Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

Maritime Region

Canadian Science Advisory Secretariat
Science Advisory Report 2012/042

REVIEW OF DEPOMOD PREDICTIONS VERSUS OBSERVATIONS OF SULFIDE CONCENTRATIONS AROUND FIVE SALMON AQUACULTURE SITES IN SOUTHWEST NEW BRUNSWICK

Aerial photo of a salmon farm in southwestern New Brunswick (courtesy of J.A. Cooper, DFO, St. Andrews Biological Station).

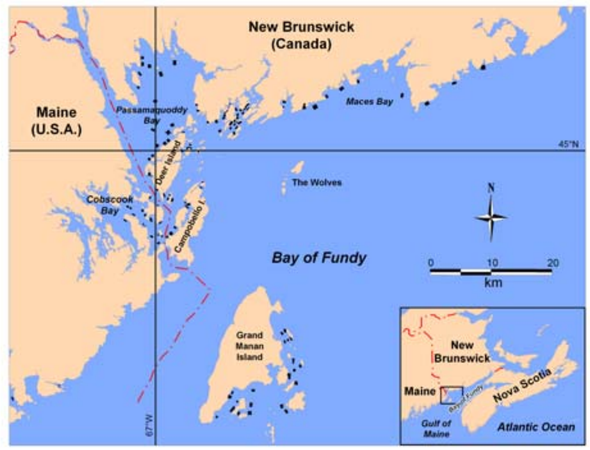

Figure 1. Map of southwestern New Brunswick, showing approved finfish farms in 2010.

Context

The risk of organic enrichment impacts to the seafloor associated with marine finfish aquaculture production has been studied extensively, and the relationship between carbon enrichment, sulfide levels, and the biodiversity of benthic infauna organisms is generally understood. Measurements of surface sediment total 'free' sulfide concentration serve as an indicator of changes in benthic biodiversity.

Low level fluxes of organic material can have both positive and negative impacts on the biodiversity of fish habitat, depending on habitat type and the resident species. However, at high rates, it is generally accepted that the flux of organic material to the seafloor is likely to cause a harmful alteration in fish habitat, a reduction in biodiversity, and changes in benthic species composition.

Models that predict potential benthic impacts can be used during the assessment stage of aquaculture site development. The most commonly used model of processes leading to the deposition of particulate wastes from marine finfish aquaculture is "DEPOMOD" (Cromey et al. 2002; Chamberlain et al. 2005).

This Science Advisory Report is from the 15-16 February 2012 review of Sulfide Concentrations around Select Aquaculture Sites in Southwest New Brunswick: Review of DEPOMOD Predictions versus Observations. This meeting reviewed the effectiveness of output from DEPOMOD and a simpler modeling approach for predicting benthic impacts in the southwest New Brunswick region. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

SUMMARY

- Science advice is presented on the effectiveness of a commercial model (DEPOMOD) for predicting the magnitude and area of seabed organic enrichment impacts from marine finfish aquaculture sites in the Maritimes Region. Model accuracy was assessed based on comparisons of predicted carbon deposition rates at five active marine finfish aquaculture sites in southwest New Brunswick with measurements of total ‘free’ sulfide concentrations collected at these sites. Sulfide levels are used as an indicator of seabed community impacts for aquaculture monitoring in the Maritimes Region.

- DEPOMOD predictions of the total area impacted by particulate waste deposition at the five sites in southwest New Brunswick did not show a strong relationship to the measured impact area.

- Comparisons of the maximum organic carbon deposition rate at each site predicted by DEPOMOD (resuspension turned off) did not show a strong relationship with the maximum measured sulfide concentrations.

- Comparisons of measured sulfide concentrations showed a positive correlation with DEPOMOD predicted carbon deposition rates (with resuspension off) at the same locations, but with much variation, and the variation in observed sulfide concentrations increased with the level of predicted carbon deposition.

- For aquaculture sites where feeding had been relatively consistent over the previous few months, observed sulfide concentrations were in the same categories (<3,000 µM) at 85% of the sampling locations where DEPOMOD predicted a low degree of impact (<5 g C m^{-1} d^{-1}; equivalent to Oxic A to Hypoxic A).

- At sampling locations where DEPOMOD predicted a high degree of impact (>5 g C m^{-2} d^{-1}; equivalent to Hypoxic B to Anoxic), observed sulfide concentrations were in the same categories (>3,000 µM) at only 63% of the sampling locations. Model accuracy for predicting impact magnitude varied among the sites.

- A simple model for predicting waste deposition was tested at the five sites. This model required much less input data compared with DEPOMOD. The simple model did not provide an estimate of the intensity of impacts but focused on predicting the spatial extent of impacts, based on median current speeds and average water depths at sites. Comparisons among sites of the spatial extent of elevated seafloor impacts predicted by DEPOMOD and the simple model showed relatively good agreement.

INTRODUCTION

The organic enrichment of seafloor sediments and related impacts on organisms living on and in sediments is one of the main environmental concerns related to finfish aquaculture. Annual environmental monitoring of finfish farms in the Maritimes Region has focused on detecting the magnitude and geographic extent of these potential impacts (NBDENV 2006; NSDFA 2011). The prediction of potential seabed organic enrichment is a component of the assessment phase for new farm proposals in the Maritimes Region. These assessments are based, in part, on the opinions of scientific experts familiar with this issue. Modeling tools such as DEPOMOD provide scientists and regulators an additional means of conducting quantitative site assessments, but they require extensive testing to ensure that they provide accurate predictions under environmental conditions in the Maritimes Region.

