# Submissions of the Friends of the Northumberland Strait in Response to the call for Public Comments on the Focus Report for the Replacement Effluent Treatment Facility Project

James Gunvaldsen Klaassen
and Sarah McDonald
Ecojustice
1801 Hollis Street, Suite 520
Halifax, NS  B3J 3N4

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## 1. Overview

1. This submission is filed on behalf of the Friends of the Northumberland Strait (FONS). FONS is a society registered under Nova Scotia's *Societies Act* and its members are residents of Pictou and the surrounding area. These materials are filed in response to the call for public comments regarding the Focus Report submitted by Northern Pulp Nova Scotia (NPNS) in respect of the proposed project to build a new Effluent Treatment Facility (ETF or the "project").

2. These submissions are made within the Environmental Assessment (EA) process for the ETF under Nova Scotia's *Environment Act*[1] (the *Act*) and *Environmental Assessment Regulations*[2] (the *EA Regs*). FONS filed its original submissions with Nova Scotia Environment (NSE) and the Minister on February 12, 2019 and March 8, 2019[3], in response to NPNS' original Environmental Assessment Registration Document (EARD) of January 31, 2019.[4] FONS relies on all of these materials in respect of this EA process and asks that all of its submissions and those of other members of the public be properly and thoroughly considered by the Minister prior to making any decisions.

3. FONS' concerns as expressed in its February 12 and March 8 submissions, and the concerns of many other Pictou and area residents, have not been addressed by the Focus Report, and NPNS and its consultants have not cured the fundamental defects in the NPNS EARD materials. The project presents significant environmental effects and adverse effects, and must

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[1] *Environment Act*, S.N.S. 1994-1995, c. 1, Part IV.
[2] *Environmental Assessment Regulations,* NS Reg 26/95 ["*EA Regs*"].
[3] Ecojustice's submissions on behalf of FONS are posted to the Environmental Assessment website of Nova Scotia Environment in four parts:

1. Part A - February 12, 2019 submission, at https://www.novascotia.ca/nse/ea/Replacement_Effluent_Treatment_Facility_Project/comments/4-Ecojustic-comment-A-part-1.pdf and https://www.novascotia.ca/nse/ea/Replacement_Effluent_Treatment_Facility_Project/comments/5-Ecojustic-comment-A-part-2.pdf
2. Part B, March 8, 2019 submission, at https://www.novascotia.ca/nse/ea/Replacement_Effluent_Treatment_Facility_Project/comments/6-Ecojustic-comment-B-part-1.pdf and https://www.novascotia.ca/nse/ea/Replacement_Effluent_Treatment_Facility_Project/comments/7-Ecojustic-comment-B-part-2.pdf

[4] NPNS EARD, as posted to the Environmental Assessment website of Nova Scotia Environment, at https://www.novascotia.ca/nse/ea/Replacement_Effluent_Treatment_Facility_Project/.

be rejected. NPNS' proposed mitigations will not prevent harm to the terrestrial and marine environment and to local communities, and will not perform as predicted in the EARD and Focus Report.

4. The process followed by the Minister is flawed and unfair. The Minister and his cabinet have demonstrated a conflict of interest and are biased toward approving this project. The Minister and his predecessor have repeatedly and unfairly limited the public's ability to participate in the process, despite the high level of concern and anxiety regarding this project in the Pictou area, in Nova Scotia, and within the Atlantic Region. The Minister's procedural choices within this EA process have undermined public confidence in the EA process and are contrary to the letter and spirit of the *Act*.

5. The Focus Report package made available to the public was incomplete and the public may never have the chance to comment on some contemplated reports and submissions before the Minister makes his decision. The various processes chosen appear to have been deliberately designed to prevent the public from reviewing and understanding the thousands of pages of technical materials, obtaining advice from experts, and making considered and focused submissions, all of which would have been of benefit to the process and to the Minister in making an appropriate decision. FONS and other interested groups and individuals requested more time for review, but all such requests were rejected by the Minister.

6. As in NPNS's original EARD, the Focus Report once again attempts to characterize the risks of this project as minimal. Some key concerns identified by FONS and others are not discussed at all, despite the clear obligation to address and respond to public concerns under the *Act* and the *EA Regs*.

7. The updated and original receiving water studies put forward by NPNS and its consultants, and the impact assessments based on those studies, are poorly done, fundamentally flawed and unreliable. Dr. Oliver Fringer, an oceanographer and expert in modelling coastal systems, is of the opinion that the Stantec modelling does "not provide science-based evidence that can be used to assess the potential environmental impacts of the near- and far-field dilution from the

proposed outfall site."[5] The Stantec reports overpredict effluent dilution rates and under predict the likelihood of sediment deposition and accumulation, both by significant margins.

8. Inaccurate information and inappropriately selective information is provided about the marine ecosystem, including fish habitat and the fisheries that are conducted there.

9. NPNS' Focus Report was filed before all requirements of its Terms of Reference were completed, although NPNS has known since 2015 that a new ETF would be required and an EA would be triggered. The Focus Report contains omissions, errors and inaccuracies. It neither complies with its Terms of Reference nor satisfactorily addresses the many omissions, information gaps and inadequate assessment in the original EARD. Important baseline studies have still not been done, planning and detailed designs are incomplete, and a number of studies are withheld from public comment. The Minister is once again asked to consider an incomplete set of materials.

10. NPNS' consultants make optimistic predictions that there will be no significant effects from this proposed ETF. As a reality check, the Boat Harbour Basin has been receiving effluent from this pulp and paper mill for over 50 years. The effects of continuous flow of the mill's treated effluent into that ecosystem are devastating and lasting and have negatively impacted generations of members of the nearby Pictou Landing First Nation. The planned cleanup of Boat Harbour will require a massive effort and is estimated to cost over $200 million dollars, all at public expense. It strains credibility to assert that the same effluent, when discharged at a similar rate into a pristine nearby ecosystem within the Caribou Channel, will somehow have no significant impact.

11. The risks associated with this project are significant. Despite two opportunities to do so, NPNS has failed to discharge its burden to show that the project will not cause significant environmental effects or adverse effects, or that any such effects can be mitigated. As discussed in detail below, ample evidence is before the Minister requiring rejection of the

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[5] Fringer, O.B., *Review of updated modeling studies by Stantec Consulting for the Northern Pulp effluent treatment facility replacement project*, 5 November 2019 at p. 16, **Appendix A-1** (Fringer update report).

project pursuant to ss 35(3)(d) and 40(c) of the *Act*, as the project is likely to cause adverse effects or significant environmental effects that cannot be mitigated and are unacceptable.

**2. Introduction**

12. In its original submissions to the Minister in February and March 2019, FONS set out its concerns which had not been addressed by the EARD. Most of these concerns remain unaddressed, as set out in the following list:

(i) The registration materials filed by NPNS are incomplete and do not comply with the requirements of section 9(1A) of the *Environmental Assessment Regulations*. The Project is therefore improperly registered and the current EA process is a nullity.

(ii) The Focus Report, as submitted, does not comply with the Terms of Reference as discussed within this submission;

(iii) All studies identified in the Terms of Reference should have been finalized and included in the Focus Report, in order that the entire Focus Report would be available to enable meaningful public comment and additional time must be granted to allow public comment on the entire Focus Report, once it is finalized;

(iv) The ongoing EA process is inadequate and unfair, as it does not allow the public to assess the large amount of scientific documentation and conduct a comprehensive review of the information contained in NPNS's EA submission and Focus Report, and all comments on each. NPNS failed to hold promised public information sessions, and held back from the public the majority of the scientific studies until registration; requests for more time to review the materials were rejected by the Minister;

(v) The Minister's connection to this project, as a member of cabinet, gives rise to a reasonable apprehension of bias, and renders the process as a nullity;

(vi) The EARD and Focus Report submissions, although lengthy, lack critical information, or sufficient detail, in crucial areas such as:

(a) Studies showing the nature and frequency of process interruptions and disruptions, leaks and spills at the NPNS facility and the impacts of same on effluent composition and effective operation of the proposed ETF;

(b) Studies showing that the proposed ETF, which is not yet constructed, can and will in fact reliably and consistently discharge effluent which will meet any particular parameter, or whether it will meet the parameters which form the basis of the discussion in the NPNS submission; and that NPNS actually will operate its facility in a manner that achieves the required parameters and in an optimally environmentally sustainable manner;

(c) Studies and analyses regarding mercury issues associated with the project, including methylmercury, mercury and other metals in effluent, and mercury contamination of the NPNS/Canso site;

(d) Full sets of baseline data obtained over full annual cycles and over the entire affected areas for all aspects of the ecosystems that will be affected;

(e) Complete ecosystem studies in relation to the marine and terrestrial environments;

(f) Thorough and accurate modelling to determine mixing capabilities in Caribou Channel and how the effluent will fare as it circulates in the Strait;

(g) Drawings or mapping/chart coordinates and detailed plans showing the precise pipeline route proposed on land, in Caribou Harbour, and in Caribou Channel;

(h) Reliable leak detection for all portions of the pipeline,

(i) Modelling in regard to spills or other accidental events;

(j) Air emissions data from current operations from all stacks and vents; and

(k) Clear, effective and comprehensive mitigation plans, with substance and that take into account actual conditions in the local environment.

The above defects, individually and collectively, show that the NPNS EA and Focus Report materials remain incomplete, are based on inaccurate information and unproven assumptions, and are not supported by credible scientific studies in relevant disciplines.

### 3. Procedural Issues

13. As stated in FONS March 8, 2019 submission, there is "[…] a duty of procedural fairness lying on every public authority making an administrative decision which is not of a legislative nature and which affects the rights, privileges or interests of an individual."[6]

[6] *Cardinal v Kent Institution*, [1985] 2 SCR 643 at 653.

14. A number of procedural issues have fundamentally compromised the fairness of the environmental assessment process for NPNS' proposed new ETF. Those procedural issues, each of which has been raised with the Minister on previous occasions, are as follows:

    (a) the Minister's reasonable apprehension of bias;

    (b) the insufficient public comment period on NPNS' Focus Report; and

    (c) the Province's failure to make certain portions of NPNS' Focus Report available for public comment.

15. In FONS' submission, each of these issues constitutes a violation of the Province's and/or the Minister's duty of procedural fairness in the context of the ongoing environmental assessment. FONS therefore calls on the appropriate authority to remedy these failings in order to restore the fairness and integrity of the environmental assessment process.

16. The following sections examine each of the three procedural issues identified by FONS in turn.

a) **Reasonable Apprehension of Bias**

17. On February 12, 2019, we submitted a package to both the Minister and the Environmental Assessment Branch on behalf of FONS. In our submission, we asked the former Minister of the Environment, Margaret Miller, to recuse herself from the EA process for NPNS' proposed ETF due to a significant conflict of interest.[7] On March 6, 2019, we received a letter dated March 5, 2019 from the former Minister Miller advising that she would not be recusing herself from the EA process.

18. On March 8, 2019, on behalf of FONS we submitted a package of substantive comments on NPNS' Registration Document for its proposed ETF. In those submissions, FONS maintained its position that the former Minister Miller's involvement in the EA process gave rise to a

[7] FONS' February 12, 2019 submission to the Minister is available on NSE's Replacement Effluent Treatment Facility Project webpage at the following addresses: https://novascotia.ca/nse/ea/Replacement_Effluent_Treatment_Facility_Project/comments/4-Ecojustic-comment-A-part-1.pdf and https://novascotia.ca/nse/ea/Replacement_Effluent_Treatment_Facility_Project/comments/5-Ecojustic-comment-A-part-2.pdf.

reasonable apprehension of bias.[8] FONS therefore continued to call on the Minister to recuse herself in order to maintain public confidence and ensure the integrity of the EA process.

19. Following the conclusion of the first stage of the EA process, additional evidence has come to light about the extensive financial ties between NPNS and the Province, and in particular about the strong financial incentives for the current Minister to approve the proposed ETF.

20. In the recently decided *Pictou Landing First Nation* case, the Nova Scotia Court of Appeal (NSCA) identified an Agreement and an Amendment between NPNS and the Province that provide for reimbursement by the Province to NPNS for engineering, design, and environmental assessment expenses for the new ETF. The Agreement is dated December 28, 2016, and the Amendment is dated September 27, 2017. In conjunction, the Agreement and the Amendment provide that the Province will reimburse NPNS for "Eligible Expenses," including reasonable costs for the design and engineering of the new ETF (up to $300,000) and the EA (up to $250,000) and "other costs approved by the Province in writing."[9]

21. The NSCA also noted that the Province and NPNS signed a second agreement on December 13, 2017. That agreement provided that the Province would reimburse NPNS' detailed design and engineering costs for the new ETF, <u>up to a maximum of $8 million.</u> Under the December 13, 2017 agreement, the Province can choose to use any contribution it makes to NPNS under the terms of the agreement to offset any future award NPNS may be granted for damages against the Province.[10] It appears that the Province is particularly concerned about potential compensation owed to NPNS as a result of the statutorily mandated closure of the Boat Harbour ETF.[11]

22. The December 28, 2016 and December 13, 2017 agreements, and the September 27, 2017 amendment will be referred to herein as the "**Funding Agreements**."

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[8] FONS's March 8, 2019 comments on the Registration Document are available on NSE's Replacement Effluent Treatment Facility Project webpage at the following addresses: https://novascotia.ca/nse/ea/Replacement_Effluent_Treatment_Facility_Project/comments/6-Ecojustic-comment-B-part-1.pdf and https://novascotia.ca/nse/ea/Replacement_Effluent_Treatment_Facility_Project/comments/7-Ecojustic-comment-B-part-2.pdf.
[9] *Nova Scotia (Aboriginal Affairs) v Pictou Landing First Nation*, 2019 NSCA 75 at para 44 ["***PLFN***"].
[10] *Ibid.*
[11] *Ibid.*

23. The NSCA commented on the impacts of these Funding Agreements on the Minister's decisions to issue approvals for the new ETF under Parts IV and V of the *Environment Act* (which include the Minister's decision to approve or reject the new ETF following the current environmental assessment). The Court wrote as follows:

> 136 […] the Funding Agreements inject their own incentives into the process of ministerial approval.
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> 137 Those incentives include the following:
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> • Provincial funds have already been paid, with more to come, toward the design, engineering, environmental assessment or capital cost of the New ETF. Without the ministerial approvals, the Province's payments would be wasted, The New ETF would not operate. Ministerial approvals are needed for the Province's investment to be productive.
> • The Funding Agreements say the Province "approves" the items of design, engineering and environmental assessment before paying Northern Pulp. Once the Province approves under the Funding Agreement, would there be an about-face that denies approval under the *Environment Act*? Likely, the contractual approval would facilitate the statutory approvals. In the past, the Province has contracted to give approvals for a new ETF. The 1995 [Memorandum of Understanding], articles 4.01(k) and (l), said the Province would "obtain all required…approvals…for the continued operation of the Reconfigured Facility." In 2008, the Province signed an acknowledgement that this provision would continue to benefit Northern Pulp. […]
> • The Funding Agreements embody partial terms of settlement of a threatened lawsuit by Northern Pulp against the Province for early termination of the Lease. A settlement is meaningful only with ministerial approvals under the *Environment Act.* The approvals would allow the Mill to operate toward the expiry date of the terminated Lease, reducing Northern Pulp's claimed damages. Denial of approval could leave Northern Pulp's alleged losses mostly intact, subject to issues of mitigation, for pursuit in litigation against the Province. The Minister might consider an avoided lawsuit to be beneficial for the Province. [12]

24. In light of the NSCA's findings, and in alignment with its previous submissions on this issue, FONS maintains its position that the Minister's role in the EA process for NPNS' proposed ETF gives rise to a reasonable apprehension of bias. As a result, FONS repeats its call for the Minister to recuse himself from the EA in order to restore public confidence in the process.

[12] *Ibid*, at paras 136-137.

### b) Insufficient time for public comment on the Focus Report

25. On October 10, 2019, we wrote to Minister Wilson on behalf of FONS to request that he grant additional time for both the public and the Administrator to review NPNS' Focus Report.[13] Specifically, FONS requested that the Minister:

    (a) Grant additional time for the submission of public comments on the Focus Report, with a new deadline of Monday, December 9, 2019; and

    (b) Add 30 more days to the 25-day period within which the Administrator must submit all comments and a recommendation to the Minister, following the deadline for public comments.

