APPLICATION OF A TRAFFIC LIGHT DECISION SYSTEM FOR MARINE FINFISH AQUACULTURE SITING ASSESSMENT IN PORT MOUTON, NOVA SCOTIA

Report submitted to Friends of Port Mouton

April 22, 2009

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INTRODUCTION

Close attention to siting criteria is recognized as an preferred way to avoid a potential Harmful Alteration, Disruption and Destruction (HADD) as defined under Canada's Fisheries Act associated with the development and operation of finfish aquaculture sites. In 2002, at the request of Habitat Management Division, Maritimes Region, Department of Fisheries and Oceans (DFO), a siting decision support system (Marine Finfish Aquaculture Decision Support System, MFADSS) was developed based on criteria specified in DFO's Aquaculture Site Application - Review Process and Guidelines (Office of Sustainable Aquaculture, January 2002). The guidelines, used by both Habitat Management and proponents of new aquaculture site development, were used to derive a set of standard questions based on aquaculture facility data, and ecosystem and site specific water column and sediment geochemical variables. The structure and application of the Excel-based MFADSS are described in Hargrave (2002) and Doucette and Hargrave (2002).

The MFADSS assesses far- and near-field variables potentially affected by marine finfish aquaculture to indicate if a proposed site has characteristics that might lead to a HADD following license approval. Positive to negative scores to ecosystem and site-specific questions are assigned to answers based on pre-determined or proposed qualitative and quantitative variables for specified threshold values for an area where sufficient background data exists to serve as a baseline against which to measure changes. The list of questions and scored responses, including critical pre-emptive variables, were developed in collaboration with DFO Maritimes Region habitat biologists involved with on-going environmental reviews of applications for new aquaculture site licensing. The MFADSS assists habitat managers in decisions about site suitability ensuring that the same variables are considered in evaluating all applications. Industry gains a clearer understanding of how regulations are applied to minimize potentially negative environmental effects and the application process is simplified for both the industry and regulators while at the same time rendering it more transparent to clients and the public. Habitat Management Division (Maritimes Region) is currently using the MFADSS as a screening tool to evaluate new license for applications.

APPLICATION OF THE MFADSS TO PORT MOUTON

Available updated information from Port Mouton including data through 2007 from the NS EMP for site characteristics of the existing salmon aquaculture lease near Spectacle Island (835) and a potential new site (now under moratorium) near Port Mouton Island (1251) were compared using the MAFDSS. Net pen depth for the existing or proposed sites could not be confirmed so a nominal industry average value of 8 m (depth of fish + predator nets) was assumed for both locations. Approved production limit numbers could also not be confirmed, so values of 100,000 and 300,000[1] smolts for stocking the number

[1] Environmental Impact Statement (EIS) proposes stocking of 200,000 and 600,000 smolts for the two sites.

of cages indicated were assumed for the two sites. Lower numbers than indicated in the EIS were used since fallowing may occur following a production cycle and/or reduced stocking may occur due to effects of disease which would reduce numbers of fish at a site. Waste loading rates, calculated as described below, are scaled linearly to numbers of smolts (Strain and Hargrave 2005). A 100% increase in stocking density (to the proposed values in the EIS) would increase calculated feed and fecal waste production rates by 100%.

Results from running the MFADSS for two locations in Port Mouton with answers and assigned scores for ecosystem and site variables are presented in Fig. 1 (existing site 835) and Fig. 2 (proposed site 1251). Both locations fail the Cumulative Ecosystem Site Index score due to assignment of a pre-emptive C score for shellfish closures within 2 km. In addition, site 1251 received a pre-emptive C score for distance from an existing operating farm since if approved for operation it would be located within 2 km of site 835. C scores were also assigned due to the location of both sites <3 km from a Marine Park (the acceptable criteria is >5 km), the presence of an endangered species (piping plover) and critical spawning, nursery or migratory areas within 1 km.

