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Fish Health and Oceanography Project of the Aquaculture Collaborative Research and Development Program

Report of the initial project meeting, 18 December 2001

by

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TABLE OF CONTENTS

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ABSTRACT

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The Fish Health and Oceanography Project received funding from the DFO Aquaculture Collaborative Research and Development Program (ACRDP) in late 2001. The project's main goal is to enhance understanding of the water circulation and water transport pathways within the Long Pond Bay area of southern Grand Manan and to use this to help assess the influence of the water circulation patterns on fish health and bay management concerns in the area. This report summarizes the presentations given at the initial meeting of the project, held on 18 December 2001.

The concepts of Bay Management Areas (BMAs) and single-year-class farming are key aspects of the fish health management strategy for the New Brunswick salmon aquaculture industry. The concept was developed and implemented largely as a result of the outbreak of infectious salmon anaemia (ISA) which started among salmon farms in New Brunswick in 1996. The fish health management strategy includes having all farms with just one year-class on a site at any one time and having all farms within a BMA on the same year-class schedule.

The existing BMA boundaries were based on a number of factors, including oceanography, groups that share the resource, wharf usage and company structure. It was recognized that the BMA boundaries could be revised as new information becomes available. In this project, we hope to conduct oceanographic work, which would help redefine the BMA boundaries in southern Grand Manan, in light of the new salmon farms approved for the area and fish health concerns.

One of the main motivations behind the project was concern over the oceanographic appropriateness of the BMA boundaries in the southern Grand Manan area, especially following the approval of new farms in the area in 2001. As a result, only one farm in the area, in northern Long Pond Bay (BMA 21), is an even year-class farm, with all the others being odd year-class sites. One of the main questions being asked is whether the sole even year-class farm (which has been operating since 1998) is sufficiently isolated from the other farms to allow it to be considered as an oceanographically-isolated site and if so, could the BMA boundaries be redrawn to reflect this.

Although some hydrographic data and current meter records have previously been collected in southern Grand Manan and a preliminary three-dimensional tidal circulation model has been developed, the work was not sufficient to adequately address the issues of concern. Encouragingly, the field observations to date have, for the most part, agreed with the model predictions. However, the current regime in the area is quite complex due to the complexity of the topography and perhaps due to seasonality in circulation-driving functions such as wind and water density structure. In addition, the oceanographic information needs and the interpretation of that information vary according to the fish health issue. Hence, additional field work and model development is required to resolve some discrepancies in observation-model comparisons,

to improve the model resolution and observational base in some areas, to characterize the importance of tidal currents to the total circulation and transport of particles and to assess the sensitivity of the model to non-tidal forcing.

In recognition of these needs and shortcomings, the project will focus on obtaining current observations from key locations in the southern Grand Manan area, refining and evaluating a high spatial resolution three dimensional tidal circulation and particle tracking model of the area and using the combination of observations and models to generate enhanced advice on the exchange of water, and by inference disease, between farm sites and the general utility of the BMAs in the area.

The project will also focus on how to better link oceanographic knowledge with fish health needs, so fish health management advice and actions can better take the oceanographic knowledge into consideration.

The specific objectives of this project are:

1. To develop a better understanding of the water circulation within the Long Pond Bay area of Grand Manan by:
    - obtaining more observations, especially in key areas,
    - more fully analyzing existing and new observations, and
    - refining a three-dimensional tidal circulation model.

2. To characterize the fish health issues of importance to the salmon aquaculture industry that may have a significant oceanographic component to their spread and management considerations, especially in the Long Pond Bay area and to define approaches and guidelines for estimating fish health risks based on oceanographic information.

3. To re-examine the implications of the water circulation in Long Pond Bay to the fish health and bay management boundaries within the area.

Field work is scheduled to take place mostly in the spring and summer of 2002. A meeting of project participants will be held at the end of the field season to review the results and preliminary analyses. The remaining time of the project will be dedicated to further data analysis, refinement of the circulation model, elaboration of linkages between oceanography and fish health, refinement of the project's conclusions, writing of the final project report(s) and convening of a workshop to present the project's findings. The project is scheduled to terminate in March 2004.

RÉSUMÉ

Le Projet sur l'océanographie et la santé du poisson a fait l'objet d'une contribution financière du Programme coopératif de recherche-développement en aquaculture (PCRDA) du MPO à la fin de 2001. Le premier but du projet est de permettre aux scientifiques de mieux comprendre la circulation de l'eau et les voies de transport de l'eau à l'intérieur de la baie Long Pond située au sud de Grand Manan. Ils pourront ensuite utiliser cette information pour évaluer les répercussions des cycles de circulation de l'eau sur la santé du poisson et sur les autres questions liées à la gestion de la baie. Le présent rapport résume les exposés présentés à la première réunion du projet qui a eu lieu le 18 décembre 2001.

Les concepts de zones de gestion de la baie (ZGB) et d'élevage de classes annuelles uniques sont deux aspects clés de la stratégie de gestion de la santé du poisson, laquelle a été établie pour l'industrie de la salmoniculture du Nouveau-Brunswick. La stratégie a été élaborée et mise en œuvre dans une large mesure à cause de l'éruption de l'anémie infectieuse du saumon (AIS) qui s'est attaquée aux exploitations salmonicoles du Nouveau-Brunswick en 1996. La stratégie de gestion de la santé du poisson préconise notamment que toutes les fermes aquacoles n'aient jamais plus d'une classe annuelle dans un site au cours d'une période donnée, et que toutes les fermes situées à l'intérieur d'une ZGB respectent le même calendrier d'élevage des classes annuelles.

Les limites actuelles des ZGB ont été établies en fonction de plusieurs facteurs, notamment des données océanographiques, les intérêts des groupes qui se partagent la ressource, l'utilisation des quais et la structure des entreprises. Au départ, il avait été établi que les limites des ZGB pouvaient être remaniées à la lumière de nouveaux renseignements. Dans le cadre du présent projet, nous espérons mener des travaux océanographiques qui nous permettront de redéfinir les limites des ZGB dans le sud de Grand Manan afin de répondre aux besoins des nouvelles fermes de salmoniculture qui ont été approuvées pour ce secteur et d'atténuer les inquiétudes liées à la santé du poisson.

Une des motivations principales du projet était l'inquiétude au sujet de la pertinence océanographique des limites des ZGB au sud de Grand Manan surtout après l'approbation, en 2001, de nouvelles fermes salmonicoles dans le secteur. En conséquence une seule ferme salmonicole dans la région, située au nord de la baie Long Pond (ZGB 21), est une ferme d'élevage de classes annuelles paires tandis que les autres élèvent des classes annuelles impaires. Une des questions principales survenues est la suivante : est-ce que la seule ferme d'élevage de classes annuelles paires (celle qui fonctionne depuis 1998) est suffisamment éloignée des autres fermes pour être considerée isolée (au point de vue océanographique) et, dans l'affirmative, comment peut-on modifier les limites des ZGB pour refléter ceci?

Nous avons déjà prélevé des données hydrographiques et des données sur les courants marins pour la zone sud de Grand Manan, et nous avons établi un modèle tridimensionnel provisoire pour la circulation des marées. Cependant, les données obtenues n'étaient pas suffisantes pour bien traiter des questions soulevées. Fait encourageant, les observations sur le terrain réalisées à ce jour correspondent pour la plupart aux prévisions du modèle. Il faut toutefois dire que le régime des courants dans le secteur est extrêmement complexe étant donné la nature très

compliquée de la topographie et peut-être aussi étant donné la saisonnalité des facteurs qui régissent la circulation de l'eau, tels le vent et la structure de densité de l'eau. En outre, les besoins en information océanographique et la façon d'interpréter l'information varient selon le problème de santé du poisson. Il faut donc faire d'autres travaux sur le terrain et développer un autre modèle pour régler certaines incompatibilités dans les comparaisons entre les observations sur le terrain et le modèle, ainsi que pour améliorer la résolution du modèle et la base d'observation dans certains secteurs, pour caractériser l'importance des courants de marée pour la circulation globale et le transport de particules et pour évaluer la sensibilité du modèle au forçage dû à des facteurs autres que les marées.

Compte tenu de ces besoins et de ces lacunes, les chercheurs du projet veulent obtenir des observations sur les courants à des points stratégiques du secteur sud de Grand Manan, peaufiner et évaluer un modèle tridimensionnel à résolution spatiale élevée de repérage des particules et de suivi des marées dans ce secteur, et agencer les observations et les modèles pour produire de meilleurs avis scientifiques sur l'échange d'eau et, par déduction de maladies, entre les fermes, et finalement déterminer la pertinence des ZGB dans le secteur.

Les auteurs du projet se pencheront également sur la meilleure façon de procéder pour relier les connaissances océanographiques aux besoins en matière de protection de la santé des poissons, afin qu'il soit davantage tenu compte des connaissances océanographiques au moment d'élaborer des avis et des mesures de gestion de la santé du poisson.

Voici les objectifs précis du projet :

1. Approfondir nos connaissances sur les cycles hydrologiques dans le secteur de la baie Long Pond, à Grand Manan, c'est-à-dire :
   - obtenir plus de données d'observation, surtout dans certains secteurs clés;
   - faire une analyse plus poussée des observations existantes et des nouvelles observations;
   - peaufiner un modèle tridimensionnel sur les courants et marées.

2. Caractériser les problèmes ichtyopathologiques graves pour l'industrie de la salmoniculture, qui pourraient être liés à l'océanographie et nuire à leurs plans d'expansion et de gestion, surtout dans le secteur de la baie Long Pond, et définir certaines démarches et lignes de conduite pour évaluer les risques ichtyopathologiques au moyen de données océanographiques.

3. Réexaminer les répercussions de la circulation de l'eau dans la baie Long Pond sur la santé du poisson et sur les limites des zones de gestion de baie, à l'intérieur de ce secteur.

La plupart des travaux sur le terrain seront effectués au printemps et à l'été de 2002. Une réunion des participants au projet aura lieu à la fin des travaux afin d'examiner les résultats et les analyses préliminaires. Pendant le reste de la durée du projet, on fera une analyse plus approfondie des données, on peaufinera le modèle de circulation de l'eau, on créera des liens entre l'océanographie et la santé du poisson, on perfectionnera les conclusions du projet, on rédigera un ou des rapports finaux, et on organisera un atelier pour présenter les conclusions du projet. Tous ces travaux doivent prendre fin en mars 2004.

Introduction and Meeting Objectives

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In the fall of 2001, the Aquaculture Collaborative Research and Development Program (ACRDP) of the Canadian Department of Fisheries and Oceans (DFO) approved funding for a project entitled "A Proposal to Begin Development of Guidelines for Assessing the Fish Health Consequences of Water Circulation Patterns by Describing Aspects of the Water Circulation in the Long Pond Bay Area of Grand Manan and Its Implications for the Local Fish Health Aspects of Salmon Aquaculture Bay Management Strategies." For practical reference purposes, this title has been shortened to the "Fish Health and Oceanography Project" (ACRDP Project MG-01-06-014).

One of the first items in the project work plan was to convene a meeting with the members of the project team (mainly the Fish Health Technical Committee, participating oceanographers, and industry partners). This initial meeting was held on 18 December 2001 at the New Brunswick Salmon Growers' Association office complex on Limekiln Road, Letang, New Brunswick. A list of the meeting participants is included in Appendix 1. The agenda for the meeting is included in Appendix 2.

The purpose of the meeting was to:

- bring the team members together for the first time within the context of the approved proposed work;
- remind participants of the proposal objectives and work plans;
- briefly review the status of the salmon aquaculture industry and its Bay Management Structure in southwest New Brunswick and particularly on Grand Manan;
- briefly review the fish health issues of relevance to the salmon farming industry and regulators and identify those that may have an oceanographic component to them;
- briefly review the general suite of oceanographic data and approaches we have available to us and the state of oceanographic work in the Long Pond Bay area; and
- review the project objectives and focus of the oceanographic work to be conducted in the Long Pond Bay and immediately adjacent areas during the project to help ensure it contributes products that are useful to the fish health community.

The remainder of this report contains summaries of the material presented at the meeting and brief summaries of the major discussion points and conclusions. Dr. Fred Page and Mr. Blythe Chang give a general perspective on the background issues leading to the development of the project. This is followed by an overview of the status of the salmon aquaculture industry in southwest New Brunswick by Dr. Sandi McGeachy, an overview of the Bay Management Area rationale by Ms. Nell Halse, and an overview of fish health issues by Dr. Sandi McGeachy. These are followed by brief overviews of the status of oceanographic fieldwork, circulation modelling, and an approach for estimating water mixing or exchange rates by Dr. Fred Page, Dr.

Dave Greenberg and Dr. Michael Dowd, respectively. The overviews are followed by a description of the project objectives and projected activities over the next two years.

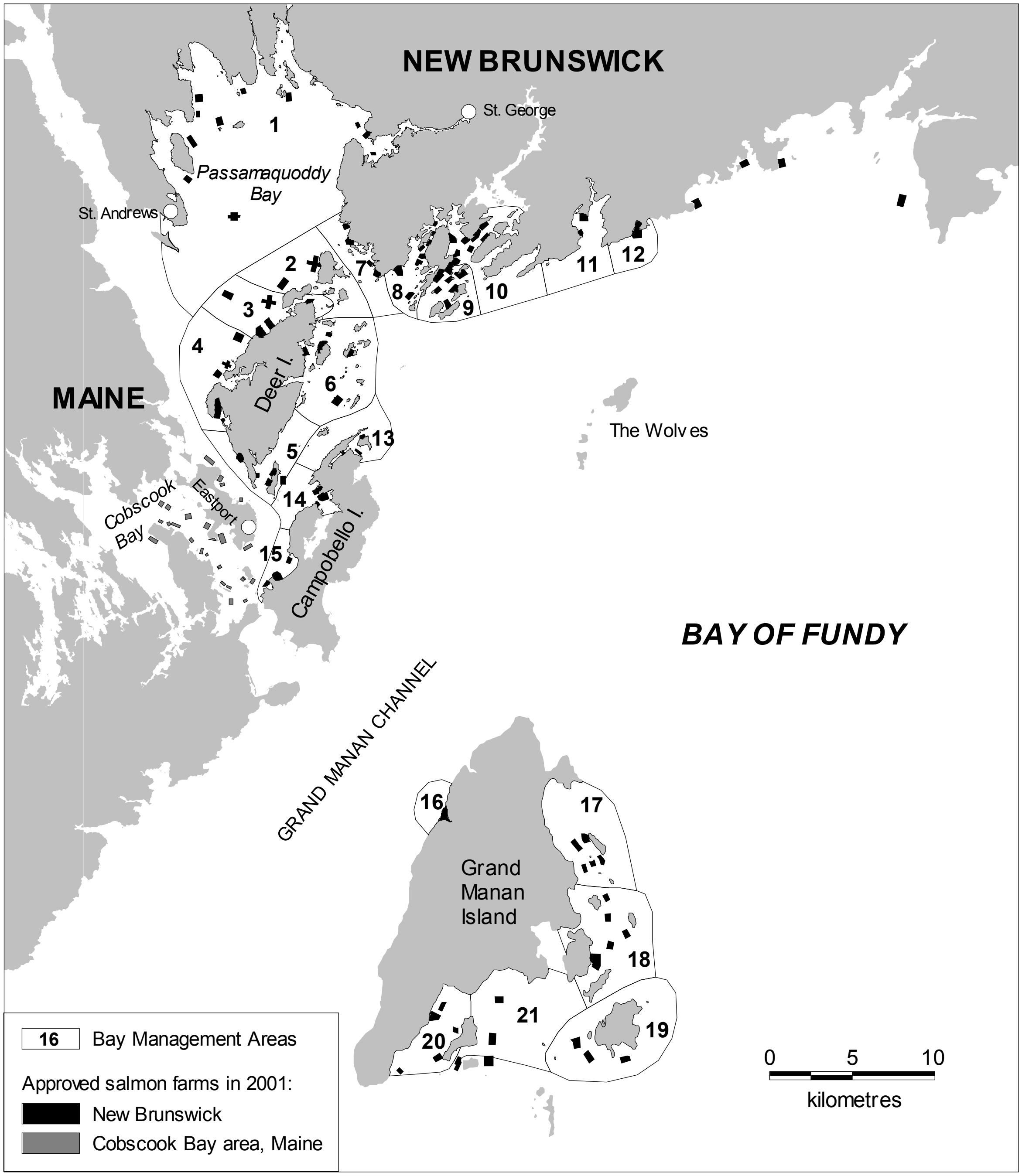

Figure 1. Map showing the locations of the 21 Bay Management Areas and salmon farms in southwest New Brunswick in June 2001. Long Pond Bay is in Bay Management Area 21 in southern Grand Manan (see also Figure 2). The map also shows the locations of salmon farms in adjacent Maine. (Based on information from the New Brunswick Department of Agriculture, Fisheries and Aquaculture and the Maine Department of Marine Resources.)

