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Proceedings of the Regional Peer Review of the State of Knowledge of the Oceanography and Water Exchange on the South Coast of Newfoundland to Support the Development of Bay Management Areas for Finfish Aquaculture

March 25-26, 2015
St. John's, NL

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Editor: E. Novaczek

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Foreword

The purpose of these Proceedings is to document the activities and key discussions of the meeting. The Proceedings may include research recommendations, uncertainties, and the rationale for decisions made during the meeting. Proceedings may also document when data, analyses or interpretations were reviewed and rejected on scientific grounds, including the reason(s) for rejection. As such, interpretations and opinions presented in this report individually may be factually incorrect or misleading, but are included to record as faithfully as possible what was considered at the meeting. No statements are to be taken as reflecting the conclusions of the meeting unless they are clearly identified as such. Moreover, further review may result in a change of conclusions where additional information was identified as relevant to the topics being considered, but not available in the timeframe of the meeting. In the rare case when there are formal dissenting views, these are also archived as Annexes to the Proceedings.

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SUMMARY

A meeting of the Newfoundland and Labrador (NL) Regional Peer Review Process on the state of knowledge of the oceanography and water exchange on the south coast of Newfoundland to support the development of Bay Management Areas for finfish aquaculture was held March 25-26, 2015 in St. John's, NL. Its purpose was to review the characterization of the oceanographic conditions and zones of influence associated with aquaculture activities in the Coast of Bays area. This included advice on the physical environment based on the current state of knowledge as well as an initial understanding of the potential exchange of water between zones where aquaculture activities take place and will support the development of Bay Management Areas (BMAs).

These Proceedings include an abstract for each working paper and a summary of the relevant discussions and the key conclusions reached at the meetings. In addition, a Science Advisory Report resulting from the meeting has been published on the Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat Website. Research Documents will also be published as they become available.

Compte rendu de l'examen régional par les pairs sur l'état des connaissances sur l'océanographie et l'échange des eaux sur la côte sud de Terre-Neuve à l'appui de l'établissement de zones de gestion des baies pour l'aquaculture de poissons à nageoires

SOMMAIRE

Une réunion régionale d'examen par les pairs de Terre-Neuve-et-Labrador (T.-N.-L.) a eu lieu les 25 et 26 mars 2015 à St. John's, à T.-N.-L., afin d'examiner l'état des connaissances sur l'océanographie et l'échange des eaux sur la côte sud de Terre-Neuve à l'appui de l'établissement de zones de gestion des baies pour l'aquaculture de poissons à nageoires. Elle avait pour objectif d'examiner la caractérisation des conditions océanographiques et des zones d'influence liées aux activités d'aquaculture dans la région de Coast of Bays. Il s'agissait, notamment, une occasion de donner des conseils à l'égard de l'environnement physique selon l'état actuel des connaissances et d'acquérir une première compréhension de l'échange potentiel d'eaux entre les zones où les activités d'aquaculture sont menées pour appuyer l'établissement de zones de gestion des baies.

Le présent compte rendu comprend un résumé de chaque document de travail de même qu'un sommaire des discussions pertinentes et des principales conclusions tirées lors de la réunion. De plus, un avis scientifique découlant de la réunion sera publié sur le site Web du Secrétariat canadien de consultation scientifique de Pêches et Océans Canada (MPO). Les documents de recherche seront publiés à mesure qu'ils seront disponibles.

INTRODUCTION

A meeting of the Newfoundland and Labrador (NL) Regional Peer Review Process on the state of knowledge of the oceanography and water exchange on the south coast of Newfoundland to support the development of Bay Management Areas for finfish aquaculture was held March 25-26, 2015 in St. John's, NL. Its purpose was to review the characterization of the oceanographic conditions and zones of influence associated with aquaculture activities in the Coast of Bays area. This included advice on the physical environment based on the current state of knowledge as well as an initial understanding of the potential exchange of water between zones where aquaculture activities take place to support the development of Bay Management Areas (BMAs).

This meeting presented the latest results from oceanographic observations and oceanographic models to help determine the best sites for industry, to identify areas of vulnerability and to limit detrimental interaction between industry and environment. Outcomes of the meeting contributed significantly to the body of knowledge used by stakeholders, industry and scientists looking at salmonid and shellfish aquaculture development on the south coast of NL. Specifically, this document presents working papers and discussion summaries regarding:

1. The geography, hydrology, and oceanography of the Coast of Bays area;
2. The seawater horizontal and vertical structure of the Coast of Bays area;
3. An analysis of the spatial variability of ocean currents of the Coast of Bays area; and
4. Oceanographic modelling and the zones of influence within the Coast of Bays area.

The four working papers presented here have been produced in support of the development of BMAs, a strategy that has been adopted to facilitate sustainable growth and management of the aquaculture industry in NL.

Participation included personnel from multiple branches of Fisheries and Oceans Canada (DFO); representatives from the fishing industry; Newfoundland Aquaculture Industry Association (NAIA); aquaculture industry; NL Department of Fisheries and Aquaculture (DFA); Memorial University; and several designated expert reviewers.

Open discussion and debate proceeded during and after each presentation. At the meeting, consensus was reached on summary bullets for the characterization of the oceanographic conditions and zones of influence associated with aquaculture activities in the Coast of Bays. These were included in a Science Advisory Report (SAR) distributed to and reviewed by the meeting participants.

WORKING PAPER ABSTRACTS AND DISCUSSION SUMMARIES

WORKING PAPER 1: METRICS OF THE AREA

Authors: S. Donnet, P. Goulet, A.W. Ratsimandresy, C. Doody, S. Burke and S. Cross

Presenter: S. Donnet

Abstract

The work described in this report is the first stage of a study on the physical oceanographic environment and water exchange in several bays on the south coast of Newfoundland (here after referred to as the ‘Coast of Bays’ where the aquaculture industry is currently operating and expanding (DFA 2014a). To provide estimates of water exchange potential among aquaculture sites, analytical and numerical modelling tools are being used in conjunction with a number of in-situ measurements which took place from 2009 to 2013. Both the analytical and the numerical modelling work require a detailed knowledge of the bathymetry and other key metrics as input data.

The study area (Figure 1) is located on the continental shelf of the south coast of Newfoundland, Canada and is characterized by complex bathymetry with a deep and large channel to the west (Hermitage Bay) connecting a two-armed fjord (Bay d’Espoir) to the ocean, and a long and deep fjord-like embayment to the east (Fortune Bay). The head of Fortune Bay opens on its northwest side to form a fairly large embayment (Belle Bay), which features deep channels and a central shallow bank. Between Fortune Bay and Hermitage Bay, there are two fairly large and open bays, Connaigre Bay to the west and Great Bay de l’Eau to the east, and a narrow inlet, Harbour Breton – Northeast Arm.

Despite the number of studies completed in the area (see Tlusty et al. 2000, Pepper et al. 2003, Pepper et al. 2004, Anderson et al. 2005, Tlusty et al. 2005, Ratsimandresy et al. 2012, Salcedo-Castro and Ratsimandresy 2013, Currie et al. 2013), no comprehensive overview of the physical environment has been attempted since the Marine Science Research Laboratory (MSRL, 1980) and the Bay d’Espoir Development Association (BDE-DA,1984) reports and very little information has been published on the new regions of aquaculture development including Belle Bay and the Connaigre Peninsula (CP). The main purpose of this report is to provide baseline data and physical description of the study area. This is important for the provision of advice for aquaculture management on aspects such as site selections, carrying capacity and zone of influences (water exchanges).