Site 835 scored C for the Cumulative Site Index. The shallow depth of the site combined with assigned net pen depth of 8 m results in <3 m under pens for 50% of the time. Low current speed, calculated as <2 cm/s for 32% of the time, approached the threshold for a pre-emptive C score (<2 cm/s 40% of the time). The proximity of cages to the bottom and low current velocities are consistent with high levels of total 'free' sulfides (S)(mean 5130 uM for 8 sampling dates in 2007), high organic matter (OM) (mean of 22.5% of sediment dry weight) and a negative redox (Eh) potential (-78 mV). Estimated rates of particulate matter sedimentation based on organic loading calculations described below indicate that feed and fecal waste would each contribute approximately equal amounts (13 and 16 g C m^{-2} d^{-1}) of organic matter to the sediments. Due to the shallow depth and assigned values for settling rates of waste feed and feces minimum dispersion of particles is expected to occur. More than 85% of material released from the pens is calculated to reach the bottom within the median dispersion area around the lease. These loading rates are very high relative to expected natural seston sedimentation rates which at a maximum during late summer/fall might be 0.5 g C m^{-2} d^{-1}. High values of S and OM observed in surface sediments are consistent with the predicted elevated sedimentation rates.

Proposed Site 1251 did not fail the Cumulative Site Index (score B+) reflecting the slightly greater average depth and the low (essentially background) values for OM, S in surface sediments. The positive Eh potentials confirm the presence of oxic sediments at the site which would be expected given no local direct source of organic loading. Current velocities are as low as those at site 835 (<2 cm/s 27% of the time) and result in a similar score (B-). Although the site is surrounded by sills of a shallower depth, this has apparently not led to an accumulation of OM (mean 2007 value of 2.35%), S (76 uM) and redox potentials are positive (+272 mV) indicative of oxic conditions in surface sediments. This would be expected if there is no local source of high organic matter input. Although the range of distance under pens over tidal cycles is slightly greater than at site 835 (<5 m for 50% of the time), a salmon aquaculture facility at this site would still be expected to alter existing oxic conditions in surface sediments. With the assumed value for stocking of 300,000 smolts in 24 cages, sedimentation rates of feed (12 g C m^{-2} d^{-1}) and fecal (10 g C m^{-2} d^{-1}) waste spread uniformly over the median dispersion area would be predicted – similar in magnitude to rates calculated for site 835. Oxic surface sediments would become hypoxic and approach anoxic conditions (>6000 uM S) as is presently occurring at site 835.

Fig. 3 shows combined data from EMP observations in Port Mouton between 2004 and 2007. The plots compare surface sediment geochemical variables for site 835 (within lease boundaries (L) and at nearby reference locations (R)) and proposed site 1251. Panels A, B and C show relationships between sediment water content (porosity) and OM, Eh and S. Sand-rich sediments tend to have lower water content (<50% water) while more fine grain silt-clay rich deposits contain more water (>50%). Fine-grained sediments which contain high OM, lower Eh potentials and high levels of S tend to occur within the lease boundaries of site 835. Lease stations with more coarse-grained deposits (water content 60 to 80%) have increased levels of OM, decreased Eh potentials and higher S concentrations in contrast to 835 reference stations with a similar range of values for water content. Thus comparing sediments with similar textural properties (based on water content) inside and outside of the lease shows organic enrichment within lease boundaries.

Panels D, E and F in Fig. 1 show relationships between S, redox potentials, OM and a derived Benthic Enrichment Index (product of Eh, OM and water content described in Hargrave et al. 2008a,b). 'free' is used as an adjective with S to indicate that measurements of soluble S ions are made after sediment samples are placed in an alkaline anti-oxidant buffer solution (as opposed to measurements with an Ag/S electrode inserted directly into sediment). The expected inverse relationship between S and Eh observed in other locations is apparent in the data from Port Mouton. The slope (-78) derived for the regression using EMP data from Port Mouton is similar to that from SWNB (-66) (dotted line in Fig. 1D). There is a clear separation between lease and reference stations at site 835 with an overlap of values in the x-y plot for 835 reference and site 1251 stations. A similar separation of 835 lease stations from all other locations can be seen in the regressions between OM and the BEI index and S (Fig. 1E, F).