26. The current public comment period is exactly 30 days, running from October 9, 2019, the date on which NSE announced receipt of the Focus Report in the Nova Scotia Gazette.[14] This is the minimum public comment period required by the *Regulations.* The Minister has the authority to grant both extensions requested by FONS, pursuant to ss 16(2) and 17(2) of the *Regulations,* respectively, if the default timelines are insufficient for public comment or the Administrator's review.

27. Following the Minister's receipt of FONS' letter, the Minister made comments in the media indicating that he would not grant the requested extensions.[15] However, he did not respond directly to FONS.

28. On October 23, 2019, we wrote to the Minister on FONS' behalf once again to request a response to our letter of October 10.[16] We received a reply from the Minister denying our requested extensions that same day.[17]

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[13] Letter from James Gunvaldsen Klaassen and Sarah McDonald to the Honourable Minister Gordon Wilson, dated October 10, 2019, **Appendix E-1**.
[14] Release of Focus Report Pursuant to the Nova Scotia *Environment Act,* (2019) NS Gaz I, 1529, **Appendix E-2.**
[15] Michael Gorman, "Minister not considering extension to comment period on Northern Pulp report," CBC News, October 10, 2019, **Appendix E-3**; Taryn Grant, "More time needed for review of Northern Pulp pipeline proposal: community group," The Star, October 10, 2019, **Appendix E-4**.
[16] Letter from James Gunvaldsen Klaassen and Sarah McDonald to the Honourable Minister Gordon Wilson, dated October 23, 2019, **Appendix E-5.**
[17] Letter from the Honourable Minister Gordon Wilson to James Gunvaldsen Klaassen, dated October 23, 2019, **Appendix E-6**.

29. Without prejudice to its submissions on the Minister's bias, FONS maintains its position that the Minister should extend the timelines for both public review and comment on the Focus Report, and for the Administrator to review the various submissions and provide a recommendation to the Minister. FONS reiterates the concerns expressed in its October 10, 2019 letter about the volume, complexity, and highly technical nature of the materials that the general public is now tasked with reviewing within a very short timeframe. A 30 day comment period is entirely insufficient to allow the general public to review, understand, and provide thoughtful comments on thousands of pages of complex, technical scientific materials. Indeed, the former Minister Miller herself echoed that concern when NPNS filed its original registration document.[18]

30. In addition, as reviewed in detail in FONS' February 12, 2019 submission to Minister Miller, the proposed ETF is highly controversial and has generated high levels of public interest and concern within the Pictou area and across Nova Scotia. As a result, it is all the more important to ensure that the public has ample time to review the Focus Report, the EARD, the many comments offered on the EARD, including government responses and determine how to respond, and what to say. Without adequate time, there is no meaningful opportunity for either the public or the Minister to understand the potential impacts of the proposed ETF on their communities and on Nova Scotia's environment and economy.

31. The Terms of Reference for the Focus Report recommended that NPNS engage with relevant stakeholders and share relevant studies and reports in the process of preparing its Focus Report. However, our understanding is that NPNS shared <u>nothing</u> with FONS or with numerous other affected groups who have consistently expressed strong concerns about the proposed ETF before submitting the various studies comprising its Focus Report *en masse* to the Province. This approach created additional and entirely unnecessary barriers to meaningful public participation in the EA process.

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[18] Jean Laroche, "Northern Pulp's plans for pipeline, effluent treatment plant now public," CBC News, February 7, 2019, **Appendix E-7**.

32. FONS therefore renews its call on the Minister to extend the timelines as requested in its October 10, 2019 and October 23, 2019 letters, in order to restore fairness and integrity to the current EA process.

**c) Failure to provide documents for public comment**

33. In the October 10, 2019 and October 23, 2019 letters to the Minister, FONS identified the following documents as missing from the Focus Report posted on the NSE website:

(a) Appendix 7.2 – states it includes as Appendix A an "Underwater Benthic Habitat Survey Video." However, no such video or link to any such video appears in this Appendix or elsewhere in the Focus Report.

(b) Appendices 10.1 and 10.2 both refer to reports which are not provided.

(c) Appendix 11.1 refers to a Mi'kmaq Ecological Knowledge Study but no such study is included in this Appendix or elsewhere in the Focus Report.

34. FONS letter went on to say: "[…] it is unclear as to whether reports are intended to be included, or submitted late, under Appendices 3.3, 3.5, 5.2, 6.1 and 7.5 of the Focus Report. If any such report will be submitted for your consideration, it must also be made available for public comment prior to any decisions being made […]".

35. The Minister did not address FONS' submission about these missing documents in any way in his comments to the media following the October 10, 2019 letter, or in his written response to the October 23, 2019 letter.

36. Jill Graham-Scanlan, president of FONS, has also corresponded with NSE's environmental assessment department via email about additional information missing from the Focus Report. On October 16, 2019, Ms. Graham-Scanlan sent two emails to EA@novascotia.ca noting the following errors and omissions:[19]

[19] Email chain between Jill Graham-Scanlan and the Environmental Assessment Web Account, dated October 23, 2019, **Appendix E-8**; Email chain between Jill Graham-Scanlan and the Environmental Assessment Web Account, dated October 24, 2019, **Appendix E-9**

(a) The Focus Report does not include information that would allow the public to determine whether the "fish and fish habitat baseline surveys for the freshwater environment" and "fish habitat baseline surveys for the marine environment" were completed to the satisfaction of Fisheries and Oceans Canada, as required by the Terms of Reference;

(b) The Focus Report does not include details of the assessment methodology for additional impact assessment of treated effluent on representative key marine fish species agreed upon by NSE in consultation with relevant federal departments, as required by the Terms of Reference; and

(c) A number of Figures in the Focus Report are blurry, and therefore partially illegible, both in the online version and in the hardcopy at the Pictou Library.

37. NSE did not address these errors and omissions in response to Ms. Graham-Scanlan's concerns. Shockingly, in one response NSE stated that "[t]he NS EA process does not include a conformity review or other check that the Focus Report contains all of the items listed in the Terms of Reference." This is in clear contrast to the press release NSE posted online upon receipt of the Focus Report, which stated that "[t]he report will be available online within 14 days <u>once department staff have done a preliminary check to confirm it is complete.</u>"[20]

38. NSE's failure to ensure that the complete Focus Report was made available for public comment clearly undermines the public's ability to participate meaningfully in the EA process. NSE requested this information from NPNS because it is necessary in order to fully understand the potential impacts of the proposed ETF. If the public cannot understand the potential impacts on their communities and environment, then they cannot provide fulsome comments and the integrity and fairness of the EA process is compromised.

39. As a result, and without prejudice to its position on the Minister's bias, FONS calls upon the Minister to make the missing documents available to the public and to provide additional time for the public to review and comment on those documents. FONS notes that the Province's failure to make the complete Focus Report available for public comment at the outset further

[20] NSE news release, "Northern Pulp Focus Report Submitted," October 2, 2019, **Appendix E-10**.

supports FONS' request for the Minister to extend the timelines for review under the *Regulations,* as outlined in the previous section.

### 4. Effluent and Sediment Transport Modelling

40. The modelling exercise conducted by Stantec, NPNS' consultants, is summarized in the set of receiving water studies contained in the original EARD. For the Focus Report, Stantec conducted a further modelling exercise and summarized those conclusions in an "Updated Receiving Water Study", dated September 27, 2019.[21] The findings of the full set of receiving water studies, including the Updated RWS, are fundamental to the overall and entirely questionable conclusion that none of the impacts of any aspect of this project will be significant. The accuracy and reliability of the modelling exercise is essential for a fulsome and in-depth evaluation of the project. If the modelling is not reliable, many of the conclusions asserted by NPNS' other consultants in relation to marine impacts and water quality will likewise be unreliable.

41. Stantec's central premise is that all contaminants will be quickly diluted. Stantec relies heavily on the questionable mixing zone concept as discussed below.

42. The Stantec Receiving Water Studies, on which much of the NPNS EA is founded, are unreliable and fundamentally inaccurate. The modelling exercise undertaken was not appropriate for the receiving environment and is not an accurate representation of effluent and sediment interaction with that environment. FONS submits that the Receiving Water Studies, and other materials based on the conclusions of those studies, must be disregarded and no assessment of environmental effects can be undertaken based on those studies.

43. FONS relies on the critique of the Receiving Water Studies prepared by Dr. Oliver Fringer. Dr. Fringer is an Associate Professor (with tenure), Department of Civil and Environmental Engineering, Stanford University. He is an oceanographer with expertise in numerical modelling of coastal dynamics.[22]

[21] Appendix 4.2, Focus Report.
[22] Oliver Fringer, CV, **Appendix A-3**

44. Dr. Fringer's original report regarding the Stantec Receiving Water Studies was submitted within the FONS submission of March 8, 2019.[23] We have again appended it to this submission. Dr. Fringer has also prepared a new report, which critiques Stantec's updated Receiving Water Study.[24] Dr. Fringer's reports speak for themselves and should be read together. We hereby submit them to the Minister for a detailed and thorough review. FONS submits that Dr. Fringer's two reports in combination make clear that all effluent modelling work done for NPNS in relation to this project is defective and unreliable, and all conclusions based on that modelling must be discounted and disregarded.

45. Dr. Fringer notes that his concerns regarding Stantec's original modelling work were not addressed within the updated receiving water study and the same flaws inherent in the original Stantec studies were carried forward into the updated study.

46. Dr. Fringer concludes that the updated studies prepared by Stantec based on the MIKE 21 and CORMIX system models are both inaccurate and misleading. They do not provide science-based evidence that can be used to assess the potential environmental impacts of the near- and far-field effluent dilution from the proposed outfall site.

47. The problems with these models arise from deficient modelling practices that Dr. Fringer criticized in his original report but were not addressed in the new studies. Dr. Fringer concludes that the Stantec studies suffer from fundamental problems associated with model setup, validation and analysis. Despite some additional measurements obtained in early summer 2019, the validation of the currents near site CH-B indicates that the Stantec model performs poorly and cannot be trusted to accurately predict the far-field transport of the effluent.

48. The models fail to take into account the stratification within the water column, which prevents the total mixing assumed by both the near-field and far-field modelling exercise. Stantec's near and far field models therefore over-predict mixing and dilution of effluent.

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[23] Fringer, O.B., *Review of near- and far-field modeling studies by Stantec Consulting for the Northern Pulp effluent treatment facility replacement project*, 7 March 2019 **Appendix A-4**

[24] Fringer, O.B., *Review of updated modeling studies by Stantec Consulting for the Northern Pulp effluent treatment facility replacement project*, 5 November 2019 **Appendix A-1** (Fringer update report)

49. Dr. Fringer finds that Stantec significantly overestimates the dilution by at least a factor of 3.5 based solely on its selection of parameters regarding effluent and receiving water density.[25] If different parameters are used, the dilution factor at 100 m from the diffuser is only 42, and not the much higher figures used by Stantec.[26] Dr. Fringer further concludes:

> This dilution factor is expected to be even lower when taking into account the effects of vertical density stratification, weaker slack currents during neap tides, and receiving water densities that should be at their lowest during late summer/early fall.[27]

50. Dr. Fringer's report also critiques the sediment transport report prepared by Stantec at Appendix 4.3. Dr. Fringer concludes that the sediment transport study is fundamentally flawed because it ignores the effect of flocculation and fails to use MIKE software designed for sediment transport modelling. Had Stantec accounted for flocculation, it would have concluded that solids within the effluent would deposit and accumulate much more rapidly and much closer to the outfall. Dr. Fringer finds:

> …owing to the use of floc diameters that are too small, and because the settling velocity is proportional to the square of this diameter, the settling velocities are vastly underpredicted and the resulting transport distances are substantially overpredicted. Substantially more flocculated effluent particulate matter will accumulate around the outfall….[28]

> The second flaw of the sediment transport study is that it is overly simplistic. The tidal currents are highly variable in the region in both space and time, and it is naïve to imply that the suspended particulate matter in the effluent will not pose an environmental or ecological problem based simply on an approximate distance it is expected to propagate away from the outfall. Not only do we expect flocculation to promote particle settling in the vicinity of the outfall, but the particles that settle far from the outfall may accumulate in sensitive fisheries habitats in deeper water or in Caribou Harbour.[29]

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[25] The parameters selected by Stantec do not match the trends shown by sampling results within Appendix 2.3. And where there is a range of results in 4.3, density and salinity factors most favourable to a higher level of dilution is selected, without explanation or justification.
[26] Fringer update report, at pp .14 and 18.
[27] Fringer update report at p 1. See also pp 10-13.
[28] Fringer update report pp 15-16.
[29] Fringer update report p. 16.

51. Stantec fails to assess the potential for fine particulate matter to accumulate within Caribou Harbour or other ecologically sensitive sites in the region.[30] Likewise, Stantec's statements that no effluent buildup will occur within Caribou Harbour are in doubt. Dr. Fringer writes:

> It is noted that "no effluent concentration buildup was found in the harbour basins, along the shorelines and in the entire model domain."[31] There is no scientific justification for this statement. Not only do the figures show buildup of effluent along the shorelines and signatures of effluent entering Caribou Harbour, but it is straightforward to compute the exact amount of effluent entering the harbour with the MIKE 21 model.[32]

52. In respect of winter scenario modelling, the report says:

> The winter scenario models ice cover simply by removing winds and waves, yet ice cover should be modeled with reduced tidal currents at the model boundaries and higher friction at the free surface. Improper ice modeling leads to an overprediction of the near- and far-field dilution.[33]

53. Dr. Fringer also finds that the modelling done by Stantec in relation to the existing Boat Harbour Facility is unreliable and incapable of being simulated accurately within the two-dimensional model used by Stantec.[34]

54. Based on the above and Dr. Fringer's detailed findings and analysis, the Stantec reports must be viewed as fundamentally unreliable, and an inappropriate tool to assess the effectiveness of the dilution of effluent, proposed as the main mitigation measure in relation to impacts on the marine environment.

55. Contrary to Stantec's assertions, it is therefore likely that there will be effluent buildup within Caribou Harbour and sediment deposition near the outfall. The effluent will not dilute to the degree asserted by Stantec, making the proposed mitigation ineffective. The proposed effluent discharge at the outfall will therefore present significant environmental effects and adverse effects for which no effective mitigation is proposed.

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[30] Fringer update report, pp 17-18.
[31] Dr. Fringer is quoting from p ii of the executive summary of the Stantec Updated Receiving Water study, Focus Report, Appendix 4.2.
[32] Fringer update report, at p. 9.
[33] Fringer update report, at p. 2 – see also p. 9.
[34] Fringer update report at p. 17.

## 5. Modelling and Marine Impact assessment

56. NPNS's consultant, Ecometrix, provided a report on its conclusions as to impacts on the marine environment and marine species.[35] The Ecometrix report relies heavily on the findings of the Stantec receiving water studies, including the last study which is dated September 27, 2019. Consequently, to the extent Ecometrix based portions of its report on unreliable or incorrect findings made by Stantec, then those Ecometrix findings must also be considered unreliable or wrong.

57. Ecometrix did not record any independent assessment or evaluation of Stantec's conclusions, but nonetheless carries them forward into the Ecometrix report. The timing of the two reports shows that, within 3 days of receiving the Stantec report, Ecometrix produced its own report which repeats Stantec's conclusions. Like Stantec, Ecometrix makes no allowance for error in respect of the modelling conclusions. Neither mentions Dr. Fringer's report and critique dated March 7, 2019, which seriously questions the reliability of the fundamentals of Stantec's work on the initial Receiving Water Studies and the accuracy of Stantec's predictions.

58. Stantec's fundamental conclusion is that all contaminants and other effluent substances will quickly dilute, within a few metres of the diffuser. Ecometrix's Marine Environment Impact Assessment (Table 4-6) characterizes the dilution effect as a "proposed mitigation", described as: "[t]he diffuser configuration promotes rapid mixing of effluent to minimize the spatial extent over which constituent concentrations are expected to be distinguishable from "background" or ambient conditions."[36] Once diluted, neither Stantec nor Ecometrix considers any effluent component to present any significant concern or risk, including by way of bioaccumulation and concentration within food chains. Underlying Ecometrix's report is the notion that dilution renders all contaminants as essentially benign despite their continuous flow into Caribou Channel, the Strait and beyond. Determining impacts to marine ecosystems and organisms is therefore mostly a mathematical exercise, dependent on dilution rates.