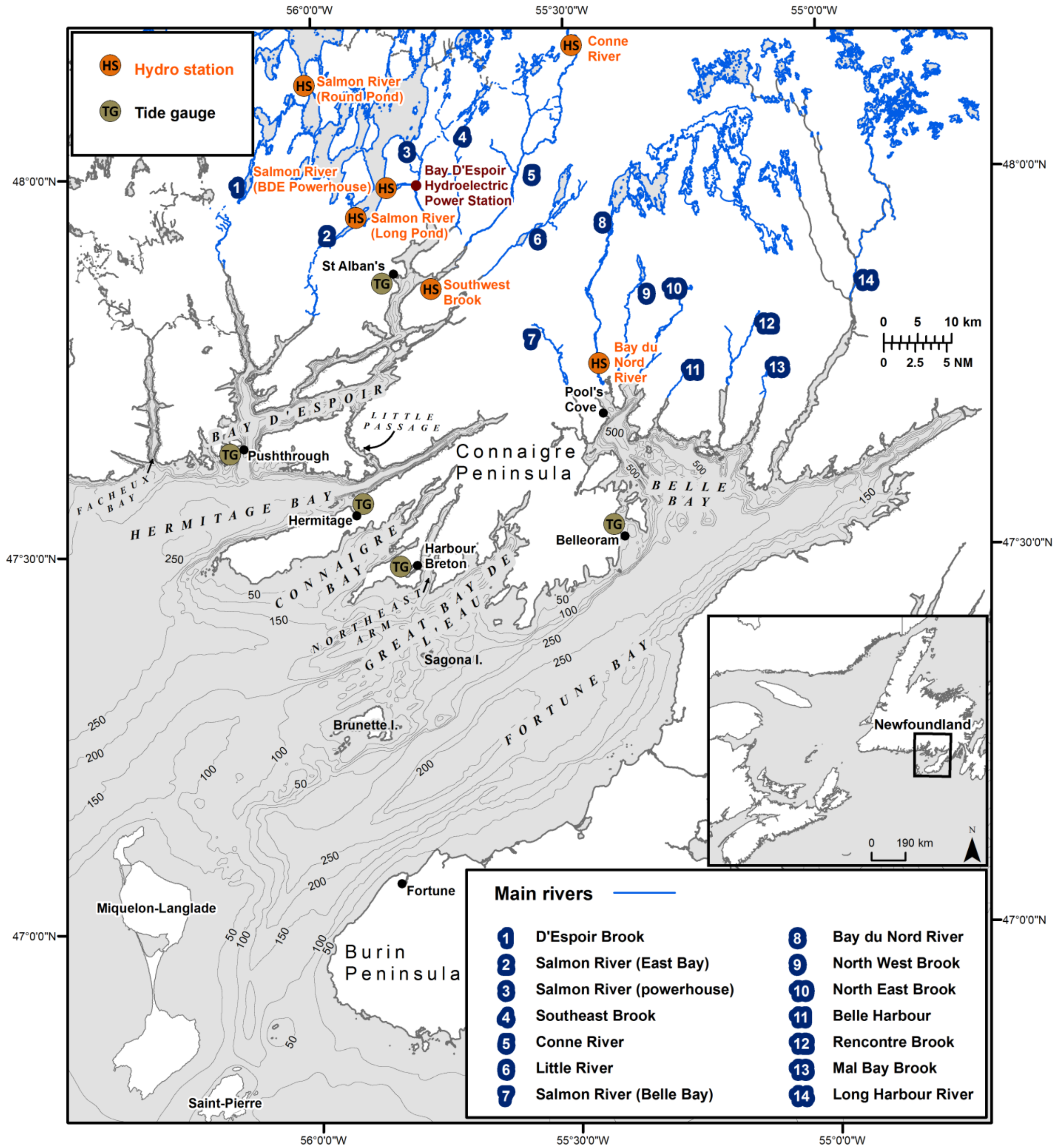

Figure 1. Study area with the locations of the main rivers and the stations where archival river flow (HS) and tide gauge (TG) data were available.

Based on this study, the following key observations can be made:

- The Coast of Bays consists of three geographically distinct regions: a long and narrow fjord (Bay d'Espoir), a deep and wide bay (Belle Bay) and a shallower region more directly exposed to the open ocean (Connaigre Penninsula) consisting of two open-bays (Connaigre Bay and Great Bay De l'Eau) and one narrow inlet (Harbour Breton – Northeast Arm).
- In addition to their geometry and geographical locations, one of the main characteristics distinguishing those three regions is their freshwater input: large in Bay d'Espoir, significant in Belle Bay and very small in the Connaigre Penninsula region. Important differences among the bays with regards to their water stratification and water circulation are expected as a result of this physical forcing.
- Tidal ranges are comparable among the bays of the area with about 1.3 to 2.1 m mean and large tides, respectively. These ranges are small in comparison to other places where similar finfish aquaculture operations are currently taking place in Canada and elsewhere. As a result of these relatively small tidal ranges and large basin volumes, flushing times due to the tides are quite large with values of the order of 26 to 66 days in Harbour Breton – Northeast Arm and Belle Bay, respectively.
- With annual amplitude of the order of 7°C, a seasonal cycle of the sea-surface temperature comparable to that reported for the Newfoundland Shelf was found in the Coast of Bays area, consistent with the regional coherence reported in Petrie et al. (1991). This seasonal amplitude of surface temperatures is large in comparison to the conditions seen in British Columbia (about 3-4°C; Gower and McLaren 2013), but comparable to some regions in Nova Scotia (e.g. zone 4Xq; DFO 2015) where similar finfish aquaculture operations are currently taking place in Canada. In addition, notable differences were found among the bays below the sea-surface; indicating geographical variations in water structure. Hence, it is suggested that a stronger stratification occurs in Bay d'Espoir and, to a lesser degree, in Belle Bay due to the larger freshwater runoff acting as a buoyancy force against vertical mixing and thermal diffusion to deeper levels than in the Connaigre Penninsula region. Disparities in wind stress among the bays could also partially account for these differences in vertical mixing of the surface layer.
- A clear seasonal cycle in both wind speed and direction is illustrated by the analysis of the data collected just offshore the Connaigre Penninsula region. In winter, strong winds from the west to northwest prevail while in summer, much weaker winds from the southwest dominate. Previous studies have indicated important oceanographic changes with regards to Fortune Bay deep water renewal due to this seasonal forcing (de Young 1983; de Young and Hay 1987; Hay and de Young 1989; White and Hay 1994).
- In Bay d'Espoir, estimates of tidal flows, surface estuarine circulation and wind induced currents in places of constriction (e.g. sill) are of the same order of magnitude; suggesting that a complex circulation pattern may occur in that area. This is consistent with the recent observations executed by DFO using drifters that revealed currents greatly varying in space and time (Ratsimandresy et al. 2012).
- The combination of the relatively small tidal ranges, geographically diverse freshwater runoff, strong regional heating and cooling seasonal cycle and what appears to be a delicate balance between main physical forces such as the tides, estuarine flow and winds results in a very complex environment.

Based on those results/observations, the following recommendations can be made:

- Further work will be necessary to understand the "what, when and where" of the physical forcing. In particular, the role of the freshwater input on the nearshore water structure and the role of the wind on the surface currents are thought to be determinant.
- Air temperatures, ice conditions and waves were not assessed in this study and were last assessed more than 30 years ago in the MSRL report of 1980 and BDE-DA report of 1984. Given their relevance to the continuous development of the aquaculture industry in the region, a more complete and up-to-date knowledge of the area would benefit from an updated study on those parameters.
- Available temperature data from other sources such as the DFA and the Marine Institute (MI) should be used to refine the near-surface temperature climatology.
- Sea Surface Temperatures (SST) from satellites such as the ones currently collected and processed at the BIO could also be used to refine analysis on the surface temperature statistics and harmonics and bring further insight on the spatial distribution.
- A refinement of the harmonic analysis, particularly with regard to the vertical mixing which has direct implication into the vertical transfer, for instance, dissolved oxygen and nutrients, could be done using more depth levels and more elaborated model of vertical diffusion such as presented in Petrie et al. (1991).
- Probability tables of frequency and/or persistence analyses of low and high surface temperatures such as reported in Petrie and Jordan (1993) for the coasts of Nova Scotia could add valuable information to the statistics provided here.
- Relationship between the atmospheric temperature and water temperatures could be investigated; expending the preliminary analysis that was provided by Taylor in 1975.
- Considering the simple scale analysis of the main forcing (tides, river runoff and wind) presented in the discussion for the Bay d'Espoir region, it appears evident that a flushing time based solely on the tides only partly represents the real flushing time of the region. As a start, time series of sea-level which include measurement of the tides but also other factors such as atmospheric forcing could be used to refine our estimates of flushing times. Further analyses based on simple 'box models' (e.g. Gurbutt and Petrie 1995) and/or a more complex hydrodynamic model could also be attempted to get much more robust and site-specific estimates.
- Under-sampled areas were identified in the bathymetry dataset which, in turn, resulted in cruder approximations of the metrics calculated. To improve the results in those areas and provide better information on the oceanography, modern surveys (multibeam) would be necessary.

Questions/Clarifications

Several participants asked about the oceanographic data employed, including the following clarifications:

- Most temperature data were collected after 1990. This includes time series data collected following methods established by the BIO (one or four-hour intervals; daily mean temperature was used to calculate the monthly average series).
- Flushing time was calculated from volume at mean tide and assumes total mixing.

- Analysis of ‘vertical mixing’ refers to the time taken for surface water to reach depth (this depends on circulation). This is not necessarily related to inversion events where cold water reaches the surface.
- Patterns in temperature and rainfall have not yet been examined, but this may be an interesting further step. Solar radiation was not included as a variable in the current study but may be incorporated in the future, as researchers believed that it would be an important physical forcing factor.
- Bathymetric data was collected at the highest resolution possible by the CHS (at 2 m resolution in some areas). However, only single beam bathymetric data from the 1970s was available in other regions. For this study, additional site specific bathymetric multibeam data was collected as needed (with differences up to 10 m from the old CHS dataset). Most bathymetric data sets used in this report are post-1990 with vertical accuracy of +/- 1 m and the data was gridded to 20 m horizontally for analysis.

