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Maritimes Region
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Science Response 2009/001

WATER CURRENTS, DRIFTER TRAJECTORIES AND THE POTENTIAL FOR ORGANIC PARTICLES RELEASED FROM LITTLE MUSQUASH COVE TO ENTER THE MUSQUASH MPA

Context

A finfish aquaculture operation has been proposed in an area (Little Musquash Harbor) adjacent to the new Musquash Marine Protected Area (MMPA). Given the potential for interaction of organic waste from the farm with the MMPA, the Habitat Protection and Sustainable Development (HPSD) Section of DFO Maritimes the Oceans, Habitat and Species at Risk Branch requested a review of the potential oceanographic connection between the proposed site and the MMPA by DFO Science. Specifically, HPSD requested that the organic particulate tracking model DEPOMOD, and site specific oceanographic data, be used to assess the connectivity between the proposed aquaculture site and the MMPA. It was agreed that this request would be addressed through the Science Special Response Process with supporting documentation provided as a Research Document.

Background

A proposal to establish and operate a finfish aquaculture site in the mouth of Little Musquash Cove, was received in January of 2008 by the New Brunswick Department of Agriculture and Aquaculture, the New Brunswick Department of Environment and subsequently Fisheries and Oceans Canada. The proposed lease boundary dimensions are approximately 680x820m which is an area of about 49.1 hectares. Within this lease the fish cages are proposed to be distributed between two grid systems, each with a 3x4 array of cages (12 cages for each array) for a total of 24 cages. Each of these cages is to be 100m in circumference (a radius of 15.9m) and each grid cell is 55m square. The nets on each cage would be 10m in depth. The area covered by a single cage is therefore 795.8m^2 and the area covered by the complete cage system would be about 19,099 m^2. The water depth within the lease area varies from between about 10 and 30m below mean low water with a mean depth of 17.9m.

Each fish cage is proposed to be stocked with about 35,000 fish for a site total of about 840,000 fish. The fish will be placed into the cages at a size of about 75 to 100g and will be harvested at an average size of about 4.5kg. The expected food conversion ratio for these fish is 1.2:1.

The proposed site location (Figure 1) is approximately 4 km to the east of Chance Harbour and 2 km to the west of Musquash Harbour, a designated Marine Protected Area. The nearest operating fish farm is located near the mouth of Haleys Cove, a distance of 3 km toward the west.

A field program was undertaken by DFO Maritimes Science, St. Andrews Biological Station staff during the spring and summer of 2008 to gather new information on the water currents and drift patterns from the area of interest. The work consisted of a series of current meter moorings, drifter releases and model simulations.

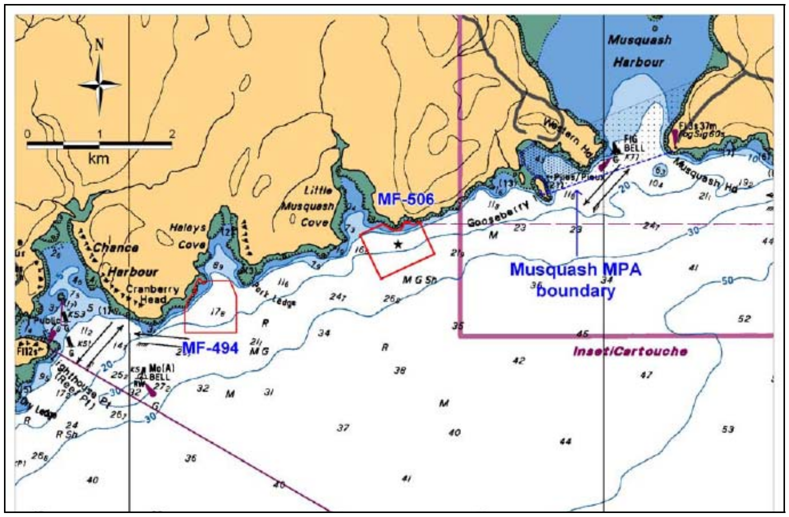

Figure 1. Map showing the Musquash Marine Protected Area (MPA), including the most seaward zone (Zone 3) within the MPA, the location of the proposed finfish aquaculture site MF-506 (thick red polygon) near Little Musquash Cove, the location of the existing fish farm (thin red polygon) at the mouth of Haleys Cove (MF-494), and the location of the current meter deployment 22 February to 27 March 2008 (indicated by a star near the centre of the site).