[35] Focus Report, Appendix 7.3.
[36] Ecometrix Report, at, for example p. 4.31 (see column under the heading "proposed mitigation").

59. As discussed above, Dr. Fringer's expert opinion is that the Stantec models are fundamental defective and unreliable. If Stantec is incorrect, Ecometrix's conclusions and predictions must also be in doubt. Some of Ecometrix's conclusions that rely on Stantec modelling are:

(i) Definition of study areas - the Marine Local Assessment Area (LAA) and the Regional Assessment Area (RAA) - in terms of Stantec's predicted dilution factors i.e areas which are predicted to be exposed to relative effluent concentrations exceeding 1% and those predicted to be lower than 1%;[37]

(ii) Assumption that effluent dispersion in winter is very similar to summer;[38]

(iii) Dilution ratios set out in table 4-4;[39]

(iv) Calculation of distances from the diffuser at which each substance reaches "ambient condition" per Table 4-3; [40]

(v) There will not be a requirement to conduct a fish community or benthic community study as part of an Environmental Effects Monitoring study[41] under the *Pulp and Paper Effluent Regulations*;[42] and,Purported impacts (or no impacts) on marine species, including Atlantic herring,[43] Rock crab,[44] American lobster,[45] Marine shellfish,[46] plankton,[47] and benthic invertebrates.[48]

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[37] Ecometrix Report, page 2.4, Appendix 7.3.
[38] Ecometrix Report, page 4.12, Appendix 7.3. "As shown by MIKE 21 2D modelling presented in Stantec (2019c), effluent dispersion in winter is very similar to summer."
[39] Ecometrix Report, "Table 4-4: Dilution Ratios at Distance"; page 4.15, Appendix 7.3.
[40] Ecometrix Report, "Table 4-3: Marine Water Quality COPCs and Estimated Dilution"; page 4.13, Appendix 7.3.
[41] Ecometrix Report, p. 5.3, Appendix 7.3.
[42] *Pulp and Paper Effluent Regulations*, SOR/92-269, Schedule IV.1, s. 3.
[43] Ecometrix Report, p. 420 and p. 4.25, Table 4-6, "Significance Determinations of Residual Effects after Mitigation on the Marine Environment VEC", Atlantic herring, Appendix 7.3.
[44] Ecometrix Report, Table 4-6, "Significance Determinations of Residual Effects after Mitigation on the Marine Environment VEC", Rock crab, page 4.27, Appendix 7.3.
[45] Ecometrix Report, Table 4-6, "Significance Determinations of Residual Effects after Mitigation on the Marine Environment VEC", American lobster, page 4.29, Appendix 7.3. "Effects are considered to be minor and encompass a small area within 5 m of the diffuser area."
[46] Ecometrix Report, Table 4-6, "Significance Determinations of Residual Effects after Mitigation on the Marine Environment VEC", shellfish, page 4.31, Appendix 7.3.
[47] Ecometrix Report, Table 4-6, "Significance Determinations of Residual Effects after Mitigation on the Marine Environment VEC", plankton, page 4.32, Appendix 7.3.
[48] Ecometrix Report, Table 4-6, "Significance Determinations of Residual Effects after Mitigation on the Marine Environment VEC", benthic invertebrates, page 4.34, Appendix 7.3.

60. The Ecometrix report provides little assessment as to what will happen to individuals of marine species that come into contact with effluent discharging from the diffuser. Based on Stantec's modelling, Ecometrix treats the "mixing zone" as a small area, and mostly concludes that the effluent will dilute quickly and any contact with marine organisms will be fleeting.[49]

61. This conclusion is reached despite the reality that an average of 65 million litres of effluent will be discharged at the site each day, amounting to 23.7 billion litres a year. At that rate, over 30 years of operation, the total effluent discharge will be 711 billion litres. As stated above, there is no indication that any testing was conducted to assess impacts of such discharges over time on marine species at all life stages, despite the nature of the ecosystem being examined and the concerns raised by the public as to potential toxicological effects of the effluent on the ecosystem. In this regard, Ecometrix simply states:

> To address these concerns, NPNS will continue to investigate the feasibility of performing toxicity testing to determine both potential acute and sublethal effects on immature stages of lobster and herring.

62. "Investigating the possibility" of doing such a test does not satisfy the requirement to consider and assess the potential risks to lobster and herring from this project. NPNS has chosen to leave this requirement unsatisfied.

Further potential errors in with application of the dilution rates

63. The information provided by NPNS' consultants in Table 7.3-1[50] of the NPNS Focus Report, appears to contain significant internal errors, in addition to being based on the erroneous predictions from the Stantec modelling exercise. The table purports to set out the distances by which each parameter in the effluent will reach "ambient conditions".

64. The right hand column of the table is clearly erroneous. That column, entitled "distance from diffuser ambient conditions are reached", says, for the most part, that concentrations of various effluent components will reach ambient conditions within less than 2 m of the diffuser. A quick look at the table shows that this is obviously not true. As the most glaring example,

[49] Ecometrix Report, page 4.20, Appendix 7.3.
[50] Table 7.3-1: Marine Water Quality COPCs and Estimated Dilution, Focus Report p. 138.

Mercury is shown not to be present in seawater in either 2018 or 2019. As it is contained in the effluent entering the seawater at the diffuser, those concentrations will be at 0.028 µg/L[51] 5m from the diffuser and the same at 100m. Yet the right hand column concludes that it will reach ambient conditions (of 0 µg/L) within 2m of the diffuser. It cannot reach 0 µg/L at 2m if it is still at 0.028 µg/L at both 5 m and 100 m. Moreover, it shows that it still exceeds the CWQG guideline of 0.016 even at 100m.

65. As another example, ambient concentrations for cadmium were measured at n/a in 2018, and 0.084 µg/L in 2019. The table says that the effluent discharge of 1.03 µg/L will reach ambient conditions by "<2m", but shows that by 5 m it has only reached 0.1 µg/L, and only reaches 0.084 µg/L by 100m. Obviously, if the ambient concentration for cadmium is n/a, then it has not reached ambient conditions even by 100m and certainly not <2m The <2m prediction is therefore not even borne out by the modelling result presented, yet it is the conclusion given in the Dillon table.

66. The table lists measurements of Caribou seawater from 2018 and 2019 and the concentrations vary from one year's measurement to the other. It is important to note that there are only a couple of measurements for each year, and no attempt was made to conduct an intensive sampling program to obtain a full set of measurements over one or more annual cycles.

67. But despite this very limited data set, Dillon consistently selects the higher level of concentrations as ambient conditions. There is no discussion as to why one is chosen over the other. Rather than attempting a balanced and neutral analysis, the table consistently uses the highest level of a particular parameter, even though a lower level was measured in another year. Again, repeating the cadmium example, measured ambient concentrations for cadmium were measured at n/a in 2018, and 0.084 µg/L in 2019. Yet 0.084 is used as the ambient condition, even though it was not measured at all in 2018. No explanation is provided as to why 0.084 was selected.

[51] Micrograms per litre

### 6. Canso chemical site and mercury contamination

68. In its March 8, 2019 submission FONS identified mercury contamination present on the NPNS property in close proximity to the proposed site for the ETF and its potential to be disturbed via construction activities.[52] FONS provided a report by Dr. Margaret Sears describing the basis for the concerns and the adverse environmental effects that can be caused by mercury contamination.[53] As shown by Appendix 1.1, many members of the public expressed similar concerns.[54]

69. FONS also provided supporting technical materials documenting the risks and known problems with mercury contamination on the NPNS/Canso Chemicals site.[55] In a Canso site decommissioning report dated January 26, 2000, Dillon consulting concluded that mercury was present in the bedrock at the site[56] and there was "potential for mercury to migrate and discharge to Pictou Harbour in the future."[57]

70. Neither the Focus Report nor the original EARD contains any discussion or assessment of this risk in connection with the proposed ETF project, or provides any mitigation measures. In response to the numerous concerns raised regarding site mercury contamination, NPNS' report only says: "Monitoring will be conducted as part of construction. Contingency plans will be in place to address contaminant if identified."[58]

71. This approach is not acceptable as the Minister must consider, *inter alia*, the "potential and known adverse effects or environmental effects of the proposed undertaking...[.]" [59] This must be done before the work commences, not after it has proceeded and a foreseeable problem has been encountered. One would expect to see an identification of the risks, delineation of the contamination, and the steps that are proposed to avoid and mitigate the risk.

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[52] FONS submission, March 8, 2019, at p. 29 and Appendices F-1 and H-2; Dr. Margaret Sears, *Comments regarding the Northern Pulp Nova Scotia Environmental Assessment Registration Document, Replacement Treatment Facility*, March 8, 2019 (Appendix F-1). Partial decommissioning report for Canso site (Appendix H-2).
[53] Dr. Sears' report, at p. 4 (Appendix F-1).
[54] Focus Report, Appendix 1.1, Public Comments, for example at pp. 20 and 122 of 125.
[55] Canso Chemicals Site materials, FONS submission, March 8, 2019, Appendix H-2.
[56] Canso Chemicals Site report, p. 35, FONS submission, March 8, 2019, Appendix H-2.
[57] Canso Chemicals Site report, p. 37, FONS submission, March 8, 2019, Appendix H-2.
[58] Focus Report, Appendix 1.1, Public Comments, for example at pp. 20 and 122 of 125.
[59] *EA Regulations*, ss 9(1A)(b)(vi) and 12(e).

72. As Dr. Sears says, gathering information and conducting analysis relating to the Canso site mercury issue should be an essential component of the EA process.[60] However, its potential impacts have not been assessed and no information has been provided regarding mercury contamination at the site. Despite advance knowledge of mercury contamination, NPNS proposes only to wait and see if any mercury is encountered while the project is underway, without assessing any associated risk within this EA process prior to beginning the work. Without any information and evaluation regarding mercury contamination, an EA cannot be conducted and the obligation to consult Indigenous peoples and the public has not been discharged.

73. Consequently, the project description and assessment cannot be considered complete and NPNS's proposed ETF must be rejected.

**7. Failure to conduct primary studies and obtain baseline data**

74. As discussed above in the context of site mercury contamination, the *EA Regs* require that NPNS provide environmental baseline information in respect of its proposed project.[61] Despite this requirement, as discussed in FONS' March 8, 2019 submission, in many cases NPNS did not provide such information when it submitted its original EARD. The subsequent Terms of Reference for the Focus Report provided NPNS with another opportunity to submit baseline information. As one example, paragraph 7.2 of the Terms of Reference requires NPNS to:

> 7.2 Conduct fish habitat baseline surveys for the marine environment, to the satisfaction of Fisheries and Oceans Canada.

75. However, in its Focus Report, while NPNS asserts that its current evaluation regarding the benthic community is comprehensive, it then suggests that more information will be gathered in the area of the effluent diffuser in fall 2019 to supplement the existing database.[62] It also appears to concede that it has not achieved a baseline for phytoplankton and zooplankton presence, diversity and relative abundance.[63] No information has been provided to the public

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[60] Dr. Sears' report, at p. 4 (Appendix F-1).
[61] *EA Regulations*, ss 9(1A)(b)(x) and 12(da).
[62] Focus Report, p. 126.
[63] Focus Report, p. 126.

as to whether any surveys were conducted to DFO's satisfaction. Consequently, it appears that the requirement to provide comprehensive baseline information has not been met.

76. As well, paragraphs 7.3 and 9.1 of the Terms of Reference require:

> 7.3 Conduct additional impact assessment of treated effluent on representative key marine fish species important for commercial, recreational and Aboriginal fisheries.
>
> 9.1 Complete baseline studies for fish and shellfish tissue (via chemical analysis) of representative key marine species important for commercial, recreational and Aboriginal fisheries in the vicinity of the proposed effluent pipeline and diffuser location.

77. While Appendix 9.1 shows some limited testing was done in September 2019, many more species have yet to be tested.[64] No testing of juvenile or larval stages was apparently conducted, even though, in its original EARD at Appendix H, Ecometrix stated that the environmental effects monitoring program would include toxicity testing to determine both potential acute and sublethal effects of effluent on immature stages of lobster and herring.[65] Despite the requirements of paragraph 7.3 of the Terms of Reference, Ecometrix's most recent report appears to indicate that no toxicity testing was done, and that NPNS is now only "considering" doing such testing.[66] It is submitted that a complete set of such tests is necessary baseline information and without a full set of tests, the Focus report is incomplete and does not satisfy the Terms of Reference.

78. Moreover, the limited testing conducted thus far provides no assurance that effluent exposure at any concentration and duration is benign for lobster, herring, rock crab or other species, at all life stages. Until comprehensive test results are available, such effects cannot be reliably assessed and the Minister will not be in a position to evaluate the risks of effluent exposure during the full life cycle of marine organisms.

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[64] Focus Report, Appendix 9.1, p. 2.
[65] NPNS EARD, January 2019, Appendix H, at p. 2.1.
[66] Ecometrix Report, p. 5.4,

79. FONS further states that the area within which the surveys were conducted appears to be relatively small, and was confined to the immediate area of the proposed pipeline corridor and diffuser location. It also appears that the Terms of Reference unduly narrowed the area in which baseline information was to be gathered. Even according to the Stantec predictions, diluted effluent will still be present in the wider area surrounding the immediate location of the diffuser. Consequently, appropriate baseline data should have been gathered beyond the pipeline corridor and diffuser location.

80. As well, the baseline data gathered represents only one point in time, and is not being conducted over a full year cycle. As effluent will be discharging year round, the full impacts of same cannot be measured against baseline data taken only in one small window of time.

81. Included with FONS March 8, 2019 was a commentary by Arthur MacKay.[67] Mr. MacKay is an experienced fisheries biologist and consultant.[68] He recommended that at least 12 monthly surveys should be conducted in order to establish a clear baseline.[69] While the Minister provided NPNS with ample time to gather significantly more baseline information, it is clear that no such comprehensive baseline has been established. No explanation is provided to explain the failure to use the allotted time to gather this crucial information.

82. FONS therefore submits that the requirement to gather baseline data in relation to the marine environment, fish and fish habitat has not been satisfied.

### 8. Herring Spawning, Fisheries and Mixing Zones

83. When responding to the original EARD, FONS[70] and many other groups and individuals raised a major concern regarding the impacts of NPNS's effluent discharge on herring spawning.[71] More specifically, the proposed outfall will discharge an average of 65,000,000 litres of treated effluent each day into one of the last remaining herring spawning grounds in the Southern Gulf

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[67] MacKay, A.A., *Northern Pulp's Effluent Disposal Plans – Issues and Answers*, February 2019 (MacKay report)(Appendix C-1)
[68] Art MacKay cv (Appendix C-1).
[69] MacKay report, p. 3 (Appendix C-1).
[70] FONS March 8, 2019 submission, at pp.
[71] Focus Report, Appendix 1.1 – Concordence [sic] Table [get references to comments]

of St. Lawrence.[72] The discharged effluent will contain Persistent Organic Pollutants, as discussed further below in relation to Dr. Cameron's report.

84. The Minister directed NPNS to respond to all comments raised by the public. The Concordence [sic] Table at Appendix 1.1 of the Focus Report package records many concerns being expressed about impacts to herring spawning. In virtually every case, NPNS's response to this concern is "[r]efer to section 7.3 for comments concerning the impact assessment of treated effluent on representative key marine fish species."

85. However, section 7.3 of the Focus Report makes no mention of herring spawning. Appendix 7.3, on which section 7.3 is based, refers only twice to herring spawning, and makes no attempt to assess impacts on spawning.[73] The reference to herring spawning appears in table 3-10 of Appendix 7.3.[74] The entry from table 3-10 relating to Atlantic Herring is set out below:

| **Occurrence** | **Group** | **Common Name** | **SARA** | **COSEWIC** | **Likely Occurrence in LAA*** | **Notes** | **CRA Fishery?** |
|---|---|---|---|---|---|---|---|
| Pelagic | Migratory | Atlantic Herring | No Status | No Status | High | Migratory and passing through the LAA to spawning areas, limited spawning habitat within the LAA | Yes |

86. Beyond this entry, and a virtually identical entry in Appendix D,[75] nothing in Appendix 7.3 or the Focus Report establishes where herring spawning takes place and how that relates to the outfall. The sparse information included in the table simply confirms the clear evidence from the fishers that NPNS proposes to place the outfall and the LAA inside a herring spawning area.