Summary of Review

Reviewers: F. Page, D. Greenberg, and S. Haigh

Reviewers agreed that this paper provides a remarkable base of knowledge relevant to the development and regulation of the aquaculture industry. The compilation of bathymetric and topographic data is particularly helpful for understanding of the coastal area. However, it was suggested that the 20 m gridded bathymetry may not be adequate for a model resolution that is only slightly larger. Regarding currents, it was suggested that there may large scale coastal currents driven from the outer shelf or the Gulf of St. Lawrence that have not been incorporated in this analysis. Reviewers were also concerned about the assumption that all water is flushed and replaced through the tides; it is likely that much more than tides are required to determine flushing rate. It was clarified that this assumption, and its limitation, is clearly stated in the working paper.

The conclusion of the paper recommends further oceanographic work, however the paper has not shown generally or specifically how the various aspects of oceanography are relevant to aquaculture in the area. Therefore, the recommendations should be strengthened with specific indications of why or how research implementation will be of use to the aquaculture sector, including how it will impact aquaculture management. It would be useful to describe how and why the oceanographic features are important to aquaculture site selectin and to provide context for the distribution of existing licensed sites (e.g. oxygen replenishment, rate of waste clearing).

General Discussion

Several meeting participants asked whether the data presented by this paper represents sufficient inputs to move forward with a robust oceanographic model. It was the participant’s opinion that this information is a substantial contribution towards a model that can support decision making throughout the Coast of Bays. However, specific data gaps should be addressed (e.g. lack of systematic wind and salinity records, influence of Labrador Current and other offshore processes).

Another recurring discussion among participants centered on the connection between the data presented and existing aquaculture management challenges, like the transfer of pests (e.g. sea lice), pathogens, and pollution. Both temperature and salinity are important to the life cycle of sea lice, and there is potential for the information presented in this paper to feed directly into the prediction and management of these problems.

WORKING PAPER 2: WATER STRUCTURE

Authors: S. Donnet, S. Cross, A. W. Ratsimandresy, and P. Goulet

Presenter: S. Donnet

Abstract

This report is the second of a series that aims to describe the physical oceanography of the Coast of Bays, an area of the Newfoundland south coast (Figure 1).

Funded by the DFO Program for Aquaculture Regulatory Research (PARR) initiative, an oceanographic monitoring program took place between 2009 and 2013. The program included the collection of Conductivity, Temperature and Depth (CTD), Acoustic Doppler Current Profiler (ADCP), and Drifter data. The results of the CTD measurement program are presented and analyzed here.

The specific objectives of this work were to:

- Provide an updated and more comprehensive description of the vertical and horizontal hydrographic structure of the study area, highlighting its spatial and temporal variability;
- To identify and enhance the understanding of the areas of water exchange and mixing; and
- Provide data and information to initialize and verify a coastal water circulation numerical model currently being implemented by DFO.

The water temperature, salinity, and density were measured using Seabird (SBE) CTD instruments. In total, 760 CTD profiles were collected from June, 2009 to November, 2013 in 11 surveys, accounting for a total of 52 days at sea. Overall, the measurements were mainly carried out in spring (April-May) and early to late summer (June-September). The last survey of the program was executed in fall (November, 2013). In the context of this report, June, 2009 is considered as a summer month which differs from the more common classification for Atlantic Canada that have: January-March as winter months, April-June as spring months, July-September as summer months and October-December as fall months such as defined in Petrie et al. climatology studies (1996a and 1996b). It should be noted, however, that the June 2009 data was collected at the end of the month (18-23), limiting the effect of this assumption. Similarly, data collected in April 2010, May 2011, May 2012 and May 2013 shall be considered comparable in terms of seasonal timing since the 2010 data was collected at the end of April-early May and the 2011, 2012 and 2013 data was collected in the first days of the month of May.

Based on the results of a five year program (2009-13), three distinct regions are described:

- **Bay d'Espoir**: a fjord of complex geometry and large freshwater discharge resulting in the presence of a sharp and shallow near-surface pycnocline for most of the year. At depth, the embayment is subject to the intrusion of both a Cold Intermediate Layer (CIL) and a warm and saline deep water layer (MSW); the latter only partially flowing into the fjord due to blockage from inner sills. As a result, the vertical water column structure of Bay d'Espoir is found to be essentially a two layered (in the inner parts) to three layered (in the outer parts) structure from spring to fall; consistent with the description of Richard and Hay (1984).
- **Fortune Bay – Belle Bay**: a large and deep fjord-like bay, subject to noticeable freshwater discharge at its head resulting in a fairly strong seasonal pycnocline from spring to summer (and, perhaps, up to the fall). Belle Bay itself is the largest embayment of the Coast of Bays area and receives a disproportionally large amount of the freshwater discharge flowing into Fortune Bay; either directly (about 45% of Fortune Bay total input; Donnet et al. 2015a) or

from the near-by Long Harbour inlet (representing about 25% of Fortune Bay total input; Donnet et al. 2015a). Fortune Bay is bounded by a series of sills and islands on its offshore boundaries limiting the influx of the warm MSW from the Hermitage Channel and is characterized by a seasonal deep-water renewal from derived Labrador Current Water (LCW; which forms the CIL in Bay d'Espoir) in summer and from the MSW in winter (e.g. Hay and de Young 1989). Thus, from spring to summer (and most likely up the late fall or early winter), when the seasonal surface layer is present Fortune Bay – Belle Bay is, for the most part, characterized by a two layered system.

- **Connaigre Peninsula**: a region consisting of two open bays (Connaigre Bay and Great Bay De l'Eau) and one narrow inlet (Harbour Breton – Northeast Arm); all having limited amount of freshwater discharge compared to Fortune Bay – Belle Bay and Bay d'Espoir. As a result of this limited input and a geographically more exposed position, the near-surface water of this region is more oceanic and more vertically mixed. Freshwater input has, nevertheless, a noticeable effect (and at times, dominant) on the stratification in Harbour Breton – Northeast Arm and Great Bay de l'Eau and brackish water (<32 in salinity) was clearly present all along the peninsula and in all our surveys (spring to fall). At depth, the CIL is found everywhere and down to the near-bottom. MSW is, however, well present in the deep offshore basin located just outside and within Great Bay de l'Eau. MSW mixture was also consistently found in the inner basins of Connaigre Bay and Harbour Breton – Northeast Arm in spring; disappearing in fall. The Connaigre Penninsula region is, therefore, essentially a two layered system from spring to fall, with some three layered structure areas (Great Bay de l'Eau and offshore basin B3, notably).

Upwelling features were seen in all three regions during the 2009-13 surveys: in September 2009 in the Hermitage Bay – Bay d'Espoir region, in May 2011 in Long Harbour (Fortune Bay region) and in May 2012 in the Connaigre Penninsula and Hermitage Bay regions. All upwelling events seem to indicate wind forcing from the northwest, inducing Ekman transport of the surface layer to the southwest; as described in Hay and de Young (1989) for a two layered system, in winter. Our data suggest that a similar mechanism occurs in spring-summer, in a two to three layered system. These findings, however, contrast with the description proposed by Yurick and Vanstone (1983) which indicated a lack of upwelling events in the region.

While a comprehensive spatial coverage of the region has been obtained through the 2009-13 PARR program, the temporal resolution is still scarce and does not allow a good understanding of the large short-term (order of hours to weeks), seasonal and inter-annual variations. In particular, and due to logistical constraints, no data were collected neither during the warmest nor during the coldest months of the year (July-August, and February-March, respectively and as reported in Donnet et al. 2015a).

The interpretation of important short-term changes/events (upwelling events, dissolved oxygen super-saturation and deep pycnocline vertical displacement, freshwater runoff) are presently impeded by the lack of data (time series in particular); requiring further data collection to better understand the related forcing.

Based on the results presented in this report and the more general and historical overview reported in Donnet et al. (2015a) it appears evident that long-term data collection of water physical conditions (i.e. temperature, salinity and dissolved oxygen) at strategic sites within the study area (e.g. one site per region) would be greatly beneficial. Such a program would allow a better understanding of the area with regard to (but not limited to):

- The winter conditions seen in the different regions and potential processes leading to more sheltered/favorable over-wintering conditions;

- The water stratification build-up and destruction timescales, vertical extension and associated processes leading to such buildup and destruction (i.e. mixing forces such winds, tides and convective overturning processes);
- The water structure short-term variations due, for instance, to wind events and/or internal waves;
- The water structure seasonality and inter-annual variability; and
- The effect of climate change on the area and how it relates to the offshore and regional/larger scale conditions presently being regularly monitored and reported as part of the Atlantic Zone Monitoring Program (AZMP).

This information would in turn:

- Strengthen the foundation laid by the PARR 2009-13 program;
- Help the aquaculture site selection process, in particular with regards to over-wintering conditions; and
- Provide critical information and data to the coastal circulation numerical model currently being developed.

