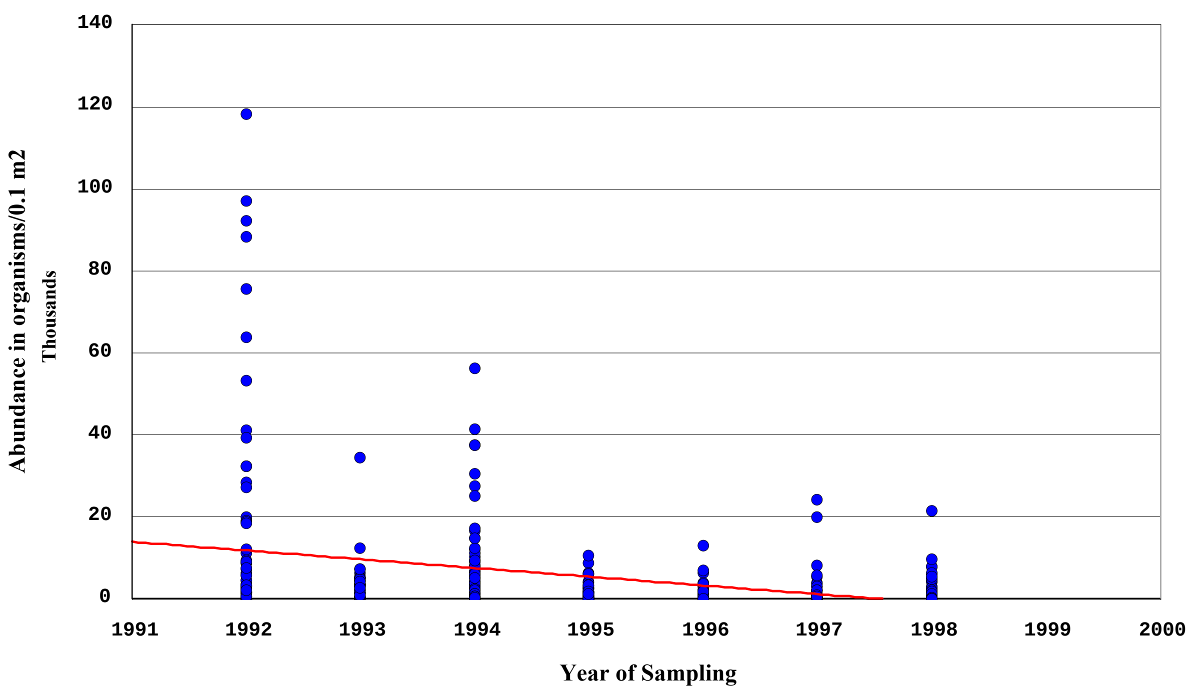


Figure 4.4.2.5.
Species richness as a function of distance from cages based on all data 1992-98
(Trend is exponential)