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72 FONS March 8, 2019 submission at Appendix B-1- Egilsson, G., and MacCarthy, A., Caribou Harbour and Caribou Channel - dynamics, tides, ice, marine species and fisheries, February 21, 2019 (Appendix B-1).
73 Focus Report Appendix 7.3.
74 Table 3-10: Potential Fin Fish Species in the RAA, Focus Report Appendix 7.3, p. 3.31. See also p. 3.33.
75 "Appendix D: Marine Fin-Fish Species Status, Occurrence, Habitat and Resource Use", Appendix 7.3, last page of table (pages not numbered).

87. An excerpt from a May 2018 DFO report states:

> Fall spawning occurs from mid-August to mid-October at depths of 5 to 20 m. Herring also show high spawning site fidelity. In recent years, the largest spring spawning areas are in the Northumberland Strait and Chaleur Bay and the largest fall spawning areas are in coastal waters off Miscou and Escuminac N.B., North Cape and Cape Bear P.E.I., **and Pictou, N.S**. When spawned, the eggs are attached to the sea floor.[76] [emphasis added]

88. The report also concludes that the estimated likelihood that the herring fall fishery will be in the "cautious zone in 2020" is 94%.[77] This is an indicator that the fishery is in decline and becoming vulnerable, consistent with the information provided by Greg Egilsson and Alan MacCarthy, both experienced herring fishers.[78]

89. As per FONS' submission dated March 8, 2019, NSE has stated that "mixing zones should not impinge upon…important fish spawning and/or fishing areas".[79] FONS's concern is noted at p 12 of 125 in the Concordence [sic] table at Appendix 1.1. NPNS' and its consultants respond by saying "refer to section 3.3 for comments concerning effluent discharge parameters". Section 3.3 says nothing about spawning and makes no attempt to explain how mixing zones can be situated within spawning areas or areas of active fisheries, despite the clear direction from NSE. In the same letter, NSE also states that persistent substances cannot be discharged in mixing zones, although we see that NPNs proposes to discharge a number of AOX substances.

90. A DFO report from 2016 makes clear that the Northumberland Strait supports many species which are fished commercially in the area. Ecometrix cites this report as "Rondeau et al. 2016".[80] The Rondeau 2016 report confirms evidence from fishers that intensive fishing for

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[76] DFO, Assessment of the Southern Gulf of St. Lawrence (NAFO Div 4T) Spring and Fall Spawner Components of Atlantic Herring (*clupea harengus)* with Advice for the 2018 and 2019 Fisheries, May 2018, Canadian Science Advisory Secretariat, Science Advisory Report 2018/029, at page 3 (DFO Herring Assessment May 2018).
[77] DFO Herring Assessment May 2018, at p. 28.
[78] FONS March 8, 2019 submission at Appendix B-1- Egilsson, G., and MacCarthy, A., Caribou Harbour and Caribou Channel - dynamics, tides, ice, marine species and fisheries, February 21, 2019 (Appendix B-1), at p. 3.
[79] FONS submission March 8, 2019, paras. 106-110 and Appendix H-6, Letter to the NPNS General Manager, from Nova Scotia Environment, Engineering Specialist, dated 14 June 2017, p. 1.
[80] The Report cited by Ecometrix is: Rondeau, A, et al. 2016 *Identification and Characterization of Important Areas based on Fish and Invertebrate Species in the Coastal Waters of the Southern Gulf of St. Lawrence,* Canadian Science Advisory Secretariat, 2016/044. It is attached to this submission at **Appendix D-4.**

lobster and herring, and other species, takes place in the area where NPNS wishes to discharge its pulp and paper effluent.

91. Via the Terms of Reference, the Minister directed NPNS to respond to public concerns about this project and to incorporate the comments in the Focus Report, where applicable.[81] The concern about the proposed position of the outfall is real and based in clear evidence from fishers.

92. NPNS and its consultants do not discuss or justify placement of a mixing zone in the middle of a spawning ground and active fishery. As stated in FONS' March 8, 2019 submission, NPNS and its consultants purport to rely on CCME and other guidance regarding mixing zones, but make no attempt to explain how the proposed ETF meets the preconditions for use of such a mixing zone.

93. The information provided in the Focus Report discussing active fisheries at or near the proposed outfall is biased, selective and unsupported. A map included in the Focus Report purports to depict lobster fishing in the vicinity of the outfall by counting density of "lobster buoy clusters". This is apparently based on 3 days of data, instead of one or more full seasons. No explanation is given as to what constitutes a "lobster buoy cluster", why data from only those dates was chosen for the map, or whether surveys were also conducted on other days. It appears designed to show that no lobster fishing takes place near the outfall, despite the direct evidence from fishers to the contrary. Likewise, the maps included in the Ecometrix report (Appendix 7.3),[82] and reproduced in the Focus Report, state that they show fishing areas of various commercial species. No source or raw data is provided to support the lines which purport to demark areas where fishing activity does or does not take place. There is no indication that the information comes from those who actually fish in those areas. Without seeing Ecometrix's sources and raw data the maps' accuracy cannot be assessed and must be viewed as unreliable. Further, the maps depict only a tiny area immediately around the outfall, despite the Stantec predictions of a much wider distribution of effluent at diluted

[81] Terms of Reference, paragraph 1.1.
[82] Focus Report, Appendix 7.3, pp 3.35-3.39.

concentrations along with sediment deposition as far away as 4.8 km from the outfall. No explanation is provided as to why the maps show only this very small area.

94. The Focus Report provides no assessment or discussion about herring spawning, and minimizes the active fisheries in the LAA and RAA. As stated in FONS' original submission, the mixing zone concept is not appropriate for the proposed outfall and ETF. It is being used to mask the fact that NPNS wishes to discharge 65,000,000 litres of treated effluent each day, which is likely to contain persistent and bioaccumulative substances such as dioxins, furans, cadmium and other harmful substances, into a vibrant ecosystem containing essential fish habitat, and an active fishery.

### 9. Toxic Substances - Dioxins and Furans

95. Test results produced as part of the Focus report show that the NPNS mill currently discharges effluent containing detectable amounts of certain dioxins and furans at Point C (into Boat Harbour Basin).[83] At table 1-12 of Appendix 2.3,[84] KSH summarizes those test results demonstrating that several dioxins, including TCDD (2,3,7,8-Tetra CDD)[85] and TCDF (2,3,7,8-Tetra CDF) are present in the effluent at Point C. These substances are toxic and bioaccumulative.

96. The KSH summary (in which the tables are included) concludes that Point C effluent "is an accurate representation of what the effluent from the new ETF will resemble."[86] If that is in fact accurate, then dioxins and furans will also be discharged at the proposed outfall in Caribou Channel.

97. Throughout the Focus report and Receiving Water Studies, NPNS and its consultants suggest that they must achieve compliance with discharges of dioxins and furans, and other problematic substances, within the mixing zone. This assumes that they are permitted to

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[83] Focus Report, Appendix 2.3, Table 1-12, page 32.
[84] Focus Report, Appendix 2.3, p. 32.
[85] TCDD is considered to be the most toxic of all dioxins and furans. See Health Canada handout
[86] Focus Report, p. 33; and Focus Report Appendix 2.3, p. 33.

discharge at exceedance levels at the diffuser, provided it dilutes to "background" within a certain distance. They purport to apply CCME guidance in this regard.

98. There is no CCME guidance as to permissible discharge of dioxins and furans. Discharge of such substances by pulp mills is governed by the *Pulp and Paper Mill Effluent Chlorinated Dioxins and Furans Regulations*,[87] made under the *Canadian Environmental Protection Act, 1999.*

Section 4 of those *Regulations* prohibits a pulp mill operator from releasing "measurable amounts" of TCDD and TCDF. It does not matter whether concentrations of these substances could be diluted after discharge into a "mixing zone" or whether the background conditions already show some concentration of such substances. If measurable amounts as defined by the *Regulations* are discharged at the diffuser, it would constitute a breach of section 4.

**Report of Dr. Lynn Cameron**

99. Dr. Lynn Cameron has provided commentary on the Focus Report detailing several significant risks associated with the proposed ETF project.[88] Dr. Cameron has a PhD in organic chemistry[89]. We submit Dr. Cameron's entire commentary to the Minister for consideration. The following summarizes only some highlights from that report.

100. Dr. Cameron states that the proposed treatment facility is unacceptable as it will not sufficiently remove substances within a grouping referred to as AOX (Adsorbable Organic Halides). Most AOX are toxic to marine and human health, and some are considered Persistent Organic Pollutants. AOX substances include dioxins, furans and PCBs.[90]

101. Dr. Cameron advises that the concentrations of AOX are likely to be higher than predicted by KSH (as depicted in the Focus Report at Figure 2.3-1). This is because Point C effluent has had about 8.5 days in the Boat Harbour Effluent Treatment Facility process to permit the

[87] *Pulp and Paper Mill Effluent Chlorinated Dioxins and Furans Regulations*, SOR/92-267.
[88] Dr. Lynn Cameron, *Comments on the Focus Report*, Nov. 8, 2019 **Appendix C-1 (**Cameron Commentary).
[89] Dr. Cameron's Resumé, **Appendix C-2**
[90] Cameron Commentary, 2d page.

heavier molecular weight AOX compounds to settle out. In contrast, the new ETF would allow for less than 13 hours settling time for such compounds.[91]

102. As well, the sampling referred to in the Focus Report, conducted to determine concentrations of AOX and other effluent constituents, was done using HDPE sampling bottles. As AOX adheres to HDPE (as well as to organic tissue and sediment), the actual amount of AOX in effluent would be expected to be higher had the appropriate glass bottles been used for sampling.

103. Dr. Cameron also identifies problems associated with effluent constituents nitrogen and phosphorous. Once again, she is concerned that these concentrations will be higher in the effluent coming from the new facility than those drawn from Point C effluent, as the 8.5 day settling time is a factor in reducing the concentrations at Point C. Nitrogen and phosphorous can cause areas of depleted oxygen or "dead zones" in marine environments. The algal blooms associated with these compounds produce toxins which cause health issues for marine life and human consumption of seafood.[92]

104. Consequently, based on Dr. Cameron's assessment, it can be concluded that the adverse effects and significant environmental effects of AOX, nitrogen and phosphorous concentrations in NPNS effluent have been underestimated by NPNS' consultants.

**10. Outstanding pipeline issues**

105. No automated leak detection system is proposed for the marine portions of the proposed pipeline.[93] There has been no explanation offered for this, nor any substantive response to any of the concerns expressed regarding serious impacts of spills due to leakage or pipe rupture within Caribou Harbour, or pipe ruptures or diffuser damage in Caribou Channel. No information is provided as to how pipe leaks, ruptures or malfunctions will be detected and addressed during storms, rough seas or in winter when ice covers the Strait and the pipeline route. The only response to any concerns expressed regarding leakage or rupture is that a

[91] Cameron Commentary, 2d page.
[92] Cameron Commentary, 3rd page.
[93] Focus Report, p. 62.

properly installed and maintained pipeline will be leak-free. Given the documented leaks over the years due to NPNS' failure to inspect and maintain its existing pipelines, this cannot be a satisfactory answer.

106. None of the precise routes to be followed by any segment of the pipeline have been determined. Regarding the land-based section of the pipeline from Pictou to Caribou, Nova Scotia Transportation and Infrastructure Renewal (TIR) says that it is "continuing to hold talks with Northern Pulp regarding a possible pipeline route."[94] Until certainty is achieved as to whether the TIR will allow the proposed pipeline, the project description cannot be viewed as complete since major changes to it would be required if a new route had to be proposed.

107. The precise route through the marine areas is also still unclear. Without a complete route which has been precisely defined via a detailed design, the impacts of this project cannot be described and assessed.

**11. Receiving environment – air quality**

108. The ETF proposal includes the burning of sludge generated from the effluent treatment. Via Terms of Reference paragraph 6.2, the Minister required NPNS to undertake Air Dispersion modelling for all potential contaminants of concern related to the project.

109. Dr. Elaine MacDonald, Senior Staff Scientist with Ecojustice has reviewed the Air Dispersion modelling report. Dr. MacDonald's written comments[95] and CV[96] are appended to this submission and are submitted in their entirety for the Minister's review within this EA and Focus Report process.

110. Dr. MacDonald concludes that the air quality analysis included with the Focus Report should be considered unreliable and incomplete. The input data is not site-specific and the chosen model is not appropriate for a coastal location with complex terrain. Transitional operating conditions such as unit start-ups and shutdowns when air emissions peak were not considered.

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[94] Focus Report, Appendix 2.1, letter of September 21, 2019 from TIR to General Manager, NPNS.
[95] Dr. Elaine MacDonald, Review of the Northern Pulp Nova Scotia Focus Report Section 6.0 and Appendix 6.2 Expanded Air Dispersion Modelling Study, FONS submission **Appendix B-1**
[96] CV of Dr. Elaine MacDonald, Ecojustice Senior Staff Scientist, **Appendix B-2**

Even if these limitations in modelling quality and methodology are ignored, the air dispersion modelling predicted exceedances of several air pollutant standards, including exceedances of cancer-causing substances benzo(a)pyrene and hexavalent chromium. The analysis also estimated that several residents would experience frequent and elevated concentrations of highly odorous reduced sulphur compounds, resulting in an unacceptable adverse impact on the community.[97]

111. As well, paragraph 6.3 required an updated air monitoring plan for the Project site based on the air dispersion modelling results. The plan must include the potential air contaminants to be monitored and proposed air monitoring location(s). However, as the air dispersion modelling exercise cannot be relied upon, and as the updated air monitoring plan provided by NPNS (section 6.3) does not include all of the contaminants for which exceedances are predicted (pp 113-114), paragraphs 6.2 and 6.3 of the Terms of Reference have not been satisfied and the environmental impacts cannot be evaluated.

## 12. Conclusion

112. In the Executive Summary of NPNS' Focus Report, the consultants advise of their prediction that, on all aspects of the project, there will be no "significant adverse residual environmental impacts".[98] This conclusion is not supportable and must be rejected, due to the evidence and material submitted within this EA and Focus Report process and referenced herein, as well as per the submissions of Pictou Landing First Nation, the fishing community and their associated organizations, the Town of Pictou, the Caribou Harbour Authority, the expert reports from qualified experts, and the vast amount of information provided others, including concerned residents and organizations within Pictou County and in other areas of Nova Scotia. FONS submits that the information and analysis provided to the Minister shows that adverse effects and non-mitigable unacceptable significant environmental effects <u>will</u> occur in respect of the ETF project.

[97] Dr. MacDonald Commentary, at p. 3 **Appendix B1.**
[98] Focus Report, Executive Summary, p. vi.

### 13. Decision Requested –ss 35(3)(d) and 40(c) of the *Environmental Assessment Act* and ss. 18(c) of the *Environmental Assessment Regulations*

113. This submission and the accompanying Appendices, as well as the information and evidence provided in FONS' previous submissions,[99] and the evidence, comments and concerns of Pictou Landing First Nation and many other participants in this EA and Focus Report process, have established that it is likely that the ETF project will cause adverse effects and/or significant environmental effects that are unacceptable and cannot be mitigated. FONS therefore requests that the Minister reject the proposed undertaking pursuant to subsection 35(3)(d) of the *Environment Act* and subsection 18(c) of the *Environmental Assessment Regulations.*

114. The Decision requested above is without prejudice to the following relief which is requested in the alternative:

(a) that the Minister recuse himself from any and all decisions in relation to the ETF project as his involvement creates a reasonable apprehension of bias that invalidates the EA process;

and,

(b) that the Minister, or alternatively the decision-maker appointed following the Minister's recusal, take all necessary steps to remedy the procedural defects that have fundamentally compromised the fairness and integrity of the process before any final decisions are made regarding the ETF project. This includes making all of the missing documents from the Focus Report available for public review, and providing an appropriate period of time for both the public and the Administrator to comment on the additional documents pursuant to ss 16(2) and 17(2) of the *EA Regs.*

115. Further and in any event of the above, FONS requests that it be provided with a written statement of the decision rendered after review of the Focus Report in respect of the EA of the

[99] See footnote 3 above.