CALCULATIONS OF ORGANIC LOADING

Particulate matter waste discharges as dry matter and organic carbon expressed as total particulate waste released per ton of fish produced are calculated using a growth model for Atlantic salmon over the full grow-out period (Strain and Hargrave 2005). Organic carbon waste discharges are determined by subtracting the carbon content stored in fish (estimated from the growth model) from the carbon content of the feed. The amount of feed utilized is the product of fish growth x the economical food conversion ratio (FCR) defined as the ratio of feed used to fish produced (both on a wet weight basis). SWNB industry averages in 2002 of a FCR of 1.1 and feed containing 10% water are used in the calculations.

The growth model uses the average size of smolts placed in cages (90 g), the average grow-out period for the salmon aquaculture industry in southwestern New Brunswick (SWNB), and predicts the average harvest weight (4.9 kg) that matches data from a 1995-97 survey of 20 SWNB salmon farms (Peterson et al. 2001, Strain and Hargrave 2005). Due to interactions between fish size, growth rate and temperature, peak waste discharges occur during September/October in years one and two in SWNB. Maximum rates of waste discharge (3.06 kg organic carbon 1000 $fish^{-1}d^{-1}$) are about 3 times higher in the second year due to greater biomass on a site when salmon reach an average body weight of 3.3 kg. Worst-case estimates of fecal matter and waste feed release are based on the maximum daily waste discharge occurring in October 2 of the second year of culture (Strain and Hargrave 2005). Organic carbon is assumed to represent 50% of fecal matter dry weight to calculate dry matter waste release. Numbers of fish on a farm are assumed to be evenly divided between all pens proposed in a site application in order to make calculations of particulate waste discharge on a farm-scale.

Determination of the fractions of particulate waste released by salmon aquaculture in the form of fecal matter and unconsumed feed pellets is important for environmental management purposes. Strain and Hargrave (2005) used mass balance models for waste discharge and observations of sediment accumulation rates at farm sites in SWNB to conclude that while sediment debris piles under fish pens are often visible, most waste is transported further from farm sites even in depositional areas where hydrographic conditions promote waste accumulation under cages. Separation of total waste released into fecal matter and waste feed (3.06 kg C $(1000\ fish)^{-1}\ d^{-1}$) to estimate waste loading rates utilizes information on feed digestibility and retention (Strain and Hargrave 2005). Fecal waste (1.595 kg C $(1000\ fish)^{-1}\ d^{-1}$) produced at the time of maximum daily discharge (October 2 in the second year of growth) is estimated from the physiological growth model. The maximum value for waste feed loss (1.465 kg C $(1000\ fish)^{-1}\ d^{-1}$) is determined by difference after assessing carbon loss through respiration and releases of dissolved waste products and fecal matter. Loss of organic carbon in waste feed exceeds that released as fecal matter (ratio of 1.09) indicating that waste feed dominated solid wastes at the food conversion ratio (FCR) achieved by the salmon aquaculture industry in SWNB in 2002. 17% of the organic carbon in the total feed utilized was unconsumed.

The calculations for total waste loading rates (organic carbon discharged as feed + fecal matter) are expressed as kg $farm^{-1}\ d^{-1}$ based on the total number of fish present at a facility. This total waste release rate is separated into two categories (feed pellets and fecal matter) as described above. Since some of the organic matter in both feed and feces is easily decomposed, both while in the water column and soon after deposition on the bottom, some fraction of the organic matter in settled material released as waste will not contribute to organic loading of sediments under and around a farm site. Variable loss rates (0 to 100%) can be assigned but a default value of 50% is assumed in organic loading is assumed. The value is comparable with 50% of the wastes being easily decomposed based on 5-day BOD measurements which showed an exponential decline in oxygen consumption of particles collected in sediment traps near fish cages and by sediments collected under fish pens (Strain 2003).

