Evaluation of Lift-Up® system in the mitigation of environmental impacts and fish health in net-pen aquaculture

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Abstract

LiftUp® technology was evaluated for its possible use in the mitigation of environmental impacts and fish health management at a commercial salmon growout facility in Machias Bay, Machiasport, Maine operated by Atlantic Salmon of Maine LLC. Four treatments, LiftUp®-equipped cages, standard cages, 30m distance from cages (regulatory compliance boundary distance), and a reference site were compared using biological and sediment chemistry metrics to measure organic enrichments and environmental degradation. Quality of the water within the LiftUp®-equipped and standard cages as well as the LiftUp® discharge was also measured. Additionally, fish health was evaluated for both LiftUp®-equipped and standard cages using measures of growth and mortality, clinical evaluation during routine veterinary site inspections, and periodic measures of packed cell volumes and white cell counts from subsets of apparently healthy fish; evaluation of potential impacts to pathogen exposure pathways was done using stable isotope concentrations as a measure of exposure to fish carcass or excretory products.

No statistically significant differences were seen between the LiftUp® and non-LiftUp® cages at the end of the project; early in the project, statistically significant differences were seen for certain parameters. Nevertheless, consistently lower states of organic enrichment were observed under the LiftUp® cages compared to the non-LiftUp® cages based on both benthic infauna and sediment chemistry results. No statistically significant differences in standard fish health metrics were noted between LiftUp® and diver-based mortality recovery systems. However, significant differences in isotopic composition of fecal material (and trends in fish growth) raise questions about alterations in diet. Dissolved and particulate material resulting from LiftUp® operation surface discharge does not raise environmental concerns due to its brevity (<100 seconds), very small area (5m x 10m oval), and intermittent frequency (1-3 times per week); however, surface discharge does raise concern over spread of disease during presence of infection or parasites.

Clogging of the china hats, due at least in part to freeze-up in winter, appears to have been the most influential/confounding factor in obscuring differences between LiftUp® and non-LiftUp® cages over the course of the project. Sediment grain size shift toward coarser material at all sampling stations was not expected, and is unexplained at the moment. This sediment grain size shift may also have contributed to obscuring differences between LiftUp® and non-LiftUp® cages.

Overall, and with several strong caveats, this project demonstrated that LiftUp® type technology may offer some potential environmental benefits for a very specific selection of site-types. However, it is unclear whether those same benefits can be achieved more cost-effectively through employment of traditional best management husbandry since environmental conditions under the non-LiftUp® pens generally remained within legal standards set forth in the MePDES permit throughout the project period. Use of LiftUp® type technology is not possible under sub-freezing conditions, in areas shallower than 65 ft. at low water, or at high energy sites and may not be warranted even under slower current regimes. LiftUp® is clearly neither warranted nor practicable at all sites and its applicability in Maine may be limited to very specific circumstances.

Introduction

Salmon aquaculture in Maine began in the late 1970s and early 1980s, the first truly commercial operation having started about 1984. Production reached 1 million pounds in 1988 and by 2000 peaked at just over 36 million pounds (MDMR, 2005). Over the same period, the number of active culture sites increased from 1 to 28 with the sites concentrated principally in the macro-tidal area of Cobscook Bay in eastern Maine. As new suitable sites in Cobscook Bay became scarce, the industry expanded westward to meso-tidal areas such as Machias and Blue Hill Bay. This expansion into areas with lower tidal amplitude and tidal velocities caused heightened concern over the potential for benthic impacts that are inversely related to depth and current velocities (Sowles et al., 1994; Silvert and Sowles, 1996).

In addition to environmental concerns, the salmon aquaculture industry has had to develop new strategies for disease management. Establishment of Infectious Salmon Anemia (ISA) resulted in the 2001/2002 eradication of over 2.6 million fish in the Cobscook Bay region. The ISA outbreaks further highlighted the need for continued improvements in fish health management. In response, the State of Maine, in cooperation with the United States Department of Agriculture Animal and Plant Health Inspection Service (USDA-APHIS Veterinary Services) and industry, introduced a new regimen of disease management protocols including biosecurity audits, fallowing, and year class separation thus reducing both individual and collective site capacities. [1]

One practice thought to minimize disease spread is the prompt removal of dead or moribund fish from the pens. Since decaying carcasses of a sick fish can be a nidus of infectious material, prompt removal of carcasses can reduce disease exposure rates. Removal of fish several times a week by divers remains a widely considered best management practice. However, because divers are expensive and may stress fish and disturb normal schooling and feeding behavior, the industry has pursued automated collection systems.

Several options exist to reduce the impacts from net pen aquaculture including the following: 1) locating in deeper offshore locations, 2) siting in faster currents, 3) reducing biomass, 4) improving feed conversion efficiencies, 5) modifying husbandry practices, and 6) application of technology. At the time this project was proposed (2002), little consideration was being given to exposed offshore sites due to engineering, logistical, and permitting concerns. More recently, however, considerable effort has been made in the offshore expansion of the industry worldwide and specifically in the Northeastern United States through the University of New Hampshire's Open Ocean Aquaculture (OOA) project. Some of these projects are yielding

[1] The situation was further complicated in 2000 when lawsuits were brought against Maine's three largest salmon growing companies for failing to hold federal Clean Water Act permits. Although the companies had applied to USEPA for the permits over a decade earlier, the EPA neglected to issue them. The court ruled against the companies. This litigation resulted in significant changes culminating in a loss of annual production to about 11 million pounds in 2005, over 150 jobs, and divestiture of aquaculture from Maine by all companies. Most relevant to this study, the trial and court ruling diverted attention of both administrators and farm managers from daily management and husbandry functions further complicating maintenance of good husbandry practices and compliance with environmental requirements. This served to reinforce the need for investigation into new techniques to further improve sustainable aquaculture.

encouraging results at an experimental level. However none have yet been sufficiently demonstrated as commercially viable.

Stock reduction is difficult since the global economy constantly pushes operators to strive for maximum production per unit area to remain competitive. Improvements in feed composition, delivery systems, and husbandry practices over the years have allowed the U.S. industry to improve feed conversion and consequently increasing site productivity without increasing, and in many cases even reducing (MER 2000), environmental impacts around salmon cages. With the scarcity of new sites with favorable environmental and logistical conditions, the expense of acquiring a new lease in Maine, and the limited technological and husbandry options, it is clear that innovative means to improve site utilization are worth investigating.

One such technology, LiftUp® system, developed by Akva S.A. of Norway, is designed to remove moribund and dead fish thus potentially meeting fish health management needs by avoiding insertion of human divers into cages. LiftUp® uses a conical shaped bottom net where dead and moribund fish collect at a central point and are airlifted up and out of the pens. We became interested in using LiftUp® to remove smaller materials such as waste feed and feces. If successful, the industry would have one more tool to optimize use of existing sites and perhaps obtain new sites in areas formerly considered environmentally marginal while still protecting environmental quality.

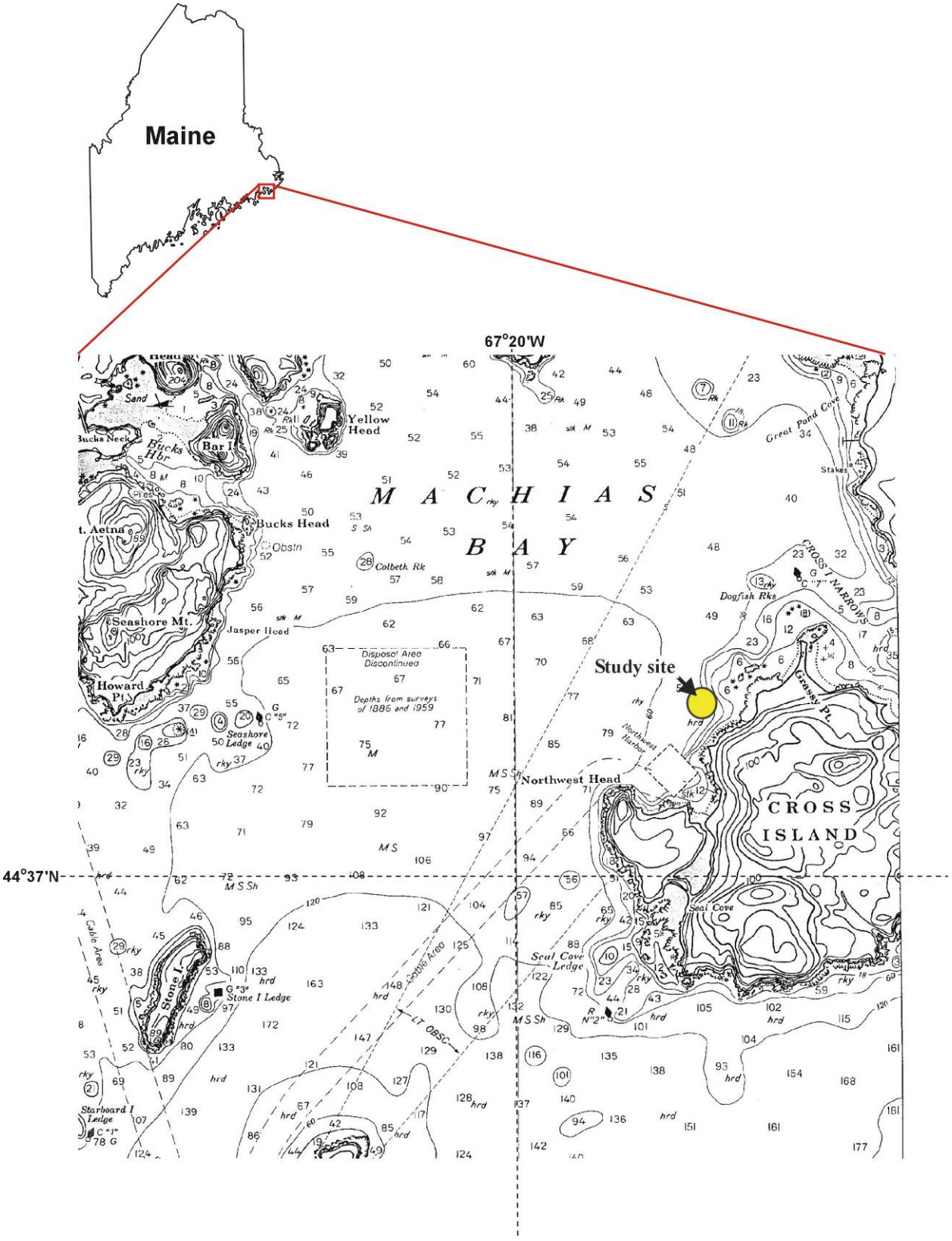
However, this posed a new concern. If solid waste products containing infectious materials are resuspended, fish could be exposed to pathogens that otherwise would have been isolated on the sea bottom. This project was therefore undertaken to determine whether use of LiftUp®, or similar technology, offers environmental and fish health management benefits under Maine's coastal conditions and whether one benefit comes at the expense of the other.

Project Site

The project was conducted at a commercial salmon growout facility owned and operated by Atlantic Salmon of Maine, LLC. located off the northwest side of Cross Island in Machias Bay, Maine and serviced out of Machiasport on the mainland to the west (Figure 1). The site is oriented along a northeast-southwest axis, generally parallel with the predominant current direction. The site is subject to weak to moderate mid-depth currents (9.4 cm/sec mean; 23.6 cm/sec max.) (MER, 2003) and bottom sediments are generally soft. The site has a history of organic matter accumulation toward the end of each 18-month production cycle, including development of anoxic sediments, prevalence of *Beggiatoa* sp., and periodic out-gassing concentrated within the footprint and immediately adjacent to the cages (MER, 1999). This predisposition to organic accumulation made this a suitable site and operation to evaluate the efficacy of LiftUp® technology.

Operationally, the site consists of a submerged mooring grid system arranged to accept 16 Polar Circle cages, 100m circumference by 10m deep, in four rows of four cages (Figure 2). The southeastern two rows of cages represent the original site where operations were first established in 1999; the site underwent a one-year fallowing period between 2001 and 2002 after which cages were once again located on the site. The two rows of cages to the northwest were added in 2003 for use in the study reported here.

Figure 1 Site location

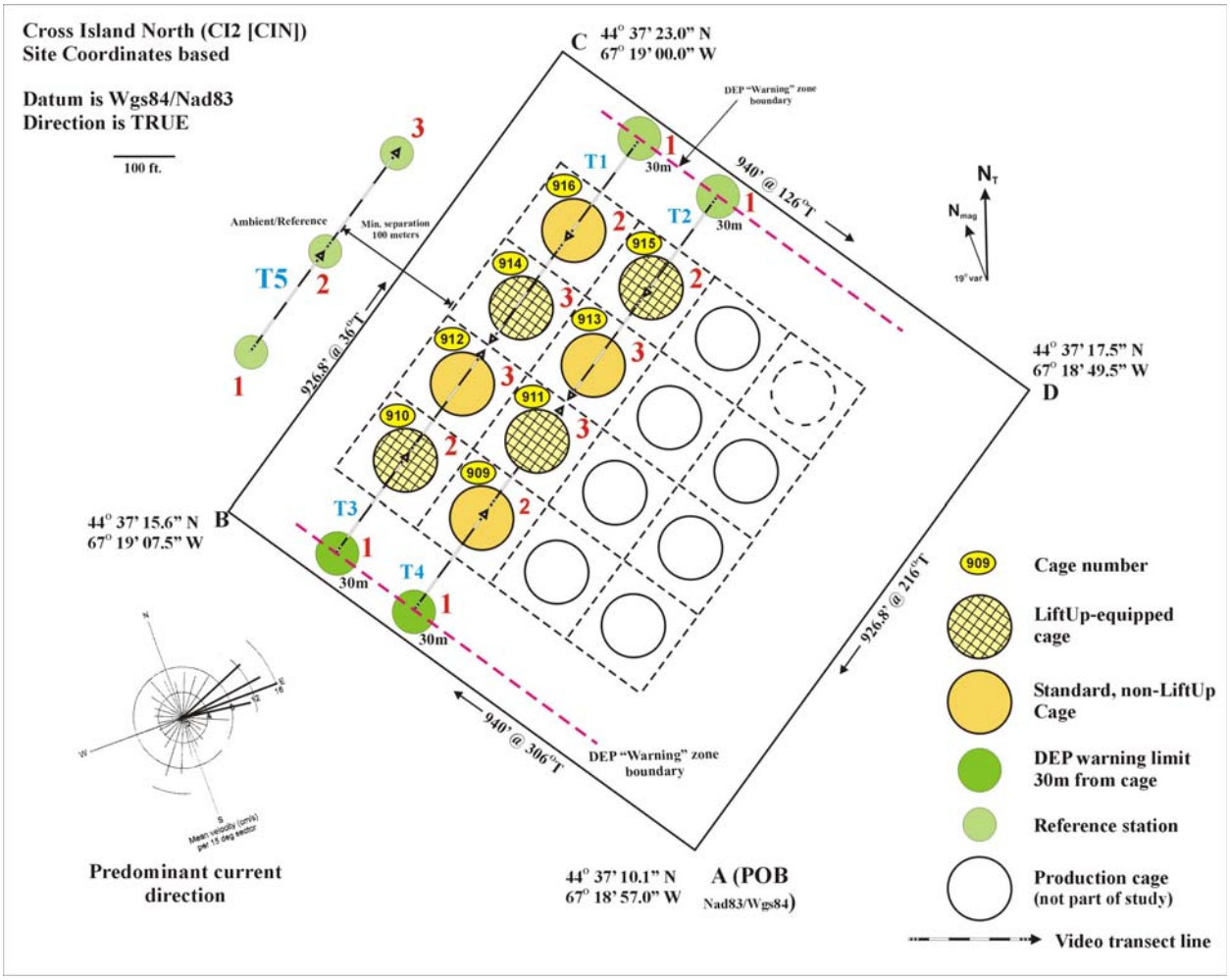


Project Design and Setup

Experimental Design

This study employed a standard BACI (Before, After, Control and Impact) experimental design consisting of four treatments: standard production cages, LiftUp®-equipped cages, 30m distance from cages, and a reference. Site arrangement and sampling layouts are shown in Figure 2.

Figure 2 Site and Sampling Layout



Originally, we had wanted to employ a randomized block design, however this was not possible given the small number of replicates for each treatment and need to fit this experiment into a working commercial operation (e.g. to locate Liftup® systems within easy access to the feed barge). Ultimately, we alternated LiftUp® equipped and standard cages as the preferred practical statistical design believing this would minimize additive or spillover effects from adjacent like-treatment cages.

The non-study cages located on the southeastern half of the site are normal production cages, indicated in Figure 2 as white circles, and were installed at the site in 2002. Given the need to stock hatchery smolts in seawater by early summer and to ensure an adequate supply of smolts for the study scheduled to begin in summer 2003, these non-study production cages were necessarily overstocked with smolts (100,000/cage) in the fall of 2002. Once stocking densities were reduced following transfer of smolts into the study cages on the northwestern portion of the site, the non-study cages, fitted with standard predator and grower nets, were maintained on the site in their original location throughout the study period as part of normal production operations.

Quadrat Layout

In early-July, prior to installing the study area cages, the site was prepared for monitoring. A set of four transect lines were installed along the bottom within the study area to be used as guides for the video recording dives. Each transect began 30m beyond the cages and ran toward and under one standard and one LiftUp® cage along the northeast-southwest axis, as indicated in Figure 2 by the alternating black and white arrow (T1-T4). A fifth transect line was located approximately 100m northwest of the site parallel with the site boundary and predominant currents and served as the reference site for the study (T5). Metal reinforcing rod staples secured the ends of each transect. Three sampling stations were located along each transect. Stations along transects T1-T4 were located at the 30m point beyond the cages, directly under the center point of the first grids, and directly under the center point of the second grids, designated “1”, “2” and “3”, respectively, in Figure 2. Transect 5 stations were located at either end and in the middle of the transect. PVC plastic frames measuring $1m^2$ and divided into four separate quadrants, identified as 1-4, were embedded in the bottom along the transect at each station to serve as sampling units, each quadrant of the frame representing a sampling date.

LiftUp - Installation and Operation

Benthic environmental degradation normally results from waste discharge from a net pen in the form of fish feces and uneaten feed passing through the bottom panel of the grower net and accumulating on the sea floor beneath. The LiftUp® principal is based on collection of dead and moribund fish on a conical fine mesh netting bottom panel of the primary, or grower net, and removal by drawing fish carcasses into an airlift-driven suction device (Figure 3). Applying the same principle and using a finer mesh net, feces and uneaten feed might also be removed with fish carcasses.

Figure 3. Schematic/artistic view of LiftUp installation in rectangular/square steel cage system
(Source: LiftUp® Akva AS)

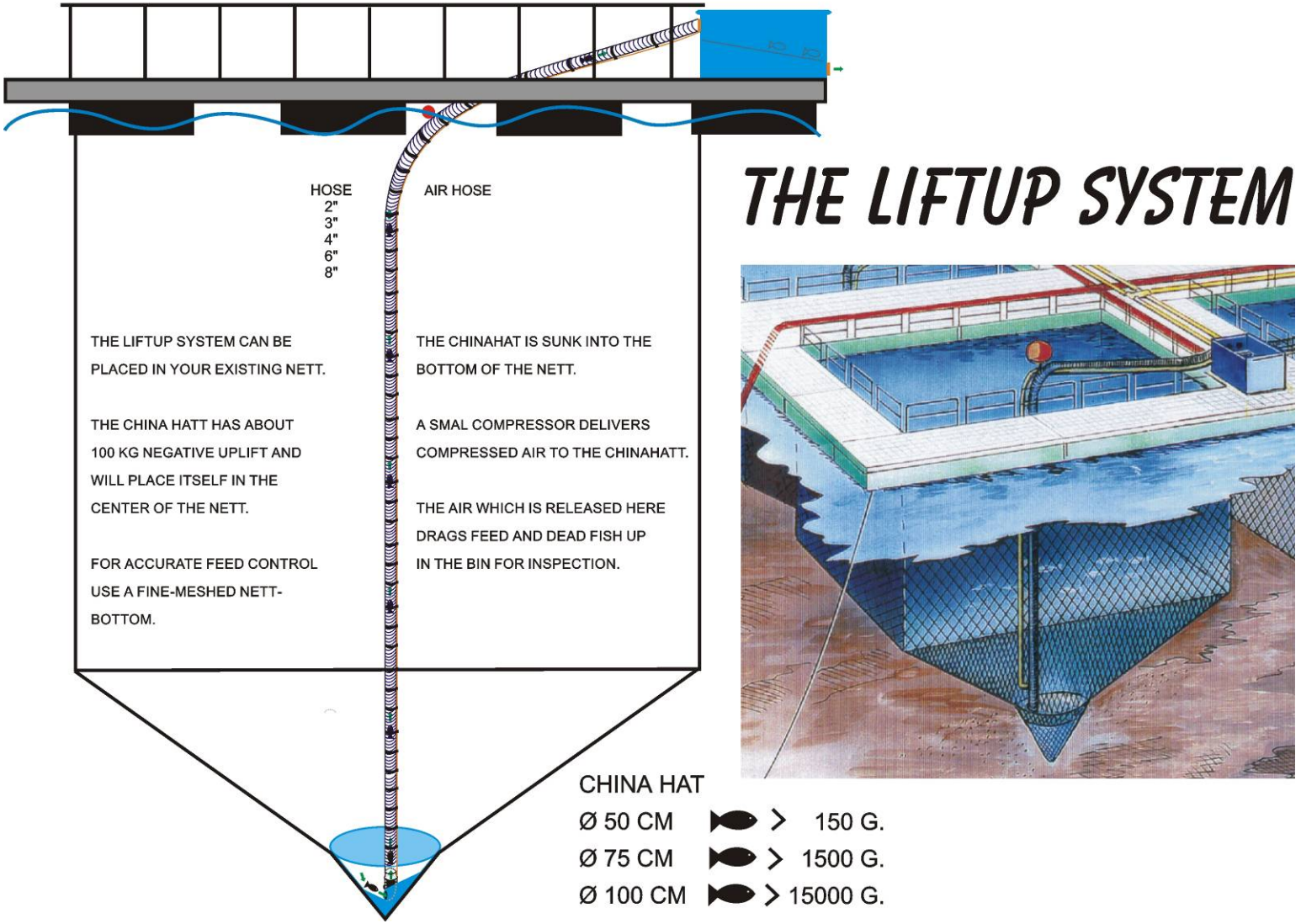


Figure 4. LiftUp® "china hat" suction unit showing intake, suction hose, and pressurized air line

(Source: LiftUp® Akva AS)

Eight experimental cages were installed on the northwestern side of the site in July/August 2003 as the study cages. Four cages (909, 912, 913, and 916) were equipped with standard predator and grower nets and served as controls for the study (solid, orange-shaded circles in Figure 2). Four other cages (910, 911, 914, and 915) (light yellow, grided circles) received LiftUp® technology (seen at left in Figure 4) and were fitted with modified fine mesh (½" stretch) bottom panels grower nets manufactured by Card Aquaculture, capable of retaining 6.5 mm feed. Installation on two cages (910 and 911) was completed in September 2003 using LiftUp® units already owned by ASM. The remaining two cages (914 and 915) had their mesh installed in September; however a shipping delay prevented installation of LiftUp® until December 2003.

Figure 5. LiftUp® "china hat" suction unit showing intake, suction hose, and pressurized air line after retrieval at end of project.

(Source: David Miller, ASM)

Prior to installing the LiftUp® "china hat," weight and suction units in the cages, the clear, corrugated 6-in. discharge pipes that normally reach to the surface, were cut to a length of four feet and attached to 6-in. blue "flat lay" discharge hose (seen at left of china hat in Figure 5) to reach the LiftUp® grading units at the surface. The grading units, designed to trap fish and large particles (Figure 6), were secured to the leeward side Polar Circle rings and handrail. The hose for air-lift air supply was also attached and secured to the handrail.

Figure 6. LiftUp® sorting/grading trap showing inflow connection at top and discharge at bottom.

(Source: David Miller, ASM)

LiftUp® operation began approximately one week following system installation; however, in two of the cages the LiftUp® systems installations were not completed until December 2003 (see Table 1, cages 914 and 915). LiftUp® operation ceased around the end of December due to problems with freeze-up; operation was re-initiated in mid-April of the following spring. During the down-time, divers manually collected the sludge and mortalities from the LiftUp® cages on a dive-schedule that matched that of the control cages. Frequency of pumping was intermittent. When feeding levels were low, the cages were pumped about once per week; when levels increased, they were pumped about three times per week.

Smolt introduction into the study area cages from the southwestern operations cages as yearling fish began September 1 and was completed on November 5, 2003 as shown below in Table 1.

Table 1. Cage and Stocking Summary

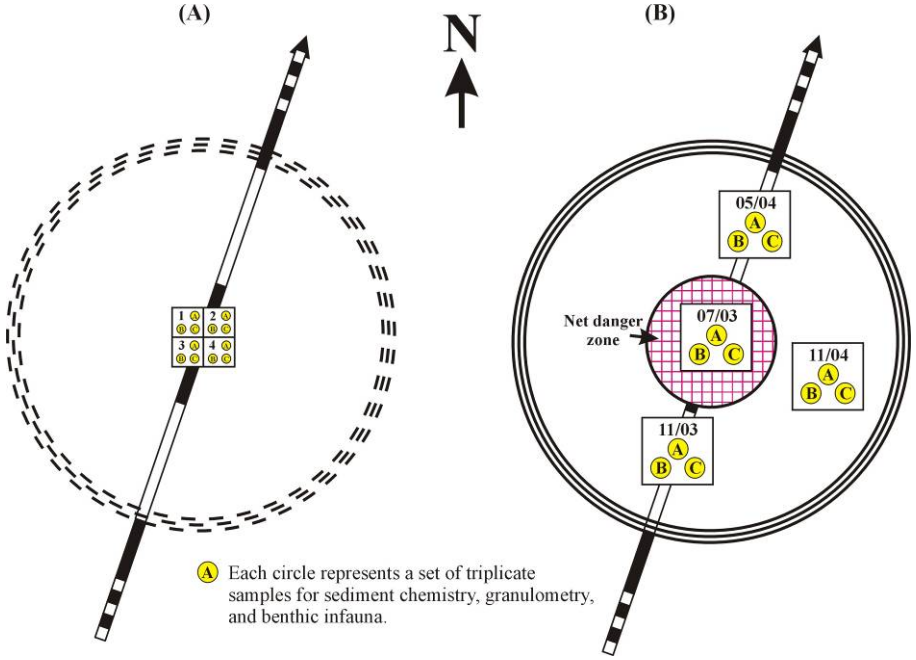
Cage number	Stocking date	Treatment	Lift-up notes	Hatchery notes	Transect/Station
909	9/17/03	Diver		Kennebec	T4-S2
910	9/11/03	Lift-up		Kennebec	T3-S2
911	9/1/03	Lift-up		Oquossic	T4-S3
912	9/3/03	Diver		Oquossic	T3-S3
913	11/5/03	Diver		Kennebec (supersmolt)	T2-S3
914	10/13/03	Lift-up	mesh only, until Dec 2003	Oquossic	T1-S3
915	10/24/03	Lift-up	mesh only, until Dec 2003	Kennebec (supersmolt)	T2-S2
916	9/25/03	Diver		Oquossic	T1-S2

Sampling schedule and station location

Because of the site's predisposition to organic accumulation, it was especially important to characterize benthic conditions prior to stocking. Video transects and sediment collection for granulometry, oxidation-reduction potential (Eh), Total Organic Carbon (TOC), Total Organic Nitrogen (TON) and benthic infauna was conducted in July 2003 to define baseline conditions. Following stocking and installation of LiftUp®, samples were collected in November 2003, in May 2004, and in November 2004. At the time the project was designed (2002), the draft waste discharge permit (MPDES) for aquaculture did not include sulfide as a parameter so was not included in baseline measurements. However, sediment sulfide was added to the suite of analytes for the November 2003 sampling.