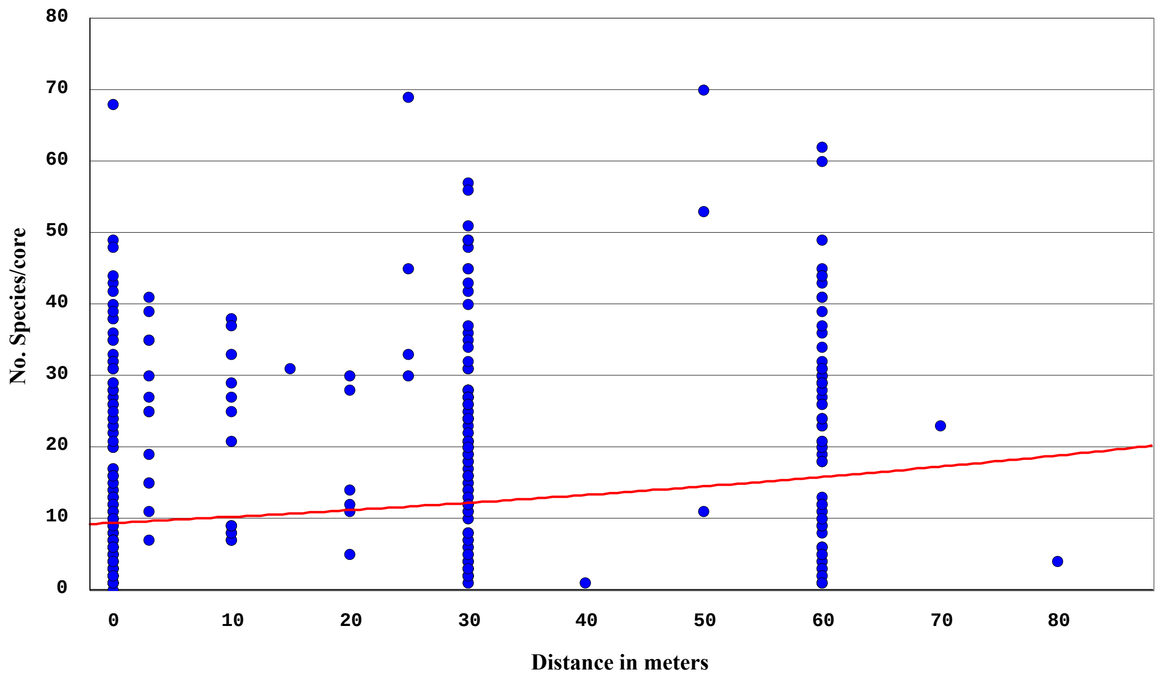


Figure 4.4.2.6.
Species richness as a function of time based on all data 1992-98
(Trend is linear)

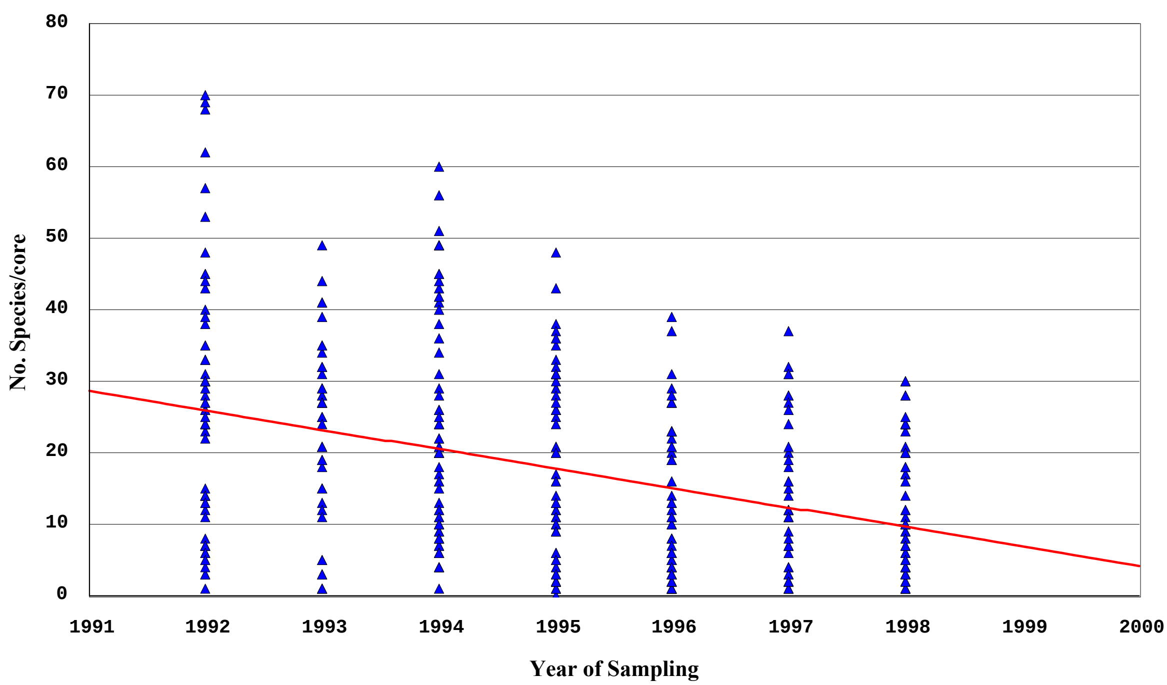


Figure 4.4.2.7.
% *Capitella capitata* as a function of distance from cages based on all data 1992-98
(Trend is exponential)