Total waste released from a farm as calculated must be expressed on an areal basis if particulate matter sedimentation under and around a farm site is to be determined. The material released as waste must be distributed over a specific area. Mean water depth (LLW + half of the tidal range), reported current velocities over a tidal cycle (from mean maximum current speed over several consecutive tidal cycles) and assigned settling rates for feed pellets and feces are used to determine the horizontal distance that deposited material would travel before reaching the bottom. The default values for settling rates of feed pellets (11 cm s^{-1}) and fecal matter (3 cm s^{-1}) are consistent with those assumed in DEPOMOD and other models of salmon particulate matter waste sedimentation (Cromey et al. 2002, 2005, Stucchi et al. 2005, Chamberlain and Stucchi 2007). Maximum distances travelled are reported separately for feed pellets and feces (Figs. 1 and 2). The lower settling velocity of feces means that they are in the water column longer and move further than feed pellets. Different settling rates can be assigned to either feed pellets or fecal matter to observe related changes in dispersal areas and sedimentation rates. However, for results in different assessments to be comparable, it is advisable for assessors not to over-ride the default values.

The percentage of wastes leaving the cage area is calculated by assuming that waste particles are distributed uniformly over a median dispersal area based on tidal current information. The total area represented by this distribution is divided by the total cage area (number of cages x individual pen area). If all fecal waste or unconsumed feed particles sank directly under all of the pens on a site, then dispersal area = cage area (0 % of the waste leaves the site). If the median dispersal area is twice as large as the cage area, then 50% of the waste is estimated to leave the pen area. The median dispersal area for feed pellets is always less than that for more slowly settling feces due to assigned differences in settling rates.

The additional information section for summarizing results of dispersion distances and sedimentation rates of feed pellets and fecal matter shown in Figs. 1 and 2 uses the same data used to derive sedimentation rates over the median dispersal area and to make separate calculations of dry matter and organic carbon accumulation rates. The density of both fecal matter and waste feed pellets is assumed to be 0.6 g cm^{-3} to allow calculation of dry matter accumulation on the bottom. Tidal currents are assumed to move material homogeneously over 360º (i.e. in a circle) around a site due to resuspension and re-deposition. Median dispersion area is used to indicate the accumulation rate as if the waste was homogeneously distributed over the bottom equivalent to this area. The calculation ignores site specific characteristics of bottom topography and the frequency and magnitude of resuspension events which could result in localized areas of feces and waste feed accumulation. Since detailed bottom topology for a site is usually not known, the mass balance calculations can only be used to infer how rapidly sediment would build up around a site given a homogenous pattern of sedimentation. Measured sediment accumulation rates in SWNB showed that values of 0.25 cm y^{-1} occurred at some farms sites (Smith et al. 2005). Sedimentation rates >1 cm y^{-1} are very high and seldom observed in SWNB. However, natural rates of sediment accumulation vary widely and depend on depth, currents and wind mixing events that cause resuspension and subject material to horizontal transport.

SUMMARY

Shallow depths and low current velocities at both the existing farm and the proposed new lease location combined with the presence of sills that create depositional basins to retain settled organic waste from netpens make both locations in Port Mouton unsuitable for salmon aquaculture. Sites with much deeper water and higher currents are required to ensure dispersion of particulate waste products. The comparison of EMP data from lease and reference sites at site 835 indicates that oxic conditions in sediments within lease boundaries have been transformed from oxic to hypoxic bordering on anoxic conditions. These sub-oxic sediment will release dissolved ammonia into the water column – a possible nutrient source for macroalgae observed in the littoral zone at Carter's Beach. Similar benthic impacts would be expected to occur at a proposed new site near Port Mouton Island should the moratorium on licensing be removed and a new facility become operational at that location.

The observed levels of benthic organic enrichment observed within site 835 are consistent with modelled sedimentation rates of waste feed and feces where >85% of material released from the pens is calculated to reach the bottom within the median dispersion area around the lease. Predicted average sedimentation rates of feed (12 to 16 g C m^{-2} d^{-1}) and fecal (10 to 13 g C m^{-2} d^{-1}) waste spread uniformly over the median dispersion area would be predicted. These rates are more than an order of magnitude higher than expected natural seston sedimentation in similar coastal areas of Nova Scotia. High OM and the presence of hypoxic sediments with 'free' S approaching approaching anoxic conditions observed in the EMP data from Port Mouton are consistent with the elevated sedimentation rates.