Analysis

From historical studies in the general area of Musquash Harbour, a typical maximum velocity for an estimate of particle displacement is approximately 1 m/s. When this velocity is assumed, particle displacement ranges from ±0.3 to 22 km with the range generated by differences in the sinking rates of particles of difference sizes and origin. Thus, crude estimates indicate that there is a potential for suspended particulates and dissolved substances, e.g., inorganic nutrients released from the proposed farm with very low sinking rates (e.g., <0.001 m/s), to enter the MMPA. The potential for particulates with higher sinking rates (e.g., 0.1 m/s), such as feed pellets, to enter the MMPA is less since they would likely sink to the bottom well before reaching the MMPA. These estimates assume that current is horizontally and vertically homogeneous throughout the displacement area and utilize very limited information on current speed that is not from the immediate area of interest. The currents off the coast of southwest New Brunswick are known to vary on small spatial scales and extrapolation of current information over spatial scales of hundreds of meters or more must be treated cautiously.

Current Speed

In an effort to collect more site specific information on current speed, an Acoustic Doppler Current Profiler (ADCP) was moored near the middle of the proposed aquaculture site for 35 days from 22 February to 27 March 2008. Results indicate there is little depth variation in the current speed at this site (Table 1). Water velocities obtained are consistent with earlier studies of circulation in this part of the Bay of Fundy (see Page et al. 2009 for additional detail on historical studies).

Table 1. The maximum, median, and minimum current speeds as recorded by an ADCP mooring located near the middle of the proposed Musquash Cove finfish aquaculture site.

	Near-surface Current Speed (cm/s) 3.6 m below surface	**Mid-depth Current Speed (cm/s)** 11.5 m below surface	**Near-bottom Current Speed (cm/s)** 3.6 m above bottom
Maximum	61.8	61.7	59.4
Median	29.6	34.8	27.7
Minimum	0.1	0.6	0.2

Particle Displacements Based on Current Data

Displacements Based on Constant Maximum and Median Velocities

Table 2 presents the results of calculations of radial displacements based on the observed maximum near-surface, mid-depth and near-bottom currents, estimated order of magnitude sinking rates (0.1 m/s for feed pellets, 0.01 m/s for fish feces, and 0.001 m/s for fines), and an assumed constant current velocity, for an aquaculture site moored at a depth of about 20m. From these calculations, the displacements for feed pellets were estimated to be 123-131m, and those of fish feces were estimated to be 1,228-1,314m. The displacements for non-sinking particles were estimated to be 14.4-15.4 km. Given that the MMPA seaward boundary is approximately 2 km away from the proposed aquaculture site, these calculations suggest feed pellets settle within the aquaculture site boundary and are not transported a distance sufficient to enter the MMPA. Fish feces are indicated to be transported beyond the aquaculture site boundary and of a sufficient distance that they come close to the MMPA boundary. Non-sinking particles are displaced a sufficient distance that they are predicted to enter the MMPA at times.

Table 2: Estimated radii of tidal excursion areas for particles that do not sink and the horizontal displacement of sinking feed pellets and feces.

Depth	Current speed (cm/s)	Estimated radius of tidal excursion (m)	Feed pellet displacement (m) (sinking rate 10cm/s)	Feces displacement (m) (sinking rate 1 cm/s)
Maximum current				
Near surface (3.5 m below surface)	61.8	14 461	124	1 236
Mid-depth (9.5 m below surface)	61.6	14 414	123	1 232
Near bottom (4.6 m above bottom)	61.4	14 368	123	1 228
All records	*65.7*	*15 371*	*131*	*1 314*
Median current				
Near surface (3.5 m below surface)	29.6	6 926	59	592
Mid-depth (9.5 m below surface)	35.1	8 213	70	702
Near bottom (4.6 m above bottom)	28.9	6 763	58	578
All records	*31.7*	*7 413*	*63*	*634*

These estimates represent maximum displacements and are likely to over-estimate the displacement of particles released from the aquaculture site for two reasons. The water velocities do not persist at the maximum rate and in the same direction for an entire half tidal cycle and the feces and feed pellet sinking rates are under-estimated by a few centimeters per second so the time scales are slightly over-estimated.