In addition, the data collected during that program is currently being added to the archived data (presented in Donnet et al. 2015a). A compilation and analysis of such dataset providing, temperature, salinity and dissolved oxygen (potentially), climatology baseline would refine and enhance our initial assessment using historical data (Donnet et al. 2015a). Such data would also be necessary to further the development of the numerical model currently being implemented by DFO.

Questions/Clarifications

Clarifications requested by participants included questions on data interpolation and information sharing:

- All interpolation was conducted with DIVA (Data-Interpolating Variational Analysis*).* This is a sophisticated spatial interpolation method, used for this study mainly because it has the ability to consider coastline and topography as boundaries so that there is no artificial interpolation across sills or across bays, for example.
- All DFO data will be made available through the Oceanography and Scientific Data (OSD); access to industry data is provided on case-by-case basis.

Summary of Review

Reviewers: M. Foreman and G. Han

The reviewers congratulated the authors on producing a well-written and well-organized manuscript that analyzes, plots, and provides interpretation of a large amount of data; this was a monumental task.

It was strongly suggested that all four reports be updated to consistently define the term BMA. This working paper refers to Murray et al. (2013), however the third working paper (analysis of the vertical structure and spatial variability of the ocean currents in the Coast of Bays area refers to Page et al. (2005) for a slightly different definition of BMA. It is important to define BMAs clearly so the subsequent model and observational analyses can feed into the development of BMAs for this region. This long-term objective guides the usage of reports and science products produced in these and similar meetings.

The data and analyses presented in this paper provide a significant contribution to a robust oceanographic model for this region. Development of a baroclinic model requires initial 3D temperature and salinity fields. However, none of the surveys presented within cover the entire model domain which presents a challenge for establishing initial conditions. It may be possible to produce seasonal or monthly climatologies using these data in combination with the archival data described in the first working paper (Donnet et al. 2015a). A starting point may be to examine the May time series; the May surveys 2011-13 visited many of the same sites and may provide a good indication of inter-annual variability in the Coast of Bays area.

As with the first working paper, reviewers recommended more detail on how the data and results relate to the current aquaculture industry, including the addition of a map of licensed aquaculture sites. Both reviewers and meeting participants agreed that there is an opportunity to include a description of how the water property analyses support the development of BMAs for this region, even before reliable oceanographic model predictions are available. It may be useful to investigate the potential relationship between temperature, salinity and aquaculture pests and pathogens such as sea lice within the archival data.

General Discussion

This report delivers useful information to stakeholders and industry and was a monumental task. It was suggested that it may be useful to evaluate water column in more detail at shallow depths. Finfish aquaculture cages do not extend to 20 m, and one participant recommended bracketing depths at 2 m, 12 m, and 15 m. Conversely, shellfish aquaculture typically extends beyond 20 m depth to avoid the variability of surface temperatures. Stakeholders expressed interest in future research on the water depths below cages and the potential for mixing to manage temperature and oxygen issues.

Participants also compared the results of this paper to industry findings. For example, temperature readings collected by researchers in St. Pierre Bank during 2014 were so high that it was thought that the instruments were broken. It was noted though that the St. Pierre Bank is outside of the primary study region. Inshore aquaculture sites recorded 2014 as one of their coldest years. Authors suggested that these cold inshore temperatures may have been driven by the harsh winter in 2013 (through convective overturning that mixes water to great depth), thus preconditioning cold temperatures into summer months. It was indicated that the duration of this potential effect is unknown and would require further measurements and analyses.

WORKING PAPER 3: OCEAN CURRENT VARIABILITY

Authors: A. W. Ratsimandresy, S. Donnet, S. Snook and P. Goulet

Presenter: A. W. Ratsimandresy

Abstract

Understanding ocean currents is a requirement for aquaculture activities. Ocean current conditions influence processes such as the spreading of waste plumes from fish farms (Venayagamoorthy et al. 2011), boundaries of mixing zones downstream of aquaculture cages (Helsley and Kim 2005), or keeping dissolved oxygen levels close to saturation (Boghen 1995) through good flushing rates. Other effects of the ocean currents and their vertical structure include an impact on the behaviour of fish within cages and the influence they have on the fish schooling structure (Oppedal et al. 2011, Johansson et al. 2014). From the point of view of cage

structure, the currents can cause the sea-cage to change shape and reduce the internal volume available for fish (Lader et al. 2008) thus creating potential stress on farmed fish. Ocean currents have also been reported to play a major role in the transport of pathogens between aquaculture sites. According to studies carried out in Norway, diseases such as Infectious Salmon Anemia (ISA) were subject to spread between farms as the virus can be passively transported by seawater movement (Vågsholm et al. 1994, Jarp and Karlsen 1997). Similar transport processes have been observed at a local scale in Scotland and the Southwest New Brunswick/Maine area (JGIWG 2000; Murray 2003).

As disease transport has been a growing concern in marine aquaculture, the aquaculture industry in New Brunswick together with the Province of New Brunswick have developed a BMA policy which consists in partitioning salmon farms by region for single-year-class farming, thus minimizing connections among farms in order to improve fish health and environmental management (Page et al. 2005). The BMAs were later evaluated by Page and his group (Chang et al. 2005) through calculation of zones of influence of aquaculture sites using a number of tools. One of them is a circulation model which provides tidal information in the area. In their study, tidal excursion was defined and used to delineate movement of water from a farm site to the surrounding area.

With the growth of the Newfoundland and Labrador aquaculture industry, provincial departments are implementing BMAs to better manage industry expansion. In Newfoundland and Labrador, finfish aquaculture activities started in the mid-1980s in the Bay d'Espoir region of the island and later in Belle Bay, both within the Coast of Bays area, with plans to further expand (DFA 2014b). This growth has been translated into an increase in the number of aquaculture licenses as well as the surface water area used to carry out such activities (DFA 2014b). Early guidelines for site separation in Coast of Bays stated that aquaculture farms should be at least 1 km apart (G. Perry, Aquaculture Management, DFO-NL Region, pers. comm.) while possible interaction of aquaculture activities with other fishing activities was assessed using a 2 km radius as mentioned in the actual Aquaculture License Application form. However, defining distance will not provide a complete set of information as it is also necessary to know the time needed to reach that distance. The time changes depending on the water circulation in the area, thus it is crucial to understand the ocean currents and the different forcings that drive the circulation. Other oceanographic measurements that can support aquaculture were carried out in the area (Taylor 1975, MSRL 1980, BDE-DA 1984, de Young 1983, Richard and Hay 1984, Tlusty et al. 1999, Pepper et al. 2003 and 2004, Anderson et al. 2005, Mansour et al. 2008, Burt et al 2012) with a focus on temperature, salinity, and/or dissolved oxygen. Little has been done with respect to the ocean current regime (including tidal, density, and wind driven). As part of the DFO's Program for PARR funded research project to carry out oceanographic study of the south coast of Newfoundland, ocean current data were collected in the Coast of Bays area between 2009 and 2013 to help understand the nearshore water circulation.

The data presented in this report were collected using a variety (300, 600 and 1200 kHz) of Acoustic Doppler Current Profilers (ADCPs; Teledyne RD Instruments, Inc., 2011). All ADCPs were configured in an upward-looking direction, and collected data using a depth cell size ranging from 0.2 to 3 m depending on instrument frequency and setup. A large majority of the deployments (73 out of a total of 76) were configured with a 1 m cell size. The ADCPs were moored at depths between 10 to 155 m (with 50% of them in the range of 50 to 70 m depth). Data were collected throughout all four seasons with an emphasis on the spring-fall seasons. Overall, the length of the data recording ranged from 26 to 181 days (with a median of 83 days).

Statistical analysis was performed on the measured current speed taking into consideration two water layers: the 'upper layer' which is defined as the layer found from the closest record to the surface down to 20 m depth, and the 'lower layer' which extends from 20 m to the depth of the instrument. The upper 20 m depth range was used for its direct relevance to fish farming activities which typically utilize fish cages of 15-20 m in height. All data records within the layer of consideration were combined as one dataset and used to compute the statistical values.

Current vectors were analyzed to provide information on the current direction (and thus information on the circulation). This was performed by looking at the mean and maximum currents, the former being the vector average for each ADCP time series and the latter representing the maximum current speed and associated direction recorded during the measurement for each depth from the surface to the depth of the ADCP. The analysis was carried out on the same two separate layers (0-20 m and 20 to bottom).

Tidal analysis was performed on the pressure and current data using the analysis routine developed by Foreman et al. (2009). This routine gives the possibility of analyzing irregularly sampled data or data with missing measurements. The method entails the embedding of nodal and astronomical argument corrections and multiple inference calculations into an overdetermined matrix that is solved using singular value decomposition technics (Golub and Van Loan 1983; Press et al. 1992).