ETF project, setting out the findings of fact upon which it is based and the reasons for the decision, pursuant to subsection 10(4) of the *Environment Act.*

Dated November 8, 2019, at Halifax Nova Scotia.

James Gunvaldsen Klaassen
Barrister and Solicitor

Sarah McDonald
Barrister and Solicitor

## APPENDICES

# APPENDIX A-1

Review of updated modeling studies by Stantec Consulting for the Northern Pulp effluent treatment facility replacement project

Prepared by:
Oliver Fringer, Ph.D.
San Francisco, CA, USA

November 5, 2019



## 1. Executive summary

Stantec, Ltd., conducted an updated receiving water study to assess the near- and far-field mixing and dilution of effluent discharged from the proposed outfall at site CH-B. They also conducted a study to assess the transport of suspended particulate matter from the outfall. For the reasons enumerated below, these studies are flawed and provide no evidence that the environmental impact of the outfall will be minimal:

1) Although additional measurements were made in the vicinity of site CH-B to justify the use of a two-dimensional model, the measurements indicate exactly the opposite because they show strong density effects that can only be simulated with a three-dimensional model. Three-dimensional currents can transport effluent in a direction that is opposite to that of the two-dimensional currents, and thus the two-dimensional far-field results are meaningless.

2) The two-dimensional MIKE 21 model does not accurately predict the observed currents, and hence we can have no confidence in its ability to simulate the far-field effluent dilution, even if the flow were two-dimensional. Although the simulated temperature matches observations, this is misleading because the temperature has no bearing on the computed currents. Similarly, a wave model accurately predicts the surface, wind-generated waves when compared to the measurements, yet no assessment as to their impact on the effluent dilution

is discussed.

3) The winter scenario models ice cover simply by removing winds and waves, yet ice cover should be modeled with reduced tidal currents at the model boundaries and higher friction at the free surface. Improper ice modeling leads to an overprediction of the near- and far-field dilution.

4) Plots of far-field effluent concentrations around site CH-B are misleading: the two-dimensional MIKE 21 model overestimates the dilution by assuming complete mixing over the water column. These plots are used to show that there is no buildup in Caribou Harbour[1], although there is clear buildup that could easily be quantified with the model.

5) The updated near-field modeling using CORMIX overpredicts the near-field dilution by a factor of 3.5 because it assumes the receiving waters are too dense. Factoring in the correct receiving water density gives a dilution factor of just 42 at the edge of the 100-m mixing zone. This dilution factor is expected to be even lower when taking into account the effects of vertical density stratification, weaker slack currents during neap tides, and receiving water densities that should be at their lowest during late summer/early fall.

6) The sediment transport study is fundamentally flawed because it ignores the effect of flocculation which will cause the fine suspended particulate matter to settle much faster and deposit in the vicinity of the outfall. The sediment transport study is also overly simplistic and does not assess the potential for fine particulate matter to accumulate in Caribou Harbour or in other ecologically sensitive sites in the region.

Stantec also conducted a study to simulate the far-field dilution of effluent discharged from the Boat Harbour weir. The results are inaccurate and cannot be trusted because (1) the hydrodynamic model is based on the poorly validated model used in the original study and (2) the buoyant surface plume emanating from Boat Harbour is highly three-dimensional and cannot be simulated with a two-dimensional model like MIKE 21.

## 2. Introduction

In this report I evaluate modeling studies conducted by Stantec Consulting, Ltd., as part of the Focus Report for the Replacement Effluent Treatment Facility Project for environmental assessment, that was submitted by Northern Pulp Nova Scotia on October 2, 2019. I review the following three components of the report:

1) Appendix 4.2: Far-field Dispersion Modelling of Treated Effluent Discharge at the Existing Weir in Boat Harbour, Pictou, Nova Scotia.
2) Appendix 4.2: Northern Pulp Effluent Treatment Facility Replacement Project: Updated Receiving Water Study, Caribou, Nova Scotia.
3) Appendix 4.3: Estimate of Sediment Transport of the NPNS treated effluent.

These three reports will be referred to as (1) The Boat Harbour study, (2) the updated receiving water study or just the updated study, and (3) the sediment transport study.

[1] In this report, Caribou Harbour refers to the semi-enclosed shallow water body with a mouth defined by the opening between Caribou Point to the north and Munroes Island to the south.

This review references my review of the original receiving water study (the Original Study) conducted by Stantec Consulting, Ltd. In the Original Study, the MIKE 21 hydrodynamic model was used to simulate the far-field transport and dilution of effluent discharged from the proposed CH-B location. The CORMIX near-field model was used to compute the dilution within 100 m of the outfall due to turbulence and mixing of the buoyant effluent. The Boat Harbour and updated studies I review in this report use the same models and setup as the Original Study.

→ *The updated study includes a wave model to compute the wind-generated waves around site CH-B. This model computes both wind-generated waves and remote swell waves, although swell is not included in the updated study.*

The primary differences between the Original Study and the updated study are the additional validation of temperature, currents, and surface wave heights at site CH-B. To compute the waves, the updated study includes a wave module that computes the distribution of surface waves driven by winds in the region. This wave module is needed to compute the surface waves because wind-generated surface waves have wavelengths less than 50 m and periods less than 5 s. These spatial scales are not resolved by the computational grid and must be modeled with what is referred to as a spectral wave model. Instead of modeling individual waves as they are generated and propagate on the free surface, which would require a three-dimensional grid with thousands to millions more grid cells, spectral wave models compute the energy of waves at different frequencies and directions in each computational cell. This gives a measure of the average wave height (the significant wave height, or the average height of the largest 1/3 of the waves) in each grid cell in response to winds, breaking, refraction and diffraction by bathymetry, and currents computed by the hydrodynamic model. The effect of waves is also fed back into the hydrodynamic model to drive currents. Such currents are strongest on beaches where waves break and drive alongshore flows. Although the spectral wave model can compute the evolution of both locally wind-generated and remotely-generated swell waves, swell waves are not considered in the updated study.

→ *New measurements of currents were obtained with an ADCP, an instrument that measures currents using sound waves in the water. New measurements of salinity and temperature were also obtained.*

Stantec conducted additional field surveys to measure currents, salinity, and temperature in the vicinity of site CH-B. Profiles, or measurements at different depths below the surface, of temperature and salinity were measured to assess their vertical variability. Currents were measured with an ADCP, or acoustic Doppler current profiler, which uses sound waves to measure the current magnitude and direction at different depths, and is a very common instrument used in oceanography. The ADCP was mounted to a boat that was driven back and forth to measure transects of currents as a function of depth and horizontal position around site CH-B. Such measurements are useful for assessing the vertical and horizontal variability of currents at different snapshots in time, for example during flood and ebb tides. The ADCP was also mounted to a bottom mooring to measure currents as a function of depth and time near CH-B. These moored measurements are useful to understand the variability of currents over a tidal cycle at a fixed location in space. The ADCP also measures water levels which can be used to validate the tidal water levels computed by the hydrodynamic model and the wave heights computed by the spectral wave model.

## 3. Review of the far-field modeling of the discharge from the Boat Harbour weir

*The far-field modeling of discharge from the Boat Harbour weir is inaccurate and cannot be trusted because (1) the hydrodynamic model is based on the poorly validated model used in the Original Study and (2) the buoyant surface plume emanating from Boat Harbour is highly three-dimensional and cannot be simulated with a two-dimensional model like MIKE 21.*

Stantec used the MIKE 21 model setup from the Original Study to simulate far-field transport of effluent from the Boat Harbour weir during the month of July 2016. The MIKE 21 model setup was identical to that in the Original Study except for the location of the outfall source: instead of being located at one of the proposed outfall sites, it was located at the location of the Boat Harbour weir. The advantage of models like MIKE 21 is that they do not distinguish between an effluent source on the bed and one at a shoreline model boundary. Both are identical in that they are simply a source of effluent into one of the model grid cells.

→ *The plume emanating from the Boat Harbour weir is confined to the surface and cannot be simulated with a three-dimensional model.*

Since this model setup is identical to that in the Original Study, all of the criticisms I made in my review of that study are applicable to the Boat Harbour study. ***The Boat Harbour study is perhaps the best possible example of a problem that should NOT be studied with a two-dimensional model like MIKE 21.*** Based on the parameters indicated in the study, the effluent is roughly 20 $kg/m^3$ less dense than the receiving waters. Therefore, the effluent discharged from Boat Harbour remains confined to a thin, near-surface layer as it flows into Pictou Harbour. Owing to the rotation of the earth, the plume turns to the right of Boat Harbour and propagates along the shoreline to the east and south. Because the plume is confined to the surface and arises as a direct result of three-dimensional, density-driven processes, it cannot be simulated with the MIKE 21 model. Nevertheless, owing to the inclusion of the earth's rotation in the MIKE 21 model, the results still indicate transport to the right of Boat Harbour (e.g. Figure 13 in the Boat Harbour study), albeit in a vertically well-mixed plume. I note that none of the results in the Boat Harbour study are validated beyond the substandard validation performed in the Original Study.

→ *Weak currents at the Boat Harbour weir lead to weak mixing and high effluent concentrations. These are underpredicted by the MIKE 21 model because it assumes complete mixing over the water column.*

It is no surprise that the far-field effluent transport simulated with the MIKE 21 model does not disperse very efficiently as it emanates from Boat Harbour, leading to effluent concentrations that are much higher than those in the original and updated studies of effluent discharged from site CH-B. Because the two-dimensional MIKE 21 model assumes complete and instantaneous mixing over the water column, these results emphasize the point I made in my original review about how the concentrations and dilution factors are a strong function of the depth. In a two-dimensional model, we expect at least a factor of 8 or greater dilution at site CH-B than we do at the Boat Harbour weir simply because the weir has a depth of 2.5 m (based on Figure 2 in the Boat Harbour study) while site CH-B has a depth of 20 m. Further lack of dilution occurs at the Boat Harbour weir because of the weak currents in the shallow waters near the weir. The two-dimensional nature of the MIKE 21 model actually overpredicts the dilution, since the effluent should remain trapped in a high-concentration buoyant surface layer with limited vertical mixing owing to the strong effects of stratification (Discussed in Section 4.1 below).

## 4. Review of the updated receiving water study offshore of Caribou Harbour

### *4.1. Two- vs. three-dimensional modeling*

*In the updated study, Stantec collected field data in the vicinity of the proposed outfall location which they use to further justify the use of a two-dimensional model. This field data demonstrates exactly the opposite, in that there are strong three-dimensional currents that can transport effluent in a direction that is opposite to that in a two-dimensional model. Such transport can lead to more buildup of effluent in, for example, Caribou Harbour.*

In the updated study, Stantec used the ADCP to measure currents in two ways:

1) The ADCP was mounted to a boat and the boat was driven back and forth across a transect line stretching from the mouth of Caribou Harbour through site CH-B. The measurements extended 1.2 km on either side of site CH-B and were taken during the flood tide on May 24, 2019, and ebb tide during May 25, 2019. These data are shown in Figures 7-10 in the updated study.
2) The ADCP was attached to a fixed mooring on the bed 490 m northwest of site CH-B and measured currents as a function of depth and time during June 17-19, 2019. These data are shown in Figure 11 in the updated study. The ADCP also has a pressure sensor that measures water level as a function of time to calculate tidal water levels and wave heights. The wave-height data are shown in Figure 19.

In addition to the ADCP data, measurements of temperature and salinity over the depth were obtained near CH-B during flood and ebb tides on May 24 and 25, 2019. These data are shown in Figures 13 and 14 of the update study.

→ *The ADCP boat transect data are too noisy to justify that the currents do not vary with depth.*

In the updated study, Stantec justifies use of a two-dimensional model by noting that the velocity profiles from the ADCP data indicate “weak stratification from near the water surface to the seabed” and that “temperature and salinity were relatively homogeneous throughout the water column, ranging from 12.6$^{o}$C to 12.9$^{o}$C and 28.8 to 29.0 ppt, respectively”. Indeed, the ADCP transect data show weak vertical variability, although these data are very noisy and cannot be trusted to infer vertical variability of currents. Furthermore, the transects reflect the velocity field at an instant in time, and thus do not reveal the potential for three-dimensionality over the entire tidal cycle. This is precisely the purpose of the moored ADCP data which very clearly indicate vertical variability in the currents that is consistent with strong density effects, as discussed below.

→ *The ADCP mooring data very clearly show the presence of three-dimensional, density driven currents that cannot be simulated with the two-dimensional MIKE 21 model.*

Figure 1 below shows how the moored ADCP data nicely captures the variability of the currents with depth and time over several tidal cycles. In the absence of density effects, the tides drive currents that are strongest near the surface and weakest near the bed where they are impeded by friction. This gives the "expected" velocity profiles that occur during flood tides indicated by the sketch in Figure 1. During the ebb tides, however, there is a peak in the velocity profile at a depth of 15 m instead of the surface. ***The only mechanism that can drive currents at this depth arises from horizontal differences in density between water masses in the region.*** Unfortunately, the ADCP boat transects were taken at times that did not coincide with the ADCP mooring observations nor were the transects taken at different phases of the tidal cycle to reveal the source of the vertical variability in currents during ebb tides. Furthermore, salinity and temperature were not measured at sufficient points in time and space needed to obtain a complete picture of the density effects over a tidal cycle or over the course of the year (i.e. during winter ice cover or during late summer/early fall when runoff is highest). Therefore, while the measurements clearly indicate the presence of density-driven currents, there is insufficient data to ascertain the source of the density-driven circulation. Regardless, these data strongly indicate that MIKE 21 is not an appropriate tool to model the three-dimensional circulation in this region. Three-dimensional currents can transport effluent in a direction that is opposite to that in a two-dimensional model and lead to more buildup in, for example, Caribou Harbour.

*4.2.Model validation*

*The validation of the far-field model with additional data indicates that the model performs poorly and cannot be trusted to assess far-field dilution of the effluent. The validation of temperature is misleading because it implies inclusion of density effects, yet these have no bearing on the two-dimensional MIKE 21 model.*

→ *There is no quantitative validation of the MIKE 21 model to indicate that it performs well.*

Like the Original Study, in the updated study Stantec included validation of currents and water level, but with new data from the moored ADCP near site CH-B. Stantec added validation of wind-generated waves and water temperature that were also measured with the moored ADCP. The validation is conducted for a simulation during May 26-June 26, 2019. As I noted in my review of the Original Study, no quantitative metrics that are well established in the coastal modeling community are computed, and only qualitative comparisons are made. Despite the addition of new data for validation, the validation is poor and provides no confidence that the model is accurately reproducing the far-field dynamics in the region.