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FIGURE CAPTIONS

Fig. 1 Results of the MFADSS for the existing salmon aquacuture site (835) at Spectacle island in Port Mouton with answers and assigned scores for ecosystem and site variables. Supplemental informational for dispersal and sedimentation of waste feed and fecal matter derived from model calculations is not used in determining site suitability based on ecosystem and site variables in the MFADSS.

Fig. 2 Results of the MFADSS for a proposed salmon aquaculture site (1251) at Port Mouton Island in Port Mouton with answers and assigned scores for ecosystem and site variables.

Fig. 3 Geochemical data for surface (0-2 cm) sediment from the Port Mouton EMP (2004-2007) comparing variables for site 835 (within lease (L) boundaries and nearby reference (R) locations) and proposed site 1251. A, B and C - relationships between sediment water content (porosity) and OM, Eh and S; D, E and F relationships between S, redox potentials, OM and BEI (product of Eh, OM and water content described in Hargrave et al. 2008a,b). Panel D shows the regression between S and Eh for salmon aquaculture areas in the Bay of Fundy (SWNB).

Marine Finfish Aquaculture Siting
Decision Support System (v2.01)

April 22, 2009

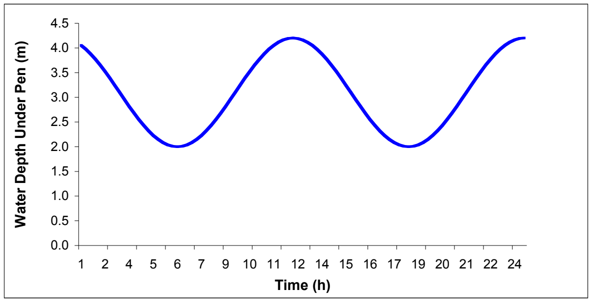
Name of Applicant	Aqua Fish Farms Ltd. (Port Mouton exisiting site at Spectacle Island)	
Name of Water Body or Nearest Community		Port Mouton
Habitat File Number		8200-02-2005-sb

% Time	Depth <0 m	0.0 on bottom
% Time	Depth <3 m	49.5
% Time	Depth <5 m	100.0
% Time	Depth <10 m	100.0
% Time	Curr <2 cm/s	32.3

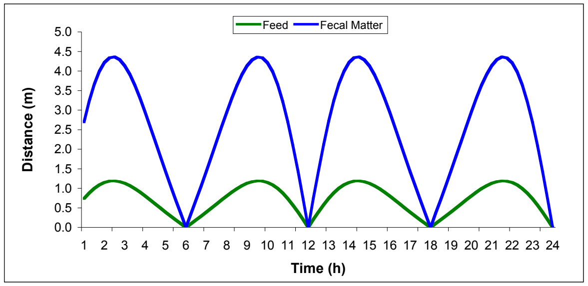
Approved Production Limit (APL)	100000
Proposed number of pens (total)	6
Cage Depth (m)	8.0

All questions to answered yes, no or as a numerical value (blank and 0 entries scored as C)

Ecosystem Variables (far field information yes or no answers determine **Cumulative Ecosystem Index**)		
Have there been shellfish closures in the area within the past year? If so give distance (km) from the proposed lease site. "0"=no closures	2	C
Are any species (fish or invertebrates) harvested for food or macroalgal beds within 250 m?	yes	B+
If there are other aquaculture sites in the area what is the distance (km) from the proposed lease site? No sites="0"	0.0	A
Is there a Marine Protected Area, Area of Interest or Marine Park within 5 km?	yes	B-
Are there any endangered fish, mammal or bird species at the site or within 5 km for which mitgation cannot be applied?	yes	C
Is there river discharge into the inlet/bay system or other factors to create stratification at any time in the year?	no	A
Is there a sill at any location within the inlet/embayment system?	yes	B-
Is there any industry (e.g. pulp and paper, logging, fish processing, marina) within 5 km of the site?	yes	B-
How many people live within 1 km of the site?	0	A
Is there a critical fish habitat (e.g. spawning or nursery area, migration route) at or within 1 km of the site?	yes	C
Cumulative Ecosystem Index (EI):	C	