Project Background

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The concept for this project began in the fall of 2000 and spring of 2001. It was generated by a combination of several motivations, the most influential of which was the review process for the 2000-2001 aquaculture site applications. In particular, there was concern expressed by members of the salmon aquaculture industry and the New Brunswick Department of Agriculture, Fisheries and Aquaculture (NBDAFA) that the new salmon farms being proposed for Long Pond Bay and adjacent areas of Grand Manan might impact the operation of existing farms within the area with respect to the year-class separation and fish health management goals in general. There was also the recognition that, as in other areas in southwest New Brunswick, the boundaries of the bay management areas in the southern Grand Manan might not adequately reflect the pattern of water circulation and exchange. Hence the existing boundaries may not be the best for achieving the goals of bay management practice. It was also recognized that the existing level of understanding with respect to the water circulation was inadequate to address these concerns. An additional motivation was an ongoing desire, on the part of several team members, to try and establish a closer link between oceanographers and fish health specialists. It was hoped that fish health specialists and oceanographers would gain mutual benefit by working more closely together to develop a better, and more general, understanding of the information needs and capabilities of each discipline and hence improve the existing approach to developing oceanographic advice for fish health specialists. Furthermore, it was hoped that by working together to help address the issues specific to Long Pond Bay, some general guidelines could be drafted concerning the types of oceanographic information, its presentation and interpretation that best suited the fish health community.

The combination of these factors motivated the Fish Health Technical Committee (FHTC), NBDAFA, the New Brunswick Salmon Growers Association (NBSGA) and the Department of Fisheries and Oceans (DFO) to express a desire for more oceanographic work in the Long Pond Bay area and to relate this work to the generation of fish health advice.

A decision was made by the interested parties in the spring of 2001 to develop a funding proposal for submission to the DFO Aquaculture Collaborative Research and Development Program (ACRDP). The proposal was prepared and submitted in June of 2001. The original proposal anticipated a project start-up in the early fall of 2001. The proposal concept was accepted by the ACRDP review committee in the late summer and early fall of 2001. However, due to start-up issues associated with the ACRDP office, and the need for some proposal clarifications and revisions, the project and its proposed budget were not fully accepted by the ACRDP funding review committee until late November and early December 2001.

The remainder of this section provides some additional details on the background and motivations for the proposal. Additional details are included in the sections by S. McGeachy, N. Halse, F. Page, D. Greenberg and M. Dowd.

Specific interest in the potential influence of new salmon farm sites on existing sites in the Long Pond Bay area

In 2000 there was only one operational salmon farm in Long Pond Bay (Figures 1 and 2). This farm (site number 303) began operations in spring 1998 in the northern portion of the bay. There were also existing sites (numbers 316 and 381) off the southwest shore of White Head Island and several sites in Seal Cove (numbers 3, 202, 270 and 292).

The above sites were divided into three Bay Management Areas (BMAs). BMA 20 included the Seal Cove sites, BMA 21 the Long Pond Bay site and BMA 19 the White Head Island Sites. BMA 21 contained even year-class fish (smolts placed on the farm site in an even number year) and BMAs 19 and 20 contained odd year-class fish (smolts placed on the farm site in an odd number year). It was hoped that this provided some buffer for mitigating the transmission of potential diseases between BMAs.

The site application review process was asked to consider the merits of allowing several new farms to operate in the area starting in spring 2001 (Figure 2). These sites were to help enable the industry as a whole to progress toward single-year-class sites and bays. For example, it has been suggested that the southern portion of Grand Manan could become an odd year-class area and the northern portion of Grand Manan could become an even year-class area.

The primary concerns discussed in the site review process for 2001 included:

- Would water from the proposed new farm sites in Long Pond Bay, particularly sites 403 and 408, flow toward and through the existing farm site in Long Pond Bay (site 303), and hence pose a potential fish health concern to the existing site?
- Would water from the proposed new farm site in Cow Passage (site 402 in BMA 19) flow toward and through the existing farm sites off White Head Island (sites 316 and 381; BMA 19) and the existing farm site in Long Pond Bay (site 303 in BMA 21) and hence pose potential fish health concerns to these sites?
- Does water from Seal Cove flow into Long Pond Bay, thereby implying that the existing farms in Seal Cove could influence the farms in Long Pond Bay? Or does the water flow from Long Pond Bay into Seal Cove implying that the existing and new farms in Long Pond Bay might influence the farms in Seal Cove?
- Are the boundaries of the BMAs 19, 20 and 21 indicative of water transport and dispersal patterns? Of particular interest was whether the offshore boundary of BMA 21 could be adjusted so it would pass between proposed sites 403 and 408 or between sites 403 and 303, with sites 403, 408 and 491 being in a new BMA 22.

After considerable discussion, four sites were eventually approved and began operations in spring 2001: sites 403 and 408 located along the eastern shore of Wood Island in Long Pond Bay proper; site 491 located in the channel between Wood Island and Outer Wood Island; and site 413 located near the southern end of Seal Cove in BMA 20. Site 416, located in Sandy Cove along the southern shore of White Head Island in BMA 19, was conditionally approved, pending finalization of site boundaries, but did not begin operations in 2001. Another site in BMA 19, site 402, located along the northern shore of White Head Island, near Cow Passage, was deferred until 2002. Four other proposed sites were rejected in 2001: site 401 south of Ox Head, site 406 near North Green Island, site 409 near South Green Island and site 410 near Kent Island.

For spring 2002, three new sites were proposed in the southern Grand Manan area: site 402 (deferred from the previous year) and sites 418 and 419 located on the eastern shore of Cheney Island, in Cow Passage.

With the approval of the new sites in 2001, all farms in southern Grand Manan, with the exception of site 303 were odd year-class operations and the fish health buffer between odd and even year-class areas was potentially reduced. Hence, the initial concerns remained, only now the advice to be generated had the potential for application to real rather than potential issues.

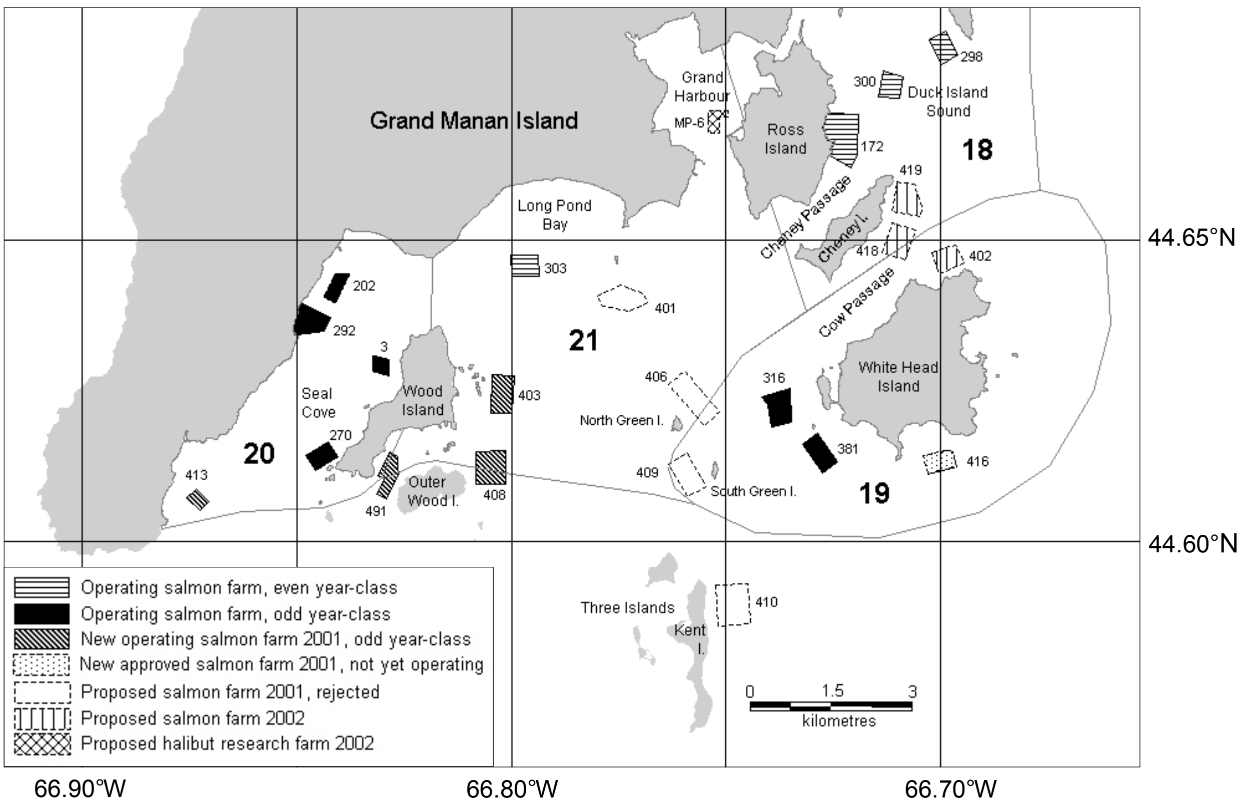

Figure 2. Map of southern Grand Manan Island showing Bay Management Areas (designated by large numbers), salmon farm locations in late 2001, and proposed new sites for 2002 (small numbers beside farm sites refer to New Brunswick Department of Agriculture, Fisheries and Aquaculture site identifiers).

State of Oceanographic Knowledge at the Time of the Site Review Process

The oceanographic information that was available and presented to the site application process and the affected members of the salmon aquaculture industry in the fall and winter of 2000-01 was limited. It consisted mainly of preliminary and cursory analyses of some hydrographic data (temperature and salinity profiles and time series) collected in 1999 and 2000, current meter records collected in 1999 and 2000 and a brief examination of output from preliminary runs of a three-dimensional tidal circulation model for the Grand Manan area. A brief summary of the highlights of this information is given below. Additional details are given in the overviews by F. Page, D. Greenberg and M. Dowd in their contributions to this report.

Preliminary analyses of the hydrographic data indicated relatively little spatial variation throughout the eastern and southeastern inshore area of Grand Manan. The temperature in Grand Harbour tended to be a bit warmer than in nearby Long Pond Bay, indicating reduced flows and enhanced residence times in Grand Harbour. The temporal variability suggested that changes in the circulation, as indicated by a rapid (few degrees) change in temperature in the winter, may occur on time scales of hours to days.

Preliminary analyses of the current meter records indicated the mean current speeds were about 10 cm/s. The direction of the mean currents suggested the flow was generally southwesterly along the western shore of Seal Cove. The flow was southerly along the eastern side of Outer Wood Island suggesting that the mean transport from site 408 would be away from the existing site 303. The flow was northeasterly between Wood Island and the Three Islands and hence into Long Pond Bay, whereas the flow was southeasterly between the Three Islands and the Green Islands and hence out of Long Pond Bay. The flow was northeasterly into Long Pond Bay between the Green Islands and White Head Island.

Examination of current data collected along a few horizontal transects suggested that the current fields can be spatially complex. For example, during the ebbing tide, water flowed into Seal Cove from Long Pond Bay and a gyral flow sometimes existed within Seal Cove. During the flood tide the flow was from Seal Cove into Long Pond Bay and the gyral flow pattern was not so pronounced. Transects within Long Pond Bay indicated a divergence in the direction of the tidal flow along the eastern shore of Wood Island and a somewhat complicated flow field within Long Pond Bay.

Preliminary estimates of the depth-averaged M_2 tidal residual currents from a tidal circulation model of the area, described by D. Greenberg in this report, suggested several flow patterns of interest. On an island-wide scale (Figure 3), the model indicated a very weak mean flow in North Head and a southerly mean flow from North Head to Cow and Cheney Passages. The mean flow through Cheney and Cow Passages was suggested to be from northeast to southwest or from Duck Island Sound (BMA 18) into Long Pond Bay (BMA 21). The mean flow pattern in Long Pond Bay appeared to be somewhat complicated. The flow through Cheney Passage continues toward Ross Island and the northern portion of the Bay. The mean flow within Grand Harbour was weak and the outflow from the harbour is suggested to join the Cheney Passage flow past Ross Island to site 303. The flow through Cow Passage seems to hug White Head Island before flowing toward the southeast and out of Long Pond Bay. There is the suggestion of three residual gyres in the Bay: a counterclockwise gyre to the east of Outer Wood Island, a clockwise gyre off the northeast corner of Wood Island and a counter-clockwise gyre in the northern section of the Bay. Immediately to the east of Outer Wood Island the flow is southerly. The mean flow connecting Seal Cove with Long Pond Bay appears to be into Long Pond Bay. The mean flow in Seal Cove is weak with a residual gyre in the middle of the Cove.

A very cursory comparison of the observations and model results indicates the mean or residual currents are generally weak in comparison to the tidal currents. It also suggests that in 4 out of 6 deployments in the Long Pond Bay area, the direction of the mean flow estimated by current meter moorings tended to agree with the model results, whereas in 2 deployments the agreement was not good. In two of the 6 moorings the mean speeds agreed, in 2 deployments the observed mean speeds were greater than those estimated by the model and in 2 deployments the observed speeds were less than that estimated by the model.

The preliminary estimates of the flow patterns imply that salmon farms near Outer Wood Island (sites 408 and 491) are in a flow regime that heads away from the other farms in the area. Hence, these might be considered as being in a bay management zone of their own. Depending upon the exact location of site 403, and the exact flow pattern in the area of the farm, the flow from this farm may be toward the outer Wood Island farms or toward Seal Cove and site 303. The existing farm in northern Long Pond Bay appears to exist within its own gyre and may be isolated to some degree from the other existing and proposed farms in that area. However, this farm appears to be in the downstream portion of the transport pathway from Grand Harbour and Cheney Passage. Similarly, existing farms on the western side of White Head Island (sites 316 and 381) appear to be downstream of the proposed farms in Cow Passage. The farms in Seal Cove may be influenced by water flowing between Seal Cove and Long Pond Bay through the channel located to the north of Wood Island. The weak mean currents in Seal Cove suggest a weak flushing of the area and hence the potential for oxygen depletion within the Cove.

Although the above information suggests some potential connections and separations between farm sites, the information and its interpretation is very preliminary in nature. It is difficult to infer transport pathways from static pictures of a time-varying and very dynamic circulation regime. Particle tracking experiments need to be conducted with a validated circulation model. Among other things, field observations on drift tracks should be made and current meter records should be obtained and analyzed to determine what proportion of the observed current appears to be tidally driven. These cautions and needs were indicated at the time of the site proposal evaluations. Hence, it was recognized that more work needed to be done to refine the model, analyze and synthesize the observations and to gain more confidence in both the observations and model results and their implications to the salmon aquaculture industry. It was also recognized that one of the key questions is what are the time scales of interest from a fish health perspective and are the higher frequency transport and dispersal patterns more important to fish health issues than the residual pattern? Another unknown is the importance of rare events, such as storms, to the spread of fish diseases.

General Desire for Oceanographic and Fish Health Linkages

Although much of the project is focused on a particular geographic area, the nature of the information required and the issues being addressed are not unique to the study area. Site specific and general oceanographic knowledge is often requested by fish health professionals for consideration in their deliberations concerning the development of advice for fish health issues. Formulation of the answers often involves estimating the pathways, rates and geographic extent of the dispersal "plume" for substances that might be released from a specified fish farm. The requests sometimes contain desires for estimates of the cumulative concerns or consequences to an area already containing fish farms and/or other activities. For example will an additional farm reduce the concentration of dissolved oxygen in an area or will the additional nutrient loading contribute to phytoplankton blooms? Although the questions are easy to ask, it is often not easy to give answers and the answers usually require some site-specific information.

The transport and dispersal of fish waste and disease in general is dependent upon many factors. The current at any specific location varies temporally on a range of time scales including the phase of the tide (time scale of hours), the strength and direction of the local wind (time scale of days), the degree of fresh water runoff (time scale of months) as well as with influences from outside the immediate area. The currents within the area of interest often vary spatially on scales of meters, to kilometers and greater. The relative importance of these temporal and spatial variations to transport and dispersal depends on such considerations as the timing of the substance release, the duration of the release, the length of time the substance is in the water and the behaviour of he substance.

As a result of this complexity, the ability of oceanographers and fish health specialists to estimate the patterns and rates of transport and dispersal and their consequences to fish health varies with the specific circumstances. Of particular importance is the amount of oceanographic and fish health information available, the availability and suitability of analytical tools to process the information, as well as the expertise, time and resources available to gather, process and digest the relevant information.

The types of approaches and information available to oceanographers for estimating patterns and rates of transport and dispersal usually range from a single current meter record of a few weeks duration to circulation model results that usually only contain specific components of the circulation (e.g. the M_2 tidal component). Some of these aspects are described in more detail in subsequent sections of this report (see sections by F. Page, D. Greenberg and M. Dowd).