Fisheries and Oceans Canada (DFO) Habitat Management Division (HMD) has shown an interest in using DEPOMOD to predict organic deposition at proposed finfish farms in New Brunswick and Nova Scotia (NS), and HMD has requested DFO Science's evaluation of the effectiveness of this model for predicting benthic impact magnitude (intensity) and extent (geographic area).

DEPOMOD is a commercial model that was developed in Scotland to predict organic deposition under finfish aquaculture sites (Cromey et al. 2002), and it has been used in Canada to assess potential salmon aquaculture impacts in British Columbia (Chamberlain et al. 2005; Chamberlain and Stucchi 2007), southwest New Brunswick (DFO 2009; Page et al. 2009), and St. Mary's Bay, NS (DFO 2011). DEPOMOD is used to predict organic carbon deposition rates resulting from feed wastage and fish feces production. Although the relationship between carbon flux and the level of total dissolved (free) sulphides in marine sediments is complex and influenced by a range of factors, previous DFO and international research shows that a relationship exists between these parameters (Hargrave et al. 2008 and references therein; Hargrave 2010). Total sulfides measurements are used in the Maritimes Region to indicate the degree of impact from organic enrichment on sediment communities. Consequently, model-based predictions of the magnitude and extent of carbon deposition under fish cages and measurements of total 'free' sulfides in sediments under the same cages should provide comparable results.

Science advice is presented on the effectiveness of DEPOMOD for predicting the magnitude and area of seabed organic enrichment impacts from marine finfish aquaculture sites in the Maritimes Region. Model accuracy was assessed based on comparisons of predicted carbon deposition rates at five active marine finfish aquaculture sites in southwest New Brunswick (SWNB) with measurements of total 'free' sulfide concentrations collected at these sites. These sites were chosen because the data necessary to run DEPOMOD were available and data on seafloor impacts (i.e., total 'free' sulfide concentrations) were available from intensive sediment sampling at these sites. Sulfide levels are used as an indicator of seabed community impacts for aquaculture monitoring in the Maritimes Region. A simple modeling approach was also employed, and the results compared with those obtained by DEPOMOD.

ANALYSIS

DEPOMOD Methods

DEPOMOD requires data on bathymetry, current velocities, cage dimensions and positions, and feed rates per cage. Bathymetry data were obtained from Canadian Hydrographic Service (CHS) field sheets and current velocities were obtained from 2 to 3 current meter deployments at or near each study site (each deployment was for 30 or more days). Where sufficient data were available, current speed and direction data were extracted for 3 depth layers (near surface, mid-depth, and near bottom). Data on cage dimensions, cage positions, and feed rates per cage were obtained from site operators. Required data on feed and fecal pellet characteristics (feed wastage rates, water content, digestibility, carbon content, and settling velocity, feces carbon content and settling velocity) were the same as recommended for use of DEPOMOD in British Columbia (Stucchi and Chamberlain, unpublished manuscript). DEPOMOD includes a resuspension module, which assumes a fixed threshold for resuspension, at a near-bed (approximately 3.5 m above bottom in this application) current speed of approximately 9.5 cm s^{-1} (Cromey et al. 2002). DEPOMOD was run with the resuspension module both turned off and on.

DEPOMOD Results

Example contour plots of predicted carbon deposition rates are shown in Figure 2 for two study sites (sites A and C). This figure shows model outputs where the resuspension module had been turned off and on. It is apparent that when resuspension processes were simulated (i.e., turned on), the model predicted that very little of the released material remained within the modeled area (domain). At the remaining three sites, the measured current velocities did not exceed the resuspension threshold as often and, thus, were not as sensitive to this module being applied. Consequently, a large fraction of the released material remained within the domain. The deposition area was sensitive to the different current meter records only when resuspension was turned on.

Variation in feeding rates between individual cages within a site influenced the distribution and areas of predicted impacts under the site. A site with similar feeding rates per cage (site C; September 2006) indicated fairly uniform impacts would occur under the site, while predictions made at a site with considerable variation in the feed rates per cage (site A) resulted in spatial variation in the predicted impacts. Maximum carbon deposition increases with feed wastage rate, and the rate of increase varied between sites (Figure 3). The above predictions were made with the resuspension module turned off.

DEPOMOD sensitivity to changes in the water depth (within the normal range in tidal elevation) at a site was examined and was shown to have little effect on predictions.

Sediment Sulfide Concentrations

Intensive sediment sampling was conducted at each of the five sites. At three of the sites, this sampling included areas within and extending away from the cage array (reported in Chang et al. 2011). Extensive sulfide sampling at two additional sites was conducted as part of New Brunswick environmental monitoring programs (NBDENV 2006). Example contour plots of total ‘free’ sulfide concentrations in sediments at sites A and C are shown in Figure 4. Sulfide concentrations showed a spatially patchy distribution at all sites. The highest observed sulfide concentrations occurred near some, but not all, of the cages receiving the most feed. At one site where all 15 cages received relatively equal amounts of feed (site C), high sulfide concentrations were only found under one cage (Figure 4).

Comparison of DEPOMOD Predictions and Sediment Sulfide Concentrations

Area of Impact: Example maps showing model predictions of the areas of carbon deposition rate (flux) and the sediment sulfide data at sites A and C are shown in Figure 5. To enable a consistent comparison of the predicted and measured areas of impact, an impact threshold equivalent to the Hypoxic B rating or worse was employed. This category has been defined to be equivalent to sediment sulfide concentrations ≥3,000 µM (NBDENV 2006; NSDFA 2011). The equivalent carbon deposition rate, according to the nomogram in Hargrave et al. (2008) is approximately 5 g C m^{-2} d^{-1}. This value was derived primarily from an analysis of data collected from British Columbia. DEPOMOD predictions of the total area impacted by particulate waste deposition at the five fish farms in SWNB did not show a strong relationship to the measured impact area (Figure 6).