Similar calculations using the median current velocity values resulted in the calculated radius of displacement of feed pellets being 58-70m, the radius of displacement of feces being 578-702m and the radius of non-sinking particles (the passive tidal excursion radius) as 6.9-8.2 km. These calculations further suggest that feed pellets will not travel a distance sufficient to enter the MMPA and that the distance traveled by fish feces is insufficient to enter the MMPA. The displacement of non-sinking fine particles is reduced by more than half, but the displacement is still large enough to suggest entry into the boundary of the MMPA.

Displacement Based on the Full Time Series of Currents

The displacements of the fish pellet, feces and non-sinking particulates based on the full time series of mid-depth water velocities is summarized in Table 3. The particles are estimated to be scattered along an east-north-east to west-south-west axis. As expected, the displacements generated from the full time series of data are somewhat less than those generated by the maximum currents alone. Hence, these slightly more complete calculations support the indication that feed pellets and fish feces will not travel a distance sufficient to enter the MMPA. The displacements of non-sinking fine particles, although reduced compared to the previous calculations, continue to be large enough to suggest entry into the MMPA.

Table 3. Displacement of feed pellets, fish feces and non-sinking particulates based on the full time series of currents available.

	Feed Pellet Displacements (m)	**Fish Feces Displacements (m)**	**Displacement of Non-sinking Particulates (m)**
Maximum	123	1050	6600
75^{th} percentile	91	816	3700
Median	70	628	2800

DEPOMOD

DEPOMOD, an aquaculture waste dispersal model developed in Scotland, was run using the near-surface, mid-depth, and near-bottom time series of water velocities obtained from the current meter deployed at the centre of the proposed site at the request of HPSD. The model was run using two feeding rates: 500 kg of feed/cage/day and 1000 kg of feed/cage/day. These rates were based on industry recorded feeding rates for cages of similar size and stocking density to those proposed for the Little Musquash site.

The feeding rate of 500 kg of feed/cage/day, resulted in the maximum estimated carbon flux being 5.5 g C/m^2/d with 96% of the carbon fluxes ≥1.0 g C/m^2/d remaining within the site boundaries (Figure 2). When the feeding rate of 1000 kg/cage/day was used the maximum carbon flux was 11.2 g C/m^2/d with 86% of the carbon fluxes ≥1.0 C/m^2/d confined within the site boundaries (Figure 3). This model suggests that an estimated 27 ha of the seafloor would receive ≥1g C/m^2/d (47% of the 49.1 ha site). A deposition rate of 1g C /m^2/d is considered to be the threshold between oxic and anoxic sediments. The DEPOMOD calculations did not include the displacements of non-sinking particles.

The zones of exposure estimated from the DEPOMOD output are reduced compared to the zones estimated from the previous calculations. This is to be expected since the DEPOMOD approach used a more accurate estimate of fish feed pellet and fecal sinking rates, the release from all of the individual cage and outputs results in terms of the concentration of the settled particles, in this case we chose units of carbon mass. The settling rate of feed pellets was assumed to be 11 cm/s rather than 10 cm/s. This 10% increase in the settling rate results in a reduced sinking time and hence a reduced horizontal displacement by about 10% relative to the simple order of magnitude calculations. The settling rate of fish feces was assumed to be 3.2 cm/s rather than 1 cm/s. This 300% increase in the settling rate results in a considerable reduced sinking time for fish feces and hence a reduced horizontal displacement by about 300% relative to the simple order of magnitude calculations. The DEPOMOD model also assumes that most of the waste from the aquaculture site is due to fish feces rather than feed pellets, so the output concentration field is dominated by the dispersal of the feces. The combination of these factors accounts for the much smaller length scale of exposure produced by the DEPOMOD compared to the simpler order of magnitude calculations.