The information available to fish health specialists about the various aspects of the fish health issue is often limited. In addition, practical considerations often dictate that relatively little time and money is available to address the issues at hand and generate the advice that is needed to guide the implementation of a fish health management strategy. Consequently, regulators and scientists often make shortcuts and ad hoc assessments. Unfortunately these actions may sometimes jeopardize the quality and accuracy of the assessment. Hence, it is apparent that summaries of the strengths and weaknesses of various levels of effort need to be produced and suitable guidelines for approaching oceanographically-linked fish health issues need to be developed.

Recognition of the above, coupled with the belief that fish health specialists will continue to request information and advice from oceanographers when generating their management advice, contributed to the definition of the objectives of this project. In particular, one of the goals is to exchange information on the above complexities and to try to develop some useful rules of thumb concerning the needs and interpretations of oceanographic information in relation to some common fish health issues. This will include identifying typical fish health situations in which oceanographic input is thought to be desirable. The level of oceanographic information needed to sufficiently address these questions will be addressed along with the relative usefulness of advice that may be developed from a range of current information that might be typically available (e.g. a single current meter record, a circulation model, a series of drifter tracks).

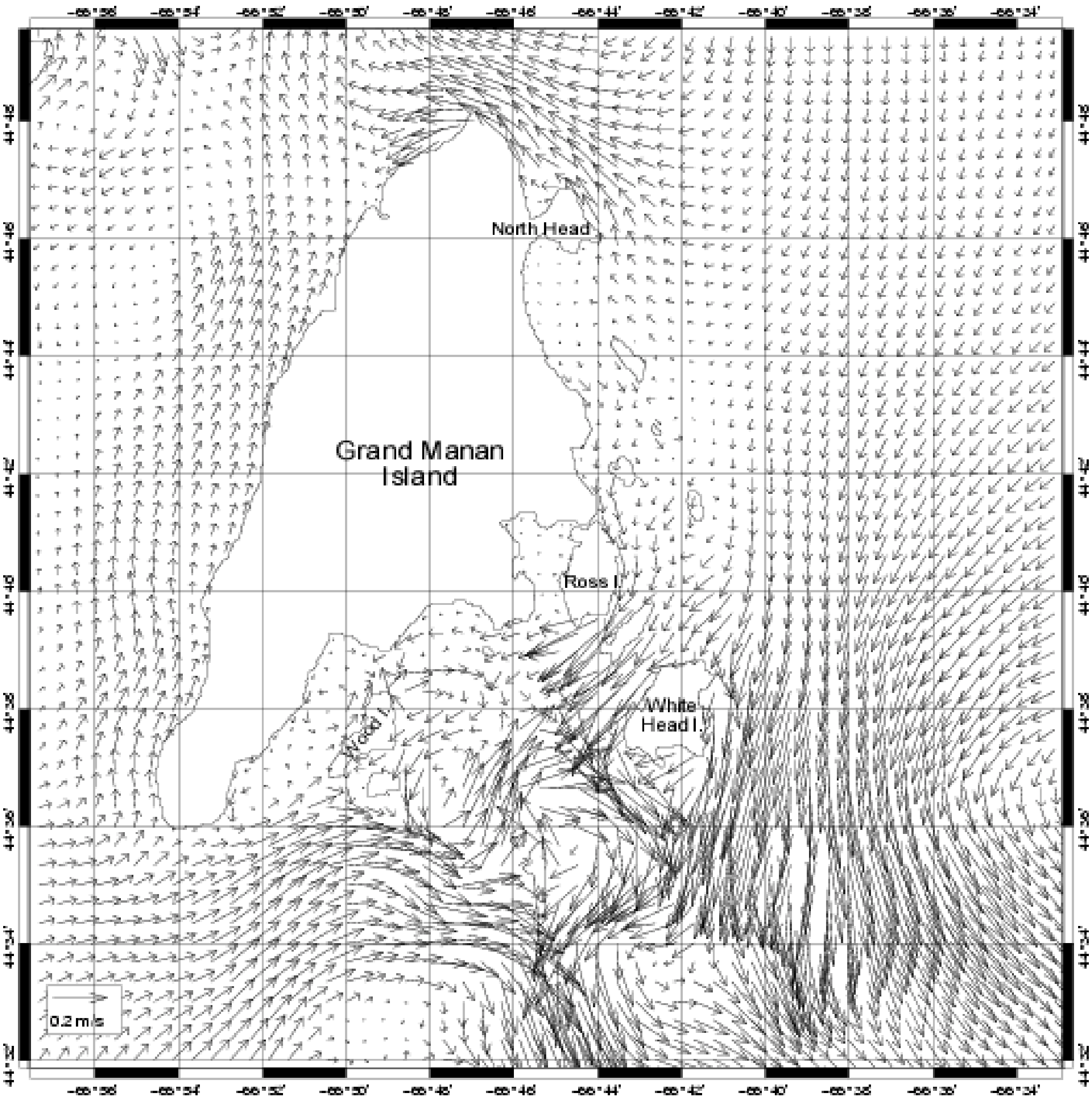

Figure 3. The depth-averaged tidal residual current field for Grand Manan Island (see section by D. Greenberg in this report).

Atlantic Salmon Farming in Grand Manan: An Overview

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Atlantic salmon (*Salmo salar*) were first cultured in Grand Manan at Dark Harbour starting in 1980 (Figure 4). This was one of the earliest sites to begin commercial salmon farming in New Brunswick, a year after the first site successfully over-wintered salmon at Lords Cove, Deer Island. There is a natural breakwater at Dark Harbour that makes this site unique and sheltered, ideal for aquaculture purposes.

During the 1980s the New Brunswick salmon aquaculture industry expanded inshore, at Limekiln Bay, Bliss Harbour and Campobello Island. While two sites were approved on Grand Manan in 1987 (in Flagg Cove and Seal Cove), they were only in production for a few years. By 1990 the total number of sites on Grand Manan stood at four, with total production close to 500,000 fish. In 1995, nine sites were licensed (of which 7 were operating), as new sites were approved in the Long Island/Duck Island Sound area and the Flagg Cove site was relocated to Deer Island. The majority of the entrants were fishermen from Grand Manan and were new to the industry. At this time, the majority of the sites were run as multi-year class sites using both spring and fall smolt entry periods. There were also a number of sites that held broodstock.

By 1998, a total of 17 sites were in operation on Grand Manan, with a capacity of about 3.5 million salmon. Most of these new sites were brought into production as single-year-class sites and Bay Management Areas (BMA) were now being established, with Grand Manan having six BMAs. However, it was not until the fall of 2000 that single-year-class sites became mandatory under the NBDAFA Aquaculture Site Allocation Policy for the Bay of Fundy. Thus in 2001, five new sites were approved on Grand Manan to facilitate single-year-class farming and balancing production. All of these new sites were in the southern end of Grand Manan, between Seal Cove and White Head Island. Currently there are 23 sites on Grand Manan with a licensed capacity of about 5,500,000 salmon.

Over the past 15 years, Grand Manan has also had a number of processing plants, one feed plant and two smolt producing units. Since 2001, exclusion areas have been established in the Duck Island Sound and Long Island areas and at the southern end of Grand Manan. Within these exclusion areas, no new salmon farms will be approved at this time, although boundary expansions and production increases will be considered at existing farms.

In 1996/1997 infectious salmon anaemia (ISA) became established in cultured Atlantic salmon in New Brunswick, with Limekiln Bay, Bliss Harbour and Seal Cove being the first areas to become infected. The three existing farms in Seal Cove became infected with ISA and were fallowed during the summer of 1998, then restocked in the spring of 1999. All of the Seal Cove sites were re-stocked as single-year-class sites in a single-year-class bay. No reinfection with ISA occurred in the 1999 year-class of fish.

For this study, fish health and salmon site proximity are being explored in relation to various oceanographic parameters in southern Grand Manan. This is an attempt to distinguish some of the major factors that may influence the risk of infection moving from one site to the next or from one Bay Management Area to the next. Some parameters that should be taken into consideration for this study or other studies investigating fish health and oceanographic interactions are: exchange of water (quantity and direction), oxygen levels, survival and infectivity of pathogens, sea lice numbers (vectors) and environmental impacts.

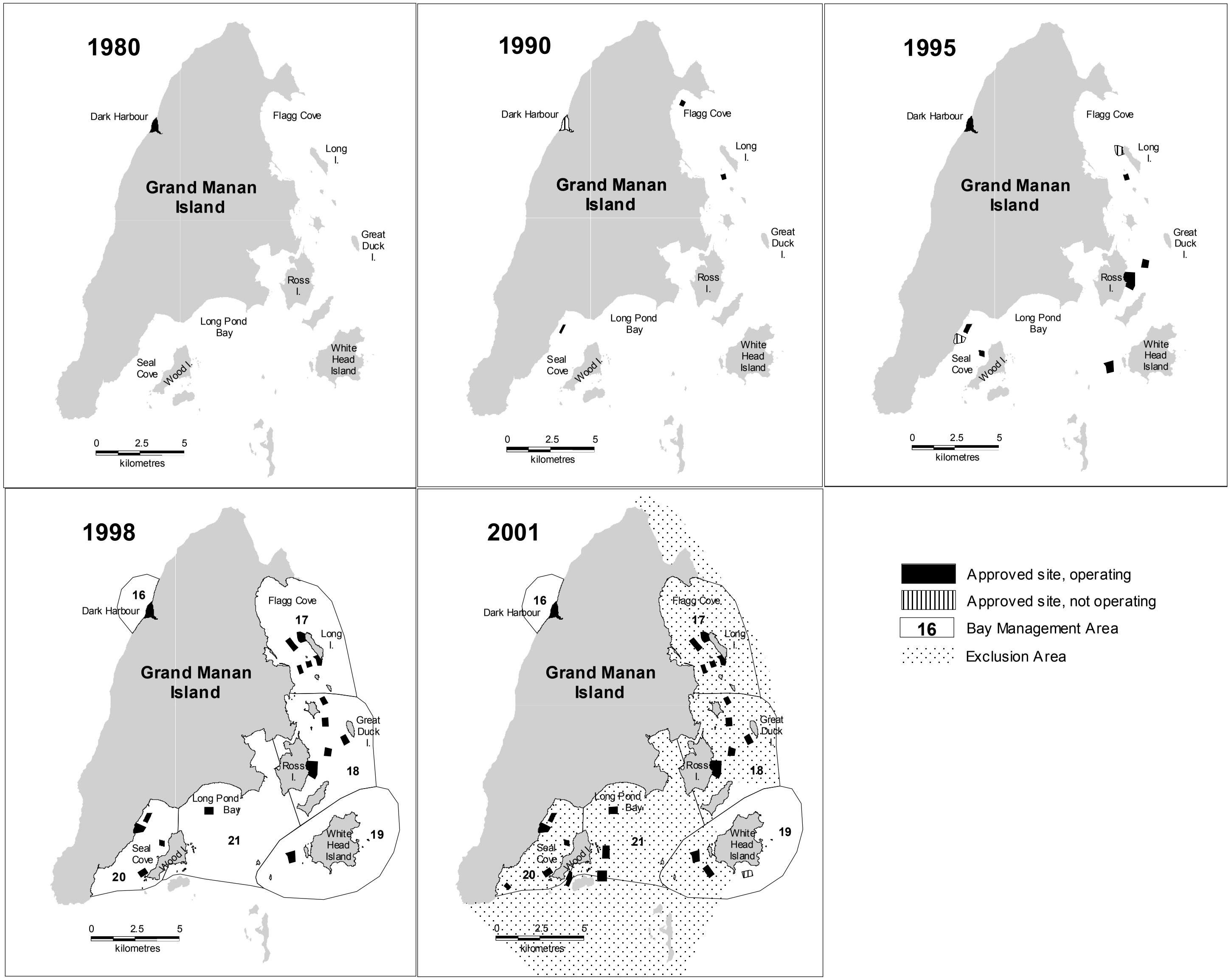

Figure 4. Historical development of salmon farming on Grand Manan Island.

Rationale for the Development of Bay Management Areas for the Salmon Farming Industry in New Brunswick

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Bay Management Areas (BMAs) were initially designed as tools for the industry's restructuring and move to single-year-class farming for environmental and fish health management reasons (see Figure 1). The industry's goal was to adopt single-year-class farming for sites and also for BMAs. This has now been achieved with a few minor exceptions, which should be resolved by spring 2002.

Considerable time and effort was devoted to finding a sound method for determining the boundaries of BMAs. Both industry and government recognized the fact that there should probably be 6 or 7 areas in the long-term. However, a number of factors were considered in the first drawing of the map: hydrographics, the locations and ownership of existing farms, wharf usage, and company structure.

Many of the initial decisions were based on what was practical at the time. It was understood that the science was not complete and that boundaries may have to be revised as more information became available.

Farmers prefer the smaller BMA units because the current fish health management strategy means that recommendations on eradication, harvest times and smolt entry are applied to the entire BMA and farmers did not want their businesses to be impacted by the fish health status of a distant site within a large BMA.

On Grand Manan, it is generally accepted by farmers that the southern part of the island (Figure 2) should be on an odd-year-class cycle while the northern section should be on an even-year-class cycle. This is largely the case with the exception of one site in Long Pond Bay. This farmer was the first company in the bay and he will need an alternate site in the opposite year-class in order to change his current practice.

In order to accommodate this farm in Long Pond Bay, farmers in the southern part of Grand Manan have proposed to NBDAFA that site 303 be the only site in BMA 21 (Long Pond Bay) for as long as it is on an even year-class. A new BMA 22 was proposed to accommodate the new sites 403, 408 and 491, which are all odd year-class sites. No response has been received from NBDAFA to date.

The current hydrographic work being carried out on Long Pond Bay and Seal Cove will assist farmers and government to make science-based decisions on the future of these Bay Management Area's boundaries.

Issues Raised During Meeting Discussion on Bay Management Areas

Not everyone agrees that the 21 BMAs as currently defined (in late 2001) are useful for fish health management. The Fish Health Technical Committee often makes recommendations which apply to much wider geographic areas than the individual BMAs.

BMA boundaries should be somewhat dynamic: BMA boundaries may change, depending on the fish health issue.

As acknowledged by the industry, F. Page noted that in January 1998, oceanographers had proposed dividing the southwest New Brunswick salmon farming area into 7 bay management areas, based on science's oceanographic knowledge at the time (see Figure 5).

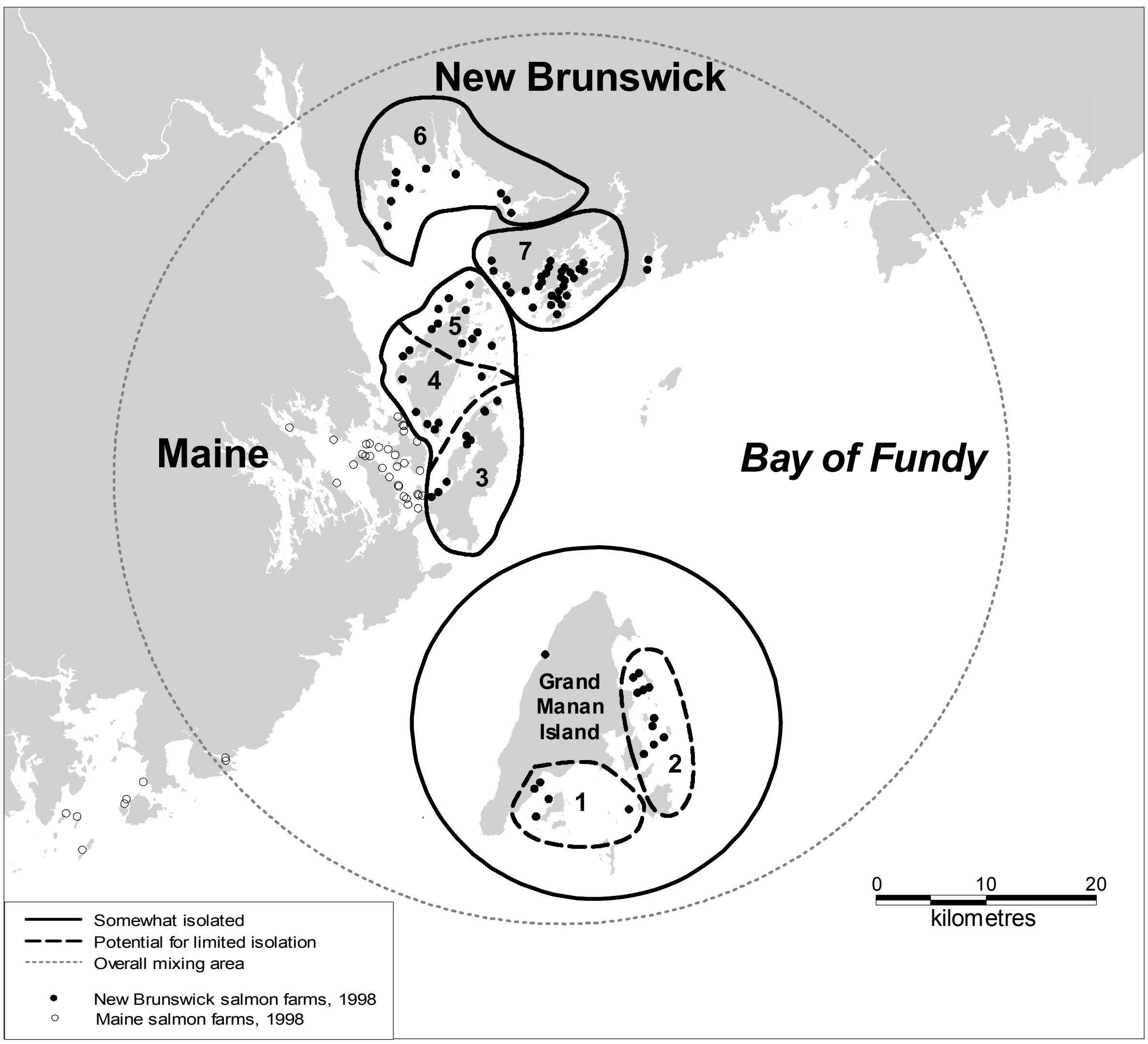

Figure 5. Proposed division of the southwest New Brunswick salmon farming area into bay management areas, based on oceanographic knowledge in January 1998. See Figure 1 for the boundaries of the 21 Bay Management Areas that existed in 2001.