Baseline samples taken in July 2003 were collected from section 1 of the quadrat at each of the 15 stations (4 @ Non-LiftUp cages, 4 @ LiftUp® cages, 4 @ 30m out, and 3 @ Reference) Figure 7 (A)). In November 2003, near complete darkness at the bottom resulting from a combination of elevated turbidity from high river runoff and low light at the surface made location of the sampling frames difficult, and in some cases impossible. Additionally, sediment covered the frames requiring probing of the bottom to locate them which caused excessive disturbance to the bottom within the sampling area. Furthermore, the proximity of the predator nets to the bottom, resulting from the high amplitude tides and additional weight in the LiftUp® cages, made working directly beneath the center of the nets under dark conditions extremely hazardous. The sampling location was therefore moved beneath and within the impact footprint of the southwestern quadrant of each cage to avoid the center portion of the net and allow sampling of undisturbed bottom sediment. Sampling in May 2004 was conducted within the impact footprint of the northeastern quadrant and in November 2004 the southeastern quadrant of each cage (Figure 7 (B)).

Figure 7. Single cage example of originally proposed sampling location directly beneath center of cage prior to cage installation, (A), and actual sampling locations post-cage installation by date, (B), to avoid danger zone to divers near center of net. Sampling location was consistent for all cages for the designated sampling date.



On each sampling date, 9 sediment samples were taken in close proximity to each other at each station shown in Figure 2 using 4 in. diameter PVC pipe coring devices that were inserted to a depth of 10cm or full resistance, whichever was greater. Three replicate cores, each, were separated for sediment chemistry, granulometry, and benthic infauna analyses.

Sampling Methods

Diver video recording

Video recordings were made using a Sony DCR-TRV310 digital video camera housed in an Amphibico VHDB0001 housing equipped with an Amphibico 35W/50W underwater arc lamp lighting package. The video recording along each transect was started 30m away from the pens and proceeded toward and under two cages. Cage transects ended midway between adjacent cages. Video recording of the reference site began at one end of the approximately 120m line and followed it to the end. Video recordings were reviewed and analyzed for comparison using a Panasonic DMR T3040 Digital Recorder allowing slow-motion and freeze-frame analysis.

Sediment chemistry and benthic infauna

Sediment granulometry was measured to ensure comparability of physical conditions between treatments and assist in the interpretation of the chemical and biological results. Analyses were performed by S.W. Cole Engineering, Inc., Gray, Maine using ASTM standard wash sediment granulometry methods C-117 and C-136. Sediment data were reduced to four grain size classes; clay, silt, sand, and gravel as prescribed by the State of Maine Department of Environmental Protection waste discharge permit.

Redox measurements were made in the field according to Wildish *et al*., (1999) on a mixed subsample of the top 2 cm of each core as recommended by Wildish, (2003). Accordingly, the sediment was placed in a small 125 ml plastic container and thoroughly mixed with a plastic spoon for approximately 1-2 minutes. Following mixing, the redox potential was measured using an Accumet® AP63 pH/mV/Ion meter equipped with a Thermo Orion model 9678BN Combination Redox electrode filled with Thermo Orion Ag/AgCl Reference Electrode Filling Solution (900011). Eh results were reported as mV.

Sulfide was also analyzed following Wildish *et al*. (1999). Subsamples were taken with a modified 5 ml plastic syringe with the needle attachment end removed to form an open cylinder; the open end was immersed into the mixed sediment slurry and the sample extracted ensuring no bubbles were contained in the sample. The open end of the syringe was covered with plastic wrap to exclude air and aluminum foil placed over the end of the syringe to secure the plastic wrap. Syringes were maintained on ice at a temperature of $<5^{O}C$ during transport to the laboratory for sulfide (S_2) analysis within <72 hrs. of sample collection. Prior to measurement, all syringes were allowed to warm to room temperature ($\approx 20^{O}C$) before analysis with the Accumet® AP63 pH/mV/Ion meter equipped with a Thermo Orion model 9616BN Combination Silver/Sulfide electrode filled with Thermo Orion Ionplus B Optimum Results™ Reference Electrode Filling Solution (900062); standards of 1.00 (100µM), 10.0 (1,000µM), and 100 (10,000µM) were prepared according to Wildish et al., (1999). All samples were analyzed within a maximum of 3 hrs.

Total organic carbon (TOC) and nitrogen (TON) analyses were performed on subsamples of the mixed sediment. TOC and TON samples were placed on ice for return to the lab, then frozen until delivered to the analyzing facility. TOC and TON analyses were performed by the University of Maine, Ira C. Darling Center chemistry lab using EPA Method 440.0, Determination of Carbon and Nitrogen in Sediments and Particulates of Estuarine/Coastal Waters Using Elemental Analysis.

Benthic infauna samples were sieved on a U.S. Standard No. 35 sieve (500µm mesh), immediately fixed in 10% buffered formalin and subsequently preserved in 70% ethanol following 7-10 days of fixing in the 10% buffered formalin and stained with 1% Rose Bengal solution. Sorting was carried out under a standard industrial circular, self-lighted fluorescent adjustable height magnification lens. Identification to the lowest practical taxonomic level (usually species but at least Family-level) was done using an Olympus Model SZ60 1.0-6.3 continuous zoom 10x binocular dissecting scope (effective magnification of 10-63x) with a Lite-Mite circular, objective mounted, fluorescent ring light. Standard benthic infauna indices of total organisms, abundance (organisms/0.1m^2), relative diversity, and % *Capitella capitata*, were calculated using Microsoft® Excel.

Water quality

Although assessing ambient water quality effects was not a principle objective of this project, because we were releasing waste material into adjacent waters, it was important to conduct some water quality measurements to evaluate its impact and inform the design of future studies. Water quality measurements and samples were taken on August 17, 2004 and consisted of collection of water column profiles and samples within cages. Dissolved oxygen, temperature, and salinity profiles were collected using a Yellow Spring Instruments (YSI) Model 6600 Sonde Serial No. 01A0870 connected to a YSI MDS 650 handheld real-time display unit Serial No. 01A0851 AB. The sonde was equipped with sensor to measure depth, temperature, conductivity sensor, and dissolved oxygen. Water samples for 5-day bio-chemical oxygen demand (BOD_5) were collected using a 1.0 L messenger-triggered Kemmerer bottle, decanted into one liter polyethylene containers and stored in a cooler on ice for delivery the next morning (~15 hours) to the Maine Health and Environmental Testing Lab in August, Maine. Measurements and analytical methods used in the study were consistent with those required by the Maine Departments of Marine Resources' Finfish Aquaculture Monitoring Program (FAMP) and Environmental Protection's proposed General Permit for Salmon Aquaculture.

LiftUp® effluent was collected on September 4, 2004 from cages 910 and 911 to characterize its nature. On that date, LiftUp® had not been operated for the 5 preceding days and fish on site were large and nearing harvest suggesting that this might represent a "worst case" condition. One liter grab samples were collected as the effluent passed through the collection box. Sampling effort was weighted toward the "first flush" part of the discharge when waste appeared more concentrated. Samples were placed on ice in a cooler and delivered the next morning (~15 hours) to the Maine Health and Environmental Testing Lab in August, Maine for analysis of BOD_5, total suspended solids (TSS), total Kjeldahl nitrogen (TKN), and Total Coliforms (TC).

Environmental Statistical Analyses

All environmental data were entered and managed in Microsoft Excel and uploaded into SYSTAT Version 11 (Systat Inc., 2004) for graphic presentation and statistical analyses. Box plots were used to display the distribution of results by treatment and sampling event. Statistical differences between LiftUp® and non- LiftUp® cages were tested using Systat's ANOVA Estimate Model with a Bonferroni post hoc test. Differences were considered significant at $p<0.1$.

Fish Health

Fish health evaluation consisted of production measures of growth and mortality, clinical evaluation during routine veterinary site inspections, and periodic measures of packed cell volumes and white cell counts from subsets of apparently healthy fish. Evaluation of potential impacts to pathogen exposure pathways was done using stable isotope concentrations as a measure of exposure to fish carcass or excretory products.

The goal of the fish health study was to identify differences in fish health or pathogen exposure between cages collecting mortalities by diver and those employing a LiftUp® system. We used traditional approaches to fish health evaluation including production measures of growth and mortality, clinical evaluation during routine veterinary site inspections, and also periodic measures of packed cell volumes and white cell counts from subsets of apparently healthy fish. Evaluation of potential impacts to pathogen exposure pathways was more difficult. We used stable isotope concentrations as a measure of exposure to fish carcass or excretory products, either of which can spread infectious organisms between fish.

Stable $\delta^{15}N$ and $\delta^{13}C$ isotope ratios of animals are typically enriched (by 3-4 ppb for $\delta^{15}N$, and 0-1 ppb for $\delta^{13}C$ relative to that of their diet (DeNiro and Epstein 1978, DeNiro and Epstein 1981, Peterson and Fry 1987). Consequently, fish that consistently consume dissolved or particulate organics from carcass or fecal materials, or that differentially supplement their nutrition with ambient micro or macrofauna, may differ isotopically from fish consuming strictly salmon feed. Likewise, bivalves or worms exposed to dissolved or particulate decomposition or excretory byproducts, in the water column or benthos respectively, may differ isotopically from those not similarly exposed. We monitored fish health indices and pathogen exposure proxies over time in four cages using LiftUp® and four cages using diver mortality collection systems at the Cross Island salmon farm in Machiasport, ME.

Study cages (4 LiftUp® and 4 non- LiftUp® or control cages) were visited within one week of MER-assigned site inspection dates. The July 2003 visit was considered a baseline visit as fish, on-site since the previous fall, had not yet been distributed to study cages. Fish were transferred (split down from higher density cages) to study cages between September 1 and November 5, 2003. Consequently, the December 2003 and May 2004 visits occurred approximately one and six months, respectively, after completion of transfer to study cages. China hats and hosing were dysfunctional in two of the four lift-up cages until after the December 2003 visit. Consequently, until full deployment, fish carcasses were removed from these LiftUp® cages by diver, though the fine mesh nets still accumulated feces and debris. Fish cohorts varied by hatchery of origin and whether or not they had received Supersmolt® (http://www.marical.biz/) additives prior to salt-water transfer (Table 1). Cage stocking dates and treatment assignments are listed in Table 1.

The site was visited three times for fish health and exposure sampling (July 2003, Dec 2003 and May 2004). These visits included visual inspection of schooling fish for clinical abnormalities, dip-net collection of five apparently healthy fish per cage for blood and fecal samples, evaluation of mortality and growth records and communication with the site veterinarian and/or fish health technician requesting notification of adverse health events. Mussels and barnacles collected from the surface of each study cage and worms collected from benthic transects by MER-team divers were analyzed for isotopic composition. Mussels and worms (up to five per cage) were run as individual samples. Barnacles were pooled by cage. MER-team divers also submitted a sediment core from each cage for isotopic analysis. Samples of feed were submitted at each change in feed size or composition.

Fish were processed on-site within a few hours of collection. Fecal matter expressed by abdominal palpation was collected, pooled by cage, and frozen for later isotopic analysis. Blood (0.5 – 1.0 cc) was collected from the caudal vein and distributed between microhematocrit tubes for packed cell volumes, and glass slide blood smears and hemocytometer for white cell counts (final visit only). The remaining volume of blood was placed in microcentrifuge tubes and frozen for later isotopic analysis. Packed cell volumes were read off the microhematocrit tubes after immediate centrifugation for five minutes at 10,000xg. Blood smears for white counts were fixed in acetone within one week of collection, then stained with Wright-Giemsa to determine the white blood cell relative percentages. The total RBC count, determined using a hemocytometer with Natt-Herrick's solution as a diluent (Hrubec et al., 2000), was intended as a method for converting percentages to absolute values. Ten times the average number of cells counted per cubic mm hemocytometer square provided an approximation of red cells per mm^3. The ratio of number of white cells per 500 red cells was estimated from the blood smears and multiplied by the total red count (and multiplied by 1000 µl /ml) to get an approximate number of white blood cells per µl. However, cell clumping limited the accuracy of the hemocytometry-derived estimates. The reported relative white cell counts are the average number of blood cells (rbcs plus wbcs) counted per cubic mm hemocytometer square. Adductor muscle tissue from mussels (five individual samples/cage) and whole body soft tissue from barnacles (1-5 animals pooled by cage) were collected and frozen for isotopic analysis. All samples intended for isotopic analysis were frozen and shipped on ice to North Carolina State University (NCSU).

Isotope compositions of fish blood, feces, mussel tissue, barnacle tissue, feed and sediment were analyzed using continuous flow isotope-ratio mass spectrometry (CF-IRMS) at NCSU's Stable Isotope Laboratory. Samples were freeze-dried for $\delta^{15}N$ and $\delta^{13}C$ analysis. Prepared samples were combusted in a Carlo Erba NC 2500 elemental analyzer and the N2 peak injected into a Finnegan Mat Delta+ XLS CF-IRMS. The $\delta^{15}N$ of the samples are reported, using δ notation, in per mil ($^{o}/_{oo}$) deviations from atmospheric nitrogen with the following convention: $\delta^{15}N\ (^{o}/_{oo}) = [(^{15}N{:}^{14}N_{sample} / {}^{15}N{:}^{14}N_{atmN2}) - 1] \times 10^3$. The $\delta^{13}C$ of samples was analyzed in a similar fashion. Results are reported in per mil ($^{o}/_{oo}$) deviations from PeeDee Limestone using the following convention: $\delta^{13}C\ (^{o}/_{oo}) = [(^{13}C{:}^{12}C_{sample} / {}^{13}C{:}^{12}C_{PDB}) - 1] \times 10^3$.

Growth and mortality rates were calculated at site visit intervals using metrics provided by site fish health and production managers. Site veterinary and fish health technicians were queried on health events of differential impact between cages at each study interval. Statistical analyses testing for differences between LiftUp® and diver removal cohorts used a general linear model in SAS (version 8e) with cage effect as the error term. We found it necessary to account for cage effect since cage histories varied by hatchery-of-origin, transfer dates, stocking densities, and smoltification procedures.

Results

LiftUp®

LiftUp® equipment was installed without significant problems. Over the course of the project, frequency of pumping varied with feeding rates. When feeding levels were low, cages were pumped about once per week and when levels increased, cages were pumped up to three times per week. However, a variety of both expected and unexpected problems arose throughout the project that affected the pumping frequency.

As ambient air and seawater temperatures declined in the fall, water in the airlift tube froze as a result of the cooling effect of compressed air expanding. By the end of December, use of Liftup® became impractical and its operation ceased, requiring diver-collection of mortalities. Operation resumed in mid-April 2004 when feeding increased and ambient temperatures climbed.

Although LiftUp® was intended to reduce the insertion of divers into the pens, divers were frequently required to enter the cages to unclog the "china hat" when drift kelp and other debris blocked the intakes. Additionally, two cages, 911 and 915, were sited in depths that reduced separation between the LiftUp® net and bottom. This caused the funnel to rest on the predator net, resulting in a reduced slope of the net bottom, thus impeding waste material from sliding freely to the "china hat" cone; a deeper predator net could not be installed because of the regulatory requirement to maintain a 3-meter minimum distance between the net-pen and the sea floor. Even if possible, changing the predator net would have required personnel that were not available due to the constraints on personnel time. Consequently, additional dives were needed in these cages to manually push the waste toward the airlift intake.

Another problem encountered was related to the fact that the discharge pipe of the LiftUp® was secured to the down lines of the containment net, therefore, as the pipe was filled with air, the pipe tended to lift the containment net partially to the surface along the plane of the pipe; the extent of this lift effect, however, was not sufficient to cause loss of accumulated material from the net.

Problems were also encountered with the fine mesh nets not hanging properly during high current velocities of astronomically high amplitude tides and storms. If this system were continuously exposed to higher currents, net deflections would become an issue.

While the site operators were able to work around all of these problems, having to do so resulted in unanticipated costs. Table 2 is an approximate breakdown of differential operational costs between the LiftUp® and non- LiftUp® cages for the project period.

Table 2. Cost differences between LiftUp® and Non-LiftUp® cages

Item	LiftUp® cage	Standard cage
Bottom panel modification of LiftUp® net	$ 2,829.14	$ -
Added cost of anti-foulant dip on fine mesh	500.00	-
LiftUp® china hats units (including install)	3,351.86	-
Additional net cleaning	500.00	
Compressor ($1,500/4 cages)	375.00	
Diver for mort collection (1/wk. summer; 2/wk winter @ $55/hr personnel + $45/hr vessel and ½ hr/dive = $50/dive)		3,350.00
Diver-related exp. (air, equip.)	-	
LiftUp® operator(s) (every 3-5 days summer; none in winter @ $24/personell + $45/hr vessel and ½ hr/pump = $34.50/pump)	5,606.00	
Total	**$ 13,162.00**	**$ 3,350.00**
Difference between LiftUp® and standard	**$ 9,812.00**	

Detailed daily recordkeeping was not as complete as initially anticipated due to the unexpected constraints placed on personnel as a result of organizational changes within Atlantic Salmon of Maine LLC during the course of the project. However, standard operating procedures and reporting requirements by the State of Maine require detailed tracking of fish inventory and feed usage. Table 3 summarizes the total amount of feed used (kg), net growth (weight gain in kg), Specific Feed Rate (SFR), and percent mortality for each cage for each interval between samplings; the final set of columns summaries the values over the entire project period. It should be noted that the amount of feed administered to LiftUp® cages and non- LiftUp® cages over each interval and the overall project period was very similar although slightly greater (5%) in the non-LiftUp® cages and net growth was slightly greater (4.6%) in the LiftUp® cages. Unusually high mortality (15.6%) occurred in one non-LiftUp® (cage 912) over the winter of 2003-2004.

Table 3. Sampling interval and full-project production summaries for Control and LiftUp® cage

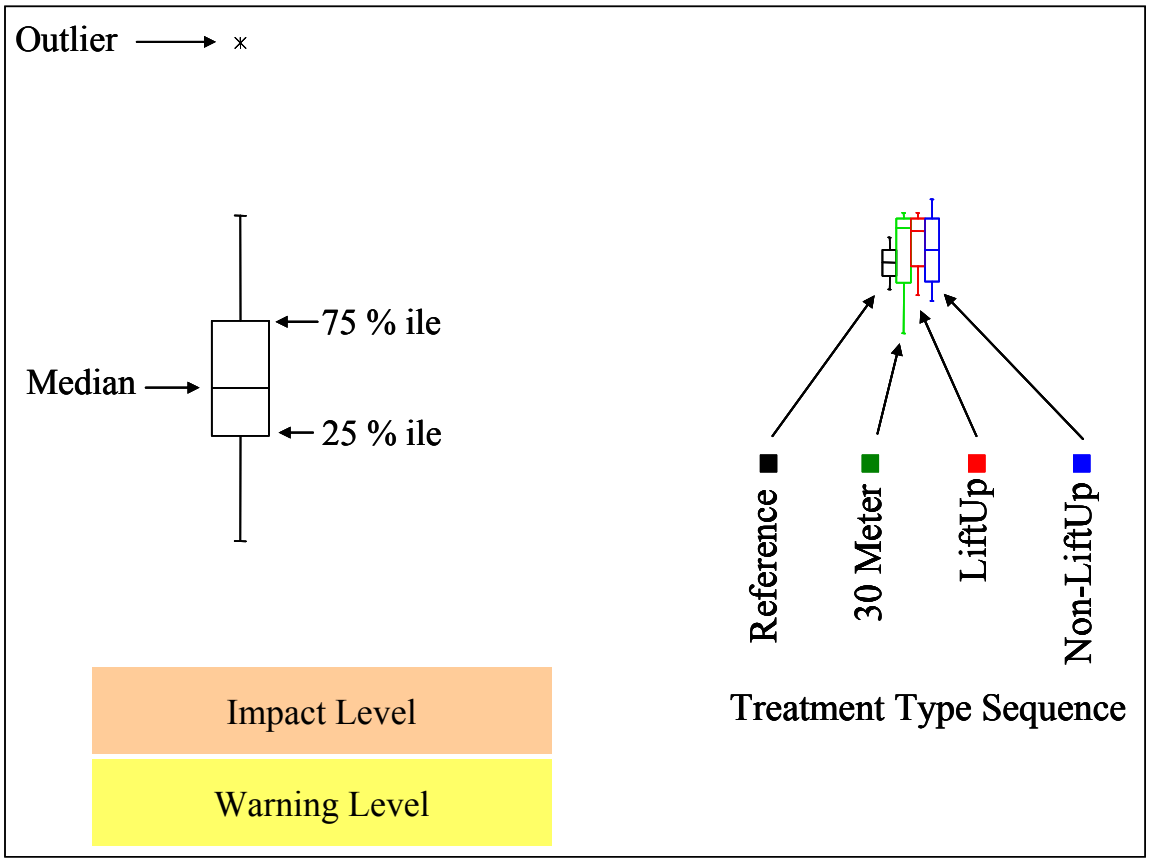
	7/1/03- 11/24/03				11/25/03 - 5/12/04				5/13/04 - 11/4/04				Date of stocking - 11/4/04			
Cage Number	**feed used (kg)**	**SFR**	**net growth (kg)**	**Mort. (%)**	**feed used (kg)**	**SFR**	**net growth (kg)**	**Mort. (%)**	**feed used (kg)**	**SFR**	**net growth (kg)**	**Mort. (%)**	**feed used (kg)**	**SFR**	**net growth (kg)**	**Mort. (%)**
Non-LiftUp®																
909	16880	0.88	14634	0.1	12023	0.17	9174	0.4	105850	0.82	64781	0.1	134753	0.60	88589	0.6
912	34747	1.10	30967	0.2	13781	0.14	950	15.2	121035	0.73	88190	0.4	169563	0.58	120107	15.6
913	3000	0.57	2894	0.4	11211	0.2	7800	2.9	96521	0.86	65095	0.4	110732	0.54	75790	3.6
916	15498	0.85	12972	0.1	12407	0.18	7581	4.5	106990	0.81	71373	0.5	134895	0.56	91927	5.0
Mean	**17531**	**0.85**	**15367**	**0.2**	**12356**	**0.17**	**6376**	**5.7**	**107599**	**0.81**	**72360**	**0.3**	**137486**	**0.57**	**94103**	**6.2**
SD	**13065**	**0.22**	**11622**	**0.1**	**1073**	**0.03**	**3686**	**6.5**	**10111**	**0.05**	**10982**	**0.1**	**24214**	**0.03**	**18679**	**6.6**
LiftUp®																
910	20605	1.05	17080	0.4	11015	0.16	7755	2.0	108257	0.79	82431	0.2	139877	0.59	107267	2.6
911	26744	0.86	23330	0.1	10940	0.12	7926	1.1	107157	0.64	89206	0.2	142466	0.47	118487	1.5
914	8415	1.28	20200?	0.0	10262	0.19	6302	4.3	100349	0.94	63669	0.1	119026	0.86	90170	4.5
915	6121	0.63	5996	0.4	10387	0.16	7593	1.7	104280	0.85	65180	0.3	120788	0.54	78769	2.3
Mean	**15471**	**0.96**	**15469**	**0.2**	**10651**	**0.16**	**7394**	**2.3**	**105011**	**0.81**	**75122**	**0.2**	**130539**	**0.62**	**98673**	**2.7**
SD	**9843**	**0.28**	**8779**	**0.2**	**382**	**0.03**	**741**	**1.4**	**3531**	**0.13**	**12673**	**0.1**	**12343**	**0.17**	**17653**	**1.3**

Environmental parameters

Explanation of Graphics

Box plots were used to show the distribution of all environmental data (Figure 8). The central fifty percent of the data values are contained within the box and the median (50 percentile) is indicated by the center horizontal line inside the box. Outliers are represented by x's and o's. The order, from left to right, of box plots is always the same from graph to graph; reference stations, 30 meter stations, Liftup® and non-Liftup®, and are respectively color coded black, green, red and blue. Where MePDES permit warning and impact levels exist, they are incorporated into box plot graphs as yellow and pink, respectively, shaded areas.

Figure 8 Explanation of statistical data graphics indicating ranges, impact level color-coding, and treatment type sequence



Video

Video recordings taken during the baseline assessment in July 2003 showed benthic surface sediment conditions and benthic macrofauna community structure to be similar across the study and reference areas. The benthic surface sediments were generally barren mud with no indications of organic enrichment, *e.g.* no black hypoxic sediments or *Beggiatoa* sp. coverage. Epilithic diatoms covered much of the bottom along most of the transects except those in slightly deeper water; flora was generally restricted to drifting kelp and *Desmarestia.* Mysid shrimp were the dominant macrofauna along all transects, but at least one lobster, *Homarus americanus*, and numerous burrows presumed to be lobster burrows, were also seen.

By November 2003, 2-3 months after the fish had been stocked in the cages, some signs of light organic enrichment were observed in the form of small amounts of feed and light *Beggiatoa sp.* No feed, but light to moderate *Beggiatoa sp*., was found directly beneath LiftUp® cage 915 which was non-operational, although the fine net had been installed; lobsters, mud shrimp, *Crangon septemspinosa*, and crabs were still active beneath the cages along with juvenile cod, sculpins. By contrast, considerable feed and moderate to heavy *Beggiatoa sp.* was found adjacent to and directly beneath non-LiftUp® cage 913. Along most transects and stations epibenthic fauna continued to be dominated by crustaceans, *C. borealis*, *Crangon*, mysid shrimp, and at least one lobster, and generally appeared to be greater in number in the vicinity of the LiftUp® cage. The epibenthic sediment condition at reference Transect 5 remained unchanged, but the number of organisms was substantially lower than in July, consisting only of a few mysid shrimp and *Crangon*, and a single *C. borealis* and sculpin, likely a seasonal effect.

In May 2004, *Beggiatoa sp*. and feed increased slightly at the 30m distance and under the non-LiftUp® cages, but remained essentially unchanged beneath the LiftUp® cages. Macroflora generally increased at all study stations, but macrofauna declined slightly at all locations except the 30m distant stations. Again, little change was seen at the reference site.

By November 2004 nearly all evidence of hypoxic or anoxic conditions had disappeared across the entire site, as did the epilithic diatoms; only sporadic small amounts of feed were seen directly beneath or in close proximity to the cages. Epifauna along the northeast end of the site was dominated by crustaceans, *C. borealis* and *C. irroratus, Crangon*, amphipods, and mysid shrimp, but a variety of other species, including one lobster under non-LiftUp® cage 913, were seen. By comparison, the southwestern end of the site was rather lacking in diversity although again little evidence of enrichment was evident as hypoxia or *Beggiatoa* sp. Small amounts of feed were seen along the bottom, but seemed to be attracting the crustaceans scavengers, *C. borealis, C. irroratus* and shrimp, both mud and mysid; other fauna included *Metridium, Tealia*, hermit crabs, and nudibranchs. The reference Transect 5 was similarly barren with fauna consisting of only mysid shrimp and *Crangon septemspinosa*, and a solitary *C. borealis;* there was no evidence of any enrichment effect along the transect.

Detailed graphic representations of the video observation along each recorded transect are included in Appendix I. Location and distribution of individual organisms shown in these representations are estimated based on the total video recording time and average swim rate.

Flora, epifauna, and bottom condition

Table 4 summarizes the mean number of flora and fauna species and relative coverage of *Beggiatoa* sp. and feed by treatment for each sampling date. According to the MePDES General Permit, relative coverage is categorized as absent (0), light (1), moderate (2), or heavy (3).