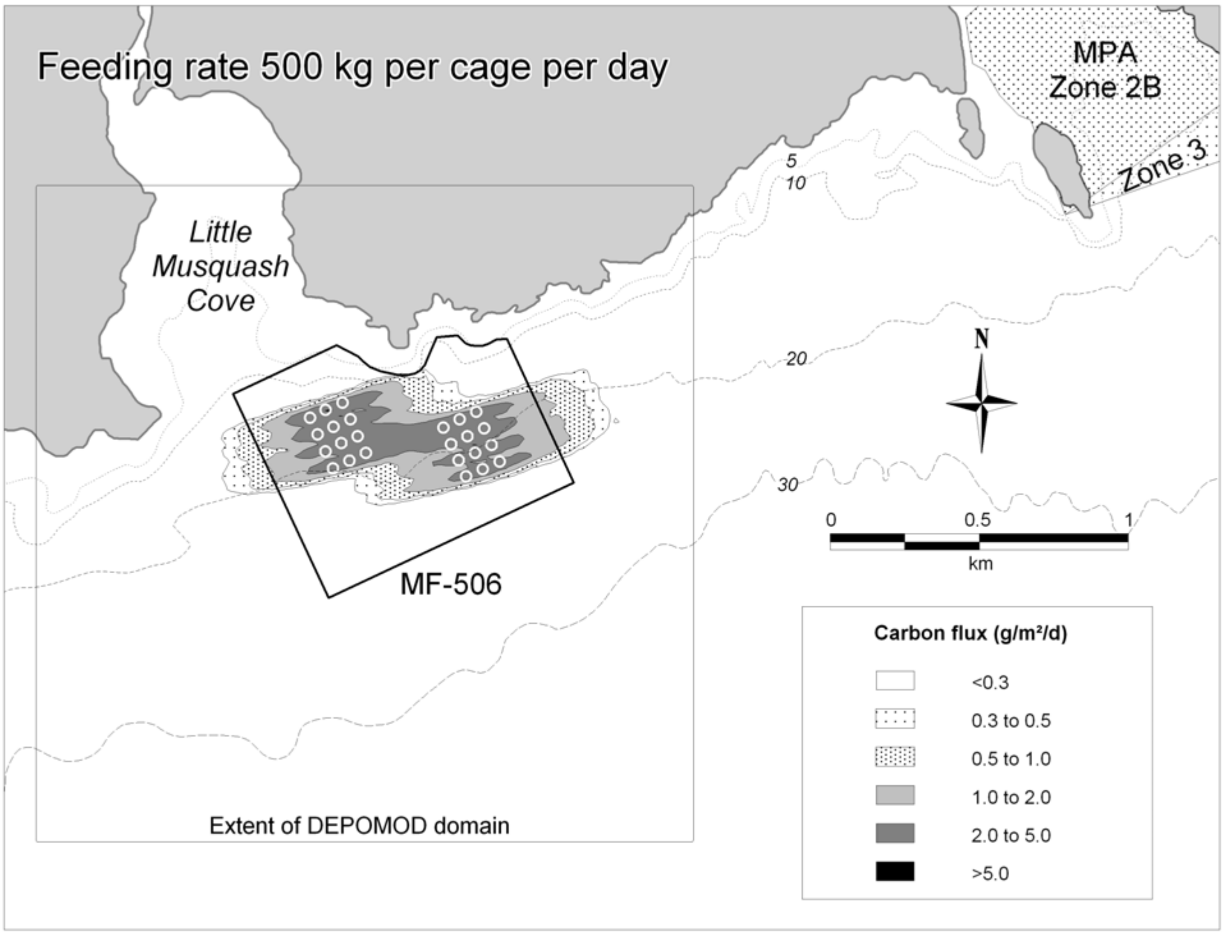

Figure 2. Carbon fluxes to the seafloor at proposed aquaculture site, as predicted by DEPOMOD, using a feeding rate of 500 kg/cage/d. The larger square represents the model domain (2000 × 2000 m). Also shown are the proposed site's boundaries (MF-506) and cage locations. The Musquash Marine Protected Area is located at the top right.