History of Infectious Salmon Anaemia (ISA) in New Brunswick

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Background

Infectious salmon anaemia (ISA) first occurred in the summer of 1996 on two to three farms in two to three bays. The clinical presentation of this disease was different from the Norwegian ISA and was named Haemorrhagic Kidney Syndrome (HKS). The main area of pathology was with the kidney and not the liver. Efforts continued over several months to identify the pathogen responsible for HKS. By late summer in 1997, the infectious salmon anaemia virus (ISAV) was identified as the causative agent. At this time, ISA had spread to several farms in the original three bays (Limekiln Bay, Bliss Harbour and Seal Cove). The ISA virus has subsequently been detected in many wild stocks of fish throughout the world (herring, trout, eels) and has been confirmed as a disease in many of the salmon producing areas (Norway 1984, New Brunswick 1996, Scotland 1998 and the Faroes 2001).

In the spring of 1998, Ministerial Orders were given to remove all fish from infected sites in Limekiln Bay, Bliss Harbour and Seal Cove (approximately 24 sites). Sites in these Bay Management Areas (BMAs) were fallowed for 12 months or longer, then restocked in 1999 as single-year-class sites. Yet, by late spring 1998, ISA had moved 5 to 10 km into the neighbouring BMAs of Back Bay and Beaver Harbour where a number of sites became infected. However, since stocking of smolts in these BMAs was prohibited in 1998, ISA infection was limited to market-size fish and the extent of ISA infection was less than that in Limekiln Bay and Bliss Harbour.

Infectious Salmon Anaemia Management and Control Program

In New Brunswick the ISA Management and Control Program centered on early detection, containment, depopulation, prevention and disinfection. The ISAV Surveillance Program was established on the premise of detecting the ISA virus as early as possible and containing the disease. All sites in the industry were visited on a regular basis with moribund fish being tested for ISA.

Epidemiological studies in Norway identified a number of factors as high-risk activities in relation to ISA infection (Vågsholm *et al.* 1994, Jarp and Karlsen 1997). Hence, mitigation measures were introduced by the industry and government in an effort to reduce the effects of ISA. Some of the measures which reduced the risk of ISA were single-year-class farming, bloodwater containment, disinfection of equipment, and containment and treatment of processing plant effluent. As a result of these measures, the impact of ISA on infected sites has been reduced dramatically. There were also some specific high-risk areas that were not permitted to stock smolt as a preventative measure (i.e. Back Bay 1998). In areas that were infected with ISA in 1997/1998 and were fallowed prior to restocking in 1999, the incidence of ISA was reduced from 21 of 28 farms to 5 of 27 farms.

Data collected between 1998 and 2000 indicate that the use of multi-year-class sites is a high-risk activity in relation to becoming infected with ISA. Throughout the New Brunswick industry, of the 1999 year-class sites that became infected, the multi-year-class sites became infected on average within 6 months of smolt transfer compared to an average of 12 months for single-year-class sites during the same time period. Also, on average, an ISA infected multi-year class site removed 6 infected cages compared to just over 3 infected cages per ISA infected single-year-class site. Thus, single-year-class sites take longer to become infected with ISA compared to multi-year-class sites and fewer fish become infected. This strategy enables the farmer to carry more fish to market size.

The Province and industry are continually refining and assessing the ISA Management and Control Program in an effort to keep ISA infection under control.

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Vågsholm I., Djupvik, H.O., Willumsen, F.V., Tveit A.M. and Tangen K. 1994. Infectious salmon anaemia (ISA) epidemiology in Norway. Preventative Vet. Medicine. 19 : 277-290.

Issues Raised During Meeting Discussion on Fish Health Management Issues

Infected fish are releasing large numbers of pathogens into the water. We need to know where these pathogens will go and at what concentrations, in order to know at what distance from infected fish it will be safe for other fish. This will be affected by dilution, survival, and speed of movement of the pathogen. The amount of loading will also depend on farm husbandry.

We do not know what dilution levels are safe, so we need to err on the conservative side at this time. It is especially difficult to determine safe dilution levels for viruses because it is extremely difficult to count virus particles.

The duration of survival of the ISA virus in the environment is probably in the order of days. More information is required on the survival of other pathogens.

Bacteria and viruses have very limited ability to move on their own and their movement is dependent on water currents and mixing processes.

Sea lice are considered to be a vector for spreading ISA. Mobile stages of sea lice can move on their own to some extent. We need to know more about sea lice movement, such as how far they move and at what depths.

It was noted that infected farms can be considered point sources of infection in a spatial sense, but not necessarily in a temporal sense. If infected fish are present at a farm over an extended time, then this would represent a continuous source for that time period.

We need to know how bloodwater and mucous will move, if discharged into the water. This includes how far these substances will move and at what depth (at the surface or vertically-mixed). It was noted that most fish are slaughtered on site, but bloodwater must be collected and treated; however, some spillage may occur.

Bloodwater is currently sent to municipal sewage treatment plants. It is now recognized, however, that the biological oxygen demand (BOD) of bloodwater is too high for the sewage treatment plants. It may be possible to reduce the BOD of bloodwater through additional pre-treatment.

It was agreed that the project should approach the oceanographic linkages from a generic disease perspective, rather than from a specific disease perspective. This was due largely to the fact that there is not sufficient information about the mode of dispersion for specific diseases.

Overview of Oceanographic Information and Approaches: Hydrographic, Current and Dispersal Concepts and Measurements

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The two main categories of the marine environment that influence fish health are water quality and water circulation. Water quality influences the physiological health and production performance of the organisms being cultured. Water circulation influences water quality and the spread and suspension of wastes, diseases and substances emanating from farms. Water circulation is studied by measuring water movements in situ and by developing hydrodynamic models of the water motion. This type of information is sometimes referred to as oceanographic information.

The oceanographic information that was available and presented to the site application process and to the affected members of the salmon aquaculture industry in the fall and winter of 2000-01 was limited. It consisted mainly of preliminary and cursory analyses of some hydrographic data and current meter records collected in the years 1999 and 2000 and a brief examination of output from preliminary runs of a three-dimensional tidal circulation model for the Grand Manan area. A brief summary of some of the highlights of the empirical observations of the hydrography and currents is given below. A brief description of the preliminary numerical circulation model that has been developed for the Grand Manan area is described in a subsequent section of this report by D. Greenberg. A description of mixing and an example of how the model can be used to estimate exchange and flushing rates are included in the section by M. Dowd in this report.

Hydrography

The aspects of water quality traditionally studied by oceanographers include the physical, chemical and biological properties of the water. These are often referred to as the hydrographic properties of the water. The physical and chemical properties include such variables as temperature, salinity, the optical properties of the water, the concentration of dissolved gases, nutrients and dissolved or suspended particulates. The biological properties include the concentrations and species composition of living organisms such as phytoplankton and zooplankton. The spatial and temporal patterns of these aspects are often closely related to, and hence sometimes indicative of, the characteristics of the water circulation. Hence, these characteristics are often useful for calibrating and validating water transport models.

In a previous project we gathered data on the temperature and salinity of the waters in the Grand Manan area. Surveys of the eastern and southern inshore areas of Grand Manan were conducted in June and July of 1999 (Figure 6). During each survey, vertical profiles of water temperature and salinity were taken at a series of stations, using a CTD (conductivity-temperature-depth) profiler. The June survey indicated that the bottom temperature throughout inshore Grand Manan varied from 8 to 9°C, a range of 1°C. The surface temperatures varied from 8 to 13°C, a range of

5°C. The temperatures were highest in the inner portions of Head Harbour, Grand Harbour, Long Pond Bay, and Seal Cove. These are perhaps suggestive of reduced flushing.

Internally recording temperature and temperature-depth recorders were also deployed in 1999 and 2000 at several locations on the eastern and southern side of Grand Manan. These recorded water temperature or water temperature and pressure at fifteen minute intervals. The instruments were deployed for various periods of time. Records from the Ingalls Head Wharf in Grand Harbour and a location along the western shore of Seal Cove are shown in Figures 7 and 8. The temperature time series show the seasonal cycle and some high frequency variation. One of the interesting features is the abrupt change in temperature that sometimes occurs in the fall and winter. For example, the rapid temperature changes around March 19 (about day 79 at Ingalls Head (Figure 7) and day 445 at Seal Cove (Figure 8)). The change is about 4°C at Ingalls Head and 1°C at Seal Cove.

The pressure data is indicative of the temporal variability in sea level. The time series show the fortnightly variation in sea level as well as variations caused by non-tidal forcings such as storm events. These types of record are useful for validating the tidal heights and storm surges generated by numerical circulation models and hence for indicating tidal and non-tidal variations in the water circulation.

Advection-Dispersion Approach

A conceptual perspective that is useful when addressing issues of water movement and the transport and dispersal of substances from a fish farm is that referred to as advection and diffusion (see Figure 9). In this perspective, a cloud of material is assumed to be released from a source location, such as a fish farm. The cloud is moved away from the farm by the currents and dispersed by mixing processes along the way. The general translation of the cloud is termed advection and the spreading out of the cloud is termed dispersal. In an oceanographic regime such as Grand Manan, where tidal currents are prominent, the cloud often follows a back and forth trajectory every tidal cycle (12.42 hours) with a smaller net motion away from the farm. The horizontal extent of these back and forth motions is called the tidal excursion and the displacement over longer time scales is referred to as the net drift. The back and forth motion is caused by the tidal currents and the net movement over several tidal cycles is termed the residual or mean current or mean drift.

Knowledge of the rates of advection and dispersion allows simple calculations of the horizontal extent of tidal excursions, mean rates of displacement and the time scales for displacement and dispersion. All of these are potentially useful for helping to assess the risk of exposure to vectors of fish health concern.

The advective currents are generally measured from two perspectives: the Eulerian and Lagrangian perspectives. The Eulerian perspective is when the currents are measured over time at a single point in space. This is typically achieved by deploying electronically recording current meters. The meters measure the speed and direction of the water flow at specified time intervals. We typically use the InterOcean S4 and the RD Instruments (RDI) Workhorse.

The S4 measures the current at a specific location and depth by inducing a magnetic field around the instrument. The field is distorted by the speed of the water flow past the instrument. This distortion is measured. The direction of the flow is estimated from a magnetic compass housed within the instrument. Because of the instrument's reliance on magnetic fields and a magnetic compass, it must be deployed away from any materials that may influence the magnetic field around the instrument.

The RDI Workhorse is an acoustic Doppler current profiler (ADCP) that measures the current throughout the water column, at specified depth intervals, by transmitting an acoustic signal into the water and measuring the Doppler shift in the signal that returns from particles in the water. Like the S4, an internal compass is used to indicate the current direction.

Both types of current meters were deployed on Grand Manan during the 1999 and 2000 mooring program. Single instruments were moored for approximately 4-6 week periods near the middle of each major channel containing offshore–inshore water flow and near several fish farm sites (Figure 10).

The Eulerian approach results in a time series of data from a specific location and depth. The record gives an indication of the temporal variability in the current at the specific deployment location and enables summary statistics of the current at the specific location to be calculated. The series can be analyzed, using time series statistical techniques, to indicate the relative contribution of various tidal constituents and winds to the generation of the currents. The time series in the Bay of Fundy are typically characterized by a diurnal variation in the current speed and direction. The speeds around fish farms typically range from near 0 cm/s to over 50 cm/s, although in some locations the speeds are somewhat higher. The mean flows can either be in a relatively consistent direction or vary over periods of several days. Estimates of displacement made from a single current meter record must be treated cautiously since the approach assumes the current at locations distant from the current meter area identical to those recorded by the current meter at its location. In areas such as Grand Manan, where the bathymetry varies sharply over short distances (meters to tens of meters), this assumption is seldom valid. Hence, real displacement trajectories will be considerably different from those estimated by a single current meter record.

Preliminary analyses of the current meter records collected from southern Grand Manan in 1999 and 2000 indicate the tidal currents range from a low of about 0 cm/s to a high of 50-100 cm/s depending upon location. The mean currents tend to be about 10 cm/s. The record from a S4 meter moored between Green Island and Long Ledge (mooring #99) is shown (Figure 11) as an example. The approximate direction of the mean currents (Figure 10) in the southern Grand Manan area, suggest the flow is south-westerly along the western shore of Seal Cove, southerly along the eastern side of Outer Wood Island, north-easterly between Wood Island and the Three Islands and hence into Long Pond Bay, south-easterly between the Three Islands and the Green Islands and hence out of Long Pond Bay, and north-easterly into Long Pond Bay between the Green Islands and White Head Island.

When the RDI Workhorse is mounted on a surface platform or vessel it can be configured to keep track of the bottom as the platform moves. This allows it to measure water velocities relative to the bottom. When this instrument is mounted on a vessel and interfaced with the vessel's global positioning system (GPS), it has the ability to measure the vertical profile of the current beneath the vessel as the vessel moves. In this mode of deployment, data have been collected at a series of fixed stations (June CTD stations, shown in Figure 6) and along a series of transects run throughout the eastern and southern inshore area of Grand Manan (Figure 12). Many of the transects were conducted across the major channels and bays. A few transects were obtained from Long Pond Bay and Seal Cove.

An example of an ADCP transect collected from Seal Cove on Grand Manan during an ebbing tide shows horizontal shears in the water velocities below the sea surface (Figure 13). The pattern of current vectors suggests the presence of gyres within the cove and a flow of water into Seal Cove from Long Pond Bay. During the flood tide the flow was from Seal Cove into Long Pond Bay and the gyral flow pattern was not so pronounced. Transects within Long Pond Bay indicated a divergence in the direction of the tidal flow along the eastern shore of Wood Island and a somewhat complicated flow field within Long Pond Bay. Such data are valuable for indicating the spatial variation in the current field and for comparison to outputs from circulation models.

Another perspective on water currents is the Lagrangian perspective. This perspective is obtained when the movements of a parcel of water are tracked. Although this cannot be done in most cases, drifters released into the water can approximate it. The drifters record their geographic position at specified time intervals. We use a CAST (configurable accurate surface tracker) drifter that records GPS positions at time intervals of approximately 12-15 minutes. The drifter can be configured to move with the currents in the top 1m of the water column or with the currents over a subsurface depth range by attaching a cylindrical drogue to the surface drifter.

The Lagrangian approach gives an indication of where particles or substances may drift or be transported and how fast the material will spread out. Unfortunately no drifter data has been collected from the Grand Manan area. The main limitations of this approach are that the drifters stay at a specific depth and many releases are required to build up a statistical description of the spatial and temporal variance in the transport pathway.

The dispersal of neutrally buoyant substances is best observed by conducting dye release experiments. However, these are very expensive to conduct and usually cannot be conducted in the vicinity of resources that will be used for human consumption. We have not conducted any dye releases in Grand Manan waters. However, releases have been made in the Passamaquoddy Bay and Letang Inlet region. The data gathered from these experiments indicated that a first order approximation to the rate of dispersal could be obtained from the empirical relationships and that the temporal decrease in dye concentration could be estimated using simple diffusion models.

Ideally one would like to deploy many current meters, release hundreds or thousands of drifters or conduct many dye release experiments to adequately describe the water circulation in a given area. However, this is obviously impractical. Hence, computer circulation models are used to help estimate the currents throughout the geographic area of interest. The models typically estimate the temporal variation in the currents in two or three dimensions. In principal, modern models can take into account the influence of the tide, wind and freshwater inputs. In practice the models need to be compared to observational data to determine how accurately they represent real flows in the area of interest. The model outputs can be used in conjunction with particle tracking models or advection-diffusion models to estimate the trajectories and dispersal patterns of drifters or particles and the dispersal of clouds of particles. Although, these models can in principal take into account the tide, wind and freshwater our experience in the southwest New Brunswick area has been largely restricted to the tide. The models that have been developed for the Grand Manan area of southwest New Brunswick area are briefly described by D. Greenberg in the next section and an example of their application to estimating mixing and dispersal rates is described in the subsequent section by M. Dowd.