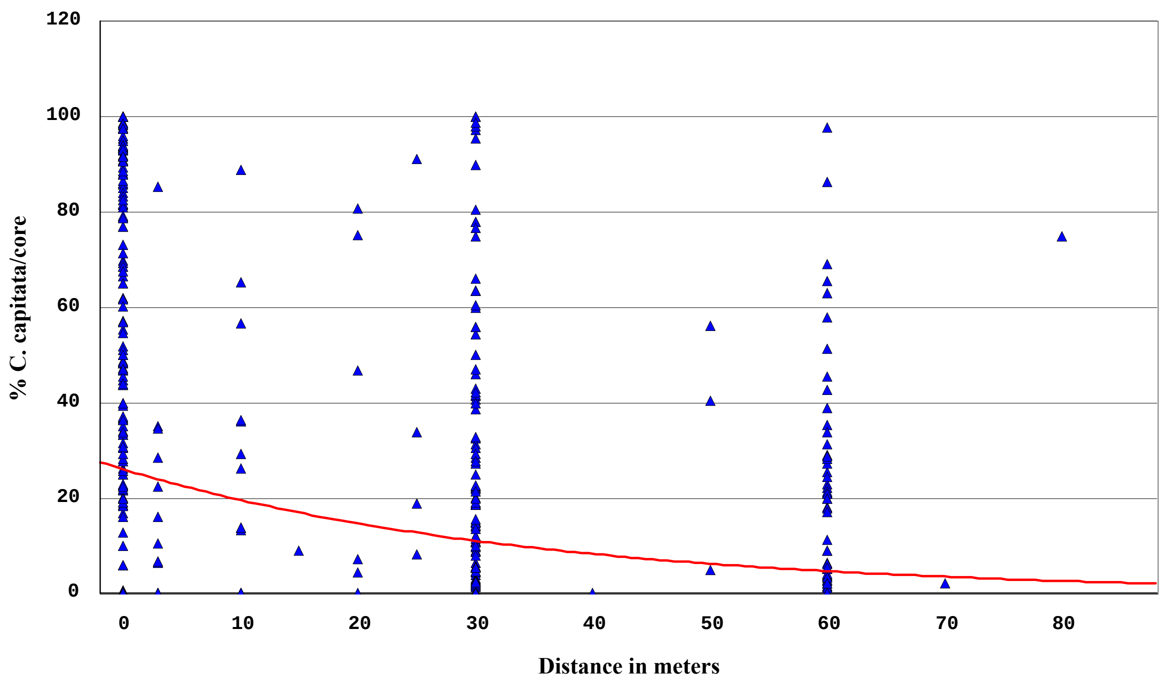
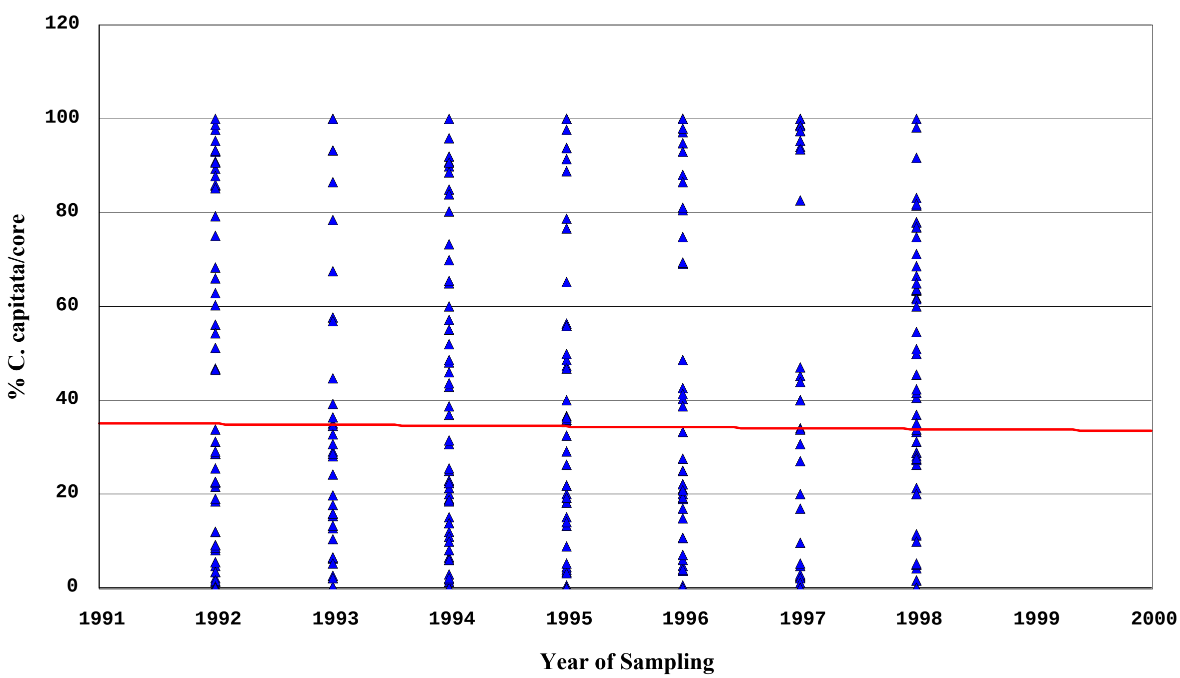