Table 4. Mean benthic surface flora and fauna and sediment surface condition

July 03	30m	Non- LiftUp®	LiftUp®	Ref
Flora	2.25	3.25	3.50	1.00
Macrofauna	2.75	4.75	4.50	2.67
***Beggiatoa* sp.**	0.00	0.00	0.00	0.00
Feed	0.00	0.00	0.00	0.00

Nov 03	30m	Non- LiftUp®	LiftUp®	Ref
Flora	1.00	0.67	0.33	0.00
Macrofauna	3.00	5.33	7.00	2.33
***Beggiatoa* sp.**	1.00	1.33	2.00	0.00
Feed	0.33	1.67	1.00	0.00

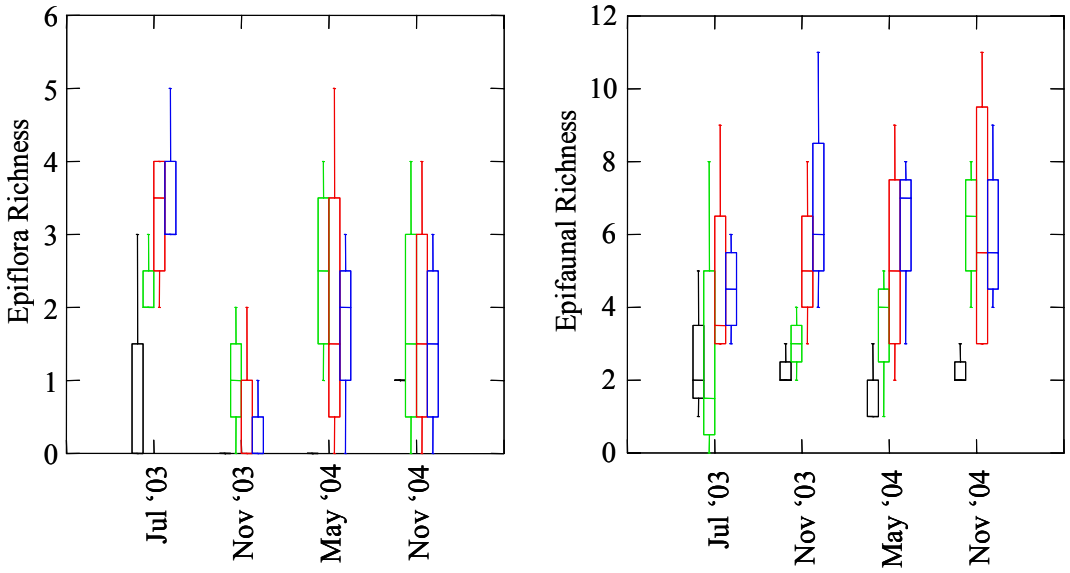
May 04	30m	Non- LiftUp®	LiftUp®	Ref
Flora	2.50	2.00	1.75	0.00
Macrofauna	3.50	5.25	6.25	1.67
***Beggiatoa* sp.**	1.75	2.25	2.00	0.00
Feed	1.25	2.25	1.25	0.00

Nov 04	30m	Non- LiftUp®	LiftUp®	Ref
Flora	1.75	1.75	1.50	1.00
Macrofauna	6.25	6.25	6.00	2.33
***Beggiatoa* sp.**	0.50	0.25	0.00	0.00
Feed	0.25	1.50	1.50	0.00

With the exception of epilithic diatoms, little macroflora actually grows on the bottom due to the absence of hard substrate for holdfast to attach. Diversity and abundance of flora are generally greater around cages since they offer a structure within the photic zone to support the growth. The flora seen beneath the cages are either isolated plants (e.g. *Ulva* sp., *Laminaria* sp., *Alaria* sp., *Fucus* sp., and *Ascophyllum* sp.) that either drifted in or dropped to the bottom off nets. The bottom at the reference site was generally barren with minimal amounts of drifting kelp (Figure 9). (Note when all values for a treatment and event are equal, such as epiflora at reference station November 2004 where there was one species, the box plot is presented as a narrow horizontal line with no spread.)

The number of epibenthic macrofauna (Figure 9) directly beneath the LiftUp® and non-LiftUp® cages, and even the 30 meters station, increased after fish were introduced while richness at the reference station remained relatively stable. These increases are typical of conditions under pens as the bottom becomes organically enriched (Pearson and Rosenberg, 1978) and the cage systems provide a more complex habitat structure than what otherwise exists on site. Additional details are included in Appendix II.

Figure 9 Mean number epiflora and epifauna species by treatment and sample date



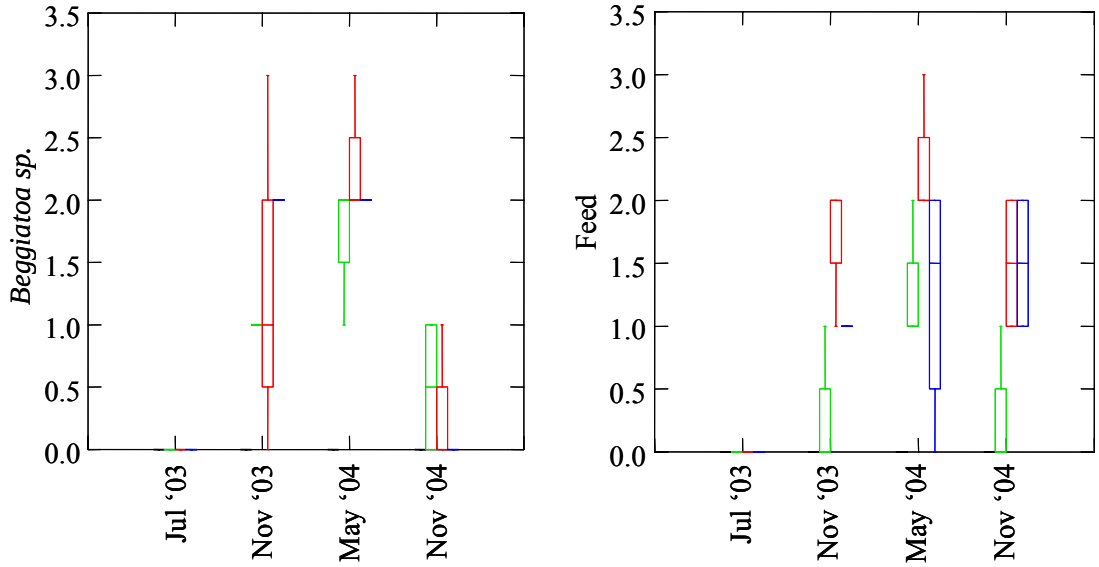
A shift in species dominance occurs over time in the vicinity of the cages from a consistent dominance by mysid shrimp along all transects at baseline to larger species of shrimp, *Crangon* and *Pandalus* and crabs, *Cancer* and *Carcinus*. The reference site showed no similar shift, although abundance both around the cages and at the reference fluctuates seasonally. Lobsters were seen along all transects in July 2003, but thereafter were only seen rarely with the exception of several found in the vicinity of one of the LiftUp® cages in November 2003. Abundance similarly declined at the reference site and can be attributed largely to seasonal migrations into deeper water in the fall.

Figure 10 shows the relative coverage of *Beggiatoa* sp. and feed along the transects where "0" represents absence, "1" light (<50% cover), "2" moderate (≈50%), and "3" heavy (>50% cover). Both are clearly associated with the cages and vicinity (30m station) with neither being found at the reference at any time.

Beggiatoa sp. first appeared after fish introduction and reached moderate coverage beneath the LiftUp® by November 2003, but percent coverage becomes similar in the vicinity of both LiftUp® and non-LiftUp®, and at the 30m distant stations by May 2004. By November 2004, however, *Beggiatoa* sp. cover virtually disappeared at the time of highest biomass, possibly related to a general coarsening of the bottom observed at all stations over the project period (see Granulometry section, following).

Feed coverage showed a similar increasing trend over time through May 2004 but then decreased (at least beneath the non-LiftUp® cages) by November 2004, despite the order of magnitude increase in the amount of feed introduced into the cages.

Figure 10 Relative abundance of *Beggiatoa* sp. and feed by treatment and sample date

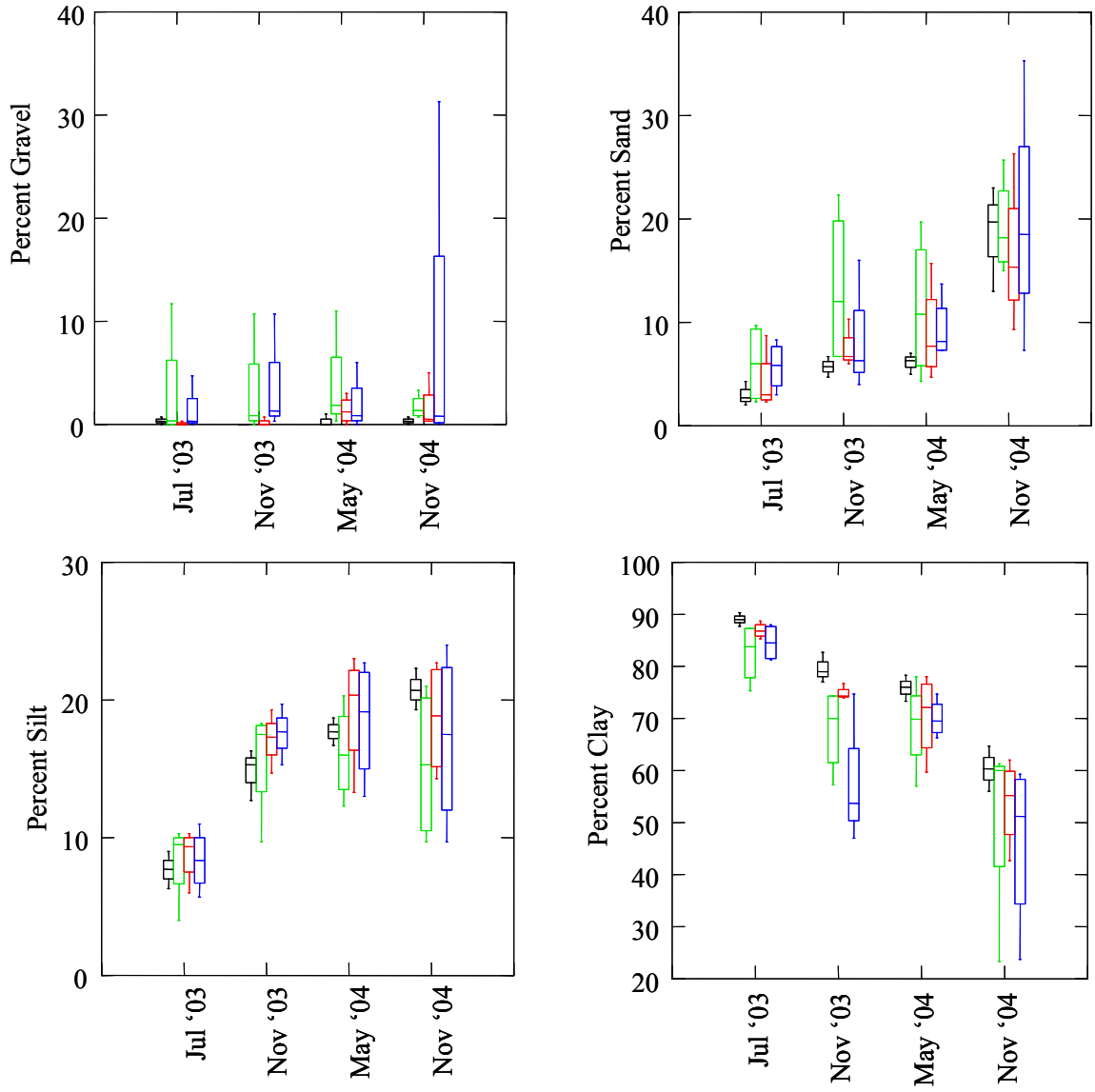


Granulometry

Sediments across the experimental area were uniformly fine grained with a silt-clay mean grain size. Baseline (July 2003) confirmed that sediment at all treatment sample stations were comparable at the initial stages of the project (Figure 11). With one exception, no differences in grain size emerged between any treatments at any point during the project that might confound results. The exception, November 2003 clay content, a significant difference ($p=0.08$) in percent clay emerged between non-Liftup® pens and the reference stations. No differences ever occurred between non-Liftup® and Liftup® pens.

Grain size became progressively coarser at all treatments, including the reference site. This unanticipated trend is especially notable in the observed decline of percent clay and silt and increase of percent sand. Because coarsening was observed at the reference site, we surmise that some large scale process, unrelated to the aquaculture operations, affected sediment quality in the overall Machias Bay area.

Figure 11 Box plots of sediment grain size distribution by treatment and date



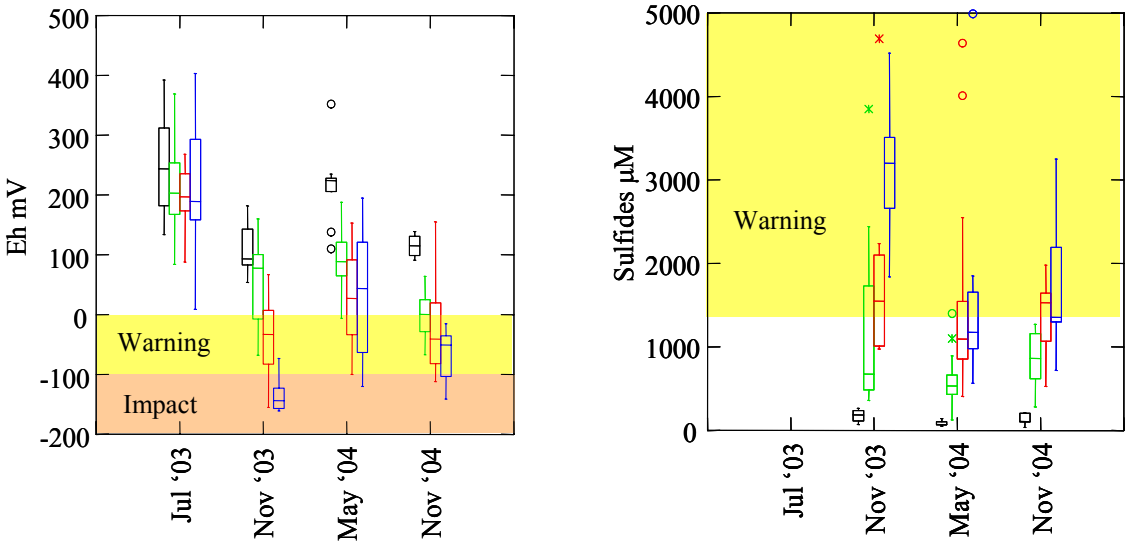
Sediment chemistry

Detailed sediment chemistry data are included in Appendix III. Figures 11-14 graphically summarize the distributions of Eh, sulfide, TOC, and TON for all station types to provide relative context. However, since the purpose of the project was to compare environmental performance between standard and Liftup® equipped pens, statistical testing for differences was only applied to Liftup® and non- Liftup® treatments.

As with grain size, baseline conditions were established from which change could be measured. Baseline results were comparable at all sites for all variables measured (note - sulfide was not part of the original proposal and was not measured during baseline characterization).

By the first fall, (November 2003), only two months after stocking, Eh values were significantly lower and sulfides significantly higher at all sites except the reference stations. (Figure 12). In fact, individual values at all sites, including stations at 30 meters, entered the MePDES warning threshold (<0mV Eh in yellow) and Eh under non-Liftup® cages fell to impact levels (< -100mV in red)[2]. By the following spring, non-Liftup® Eh rose to warning conditions. Sulfides under both pen treatments entered the warning range (1,300-6,000 uM sulfides in yellow) but by the following spring, sulfides were again generally less than 1,300 uM. At the end of the project, November 2004, sulfide values under both Liftup® and non-Liftup® had again exceeded the warning threshold but at a lower level than the previous November. In general, non-Liftup® systems indicated higher organic enrichment than Liftup®, although the only time differences between Liftup® and non-Liftup® was ever significant ($p < 0.1$) occurred November 2003.

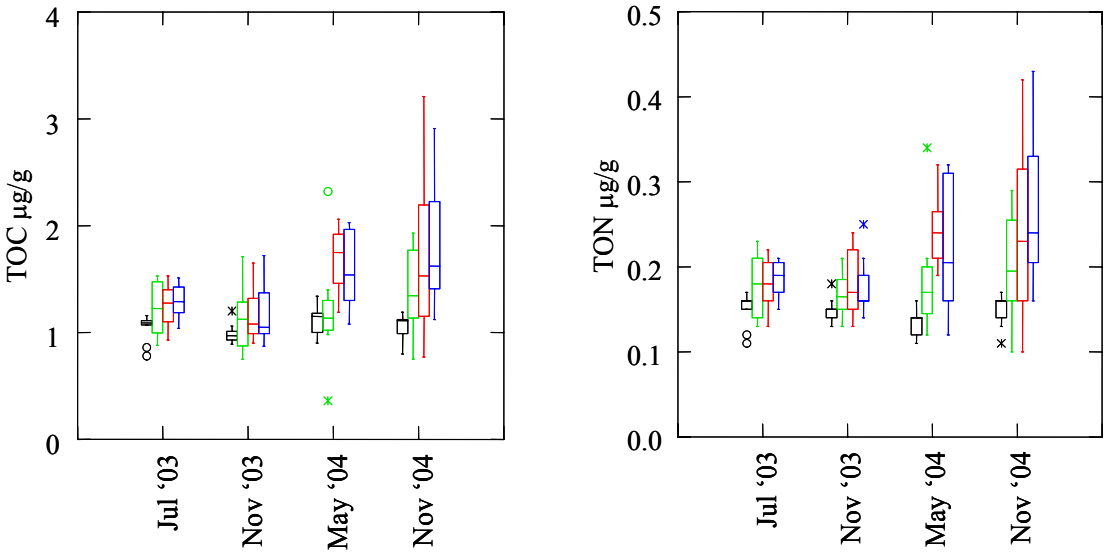
Figure 12 Box plots of redox and sulfides by treatment and date



Total organic carbon (TOC) and total organic nitrogen (TON) concentrations remained relatively similar at both the reference and 30 meter stations throughout the project Sediments under fish pens increased slightly by May 2004 after fish had been on site about 8 months (Figure 13) and variance increased under both pen treatments and the 30 meter station indicating the patchy nature of organic accumulation. While sediments under non-Liftup® pens were generally more enriched than those under Liftup®, no differences were ever significant at $p<0.1$.

[2] Because redox and sulfide values are frequently contradictory (i.e. one result may indicate a warning while the other may not), permit compliance actions are taken only when the two corroborate one another. Hence, the November 2003 non-LiftUp Eh impact result was not supported by the November 2003 sulfide

Figure 13 Box plots of total organic carbon and total organic nitrogen by treatment and date



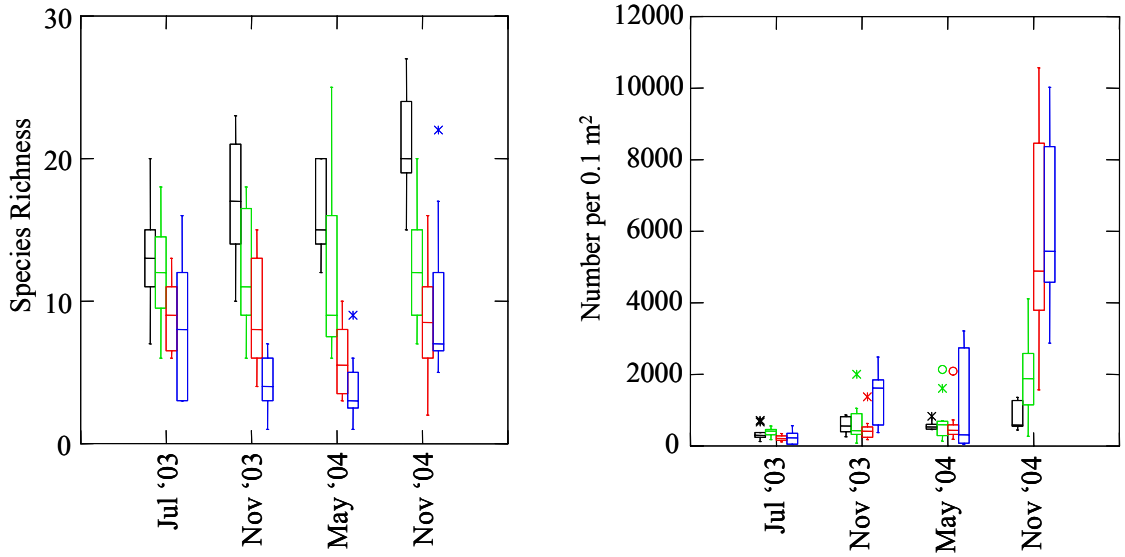
Benthic infauna

Detailed results of infauna communities are presented in Appendix IV and are summarized in Figures 14 and 15. As with chemical parameters, baseline conditions for all four biological community structure parameters were approximately equivalent.

Median baseline species richness in July 2003 was generally similar (8-12) at all stations (Figure 14). While richness at the reference station increased slightly over the project period, richness at the 30 meter station remained the same. Richness at both LiftUp and non- Liftup® cage sites declined slightly in the middle of the project period although both recovered to baseline levels by the end of the project. The only significant difference between Liftup® and non-Liftup® cages occurred November 2003 when chemistries were also significantly different.

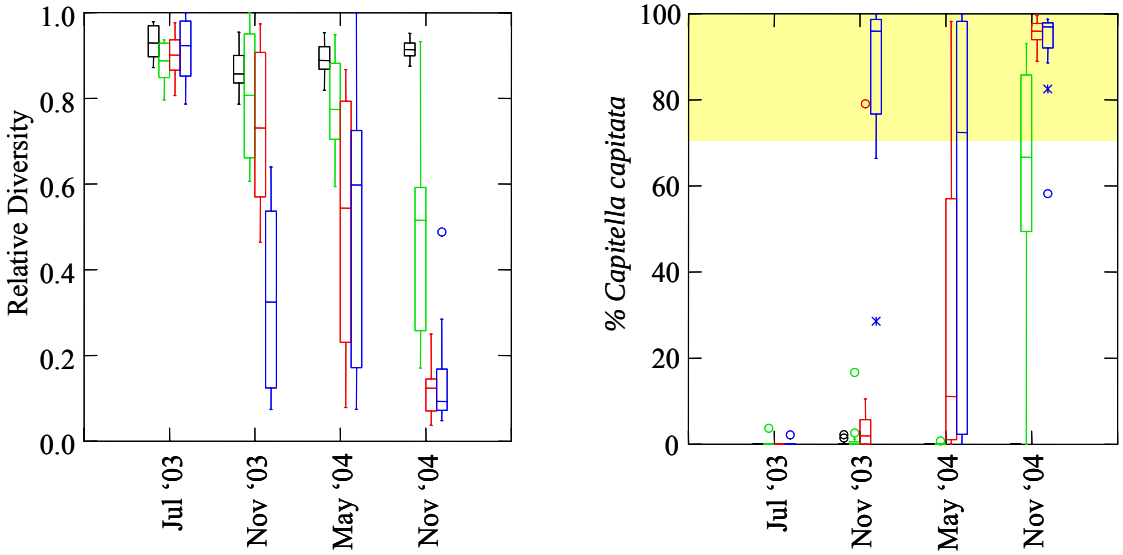
Abundance at all stations, including reference, gradually increased over the project period (Figure 14). Abundance appears to have increased more rapidly under the non-Liftup® pens than under Liftup® however, by the final sampling event, abundance of organisms under both pen treatments had increased almost six-fold. The Maine MPDES permit warning threshold is triggered when a reduction in abundance occurs that is greater than 50% from baseline conditions or reference. In this case, the converse occurred. This biostimulative phenomenon has often been observed where organic loading and sufficient oxygen supply is available leading to population explosions, particularly amongst opportunistic species (Pearson and Rosenberg, 1978; Heinig, 2001).

Figure 14 Box plots of species richness and abundance per 0.1 m^2 by treatment and date



Relative diversity at baseline was also similar for all treatments (Figure 15). Reference station diversity remained consistently high throughout the project. Significant differences emerged between non-Liftup® and Liftup® treatments at the November 2003 sampling but disappeared in subsequent sample events. By project end (November 2004), diversity at both the Liftup® and non- Liftup® had dropped to less than 0.2 with no difference between them.

Figure 15 Box plots of relative diversity and % *Capitella capitata* by treatment and date



Capitella capitata, an opportunistic species frequently used as an indicator of organic enrichment, was rare to absent in all baseline samples, once cages were stocked, *C. capitata* became an increasingly important taxa for treatments containing fish. Using the DEP MePDES warning limit of 70% hyperdominance (yellow area of graph), the warning threshold was crossed first in the non-Liftup® treatment cages early on in the project at the November 2003 sampling, shortly after stocking. This led to the only significant difference between Liftup® and non-Liftup® systems. By the end of the project, *C. capitata* had become hyperdominant under both pen treatments and both had exceeded the 70% hyperdominance warning threshold. Even 30-meter stations had some samples where *C. capitata* were hyperdominant. This hyperdominance by *Capitella capitata,* of course, is manifested in both the high abundances and low relative diversities noted in Figures 14 and 15.

Water Quality

Temperature and salinity, the two variables unaffected by fish, were virtually identical inside the cages. Although the non-Liftup® cages had slightly lower oxygen and turbidity, because of the very cursory nature of this sampling, testing for statistical differences would have been inappropriate. Concentrations of oxygen were consistently above the 6.0 mg/l MePDES permit impact level required within cage systems.

Table 5 - Summary of Mean Vertical Profile Water Quality Conditions

	Depth	Temp	Salinity	Mean DO Conc	Mean DO sat	Turbidity
Cage type	**m**	**C**	**ppt**	**mg/L**	**%**	**NTU**
Non-Liftup®						
909	10.2	9.5	32.4	8.4	91.0	1.5
912	11.6	9.9	32.3	7.6	82.4	1.4
913	9.9	10.2	32.3	8.1	89.1	1.6
916	9.8	10.1	32.3	8.8	95.6	1.3
	10.4	**9.9**	**32.3**	**8.2**	**89.5**	**1.4**
Liftup®						
910	12.8	9.8	32.3	8.7	95.0	1.4
911	12.2	9.8	32.3	8.0	87.0	1.7
914	11.3	10.1	32.3	8.9	96.9	1.6
915	12.1	10.0	32.4	8.4	91.3	1.3
	12.1	**9.9**	**32.3**	**8.5**	**92.5**	**1.5**

"First flush' effluent discharged from the LiftUp® systems was dark colored and had a strong fish - rotten egg odor typical of anoxia. Constituents measured in the effluent are presented in Figures 16 and 17. After less than 100 seconds, BOD_5 and TSS fell to close to method detection limits. For budget reasons, TKN was measured from cage 911 that was more discolored and turbid and higher BOD and TSS. As with BOD_5 and TSS, TKN responded similarly with a strong first flush effect (Fig 18) and levels falling to near method detection limits after about 50 seconds.