Intensity of Impact: Comparisons of the maximum organic carbon deposition rate at each site predicted by DEPOMOD (resuspension turned off) did not show a strong relationship with the maximum measured sulfide concentrations (Figure 7). Although there is considerable scatter in this relationship, measured sediment sulfide concentrations generally increase as DEPOMOD predictions of carbon deposition rate increase (Figure 8). This relationship was strongly influenced by data collected at one site, as a result of uncertainty regarding the appropriate feeding rate to use at this site. Subsequent information obtained on actual feeding rates at this site required the model results from this site to be excluded from our comparisons, and, thus, they are not included in Figure 8.

Location of Impact: DEPOMOD (with resuspension off) predicted that areas of elevated deposition rates would occur under the cage arrays, with highest impacts under cages receiving the most feed. Sulfide concentrations at site A in September 2005 were mainly under the cage array, with higher concentrations under some of the cages receiving more feed, and in some cases, an offset relative to the cages. At site A in May 2006, the offset was more pronounced, with some elevated sulfide concentrations extending to the edge of the sampling area. At two sites, elevated sulfide concentrations were found under some but not all cages. At two other sites, elevated sulfide concentrations were found under most of the cage arrays, but because sampling did not extent outside the cage arrays, it is not known if elevated sulfide concentrations extended beyond the cage areas. Thus, comparisons of measured sulfide concentrations showed a positive correlation with DEPOMOD predicted carbon deposition rates (with resuspension off) at the same locations, but with much variation, and the variation in observed sulfide concentrations increased with the level of predicted carbon deposition.

For aquaculture site where feeding had been relatively consistent over the previous few months, observed sulfide concentrations were in the same categories (<3,000 μM) at 85% of the sampling locations where DEPOMOD predicted a low degree of impact (<5 g C m^{-1} d^{-1}; equivalent to Oxic A to Hypoxic A). At sampling locations where DEPOMOD predicted a high degree of impact (>5 g C m^{-2} d^{-1}; equivalent to Hypoxic B to Anoxic), observed sulfide concentrations were in the same categories (>3,000 μM) at only 63% of the sampling locations. Model accuracy for predicting impact magnitude varied between the sites. When DEPOMOD predicted a low degree of impact (less than 5 g C m^{-2} d^{-1}), the measured sulfide value at that sampling location generally (>85% of data points, excluding the site referred to in the previous paragraph) reflected a low degree of impact (<3,000 μM S) (Figure 9). When DEPOMOD predicted deposition rates greater than 5 g C m^{-2} d^{-1}, approximately 63% of the corresponding sulfide values (excluding the one site indicated above) indicated elevated impacts (Hypoxic B classification or worse; >3,000 μM sulfide) (Figure 9). This percentage is different for individual sites. At 1 of the 4 sites, predicted deposition rates greater than 5 g C m^{-2} d^{-1} corresponded with only 1% of measured sediment sulfide concentrations indicating impacted conditions.

Simple Model Methods and Results

A simple model for predicting waste deposition was tested at the five sites. This model required much less input data compared with DEPOMOD (average water depth, median current speeds (not direction), and a value for the waste particle settling velocity). For waste particle settling velocity, the value recommended in DEPOMOD for feed pellets (Stucchi and Chamberlain, unpublished manuscript) was chosen since Chamberlain and Stucchi (2007) found that waste feed was the major contributor to organic deposition in their British Columbia study. Using the median current speed, the horizontal distance that waste feed particles would travel until they reached the seafloor was calculated. Circular zones were then drawn around each cage using this distance from the cage edge. The zones for each cage were combined to provide an estimate of the total area of elevated impacts for the farm. The simple model did not provide an estimate of the intensity of impacts but focused on predicting the spatial extent of impacts, based on median current speeds and average water depths at sites. Example predictions for sites A and C are shown in Figure 10.

Comparisons among sites of the spatial extent of elevated seafloor impacts predicted by DEPOMOD (resuspension off) and the simple model showed relatively good agreement (Figures 5 and 11).

Sources of Uncertainty

The major sources of uncertainty in making decisions on how DEPOMOD should be run (data inputs) include the choice of appropriate feed rates and the characteristics of the waste particles. DEPOMOD does not permit the input of site-specific current thresholds for waste resuspension, and the use of the resuspension module has always been of considerable concern wherever it has been employed. There is also uncertainty in the time required for deposited carbon to be consolidated (i.e., no longer available for resuspension). That will affect the potential for resuspension and the degree of impact. While this study is considered to be extensive from the perspectives of the degree of sampling and computation effort, the small sample size (five sites) makes it difficult to draw conclusions on the accuracy of DEPOMOD for predicting carbon deposition in other locations. The sites studied also do not fully represent environmental conditions at finfish aquaculture sites in the Maritimes region as a whole, particularly at more exposed (i.e., wind and waves) locations. Further model applications are required to more fully test model predictions under these conditions.

An issue with the comparisons between DEPOMOD predictions and observed sediment impacts is that DEPOMOD predicts organic carbon deposition rates, while the observed impacts are measured as sediment sulfide concentrations. There are many processes involved in the conversion of a carbon deposition rate into a sediment sulfide concentration, and the DEPOMOD model does not include these processes. Additional research efforts within DFO are exploring aquaculture waste dose-response relationships and alternative models for assessing environmental risks at proposed finfish aquaculture sites. The latter include efforts to:

- improve the modeling of waste resuspension processes,
- increase flexibility of model parameterization beyond DEPOMOD capabilities,
- increase the modeled area to include multiple sites, and
- combine waste transport and hydrodynamic models.