Figure 4.4.2.8.
% *Capitella capitata* as a function of time based on all data 1992-98
(Trend is linear)



In each of these figures the benthic index in question is plotted along the Y-axis and the distance, or year of sampling, whichever the case, along the X-axis. When the X-axis represents distance, 0 meters represents the edge of the cage; values are plotted according to distances irrespective of whether upcurrent or downcurrent of the predominant current direction. Each circle represents a value derived from a single sample, and the entire array of circles represents values for all samples taken since 1992.

Figure 4.4.2.1. shows the relative diversity values are plotted against distance from the cage in meters. The overall range of distribution of the values is similar at the three primary sampling distances, 0. 30 and 60 meters. However, the clustering of values changes with distance from the cage. Near the cage the values are nearly equally distributed along the entire range from 0.000 to 1.000. At 30 meters, the values are clustered between 0.400 and 1.000, and at 60 meters, between 0.600 and 1.000. The trend, as indicated by the curve, is clearly upward toward 1.000, the theoretical maximum value. According to the curve, this maximum theoretical value is reached at a distance of just over 80 meter from the cage. Relative diversity values calculated from baseline survey samples under pre-development conditions indicate that normal relative diversity values for ambient conditions normally range between 0.750 and 0.900. The fact that the trend curve reaches the 0.800 level at the 60 meter distance indicates that benthic conditions, at least as represented by relative diversity calculations, reach or approach ambient values only a short distance from the cage or cage system. These results continue to support similar results seen in previous years and continues to demonstrate that the effects of the cage operations are generally confined to within 60-80 meters of the cages.

Figure 4.4.2.2. presents the relative diversity values grouped within each year of sampling, thus the distribution of points for any given year represents the range of relative diversity values obtained from all samples taken in that year. Once again, although in each year the values range from 0.000 to 1.000 or just under, the clustering of values shows a slight trend toward higher values over time, a trend indicated by the line. The slope of the line is shallow, however, indicating that the trend is not very strong; a clustering slightly below 0.600 for the 1999 samples could essentially flatten the trend line. Nevertheless, even though the trend may not be strongly upward, it does suggest that the effects of cage operation are stable over time.

Figure 4.4.2.3. shows the distribution of abundance values as a function of distance. Here, the range of values at 0, 30, and 60 meters is significantly different, the near cage samples showing as many as circa 120,000 organisms/0.1m^2 while at 60 meters the highest value is only 40,000 organisms/0.1m^2. The trend of the range is clearly downward with distance from the cage(s), but the clustering of values at each distance, however, occurs between 0 and 20,000 and the trend is therefore nearly flat. It should again be borne in mind that the abundance values have been artificially influenced by the change in mesh size in 1995 and the concentration of samples at near cage stations that began in 1998. It is also worth noting that the extremely high abundance values, i.e. >85,000, seen adjacent to the cages, were found during the first year or two of sampling when loading rates were much higher than today, as explained earlier in Section 4.4.1.