Figure 16 Change in biological oxygen demand (BOD_5) and suspended solids of Liftup® cage 910 effluent over time

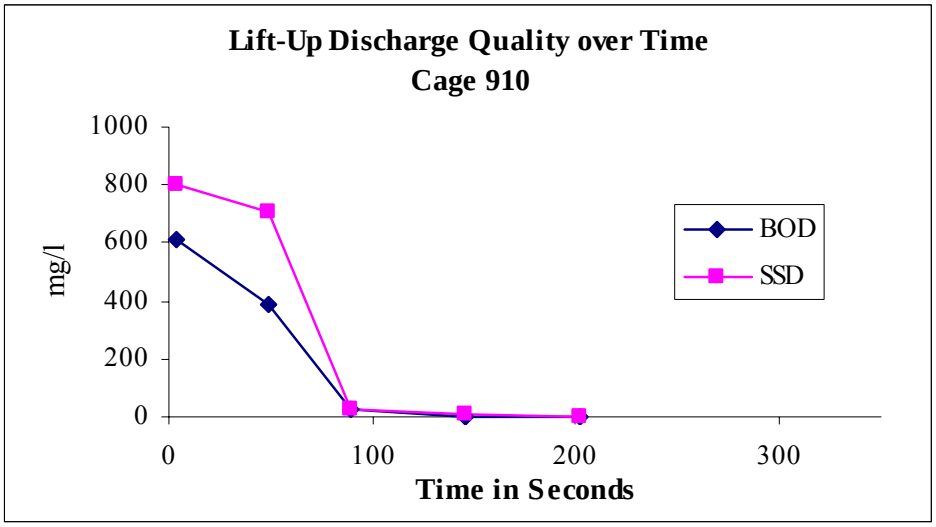


Figure 17 Change in biological oxygen demand (BOD_5) and suspended solids of Liftup® cage 911 effluent over time

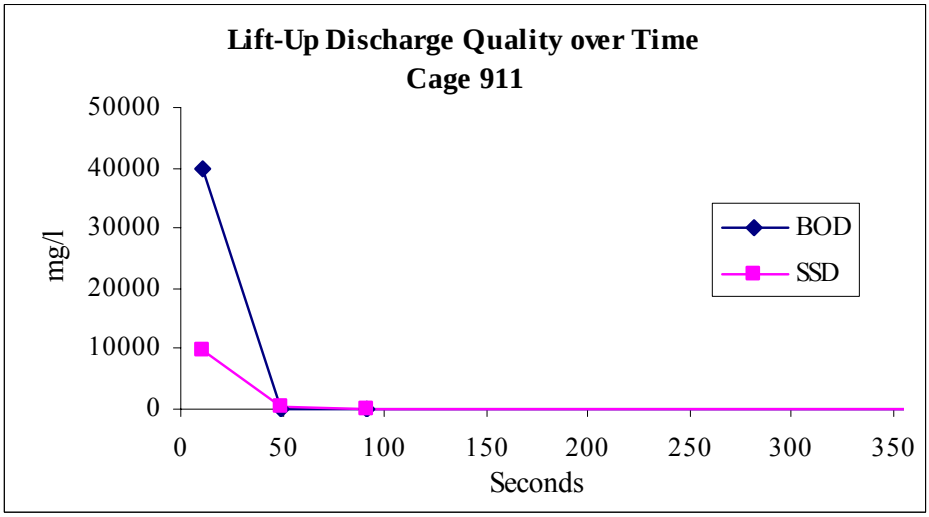
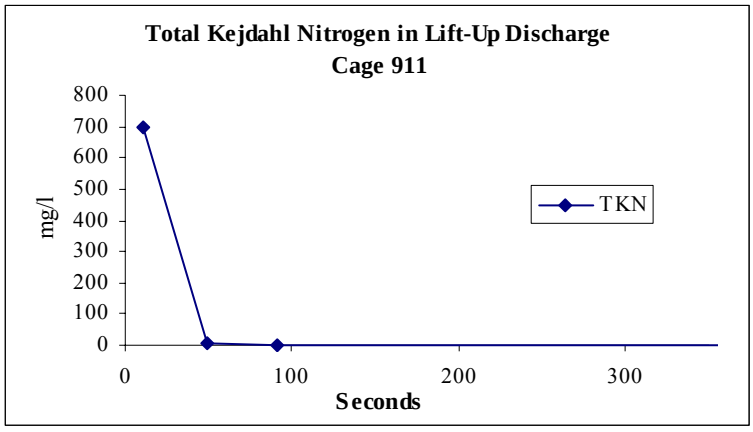
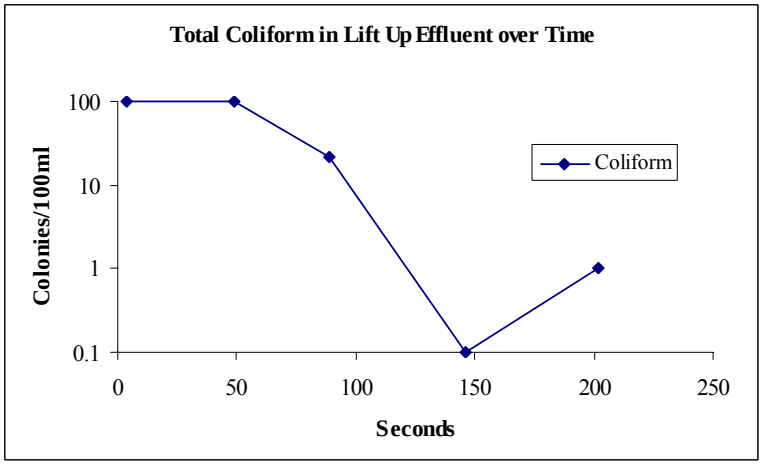


Figure 18 Change in total Kjeldahl nitrogen (TKN) of Liftup® cage 911 effluent over time



Total coliforms (TC) (Fig 19) were measured as a surrogate for potential pathogen exposure. Problems in methodology became immediately apparent when the membrane filters quickly clogged with grease, oil and solids. Dilutions reduced this problem somewhat but even with 1:100 dilution, particulates on the filter made reading the plates difficult. Nevertheless, TC results follow a similar pattern (note log scale) of highest concentrations at the beginning of discharge with a rapid decline as the airlift empties material from the pen bottom.

Figure 19 Change in total coliform bacteria in Liftup® effluent over time



To estimate constituent load, we measured the average time to fill a standard fish tote (~ 20 gallons) to be 3.6 seconds (n=4) or about 21 L/sec. Assuming that this amount of waste were discharged daily, the amount of material discharged in the first 100 seconds (about 2.1 cubic meters) would have an immeasurable impact on ambient environmental conditions only a short distance from the pens, each of which has a volume of about 8,000 cubic meters. After approximately 60 seconds, however, the effluent became clear and odorless. The effluent created a small surface plume (2m x 5m oval) of turbid water that drifted away from the pens on tidal currents. Within 30 meters, the plume was no longer visible. The discharge does, however, raise concerns over the possible transmission of infected material to nearby cages.

Fish Health

Descriptive statistics for isotopic signatures are displayed (by sample date) in Table 6. Statistical comparisons for health indices, $\delta^{15}N$, and $\delta^{13}C$ between cage averages for LiftUp® and diver systems are shown in Tables 7, 8 and 9 respectively. The only statistically significant difference ($p < 0.05$) was between $\delta^{15}N$ of fecal material from fish in lift-up vs. fish in non-lift-up cages. To avoid bias caused by cage effect, statistical hypothesis tests used cage averages (rather than individual fish) as the unit of observation. Production measures did not vary significantly between LiftUp® and non-LiftUp® cages. Surveys of site veterinary and fish health technicians revealed no adverse health events of differential impact between cages. Mean compositions of fish blood were slightly more enriched in $\delta^{13}C$ than expected from a diet comprised solely of salmon feed (Figures 20 and 21).

Table 6: Isotope values by sample date

variable	date	n samples	$\delta^{15}N$ mean	$\delta^{15}N$ std dev	$\delta^{13}C$ mean	$\delta^{13}C$ std dev
salmon blood	July 03	20	11.34	0.34	-19.04	0.19
	Dec 03	40	12.31	0.35	-18.58	0.23
	May 04	40	12.74	1.75	-18.34	0.39
salmon feces	July 03	6 pools	8.82	0.34	-21.45	0.46
	Dec 03	8 pools	9.74	1.11	-19.55	0.91
	May 04	8 pools	9.78	0.98	-20.03	0.55
mussels	July 03	6	7.47	0.60	-19.46	0.56
	Dec 03	40	7.65	0.35	-17.98	0.34
	May 04	40	7.50	0.62	-19.31	0.72
barnacles	Dec 03	6	8.96	0.44	-17.30	0.56
	May 04	6	8.20	1.08	-18.32	0.79
sediment	July 03	10	5.93	0.31	-18.93	1.01
	Dec 03	8	6.56	0.72	-16.39	3.37
	May 04	8	5.86	0.26	-18.49	1.07
feed	July 03	3	8.34	1.78	-20.31	0.42
	Dec 03	4	10.11	0.46	-20.69	0.64
	May 04	2	8.48	0.45	-20.20	0.80
sludge from LiftUp® pipe	May 04	4	9.07	0.87	-20.92	1.75
unidentified benthic worm	July 03	2	9.85	0.13	-21.04	2.34
oligochaetes	Dec 03	2	10.43	0.94	-19.93	2.02
capitellids	May 04	4	9.04	1.29	-19.67	0.84
syllid polychaete (*Autolytus* sp)	May 04	2	9.11	1.35	-19.65	2.14
clamworm (*Neries* sp)	May 04	2	10.67	1.03	-18.55	9.04

Table 7: Production and hematologic measures with comparisons by treatment group. Reported white cell counts are relative only, as clumping precluded accurate estimations of absolute counts.

meristic	date	LiftUp® cages	mean	std dev	diver cages	mean	std dev	p value
period % mortality	11/25/03 – 5/12/04	4	2.27	1.44	4	5.73	6.54	0.58
	5/13/04 – 11/4/04	4	0.19	0.06	4	0.34	0.14	0.33
period net g gain/fish	11/25/03 – 5/12/04	4	303	42	4	349	24	**0.10**
packed cell volume	Dec 03	4	36.3	3.2	4	35.2	2.5	0.60
	May 04	4	30.9	2.6	4	28.7	4.5	0.43
relative white cell count / µl	May 04	4	17300	8000	4	16900	5400	0.94

Table 8: Comparison of $\delta^{15}N$ cage averages by treatment group

measure	date	LiftUp® cages			Diver cages			p value
		n	mean	std dev	n	mean	std dev	
salmon blood	Dec 03	4	12.24	0.19	4	12.39	0.06	0.18
	May 04	4	12.70	0.07	4	12.78	0.52	0.89
salmon feces	Dec 03	4	9.14	1.13	4	10.33	0.81	0.14
	May 04	4	**9.10**	0.38	4	**10.45**	0.34	**0.04**
mussels	Dec 03	4	8.80	0.59	4	9.11	0.25	0.99
	May 04	4	7.48	0.10	4	7.53	0.24	0.87
barnacles	Dec 03	3	8.80	0.59	3	9.11	0.25	0.45
	May 04	4	8.63	0.74	4	7.78	0.11	0.29
sediment	Dec 03	3	6.38	0.84	2	7.02	1.02	0.49
	May 04	4	5.79	0.05	4	5.92	0.19	0.52
capitellid	May 04	2	9.09	0.56	2	9.00	2.16	0.96

Table 9: Comparison of $\delta^{13}C$ cage averages by treatment group

measure	date	LiftUp® cages			Diver cages			p value
		n	mean	std dev	n	mean	std dev	
salmon blood	Dec 03	4	-18.6	0.20	4	-18.56	0.03	0.72
	May 04	4	-18.31	0.04	4	-18.36	0.10	0.64
salmon feces	Dec 03	4	-19.35	0.37	4	-19.74	1.30	0.59
	May 04	4	-20.16	0.28	4	-19.90	0.30	0.54
mussels	Dec 03	4	-17.41	0.57	4	-17.19	0.65	0.15
	May 04	4	-19.36	0.27	4	-19.51	0.13	0.25
barnacles	Dec 03	3	-17.41	0.57	3	-17.19	0.65	0.68
	May 04	4	-18.18	0.57	4	-18.45	0.17	0.66
sediment	Dec 03	3	-15.15	3.63	2	-19.01	2.04	0.28
	May 04	4	-18.51	0.73	4	-18.48	0.38	0.97
capitellid	May 04	2	-19.96	0.70	2	-19.38	1.15	0.61

Figure 20: Isotopic composition by sample type (December 04). Blue symbolizes Liftup® system means. Green symbolizes diver system means. Feed composition mean is shown in red.

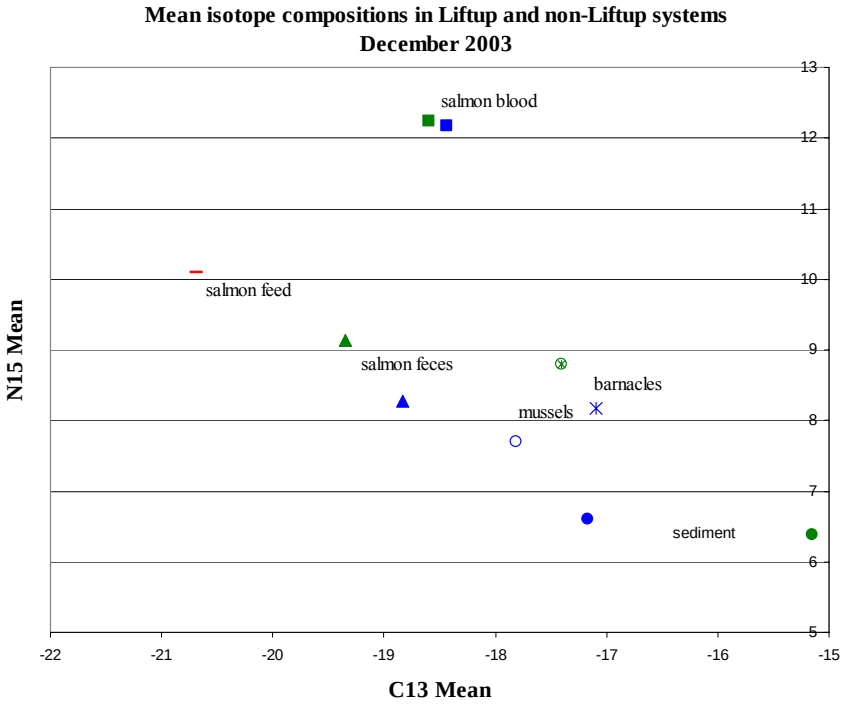
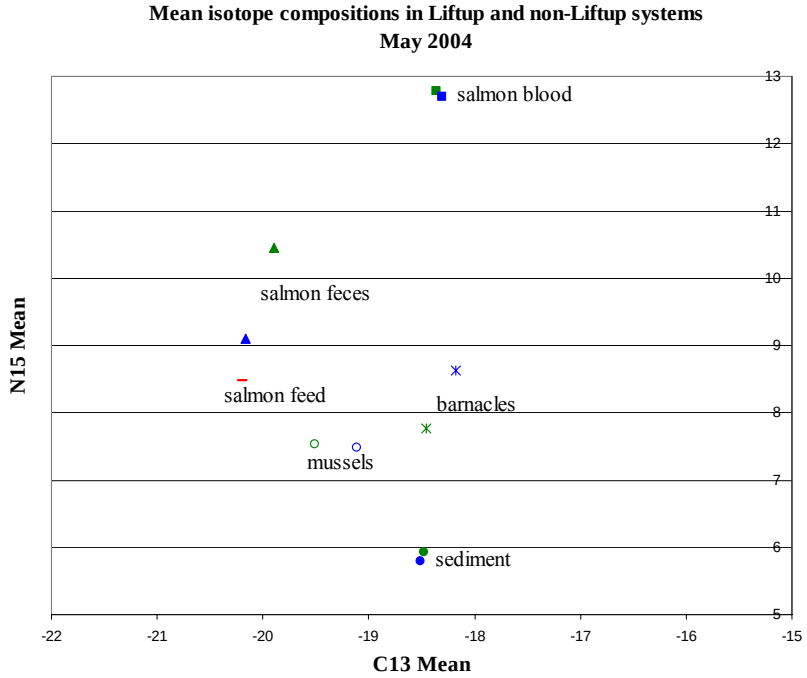


Figure 21: Isotopic composition by sample type (May 04). Blue symbolizes Liftup® system means. Green symbolizes diver system means. Feed composition mean is shown in red.



Discussion

Conducting an experiment within a business enterprise poses a unique set of challenges and expectations that must be reasonably accommodated. Day-to-day duties at any net-pen farm on the Maine coast requires continuous adaptation to ever-changing conditions. Storms, personnel changes, fish health, situations at other sites, and bottom line economic considerations redirect personnel away from the needs of any experiment toward higher priorities. This project was designed, incorporated, and conducted within the normal constraints of a commercial salmon farm where a farm managers' primary obligation is to fish husbandry. From the outset, we understood that record keeping and operation and maintenance of LiftUp® equipment would be secondary to the demands of fish husbandry. In this respect, this project may have been a more realistic test of the technology than an academic study conducted within a strictly controlled environment.

One event had especially serious consequences to this study. The project began in the middle of a federal lawsuit that forced the sale of Atlantic Salmon of Maine, Inc. half way into the project. Although the new owner indicated his desire to complete the project, the real effect of direct and indirect court imposed constraints, including the requirement to fallow half the company's net pens sites, closing a state-of-the-art fish processing plant, and laying off more than 60% (40-50) of its employees, resulted in severe changes in personnel, operations, and management. Most significantly, the reduction in personnel meant that daily work demands of remaining farm employees allowed less time for operation, maintenance and detailed record keeping than we initially planned. While one could easily have justified abandoning this project, the new owner and personnel maintained their commitment to completing the project to the best of their ability.

LiftUp® is designed as a mortality collection device to benefit fish health by reducing the use of divers inside cages and by isolating carcasses and potentially infectious material from the water column during removal from the cages. The personnel reductions prevented operation of LiftUp® at optimal frequencies and that in turn led to clogging of the system and the need for divers to clear the intakes of debris and twists in the "flat lay" pipe. It also became apparent that the slope of the conical LiftUp® net of cages located in the shallower portions of the lease was insufficient to allow feed, feces and other debris to slide and roll to the suction unit. In those cages, the suction unit had a limited zone of influence leaving a ring of material resting on the net bottom that needed to be manually disrupted and directed toward the suction unit by a diver. According to the site operator, to hold an economically feasible number of fish and achieve an effective cone angle, the minimum site depth for a LiftUp® cage is 65-70 ft. at mean low water.

Anecdotally, operations staff thought that divers may have been deployed almost equally between LiftUp® and non-LiftUp® cages, either to unclog the suction unit, to move material toward the suction mouth, and during winter to collect mortalities, thereby reducing the intended benefit of LiftUp® and subjecting the fish in both LiftUp® and non-LiftUp® cages to similar levels of stress.

Over the course of the project, LiftUp® appeared to offer some marginal environmental benefit although that benefit was only statistically significant early in the project. In general, where chemistry results exceeded the MePDES warning thresholds, LiftUp® indicated lower organic enrichment although high variability obscured statistical differences. Biologically, LiftUp® tended toward greater biologically diversity, species richness, and lower overall abundance. We believe that differences may have been stronger were it not for several factors, some controllable and others not.

The shift in sediment grain size toward coarser material at all sample stations was unexpected and uncontrollable, yet we believe important in affecting results. Sample results on any single sample event indicate that bottom sediments are relatively homogenous making it unlikely that this coarsening trend was an artifact of sampling different populations of sediment. Furthermore, we do not believe that a venturi effect under cages was responsible since sediments at the reference station also coarsened. Rather, we suspect natural oceanographic processes are at play. This part of the Maine coast is exposed to severe storms and periodic strong currents. Most coarsening occurred between July 2003 and November 2003 and again between May 2004 and November 2004. The "scouring" that presumably coarsened the grain size may have also been responsible for muting environmental differences between LiftUp® and non-LiftUp®. It is also possible that currents increased the radius of the depositional area under each cage so that the influences from two cage treatments were overlapping. This is suggested by results from the 30 meter stations where most enrichment parameters responded.

Regardless of mechanism, the change in grain size and the influences of such changes on the benthic community structure over time have important regulatory implications. Compliance with the MePDES permit is based on a comparison of monitoring results to "baseline" and/or reference conditions as one means of determining whether or not conditions are a result of natural or human activity. The sediment coarsening demonstrates that "baseline" conditions are ephemeral. Using baseline conditions alone to draw conclusions regarding cause and effect in marine systems for this industry in particular is misleading. This emphasizes the need to better understand spatial and temporal variability of all variables before incorporating them into regulatory schemes.

The plume of dissolved and particulate material resulting from LiftUp® surface discharge did not raise environmental concerns due to its brevity (<100 seconds), very small area (5m x 10m oval), small volume (2.1m^3) and intermittent frequency (1-3 times per week). However, the plume did raise concerns about fish health. While we did not see differences in fish health parameters between LiftUp® and non-LiftUp® cages, at sites where disease pathogens or parasites are known, it would certainly be prudent to develop a method that minimized, or avoided altogether, release of material to the water column adjacent to or upcurrent of other cages. Rather than conducting additional work to investigate whether exposure to the plume affects fish behavior, reduces feeding or causes some off-flavor, given the small volume, it may be more practical to simply contain the "first flush," for removal off-site.

Few significant differences in fish health parameters were noted between LiftUp® and non- LiftUp® diver-based systems. The only parameter that varied significantly ($p<0.05$) was fecal $\delta^{15}N$ composition, which ran higher in the cages lacking Lift-up® systems. The paucity of statistically significant differences in fish health meristics suggests that the current best management practice of mortality removal by diver is just as good, from a fish health standpoint, as that achieved by the LiftUp® system. However, we believe difference may have been obscured because divers were ultimately needed to enter LiftUp® cages more frequently than planned. Substantial variation in historical circumstances between different cohorts of fish (involving two different hatcheries and two different smoltification strategies) required statistical accounting of cage variation, limiting the power of our study design to detection of differences that were only large in effect. Once operational problems specific to the nature of our application of LiftUp® are resolved, a future study involving more cages and/or more sites may detect more subtle differences between treatments.

Animal stable isotope compositions typically approximate the signatures of their diet: $\delta^{15}N$ is usually about 3-5 ppt heavier than diet; $\delta^{13}C$ is usually 0-1 ppt heavier than diet (DeNiro and Epstein 1978, DeNiro and Epstein 1981, Peterson and Fry 1987). Though not statistically significant, the $\delta^{15}N$ of the salmon from diver-based cages was consistently higher than that of salmon from LiftUp® cages. Coprophagy and/or consumption of suspended carcasses fragments by the fish, or indirectly by zooplankton or other organism entering a food web leading to the salmon, could alter the values of salmon $\delta^{15}N$ (Sara et al. 2004; Pilati et al., 2004). However, the statistically significant difference between fecal compositions of salmon from LiftUp® vs. diver-based systems, as well as a consistently disproportionate enrichment of $\delta^{13}C$ of salmon tissue relative to that of the fed feed pellets, raises the possibility that the salmon were differentially supplementing their diets with native faunal organisms. The mesh size of the LiftUp® conical bottom panels was finer than that of traditional netting, which could possibly limit the entry of britt herring or krill or other free-ranging fauna organisms that the salmon might be consuming. Future studies may benefit from further evaluation of impacts of LiftUp® systems on feed supplementation and nutritional requirements.

Conclusions and Recommendations

Overall and despite few statistically significant differences, this project suggests that LiftUp® type technology may offer environmental benefit under special circumstances. It is unclear, however, whether those same benefits might not be cost-effectively achieved through employment of traditional best management husbandry. Use of LiftUp® is not possible where currents cause the net to deflect and distort. Furthermore, even within slow current regimes, such as encountered at this study site, environmental conditions under the non-LiftUp® pens may remain well within legal standards. This site, is an example of an operation that did remain within its MePDES permit (below impact) and thus, from a strictly legal basis, Liftup® was unnecessary.

Where LiftUp® may be advantageous, however, would be at a low energy site that was trending toward a regulatory threshold during the production cycle. In such a case, deployment of LiftUp® nets might avoid the need for early harvest or a permit violation. Indeed, some of the early data (November 2003) suggest that interception of material leaving the net pen by the finer LiftUp® net prevented early enrichment and degradation of the bottom beneath the nets even when the LiftUp® airlifts were not yet installed.

This project afforded the State of Maine an opportunity to look at patterns of organic enrichment in more detail than had been previously available. Furthermore, it enabled us to evaluate the appropriateness of variables and regulatory endpoints of the MPDES permit, many of which had not been field tested when the permit was written.

Considering the multiple challenges faced during the project, the fact that statistically significant differences were seen between the LiftUp® and non-LiftUp® cages early in the project, followed by consistently lower states of organic enrichment under the LiftUp® cages compared to the non-LiftUp® cages thereafter, is encouraging and suggests that further reduction in benthic impacts might be achieved with some operational and equipment changes to LiftUp® as well as modifications to the study design. Some suggestions follow:

LiftUp®

- To minimize clogging by more frequently operating the airlift, dedicate a team to the task of operating the LiftUp® systems. This would require a dedicated vessel and rotation crew, all of which could prove expensive, perhaps prohibitively so; however, this would not address the problem of system freeze-up in winter.

- Flat lay pipe may not be a proper substitution of hard pipe that is recommended by the manufacturer.

- A second option to prevent clogging might be to retain the fine-mesh bottom nets to collect waste, but to substitute a moderate-duty grinding pump, also known as a "trash pump", for the air compressor of the pneumatically-driven LiftUp® system. Such a pump would have the capacity to breakup and grind potentially clogging or blocking material and would not be susceptible to freeze-up. However, deploying and recovering the pump and discharge hose into the center of each pen would present certain technical challenges; additionally, the entire device, pump and hose, would need to be thoroughly cleaned between deployments to ensure against disease transmission from cage to cage if infection is present on the site. Although such a system might prove effective in surmounting some of the clogging and freeze-up problems encountered with LiftUp®, the destruction of mortalities would make inventory tracking virtually impossible; some manner of separating mortalities from waste would therefore be required and such an approach might continue to required diver mortality collection.

- To address fish health concerns resulting from the discharge, the collection and containment of the most concentrated portion of the discharge for offsite disposal or processing might be easily and affordably accomplished.

Study Design

- To avoid treatment effects overlapping, treatments should be separated farther apart. This study design was constrained by the configuration of the existing salmon farm. In hindsight, it may have been better to have located same treatments together as a block rather than distributing them over the site. However, then arises the problem of unequal depth and currents from one end of the site to the other.

- Continuous recording bottom current meters might have enabled us to better understand sediment coarsening and whether or how currents may have affected differences, or lack thereof, under each treatment.

- Statistical problems were not anticipated but nevertheless should be pointed out to others who may follow. The initial baseline sampling was delayed from May until July to be able to be covered under the grant. Sampling the following spring probably should have also been changed to keep the index periods consistent. At the reference site, for budget purposes, we had one fewer sample station thus resulting in an uneven number of replicates per treatment. We might have avoided this by augmenting the reference samples at the expense of samples taken at the 30 meter stations which were required by the MePDES permit. Lastly, replicate samples at each station showed relatively high variance. As the budget allows, increasing the number of replicates should be considered.