Box Model Approach

Another conceptual perspective is to define a geographic area and volume of water and determine how quickly the water within this volume is exchanged. This approach describes the details of the circulation within a bay. It is useful for estimating the general impact of sources and sinks of substances, such as dissolved oxygen or farm waste products, on the average concentration of the substances within the bay. Extensions of this type of model can be made to include processes that utilize or degrade the substances or functions that assess the impacts of the substance on specified living resources.

We have not yet developed this type of model for the Long Pond Bay area.

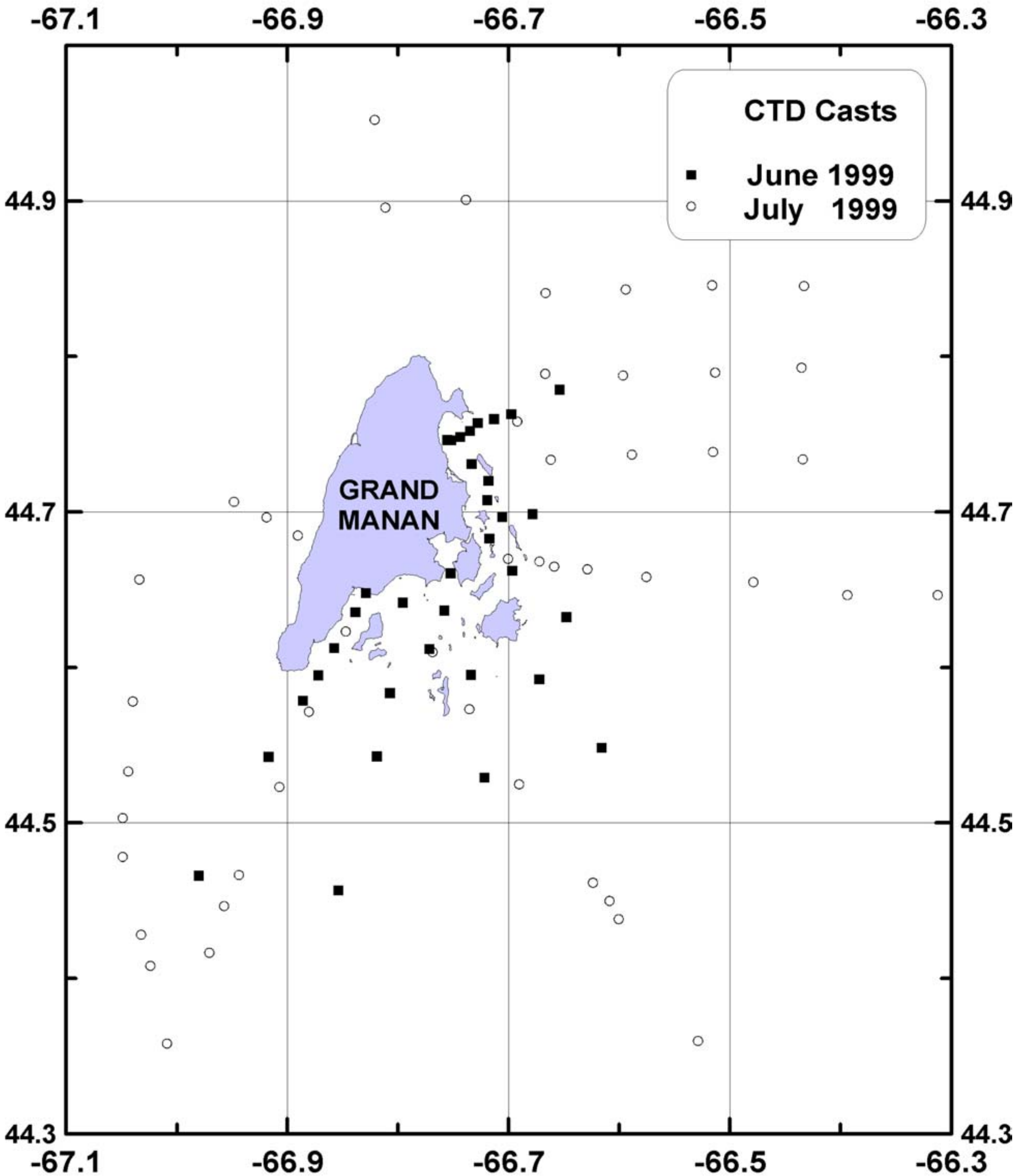

Figure 6. Map of Grand Manan showing the locations of CTD (conductivity-temperature-depth) stations taken in June and July of 1999. ADCP profiles were also taken at each June CTD station.

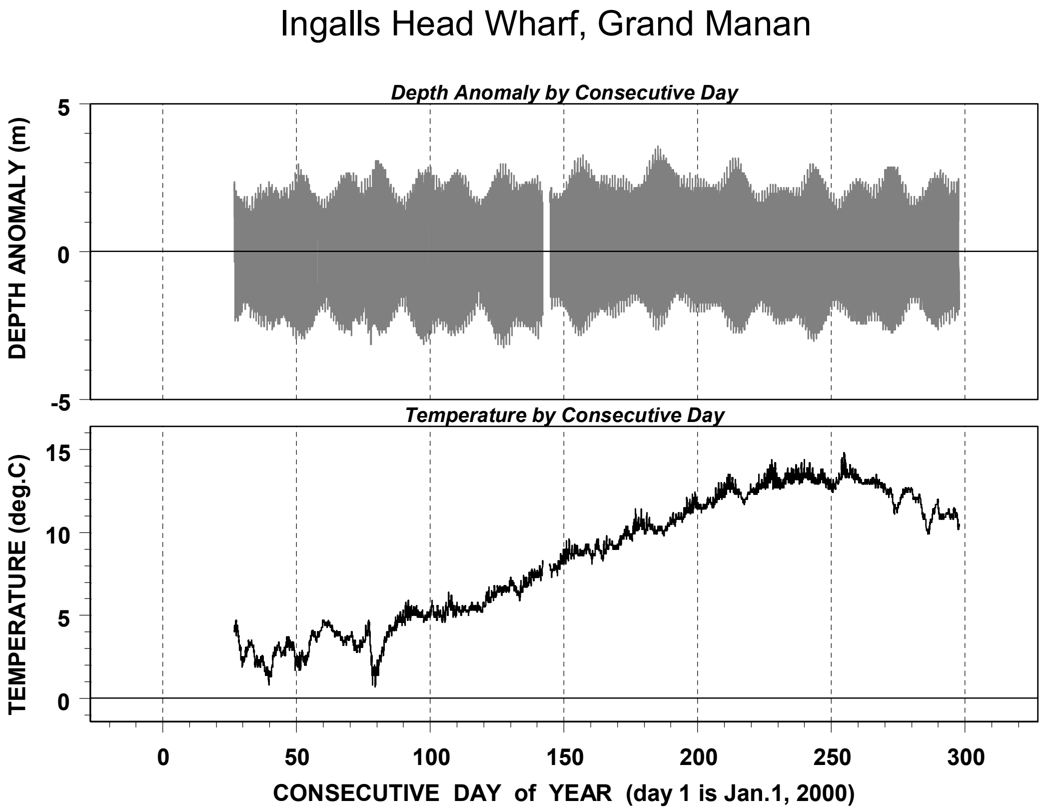

Figure 7. Time series of water temperature and depth anomaly from temperature-pressure recorders moored off the Ingalls Head wharf in Grand Harbour, Grand Manan during the year 2000. The gap in the time series is when the recording instrument was being changed. The depth anomaly is the instantaneous depth minus the time-averaged depth.

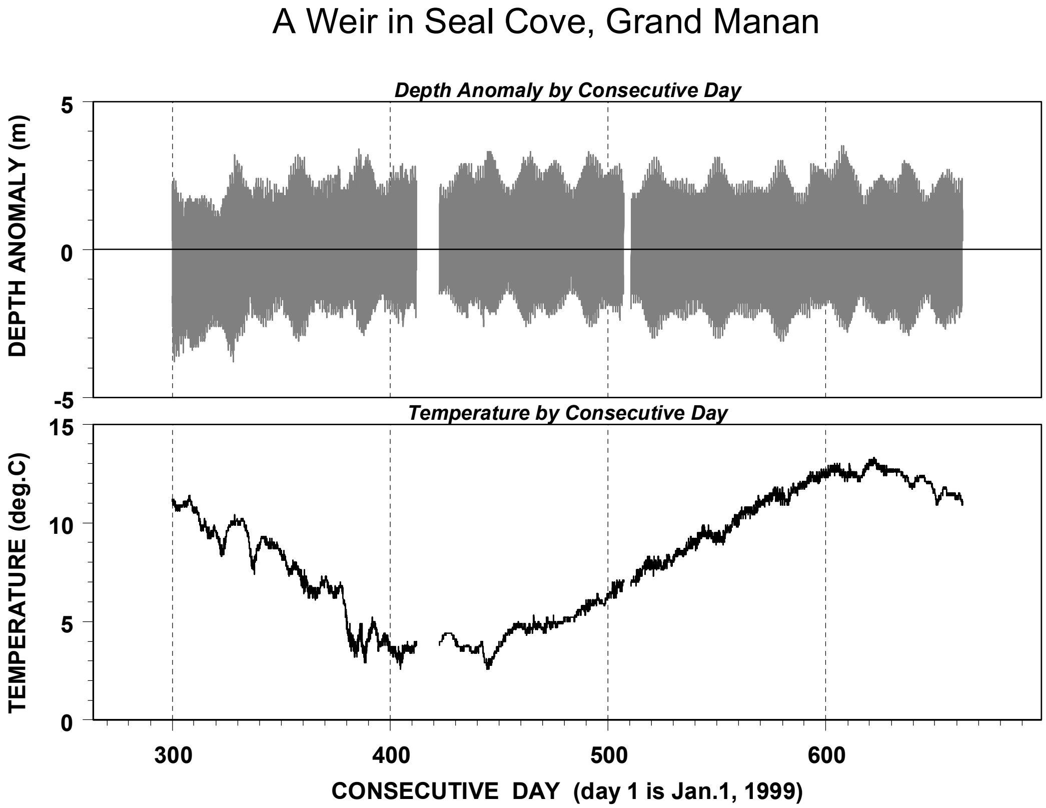

Figure 8. Time series of water temperature and depth anomaly from temperature-pressure recorders moored off a weir in Seal Cove, Grand Manan during the year 1999 and 2000. The gaps in the time series are when the recording instrument was being changed. The depth anomaly is the instantaneous depth minus the time-averaged depth. The low frequency trend in the depth data is probably due to the effect of temperature on the pressure sensor.

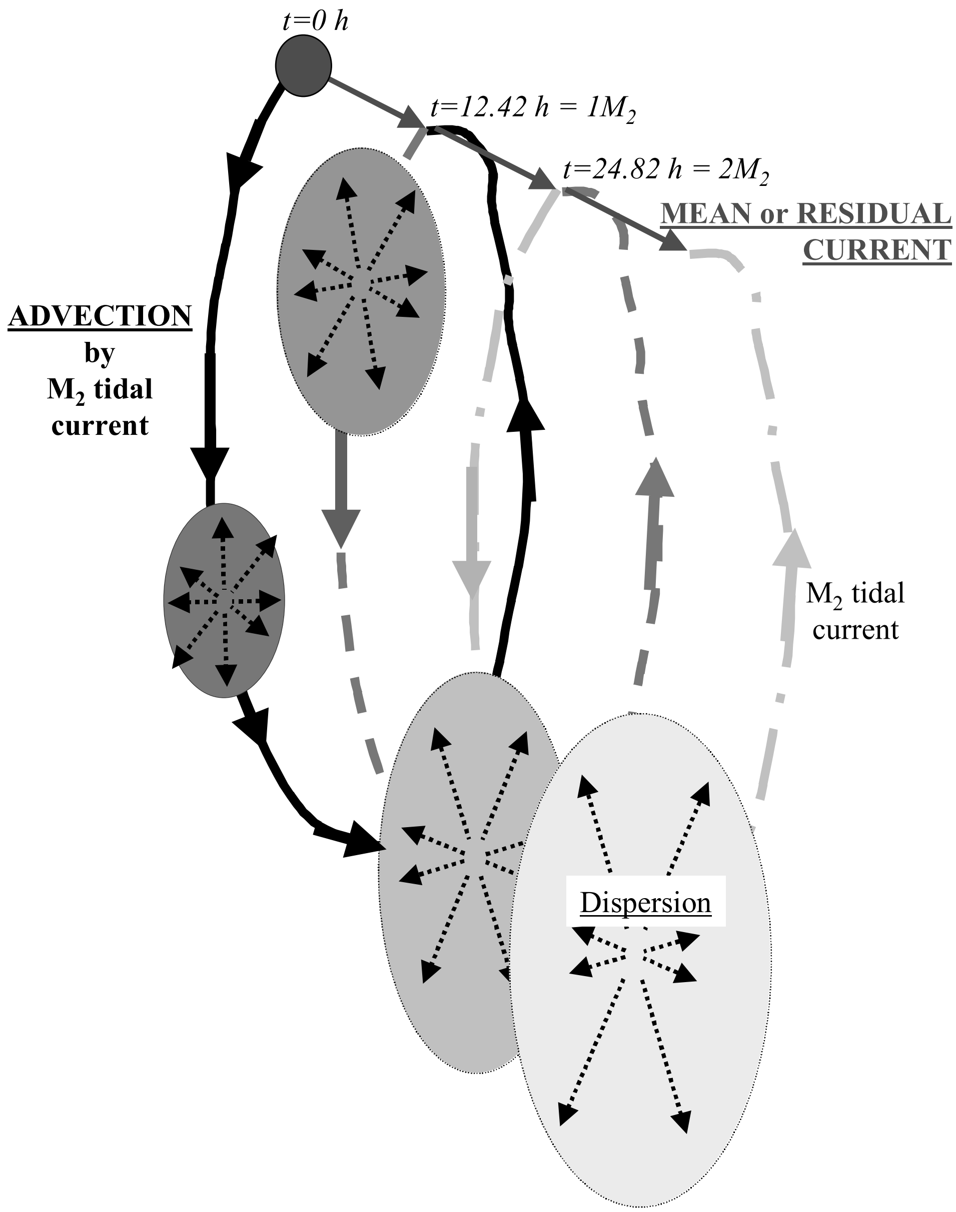

Figure 9. Illustration showing the conceptual framework for how a patch of particles or a dissolved substance disperses over time in a tidally dominated flow field that has little spatial structure. The arrows indicate how the patch is advected (i.e. translated) by the principal lunar semi-diurnal (M_2) tide. The net displacement of the patch over an even multiple of the M_2 tidal period (12.42 h) is referred to as the residual or mean displacement or motion. The spreading and dilution of the patch as it is advected is illustrated by the increasing size of the ellipses and the decreasing intensity of the ellipse grey shading.