Viewed over time, as shown in Figure 4.4.2.4., the trend is clearly downward, particularly with respect to the range, as in the previous figure. The rather precipitous decrease in the range between 1992 and 1994 supports the previous discussion on the shift from moist to dry feed, density reduction, etc., that occurred during those years. The sharp decline between 1994 and 1995 reflects the change in mesh size used in sample processing from 0.5F to 1.0mm. It is significant that, in the years following 1995, abundance appears to have stabilized, with respect to range as well as clustering, again indicating stability in the effects of the operations on the benthos.

Figures 4.4.2.5 and 4.4.2.6. present the values for species richness over distance and time, respectively. The range of distribution is basically similar with distance from the cage(s), although the uppermost three values show a trend upward. The clustering of values is also similar with increasing distance, but the mean of the clusters moves steadily upward with increasing distance, thus the trend line's upward direction with distance.

The distribution of species richness values as a function of time is in sharp contrast to the distribution over distance, declining somewhat steadily, albeit by step, from 1992 through 1998. Such a trend might normally be cause for concern, but similar to the abundance trends over time, much of the decline in species richness can be attributed to operational changes at the sites and in the FAMP procedures and protocols.

The trend line in Figure 4.4.2.6. suggests a constant decline. However, as Table 4.4.2.1. below shows, the decline follows a step pattern.

Table 4.4.2.1.
Details of species richness data for samples taken during the period 1992-98

Year	No. samples	Mean no. species	Max. no. species	Min. no. species
1992	54	26.9.	70	1
1993	42	22.8	49	1
1994	64	23.1	60	1
1995	63	16.7	48	0
1996	57	12.2	39	1
1997	43	13.0	37	1
1998	66	10.9	30	1

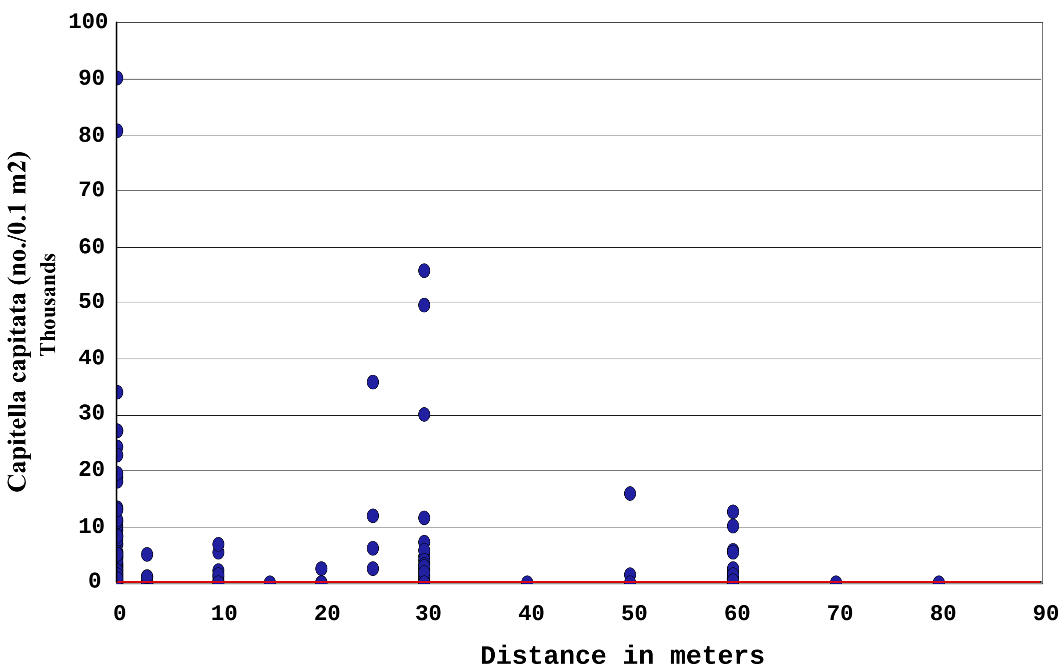
The fluctuations observed between 1992, 1993 and 1994, as discussed earlier, are likely due to operational changes made by the industry during that period, already discussed above. The sharp decline seen in 1995 is directly related to the mesh size change that resulted in the smaller species previously retained by the 0.5 mm screen passing through the 1.0 mm screen. The reasons for the decline between 1995 and 1996 are not immediately clear, but may simply be related to different habitats at the sites sampled in 1996 compared to 1995. The difference between 1996 and 1997 is negligible and probably statistically insignificant. The continued decline observed in 1998 is likely related to the proportionally greater number of samples taken in proximity to the cages as part of the FAMP's focus on areas greatest impact.