Acknowledgements

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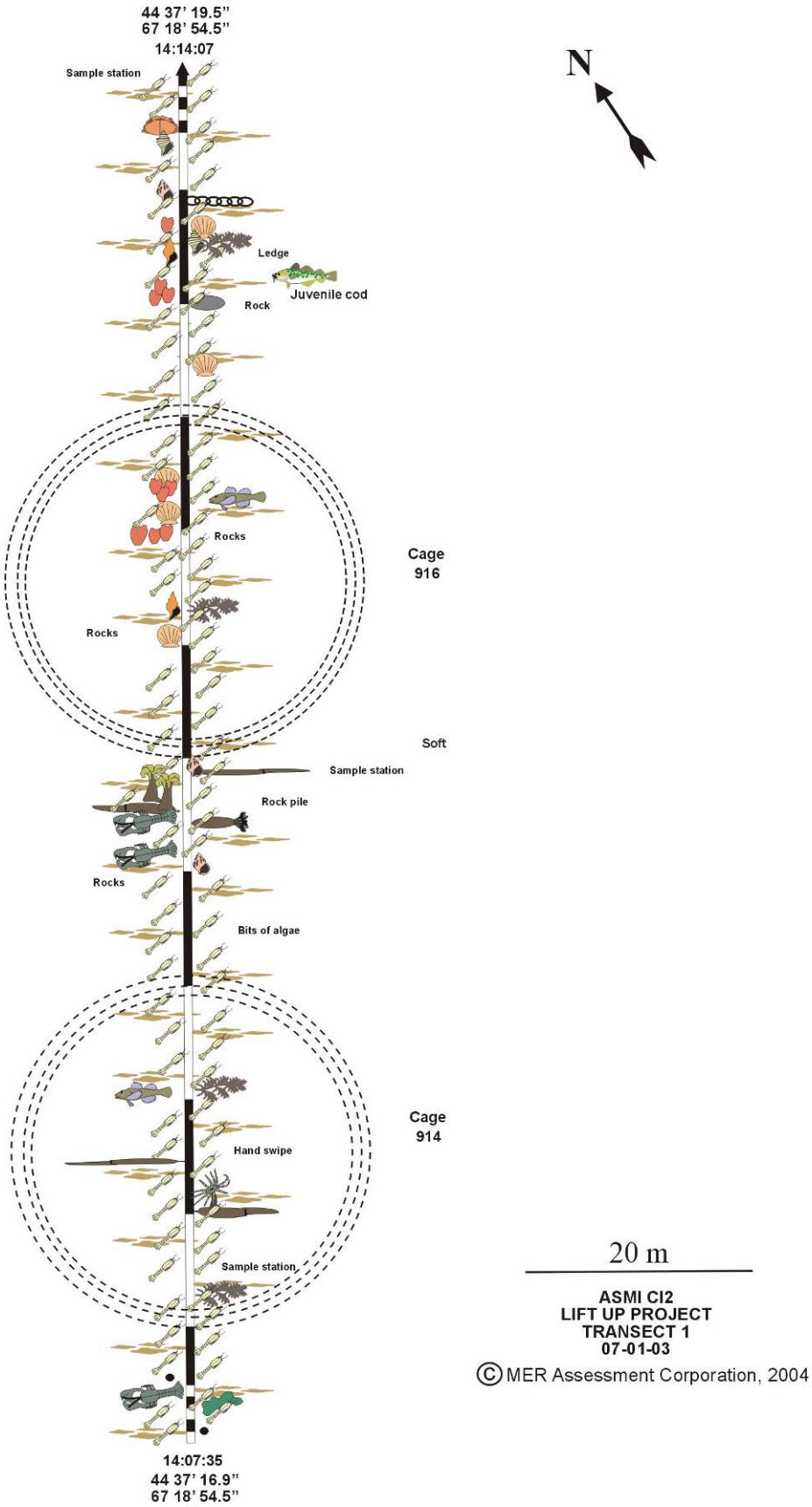
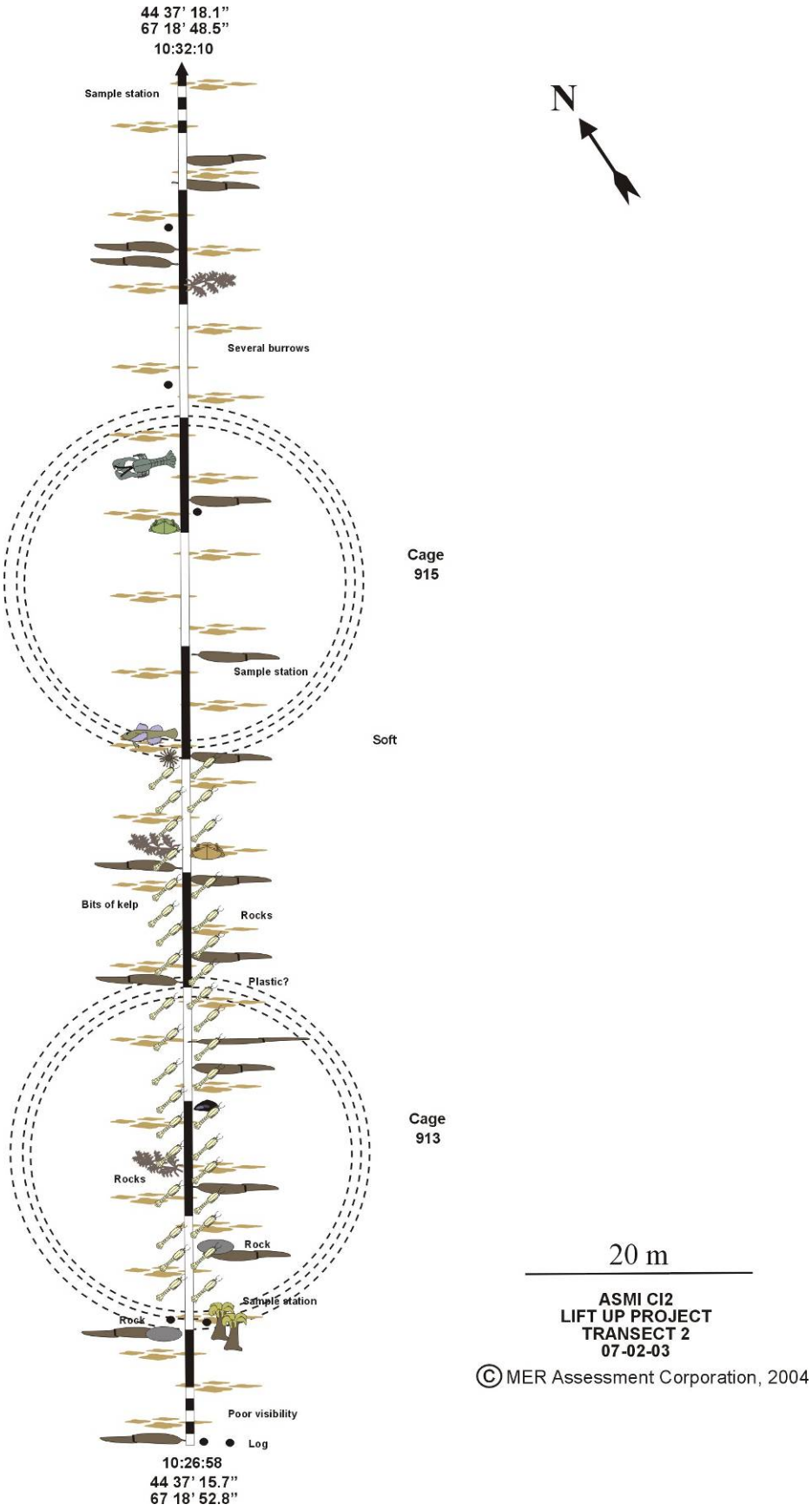
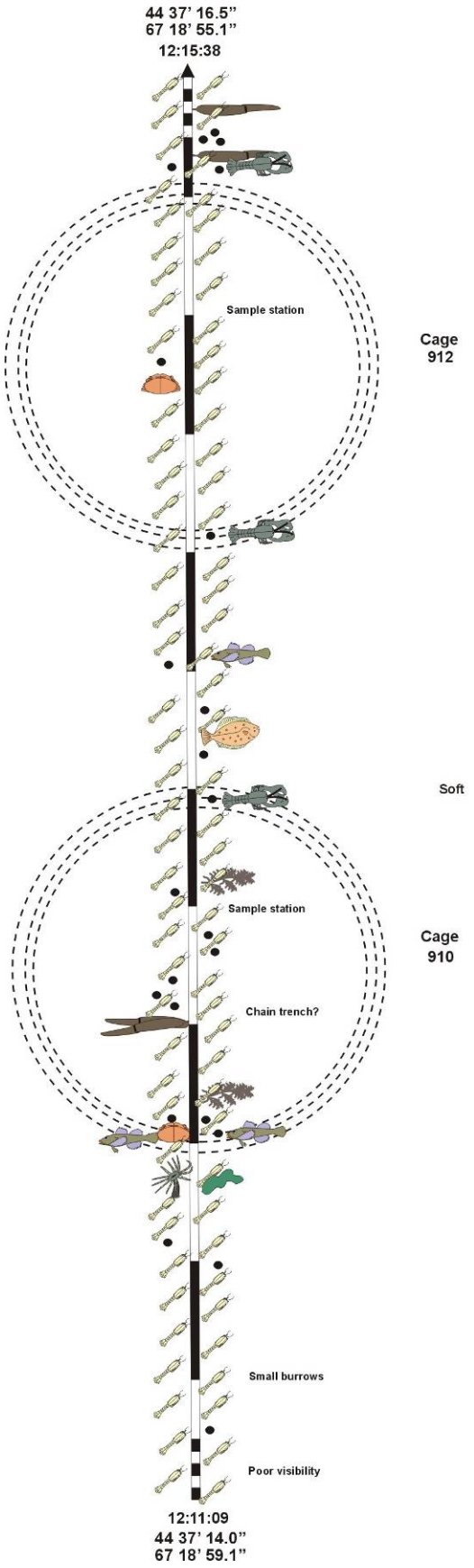
APPENDIX I

Video Recording Graphics Representations by Transect by Sampling Date

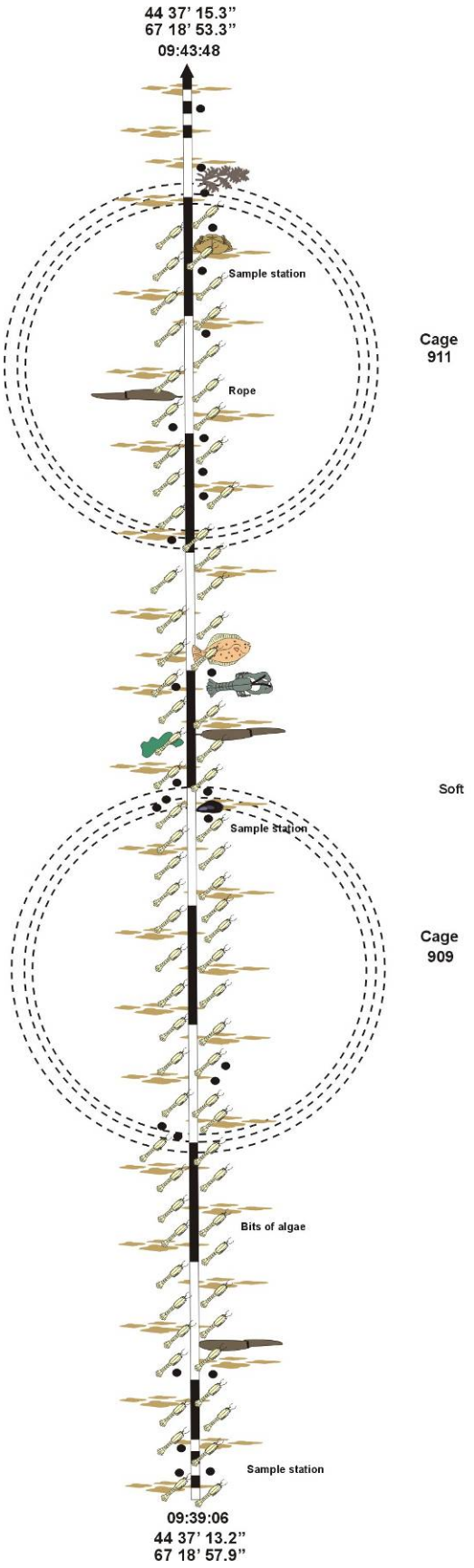

44 37' 19.5"
67 18' 54.5"
14:14:07
Sample station
N
Ledge
Juvenile cod
Rock
Rocks
Cage
916
Rocks
Soft
Sample station
Rock pile
Rocks
Bits of algae
Cage
914
Hand swipe
Sample station
20 m
ASMI CI2
LIFT UP PROJECT
TRANSECT 1
07-01-03
© MER Assessment Corporation, 2004
14:07:35
44 37' 16.9"
67 18' 54.5"

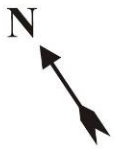

44 37' 18.1"
67 18' 48.5"
10:32:10
Sample station
N
Several burrows
Cage
915
Sample station
Soft
Bits of kelp
Rocks
Plastic?
Cage
913
Rocks
Rock
Sample station
Rock
Poor visibility
Log
10:26:58
44 37' 15.7"
67 18' 52.8"
20 m
ASMI CI2
LIFT UP PROJECT
TRANSECT 2
07-02-03
© MER Assessment Corporation, 2004



20 m

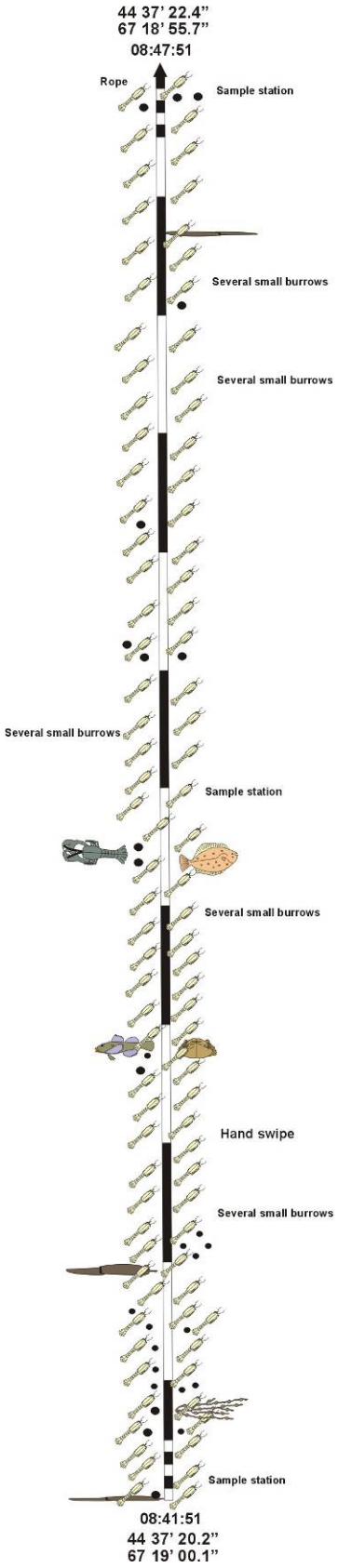
ASMI CI2
LIFT UP PROJECT
TRANSECT 3
07-01-03





20 m

ASMI CI2
LIFT UP PROJECT
TRANSECT 4
07-02-03

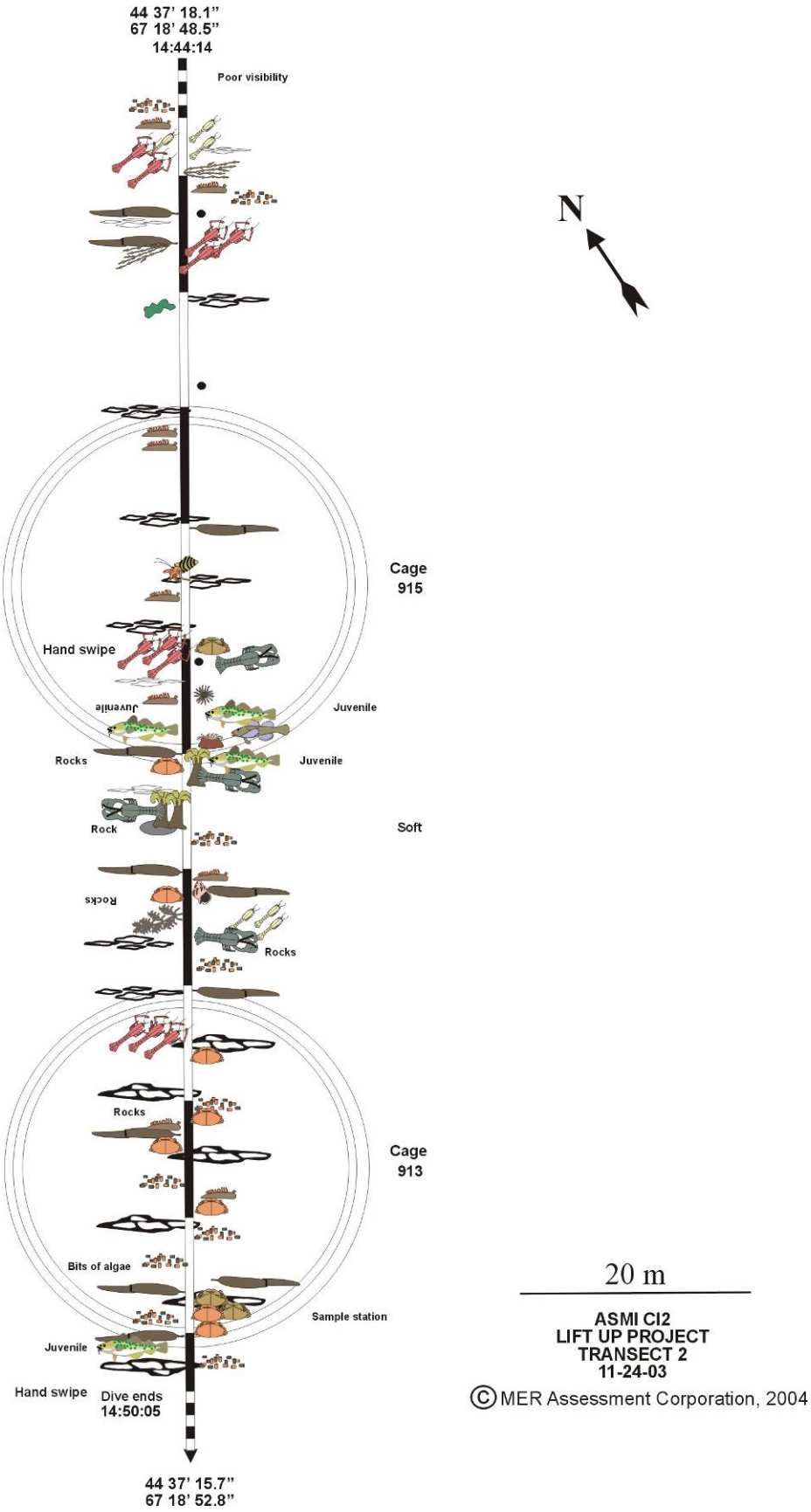


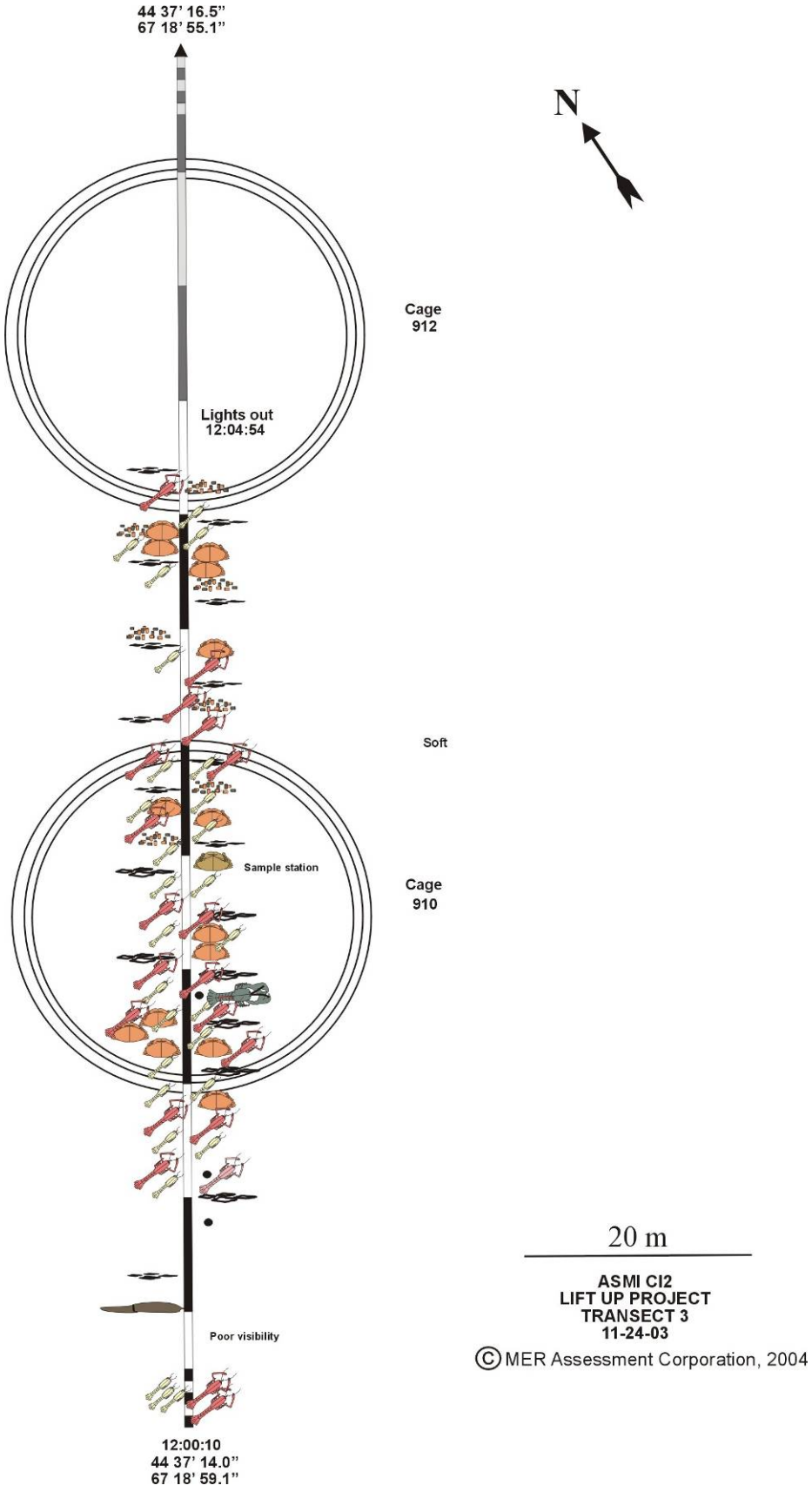
Soft

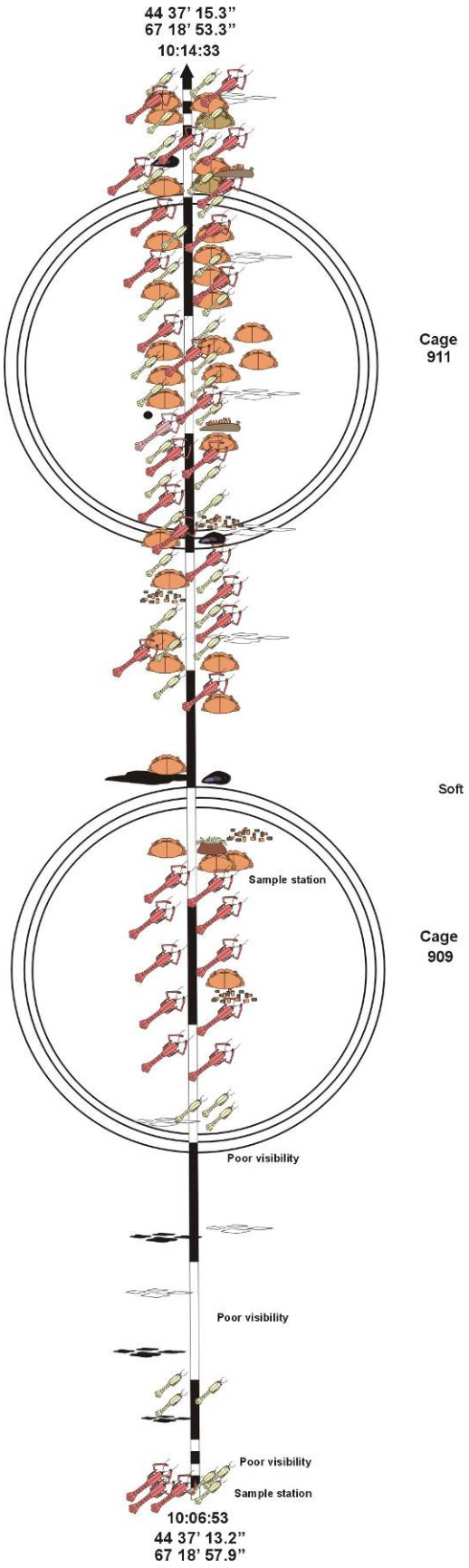
20 m

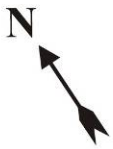
ASMI CI2
LIFT UP PROJECT
TRANSECT (Reference) 5
07-01-03

No recording of Transect 1 on 11/24/03


44 37' 18.1"
67 18' 48.5"
14:44:14
Poor visibility
N
Cage
915
Hand swipe
Juvenile
Juvenile
Rocks
Juvenile
Rock
Soft
Rocks
Rocks
Rocks
Cage
913
Bits of algae
Sample station
Juvenile
Hand swipe
Dive ends
14:50:05
44 37' 15.7"
67 18' 52.8"
20 m
ASMI CI2
LIFT UP PROJECT
TRANSECT 2
11-24-03
© MER Assessment Corporation, 2004

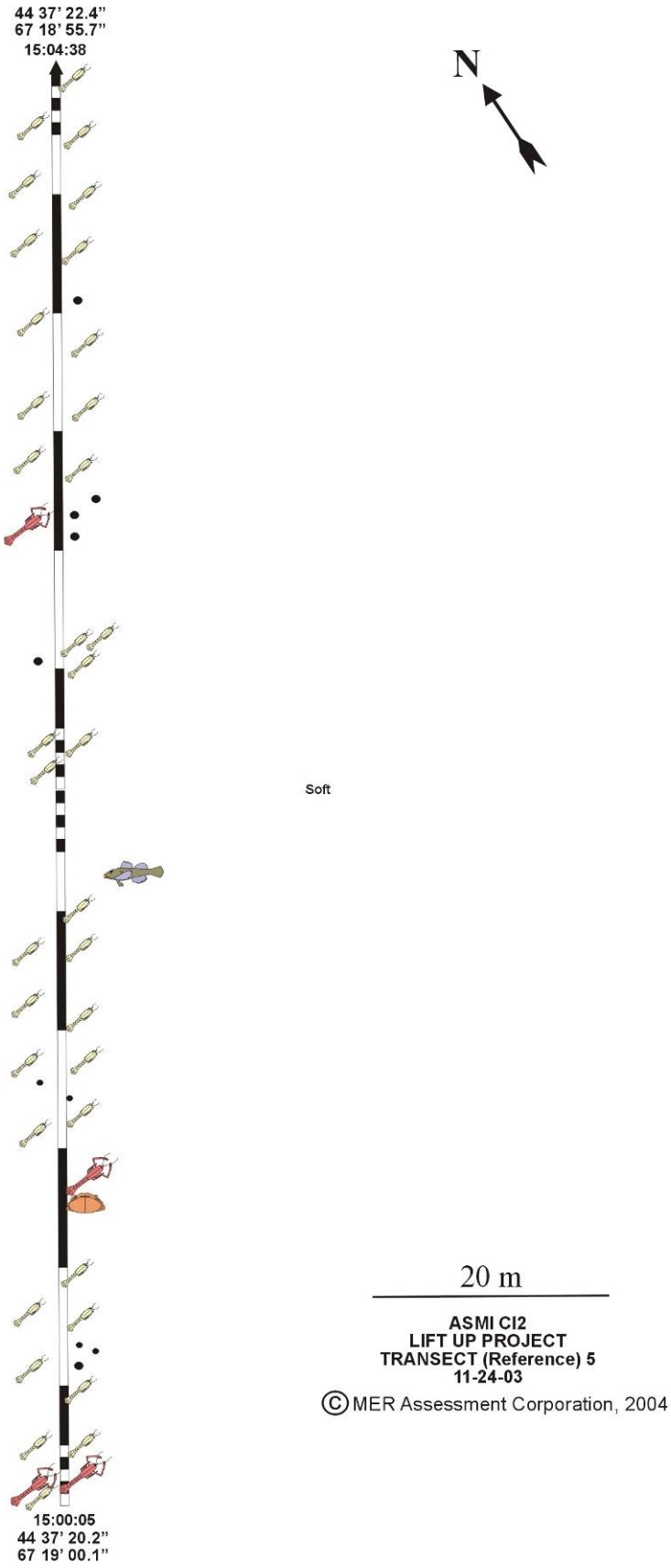

44 37' 16.5"
67 18' 55.1"
N
Cage
912
Lights out
12:04:54
Soft
Sample station
Cage
910
Poor visibility
12:00:10
44 37' 14.0"
67 18' 59.1"
20 m
ASMI CI2
LIFT UP PROJECT
TRANSECT 3
11-24-03
© MER Assessment Corporation, 2004