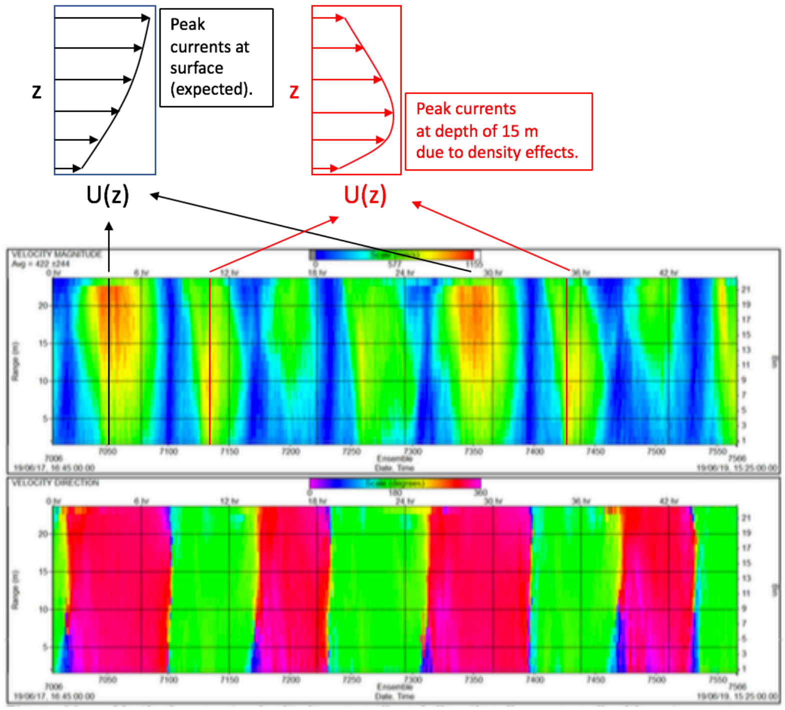


*Figure 1: ADCP mooring data from Figure 11 in the updated study. The top panel shows current magnitude while the bottom panel shows current direction. The sketches illustrate velocity profiles that produce the observed ADCP data.*

→ *The MIKE 21 model does not accurately predict the tidal water levels or currents. The three-dimensional nature of the density-driven currents explains in part the failure of the two-dimensional model to predict them.*

The simulated water levels in Figure 20 of the updated study appear to match the observations, but closer inspection reveals that the model fails to predict the full tidal range for most of the tides, particularly after June 9. Similarly, the simulated currents appear to match the observations, but closer inspection reveals that the strength of the currents only qualitatively matches the growth and decay over the spring-neap cycle. The peak magnitudes of the simulated currents only match a small fraction of the observed peaks, while the model over- or under-predicts a majority of the peaks by 25-100%. Stantec explains these errors by noting that the ADCP-derived observations are depth-averaged, while the model is two-dimensional. This is not correct, because a two-dimensional model should reproduce the depth-averaged currents if they arise from two-dimensional processes. However, as explained in Section 4.1 of this report, the processes in the region are highly three-dimensional, making it impossible for the two-dimensional MIKE 21 model to reproduce them. The substantial errors between the simulated and observed currents are not reflected by the metrics in Table 10 of the updated report because these metrics tend to obscure errors incurred during individual tidal cycles. As I discussed in my review of the Original Study, a better representation of the error is obtained with metrics like the root-mean-square error or skill score, which would show that the model performs poorly.

→ *Surface wind-generated waves are validated, yet there is no discussion of how they affect the currents. Temperature is also validated, but temperature has no bearing on the results because the model is two-dimensional.*

The addition of a wave model to simulate wind-generated waves in the updated study was validated with observations at the moored ADCP in Figure 19 of the updated report. While the simulated waves appear to match the observed waves, they have no bearing on the observed currents and no discussion is made as to the relevance of the waves to the characteristics of the far-field dispersion. Similarly, the temperature is validated via comparison of simulated to observed temperature at the moored ADCP in Figure 22 of the updated report. As discussed in Section 4.3, because the temperature field has no effect on the two-dimensional currents, validation of the temperature field as predicted by the two-dimensional MIKE 21 model is irrelevant. Furthermore, it is odd that the salinity field is not validated given that the salinity has a much stronger effect on the density than the temperature.

*4.3.Model setup and scenarios*

*The updated report is misleading because there is extensive discussion of temperature and salinity modeling, yet these play no role in the circulation of the two-dimensional MIKE 21 model. Furthermore, simply removing winds and waves to account for ice cover does not correctly account for the more significant reduction in currents that is expected during winter.*

→ *The two-dimensional MIKE 21 model in the updated study only has the ability to predict two-dimensional tidally-driven currents. It cannot predict the effects of temperature or salinity since these only affect the three-dimensional dynamics.*

On p 2.19 of the updated study, it is noted that "A coupled hydrodynamic model was developed to simulate the physical oceanographic conditions under the complex forcings of tide, current, wind, wave, air heat, and water temperature and salinity." As discussed in my review of the Original Study, the updated study only demonstrates the ability to simulate the effects of tidal currents in the region. Winds and waves can impact the circulation, and while wave heights are validated in the updated study, their effects on the currents are not validated or discussed. Although there is extensive discussion of details related to modeling the effects of air, heat and water temperature and salinity, this is misleading because the temperature and salinity fields have little to no effect on the currents predicted by the MIKE 21 model because it is two dimensional. Density dynamics can only be computed with a three-dimensional model like MIKE 3. Furthermore, it is very difficult if not impossible to correctly predict temperature and salinity dynamics in a two-dimensional model because these quantities vary strongly in the vertical, as clearly indicated by the temperature and salinity profiles in Figures 13 and 14 of the updated study (also Figure 3 below). It is also difficult to model temperature and salinity because these quantities require a lot more data than indicated in the updated report, which only mentions use of air temperature and humidity but does not say anything about other important quantities like incoming solar radiation, cloud cover, optical clarity, and evapotranspiration. Given that these details were not mentioned, it is likely that the parameters needed to compute the temperature field in the model were simply tuned to obtain a match to the observations. Predictions of salinity are also very sensitive to freshwater inflows, yet these are not mentioned in the updated study, nor is the model-predicted salinity validated.

→ *The winter scenario does not correctly account for the effects of ice cover which should act to reduce the effects of the tidal currents and the associated mixing and dilution.*

To assess the effects of winter ice cover, a scenario is devised to simulate far-field dispersion during February 2019. The effects of ice cover are modeled by eliminating waves, winds, and air heat exchange. A constant ice sheet thickness of 0.7 m was assumed based on observations, yet it is unclear how this was exactly implemented in the MIKE 21 model. Was the mean water level lowered by 0.7 m, or was the depth data raised by 0.7 m? Nevertheless, as discussed in my review of the Original Study, the scenario simulates absolutely no physical mechanisms that one would expect to occur in the presence of ice. There is no added friction by the ice cover which would reduce the magnitude of the tidal currents, and the strength of the tides at the boundaries is not reduced as it should be when there is large-scale ice cover in the Northumberland Strait during winter. The result is a "winter" scenario that simply evaluates the effect of the tides in February. Given the inaccuracy of the results as indicated by the validation, elimination of winds and wave effects in this scenario is meaningless because their effects are smaller than the overall errors in the modeled currents.

*4.4.Analysis of model results*

*The plots of effluent concentrations are misleading because the two-dimensional MIKE 21 model overestimates the dilution by assuming complete mixing over the water column. These plots are used to show that there is no buildup in Caribou Harbour, although there is clear buildup that could easily be quantified with the model.*

→ *Far-field dilution results cannot be trusted because they are overpredicted by the two-dimensional model.*

As in the Original Study, the far-field dilution results in the updated study are misleading because they assume complete mixing over the water column. This gives an instantaneous dilution of roughly 100 at the location of the outfall that is a strong function of its depth. This instantaneous dilution would be significantly reduced in a three-dimensional model that included the effects of stratification in the region, as discussed in Section 4.5.

→ *It would be straightforward to show that there is effluent buildup in Caribou Harbour.*

It is noted that "no effluent concentration buildup was found in the harbour basins, along the shorelines and in the entire model domain." There is no scientific justification for this statement. Not only do the figures show buildup of effluent along the shorelines and signatures of effluent entering Caribou Harbour, but it is straightforward to compute the exact amount of effluent entering the harbour with the MIKE 21 model. Such a calculation would quantitatively assess the rate at which effluent enters the harbour under different conditions, yet this is ignored in favor of misleading plots of effluent concentrations at the end of the one-month simulations.

*4.5.Near-field modeling*

*The updated near-field modeling using CORMIX overpredicts the near-field dilution factor by at least 3.5 because it assumes the receiving water is too dense, implying that the dilution factor 100 m from the outfall should be at most 42 instead of the worst-case value of 145.7 in the updated study. The true worst-case dilution scenario is expected to be even lower when accounting for the effects of vertical density stratification, weaker neap tidal currents, and a receiving water density that is at its lowest in late summer/early fall.*

→ *The currents used in the updated study are stronger than they should be and hence they overpredict the mixing. The salinity in the updated study is too high and also overpredicts the effluent buoyancy and associated mixing.*

As in the Original Study, the near-field modeling with CORMIX gives near-field dilution results using parameters that do not reflect the possible worst-case scenarios. Table 1 compares values used in Scenario 2 of the Original Study and Scenarios A, B, and C of the updated study. The main parameters that differ between the original and updated studies are:

1) The updated study employs cases with weaker slack tidal currents (Scenarios B, C)
2) The updated study employs a denser receiving water for all cases
3) The updated study employs a less dense effluent for all cases
4) The updated study includes a case with a lower effluent flow rate (Scenario C)

The CORMIX results in the updated study show that, when compared to dilution with average currents, weaker slack currents reduce the near-field dilution factor from 113.5 to 33.0 at a distance of 2.0 m from the diffuser (Scenario A vs. Scenario B in Table 2 below). In this regard, the use of slack tidal currents represents a more realistic scenario in which dilution is significantly weaker in the presence of slack tides. However, these slack tidal currents still do not represent the worst-case scenario in which the slack tidal currents are even weaker during a neap tide. Furthermore, the updated study uses an ambient receiving water salinity of 30 ppt as opposed to 28 ppt as in the Original Study. It also assumes an effluent salinity of 2 ppt, 50% lower than the value of 4 ppt used in the Original Study (No justification for the lower effluent salinity is provided). This leads to an effluent that is 28.2 $kg/m^3$ less dense than the receiving waters in the updated study, significantly more than the value of 23.7 $kg/m^3$ used in the Original Study. As a result, the mixing induced by the effluent buoyancy in the Original Study is weaker, leading to a dilution of 32.4 at a distance of 2.0 m from the diffuser, roughly the same as Scenario B in the updated study which has a lower dilution factor than Scenario A due to the slack tidal currents (See Table 2 below).

→ *The receiving water density is expected to be at its minimum, giving the worst-case scenario for buoyancy-driven effluent mixing, in late summer/early fall when waters are warmest and salinity is lowest.*

Unlike temperature, Stantec did not conduct a historical analysis of salinity in the updated study that can be used to estimate the minimum receiving water salinity at the outfall. However, the salinity profiles in Figure 14 of the updated study (and Figure 3 below) indicate a minimum salinity closer to 29.25 ppt (0.75 ppt lower than the assumed value of 30 ppt), a value that is expected to decrease as precipitation and the associated runoff in the region increase to their maximum in September, as shown in Figure 2 below. As indicated by the temperature data in Figure 16 of the updated study, the decreased salinity of the receiving waters is accompanied by an increase in temperature that peaks at a maximum of 20$^{o}$C in August, further decreasing the density of the receiving waters beyond the scenarios in the updated study, which assume a receiving water temperature of 16.8$^{o}$C. Therefore, the worst-case scenario should employ slack neap tides and receiving water density values that are at their lowest in the late summer/early fall.

→ *The vertical variations in density are strong enough to decrease or eliminate vertical mixing, yet this effect is not accounted for in the CORMIX modeling.*

In addition to using parameters that do not reflect worst-case scenarios for the near-field effluent mixing, the updated near-field CORMIX studies also do not include the effects of vertical density stratification, even though the ADCP, salinity, and temperature data discussed in Section 4.1 clearly show that vertical stratification effects are important. In Figure 3 below I show salinity and temperature profiles taken from Figures 13 and 14 in the updated study. These data show that the top-bottom temperature and salinity differences are roughly 0.3$^{0}$C and 0.4 ppt, respectively, which translates to a top-bottom density difference of 0.4 kg/m$^3$. While these may seem small, an assertion employed by Stantec to justify ignoring vertical stratification effects, the CORMIX manual suggests including stratification effects when the vertical variation in density exceeds 0.1 kg/m$^3$ (Page 33 of Jirka et al. 1996).

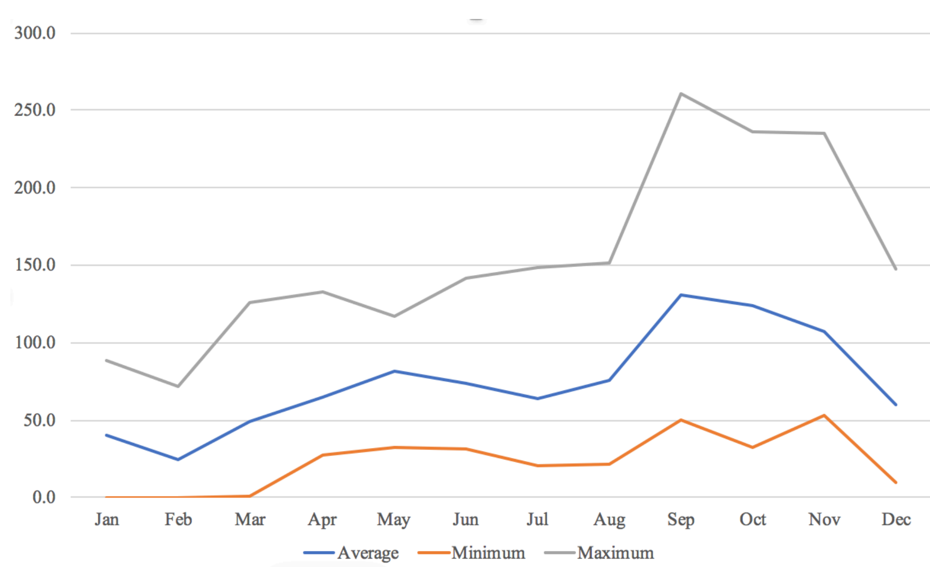


*Figure 2: Monthly-averaged precipitation in mm during 1994-2005 in Tatamagouche[3], Nova Scotia (data from climate.weather.gc.ca).*

[3] There is insufficient monthly precipitation data at the nearby Caribou Point station, so Tatamagouche was used as a representative station which reflects the precipitation patterns at Caribou Point.

| | Original Study | Updated study |
|---|---|---|
| Avg depth in mixing zone (m) | 18.0 | 18.9 |
| Depth at outfall (m) | 20 | 20.3 |
| Avg slack currents (m/s) | - | 0.10 |
| Max currents (m/s) | 0.27 | 0.85 |
| Mean currents (m/s) | 0.10 | 0.41 |
| Avg winds (m/s) | 3.75 | 3.79 |
| Ambient temperature (ºC) | 17.6 | 16.8 |
| Ambient salinity (ppt) | 28.0 | 30.0 |
| Ambient density ($m^3/s$) | 1020.06 | 1021.76 |
| Effluent temperature (ºC) | 37.0 | 37 (Scenario A)<br>35 (Scenarios B+C) |
| Effluent salinity (ppt) | 4.0 | 2.0 |
| Effluent density ($kg/m^3$) | 996.32 | 993.36 (Scenario A)<br>993.55 (Scenarios B+C)[4] |
| Difference between receiving water and effluent density ($kg/m^3$) | 23.74 | 28.4 (Scenario A)<br>28.2 (Scenarios B+C) |
| Wastewater flow rate ($m^3/s$) | 0.980 | 0.984 (Scenarios A+B)<br>0.579 (Scenario C) |

*Table 1: Comparison of CORMIX values used in Scenario 2 of the Original Study and Scenarios A, B, and C of the updated study.*

| Scenario | Distance from Diffuser (in m) and Dilution Factor | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 50 | 100 | 200 |
| Updated Scenario A | 113.5 | 178.6 | 251.6 | 353.8 | 407.5 | 427.2 | 454.3 |
| Updated Scenario B | 33.0 | 51.4 | 71.8 | 100.1 | 129.9 | 145.7 | 164.1 |
| Updated Scenario C | 50.1 | 78.3 | 109.6 | 152.8 | 195.6 | 219.0 | 247.9 |
| Original Scenario 2 | 32.4 | 50.5 | 70.8 | 99.1 | 128.3 | 144.1 | 159.8 |

*Table 2: Comparison of dilution results from Scenarios A, B, and C in the updated study to those from Scenario 2 in the Original Study.*

[4] The density of 955.55 $kg/m^3$ is unreasonably small in the updated report, likely a typo. Here I assume it to be 993.55 $kg/m^3$, slightly more dense than Scenario A due to the colder temperature by 2ºC.