Siting Variables (near field data to determine **Cumulative Site Index**)		
LLW water depth (CHS Chart Datum) (m)	10	
Tidal amplitude (spring tide depth variation)(m)	2.2	C
Mean peak current speed (cm s^{-1}) for current meter record duration	4	B-
Percent oxygen saturation in surface water in late summer/early fall months (or annual minimum)	96.5	A
Secchi disc depth (m)	5	B-
Percent sediment dry weight as silt + clay	32.1	B+
Sediment organic matter content (% weight loss on ignition) (upper 2 cm)	22.5	C
Sediment total sulfide (uM)	5130	B-
Sediment Eh potential (mV)	-78	B-
Number of sediment sampling locations in potential lease area	8	A
Length of current meter record (days)	14	B+
Cumulative Site Index (SI):	C	
	EI	**SI**
Cumulative Ecosystem (EI) and Site (SI) Indices :	C	C



Dispersal of Feed and Fecal Matter	
Assumed Feed Pellet Settling Rate (default 11 cm s^{-1})	11
Assumed Fecal Matter Settling Rate (default 3 cm s^{-1})	3
Feed Pellets: maximum dispersal distance (m)	1
percentage feed waste leaving cage area	4.0
Fecal Matter: maximum dispersal distance (m)	4
percentage of feces waste leaving cage area	13.6

Additional Information on Dispersal of Feed and Feces

Feed Pellets	
median ratio for dispersal area to cage area	1.0
feed pellet sedimentation rate (g C $m^{-2}d^{-1}$)	16.1
feed pellet sedimentation rate (dry weight m^{-2} d^{-1})	32.1
sediment accumulation rate due to feed pellets over median dispersion area (cm y^{-1})	0.98

Fecal Matter	
median ratio for dispersal area to cage area	1.2
fecal matter sedimentation rate (g C $m^{-2}d^{-1}$)	13.3
fecal matter sedimentation rate (dry weight m^{-2} d^{-1})	26.6

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Marine Finfish Aquaculture Siting
Decision Support System (v2.01)

Name of Applicant Aqua Fish Farms Ltd. (proposed new site 1251 at Port Mouton Island)		
Name of Water Body or Nearest Community	Port Mouton	
Habitat File Number	8200-02-2005-sb	
Approved Production Limit (APL)	300000	
Proposed number of pens (total)	24	
Cage Depth (m)	8.0	
All questions to answered yes, no or as a numerical value (blank and 0 entries scored as C)		
Ecosystem Variables (far field information yes or no answers determine **Cumulative Ecosystem Index**)		
Have there been shellfish closures in the area within the past year? If so give distance (km) from the proposed lease site. "0"=no closures	2	C
Are any species (fish or invertebrates) harvested for food or macroalgal beds within 250 m?	yes	B+
If there are other aquaculture sites in the area what is the distance (km) from the proposed lease site? No sites="0"	2.4	B-
Is there a Marine Protected Area, Area of Interest or Marine Park within 5 km?	yes	B-
Are there any endangered fish, mammal or bird species at the site or within 5 km for which mitgation cannot be applied?	yes	C
Is there river discharge into the inlet/bay system or other factors to create stratification at any time in the year?	no	A
Is there a sill at any location within the inlet/embayment system?	yes	B-
Is there any industry (e.g. pulp and paper, logging, fish processing, marina) within 5 km of the site?	yes	B-
How many people live within 1 km of the site?	0	A
Is there a critical fish habitat (e.g. spawning or nursery area, migration route) at or within 1 km of the site?	yes	C
Cumulative Ecosystem Index (EI):	C	
Siting Variables (near field data to determine **Cumulative Site Index**)		
LLW water depth (CHS Chart Datum) (m)	12	
Tidal range (spring tide depth variation)(m)	2.2	B-
Mean peak current speed (cm s^{-1}) for current meter record duration	5	B-
Percent oxygen saturation in surface water in late summer/early fall months (or annual minimum)	96.5	A
Secchi disc depth (m)	5	B-
Percent sediment dry weight as silt + clay	70	B-
Sediment organic matter content (% weight loss on ignition) (upper 2 cm)	2.35	A
Sediment total sulfide (uM)	76	A
Sediment Eh potential (mV)	272	A
Number of sediment sampling locations in potential lease area	10	A
Length of current meter record (days)	14	B+
Cumulative Site Index (SI):	B+	
	EI	**SI**
Cumulative Ecosystem (EI) and Site (SI) Indices :	C	B+