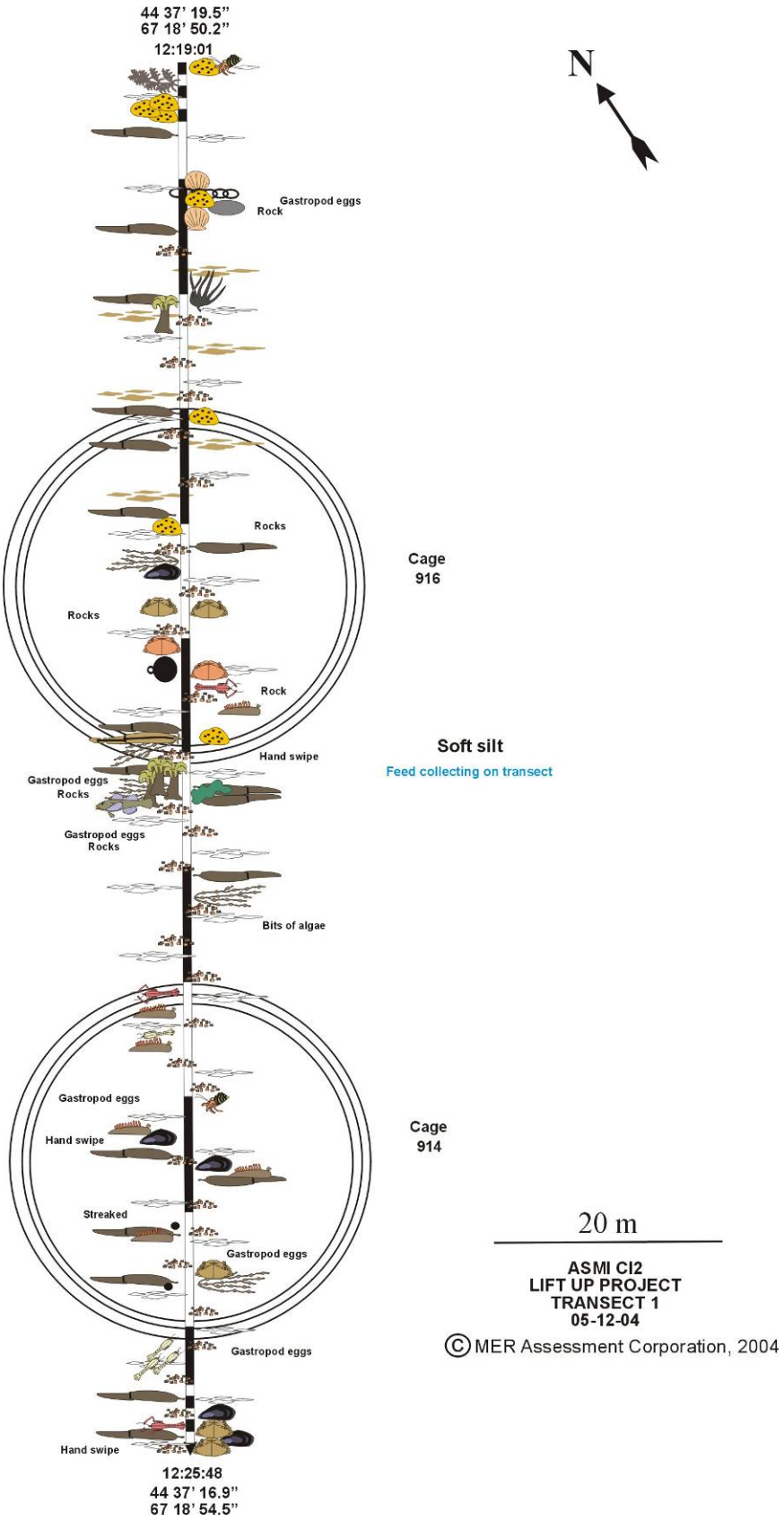


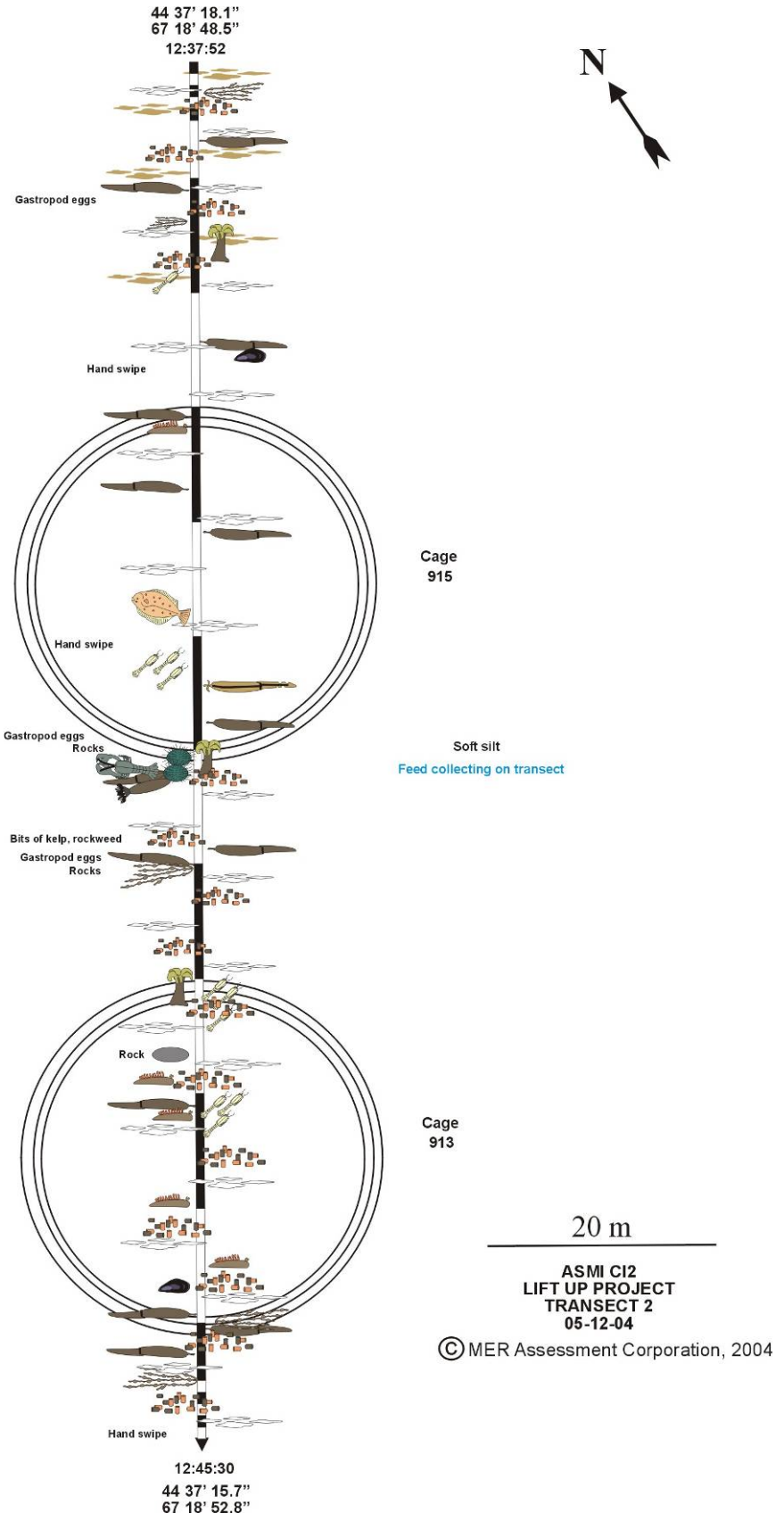


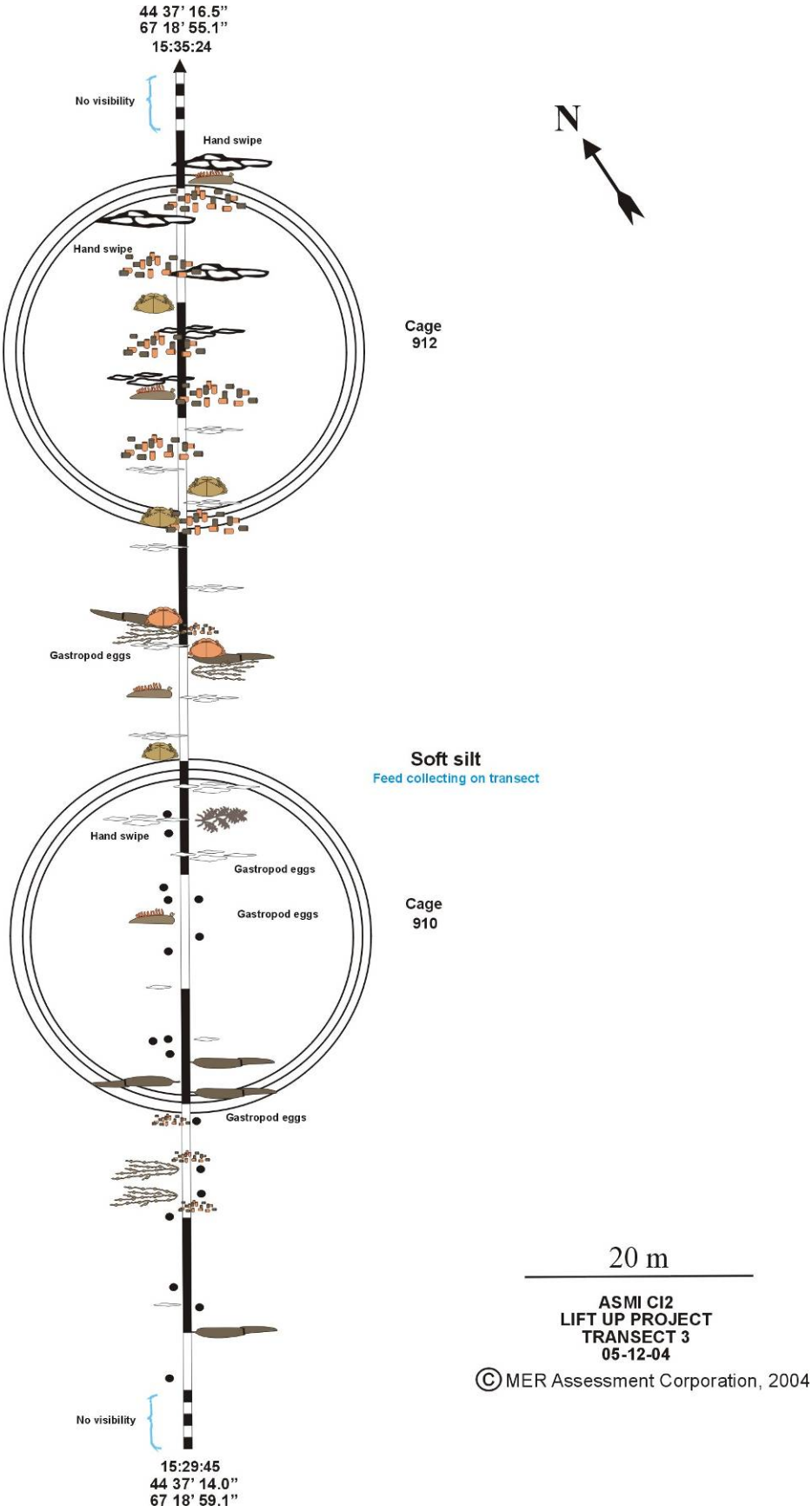
20 m

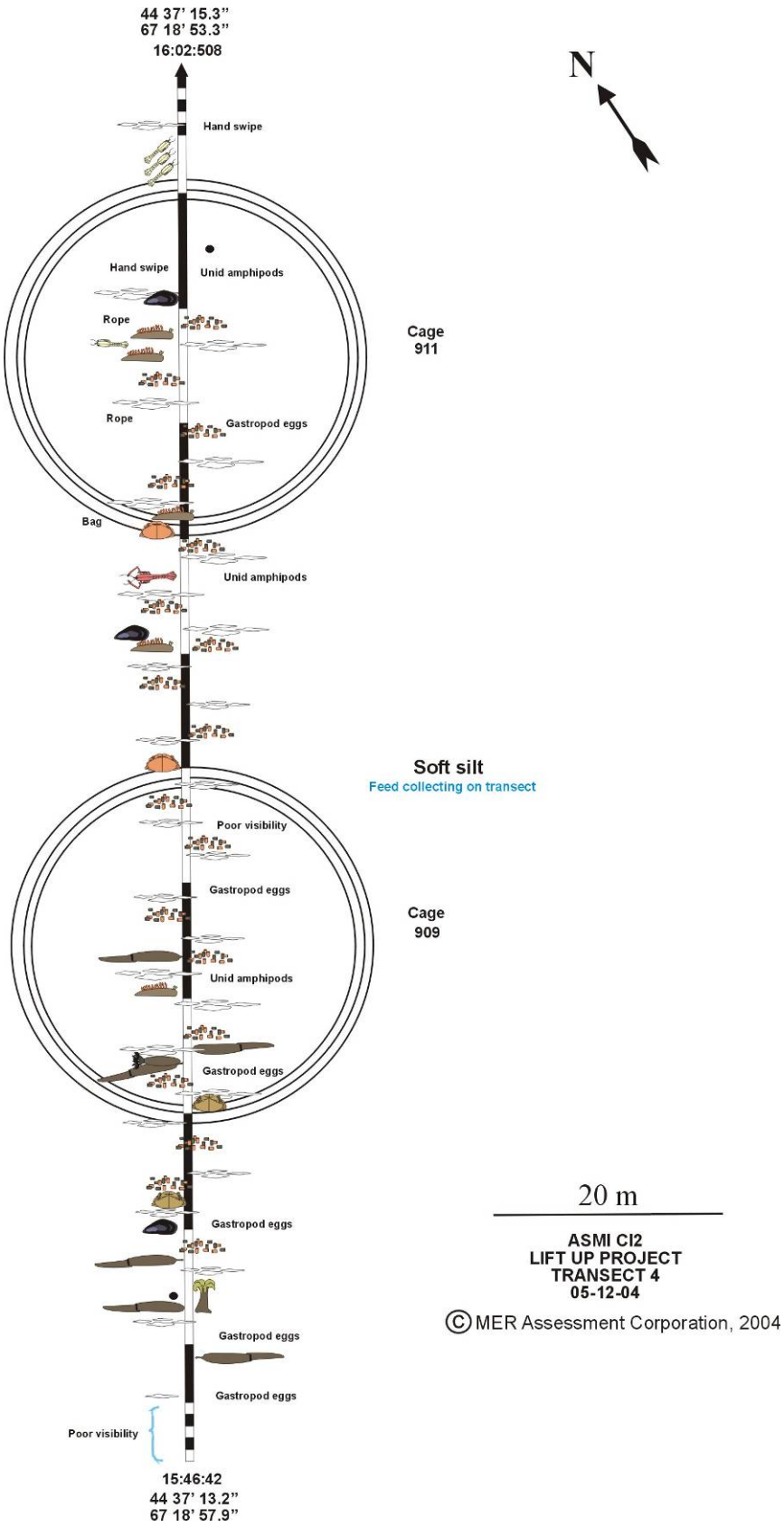
ASMI CI2
LIFT UP PROJECT
TRANSECT 4
11-24-03

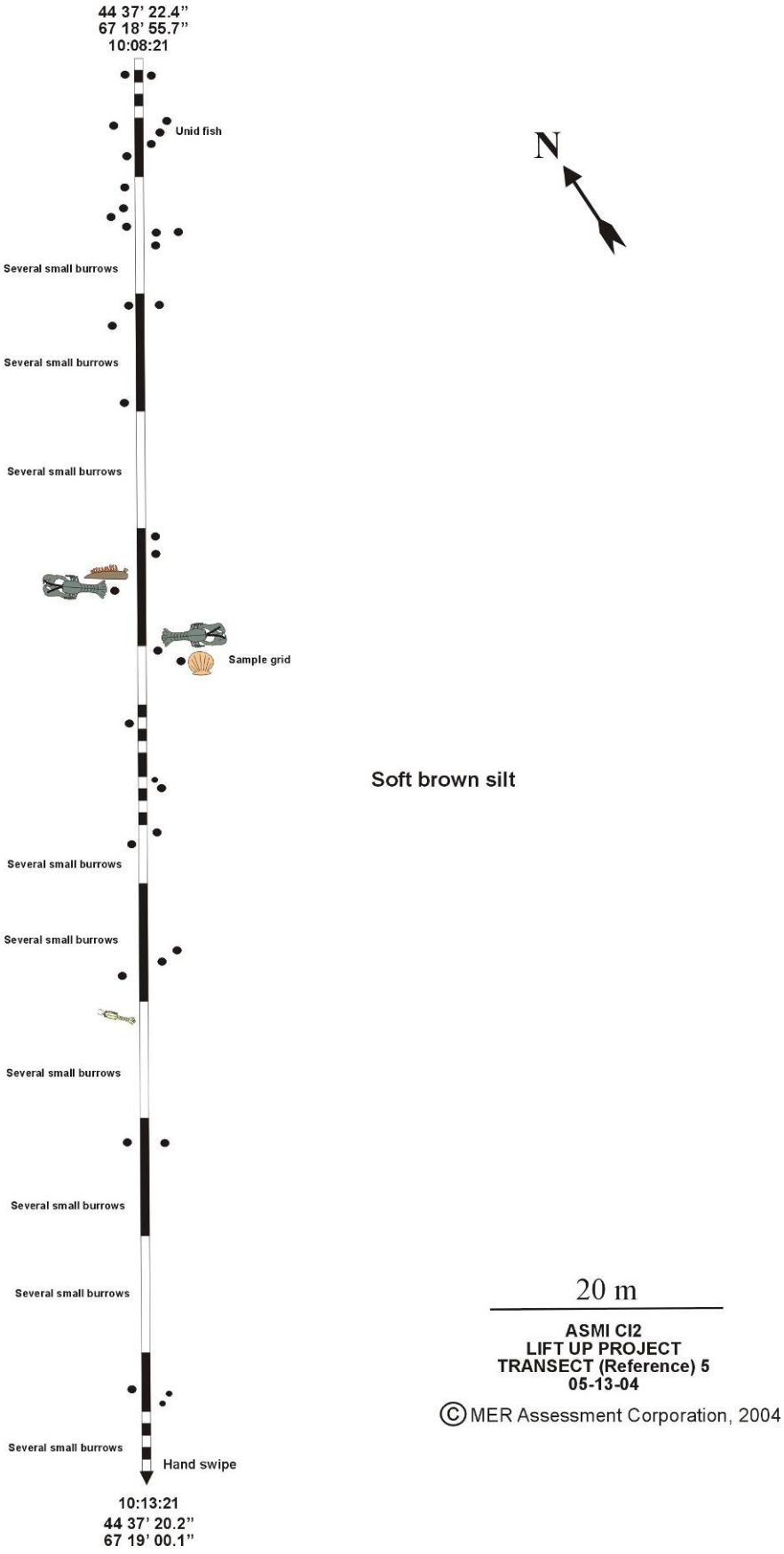

44 37' 22.4"
67 18' 55.7"
15:04:38
N
Soft
20 m
ASMI CI2
LIFT UP PROJECT
TRANSECT (Reference) 5
11-24-03
© MER Assessment Corporation, 2004
15:00:05
44 37' 20.2"
67 19' 00.1"

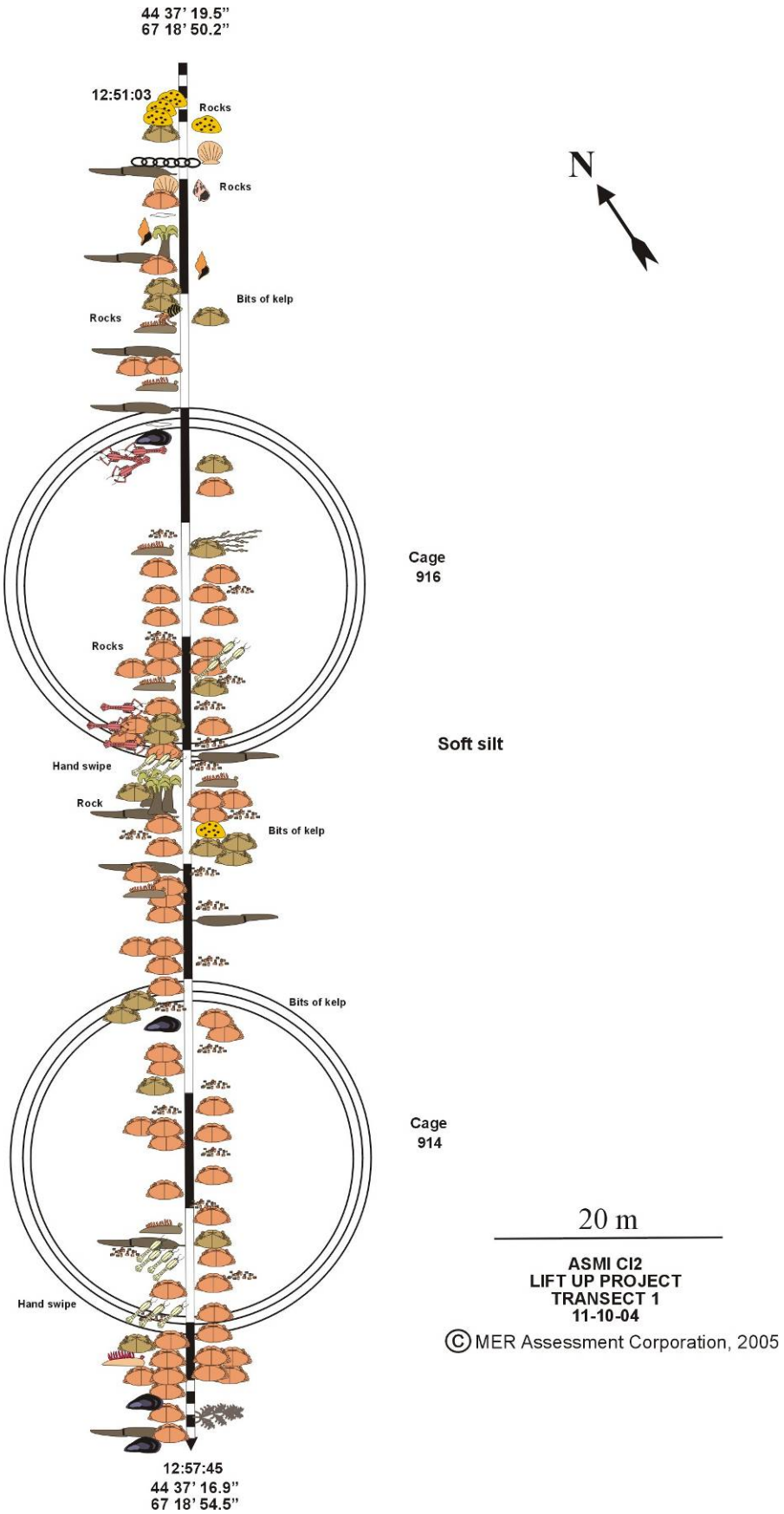

44 37' 19.5"
67 18' 50.2"
12:19:01
N
Gastropod eggs
Rock
Rocks
Cage
916
Rocks
Rock
Hand swipe
Soft silt
Feed collecting on transect
Gastropod eggs
Rocks
Gastropod eggs
Rocks
Bits of algae
Gastropod eggs
Hand swipe
Cage
914
Streaked
Gastropod eggs
Gastropod eggs
Hand swipe
12:25:48
44 37' 16.9"
67 18' 54.5"
20 m
ASMI CI2
LIFT UP PROJECT
TRANSECT 1
05-12-04
© MER Assessment Corporation, 2004

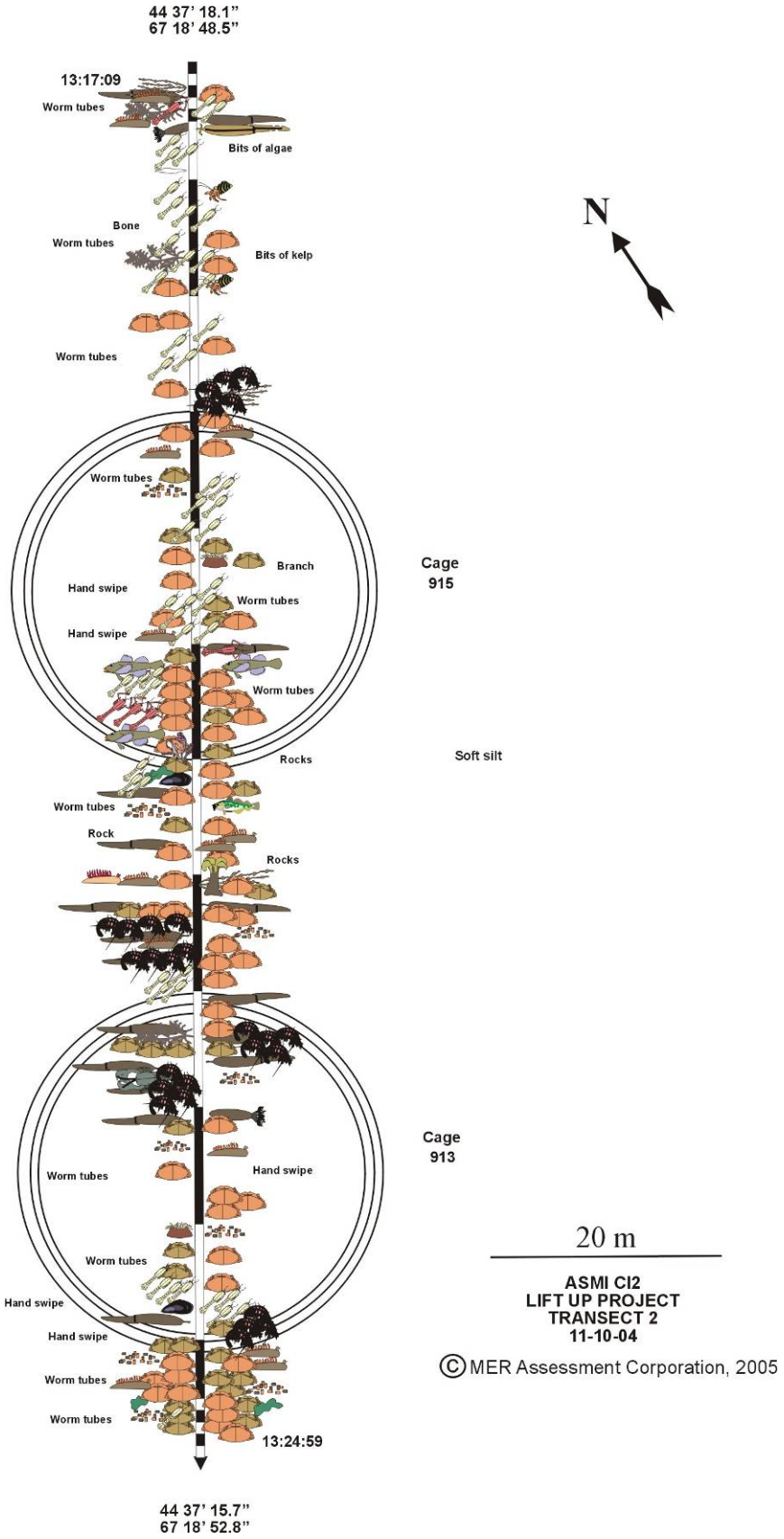

44 37' 18.1"
67 18' 48.5"
12:37:52
N
Gastropod eggs
Hand swipe
Cage
915
Hand swipe
Gastropod eggs
Rocks
Soft silt
Feed collecting on transect
Bits of kelp, rockweed
Gastropod eggs
Rocks
Rock
Cage
913
20 m
ASMI CI2
LIFT UP PROJECT
TRANSECT 2
05-12-04
© MER Assessment Corporation, 2004
Hand swipe
12:45:30
44 37' 15.7"
67 18' 52.8"