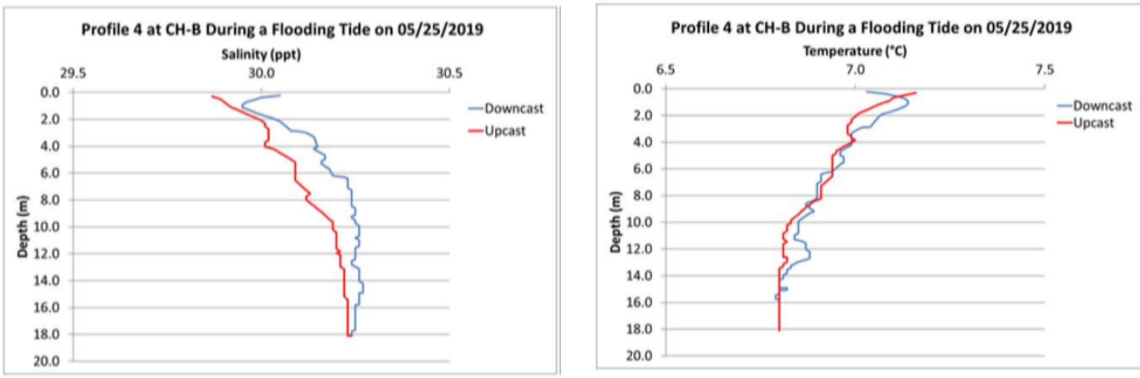


*Figure 3: Vertical profiles of salinity (left) and temperature (right) taken from Figures 13 and 14 in the updated study. "Downcast" implies measurements taken with the instrument as it sinks downward, while "upcast" implies measurements taken as the instrument is raised to the surface.*

→ *Theory can be used to show that the vertical density stratification in the region reduces effluent mixing and dilution.*

The potential effects of stratification on the near-field mixing can be assessed by noting that mixing occurs because of turbulence driven by differences in the horizontal velocity with depth: a large change in the velocity in the vertical is likely to produce strong turbulence and mixing. This explains why turbulence and mixing are strongest near the free-surface and bed, since these are locations where the vertical changes in velocity strong. At the same time, however, vertical density stratification damps the turbulence and mixing by creating layers of different densities that stabilize the water column, making it harder for layers to mix. The strength of the damping effect of the stratification relative to the potential to generate turbulence by the currents is given by the gradient Richardson number, which is defined by

$$Ri_g = \frac{g\Delta\rho D}{\rho_0(\Delta \mathrm{U})^2}.$$

The different terms in this equation and the source of data from which values were approximated are shown in Table 3. Using these values, the gradient Richardson number around location CH-B is roughly $Ri_g = 0.31$, which is a lower bound given that this value is estimated during a period in which the bottom-top difference in currents ($\Delta$U) is large. It is well known that, when the gradient Richardson number is larger than 0.25, the damping effect of stratification is so strong that it all but eliminates mixing. This suggests that the mixing and dilution will be substantially reduced by the vertical stratification, an effect that is ignored in the near-field CORMIX modeling. It also suggests that the far-field effluent transport is likely to be confined to shallow vertical layers and not mix over the water column, further justifying the use of a three-dimensional far-field model. The resulting dilution factors are thus significantly overpredicted in both the near- and far-field modeling in the updated study.

→ *When accounting for the correct lower receiving water density in addition to slack tidal currents, the dilution factor 100 m from the outfall should be at most 42, which is 3.5 times lower than the value of 145.7 in the updated study. This dilution factor will be further reduced when accounting for vertical density stratification, slack water during neap tides, and the lowest receiving water densities during late summer/early fall.*

The data from the original and updated near-field studies in Table 2 show that the effect of using slack tides reduces the dilution by a factor of 3.4 (Updated Scenario A dilution of 113.5 compared to Updated Scenario B dilution of 33.0, both 2 m from the outfall). However, the Original Study essentially shows that the effect of less buoyancy-driven mixing when the receiving water is less dense is also to reduce the dilution by a factor of 3.5 (Updated Scenario A dilution of 113.5 compared to Original Scenario 2 dilution of 32.4). This suggests that the combined effects of both slack tides and reduced buoyancy of the effluent can reduce the dilution factor from that in Scenario A of 113.5 by a factor of 11.9 (3.5×3.4) to just 9.5. The dilution factor 100 m from the outfall will thus be closer to 42 instead of 145.7 (based on the dilution in Scenario B at 100 m of 145.7, reduced by 3.5 due to decreased buoyancy). This dilution of 42 is likely an upper bound, since neap slack tides are weaker and the receiving water density is expected to be even lower during late summer/early fall. The reduction of vertical mixing due to density stratification will reduce the dilution factor even further. The result is that the near-field effluent concentrations will be in excess of the estimates in the updated study by at least a factor of 3.5, thus making it unlikely that many of the CCME water quality guidelines will be met in the mixing zone for the true, worst-case scenario.

| Variable | Name/description | value | Source |
|---|---|---|---|
| $D$ | Approximate water depth at ADCP mooring. | 20 m | ADCP mooring; Figure 1. |
| $g$ | Gravitational acceleration. | 9.81 m/s$^2$ | Known constant. |
| $\Delta\rho$ | Bottom-top density difference. | 0.4 kg/m$^3$ | Salinity and temperature profiles; Figure 3. |
| $\Delta U$ | Bottom-top difference in currents. | 0.5 m/s | ADCP mooring; Figure 1. |
| $\rho_0$ | Reference density (average density of profile). | 1023.6 kg/m$^3$ | Salinity and temperature profiles; Figure 3. |

*Table 3: Variables used to estimate the gradient Richardson number, $Ri_g$.*

## 5. Review of the sediment transport modeling

*The sediment transport study is fundamentally flawed because it ignores the effect of flocculation which will cause the fine suspended particulate matter to settle much faster and deposit in the vicinity of the outfall. Furthermore, it is much too simplistic and does not accurately reflect where we expect the fine particulate matter to accrete in the region – such an assessment should be made with the sediment transport modules that are part of the MIKE modeling software.*

→ *The distance from the outfall at which fine particulate matter settles can be estimated based on the distance it travels due to the tidal currents over the time it takes to settle onto the bed.*

Stantec, Ltd., analyzed samples of suspended particulate matter, or "sediment", from treated effluent similar to what is expected at the proposed outfall. To estimate the distance at which the sediment is expected to settle onto the bed after ejected from the outfall, Stantec assumed that the particles will settle from some height above the outfall while transported horizontally by the ambient currents. The distance they will travel is proportional to the time it takes for them to settle onto the bed while they are transported horizontally. Since a sediment sample consists of a distribution of particle sizes, it is common to refer to the 50$^{th}$ or 90$^{th}$ percentile particle diameters $D_{50}$ or $D_{90}$, corresponding to the particle diameter that is larger than 50 or 90 percent of the particles in the sample. The distance at which a particle with size $D_{50}$ or $D_{90}$ is then the minimum distance we expect 50% or 90% of the total volume of particles to be transported.

→ *A simple analysis shows that fine particulate matter will settle at least 1 km from the outfall, which is an overestimate.*

Average slack tidal currents of 0.08 m/s and average total tidal currents of 0.35 m/s are obtained from the updated receiving water study. Owing to the small particle sizes of the samples, particles originating 1 m above the bed settle slowly enough to allow 90% of the sediment to be transported at least 1 km from the outfall for the average slack tidal currents and 4.2 km for the average total tidal currents. The same analysis shows that 50% of the sediment (based on the settling velocity of $D_{50}$) is expected to be transported at least 33.4 km and 148.2 km from the outfall for the slack and average currents, respectively. This is confirmed by analysis of sediment samples at location CH-B which indicate the presence of medium- to coarse-grained sand. The lack of fine-grained particles on the bed is proof that the local currents are too strong to enable settling of fine suspended particulate matter in the effluent.

→ *The analysis is flawed because fine particulate matter aggregates into larger particles, or flocs, which will deposit in the vicinity of the outfall because they settle faster.*

This sediment transport analysis is suitable to estimate the approximate distance at which particles are expected to travel under the influence of tidal currents. However, the analysis is flawed in two ways. First, the effluent is composed of organic material which has the tendency to make the fine-grained particles flocculate, or stick together to form "flocs". Therefore, the particle size distribution based on the laboratory sampling is not representative of the actual distribution of floc sizes at the outfall which can be much larger. Because flocs are composed of loosely packed suspended particulate matter, they are composed mostly of water, and hence their densities are much smaller than the density of individual mineral particles. This is why the density of 1060 kg/m$^3$ was used in the study rather than the value of ambient marine sediment density of 2650 kg/m$^3$. While this is a fair estimate, one cannot use such a low floc density to estimate the settling velocity without also assuming a floc diameter that can be much larger than the individual sizes based on the laboratory sampling. Therefore, owing to the use of floc diameters that are too small, and because the settling velocity is proportional to the square of this diameter, the settling velocities are vastly underpredicted and the resulting transport distances are substantially overpredicted. Substantially more flocculated effluent particulate matter will accumulate around the outfall.

→ *A sediment transport model should be employed with the MIKE modeling software to predict with more confidence whether the fine particulate matter is expected to settle in sensitive fisheries habitats in the region.*

The second flaw of the sediment transport study is that it is overly simplistic. The tidal currents are highly variable in the region in both space and time, and it is naïve to imply that the suspended particulate matter in the effluent will not pose an environmental or ecological problem based simply on an approximate distance it is expected to propagate away from the outfall. Not only do we expect flocculation to promote particle settling in the vicinity of the outfall, but the particles that settle far from the outfall may accumulate in sensitive fisheries habitats in deeper water or in Caribou Harbour. A more science-based and quantitative study of the fate of the suspended particulate matter should be done with the sediment transport modules that are part of the MIKE modeling software. A well calibrated hydrodynamic model that accurately computes the three-dimensional currents in the region would enable use of the sediment transport modules that could provide an accurate assessment of the potential environmental impacts of fine effluent particulate matter throughout the region.

## 6. Conclusions

The updated studies using the MIKE 21 and CORMIX models are both inaccurate and misleading. They overpredict the mixing and dilution of the effluent and do not provide science-based evidence that can be used to assess the potential environmental impacts of the near- and far-field effluent dilution from the proposed outfall site. This is based on sloppy modeling practices that I criticized in my original report but were not addressed in the new studies.

→ *New data show that density effects are very important in the region. Therefore, not only does the two-dimensional model give meaningless effluent concentration fields, but both the near- and far-field models overpredict the mixing and dilution.*

The most important aspect of the dynamics in the region that continues to be ignored by Stantec is the effect of density stratification. In the updated study, while Stantec set out to discount the importance of density effects with a series of oceanographic measurements, these measurements only serve to strengthen a case for their importance in the region. The ADCP data reveal peaks in the horizontal currents 15 m below the surface that arise from three-dimensional, density-driven flows that cannot be simulated with the two-dimensional MIKE 21 model used in the studies. The vertical profiles of salinity and temperature show that the density varies by 0.4 $kg/m^3$ over the water column. Nevertheless, Stantec argues that this density variability is small and ignores its effects even though the CORMIX manual suggests a threshold of just 0.1 $kg/m^3$. Because the vertical density variability is large enough to damp vertical turbulent mixing, ignoring its effects has important ramifications for both the near- and far-field modeling. The near-field dilution with CORMIX is overpredicted because the turbulence and mixing at the outfall are not damped as they should be. The far-field dilution is also overpredicted because the two-dimensional MIKE 21 model assumes complete mixing over the water column even though the stratification promotes effluent transport in shallower layers with higher concentration.

→ *The simulations of the far-field dilution of effluent discharged from the Boat Harbour weir are meaningless because the buoyant effluent can only be simulated with a three-dimensional model.*

Three-dimensional, density-driven effects are particularly important for simulating the effluent discharged from the Boat Harbour weir, where the effluent plume is confined to a near-surface, buoyant layer that cannot be represented with the two-dimensional MIKE 21 model. The effluent concentrations are expected to be higher at the Boat Harbour weir than at site CH-B because of the shallow water, weaker tidal currents and a lack of an outfall diffuser to promote near-field mixing. The shallowness and the effect of the weak tidal currents can be simulated with the MIKE 21 model to produce far-field effluent concentrations at the Boat Harbour weir that are significantly higher than those simulated at site CH-B. However, the dynamics of the buoyant plume are not accurately simulated with a two-dimensional model, and so the results do not accurately reflect the far-field dilution of the effluent discharged from Boat Harbour.

→ *Based on the validation results, the far-field model performs poorly and the resulting effluent fields cannot be trusted. Waves and temperature are validated yet they have no bearing on the results, and sea ice is not correctly represented in the model.*

Regardless of the lack of density effects, the studies suffer from fundamental problems associated with model setup, validation and analysis that I pointed out in my review of the Original Study. Despite the additional measurements, the validation of the currents near site CH-B indicates that the model performs poorly and cannot be trusted to accurately predict the far-field effluent transport. Although validation shows reasonably accurate predictions of wind-generated waves, their impacts are not quantified, and the relatively minor impact they may have is overwhelmed by errors in simulation of the tidal currents. The simulated temperature is shown to match observations to a reasonable degree, and there is extensive discussion of temperature and salinity modeling in the updated study. However, this discussion is misleading because the associated density effects related to temperature and salinity have no effect on the circulation in the two-dimensional MIKE 21 model. Also misleading is the implementation of the winter scenario, which accounts for sea ice simply by eliminating wind and waves from the study without accounting for reduced tidal currents due to the ice.

→ *Stantec states that there is no effluent buildup in Caribou Harbour, although this is clearly not the case and could easily be quantified with the MIKE 21 model.*

In the end, the MIKE 21 model setup as it is implemented can only assess the effects of tidal currents on the far-field effluent transport during different months of the year – in this case February and July 2019. Not only are the results inaccurate, but the resulting plots of the effluent at the end of each month are misleading because the two-dimensional MIKE 21 model overpredicts the dilution factors. Nevertheless, Stantec uses these plots to falsely claim that there is no effluent buildup in Caribou Harbour even though this is clearly not the case. It would be straightforward to compute the effluent accumulation in the Harbour with the model and assess the relative impact of realistic scenarios on this buildup. However, such science-based analysis is clearly beyond the scope of the Stantec studies.

→ *Including the correct receiving water density in the near-field CORMIX model, the dilution factor 100 m from the outfall is 42, 3.5 times lower than the value of 145.7 in the updated study. A more realistic worst-case scenario would give an even lower dilution factor when accounting for vertical density stratification effects, weaker slack tidal currents during neap tides, and less buoyant effluent during late summer/early fall.*

While the updated near-field modeling with CORMIX correctly accounts for the potential for reduced mixing during slack tidal currents, the scenario employs a receiving water density that is too high. Use of a more realistic, less dense receiving water gives less vigorous buoyancy-driven mixing and an effluent dilution factor of 42 at the edge of the mixing zone 100 m from the outfall, 3.5 times lower than the value of 145.7 with the denser receiving water. Although this scenario includes less dense receiving waters and slack tides, a more realistic worst-case scenario should include slack tidal currents during neap tides, which can be significantly weaker. The worst-case scenario should also use a receiving water density in late summer/early fall when waters are expected to be at their warmest and freshest, or least dense. Finally, the potential for reduced vertical mixing due to strong vertical density stratification should be accounted for in the CORMIX model. The full nature of the temperature and salinity dynamics and the vertical stratification in the region would need to be assessed with more observations of salinity along with three-dimensional modeling.

→ *Fine particulate matter will settle in the vicinity of the outfall due to particle aggregation and setting rates that are much faster than those predicted by Stantec. Accurate sediment transport modeling should be conducted with the MIKE sediment transport modules.*

The sediment transport modeling conducted by Stantec is fundamentally flawed because it does not account for flocculation of fine particulate matter in the presence of organic material in the effluent. Flocculation produces large particles, or flocs, that settle much faster than the fine particulate matter, thus incurring settling and buildup in the vicinity of the outfall. The fate of the smaller particles that are transported further from the outfall cannot be assessed with the model employed by Stantec, since it makes too many overly simplistic assumptions about the currents. Instead, transport of fine particulate matter can be computed with the sediment transport modules in the MIKE modeling software. This would enable assessment of the ultimate fate of the particles and their potential to impact sensitive fisheries habitats in the region.

## 7. Reference

Jirka, G. H., Doneker, R. L., and S. W. Hinton, 1996, User's manual for CORMIX: A hydrodynamic mixing zone model and decision support system for pollutant discharges into surface waters, DeFrees Hydraulics Laboratory, School of Civil and Environmental Engineering Cornell University, (https://www.epa.gov/sites/production/files/2015-10/documents/cormix-users_0.pdf).

# APPENDIX A-2

The **tidal period (PERIOD)** must be supplied; in most cases it is 12.4 hours, but in some locations it may vary slightly. The **maximum tidal velocity (UAmax)** for the location must be specified; this can usually be taken as the average of the absolute values of the two actual maxima, independent of their direction. A CORMIX design case consists then of an instantaneous ambient condition, before, at or after one of the two slack tides. Hence, the analyst must specify the **time** (in hours) **before, at, or after slack** that defines the design condition, followed by the actual **tidal ambient velocity (UA)** at that time. The ambient depth conditions are then those corresponding to that time.