A statistical analysis of currents at the upper 20 m and those below 20 m is reported together with the characteristics and role of tides in the variation of sea level and variation of currents in the nearshore water of the Coast of Bays area. To the author’s knowledge, the present study is the first to give detailed information on the current regime and the tidal information at different locations within the area. The information can improve our knowledge on topics related to transport of particles from one location to another, this includes solid and soluble waste to/from aquaculture farms as well as virus and pathogens present in the area, and on other topics related to water renewal time in the region (as computed by Donnet et al. 2015a). It also provides information that can be used for aquaculture site selection and site licensing processes. On a larger frame, it extends the general knowledge of the tides in bay regions that were not available from earlier studies such as Han et al. (2010) or Petrie et al. (1987). The circulation model development carried out for the region also benefits from this information and it will be used to carry out different stages of the validation of the model.

Through the analysis, the following key observation can be made:

- The study provides information on the current speed in the Coast of Bays area, the median speed varies between regions ranging from 2.2 to 12.7 cm/s in the upper 20 m and from 1.8 to 13.3 cm/s in the layer below 20 m depth. Variability is found among bays and among the different part of the same bay. Of the three main regions considered in the study, median speeds in the upper and lower layers in Bay d’Espoir are generally the highest and those of Connaigre Bay the lowest.
- Current speed in the upper layer is found to be higher than that in the lower layer. Maximum measured speed was nine times, or more, larger than the median current speed.
- The variability of sea level is well described by tides. On average, the tidal contribution explains over 84% of the variability with higher contribution in the Hermitage Bay/Bay d’Espoir region, followed by the Connaigre Peninsula, then Belle Bay region. In contrast, the contribution of the tides to the currents shows a different picture. Only currents in Bay d’Espoir-Lampidoes Passage show some degree of tidal contribution. The maximum contribution was found at the southern mouth of Lampidoes Passage with a contribution above 55% in the meridional component of the velocity when considering the vertically averaged currents over the whole water column.

- In the region of Bay d'Espoir where tidal current contribution is higher, the currents in the upper 20 m of the water column shows less tidal contribution than the whole water column suggesting the presence of other forcings that drive the circulation in that layer.
- Median current speed around aquaculture leases is generally between 4 and 6 cm/s. Maximum current speeds recorded at these locations is in the same range as those found in the whole bay except for sites with relatively low median current speed (below 3.5 cm/s). At these sites, the maximum recorded current speed was also low suggesting low circulation around the sites.
- On average, export of water towards lower Bay d'Espoir is found in the upper 20 m of the water column at the southern entrance of Lampidoes Passage.

Based on the results obtained from the analysis, the following recommendations can be made without any specific order of importance:

- A better characterization of the currents at the surface will complete the information reported in this work. This can be achieved through an improved design of surface current measurements which have always been a challenge for coastal and open ocean water.
- Further work on analyzing the current regime at different depths in relation to wind conditions and to water stratification will provide a better understanding of the variability of the currents that is not explained by tides. A large part of the current variability in Little Passage, in Belle Bay, and in the Connaigre Peninsula is in that category.
- Further work will be needed to understand the mechanisms that drive the observed high current speed. Understanding the response time of the water to the driving force as well as the duration of the strong currents will be of importance as they will have an impact on the transport of floating particles within the water column. From a fish health perspective, this short-term temporal variability of the currents can affect processes such as transport and dispersion of pesticides released from tarp or well-boat bath treatment of lice. Knowing where and when the currents will be low or strong can define the timing of the treatment.

Questions/Clarifications

One point was clarified on data comparison. The report indicates that a direct comparison between current databases was not possible. This was not possible due to differences in depth of analysis or differences in timing of the surveys.

Summary of Review

Reviewers: F. Page, D. Greenberg, and S. Haigh

Across the entire Canadian shelf current data is extremely rare but there is now demand and this study has provided consistent results to fill part of the knowledge gap. Reviewers encourage the authors to continue this research, including the analyses they suggest on pages 28 and 31, as well as:

- A more detailed understanding of the circulation patterns in the region;
- Temporal and spatial variability;
- Forcing mechanisms that cause them;
- Predictability, and their impact on aquaculture operations and management; and
- Spectral analysis of non-tidal current to identify dominant frequencies.

Further understanding of the forcing mechanisms may be directly applicable to industry decision making. Flushing time may be affected by storm strength and previous analyses indicate that these effects may last for days after the storm event. This work may give guidance on how to manage storm response.

General Discussion

The paper emphasizes tidal forcing, however non-tidal and non-local forcings are poorly understood. The simple calculation of current from the known processes (wind, tide, freshwater) shows that all inputs are in the same range. However, when only a small portion of the current is explained by the tides, it is indicated that important variable(s) are missing. Spectral analysis was suggested for assessment of other sources of current forcing. A previous study conducted in Quebec on the currents in Gulf of St. Lawrence was based on models and provided some climatology of the currents; the model suggests seasonal variability. That research may contribute to future work on a Coast of Bays model, and could influence the calculation and inclusion of boundary conditions in the current model.

WORKING PAPER 4: ZONES OF INFLUENCE

Authors A. W. Ratsimandresy, P. Goulet, S. Donnet and S. Snook

Presenter: A. W. Ratsimandresy

Abstract

This document is the fourth in a series of analyses to understand the oceanographic conditions in the Coast of Bays region of NL. The analyses cover various aspects of the oceanography of the area including:

1. Physical characteristics (dimensions with regards to its geography, hydrology, and oceanography;
2. Seawater structure and variability (spatial and temporal);
3. Vertical current structure and spatial variability; and
4. Water circulation.

This study became a necessity due to the rapid growth of the NL finfish aquaculture industry which translates into an increase in the production, an increase in the number of licenses, as well as an increase in the areas used to carry out this activity (DFA 2014a). With the growth of industry, provincial departments are implementing BMAs to enhance biosecurity and reduce the potential spread of pathogens. This set of analyses will help in the development of the BMA but will also serve as scientific basis for management decisions on sustainable aquaculture by Federal departments.

Understanding water circulation is crucial because of its effect on numerous processes related to aquaculture activities. Of specific importance is the transport of particles to and from aquaculture sites sourced from either other sites or any other activity in the surrounding areas (e.g. commercial fishing, residential or industrial settlement). The particles can be parasitic or pathogenic in nature. Studies carried out to understand the transfer of disease between aquaculture farms in different parts of the world reported that ISA can be passively transported by seawater movement (Vågsholm et al. 1994 and Jarp and Karlsen 1997 in Norway; JGIWG 2000 in Scotland).

Transport of parasitic copepods by seawater movement is also a concern. Costelloe et al. (1996, 1998) and Brooks (2005) reported on such transport in Ireland and in the Broughton, BC area, respectively.

Their results show that the density of lice at different locations is also affected by changes in the current pattern. The changes in the current were related to wind, freshwater run-off, or tides.

Transport and dispersal of therapeutants used to treat parasites also rely on water circulation (Page et al. 2014). It can put non-targeted species at risk depending on the flushing rate and the rate of dilution of the pesticide released in the water after the treatment.

To study the water circulation, in-situ measurements of currents were performed. The instrument types vary depending on the different physical processes that are of interest. Surface and subsurface drifters were used to follow the movement of the surface water for periods of a few days while current profilers were used to measure currents in the whole water column for longer periods. A numerical model was also developed to simulate nearshore water circulation in the region. We estimate the zones of influence as the area covered by the trajectory of particles or drifters released in the water computed from the measured and modeled water currents. The potential for water exchange between regions will be the combination of various zones of influence when they overlap or are very close to each other.