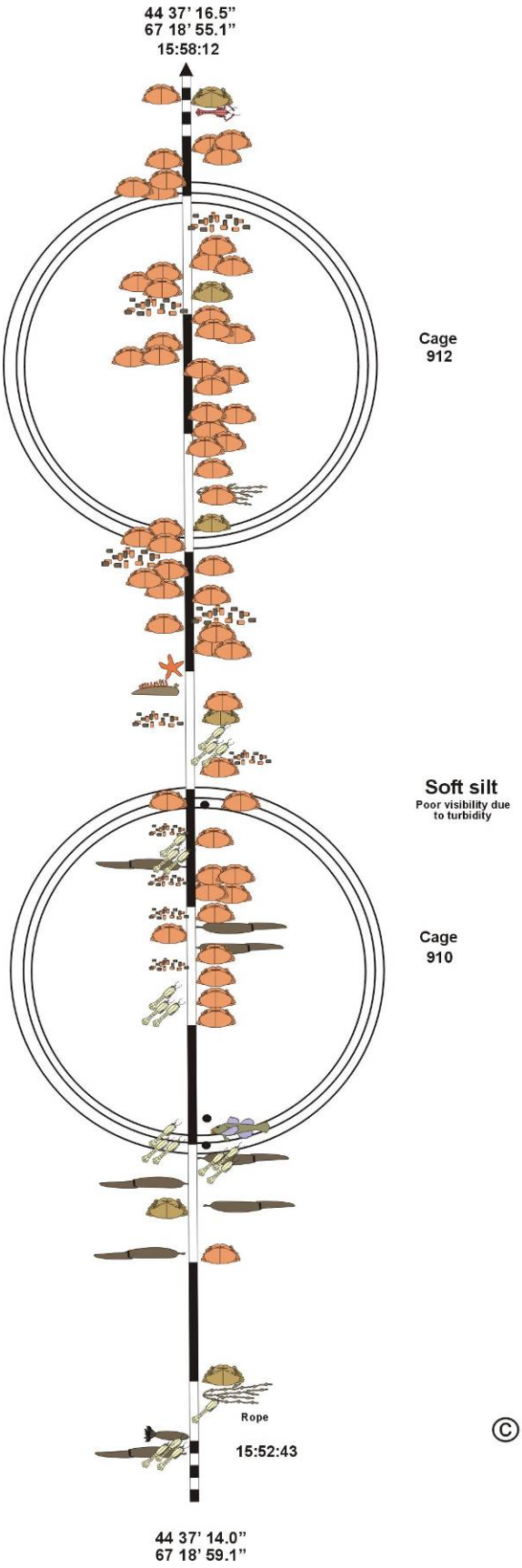

44 37' 16.5"
67 18' 55.1"
15:35:24
No visibility
Hand swipe
Hand swipe
Cage
912
Gastropod eggs
Soft silt
Feed collecting on transect
Hand swipe
Gastropod eggs
Gastropod eggs
Cage
910
Gastropod eggs
No visibility
15:29:45
44 37' 14.0"
67 18' 59.1"
N
20 m
ASMI CI2
LIFT UP PROJECT
TRANSECT 3
05-12-04
© MER Assessment Corporation, 2004


44 37' 15.3"
67 18' 53.3"
16:02:508
N
Hand swipe
Hand swipe
Unid amphipods
Rope
Rope
Gastropod eggs
Cage
911
Bag
Unid amphipods
Soft silt
Feed collecting on transect
Poor visibility
Gastropod eggs
Cage
909
Unid amphipods
Gastropod eggs
Gastropod eggs
Gastropod eggs
Gastropod eggs
Poor visibility
15:46:42
44 37' 13.2"
67 18' 57.9"
20 m
ASMI CI2
LIFT UP PROJECT
TRANSECT 4
05-12-04
© MER Assessment Corporation, 2004


44 37' 22.4"
67 18' 55.7"
10:08:21
Unid fish
Several small burrows
Several small burrows
Several small burrows
Sample grid
Several small burrows
Several small burrows
Several small burrows
Several small burrows
Several small burrows
Several small burrows
Hand swipe
10:13:21
44 37' 20.2"
67 19' 00.1"
N
Soft brown silt
20 m
ASMI CI2
LIFT UP PROJECT
TRANSECT (Reference) 5
05-13-04
© MER Assessment Corporation, 2004

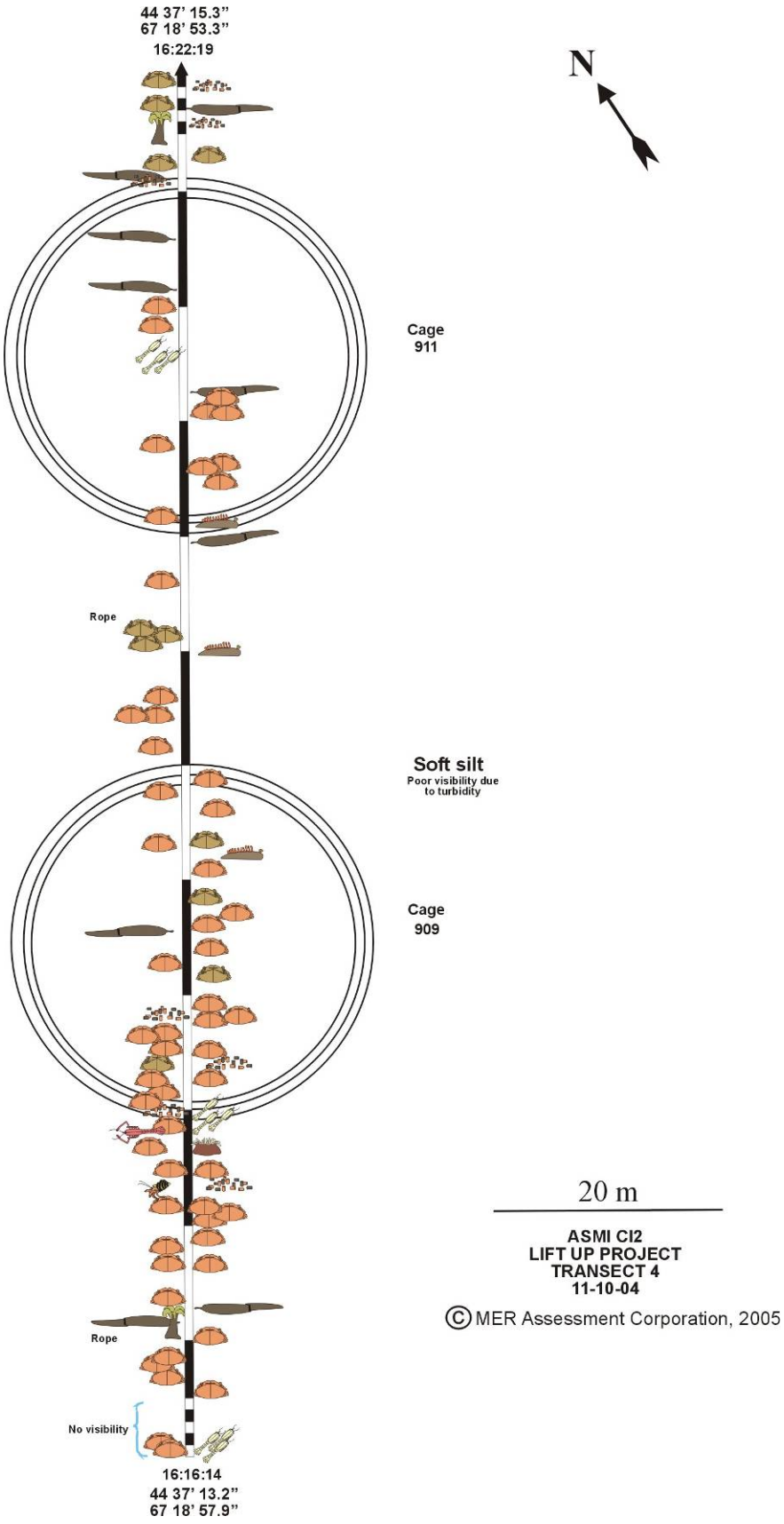

44 37' 19.5"
67 18' 50.2"
12:51:03
Rocks
Rocks
Bits of kelp
Rocks
Cage
916
Rocks
Soft silt
Hand swipe
Rock
Bits of kelp
Bits of kelp
Cage
914
Hand swipe
12:57:45
44 37' 16.9"
67 18' 54.5"
N
20 m
ASMI CI2
LIFT UP PROJECT
TRANSECT 1
11-10-04
© MER Assessment Corporation, 2005

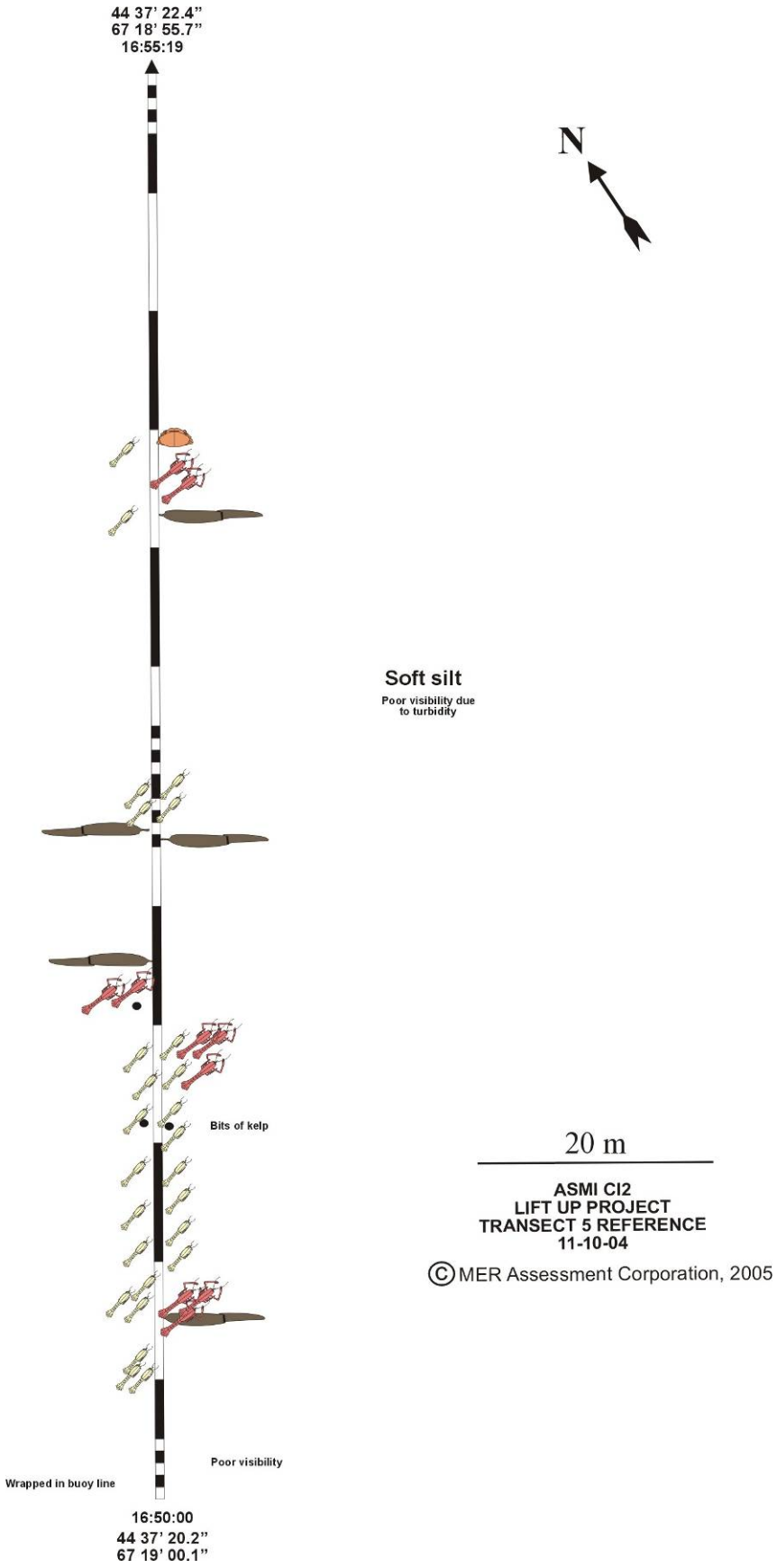

44 37' 18.1"
67 18' 48.5"
13:17:09
Worm tubes
Bits of algae
Bone
Worm tubes
Bits of kelp
Worm tubes
Worm tubes
Branch
Hand swipe
Worm tubes
Hand swipe
Worm tubes
Rocks
Worm tubes
Rock
Rocks
Worm tubes
Hand swipe
Worm tubes
Hand swipe
Hand swipe
Worm tubes
Worm tubes
13:24:59
44 37' 15.7"
67 18' 52.8"
N
Cage
915
Soft silt
Cage
913
20 m
ASMI CI2
LIFT UP PROJECT
TRANSECT 2
11-10-04
© MER Assessment Corporation, 2005



20 m

ASMI CI2
LIFT UP PROJECT
TRANSECT 3
11-10-04


44 37' 15.3"
67 18' 53.3"
16:22:19
N
Cage
911
Rope
Soft silt
Poor visibility due
to turbidity
Cage
909
20 m
Rope
No visibility
16:16:14
44 37' 13.2"
67 18' 57.9"
ASMI CI2
LIFT UP PROJECT
TRANSECT 4
11-10-04
© MER Assessment Corporation, 2005


44 37' 22.4"
67 18' 55.7"
16:55:19
N
Soft silt
Poor visibility due to turbidity
Bits of kelp
Poor visibility
Wrapped in buoy line
16:50:00
44 37' 20.2"
67 19' 00.1"
20 m
ASMI CI2
LIFT UP PROJECT
TRANSECT 5 REFERENCE
11-10-04
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APPENDIX II

Benthic epifauna and epiflora data summaries

	T1			T2			T3			T4			T5		
July 03	**30m**	**NLU 916**	**LU 914**	**30m**	**LU 915**	**NLU 913**	**30m**	**LU 910**	**NLU 912**	**30m**	**NLU 909**	**LU 911**	**Ref**	**Ref**	**Ref**
Epiflora	2	4	5	3	3	4	2	3	2	2	3	3	3	0	0
Epifauna	8	9	4	0	6	3	2	5	4	1	3	3	1	5	2
Beg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	T1			T2			T3			T4			T5		
Nov 03	**30m**	**NLU 916**	**LU 914**	**30m**	**LU 915**	**NLU 913**	**30m**	**LU 910**	**NLU 912**	**30m**	**NLU 909**	**LU 911**	**Ref**	**Ref**	**Ref**
Epiflora	N/A	N/A	N/A	2	1	2	1	0	0	0	0	0	0	0	0
Epifauna	N/A	N/A	N/A	3	11	8	4	4	3	2	5	6	3	2	2
Beg	N/A	N/A	N/A	1	2	3	1	2	0	1	1	2	0	0	0
Feed	N/A	N/A	N/A	1	1	2	0	1	2	0	1	1	0	0	0

	T1			T2			T3			T4			T5		
May 04	**30m**	**NLU 916**	**LU 914**	**30m**	**LU 915**	**NLU 913**	**30m**	**LU 910**	**NLU 912**	**30m**	**NLU 909**	**LU 911**	**Ref**	**Ref**	**Ref**
Epiflora	4	5	2	3	2	2	2	3	0	1	1	0	0	0	0
Epifauna	5	9	7	4	8	4	1	3	2	4	6	7	1	3	1
Beg	2	2	2	2	2	2	1	2	3	2	2	2	0	0	0
Feed	1	2	2	2	1	2	1	0	3	1	2	2	0	0	0

	T1			T2			T3			T4			T5		
Nov 04	**30m**	**NLU 916**	**LU 914**	**30m**	**LU 915**	**NLU 913**	**30m**	**LU 910**	**NLU 912**	**30m**	**NLU 909**	**LU 911**	**Ref**	**Ref**	**Ref**
Epiflora	1	2	2	4	3	4	2	1	1	0	0	0	1	1	1
Epifauna	8	8	6	7	9	11	4	5	3	6	3	4	2	2	3
Beg	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Feed	0	2	2	0	1	2	0	2	1	1	1	1	0	0	0

APPENDIX III

Sediment chemistry data summaries

Sampling Date:		Cage	Date Fish	Eh		µM S_2		TOC		TON	
7/4/2003		Number	Introduced	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Transect 1	Sta 1	No cage	N/A	222	41	NT	NT	1.42	0.05	0.21	0.02
	Sta 2	916	9/26/2003	292	110	NT	NT	1.35	0.06	0.20	0.01
	Sta 3	914	10/13/2003	230	27	NT	NT	1.22	0.03	0.18	0.01
Transect 2	Sta 1	No cage	N/A	147	57	NT	NT	1.49	0.03	0.22	0.01
	Sta 2	915	10/242003	134	41	NT	NT	1.50	0.04	0.22	0.01
	Sta 3	913	11/5/2003	114	91	NT	NT	1.47	0.04	0.21	0.01
Transect 3	Sta 1	No cage	N/A	233	134	NT	NT	1.03	0.04	0.15	0.01
	Sta 2	910	9/11/2003	246	23	NT	NT	0.96	0.04	0.14	0.01
	Sta 3	912	9/3/2003	293	8	NT	NT	1.18	0.02	0.17	0.00
Transect 4	Sta 1	No cage	N/A	227	47	NT	NT	0.92	0.07	0.13	0.01
	Sta 2	909	9/17/2003	154	42	NT	NT	1.18	0.12	0.17	0.02
	Sta 3	911	9/1/2003	182	5	NT	NT	1.33	0.02	0.19	0.01
Transect 5	Sta 1	No cage	N/A	258	37	NT	NT	1.01	0.13	0.15	0.02
	Sta 2	No cage	N/A	351	40	NT	NT	0.99	0.18	0.14	0.03
	Sta 3	No cage	N/A	164	26	NT	NT	1.12	0.04	0.17	0.01

Sampling Date:		Cage	Date Fish	Eh		µM S_2		TOC		TON	
11/24-25/2003		Number	Introduced	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Transect 1	Sta 1	No cage	N/A	75	45	623	397	1.22	0.48	0.18	0.03
	Sta 2	916	9/26/2003	No sample taken		No sample taken		No sample taken		No sample taken	
	Sta 3	914	10/13/2003	No sample taken		No sample taken		No sample taken		No sample taken	
Transect 2	Sta 1	No cage	N/A	65	24	641	199	1.33	0.08	0.19	0.01
	Sta 2	915	10/242003	-90	61	2633	1814	1.52	0.18	0.23	0.01
	Sta 3	913	11/5/2003	-129	16	3180	456	1.60	0.20	0.22	0.03
Transect 3	Sta 1	No cage	N/A	129	33	599	195	0.84	0.08	0.14	0.01
	Sta 2	910	9/11/2003	40	31	999	19	0.95	0.05	0.14	0.01
	Sta 3	912	9/3/2003	-118	42	3290	1353	1.11	0.16	0.17	0.02
Transect 4	Sta 1	No cage	N/A	-49	16	2890	832	1.06	0.17	0.17	0.01
	Sta 2	909	9/17/2003	-154	9	2923	357	0.95	0.07	0.15	0.01
	Sta 3	911	9/1/2003	-73	57	1963	365	1.10	0.07	0.17	0.01
Transect 5	Sta 1	No cage	N/A	159	20	94	22	1.02	0.16	0.16	0.02
	Sta 2	No cage	N/A	84	3	256	14	1.02	0.04	0.15	0.01
	Sta 3	No cage	N/A	85	28	176	55	0.93	0.04	0.13	0.01
Sampling Date:		Cage	Date Fish	Eh		µM S_2		TOC		TON	

Sampling Date:		Cage	Date Fish	Eh		µM S_2		TOC		TON	
05/26-27/2004		Number	Introduced	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Transect 1	Sta 1	No cage	N/A	72	60	637	199	1.13	0.08	0.16	0.02
	Sta 2	916	9/26/2003	-98	24	1460	356	1.96	0.07	0.31	0.01
	Sta 3	914	10/13/2003	-60	42	1580	512	1.54	0.24	0.23	0.04
Transect 2	Sta 1	No cage	N/A	57	55	567	96	1.70	0.54	0.25	0.08
	Sta 2	915	10/242003	-44	44	1773	673	1.86	0.14	0.29	0.03
	Sta 3	913	11/5/2003	-53	20	1583	319	1.81	0.33	0.28	0.06
Transect 3	Sta 1	No cage	N/A	62	17	512	76	0.87	0.45	0.18	0.02
	Sta 2	910	9/11/2003	129	34	625	321	1.37	0.16	0.20	0.02
	Sta 3	912	9/3/2003	92	36	788	208	1.29	0.21	0.15	0.03
Transect 4	Sta 1	No cage	N/A	106	22	436	111	1.05	0.09	0.13	0.01
	Sta 2	909	9/17/2003	-28	44	1076	131	1.39	0.17	0.17	0.03
	Sta 3	911	9/1/2003	-5	30	890	183	1.97	0.08	0.24	0.01
Transect 5	Sta 1	No cage	N/A	264	76	95	42	1.16	0.17	0.14	0.02
	Sta 2	No cage	N/A	223	15	88	25	1.23	0.10	0.14	0.01
	Sta 3	No cage	N/A	158	60	85	45	0.98	0.10	0.12	0.01

Sampling Date:		Cage	Date Fish	Eh		µM S_2		TOC		TON	
11/5/2004		Number	Introduced	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Transect 1	Sta 1	No cage	N/A	31	24	985	223	1.82	0.09	0.27	0.02
	Sta 2	916	9/26/2003	-98	13	1490	312	1.33	0.24	0.20	0.04
	Sta 3	914	10/13/2003	-76	24	1603	289	1.83	0.24	0.27	0.03
Transect 2	Sta 1	No cage	N/A	-31	42	1134	157	1.55	0.25	0.23	0.03
	Sta 2	915	10/242003	75	91	1199	678	2.74	0.46	0.38	0.05
	Sta 3	913	11/5/2003	-41	12	1720	1133	2.71	0.33	0.40	0.05
Transect 3	Sta 1	No cage	N/A	-2	63	651	449	0.92	0.20	0.13	0.03
	Sta 2	910	9/11/2003	-25	68	1145	564	0.88	0.12	0.12	0.02
	Sta 3	912	9/3/2003	-98	72	2367	982	1.63	0.47	0.24	0.07
Transect 4	Sta 1	No cage	N/A	-2	19	647	53	1.27	0.12	0.18	0.02
	Sta 2	909	9/17/2003	-38	16	1297	101	1.63	0.07	0.23	0.01
	Sta 3	911	9/1/2003	-54	52	1560	79	1.37	0.06	0.20	0.01
Transect 5	Sta 1	No cage	N/A	98	7	208	3	1.12	0.01	0.16	0.01
	Sta 2	No cage	N/A	122	8	109	12	1.11	0.09	0.16	0.01
	Sta 3	No cage	N/A	125	24	82	40	0.92	0.10	0.13	0.02

APPENDIX IV

Benthic infauna data summaries

7/1/2003	Transect 1			Transect 2			Transect 3			Transect 4			Transect 5		
	Sta. 1	Sta. 2	Sta. 3	Sta. 1	Sta. 2	Sta. 3	Sta. 1	Sta. 2	Sta. 3	Sta. 1	Sta. 2	Sta. 3	Sta. 1	Sta. 2	Sta. 3
Species level analysis															
Total organisms	32.3	38.7	18.3	34.3	13.3	3.7	34.0	22.0	24.7	25.0	8.3	16.3	40.7	24.3	20.7
Abundance (organisms/0.1 m²)	399.2	477.3	226.3	423.8	164.6	45.3	419.7	271.6	304.5	308.6	102.9	201.6	502.0	300.4	255.1
Species richness (No. species)	14.3	12.7	9.3	11.0	7.0	3.3	13.0	11.7	11.3	9.3	4.3	8.0	14.0	13.0	13.0
Rel. Diversity	0.923	0.875	0.874	0.840	0.879	0.987	0.857	0.931	0.884	0.913	0.911	0.918	0.913	0.933	0.947
% CAPITELLA	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0
Family level analysis															
Total organisms	32.3	38.7	18.3	34.3	13.3	3.7	34.0	22.0	24.7	25.0	8.3	16.3	40.7	24.3	20.7
Abundance (organisms/0.1 m²)	399.2	477.3	226.3	423.8	164.6	45.3	419.7	271.6	304.5	308.6	102.9	201.6	502.0	300.4	255.1
Family richness (No. families)	11.0	10.7	8.3	10.0	6.0	3.3	12.0	11.7	9.0	8.0	3.3	6.3	13.3	11.7	12.3
Rel. Diversity	0.887	0.843	0.858	0.807	0.810	0.987	0.857	0.931	0.848	0.831	0.962	0.891	0.918	9.490	0.954
% CAPITELLIDAE	0.0	1.5	0.0	1.9	0.0	0.0	0.8	1.2	2.9	2.4	0.0	2.9	0.0	0.0	0.0

11/24/2003	Transect 1			Transect 2			Transect 3			Transect 4			Transect 5		
	Sta. 1	Sta. 2	Sta. 3	Sta. 1	Sta. 2	Sta. 3	Sta. 1	Sta. 2	Sta. 3	Sta. 1	Sta. 2	Sta. 3	Sta. 1	Sta. 2	Sta. 3
Species level analysis															
Total organisms	91.7	N/T	N/T	54.7	60.3	71.3	31.0	25.7	142.3	23.0	137.0	31.7	50.0	63.0	27.0
Abundance (organisms/0.1 m²)	1131.6			674.9	744.8	880.6	382.7	316.9	1757.1	283.9	1691.3	390.9	617.3	777.7	333.3
Species richness (No. species)	15.7			9.3	9.3	6.3	15.7	13.0	3.7	8.3	2.3	5.3	19.7	19.7	11.7
Rel. Diversity	0.705			0.741	0.777	0.505	0.923	0.937	0.107	0.841	0.174	0.534	0.833	0.845	0.925
% CAPITELLA	0.9			0.4	5.7	60.7	0.0	0.0	97.4	5.6	92.2	28.3	0.7	0.5	0.0
Family level analysis															
Total organisms	91.7	N/T	N/T	54.7	60.3	71.3	30.7	25.0	142.3	23.0	137.0	31.7	50.0	63.0	27.0
Abundance (organisms/0.1 m²)	1131.6			674.9	744.8	880.6	382.7	316.9	1757.1	283.9	1691.3	390.9	625.5	777.7	333.3
Family richness (No. families)	12.7			8.0	7.3	5.3	13.0	10.7	2.7	7.0	2.0	4.0	16.3	17.0	11.0
Rel. Diversity	0.704			0.752	0.747	0.432	0.916	0.971	0.081	0.832	0.184	0.450	0.853	0.848	0.922
% CAPITELLIDAE	23.6			8.0	20.1	67.8	1.3	10.7	98.6	5.6	92.2	29.2	0.7	4.7	0.0