Dispersal of Feed and Fecal Matter

Assumed Feed Pellet Settling Rate (default 11 cm s^{-1})	11
Assumed Fecal Matter Settling Rate (default 3 cm s^{-1})	3
Feed Pellets: maximum dispersal distance (m)	2
percentage feed waste leaving cage area	4.1
Fecal Matter: maximum dispersal distance (m)	9
percentage of feces waste leaving cage area	13.9

Additional Information on Dispersal of Feed and Feces

Feed Pellets

median ratio for dispersal area to cage area	1.0
feed pellet sedimentation rate (g C $m^{-2}d^{-1}$)	12.0
feed pellet sedimentation rate (dry weight m^{-2} d^{-1})	24.1
sediment accumulation rate due to feed pellets over median dispersion area (cm y^{-1})	0.73

Fecal Matter

median ratio for dispersal area to cage area	1.2
fecal matter sedimentation rate (g C $m^{-2}d^{-1}$)	9.9
fecal matter sedimentation rate (dry weight m^{-2} d^{-1})	19.8
sediment accumulation rate due to fecal matter over median dispersion area (cm y^{-1})	0.60

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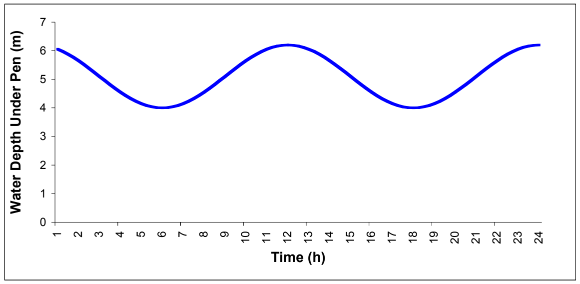
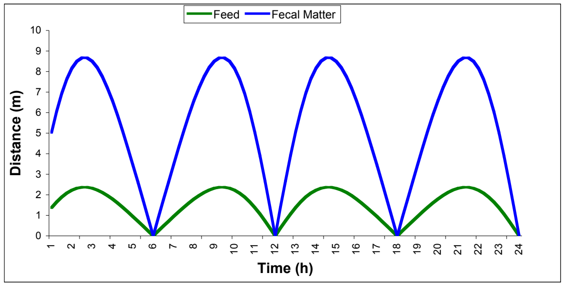
% Time	Depth <0 m	0.0	on bottom
% Time	Depth <3 m	0.0	
% Time	Depth <5 m	49.5	
% Time	Depth <10 m	100.0	
% Time	Curr <2 cm/s	26.9	