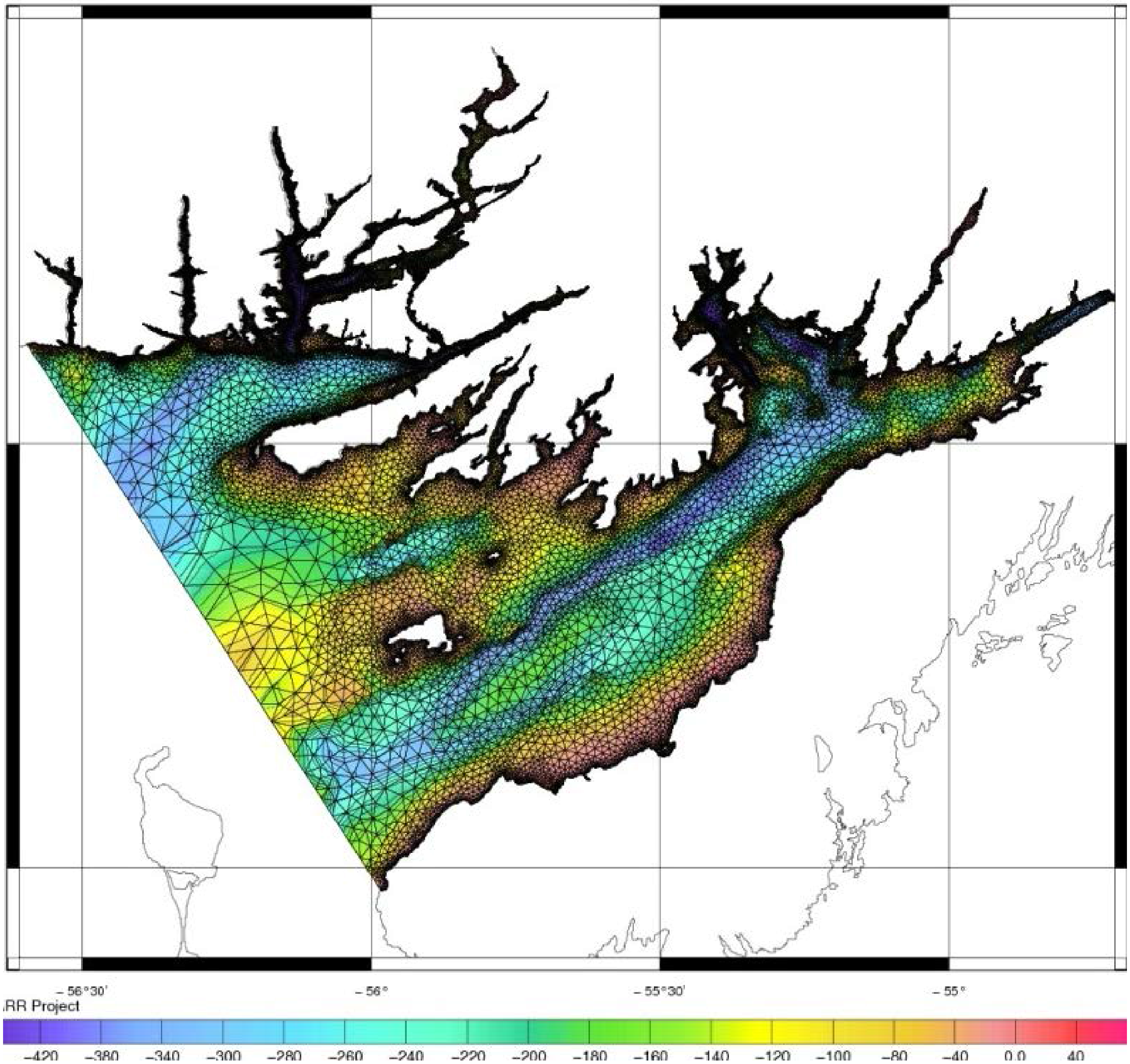

Figure 2. Map of the domain of study with the bathymetry and the mesh used in the circulation model.

The sea level variation from our model compares relatively well with observations from the ADCP data collected in the area. Difficulty in resolving the diurnal tides near the shore was also experienced by previous analysis (Han et al. 2010). Comparison of the model with the observations shows that larger error in the M2 and S2 tides was observed at the head of Bay d'Espoir; this might be attributed to a combination of sources including model bathymetry, observational error, and/or model resolution (Dunphy et al. 2005). Considering that the tides account for an average of 84% of the sea level variation in the area (Donnet 2017c), the present model can be used to predict a large part of the variability of the sea surface elevation. Improvements may be made by enhancing the bathymetric data used in the model.

The analysis shows that the zones of influence are spatially variable and depend on the forcing(s) that drives the circulation at the time of measurement. In the drifter experiments, drifter releases in the same area but at different dates show that the zones of influence (inferred from the maximum straight line distance from the point of release) vary. This is probably due to changes in the forcing that drove the circulation; for example, changes in the freshwater run-off (Donnet et al. 2015 and 2015b) as well as in the direction of the wind has been reported in Bay d'Espoir. These changes in the zones of influence are also seen in the output of the particle tracking model using different wind fields. Little is known on how fast circulation responds to the change of forcing. From the aquaculture perspective, since the zones of influence change depending on the various forcing fields that might be present in the area, understanding these forces, their variability, and the response of the water is of importance. This can provide information on timing for optimization of activities such as underwater cleaning of nets or the use of chemicals for various purposes (e.g. therapeutants for treatment).

Comparison of the zones of influence from the model with those from the drifter resulted in zones of influence with similar size. A further look at the drifter measurements shows that the wind during the experiments was gentle (~16 km/h or ~4.4 m/s) and going north. In addition, the upper 10 m surface layer moved with the same speed. In contrast, experiments performed on the other side of the bay shows the surface and subsurface layer not moving with the same speed. The fact that the wind was low while blowing opposite to the direction of the currents shows that other forcing fields are present. The model simulation shows that in a barotropic condition, a wind going to the southwest at a speed of 20 m/s generates similar subsurface particle movement as that observed with the drifter. These results highlight the complexity of the system in that the forcing can be of one type or a combination of various types.

The circulation model was run in a barotropic mode, in this case the whole water column moves together. More energy is then necessary to achieve the movement. This explains the strong wind used in order to get the same surface trajectory as that of the drifter. As the analysis of the water structure (Donnet et al. 2015a) shows substantial stratification near the surface in the summer season, interaction between the surface and the underlying layers are reduced resulting in differences in the movement of the surface layer and that below. A much thinner layer will be moved which in turn requires a lower wind stress than that used in the present study. This can be achieved by considering an improved initial condition of temperature and salinity profiles as well as wind forcing that are more realistic. Stucchi et al. (2011) used climatological temperature and salinity values to initialize their model when studying the transport of lice in the Broughton Archipelago.

Data from three calculations were used to assess the zones of influence at different locations of the Coast of Bays area and subsequently the region with potential for exchanging water. The main characteristics of each calculation is presented below.

Drifter experiments were carried out at the end of spring-early summer period. During this period, water was generally stratified (Donnet et al. 2015a). The wind during the experiments was normally from calm to moderate (up to 8.3 m/s, or 30 km/h) except within Bay d'Espoir where stronger wind (up to 14 m/s) did not pose safety issue for vessel operation and drifters could be released and recovered. Surface and subsurface measurements were performed at various locations. The duration of the experiments were in the order of days and the results provide a spatial snapshot of the area having potential for water exchange.

Water currents were measured using ADCP moored for a 1 to 6 month period. These periods covered different seasons of the year and variable water structure corresponding to periods of variable stratification conditions, that is, a less stratified water column occurring in winter season and a strong stratification in summer. With such a long period of measurement, the wind was also variable with a possibility of storm wind conditions. Calculation of zones of influence and areas with potential exchange of water was performed at the subsurface layer. The calculation uses statistics on drifting distance and assumes that the water currents were spatially uniform. It was done at various locations where the ADCP was moored.

As for the circulation model, simulation was run for a period of one day with the possibility of doing longer runs. A well-mixed water column was considered for the whole domain and strong wind was used to force the model. While the strong wind conditions are normal during storm events occurring in the region, the well mixed water column would be closer to conditions during the winter season. Different conditions of wind were considered. Zones of influence were computed for any location in the domain of study and the result of the analysis with particles released in the upper 5 m was presented.

For the exchange of water between regions with implication to BMAs, the observation data show that Bay d'Espoir and Hermitage Bay have potential for exchange of water near the surface. Similar potential is found for the entire Belle Bay and the head of Fortune Bay. Connaigre Bay, Northeast Arm, and Great Bay de l'Eau are separated by land but connected from the southern part. Exchange of water would be possible when considering the maximum distance computed from the ADCP data.

Based on the results, the following recommendation can be made:

- The use of in-situ measurements and numerical model is complementary as observational data are also used to initialize and validate the model. Model simulation can then be run for different case studies that are difficult to measure in-situ (e.g. storm conditions).
- A number of issues related to model simulation have not been addressed in this study. The most important one is the consideration of the stratification within the water column. The stratification within the water column in the region depends on the season (Donnet et al. 2015a). A more representative vertical and spatial distribution of temperature and salinity is necessary to initialize the model for different seasons of the year.
- Improving the resolution of the bathymetry should lead to getting a better comparison between model and observation.
- Comparison of observed with modeled ocean currents needs to be performed after consideration of more realistic forcing fields.
- Little is known about the response time of the water circulation to changing wind forcing. Further analysis with the circulation will provide insight on the response of the water to these changes.

Questions/Clarifications

Participants sought clarification on the further requirements to run a baroclinic model. Currently all models are run on the high performance computing system at the BIO. A model run under barotropic conditions requires about 7.5 hours ramp up (instead of a shock start) and a four day run before results can be analyzed. Spin-up time and the response time to change in forcing is worth investigating. Baroclinic models are still under development, and will require significantly longer computing times and the spin up will be different, as the model will take longer to settle down.

A summary of the differences between model runs and drifter trials was also requested. The model was run under constant strong northeast winds (72 km/h). The drifter studies were conducted under variable, low north winds. There are, however, significant topographic features that could alter the wind pattern that have not been accounted for. In the model, wind is reduced to 0 km/h at the edge of steep coastal features. In the future, wind could be separates into wind parallel and perpendicular to the coast. It was suggested that the discipline of urban planning may have some insight into empirical results on how winds run across a fjord with a plateau. The scale may be different, but the physics and interactions with structures will be consistent.