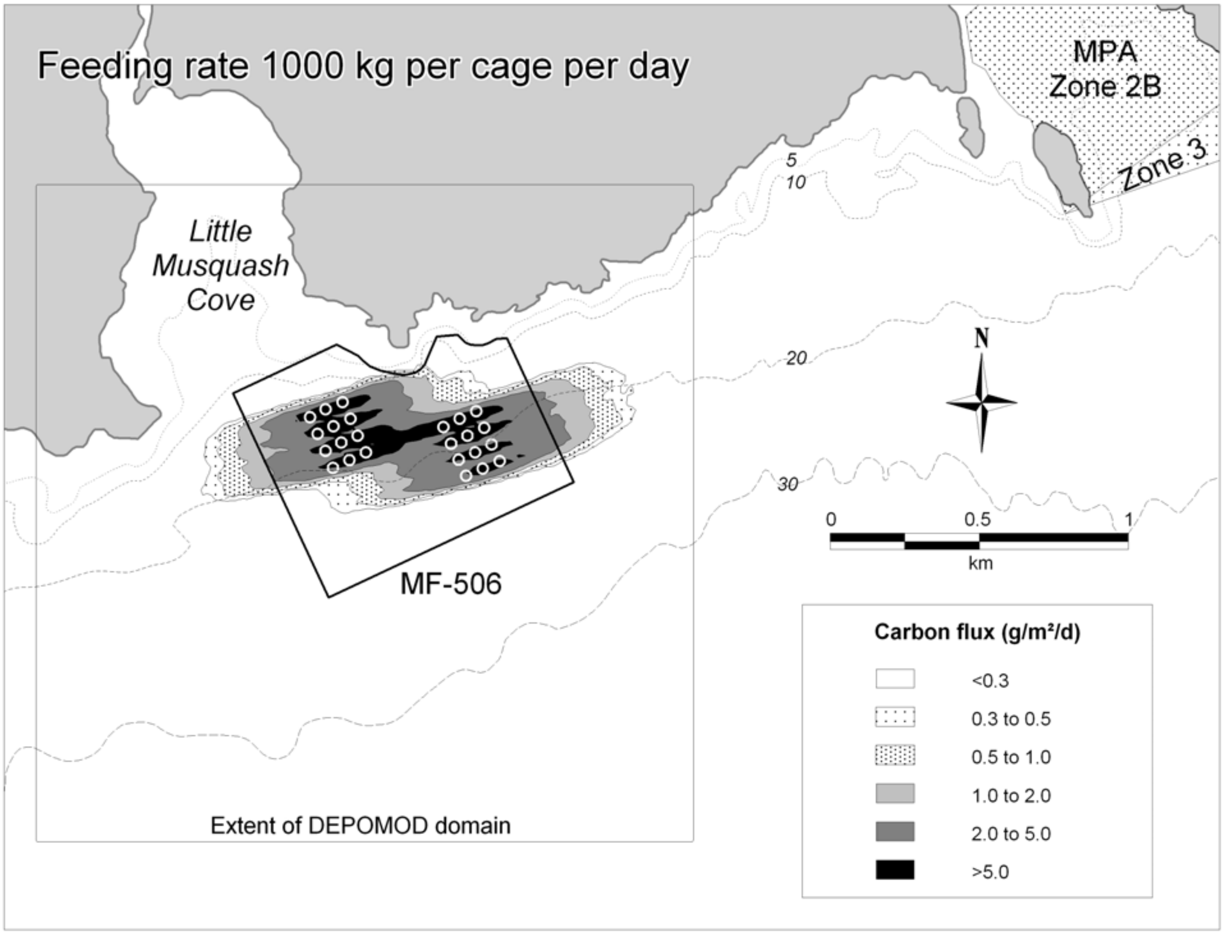

Figure 3. Carbon fluxes to the seafloor at proposed aquaculture site, as predicted by DEPOMOD, using a feeding rate of 1000 kg/cage/d. The larger square represents the model domain (2000 × 2000 m). Also shown are the proposed site's boundaries (MF-506) and cage locations. The Musquash Marine Protected Area is located at the top right.