CONCLUSIONS

Predictions of the spatial extent of elevated impacts using DEPOMOD and a simple model showed relatively good agreement. However, the model predictions did not consistently agree with measurements of the spatial extent of impacted sediments based on sulfide concentrations. DEPOMOD predictions of the intensity of impacts also did not consistently align with actual measurements of the intensity of sulfide concentrations in seafloor sediments. However, model predictions of waste deposition often corresponded with the observed impact, particularly when the impact was relatively small and, notwithstanding a high degree of scatter, previously reported relationships between waste deposition rates and sulfide concentrations were observed.

OTHER CONSIDERATIONS

DEPOMOD is a commercial product. Details of the software code are not available and cannot be changed by users. Therefore, to address some of the model's shortcomings and to improve accuracy, consideration should be given to developing another model. Several issues are identified, which may affect the accuracy of DEPOMOD predictions: the model uses a temporally constant sea level; the current speed threshold for resuspension cannot be altered; and model runs use current velocity data from only one current meter location. The development of a model that incorporates spatial variation in water circulation, temporal variation in sea level, sediment grain size, an improved resuspension module, and a model converting the carbon deposition rate to sediment sulfide concentration is needed to substantially improve predictions of benthic impact.

SOURCES OF INFORMATION

This Science Advisory Report is from the 15-16 February 2012 review of Sulfide Concentrations Around Select Aquaculture Sites in Southwest New Brunswick: Review of DEPOMOD Predictions Versus Observations. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

Chamberlain, J., and D. Stucchi. 2007. Simulating the effects of parameter uncertainty on waste model predictions of marine finfish aquaculture. Aquaculture 272: 296-311.

Chamberlain, J., D. Stucchi, L. Lu, and C. Levings. 2005. The suitability of DEPOMOD for use in the management of finfish aquaculture sites, with particular reference to Pacific Region. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/035.

Chang, B.D., F.H. Page, R.J. Losier, E.P. McCurdy, and K.G. MacKeigan. 2011. Characterization of the spatial pattern of sulfide concentrations at six salmon farms in southwestern New Brunswick, Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 2915: 28p. Available from: http://www.dfo-mpo.gc.ca/Library/342675.pdf (accessed January 2012).

Cromey, C.J., T.D. Nickell, and K.D. Black. 2002. DEPOMOD – modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture 214: 211-239.

DFO. 2009. Water currents, drifter trajectories and the potential for organic particles released from Little Musquash Cove to enter the Musquash MPA. DFO Can. Sci. Advis. Sec. Sci. Resp. 2009/001.

DFO. 2011. Landings, lifecycle, and utilization of habitat for lobster in the vicinity of two proposed finfish aquaculture sites in St. Mary's Bay, Nova Scotia. DFO Can. Sci. Advis. Sec. Sci. Resp. 2011/002.

Hargrave, B.T. 2010. Empirical relationships describing benthic impacts of salmon aquaculture. Aquacult. Environ. Interact. 1: 33-46.

Hargrave, B.T., M. Holmer, and C.P. Newcombe. 2008. Towards a classification of organic enrichment in marine sediments based on biogeochemical indicators. Mar. Pollut. Bull. 56: 810–824.

NBDENV (New Brunswick Department of Environment). 2006. The Environmental Management Program for the marine finfish cage aquaculture industry in New Brunswick, version 2.0. NBDENV, Fredericton, NB. 21 p. Available from: http://www.gnb.ca/0009/0369/0017/pdfs/0010-e.pdf (accessed January 2012).

NSDFA (Nova Scotia Department of Fisheries and Aquaculture). 2011. Environmental Monitoring Program Framework for Marine Aquaculture in Nova Scotia. NSDFA, Halifax, NS. 19 p. Available at: http://www.gov.ns.ca/fish/aquaculture/ns-emp-framework-march2011.pdf (accessed January 2012).

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. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/003.