The model output is every hour, and the drifter reported position every half an hour or every five minutes. Particle drift analysis is limited to the top 5 m. The particle is allowed to move between the layers of the upper 5 m depending on vertical thrust in the model (but if there is only one layer, it will be fixed). However, the drifter observations are fixed depth. Further model runs can be restricted to one depth for better comparison with observations.

There was also discussion of the potential BMAs that would result from this research. Authors clarified that the three zones of influence identified are not BMAs. The zones of influence provide information for further management decisions, which will depend upon the acceptable level of risk identified by managers and stakeholders.

Summary of Review

Reviewers: F. Page, D. Greenberg, and S. Haigh

The reviewers agreed that this paper contributes considerably to the objectives of this meeting. Figure 3 indicates that spatial variability has to be included in the model. One reviewer suggested a vector diagram could solve this, indicating how to steer the wind around the topographic features. Within the model, wind is applied uniformly except behind wind barriers. Wind data was collected by 10 coastal stations in addition to Environment Canada's offshore wind data. The data could be used to create a more realistic wind field in the model. The next steps will be to generate a new, data-rich wind field. However, significant challenges remain as there is no correlation between the different bay areas and it is extremely difficult to fill gaps in the dataset.

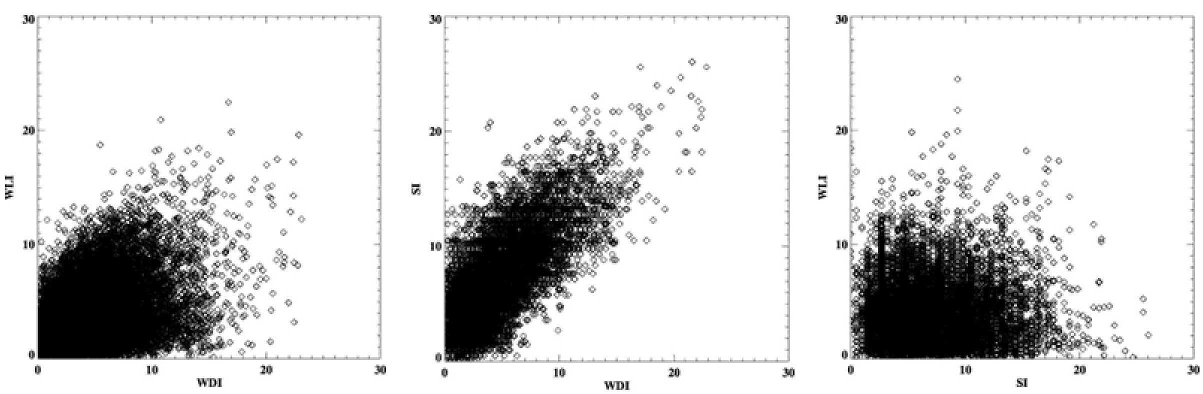

Figure 3. Scatterplot of wind speed [m/s] comparing Little Island with Dog Island (left panel), Sagona Island with Dog Island (center panel), and Little Island with Sagona Island (right panel).

Results thus far are encouraging. Figure 4 indicates agreement with a simple model. Another reviewer pointed out that the comparison between observed and modeled tidal amplitude does not mean the model can predict current. More investigation on the winds is needed as well as more model/observation comparisons. As with the previous papers, reviewers pointed out that this report does not discuss application to aquaculture management, BMAs, pathogen transport oxygen, etc. This discussion will be augmented in future work.

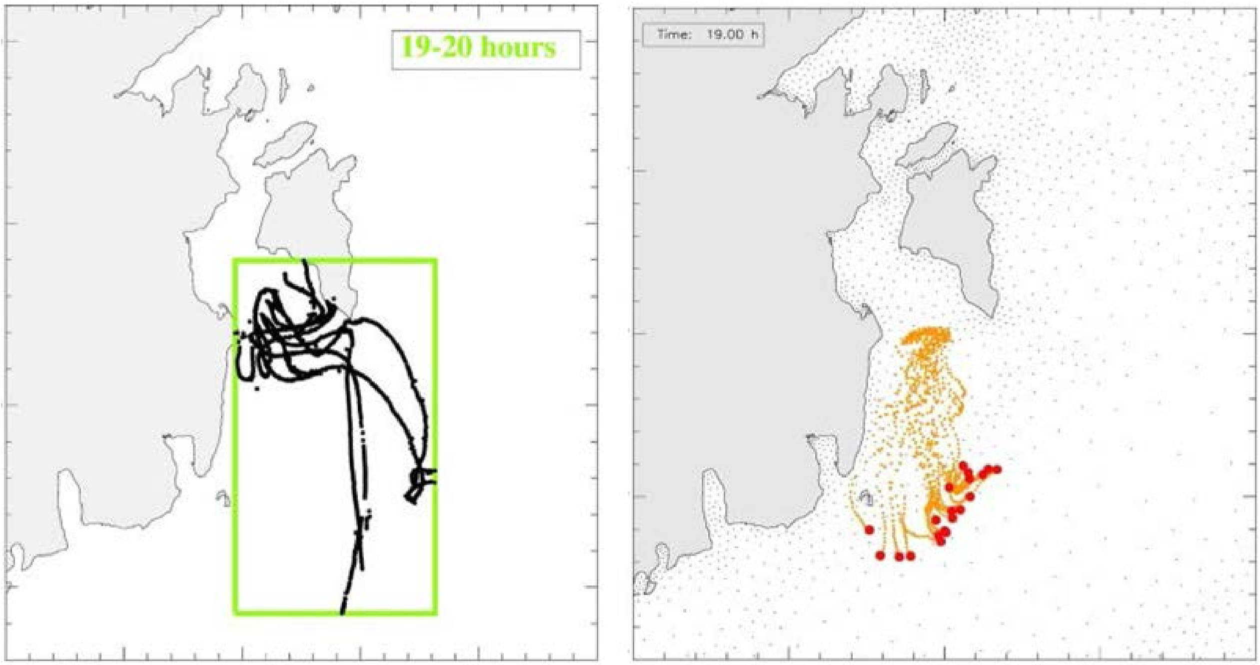

Figure 4. Comparison of surface and sub-surface drifter positions (left panel) with sub-surface particle positions (right panel) after 19 hours from release.

Reviewers questioned whether the results are sufficient to conclude that limited particle exchange occurs between the bays in the study area. Reviewers further asked whether the bays be considered separate, and specifically, whether farm sites can be plotted with potential drift ranges. The questions reiterated a recurring topic of this meeting: How sufficiently developed do the models need to be to allow for application to the Coast of Bays? It was suggested that one way forward would be to develop a high resolution atmospheric model. Wind appears to be more important in NL than in New Brunswick (NB) or British Columbia (BC), where similar research has been conducted.

General Discussion

Drifter observations were restricted to low wind conditions for safe recovery of the drift units. Participants asked whether these results can really be considered representative. A lot of drifter work has been conducted in the Bay of Fundy and on the BC coast, however different relative movement of particles (more movement, greater distances) is occurring in NL. If these results are correct, the large scale particle movement will determine how future work progresses. The particular challenge is wind forcing; the sharp fjord environment requires complex ocean models. In similar modeling efforts, substantial amounts of time have been spent achieving satisfactory climatology inputs. Additional inputs, such as realistic temperature and salinity fields, will contribute to a better model. Diagnostic approaches will help create a better understanding of the role and magnitude of wind forcing. High resolution satellite imagery may provide an opportunity to track marine waves, and then predict spatial wind distribution. Although the satellite information within the fjord may identify wave forms, the open bays should provide reasonable information.

Further development of the model may also help interpret existing data. For example, reviewers asked whether model simulation with upwelling winds produce the lower temperature and higher salinity values seen in the September, 2009 survey.

CLOSING DISCUSSION

There are a number of factors driving the evolution of aquaculture management zones. The BMA regime is a system in progress that adapts as information becomes available. The province of NL is being proactive by beginning the BMA process and aligning management regions as data become available.

BMAs are currently used in NB, and have changed at least three times. The guiding principles are:

1. Fish health: How does one aquaculture site impact another?
2. Environment: What are the benthic impacts of farms?
3. Production: Many farms are already in production and any shifts in management must take production cycles into account.

In NB, the current model identifies three major production areas on three year production cycles with a fallow period between productions. As this process moves forward, an understanding should be developed regarding the driving need for BMAs in NL. It should also be understood that the BMAs will evolve. Throughout the process new considerations will emerge and priorities will change as new areas open such as the Burin Peninsula. NB has had a 15 year continuous process.

The epidemiological work of Dr. Whalen and other researchers at the University of Prince Edward Island should be considered in conjunction with the research presented today. Epidemiology and oceanography need to be combined to meet the management needs of a developing industry. With limited infrastructure and a handful of sites, the NL aquaculture industry is trying to learn from experiences in NB, NS, Norway, and Chile. Information pertaining to the interconnectedness of water bodies is still missing. The goal at this meeting is to establish a foundation of oceanographic knowledge to refine the basic BMA model, limiting risk and reducing pathogen transfer.