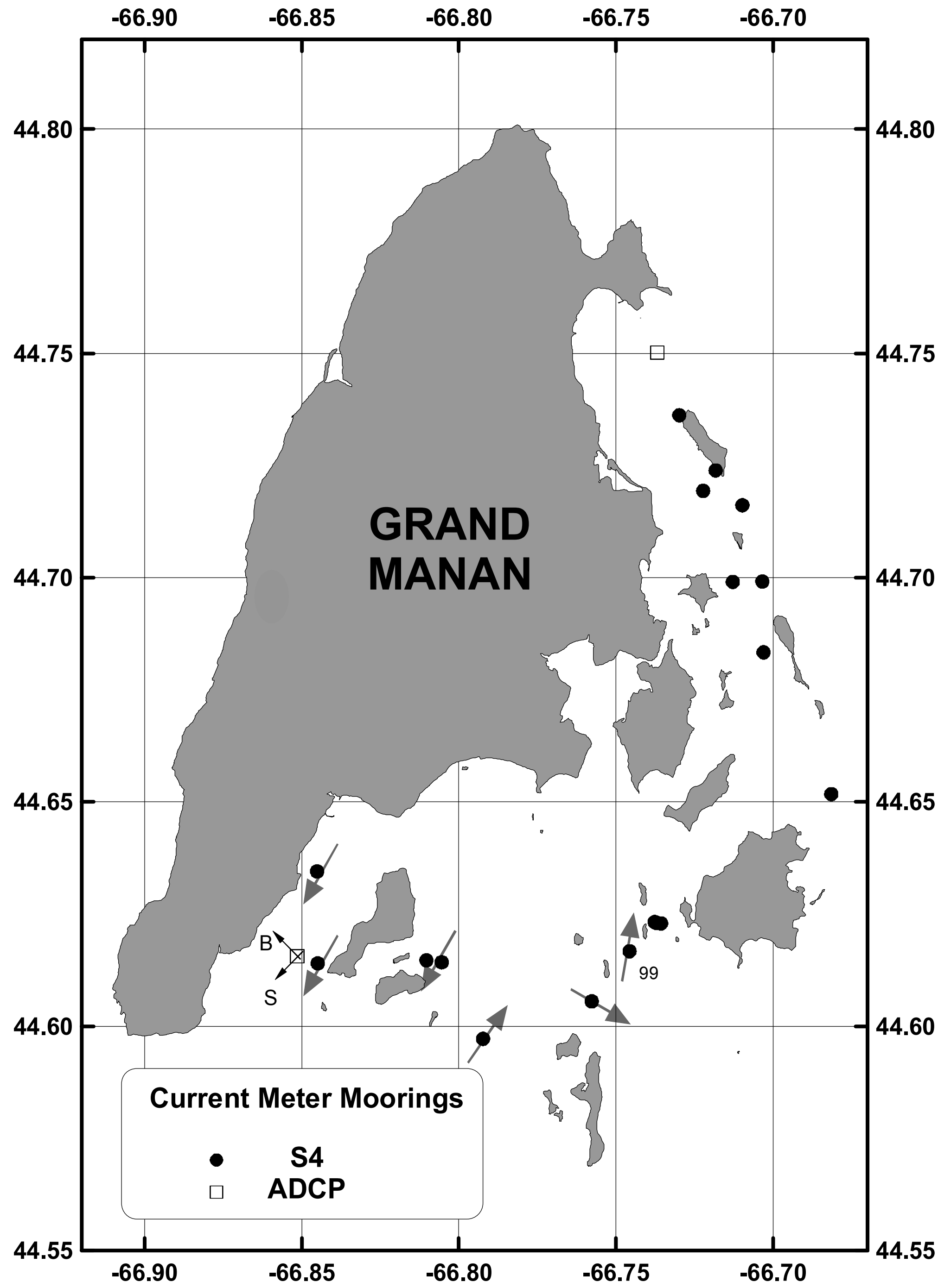

Figure 10. Map of Grand Manan showing the locations of S4 and ADCP (acoustic Doppler current profiler) current meter moorings deployed and recovered in 1999 and 2000. The arrows overlying the current meters southern Grand Manan indicate the general direction of the measured mean flow. S – near-surface. B – near-bottom. The number 99 indicates the specific mooring referred to in the text and in the following figure.

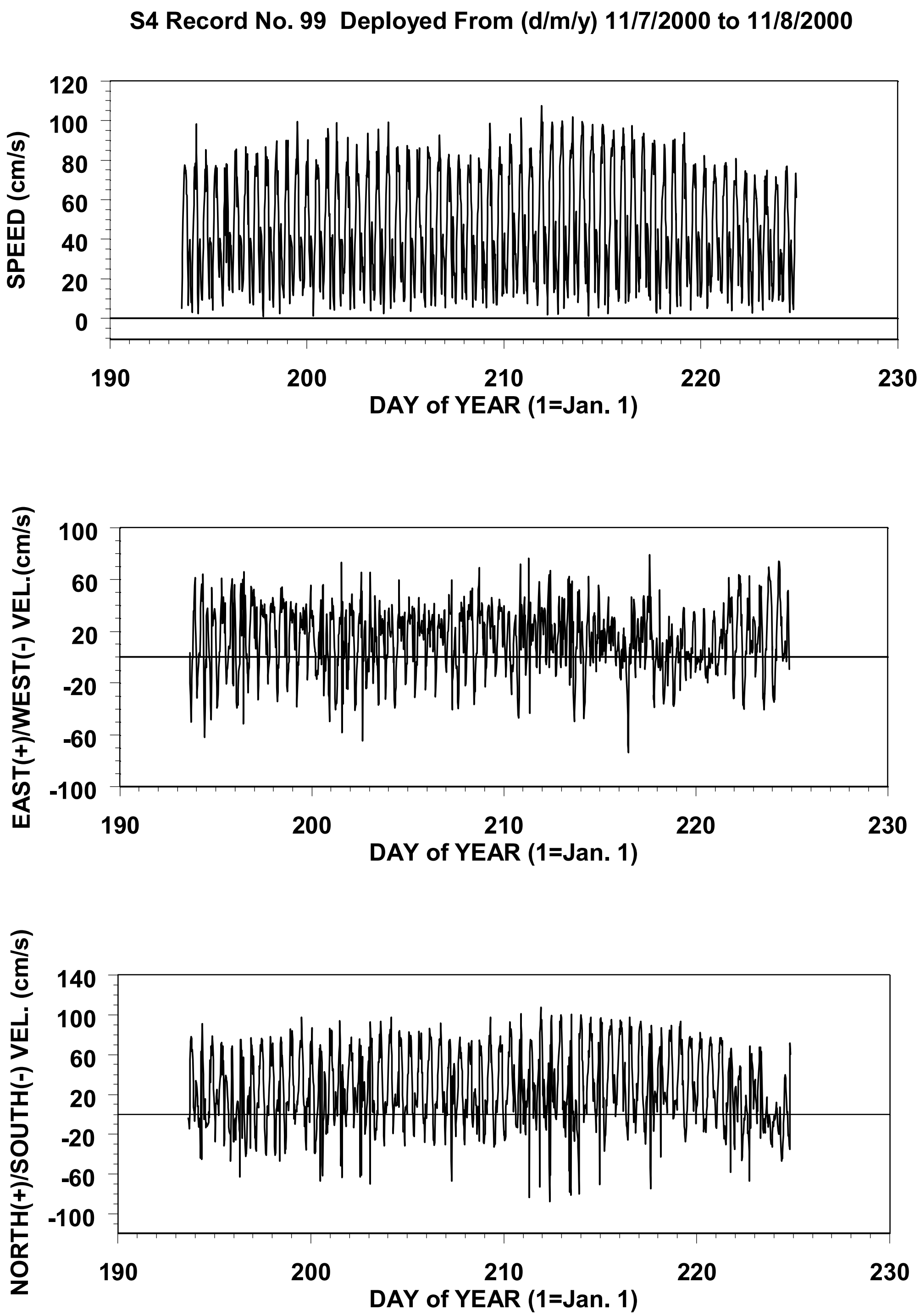

Figure 11. Time series of total current speed (top panel), speed along the east-west axis (middle panel) and speed along the north-south axis (lower panel) from a S4 mooring located between Green Island and Long Ledge, within Long Pond Bay, Grand Manan.

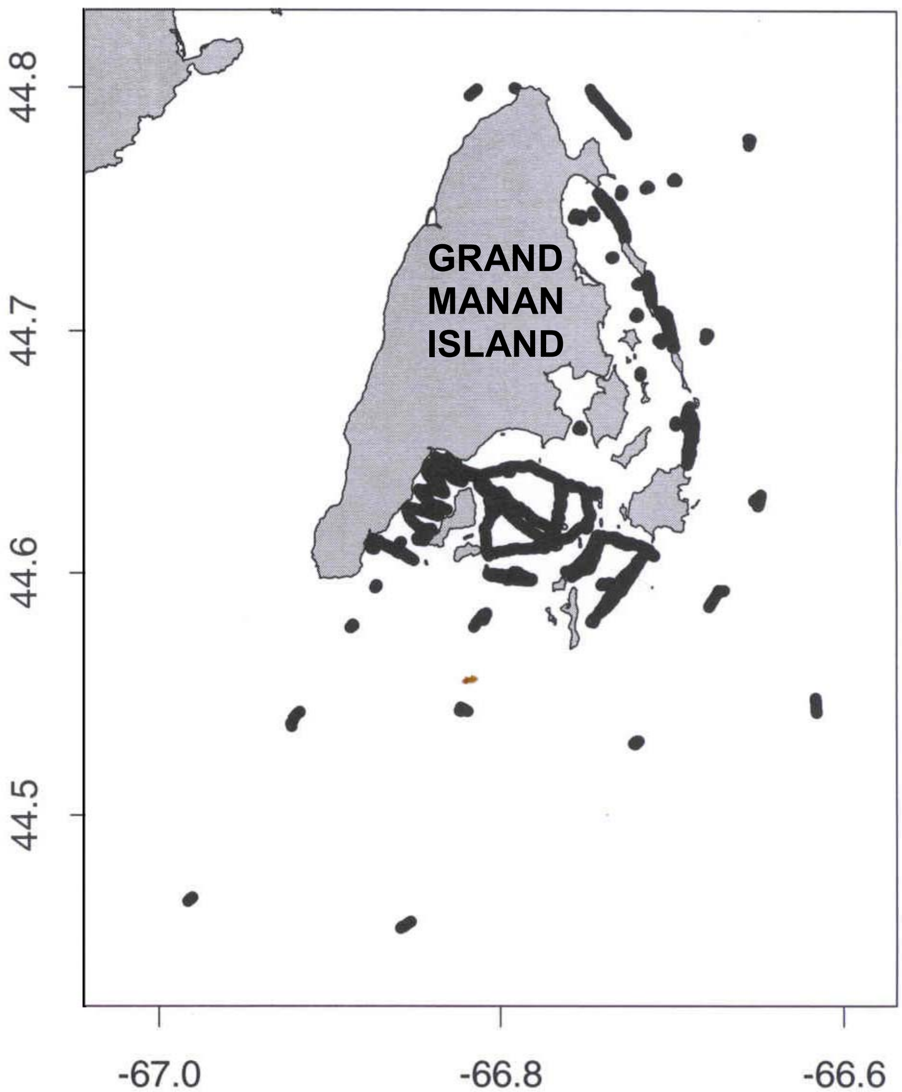

Figure 12. Map of Grand Manan showing the locations of acoustic Doppler current profiler (ADCP) transects and single stations occupied in 1999. The single stations correspond to the locations of CTD (conductivity-temperature-depth) profiles obtained in June 1999 (see Figure 6).

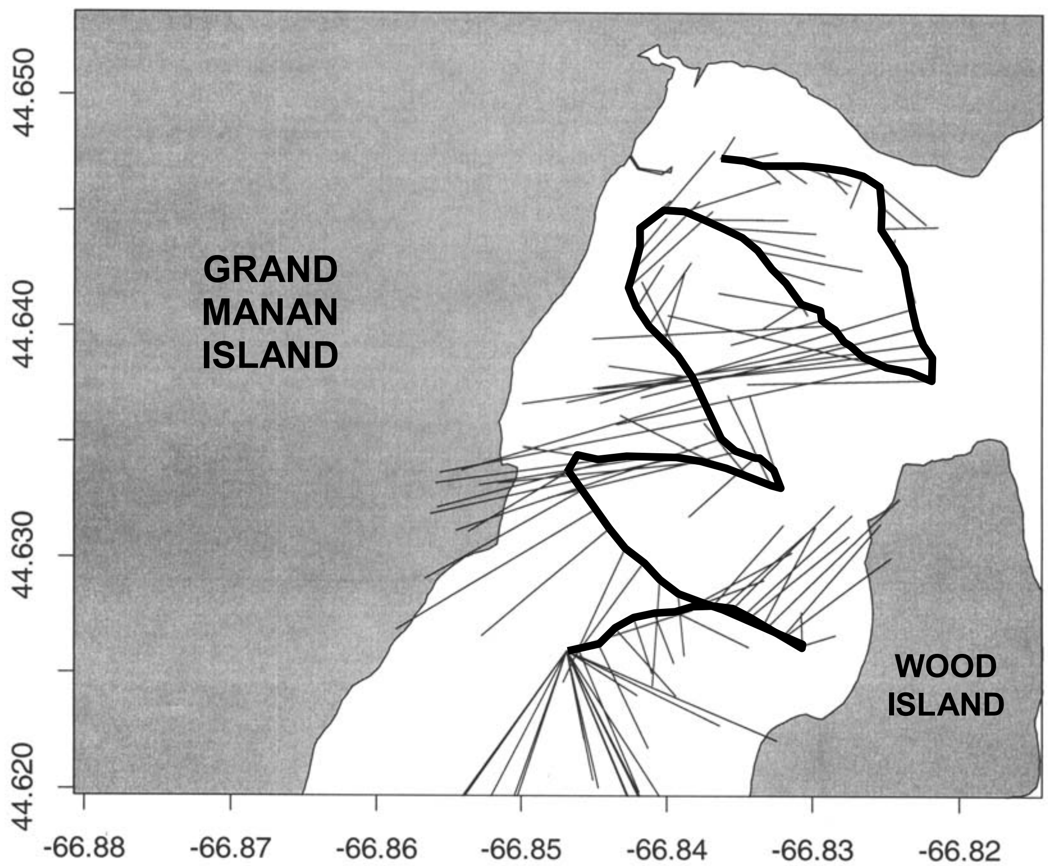

Figure 13. Acoustic Doppler current profiler (ADCP) survey track line (thick continuous line) within Seal Cove showing the speed and direction of the water current at 5.9 m below the sea surface and at regular points along the track line. The transect was done on 15 August 2000, during an ebbing tide. The current speed is proportional to the line length and the direction is indicated by the angle of the line.

Overview of Oceanographic Information and Approaches: Modelling Currents for Grand Manan Aquaculture

D. Greenberg
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Bedford Institute of Oceanography, Dartmouth, NS

The computer circulation model that has been developed for the Grand Manan area is a three-dimensional model. The model estimates the tidal currents by dividing the geographic area into triangles (called finite elements) and by numerically solving the equations of motion at each x,y,z grid point within the model domain. The geographic domain of the model includes the entire Bay of Fundy and Gulf of Maine (Figure 14). The model divides the geographic domain up into triangles. When the model is run, a depth profile of the current is calculated at each corner of every triangle every 1.6 seconds. The spatial resolution of the model is relatively coarse in the middle of the Gulf of Maine (large triangles) and quite fine around Grand Manan. The smallest triangles in the inshore area of southern Grand Manan have a width of about 110 m (Figure 15). This feature of the finite-element model makes it well suited for covering the wide domain of influence with the required detail in the area of interest needed to resolve local characteristics. The model also has the capability of simulating wetting and drying of intertidal areas. Although the generic model code has the capability of including boundary forcing, internal water density and surface winds as current driving forces, the customized model for the Grand Manan area has only been run using boundary forcing by the principal diurnal lunar tide, the M_2 tide. For clarity of presentation the model currents are often interpolated to a square grid (e.g. Figures 16 and 17).

Initial runs from the preliminary numerical model have been made looking at the M_2 tidal current characteristics of the region south of Grand Manan Island. These runs have indicated the need for even greater resolution in some areas. The model-produced picture from mid-flood tide (Figure 16) and mid-ebb tide (Figure 17) show a very rich structure with currents exceeding 1 m/s in places and eddies that are present at only some stages of the tide. The current averaged over a tidal cycle (Figure 18) indicate a complex residual current pattern with several eddies and currents exceeding 0.3 m/s in same areas. Preliminary comparisons with data are promising, but suggest that more detail would be useful in this local area. When this refinement is done there will be further runs and comparison with data which could include the influence of wind on this area.

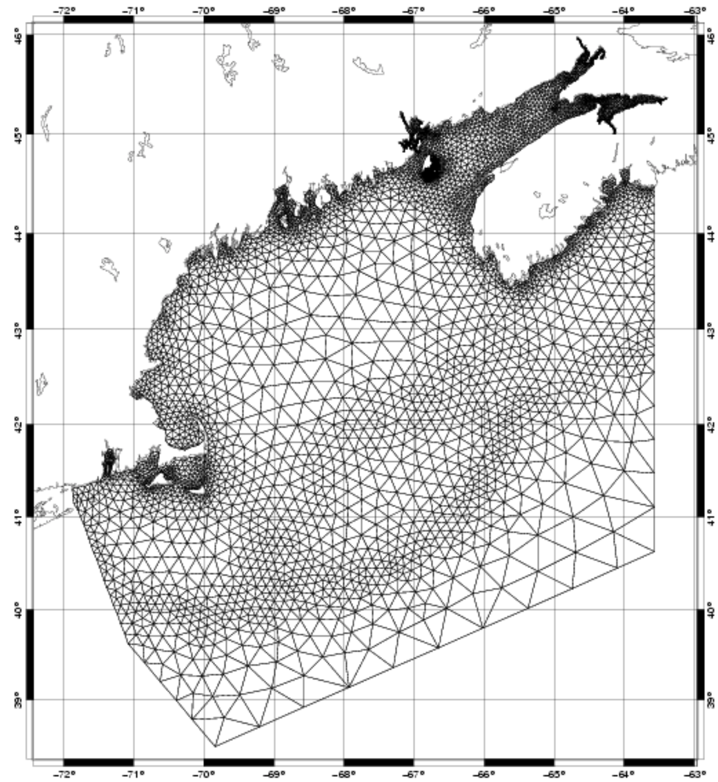

Figure 14. The full model domain covers the whole Bay of Fundy, the Gulf of Maine and parts of the adjacent shelves and deep sea.