5/12/2004	Transect 1			Transect 2			Transect 3			Transect 4			Transect 5		
	Sta. 1	Sta. 2	Sta. 3	Sta. 1	Sta. 2	Sta. 3	Sta. 1	Sta. 2	Sta. 3	Sta. 1	Sta. 2	Sta. 3	Sta. 1	Sta. 2	Sta. 3
Species level analysis															
Total organisms	117.7	30.3	32.0	53.7	24.0	4.3	19.3	87.0	229.3	32.3	95.7	39.7	50.0	47.7	42.7
Abundance (organisms/0.1 m²)	1452.6	374.5	395.0	662.5	296.3	53.5	238.7	1074.0	2831.1	399.2	1181.0	489.7	617.3	588.4	526.7
Species richness (No. species)	22.7	6.7	6.7	9.3	7.7	2.7	8.7	5.3	3.0	7.3	3.0	3.3	16.0	15.7	17.3
Rel. Diversity	0.783	0.598	0.781	0.648	0.766	0.881	0.917	0.285	0.053	0.776	0.225	0.228	0.870	0.880	0.918
% CAPITELLA	0.3	1.5	29.3	0.0	0.0	27.0	0.0	88.4	98.8	0.0	91.3	2.6	0.0	0.0	0.0
Family level analysis															
Total organisms	117.7	30.3	32.0	53.7	24.0	4.3	19.3	87.0	229.3	32.3	95.7	39.7	50.0	47.7	42.7
Abundance (organisms/0.1 m²)	1452.6	374.5	395.0	662.5	296.3	53.5	238.7	1074.0	2831.1	399.2	1181.0	489.7	617.3	588.4	526.7
Family richness (No. families)	19.0	5.0	5.3	8.3	6.7	2.7	8.0	4.7	3.0	6.0	3.0	3.0	15.0	14.7	15.7
Rel. Diversity	0.775	0.522	0.760	0.621	0.682	0.881	0.898	0.287	0.053	0.794	0.225	0.216	0.877	0.882	0.910
% CAPITELLIDAE	10.2	5.5	32.9	0.6	1.9	38.1	0.0	88.6	98.8	1.4	91.3	2.6	0.0	0.0	0.0

11/10/2004	Transect 1			Transect 2			Transect 3			Transect 4			Transect 5		
	Sta. 1	Sta. 2	Sta. 3	Sta. 1	Sta. 2	Sta. 3	Sta. 1	Sta. 2	Sta. 3	Sta. 1	Sta. 2	Sta. 3	Sta. 1	Sta. 2	Sta. 3
Species level analysis															
Total organisms	233.0	684.7	478.3	134.0	762.3	511.3	87.7	257.0	494.0	174.0	343.0	367.7	76.7	80.7	43.3
Abundance (organisms/0.1 m²)	2876.4	8452.2	5905.0	1654.2	9411.0	6312.4	1082.2	3172.7	6098.4	2148.0	4234.3	4538.8	946.5	995.8	535.0
Species richness (No. species)	14.3	18.0	8.7	10.3	13.0	7.7	13.3	6.7	7.0	12.3	6.0	6.3	23.0	21.7	18.7
Rel. Diversity	0.443	0.326	0.102	0.431	0.156	0.085	0.673	0.124	0.078	0.424	0.090	0.092	0.914	0.905	0.921
% CAPITELLA	68.0	76.4	96.4	74.2	92.8	97.3	32.6	95.3	97.6	66.7	97.3	97.2	0.0	0.0	0.0
Family level analysis															
Total organisms	233.0	684.7	478.3	134.0	762.3	511.3	87.7	257.0	494.0	174.0	343.0	367.7	76.7	80.7	43.3
Abundance (organisms/0.1 m²)	2876.4	8452.2	5905.0	1654.2	9411.0	6312.4	1082.2	3172.7	6098.4	2148.0	4234.3	4538.8	946.5	995.8	535.0
Family richness (No. families)	10.0	13.7	6.7	7.3	11.0	6.3	12.0	6.0	6.7	9.6	4.7	5.3	19.0	19.0	16.0
Rel. Diversity	0.433	0.243	0.097	0.411	0.150	0.076	0.672	0.127	0.079	0.430	0.091	0.096	0.911	0.906	0.925
% CAPITELLIDAE	71.0	86.6	96.8	76.7	93.3	97.8	33.4	95.3	97.6	66.8	97.6	97.3	0.0	1.6	0.0

07/01/2003	Transect 1 Station 1			Transect 1 Station 2			Transect 1 Station 3								
SPECIES	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.
Total organisms	97	32.3	176.2				116	38.7	59.6				55	18.3	6.9			
Abundance (organisms/0.1 m²)	1197	399.2	26856				1432	477.3	9076				679	226.3	1050			
Species richness (No. species)	24	14.3	14.9				23	12.7	8.2				16	9.3	0.2			
Distance in meters		30						0						0				
Rel. Diversity		0.923	0.000					0.875	0.001					0.874	0.000			
% CAPITELLA		0.0	0.0					0.7	1.1					0.0	0.0			
FAMILY																		
Total organisms				97	32.3	176.2				116	38.7	59.6				55	18.3	6.9
Abundance (organisms/0.1 m²)				1197	399.2	26856				1432	477.3	9076				679	226.3	1050
Family richness (No. families)				20	11.0	4.7				18	10.3	8.2				14	8.3	0.2
Distance in meters					30						0						0	
Rel. Diversity					0.887	0.000					0.854	0.001					0.858	0.001
% CAPITELLIDAE					0.0	0.0					1.5	1.2					0.0	0.0

	Transect 2 Station 1			Transect 2 Station 2			Transect 2 Station 3								
SPECIES	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.
Total organisms	103	34.3	5.6				40	13.3	22.9				11	3.7	0.9			
Abundance (organisms/0.1 m²)	1272	423.8	847				494	164.6	3488				136	45.3	135.5			
Species richness (No. species)	19	11.0	2.0				14	7.0	0.7				6	3.3	0.2			
Distance in meters		30						0						0				
Rel. Diversity		0.840	0.000					0.879	0.005					0.987	0.000			
% CAPITELLA		0.0	0.0					0.0	0.0					0.0	0.0			
FAMILY																		
Total organisms				103	34.3	5.6				40	13.3	22.9				11	3.7	0.9
Abundance (organisms/0.1 m²)				1272	423.8	847				494	164.6	3488				136	45.3	135.5
Family richness (No. families)				18	10.0	2.0				13	6.0	0.7				6	3.3	0.2
Distance in meters					30						0						0	
Rel. Diversity					0.807	0.000					0.810	0.010					0.987	0.000
% CAPITELLIDAE					1.9	6.9					0.0	0.0					0.0	0.0

07/01/2003	Transect 3 Station 1						Transect 3 Station 2						Transect 3 Station 3					
SPECIES	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.
Total organisms	102	34.0	68.7				66	22.0	34.7				74	24.7	17.6			
Abundance (organisms/0.1 m²)	1259	419.7	10465				815	271.6	5283				914	304.5	2675			
Species richness (No. species)	22	13.0	6.0				20	11.7	0.9				20	11.3	0.9			
Distance in meters		30						0						0				
Rel. Diversity		0.857	0.002					0.931	0.001					0.884	0.003			
% CAPITELLA		0.0	0.0					0.0	0.0					0.0	0.0			
FAMILY																		
Total organisms				102	34.0	68.7				66	22.0	34.7				74	24.7	17.6
Abundance (organisms/0.1 m²)				1259	419.7	10465				815	271.6	5283				914	304.5	2675
Family richness (No. families)				20	12.0	6.0				16	10.3	0.9				16	9.0	0.7
Distance in meters					30						0						0	
Rel. Diversity					0.857	0.002					0.938	0.001					0.848	0.003
% CAPITELLIDAE					0.8	1.2					1.2	2.8					2.9	4.8

	Transect 4 Station 1						Transect 4 Station 2						Transect 4 Station 3					
SPECIES	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.
Total organisms	75	25.0	18.7				25	8.3	46.9				49	16.3	24.9			
Abundance (organisms/0.1 m²)	926	308.6	2845				309	102.9	7146				605	201.6	3793			
Species richness (No. species)	16	9.3	6.2				8	4.3	3.6				14	8.0	8.0			
Distance in meters		30						0						0				
Rel. Diversity		0.913	0.001					0.911	0.008					0.918	0.001			
% CAPITELLA		1.2	3.0					0.0	0.0					0.0	0.0			
FAMILY																		
Total organisms				75	25.0	18.7				25	8.3	46.9				49	16.3	24.9
Abundance (organisms/0.1 m²)				926	308.6	2845				309	102.9	7146				605	201.6	3793
Family richness (No. families)				11	8.0	4.7				6	3.3	0.2				11	6.3	3.6
Distance in meters					30						0						0	
Rel. Diversity					0.831	0.004					0.962	0.001					0.891	0.000
% CAPITELLIDAE					2.4	2.9					0.0	0.0					2.9	16.8

07/01/2003	Transect 5 Station 1						Transect 5 Station 2						Transect 5 Station 3					
SPECIES	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.
Total organisms	122	40.7	472.9				73	24.3	20.2				62	20.7	38.2			
Abundance (organisms/0.1 m²)	1506	502.0	72068				901	300.4	3082				765	255.1	5825			
Species richness (No. species)	24	14.0	28.7				22	13.0	2.7				20	13.0	6.0			
Distance in meters		>100						>100						>100				
Rel. Diversity		0.913	0.002					0.933	0.000					0.947	0.002			
% CAPITELLA		0.0	0.0					0.0	0.0					0.0	0.0			
FAMILY																		
Total organisms				122	40.7	472.9				73	24.3	20.2				62	20.7	38.2
Abundance (organisms/0.1 m²)				1506	502.0	72068				901	300.4	3082				765	255.1	5825
Family richness (No. families)				21	13.0	18.7				19	11.7	1.6				19	12.3	4.2
Distance in meters					>100						>100						>100	
Rel. Diversity					0.918	0.002					0.949	0.001					0.954	0.001
% CAPITELLIDAE					0.0	0.0					0.0	0.0					0.0	0.0

11/24/2003	Transect 1 Station 1			Transect 1 Station 2			Transect 1 Station 3								
SPECIES	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.
Total organisms	275	91.7	2754															
Abundance (organisms/0.1 m²)	3395	1131.6	419639															
Species richness (No. species)	29	15.7	10.9															
Distance in meters		30					N/T						N/T					
Rel. Diversity		0.705	0.002															
% CAPITELLA		0.9	1.5															
FAMILY																		
Total organisms				275	91.7	2754												
Abundance (organisms/0.1 m²)				3395	1131.6	419639												
Family richness (No. families)				20	12.7	4.2					N/T						N/T	
Distance in meters					30.0													
Rel. Diversity					0.704	0.002												
% CAPITELLIDAE					23.6	38.7												

	Transect 2 Station 1						Transect 2 Station 2						Transect 2 Station 3					
SPECIES	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.
Total organisms	164	54.7	1040				181	60.3	1454				214	71.3	1444			
Abundance (organisms/0.1 m²)	2025	674.9	158528				2234	744.8	221622				2642	880.6	220098			
Species richness (No. species)	16	9.3	1.6				15	9.3	6.9				11	6.3	0.2			
Distance in meters		30						0						0				
Rel. Diversity		0.741	0.027					0.777	0.007					0.505	0.018			
% CAPITELLA		0.4	0.3					5.7	12.9					60.7	589.6			
FAMILY																		
Total organisms				164	54.7	1040				181	60.3	1454				214	71.3	1444
Abundance (organisms/0.1 m²)				2025	674.9	158528				2234	744.8	221622				2642	880.6	220098
Family richness (No. families)				12	8.0	0.0				12	7.3	6.9				10	5.3	0.2
Distance in meters					30						0						0	
Rel. Diversity					0.752	0.025					0.747	0.003					0.432	0.018
% CAPITELLIDAE					8.0	39.2					20.1	54.2					67.8	607.3

11/24/2003	Transect 3 Station 1						Transect 3 Station 2						Transect 3 Station 3					
SPECIES	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.
Total organisms	93	31.0	50.0				77	25.7	69.6				427	142.3	64.9			
Abundance (organisms/0.1 m²)	1148	382.7	7620.0				951	316.9	10600				5271	1757.1	9889			
Species richness (No. species)	26	15.7	2.9				22	13.0	4.7				5	3.7	0.2			
Distance in meters		30						0						0				
Rel. Diversity		0.923	0.002					0.937	0.001					0.107	0.001			
% CAPITELLA		0.0	0.0					0.0	0.0					97.4	1.2			
FAMILY																		
Total organisms				93	31.0	50.0				77	25.7	69.6				427	142.3	64.9
Abundance (organisms/0.1 m²)				1148	382.7	7620.0				951	316.9	10600				5271	1757.1	9889
Family richness (No. families)				20	13.0	2.7				18	10.7	2.9				4	2.7	0.2
Distance in meters					30						0						0	
Rel. Diversity					0.916	0.002					0.971	0.002					0.081	0.000
% CAPITELLIDAE					1.3	3.3					10.7	67.7					98.6	0.3

	Transect 4 Station 1						Transect 4 Station 2						Transect 4 Station 3					
SPECIES	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.
Total organisms	69	23.0	146.0				411	137.0	5798.0				95	31.7	118.2			
Abundance (organisms/0.1 m²)	852	283.9	22250				5074	1691.3	883610				1173	390.9	18017			
Species richness (No. species)	14	8.3	2.9				5	2.3	3.6				9	5.3	0.9			
Distance in meters		0						0						0				
Rel. Diversity		0.841	0.018					0.174	0.061					0.534	0.002			
% CAPITELLA		5.6	61.7					92.2	121.0					28.3	1296.2			
FAMILY																		
Total organisms				69	23.0	146.0				411	137.0	5798.0				95	31.7	118.2
Abundance (organisms/0.1 m²)				852	283.9	22250				5074	1691.3	883610				1173	390.9	18017
Family richness (No. families)				12	7.0	0.7				4	2.0	2.0				7	4.0	0.7
Distance in meters					30						0						0	
Rel. Diversity					0.832	0.019					0.184	0.068					0.450	0.001
% CAPITELLIDAE					5.6	61.7					92.2	121.0					29.2	1255.1

11/24/2003	Transect 5 Station 1						Transect 5 Station 2						Transect 5 Station 3					
SPECIES	**Total**	**Mean**	**Std. Dv.**	**Total**	**Mean**	**Std. Dv.**	**Total**	**Mean**	**Std. Dv.**	**Total**	**Mean**	**Std. Dv.**	**Total**	**Mean**	**Std. Dv.**	**Total**	**Mean**	**Std. Dv.**
Total organisms	150	50.0	134.0				189	63.0	98.0				81	27.0	20.7			
Abundance (organisms/0.1 m²)	1852	617.3	20421				2333	777.7	14935				1000	333.3	3150			
Species richness (No. species)	33	19.7	6.2				29	19.7	3.6				17	11.7	2.9			
Distance in meters		>100						>100						>100				
Rel. Diversity		0.833	0.001					0.845	0.002					0.925	0.001			
% CAPITELLA		0.7	1.1					0.5	0.5					0.0	0.0			
FAMILY																		
Total organisms				150	50.0	134.0				189	63.0	98.0				81	27.0	20.7
Abundance (organisms/0.1 m²)				1852	617.3	20421				2333	777.7	14935				1000	333.3	3150
Family richness (No. families)				25	16.0	2.7				23	17.0	0.7				15	11.0	0.7
Distance in meters					>100						>100						>100	
Rel. Diversity					0.852	0.001					0.848	0.001					0.922	0.001
% CAPITELLIDAE					0.7	1.1					4.7	8.7					0.0	0.0

05/12/2004	Transect 1 Station 1						Transect 1 Station 2						Transect 1 Station 3					
SPECIES	**Total**	**Mean**	**Std. Dv.**	**Total**	**Mean**	**Std. Dv.**	**Total**	**Mean**	**Std. Dv.**	**Total**	**Mean**	**Std. Dv.**	**Total**	**Mean**	**Std. Dv.**	**Total**	**Mean**	**Std. Dv.**
Total organisms	353	117.7	2598				91	30.3	72.2				96	32.0	160.7			
Abundance (organisms/0.1 m²)	4358	1452.6	395865				1123	374.5	11007				1185	395.0	24485			
Species richness (No. species)	32	22.7	2.9				13	6.7	2.9				12	6.7	6.9			
Distance in meters		30						0						0				
Rel. Diversity		0.783	0.008					0.598	0.022					0.781	0.003			
% CAPITELLA		0.3	0.1					1.5	4.6					29.3	50.4			
FAMILY																		
Total organisms				353	117.7	2598				91	30.3	72.2				96	32.0	160.7
Abundance (organisms/0.1 m²)				4358	1452.6	395865				1123	374.5	11007				1185	395.0	24485
Family richness (No. families)				24	19.0	2.0				10	5.0	2.7				9	5.3	2.9
Distance in meters					30						0						0	
Rel. Diversity					0.775	0.006					0.522	0.030					0.760	0.002
% CAPITELLIDAE					10.2	35.8					5.5	15.6					32.9	25.7

SPECIES	Transect 2 Station 1						Transect 2 Station 2						Transect 2 Station 3					
Total organisms	161	53.7	8.2				72	24.0	78.0				13	4.3	3.6			
Abundance (organisms/0.1 m²)	1988	662.5	1253				889	296.3	11887				160	53.5	541.9			
Species richness (No. species)	15	9.3	1.6				15	7.7	4.2				6	2.7	0.2			
Distance in meters		30						0						0				
Rel. Diversity		0.648	0.003					0.766	0.012					0.881	0.013			
% CAPITELLA		0.0	0.0					0.0	0.0					27.0	821.4			
FAMILY																		
Total organisms				161	53.7	8.2				72	24.0	78.0				13	4.3	3.6
Abundance (organisms/0.1 m²)				1988	662.5	1253				889	296.3	11887				160	53.5	541.9
Family richness (No. families)				13	8.3	1.6				14	6.7	4.2				5	2.7	0.2
Distance in meters					30						0						0	
Rel. Diversity					0.621	0.007					0.682	0.008					0.881	0.013
% CAPITELLIDAE					0.6	0.7					1.9	6.9					38.1	468.6

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SPECIES	Transect 3 Station 1						Transect 3 Station 2						Transect 3 Station 3					
Total organisms	58	19.3	38.9				261	87.0	3475				688	229.3	131.6			
Abundance (organisms/0.1 m²)	716	238.7	5927				3222	1074	529536				8493	2831	20049			
Species richness (No. species)	14	8.7	1.6				11	5.3	0.9				7	3.0	2.7			
Distance in meters		30						0						0				
Rel. Diversity		0.917	0.001					0.285	0.026					0.053	0.001			
% CAPITELLA		0.0	0.0					88.4	63.0					98.8	0.8			
FAMILY																		
Total organisms				58	19.3	38.9				261	87.0	3474.7				688	229.3	131.6
Abundance (organisms/0.1 m²)				716	238.7	5927				3222	1074	529536				8493	2831	20049
Family richness (No. families)				12	8.0	0.7				8	4.7	1.6				7	3.0	2.7
Distance in meters					30						0						0	
Rel. Diversity					0.898	0.002					0.287	0.030					0.053	0.001
% CAPITELLIDAE					0.0	0.0					88.6	67.0					98.8	0.8

SPECIES	Transect 4 Station 1						Transect 4 Station 2						Transect 4 Station 3					
Total organisms	97	32.3	197.6				287	95.7	13562				119	39.7	27.6			
Abundance (organisms/0.1 m²)	1197	399.2	30107				3543	1181	2066971				1469	489.7	4199			
Species richness (No. species)	13	7.3	1.6				7	3.0	2.7				6	3.3	0.2			
Distance in meters		30						0						0				
Rel. Diversity		0.776	0.002					0.225	0.044					0.228	0.000			
% CAPITELLA		0.0	0.0					91.3	88.6					2.6	0.1			
FAMILY																		
Total organisms				97	32.3	197.6				287	95.7	13563				119	39.7	27.6
Abundance (organisms/0.1 m²)				1197	399.2	30107				3543	1181	2066971				1469	489.7	4199
Family richness (No. families)				11	6.0	0.7				7	3.0	2.7				5	3.0	0.0
Distance in meters					30						0						0	
Rel. Diversity					0.794	0.002					0.225	0.044					0.216	0.000
% CAPITELLIDAE					1.4	4.2					91.3	88.6					2.6	0.1

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SPECIES	Transect 5 Station 1						Transect 5 Station 2						Transect 5 Station 3					
Total organisms	150	50.0	122.0				143	47.7	186.9				128	42.7	20.2			
Abundance (organisms/0.1 m²)	1852	617.3	18593				1765	588.4	28482				1580	526.7	3082			
Species richness (No. species)	24	16.0	8.0				22	15.7	10.9				26	17.3	6.2			
Distance in meters		>100						>100						>100				
Rel. Diversity		0.870	0.000					0.880	0.003					0.918	0.000			
% CAPITELLA		0.0	0.0					0.0	0.0					0.0	0.0			
FAMILY																		
Total organisms				150	50.0	122.0				143	47.7	186.9				128	42.7	20.2
Abundance (organisms/0.1 m²)				1852	617.3	18593				1765	588.4	28482				1580	526.7	3082
Family richness (No. families)				22	15.0	8.0				20	14.7	10.9				20	15.7	4.2
Distance in meters					>100						>100						>100	
Rel. Diversity					0.877	0.001					0.882	0.003					0.910	0.000
% CAPITELLIDAE					0.0	0.0					0.0	0.0					0.0	0.0

11/04/2004	Transect 1 Station 1						Transect 1 Station 2						Transect 1 Station 3					
SPECIES	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.	Total	Mean	Std. Dv.
Total organisms	699	233.0	5864.0				2054	684.7	28758				1435	478.3	23368			
Abundance (organisms/0.1 m²)	8629	2876.4	893668				25357	8452.2	4382623				17715	5905.0	3561294			
Species richness (No. species)	20	14.3	20.2				28	18.0	8.7				16	8.7	6.2			
Distance in meters		30						0						0				
Rel. Diversity		0.443	0.038					0.326	0.014					0.102	0.001			
% CAPITELLA		68.0	344.4					76.4	172.3					96.4	2.1			
FAMILY																		
Total organisms				699	233.0	5864.0				2054	684.7	28758				1435	478.3	23368
Abundance (organisms/0.1 m²)				8629	2876.4	893668				25357	8452.2	4382623				17715	5905.0	3561294
Family richness (No. families)				13	10.0	6.0				22	13.7	2.9				12	6.7	2.9
Distance in meters					30						0						0	
Rel. Diversity					0.433	0.033					0.243	0.007					0.097	0.001
% CAPITELLIDAE					71.0	281.1					86.6	28.4					96.8	1.5

SPECIES	Transect 2 Station 1						Transect 2 Station 2						Transect 2 Station 3					
Total organisms	402	134.0	632.7				2287	762.3	4936.2				1534	511.3	25006			
Abundance (organisms/0.1 m²)	4963	1654.2	96418				28233	9411.0	752275				18937	6312.4	3810924			
Species richness (No. species)	17	10.3	16.2				23	13.0	6.0				12	7.7	0.9			
Distance in meters		30						0						0				
Rel. Diversity		0.431	0.020					0.156	0.001					0.085	0.000			
% CAPITELLA		74.2	112.7					92.8	5.0					97.3	0.5			
FAMILY																		
Total organisms				402	134.0	632.7				2287	762.3	4936.2				1534	511.3	25006
Abundance (organisms/0.1 m²)				4963	1654.2	96418				28233	9411.0	752275				18937	6312.4	3810924
Family richness (No. families)				12	7.3	6.9				19	11.0	2.0				9	6.3	1.6
Distance in meters					30						0						0	
Rel. Diversity					0.411	0.015					0.150	0.001					0.076	0.000
% CAPITELLIDAE					76.7	86.2					93.3	4.6					97.8	0.0

11/04/2004	Transect 3 Station 1						Transect 3 Station 2						Transect 3 Station 3					
SPECIES																		
Total organisms	263	87.7	6264.2				771	257.0	11624.0				1482	494.0	20124.7			
Abundance (organisms/0.1 m²)	3246.74	1082.2	954661				9518	3172.7	1771486				18295	6098.4	3066979			
Species richness (No. species)	25	13.3	22.9				14	6.7	10.9				13	7.0	0.7			
Distance in meters		30						0						0				
Rel. Diversity		0.673	0.123					0.124	0.008					0.078	0.000			
% CAPITELLA		32.6	1827.2					95.3	20.7					97.6	0.8			
FAMILY																		
Total organisms				263	87.7	6264.2				771	257.0	11624.0				1482	494.0	20124.7
Abundance (organisms/0.1 m²)				3246	1082.2	954661				9518	3172	1771486				18295	6098	3066980
Family richness (No. families)				21	12.0	8.7				11	6.0	8.0				12	6.7	0.2
Distance in meters					30						0						0.0	
Rel. Diversity					0.672	0.122					0.127	0.009					0.079	0.001
% CAPITELLIDAE					33.4	1784.3					95.3	20.7					97.6	0.8

	Transect 4 Station 1						Transect 4 Station 2						Transect 4 Station 3					
SPECIES																		
Total organisms	522	174.0	5408.0				1029	343.0	7064.0				1103	367.7	7627.6			
Abundance (organisms/0.1 m²)	6444	2148	824173				12703	4234	1076546				13617	4538	1162432			
Species richness (No. species)	21	12.3	0.9				9	6.0	0.7				12	6.3	1.6			
Distance in meters		30						0						0				
Rel. Diversity		0.424	0.013					0.090	0.001					0.092	0.001			
% CAPITELLA		66.7	174.7					97.3	1.5					97.2	1.6			
FAMILY																		
Total organisms				522	174.0	5408.0				1029	343.0	7064				1103	367.7	7627.6
Abundance (organisms/0.1 m²)				6444	2148.0	82417372				12703	4234	1076547				13617	4538.8	1162432
Family richness (No. families)				15	9.6	1.6				7	4.7	1.6				9	5.3	3.6
Distance in meters					30						0.0						0	
Rel. Diversity					0.430	0.013					0.1	0.0					0.096	0.002
% CAPITELLIDAE					66.8	178.7					97.6	1.6					97.3	1.8

11/04/2004	Transect 5 Station 1						Transect 5 Station 2						Transect 5 Station 3					
SPECIES																		
Total organisms	230	76.7	668.2				242	80.7	997.6				130	43.3	6.2			
Abundance (organisms/0.1 m²)	2839	946.5	101836				2987.5	995.8	152026				1605	535.0	948.3			
Species richness (No. species)	31	23.0	8.7				32	21.7	22.9				25	18.7	0.2			
Distance in meters		>100						>100						>100				
Rel. Diversity		0.914	0.001					0.905	0.000					0.921	0.000			
% CAPITELLA		0.0	0.0					0.0	0.0					0.0	0.0			
FAMILY																		
Total organisms				230	76.7	668.2				242	80.7	997.6				130	43.3	6.2
Abundance (organisms/0.1 m²)				2839	946.5	101836				2987.5	995.8	152026				1605	535.0	948.3
Family richness (No. families)				24	19	4.7				26	19	12.7				20	16	0.7
Distance in meters					>100						>100						>100	
Rel. Diversity					0.911	0.001					0.906	0.000					0.925	0.000
% CAPITELLIDAE					0.0	0.0					1.6	1.5					0.0	0.0