RECOMMENDATIONS

Upon reviewing the working papers, participants agreed that researchers present at the meeting are on track to generate a meaningful oceanographic model to inform development of BMAs in the Coast of Bays. However, several questions remain such as:

- What are the non-tidal driving forces?
- Which processes drive trends such as the 2014 superchill event? Are these events predictable?

Throughout the meeting, the following recommendations were developed:

1. A number of additional analyses can be done to refine the first working paper. As the aquaculture industry expands, similar studies should be conducted in emerging areas of interest.
2. Construct a temperature and salinity climatology field based on the historical data and data collected throughout this study. From preliminary investigation of historical data, it is unlikely that sufficient salinity data is currently available. It may also be recommended that researchers collect a time-series of T-S at discreet points throughout the study area.
3. For dispersion, the model provides maximum distance and speed; probability and risk have not been analyzed. ADCP data could be re-analyzed to fill this gap. Maps of ADCP data

were isotropic and this can be refined in further analysis by representing directionality patterns.

4. Progress from a barotropic model to a more complex baroclinic model (through diagnostic analyses in stages). Analyze the results of the barotropic model output to determine effect of wind forcing.
5. Conduct spectrum analyses to show dominant frequencies of fluctuations.
6. Carry out principal components analysis for the non-tidal currents.
7. In terms of the vertical structure, normal-mode and/or empirical orthogonal function (EOF) analyses could be carried out to reveal some typical patterns.
8. Investigate surface currents using improved design of measurement.
9. Compare observed and modeled ocean currents after consideration of more realistic forcing fields.
10. An analysis of the response of the water circulation to changing wind forcing is required.

Participants agreed throughout the meeting that study outcomes should be linked to BMA policies, and also that the implications of results for farm success and sustainability should be presented in each paper. This will require input from stakeholders regarding their needs.

Further, the delineation of BMAs requires input from a number of sources (regulators, industry, etc.). The information brought to this meeting is one among many inputs that will require integration for the support of BMAs. There are technical components beyond the scope of this meeting. It may be helpful to strike a working group to develop these priorities.

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APPENDIX I: TERMS OF REFERENCE

State of knowledge of the oceanography and water exchange on the south coast of Newfoundland to support the development of Bay Management Areas for Finfish Aquaculture

Regional Peer Review - Newfoundland and Labrador

March 25-26, 2015
St. John’s, NL

Chairperson: Ben Davis, Aquatic Resources, Science Branch, NL Region

Context

The expansion of aquaculture operations in the Coast of Bays, an area of the south coast of Newfoundland, presents a challenge to departments and agencies responsible for regulating the industry. Regulation requires a good understanding of the environment where the aquaculture takes place. The Coast of Bays is a harsh environment with cold water temperature, strong stratification and potential hypoxic conditions within salmonid cages. The area is also regularly exposed to severe storms. The limited oceanographic knowledge of this area has precluded the development of comprehensive management strategies to support the sustainable development of aquaculture in Newfoundland.

Research efforts have been undertaken by Fisheries and Oceans Canada, Newfoundland and Labrador Region, to carry out coastal oceanographic studies in the Coast of Bays area in order to help in the development of scientifically-based Bay Management Areas (BMAs) which support optimal fish health management. The studies consisted of the collection of in-situ oceanographic data and the development of a coastal water circulation model (i.e., Finite Volume Coastal Ocean Model) which will help understand the physics of the ocean in the area and map potential zones of influence associated with aquaculture activities.

DFO-Aquaculture Management – and other sectors – can use this information to quantify, model, and mitigate the interactions among aquaculture operations and the environment. The information is also expected to serve as a knowledge base for regulatory decisions and procedures associated with site selection and licensing, production planning, and for sustainable site management of the industry.

Objectives

The Regional Peer Review meeting will review the characterization of the oceanographic conditions and zones of influence associated with aquaculture activities in the Coast of Bays area. The information and advice will describe the physical environment based on the current state of knowledge as well as provide an initial understanding of the potential exchange of water between zones where aquaculture activities take place and will support the development of BMAs.

Specific objectives include an evaluation, analysis, and update of the information available, including the identification of knowledge gaps, as described below:

- An analysis of the geography, hydrology, bathymetry, and oceanography of the Coast of Bays area based on historical data.
- An analysis of the water column vertical and horizontal structure, as well as seasonality (temperature, salinity, density and dissolved oxygen) in the Coast of Bays area.
- An analysis of the vertical structure and spatial variability of the ocean currents in the Coast of Bays area.

- The development of a circulation model for the Coast of Bays area and its application to identify geographic zones of influence associated with the surface transport of particles: comparison with in-situ measurements.

Expected Publications

- Science Advisory Report
- Proceedings
- Four Research Documents

Participation

- Fisheries and Oceans Canada (DFO) (Science, and Fisheries Management)
- Newfoundland and Labrador Provincial Department of Fisheries and Aquaculture
- Aquaculture Industry
- Stakeholders
- Other invited experts

APPENDIX II: AGENDA

Regional Peer Review – State of knowledge of the oceanography and water exchange on the south coast of Newfoundland to support the development of Bay Management Areas for Finfish Aquaculture

Newfoundland & Labrador

Hampton Inn, St. John's, NL

March 25 – 26, 2015

Wednesday, March 25th

Time	Activity	Presenter
9:00 AM	Welcome/Opening	B. Davis (Chair)
N/A	WP 1: Metrics of the Area	S. Donnet
9:45 AM	Review	F. Page /D. Greenberg/S. Haigh
10:30 AM	Coffee/Tea	N/A
10:50 AM	Discussion	All
11:30 AM	WP 2: Water Structure	S. Donnet
12:00 PM	Lunch	N/A
1:00 PM	Review	Foreman/E. Colbourne
1:30 PM	Discussion	All
2:00 PM	WP 3: Ocean Current Variability	A. Ratsimandresy
3:00 PM	Coffee/Tea	N/A
3:20 PM	Review	M. Foreman/G. Han
3:50 PM	Discussion	All

Thursday, March 26th

Time	Activity	Presenter
9:00 AM	WP 4: Zones of Influence and Modelling	A. Ratsimandresy
9:30 AM	Review	F. Page/D. Greenberg/ S. Haigh
10:00 AM	Discussion	All
10:30 AM	Coffee/Tea	N/A
10:50 AM	WP 4 Discussion (continued)	All
11:15 AM	Drafting of SAR bullets	All
12:00 PM	Lunch	N/A
1:00 PM	Discussion	All
N/A	Discussion	All
N/A	SAR, Res. Docs., Science Research Recommendations	All
3:00	Coffee/Tea	N/A
N/A	Conclusions	All
N/A	Closing/Next Steps	B. Davis

Notes:

- Coffee and Tea will be provided 10:30 AM and 3 PM Wednesday and Thursday.
- Lunch (not provided) will normally occur 12:00 PM-1:00 PM
- Agenda remains fluid – BREAKS to be determined as meeting progresses.
- This agenda may change.

APPENDIX III: LIST OF PARTICIPANTS

Name	Affiliation
Laura Halfyard	Connaigre Fish Farms Inc./NAIA
Sheldon George	Cooke Aquaculture
Steve Mayse	Department of Fisheries and Aquaculture
Geoff Perry	DFO Aquaculture Management
Mike Foreman	DFO Science
Susan Haigh	DFO Oceanography
Daria Gallardi	DFO Aquaculture
Harry Murray	DFO Science
Dwight Drover	DFO Science
Steve Snook	DFO Science
Sebastien Donnet	DFO Aquaculture Science
Andry Ratsimandresy	DFO Aquaculture Science
Jay Parsons	DFO Strategic and Regulatory Science Directorate
Ingrid Burgetz	DFO Aquaculture Science
Fred Page	DFO Science
Pierre Goulet	DFO Aquaculture
Shannon Cross	DFO Aquaculture
Chris Hendry	DFO Aquaculture Management
Ellen Careen	DFO Aquaculture Management
Flora Salvo	DFO Aquaculture Science
Dounia Hamoutene	DFO Aquaculture Science
Dale Richards	DFO Centre for Science Advice – NL Region
Guogi Han	DFO Oceanography
Sara Lewis	DFO Oceanography
Jennifer Holden	DFO Oceanography
Ben Davis	DFO Science
Dave Senciall	DFO Science
David Greenberg	DFO, Bedford Institute of Oceanography
Robyn Lee	FFAW Industry Liaison
Janice Duggan	Gray Aqua Group Ltd.
Mark Abrahams	Memorial University
Emilie Novaczek	Memorial University
Darrell Green	Newfoundland Aquaculture Industry Association
Mark Lane	Newfoundland Aquaculture Industry Association
Dean Foss	Nova Fish Farms
Bob Sweeney	Simcorp Marine Environmental