APPENDICES

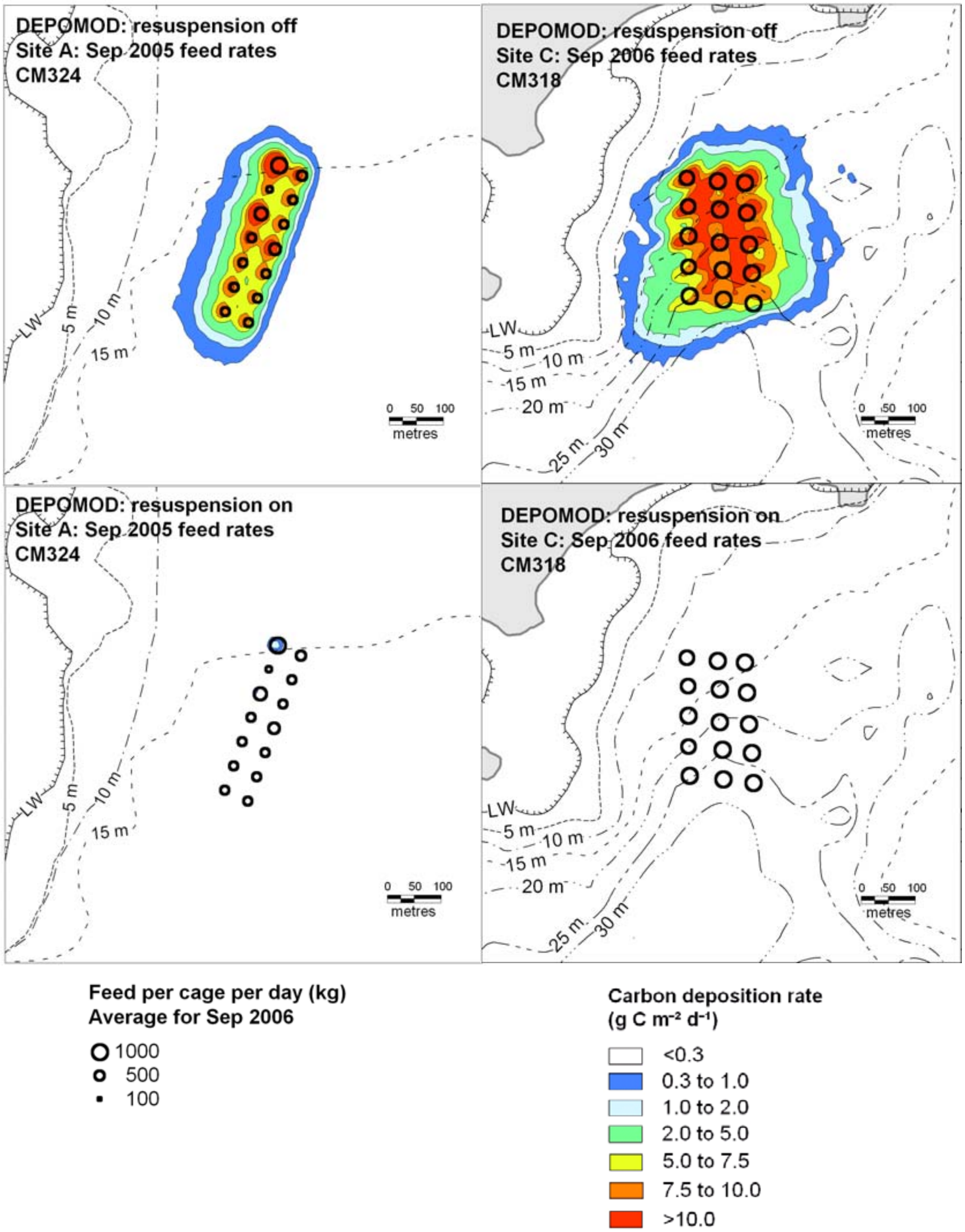

Figure 2. Contour plots of DEPOMOD predicted carbon deposition rates at sites A and C, with resuspension off (top) and on (bottom). Black circles represent cages, with circle sizes representing the feed rate.

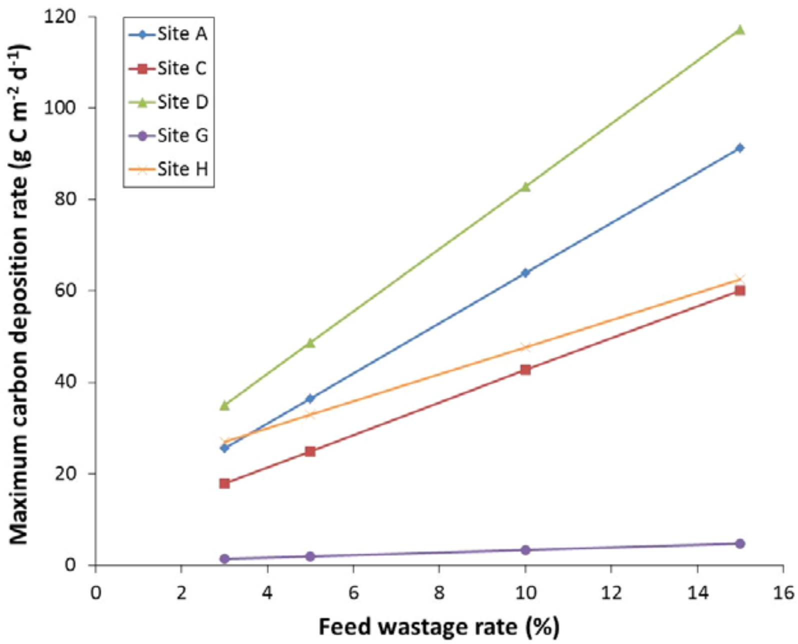

Figure 3. Plots of feed wastage rate vs. maximum predicted carbon deposition rate at 5 study sites.