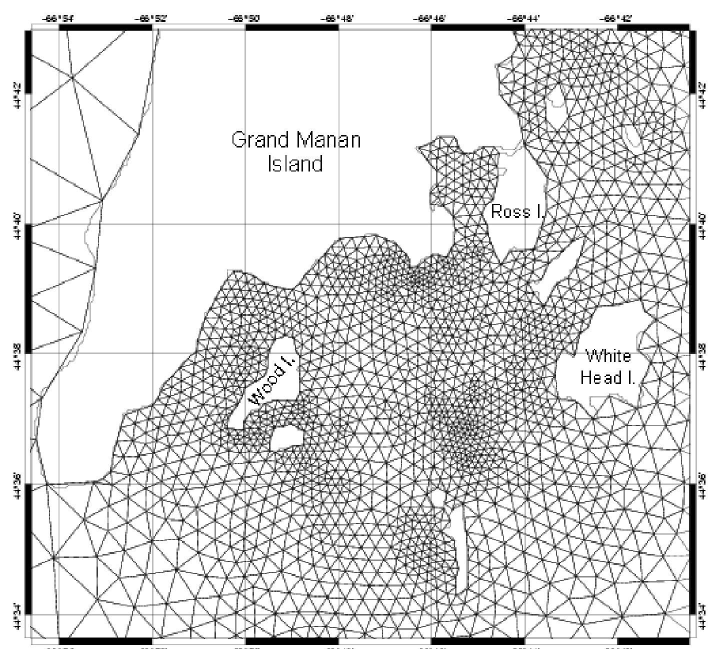

Figure 15. The model grid in the area south of Grand Manan Island has node separation as small as 110 metres. Further refinement is planned for continuing studies.

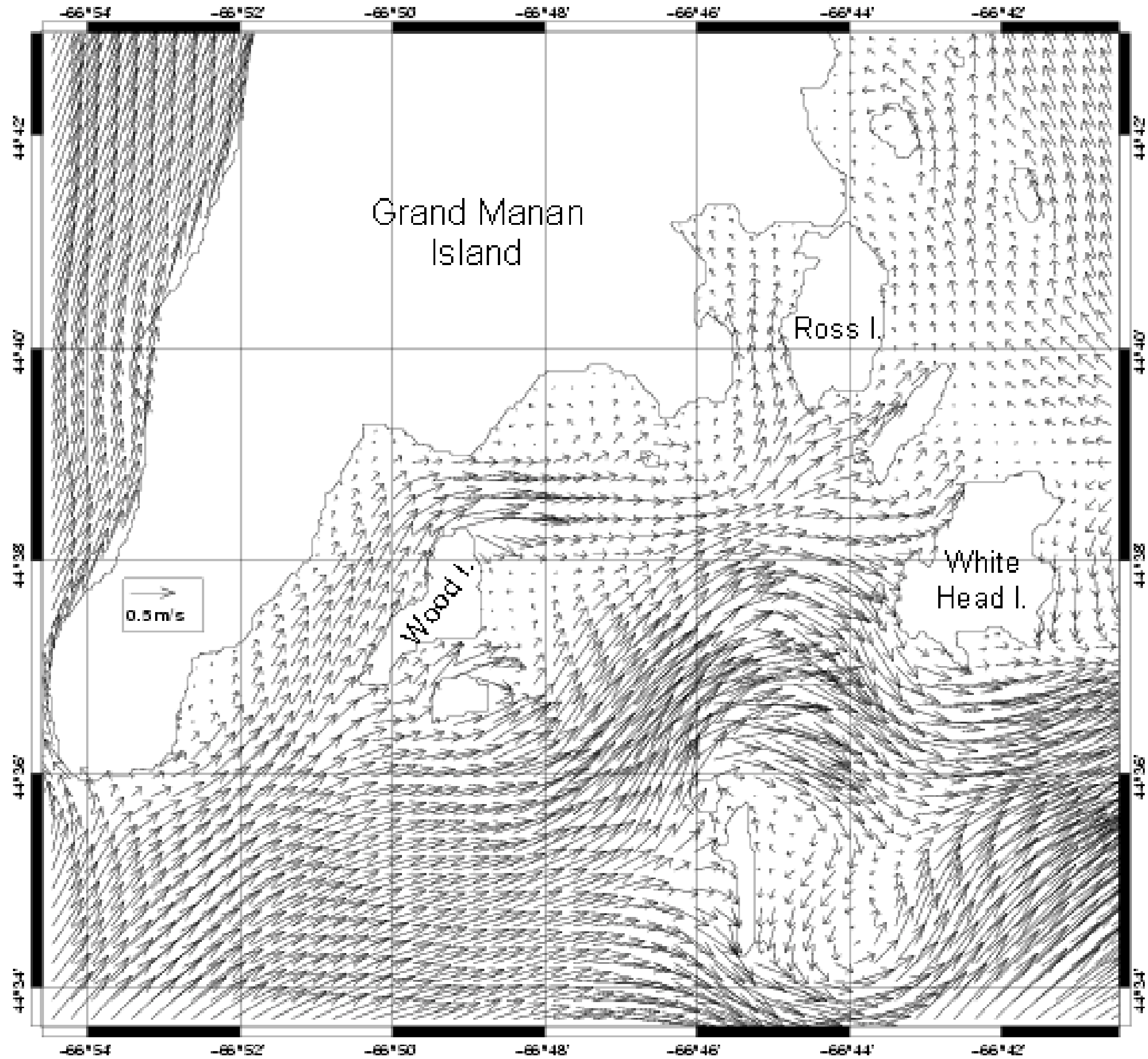

Figure 16. A snapshot of the depth-averaged model currents at mid-flood tide.

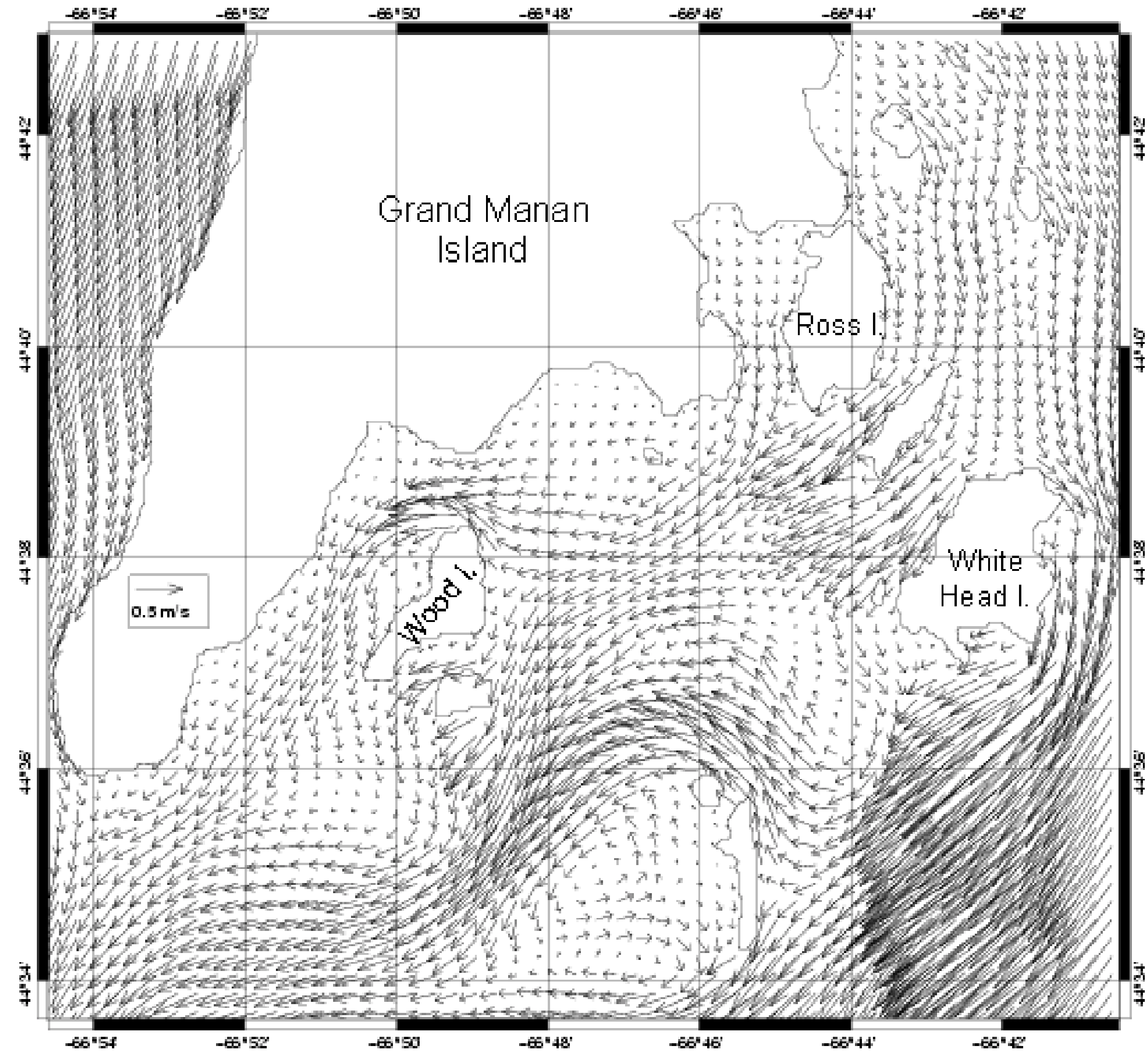

Figure 17. A snapshot of the depth-averaged model currents at mid-ebb tide.

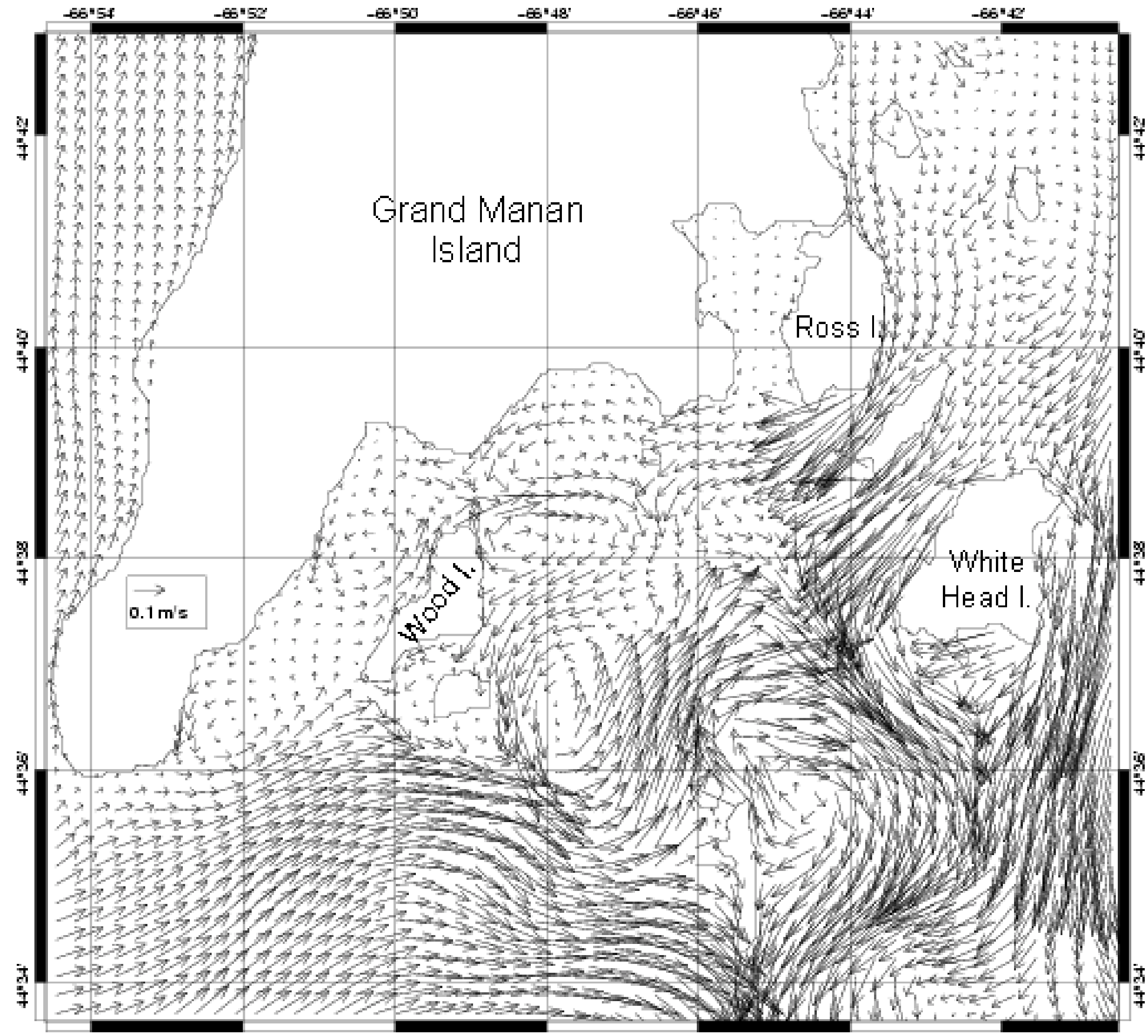

Figure 18. The depth-averaged tidal residual current field computed by averaging model currents over one M_2 tidal cycle.

Overview of Oceanographic Information and Approaches: A Review of Transport and Dispersion in Coastal Waters with Reference to the Quoddy Region

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Predicting the transport, dispersal, pathways and ultimate fate of dissolved substances or suspended particles in ocean waters is of central importance to many coastal zone issues. Of particular interest in the Quoddy region are aquaculture-related issues such as waste dispersal from fish pens, and fish health concerns. An important element of the latter issue is the transport and dispersal of water-borne disease from one finfish culture site to another. The notion of Bay Management Areas was established in order to combat disease spread and hinges on this idea of defining distinct geographical areas so that the risk of disease transmission through water exchange is minimized.

The movement and distribution of dissolved and suspended substances in ocean waters is governed by fluid motion. These processes are collectively referred to as mixing and may be defined as follows.

> ***Definition**:* Mixing is any process that causes a parcel of water to be mingled with or diluted by another.

Here, a parcel of water refers to a small volume element of ocean water, which we often (and somewhat inaccurately) may refer to as a particle. Coastal ocean mixing therefore includes the processes of (i) *transport* (which moves water parcels about with the prevailing currents), and (ii) *dispersion* (which allows water parcels in close proximity to blend their material properties with one another). Transport provides for large scale movement and defines pathways, while dispersion results in dilution of water properties.

Environmental mixing problems typically consider a number of scenarios, one of which is the release of a substance from a point source. This is the classic problem of pollutant release from a smokestack in the atmospheric boundary layer. The goal is to track the cloud of pollutant as it moves and disperses. Such a problem may parallel the release of water-borne diseases from a finfish cage, and the mathematical and computational techniques to solve these problems can be directly applied. Often the case of neutrally buoyant particles that move with the fluid are considered initially, prior to addressing more complex scenarios which allow for sinking and decay of particles. A complicating feature of mixing in the coastal ocean results from the complex structure and variability of the fluid flow. Oceanographic studies of coastal mixing generally use a mixture of theory (turbulence), observations (drifters/dye), and models (circulation/particle tracking).

Irregular coastlines and topography are characteristic of many coastal environments and often lead to highly structured tidal flows. Such complex flows are clearly evident in model simulations of the tidal flows in the Quoddy region. Particles released in such flows may take a variety of pathways, a result which is clearly evident in field studies of drifter trajectories in the region. The study of (tidal) mixing in coastal waters has a long history, including the now-classic works of Taylor (1953, 1954) and Okubo (1968) on shear dispersion. More recently, the study of "Lagrangian chaos" in fluids has lead to a recognition that very complex mixing regimes can arise from quite simple periodic flows.

Figure 19 shows an example of this phenomenon in the Quoddy region using the trajectories of a large number of simulated particles. To illustrate mixing in the region, the geographical domain was seeded with particles that move with the surface flow as predicted from a high-resolution, finite element model of the region (see section by D. Greenberg in this report). The particles were then advected by the model flow field for many tidal cycles and their positions recorded at the end of each tidal cycle. After one tidal cycle there is clear evidence of differential advection (streaking) in the sheared flow of the narrow passages. As expected, the inner parts of the bay exhibit fairly small net displacements due to the relatively small tidal excursions found there. After 4 and 10 tidal cycles, vigorous stirring has resulted in a significant exchange of particles within and amongst the various regions. An increasing number of particles can be seen leaving the model domain through the offshore boundary as time progresses.

One question in our ongoing research of mixing in coastal waters is concerned with characterizing water exchange and mixing in complex situations, such as the one illustrated in Figure 19. Consider the division of the Quoddy region in a number of discrete geographic boxes (Figure 20). Simulations are carried out that release 10^5 particles into tidal flow fields from a numerical circulation model of the region. This information is used to derive the probability of water exchange within and amongst each of the regions. This is summarized in a matrix, **P**, whose elements, p_{ij}, describe the probability of a particle transitioning from region i to region j in one tidal cycle. Once this quantity is established, Markov Chain theory is used to predict the retention, flushing and exchange properties of the Quoddy region. These were found to compare reasonably well to results based directly on the trajectories of tracked particles.