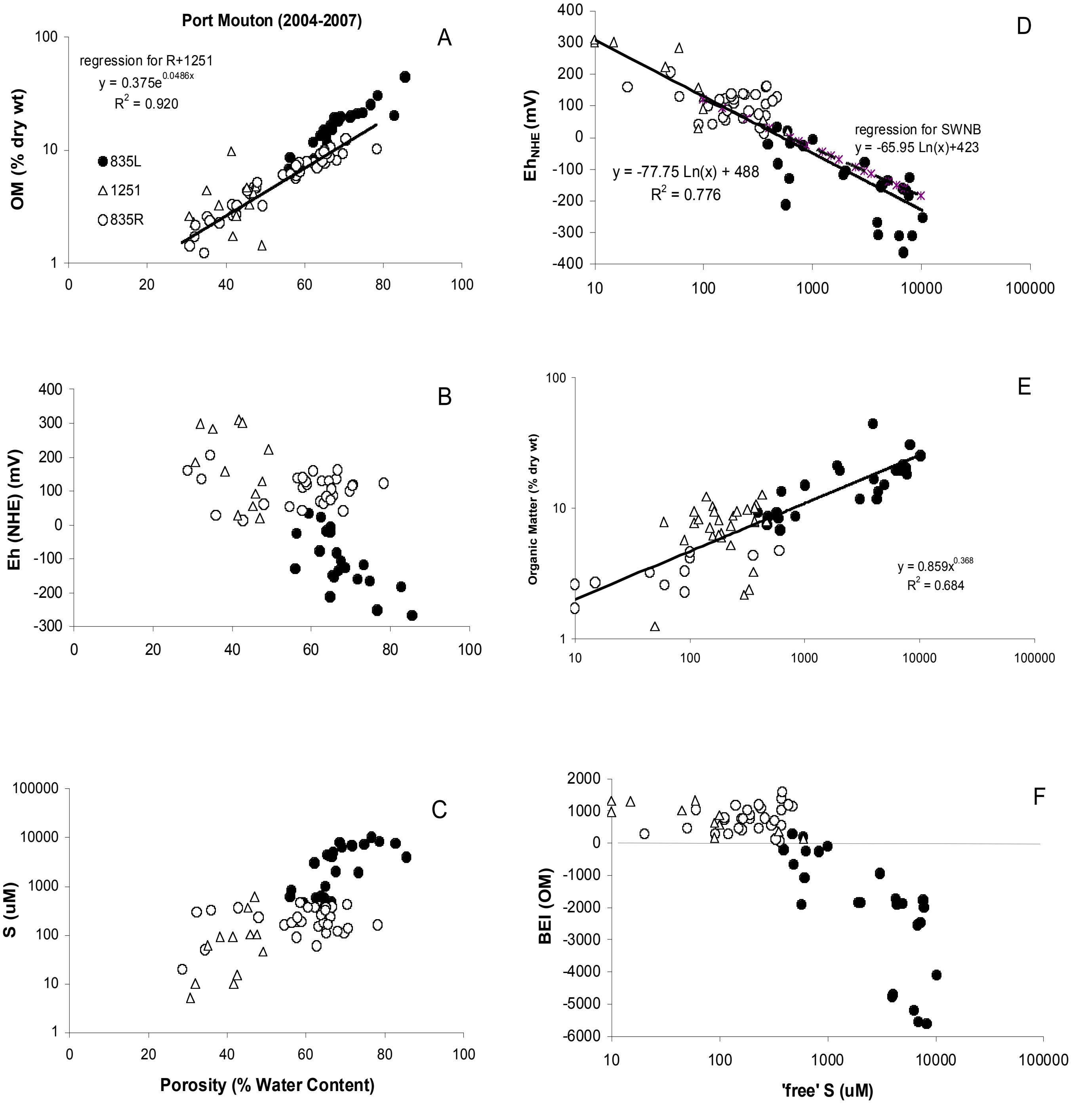

Port Mouton (2004-2007)
A
regression for R+1251
y = 0.375e^0.0486x
R^2 = 0.920
835L
1251
835R
OM (% dry wt)
D
Eh_NHE (mV)
regression for SWNB
y = -65.95 Ln(x)+423
y = -77.75 Ln(x) + 488
R^2 = 0.776
B
Eh (NHE) (mV)
E
Organic Matter (% dry wt)
y = 0.859x^0.368
R^2 = 0.684
C
S (uM)
Porosity (% Water Content)
F
BEI (OM)
'free' S (uM)

Fig. 3