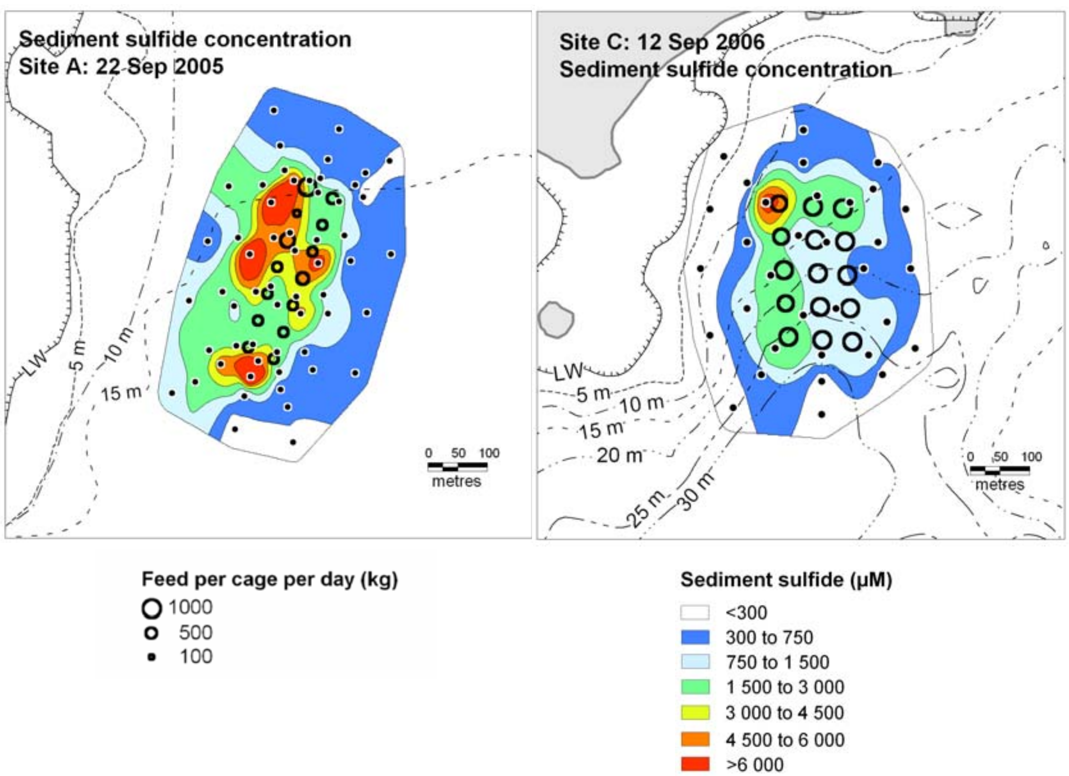

Figure 4. Contour plots of sediment sulfide concentrations on the seafloor under 2 salmon aquaculture sites (A and C). Black circles represent cages, with circle sizes representing the feed rate.

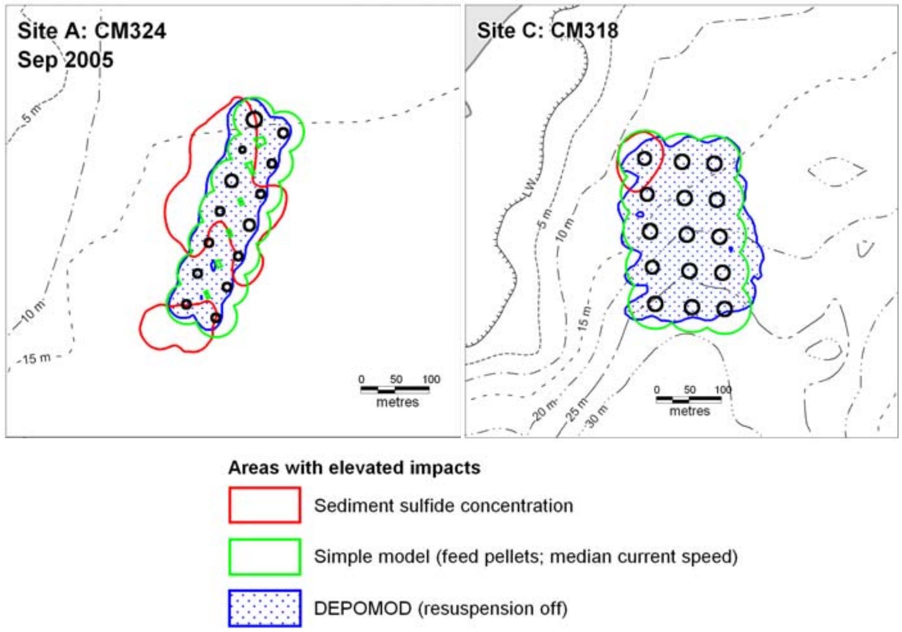

Figure 5. Comparisons of estimated areas of elevated benthic impacts at sites A and C. Black circles represent cages, with circle sizes representing the feed rate.

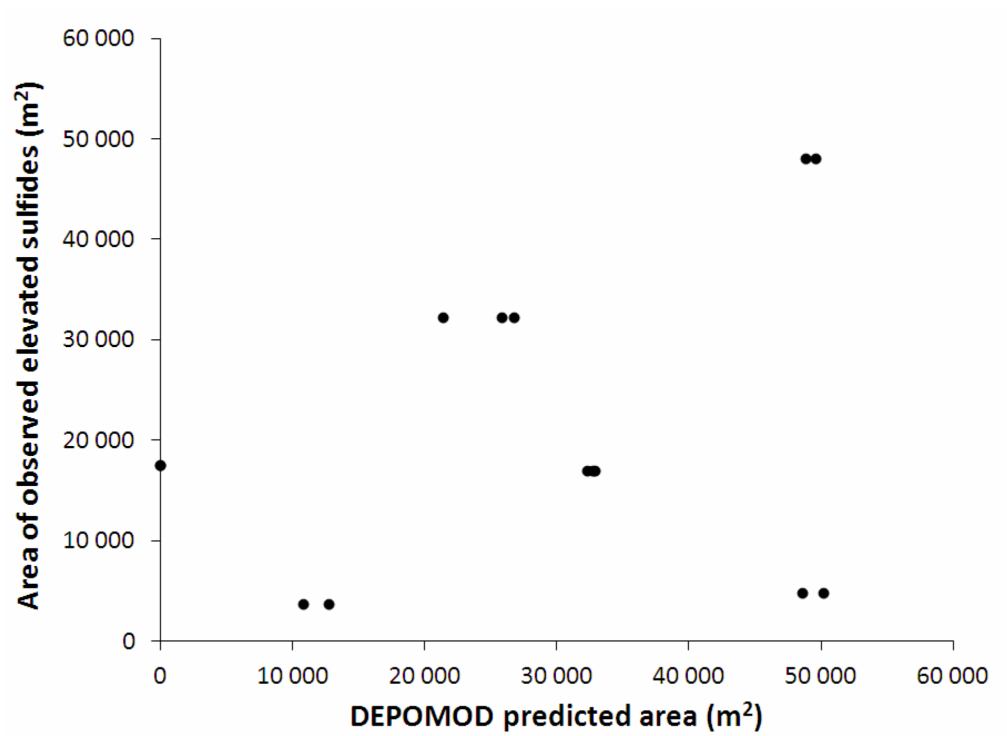

Figure 6. Relationship among study sites between DEPOMOD predictions of areas of elevated impacts (>5 g C m^{-2} d^{-1}; resuspension off, using feed rates at the time of sediment sampling) and areas of elevated sediment sulfide concentrations (≥3,000 µM).