The procedures and protocols used in the 1999 sampling were the same as those used in 1998. Consequently the results of the 1999 benthic analysis should be similar to those of 1998. A further decline in species richness in 1999 would suggest that the loss of species may not simply be an artefact of sampling procedure modification, but rather an indication of a real decline, possibly cage operation-related.

Figures 4.4.2.7. and 4.4.2.8. shows the distribution of % *C. capitata* as a function of distance and time, respectively. The reporting of *C. capitata* as a percent of total population is an indication of the level of dominance the species exhibits over the other species in the population. The range of distribution is similar at all distances, ranging from 0% to 100%, or just under. However, the values cluster at progressively lower levels with increased distance from the cage. As a result, the trend curve, which starts at ~30% near the cage, approaches 0% at 80 to 90 meters from the cage. Over time, the range distribution is also similar with increased distance, but the trend, although slightly downward, has remained essentially unchanged

It is important to realize that similar percent population composition values does not suggest similar population densities. In other words, complete species dominance (90-100%) may in one case (93.0%) represent a very dense population, i.e. ~90,000 *C. capitata*/0.1 m^2 and in another (93.3%) represent only a moderate population density, i.e. ~2,000 *C. capitata*/0.1 m^2. Figure 4.4.2.9., below, shows the population density distribution of *C. capitata* as a function of distance from the cages.

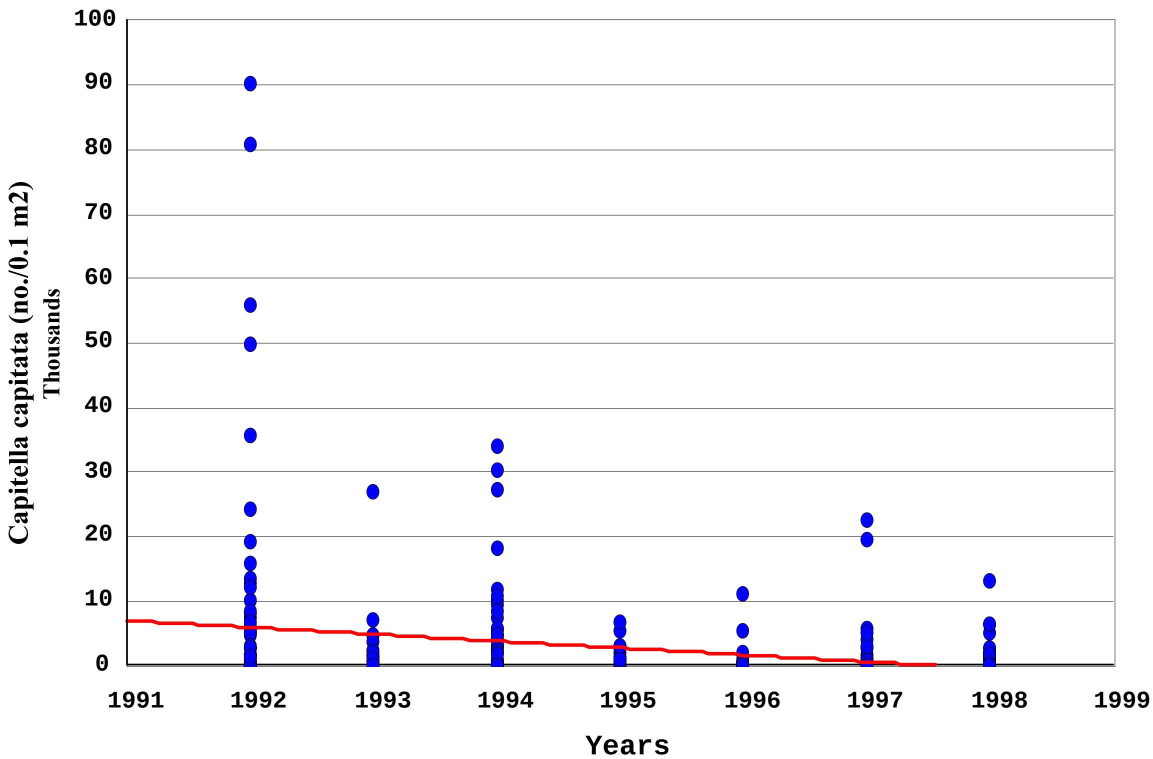
Figure 4.4.2.9.
***Capitella capitata* population density as a function of distance from cages**