Particle Displacements Based on Drifter Data

Surface drift in the vicinity of the proposed aquaculture site was studied using Convertible Accurate Surface Tracker (CAST) drifters. The drifters were released in clusters of 5-6. Clusters were deployed in the vicinity of the proposed aquaculture site and the MMPA in July and August 2008 (Table 4). Drifters were recovered on the following day, about 17-24 h after release; although in some cases, the drifters had become stranded on shore within a few hours after release (Table 4). These drifter studies are the first to resolve drift trajectories within a tidal cycle in the Musquash area and the first to accurately record the time at which drifters reach the shoreline within the Musquash area. The results are consistent with the information derived from historical drifter studies (see Page et al. 2009 for additional details on historical studies).

Table 4: Date, time, location, number of drifters, tide, and wind conditions at time of drifter releases.

Date	Time (UTC)	Location	No. of drifters	Nearest tide (Musquash Harbour)		Wind at release time (Point Lepreau)	
				Type	Time (UTC)	Direction (degrees)	Speed (km/h)
22 Jul 2008	12:21	Farm	6	Low	12:10	60 (NE)	13
24 Jul 2008	14:18	Farm	6	Low	13:37	50 (NE)	11
28 Jul 2008	11:12	MPA	6	High	11:11	170 (S)	7
30 Jul 2008	13:36	Farm	5	High	13:19	250 (SW)	9
6 Aug 2008	13:03	Farm	6	Low	13:06	320 (NW)	6
20 Aug 2008	11:57	Along the Coast to the east and west of the Farm	5	Low	11:41	300 (NW)	15

All 6 drifters released on 22 July 2008 entered Zone 2B of the MMPA. Four landed on the cove shore within 7 hours after release. Two left the MMPA, after which 1 landed in Little Musquash Cove and 1 in Haleys Cove about 16 hours after release. None of the other drifters released near the proposed aquaculture site entered the MMPA and none of the drifters released during the ebbing phase of the tide entered the MMPA. The average displacement of surface drifters over of a single tidal period (12.42 h) was approximately 10 km and 6 of 19 drifters, or 32%, of the drifters released near the proposed farm site during the flooding phase of the tide entered the MMPA. Another 5 of these 19 drifters came close to entering the MMPA.

Of the drifters that were released from the northern boundary of MMPA Zone 2 on the ebbing tide, all except one drifter remained within Musquash Harbour, eventually running aground within Zone 2. The other drifter left the MMPA, entering the Bay of Fundy before returning to the MMPA Zone 2. This suggests that materials released immediately seaward of the mouth of the MMPA also have a chance of entering the MMPA.

It should be recognized that these drifter studies occurred during the time of year when fresh water discharge and the rate of the westward residual flow is relatively low and the predominant winds are weak and from the southwest. This suggests that the eastward tidal trajectories of particles may be relatively large and the surface flow out of the MMPA relatively weak, suggesting that the potential for exchange into the MMPA may be at a seasonal high. Releases during other times of the year when the rate of westward flow is larger and winds are from the northwest might result in fewer drift tracks entering the MMPA. Hence, on an annual basis the probably of surface particles entering the MMPA may be lower than indicated above. This suggestion is supported by the drifter studies conducted by Bumpus and Lauzier (1965) and Bugden (1980) which indicate the predominant flow along the coast is toward the west and that a net eastward drift, and hence entrance into the MMPA, is not a common event. A more detailed consideration of this probability will require much more extensive field and modeling work.

Conclusions

The currents in the Musquash area, and hence the transport and dispersal of substances released from the proposed aquaculture site, are dominated by strong tidally periodic currents superimposed on a weaker and seasonally varying residual flow. These tidal currents are expected to vary throughout the year due to variations in the tidal forcing, but this variation is expected to be within several tens of percentages.

The residual currents and associated drift trajectories have a strong annual variation associated with the influence of seasonal variation in river discharge. Although the residual flow is consistently toward the west, the speed of this flow is enhanced during periods of high discharge and reduced during the periods of low river discharge. Over timescales greater than 1 tidal cycle, the residual flow results in the net displacement of particles being progressively further toward the west.

In addition to seasonal variation, the currents may vary on small spatial scales (hundreds of meters) that were not captured in the single current meter mooring results provided.