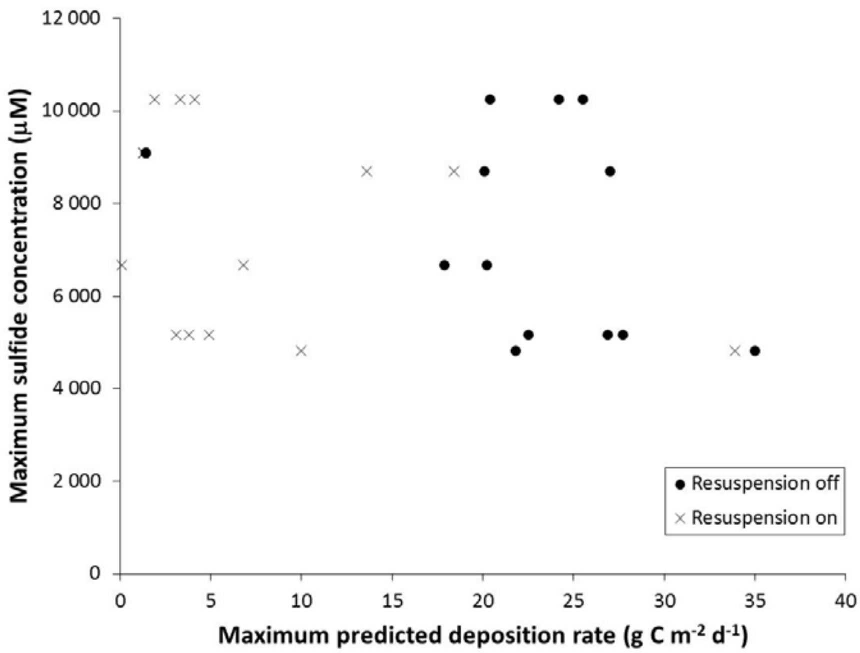

Figure 7. Relationship among study sites between maximum carbon deposition rate predicted by DEPOMOD and maximum sulfide concentration in seafloor sediment samples. Data for 5 aquaculture sites are shown, with DEPOMOD predictions from 2-3 sets of current velocity data per site.

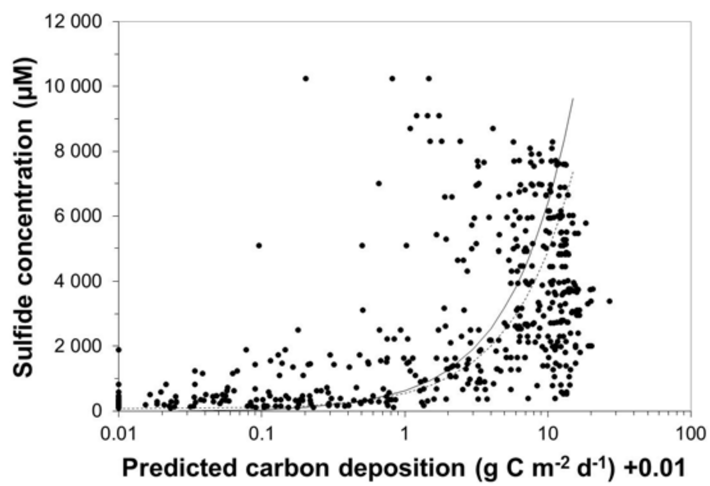

Figure 8. Relationship between sediment sulfide concentrations and DEPOMOD predictions of carbon deposition rates (resuspension off, using feed rates at the time of sediment sampling) at the same locations, excluding one site. The lines represent equations for the relationship between these parameters from Hargrave (2010).

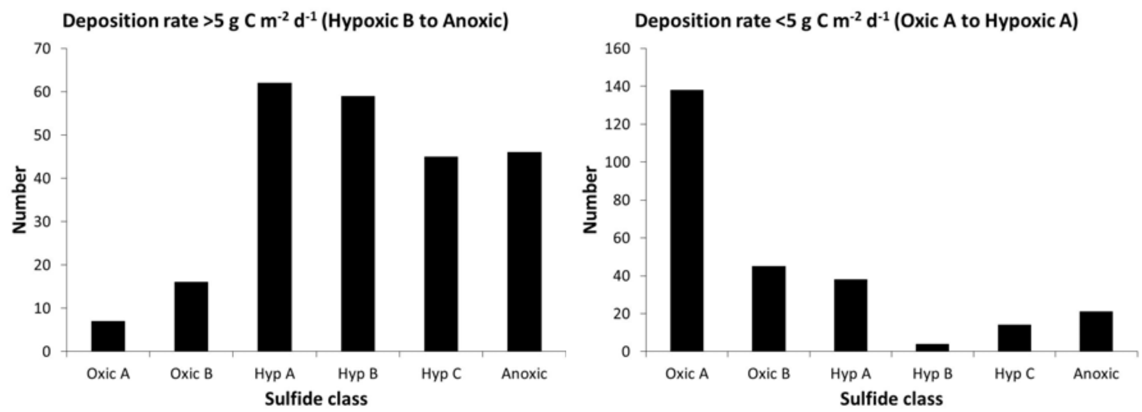

Figure 9. Left: Sulfide concentrations for DEPOMOD predictions >5 g C m^{-2} d^{-1}. Right: Sulfide concentrations for DEPOMOD predictions <5 g C m^{-2} d^{-1}. Hyp = hypoxic.