Although clustering is still shown between 0 and 10,000 *C. capitata*/0.1 m^2 at 30 and 60 meters, in contrast to Figure 4.4.2.8., here the distribution range clearly decreases with distance from the cages. Few samples have been taken at a distance greater than 60 meters, however, it is reasonable to assume, based on the few sample that have been taken, that *C. capitata* population density would continue to decline with increased distance from the cages.

Finally, in Figure 4.4.2.10., below, the population density of *C. capitata* is plotted as a function of time. This graph clearly shows the decrease in population density, both in terms of individual values as well as their range, over the course of time, again supporting the conclusion that the effects of the pen operations are confined to the area immediately adjacent to the cage(s).

Figure 4.4.2.10.
***Capitella capitata* population density as a function of time**



In summary, all of the benthic data presented above support the conclusion that impacts to the benthos resulting from finfish net pet aquaculture operations are generally confined to the immediate vicinity of the cages. This conclusion is not unique to the FAMP nor to Maine. Findlay, *et al.* (1995) arrived at a similar conclusion after intensive study of a site off of Swans Island, Maine. Crawford, *et al.* (1999) reached the same conclusion after analyzing benthic data from salmon farms in Tasmania.

The time series data, with the exception of species richness, further suggest that the impacts also appear to be decreasing with time. However, changes to the benthic monitoring procedures and protocols of the FAMP in 1995 and 1998 make it difficult to interpret and directly compare the data across time. It therefore remains to be seen if the data continue to remain consistent under fully standardized procedures and protocols.

4.5. Identified problems

4.5.1. Reevaluation of procedure and protocol changes

The procedures and protocols used in the benthic monitoring portion of the FAMP are standard procedures that are universally used for benthic studies. Consequently, no specific problems have been identified with the procedures themselves. Two problems have been identified that relate to the data and data interpretation, and the other to data not currently collected.

The first problem has already been discussed to a certain extent and centers on the decline in species richness, the decline over time more so than the decline over space. As has already been explained, some of the decline is very likely related to fluctuating biomass and changes in organic loading from cages resulting from operational changes at the sites. The more significant decline, in 1995, is undoubtedly related to the sieve mesh size change and reduction in level of identification from species to family that occurred that year. Similarly, the decline in 1998 is likely due to the concentration of sampling on near-cage stations. These changes were made to reduce the cost of monitoring, but they have made interpretation of the data difficult, particularly the interpretation of significance of changes over time.

In 1999, MER was contacted regarding a review of the FAMP benthic data being conducted by the Food and Drug Administration (FDA) during analysis of data associated with an Investigational New Animal Drug (INAD) review involving cypermethrin. The FDA expressed concern that the decline in species richness in 1966 and following years might be related to the use of cypermethrin. MER responded to these concerns with an explanation of the various changes that had been made to the FAMP procedure and protocols since 1995 that might equally account for the declines.