Materials that sink (e.g., fish feed and feces) and that would be released from the proposed aquaculture site location are expected to remain within the vicinity of the proposed site and are not expected to enter into the MMPA. Although the length scale of the particle displacements is sensitive to the sinking rate of the particles, this conclusion is robust to the conservative order of magnitude sinking rates assumed in this report. DEPOMOD runs using feeding rates of 500 and 1000 kg of feed/cage/day estimate the carbon flux associated with the sinking particles to be ≥ 5 g C/m^2/day in some areas within the site boundaries.

Substances that remain suspended or dissolved in the water column will likely be displaced from the site by distances in the order of 10 km on each tidal cycle (the average displacement excursion of surface drifters deployed in this study) and some of these are likely to enter the MMPA. Ten kilometers is greater than the distance between the proposed aquaculture site and the MMPA, and 6 of 19 (32%) drifters released at the proposed aquaculture site during the flooding phase of the tide entered the MMPA. An additional 5 of the 19 drifters came close to the boundary of the MMPA. None of the drifters released at the proposed aquaculture site during the falling phase of the tide (0 of 11) entered the MMPA.

This response does not consider the particle displacements that might occur due to possible resuspension of particles. The possibility that secondary movement of settled and resuspended materials toward the shore and the MMPA is suggested by historical bottom drifter data, the residual flows estimated from near-bottom current meter records, and the observation that the maximum speed of the flood current is greater than that of the ebb current. The time scale over which this transport might occur is unknown and a lack of knowledge of sediment resuspension and transport dynamics in the area means a more extensive assessment of the possibility of this transport mechanism resulting in material entering the MMPA was beyond the scope of this report.

The mouth of the MMPA is only likely to receive some of the output from the proposed aquaculture site, specifically outputs that remain suspended or floating in the water column. Input from resuspended or bottom transported materials remains an unquantified possibility, and additional work would be required to determine specific ecological consequences of this input.

Although additional current records from this area could be beneficial for quantifying the annual changes in the spatial and temporal current regime and could modify the details of the estimated transport and dispersal patterns described here, it is not expected that additional information would substantially change the conclusion that the fish feed pellets and well formed fish feces are unlikely to be directly transported into the MMPA. The information would, however, be useful for refining the assessment of the exposure of the MMPA to slowly sinking, suspended and dissolved substances, and resuspended substances, as well as perhaps improving the estimate of the flux rate of carbon to the bottom.

A more extensive multi-year effort would be needed to estimate the concentration exposure pattern and to assess whether this exposure would have any ecologically significant influences. In general, these "far-field" effects are not well understood. An assessment of these influences could include a good characterization of the existing state of the ecosystem within the mouth of the MMPA, a quantification of the degree of the incremental organic loading, and an assessment of the associated biological consequences that might be caused by this loading.

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Sources of Information

Bugden, G.L. 1980. Point Lepreau Environmental Monitoring Ocean Drifter Release Program. Bedford Institute of Oceanography Report Series, BI-R-80-4.

Bumpus, D.F., and L.M. Lauzier. 1965. Surface circulation on the continental shelf off eastern North America between Newfoundland and Florida. Serial Atlas of the marine Environment, Folio 7, American Geophysical Society.

Forrester, W.D. 1959. Chapter 3 Current measurements in Passamaquoddy Bay and the Bay of Fundy 1957 and 1958. International Passamaquoddy Fisheries Board Report to International Joint Commission Appendix 1, Oceanography, October 1959.

Godin, G. 1968. The 1965 current survey of the Bay of Fundy - A new analysis of the data and the interpretation of the results. Marine Sciences Branch, Department of Energy, Mines and Resources, Ottawa, Manuscript Report Series No. 8.

Mavor, J.W. 1921. Circulation of Water in Bay of Fundy and Gulf of Maine. Trans. Amer. Fish. Soc. 50: 334-344.

Page, F.H., B. Chang, R. Losier, and P. McCurdy. 2009. Water currents, drifter trajectories and the estimated potential for organic particles released from a proposed salmon farm operation in Little Musquash Cove, southern New Brunswick to enter the Musquash Marine Protected Area. CSAS Research Document 2009/003.

Watson, E.E. 1936. Mixing and Residual Currents in Tidal Waters as Illustrated in the Bay of Fundy. J. Biol. Bd. Can. 2(2): 141-208.

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