The goal of this work has been to establish robust and reliable parameterizations for the ensemble effects of mixing and exchange processes in complex coastal situations. The hope is that such a representation might prove useful in situations where a complete description of advective stirring and mixing is not warranted, but instead a quantitative description of bulk exchange processes is sought. This is the case for box models for ecosystem and biogeochemical processes. It might also prove useful for defining and testing the Bay Management Areas for finfish aquaculture that are used to control disease spread in the Quoddy region.

References

Okubo, A. 1968. Some remarks on the importance of the shear effect on horizontal diffusion. J. Oceanographic Soc. Japan 24:60--69.

Taylor, G.I. 1953. Dispersion of soluble matter in solvent flowing slowly through a pipe. Proc. Roy. Soc. London A219: 186--203.

Taylor, G.I. 1954. The dispersion of matter in turbulent flow through a pipe. Proc. Roy. Soc. London A223: 446--468.

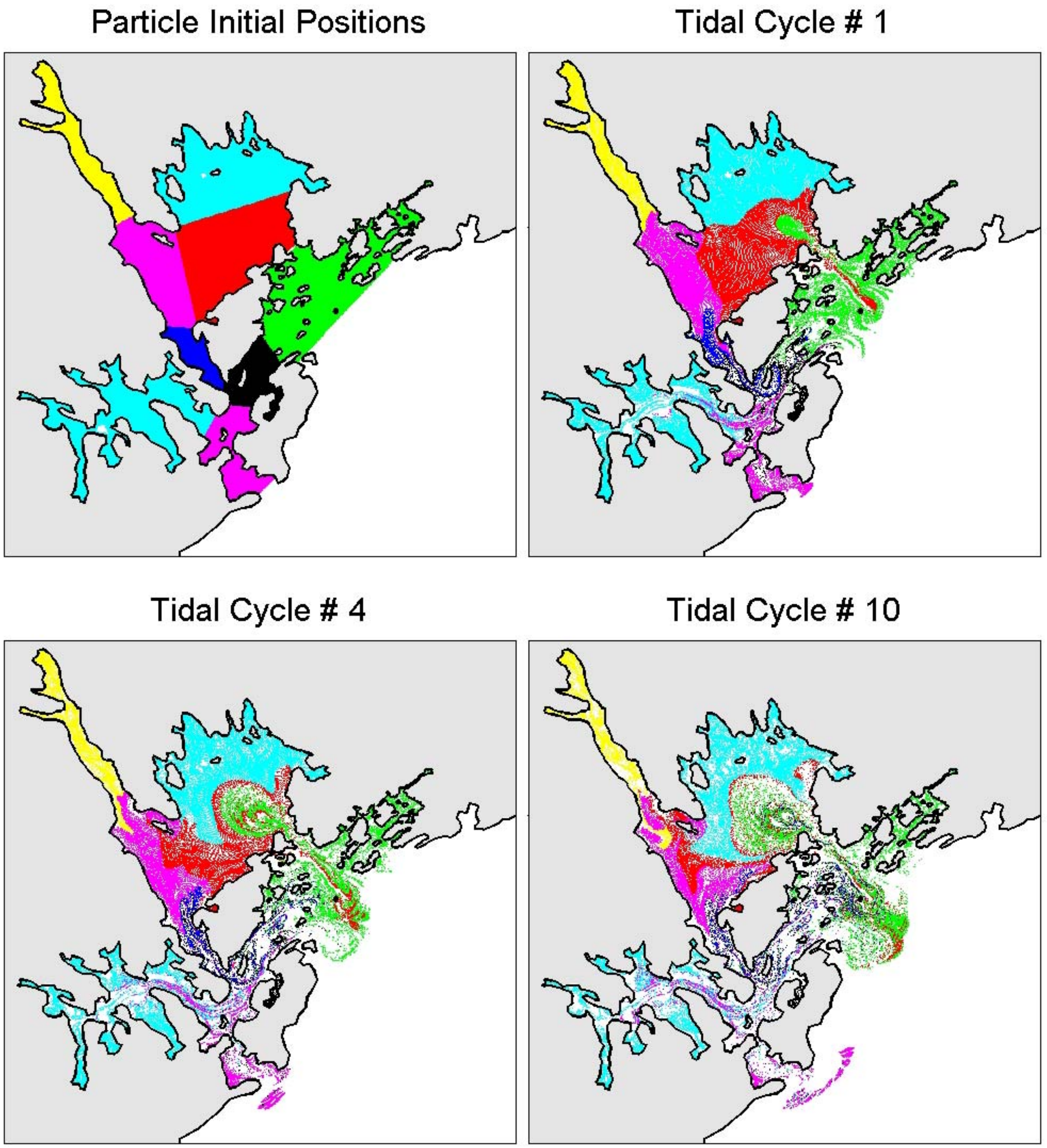

Figure 19. Advective stirring in the Quoddy region. The upper left panel shows the initial particle positions. They have been color-coded according to position. Particle positions at the end of 1, 4, and 10 tidal cycles are shown in the remaining panels. These computed positions are based on particle tracking using the M_2 tidal streams and the rectified flow from a numerical circulation model.

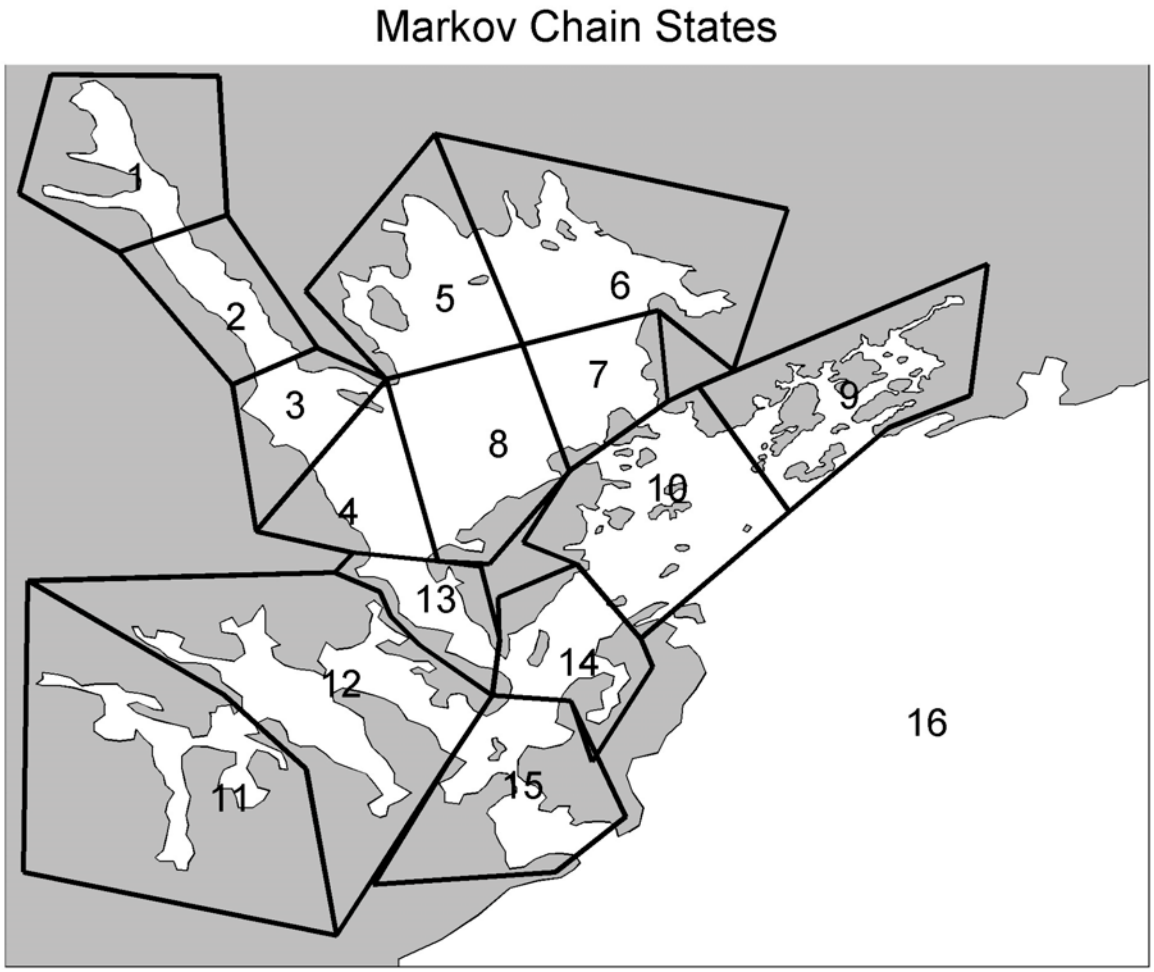

Figure 20. Boundaries for the boxes used to dividing the Quoddy region into geographical sub-domains. These were used as the basis for the Markov Chain model used to describe water exchange between the regions.

Project Objectives and Activities

F. Page[1] and B. Chang[2]
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Based on the concerns raised and the information and understanding available at the time of the proposal preparation (outlined in the previous sections of this report) the following objectives were defined in the proposal for the project.

The umbrella objective of the project was to estimate the exchange of water between existing and proposed salmon farm sites within Long Pond Bay and adjacent areas and to evaluate the appropriateness of the boundaries for salmon aquaculture Bay Management Areas (BMAs) 19, 20, and 21, from the perspective of water circulation and associated fish health concerns.

The specific objectives were:

1. To develop a better understanding of the water circulation within the Long Pond Bay area of Grand Manan by:
   - obtaining more observations, especially in key areas;
   - more fully analyzing existing and new observations; and
   - by refining a three-dimensional tidal circulation model.

2. To characterize the fish health issues of importance to the salmon aquaculture industry that may have a significant oceanographic component to their spread and management considerations, especially in the Long Pond Bay area and to define approaches and guidelines for estimating fish health risks based on oceanographic information.

3. To re-examine the implications of the water circulation in Long Pond Bay to the fish health and BMA boundaries within the area.

The proposed activities defined to achieve these objectives were spread out over a three year period.

In year one of the project (June 2001 to March 2002) it was initially anticipated that:

- approval to proceed with the project would be received by September 2001;
- Joint Project Agreements or Collaborative Agreements and funding would be in place by December 2001 or January 2002;
- A meeting, whose proceedings are recorded in this report would be held in the late fall of 2001;
- tools for initializing computer model runs, extracting and visualizing data from the circulation model and for comparing model output and observational data would be developed and in place by the winter of 2002;

- initial refinements to the circulation model grid would be completed and a preliminary examination of the influence of wind inputs on the circulation model output would be generated by the end of the 2002 winter;
- enhanced comparisons of model and observed currents would be conducted; and
- preparations for the 2002 spring and summer field season would be made.

The proposed activities for the second (April 2002 to March 2003) and third years (April 2003 to March 2004) of the project are:

Year 2

- conduct oceanographic field work in the Long Pond Bay area during the spring and summer;
- conduct analysis of current meter records obtained during the 2002 field season;
- compare observations with the circulation model and fine tune circulation model;
- conduct preliminary particle tracking runs to characterize the exchange of water between salmon farm sites in the southern Grand Manan area and to give insights into the suitability of the BMA boundaries as indicators of somewhat distinct cells of water circulation;
- convene a meeting to review progress to date and begin to draft the implications of the oceanographic results to date to the salmon health considerations in the study area, including the issue of BMA definition; and
- produce drafts of written reports on the field observations.

Year 3:

- convene a meeting to discuss and agree on the final results and interpretations on the work conducted within the project;
- complete data analyses and model runs, complete technical reports and manuscripts on the circulation within the study area and the linkages between oceanography and fish health issues; and
- present the activities and findings of the work at an end-of-project workshop and at other conferences and meetings.

As indicated in the Introduction and Meeting Objectives section of this report, one of the objectives of the meeting was to review the focus of the oceanographic work to help ensure it contributes products that are useful to the fish health community. The project proposal had been prepared more than eight months previous to the meeting and issues tend to evolve rapidly in the aquaculture industry. Fortunately, the reviews presented at the meeting, and included in this report, along with the general discussion, confirmed and clarified the need and focus for the proposed work. Hence, no major changes to the project objectives and activities were deemed necessary at this point in time. The delayed start-up of the Aquaculture Collaborative Research and Development Program resulted in the work associated with this project not being able to commence until December 2001 and January 2002 rather than earlier in the fall of 2001 as proposed. This delay has affected some of the administrative and scientific aspects of the project. Administratively, the development of collaborative agreements and getting funding in place has been delayed. Hopefully these aspects will still be completed within the first fiscal year of the project. Scientifically, the delays have resulted in a delay in the initiation of most aspects of the scientific objectives for the first fiscal year. Hopefully, the delays can be mitigated and the work can be back on schedule by early in the 2002-03 fiscal year.

Issues Raised During Meeting Discussion on the Project Proposal

Dissolved oxygen will not be a major part of the study, but some measurements can be taken. In recent summers, some low dissolved oxygen levels have occurred in Seal Cove. Current speeds in Seal Cove are reasonable, but mean flows (residuals) are relatively low. This means that flushing rates may be low (i.e. it may be mostly the same water moving back and forth). Dissolved oxygen levels may also be influenced by a fish processing plant which discharges waste into Seal Cove.

It was noted that there are existing data on circulation and disease in the Limekiln Bay and Bliss Harbour area and it was asked if these data could be used to determine linkages between oceanography and the spread of fish diseases. It was also noted, however, that the existing disease data describes mortality, which may not be sufficient for determining such linkages. Larry Hammell is currently involved in a study which is trying to detect infection (not just clinical disease). This, however, is difficult to do, since there are many factors involved, not just exposure to disease.

It was noted that geographic distances alone are not sufficient when determining BMA boundaries. The circulation model will show the range of influence, accounting for the direction and size of residual currents.

The exact locations for the deployment of oceanographic instruments have not yet been determined. To better understand the water circulation in the Long Pond Bay area, the project needs to concentrate on the channels in southern Grand Manan, such as Cow Passage, Cheney Passage, and the channel between Seal Cove and Long Pond Bay. It was noted that Cheney and Cow Passages dry out at low tide. These two passages are not heavily fished but are used by boat traffic.

The project also needs to study the areas around sites MF-0303 (Long Pond Bay) and site MF-0403 (east side of Wood Island); we already have some data from site MF-0408 (Outer Wood Island). The operators of MF-0303 and MF-0403 gave approval to put equipment on their sites. For model verification, more data is also needed around the Green Islands, where the model bathymetry data appears to be relatively poor.

To get meaningful residual flows, current meters should be moored for 30-40 days. Most of the field work is planned for May-September 2002 (when winds are relatively low). Some winter field work may also be conducted, weather permitting.

Project boats visiting site MF-0303 will use the Ingalls Head wharf. Project boats visiting the three new sites near Wood Island (MF-0403, MF-0408, and MF-0491) will use the Seal Cove wharf.

Project Communications Plan

- an initial project meeting will be held (this meeting) and a meeting report will be produced.
- a draft plan for the field work will be developed in spring 2002. This will include a map showing where deployments are planned. The draft plan will be distributed to site operators in the area. A talk or poster about the project may be presented on Grand Manan.
- another meeting will be held at the end of the 2002 field season.
- an "end-of-project" workshop will be held. Presentations may also be given at scientific conferences and meetings (e.g. Atlantic Aquaculture Fair and/or the annual meeting of the Aquaculture Association of Canada).
- the meeting and workshop reports will be distributed via industry associations and the Grand Manan Fishermen's Association.

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Agenda of the Initial Meeting of the Fish Health and Oceanography Project

Date and Time: 18 December 2001 from 9:30am - 4:00pm
Location: New Brunswick Salmon Growers' Association Boardroom, Letang, NB

1. Introductions:
    - Structure of meeting report
    - Project communications to participants and interested parties
    - Coffee and snacks available during meeting

2. Brief overview of the project proposal (objectives and time-lines) and funding status (F. Page)

3. Brief overview of salmon farm locations, year-class status, farm sizes and overall production (S. McGeachy)

4. Brief overview of existing Bay Management Areas and rationale (N. Halse)

5. Brief overview of fish health issues of potential relevance to oceanography and specifically those in the Long Pond Bay and adjacent areas of Grand Manan (S. McGeachy)

6. General discussion for identification of potential (past, present or future) finfish health and bay management issues, particularly in the Long Pond Bay area

7. Overviews of oceanographic information and approaches available for the SWNB area:
    - Hydrographic and current observations (F. Page)
    - Circulation modeling (D. Greenberg)
    - Mixing and flushing (M. Dowd)

8. General discussion and preliminary identification of oceanographic–fish health issues to address for the Long Pond Bay area of Grand Manan