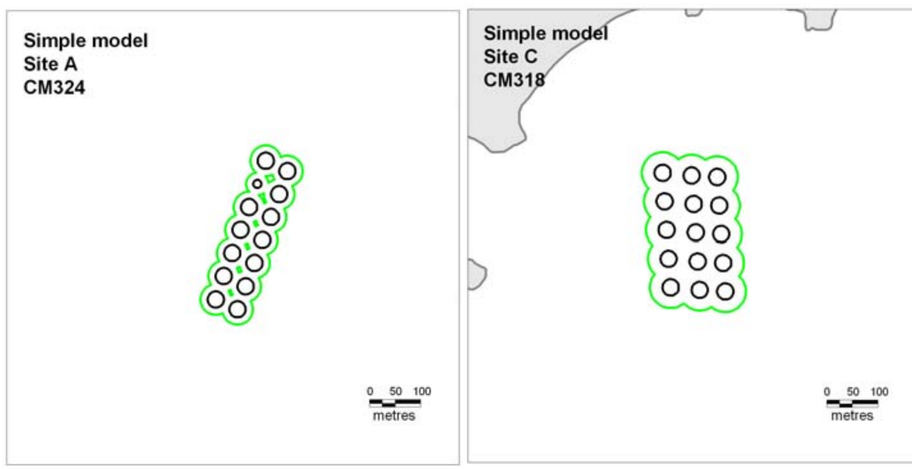

Figure 10. Simple model predictions of the areas of elevated impacts at sites A and C. Black circles represent cage locations and sizes. Green lines represent the horizontal displacement of feed pellets released at the water surface at the cage edges until they hit the seafloor, at median current speeds.

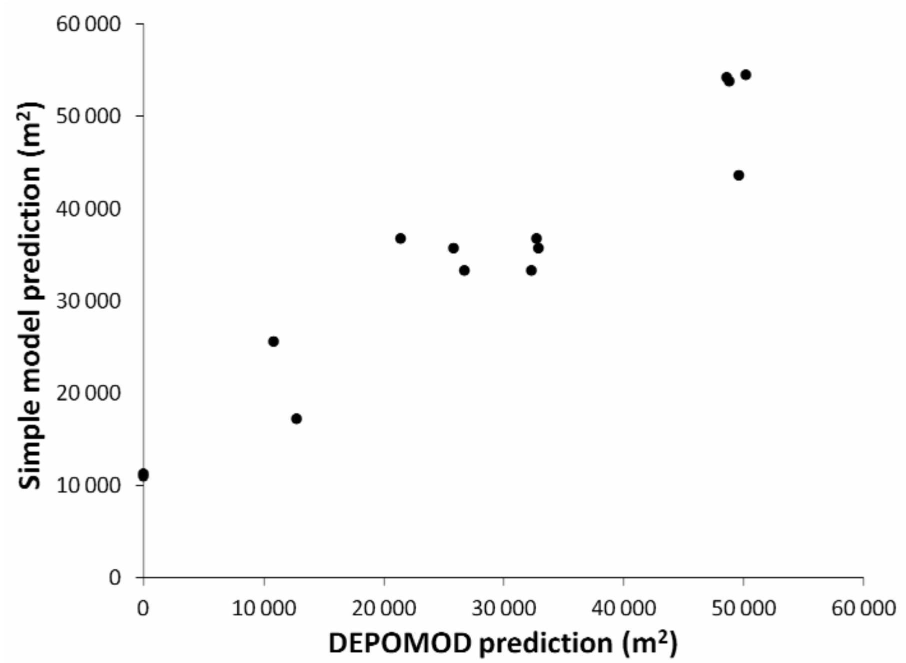

Figure 11. Relationship among study sites between DEPOMOD predictions of areas of elevated impacts (> 5 g C m^{-2} d^{-1}; resuspension off, using feed rates at the time of sediment sampling) and simple model predictions (using median current speeds and settling rates for waste feed pellets).

FOR MORE INFORMATION

Contact: Blythe Chang or Fred Page
Fisheries and Oceans Canada
St. Andrews Biological Station
531 Brandy Cove Road
St Andrews, NB
E5B 2L9

Tel: Blythe Chang: (506) 529-5907 / Fred Page: (506) 529-5935
Fax: (506) 529-5868
E-Mail: Blythe.Chang@dfo-mpo.gc.ca or Fred.Page@dfo-mpo.gc.ca

This report is available from the:

Center for Science Advice (CSA)
Maritimes Region
Fisheries and Oceans Canada
PO Box 1006, Station B203
Dartmouth, Nova Scotia
Canada B2Y 4A2

Telephone: 902-426-7070
Fax: 902-426-5435
E-Mail: XMARMRAP@mar.dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas

ISSN 1919-5079 (Print)
ISSN 1919-5087 (Online)

La version française est disponible à l'adresse ci-dessus.

CORRECT CITATION FOR THIS PUBLICATION

DFO. 2012. Review of DEPOMOD Predictions Versus Observations of Sulfide Concentrations Around Five Salmon Aquaculture Sites in Southwest New Brunswick. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/042.