The potential loss of certain small species as a result of the change in mesh size was well understood at the time the change was implemented. The "apparent" loss of species resulting from identification of organisms at the family level (grouped species/genera) rather than at the individual species level was also well understood. The data were intended to be used solely for the purposes of the FAMP and interpreted in light of other FAMP components, *i.e.* production data and video recordings. However, the recent interpretation of FAMP data by the FDA shows that data developed under the program will likely be reviewed and interpreted in ways never anticipated or intended by the FAMP. The DMR has little, if any, control over how these data are interpreted, but in light of the recent situation, the Department may wish to reevaluate the cost/benefit of the changes implemented in 1995. Such a reevaluation should probably await the results of the 1999 benthic sample analyses.

4.5.2. Consideration of "ambient" controls

The FAMP's benthic monitoring protocols have not included ambient controls stations beyond the influence of cages. This is principally due to the difficulty of finding appropriate sampling sites in areas representing similar habitats to those found at cage sites that are in similar depths of water ***and*** unaffected by other activities, specifically dragging. However, inclusion of such ambient controls would allow near-cage sampling results to be compared to those of "unaffected" sites to determine if changes are indeed cage-related, natural and broad-based, or an artefact of sampling as suggested in the case of the decline in species richness. Again, in view of the broader use and interpretation of FAMP benthic data, the Department may wish to revisit the possible inclusion of such ambient controls in future benthic surveys. Determination of appropriate sampling sites will likely be difficult and sufficient time and resources will have to be made available for such determinations to be made.

4.6. Considerations/recommendations for future

See preceding Section 4.5.

5.0 Areas for future investigation

5.1. Nutrients

Testing for nutrients, *i.e.* NO_3, NO_2, NH_4, TKN, and PO_4, was formerly part of the U.S. Army Corps of Engineers/National Marine Fisheries Service's aquaculture site environmental monitoring requirements. After several years of testing, however, no specific effects were observed and the requirements were dropped. At the time nutrient testing was being conducted most sites were located in Cobscook Bay or proximity to open ocean. Recent applications for aquaculture lease sites in more confined areas, removed from the open ocean and having lower rates of flushing, have rekindled concerns over the potential impacts of nutrients released from net-pen operations.

A study coordinated by The Nature Conservancy and conducted in Cobscook Bay showed that at certain times and under certain conditions the nutrient contribution from net-pen operations could become important to the overall nutrient flux, but under normal circumstances was relatively small compared to the contribution from renewal water brought in from the open ocean on each tide. However, if finfish aquaculture continues to expand further westward into increasingly sheltered waters, the impact of finfish aquaculture on nutrient flux may become a matter of increased concern. In response, the DMR may which to consider incorporation of nutrient testing into the FAMP. Individual site monitoring is probably not warranted since the concern is on impacts on water bodies as a whole rather than site-specific effects. The DMR might therefore consider establishment of "ambient" monitoring stations for nutrient testing, perhaps the same stations used as control stations for the dissolved oxygen monitoring portion of the FAMP.

The cost associated with inclusion of nutrient sampling, particularly if coupled with dissolved oxygen sampling, would likely be negligible since the labor associated with sample collection would be insignificant. The cost of sample analysis would vary depending on the methods required and the level of precision requested. The DMR may wish to coordinate with the Department of Environmental Protection (DEP) to determine if mutual programatic benefits and cost-sharing possibilities might exist.

5.2. Deep site monitoring

The "drop" video technique developed for the one existing deep site and discussed under Section 3.2.3. has proven effective to-date, albeit time- and energy-consuming. The number of recent applications for sites with depths in excess of 46 meters (150 feet) suggests that monitoring in depth >46 meters may become more common. Although the "drop" video technique is currently adequate, it is not ideal and may no longer be adequate if numerous deep sites need to be monitored.

In 1998, MER and the DMR investigated the possible use of a sled developed by others at DMR for deep video monitoring during baseline surveys of deep site. Although satisfactory videos were eventually obtained, the system would require substantial improvement to be sufficiently useful and reliable for use in monitoring. Therefore, if it appears that deep site monitoring will be required in the future, additional work will need to be done to perfect the sled technique, possibly including the addition of realtime video capability.

6.0 References

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