In general, tidal simulations should be repeated for several time intervals (usually hourly or two-hourly intervals will suffice) before and after slack time to determine plume characteristics in unsteady ambient conditions.

Strongly unsteady conditions can also occur in other environments, such as in wind-induced current reversals in shallow lakes or coastal areas. In this case, any typical reversal period can be analyzed following an approach similar to the above.

4.3.4 Ambient Density Specification

Information about the density distribution in the ambient water body is very important for the correct prediction of effluent discharge plume behavior. CORMIX first inquires whether the ambient water is **fresh water** or **non-fresh** (i.e. brackish or saline). If the ambient water is fresh and above 4 $^{o}$C, the system provides the option of entering ambient temperature data so that the ambient density values can be internally computed from an equation of state. This is the recommended option for specifying the density of fresh water, even though ambient temperature per se is not needed for the analysis of mixing conditions. In the case of salt water conditions, Figure 4.3 is included as a practical guide for specifying the density if "salinity values" in parts-per-thousand (ppt) are available for the water body. Typical open ocean salinities are in the range 33 - 35 ppt.

The user then specifies whether the ambient density (or temperature) can be considered as **uniform** or as **non-uniform** within the water body, and in particular within the expected plume regions. As a practical guide, vertical variation in density of less than 0.1 kg/m$^3$ or in temperature of less than 1 $^{o}$C can be neglected. For uniform conditions, the **average ambient density** or **average temperature** must be specified.

When conditions are non-uniform, CORMIX requires that the actual measured vertical density distribution be approximated by one of three schematic stratification profile types illustrated in Figure 4.4. These are: Type A, linear density profile; Type B, two-layer system with constant densities and density jump; Type C, constant density surface layer with linear density profile in bottom layer separated by a density jump. Corresponding profile types exist for approximating a temperature distribution when it is used for specifying the density distribution.

*Note:* When in doubt about the specification of the ambient density values it is reasonable to first simplify as much as possible. The sensitivity of a given assumption can be explored in subsequent CORMIX simulations. Furthermore, if CORMIX indicates indeed a flow configuration (flow class) with near-field stability, additional studies with the post-processor option CORJET (see Section 6.1) can be performed to investigate *any arbitrary density distribution*.

After selecting the stratification approximation to be used, the user then enters all appropriate density (or temperature) values and **pycnocline heights (HINT)** to fully specify the profiles. The pycnocline is defined as zone or level of strong density change that separates the upper and lower layers of the water column. The program checks the density specification to insure that stable ambient stratification exists (i.e. the density at higher elevations must not exceed that at lower elevations).

Note that a dynamically correct approximation of the actua ldensity distribution should keep a balance between over-and under-estimationof the actual data similar to a best-fit in regression analysis. If simulation results indicate internal plume trapping, then it is

# APPENDIX A-3

Oliver B. Fringer

Curriculum Vitae

**Academic History**

2003 Ph.D. in Civil and Environmental Engineering
Stanford University, Department of Civil and Environmental Engineering
Dissertation: Numerical simulations of breaking interfacial waves

1996 Master of Science in Aeronautics and Astronautics
Stanford University, Department of Aeronautics and Astronautics

1995 Bachelor of Science in Aerospace Engineering, *cum laude*
Princeton University, Department of Mechanical and Aerospace Engineering

**Employment Record**

2011-present Associate Professor (with tenure), Dept. of Civil and Environmental Engineering, Stanford University

2003-2011 Assistant Professor, Dept. of Civil and Environmental Engineering, Stanford University

2006 Engineering Consultant, Chevron Energy Technology Company

2002-2003 Acting Assistant Professor, Dept. of Civil and Environmental Engineering, Stanford University

2002-2003 Lecturer, Depts. of Mathematics and Computer Science, University of the Western Cape, Cape Town, South Africa

2001-2002 Postdoctoral Researcher, Environmental Fluid Mechanics Laboratory, Stanford University

1996-2001 Research Assistant, Dept. of Civil and Environmental Engineering, Stanford University.

1994-1995 Summer Research Assistant, Dept. of Mechanical and Aerospace Engineering, Princeton University.

1993 Summer Intern, U. S. Dept of State, Foreign Building Operations, La Paz, Bolivia.

1992 Summer Intern, U. S. Consulate, La Paz, Bolivia.

## Professional Activities

### *Scientific committees and conference sessions organized*

Co-organizer for session, “Internal Waves/Tides and Sediment Processes on Continental Margins”, 2018 Ocean Sciences Meeting.

Co-organizer and chair for session, “Multiscale topographic effects on large-scale flow: From wakes and lee waves to small-scale turbulence and mixing”, 2018 Ocean Sciences Meeting.

Conference Chair, 16th International Workshop on Multi-scale (Un)-structured mesh numerical Modelling for coastal, shelf and global ocean dynamics, Stanford, CA, August 29-September 1, 2017.

Scientific Committee, 15th International Workshop on Multi-scale (Un)-structured mesh numerical Modelling for coastal, shelf and global ocean dynamics, Toulouse, France, September 27-29, 2016.

Scientific Committee, 14th International Workshop on Multi-scale (Un)-structured mesh numerical Modelling for coastal, shelf and global ocean dynamics, Portland, OR, September 28-30, 2015.

Co-organizer for Session, “Measuring and modeling internal waves and the turbulence cascade: a tribute to David Tang”, 2014 Ocean Sciences Meeting.

Organizing Committee, 63rd Annual Meeting of the APS Division of Fluid Dynamics, 2014.

International Scientific Committee, 7$^{th}$ International Symposium on Environmental Hydraulics, Singapore, 2014.

Scientific Committee, 11th International Workshop on Multi-scale (Un)-structured mesh numerical Modelling for coastal, shelf and global ocean dynamics, Delft, Netherlands, 28-30 August 2012.

Co-organizer for Session, “Transport and mixing due to nonlinear internal gravity waves”, 2012 Ocean Sciences Meeting.

Co-organizer for Session, "Mini-Symposium on Computational Strategies for the Simulation of Nonlinear Waves and Turbulence in Environmental Flows", 63rd Annual Meeting of the APS Division of Fluid Dynamics, 2010.

Scientific Committee, Geophysical and Astrophysical Waves, Les Houches, Chamonix, Feb 6-11, 2011.

Scientific Committee, 9th International workshop on Multiscale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Cambridge, MA, 17-20 August 2010.

Scientific Committee, Third International Symposium on Shallow Flows, June 2012, U. Iowa.

Scientific Committee, Ninth International Workshop on Unstructured Grid Modeling of Coastal and Ocean flows (2009).

Session organizer and chair (jointly with T. Peacock and D. Farmer) for AGU Fall Meeting Session OS15: "Internal Waves" (2008)

Session organizer and chair (jointly with S. Ramp and J. Lynch) for AGU Ocean Sciences Session O86: " Nonlinear Internal Wave Observations, Dynamics, and Acoustic Impacts" (2008)

International Scientific Committee, 15th Congress of Asia and Pacific Division of International Association of Hydraulic Engineering and Research, Chennai (2006)

Session organizer and chair (jointly with J. Nash) for AGU Ocean Sciences Session OS11J: "Dynamics of highly nonlinear internal waves" (2006)

***External thesis evaluator***

1. Subasha Wickramarachchi, "The hydrodynamics of two-dimensional oscillating flows over ripples: The effects of asymmetries in ripple shape and currents", The University of Waterloo, 2017.
2. Cintia Luz Ramón Casañas, "Hydrodynamics and mixing at river confluences: On the influence of buoyancy and the tides", The University of Granada, 2016.
3. Mario César Acosta Cobos, "Computational improvement of 3D hydrodynamic semi-implicit models for oceans and continental water simulations", The University of Granada, 2016.
4. Olga Kleptsova, "On techniques for modelling coastal and ocean flows with unstructured meshes", Technical University of Delft, 2013.

***Reviewer/advisory service***

NERRS Science Collaborative Research & Integrated Assessment Reviewer (2016)

San Francisco Estuary Institute Bay Modeling Advisory Team (2013)

Link Foundation Selection Committee (2013, 2014)

National Science Foundation (NSF) Reviewer, Physical Oceanography Program (2003-)

National Science Foundation (NSF) Panelist, Collaboration in Mathematical Geosciences, Jun 2-4, 2010.

Dept. of Energy (DOE) Computational Science Graduate Fellowship (CSGF) application screening committee, (2009-)

***Journal referee***

Advances in Water Resources (2009, 2010)
Boundary-Layer Meteorology (2009)
Coastal Engineering (2009)
Communications in Nonlinear Science and Numerical Simulation (2011)
Computers and Fluids (2010, 2011)
Computers and Geosciences (2009)
Continental Shelf Research (2004, 2013)
Deep-Sea Research (2011)
Dynamics of Atmospheres and Oceans (2007)
Ecological Applications (2006)
Environmental Fluid Mechanics (2013, 2015, 2017)
Environmental Practice (2015)
Estuaries and Coasts (2007, 2015, 2016)
European Journal of Mechanics - B/Fluids (2008, 2011)
Flow, Turbulence and Combustion (2013)
Geophysical Research Letters (2008, 2009, 2011, 2012, 2016)
International Journal for Numerical Methods in Fluids (2007, 2008, 2012, 2013, 2015)
International Journal of Computational Methods (2014)
Journal of Computational Physics (2006, 2010)
Journal of Fluid Mechanics (2003, 2006, 2007, 2008, 2010, 2011, 2012, 2013, 2014, 2015, 2016)
Journal of Geophysical Research: Earth Surface (2015)
Journal of Geophysical Research: Oceans (2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2016, 2017)
Journal of Hydraulic Engineering (2006, 2007, 2009, 2011, 2013, 2014, 2015)
Journal of Hydraulic Research (2013, 2016)
Journal of Hydrodynamics (2012)
Journal of Hydrology (2014)
Journal of Physical Oceanography (2006, 2010, 2011, 2013, 2014, 2015, 2016)
Limnology and Oceanography Letters (2017)
Limnology and Oceanography Methods (2008)
Marine Geology (2012)
Monthly Weather Review (2007)

Nonlinear Processes in Geophysics (2017)
Ocean Dynamics (2010)
Ocean Modelling (2007, 2008, 2010, 2011, 2012, 2013, 2016, 2017)
Oceanography (2017)
Physics of Fluids (2006, 2007, 2008, 2009, 2010, 2011, 2014, 2015)
San Francisco Estuary and Watershed Science (2014, 2016)
The Sea (2017)
Water Resources Research (2013)

***Editorial boards***

Ocean Modelling – Editor (2018-)

Journal of Water Waves – Associate Editor (2017-)

Environmental Fluid Mechanics (2017-)

**University and Departmental Service**

Stanford Interdisciplinary Graduate Fellowship selection committee (2017)

Environmental Fluid Mechanics and Hydrology Program Coordinator (2014-)

Chair, Promotion Committee (associate professor) (2014-2015)

CEE Vision Committee (2014-2016)

SOE Undergraduate Council (2013)

Woods Institute EVP Selection Committee (2013-2016)

CEE Undergraduate Curriculum Committee (2012-2015)

CEE ABET Representative for Environmental Engineering Degree (2011-2012)

CEE Faculty search committee (2012)

Premajor advisor (2012-2014)

Faculty Member, Institute for Computational and Mathematical Engineering (ICME) (2003-)

DOE Computational Science Graduate Fellowship (CSGF) coordinator for Stanford University (2004-)

Admissions chair, Environmental Fluid Mechanics and Hydrology Program, Dept. of Civil and Environmental Engineering (2009-2011, 2013, 2016, 2017)

Sophomore academic advisor (2005-2006)

Mechanical Engineering Flow Physics and Computation faculty search committee member (2005)

Freshman academic advisor (2004-2005)

Institute for Computational and Mathematical Engineering (ICME) curriculum committee member (2003-2004)

Center for African Studies (CAS) search committee member for South Africa Teaching Fellowship (2003)

Dissertation Reading Committee Member:

M. Barkdull, (Principal advisor: S. Monismith) Ph.D. 2016.
K. Cheng, (Principal advisor: L. Hildemann) Ph.D. 2010.
M. Chui, (Principal advisor: D. Freyberg) Ph.D. 2009.
K. Davis (Principal advisor: S. Monismith) Ph.D. 2008.
J. Dunckley (Principal advisor: J. Koseff) Ph.D. 2012.
S. Giddings, (Principal advisor: S. Monismith) Ph.D. 2010.
K. Gleichauf (Principal advisor: S. Monismith) Ph.D. 2015
R. Holmes (Principal advisor: L. Thomas) Ph.D. 2016.
J. Krall (Principal advisor: D. Freyberg) Ph.D. 2014
R. Moniz (Principal advisor: S. Monismith) Ph.D. 2014
N. Nidzieko (Principal advisor: S. Monismith) Ph.D. 2009.
T. Reddy, (Principal advisor: K. Arrigo) Ph.D. 2009.
J. Rogers, (Principal advisor: S. Monismith) Ph.D. 2015
L. Samuel, (Principal advisor: S. Monismith) Ph.D. 2014
M. Squibb, (Principal advisor: S. Monismith) Ph.D. 2014
E. Sta. Maria, (Principal advisor: M. Jacobson) Ph.D. 2013
J. Steinbuck (Principal advisor: S. Monismith) Ph.D. 2009.
L. Walter (Principal advisor: S. Monismith) Ph.D. 2011
R. Walter (Principle advisor: S. Monismith) Ph.D. 2014
J. Weitzman (Principal advisor: J. Koseff) Ph.D. 2013
D. Whitt (Principal advisor: L. Thomas) Ph.D. 2014
V. Sridharan (Principal advisor: S. Monismith) Ph.D. 2015
G. Zhao, (Principal advisor: R. Street) Ph.D. 2009.
R. Zeller, (Principal advisor: J. Koseff) Ph.D. 2014.
D. Zheng, (Principal advisor: L. Hildemann) Ph.D. 2016.

University Oral Examination (Chair)

J. Bae, Computational and Mathematical Engineering (2018)
S. Bose, Aeronautics and Astronautics (2012)
P. Constantine, Computational and Mathematical Engineering (2009)
S. Davis, Geological and Environmental Sciences (2008)
H. Hamilton, Aeronautics and Astronautics (2004)
C. Hamman, Mechanical Engineering (2015)
K. Hosseini, Aeronautics and Astronautics (2005)
S. Infeld, Aeronautics and Astronautics (2005)
M. Ji, Mechanical Engineering (2006)
S. Kang, Mechanical Engineering (2008)
S. Kumar, Aeronautics and Astronautics (2012)
M. Lande, Mechanical Engineering (2011)
G. Lotto, Geophysics (2018)
D. Macklin, Bioengineering (2017)
M. McDowell, Materials Science and Engineering (2013)
K. Moffett, Environmental Earth System Science (2010)
M. Mortazavi, Mechanical Engineering (2015)
L. Katrina ole-MoiYoi, E-IPER (2016)
B. Olson, Aeronautics and Astronautics (2013)
D. Phillips, Mechanical Engineering (2012)
B. Saenz, Environmental Earth System Science (2011)
N. Santhanam, Aeronautics and Astronautics (2004)
J. Seo, Mechanical Engineering (2016)
M. Shoeybi, Mechanical Engineering (2010)
V. Somandepalli, Mechanical Engineering (2006)
D. You, Mechanical Engineering (2003)
C. Yu, Aeronautics and Astronautics (2014)

University Oral Examination (Examiner)

L. Samuel, Civil and Environmental Engineering (2014)
I. Benekos, Civil and Environmental Engineering (2005)
N. Grumet, Geological and Environmental Sciences (2004)
P. Ray, Mechanical Engineering (2006)
A. Santoro, Civil and Environmental Engineering (2008)
R. Simons, Civil and Environmental Engineering (2004)
J. Thompson, Civil and Environmental Engineering (2015)

**Awards and Honors**

Outstanding Reviewer, Ocean Modelling, 2016

Lorenz G. Straub Award for best dissertation by former Ph.D. student Bing Wang, 2011.

Lorenz G. Straub Award for best dissertation by former Ph.D. student Subhas Karan Venayagamoorthy, 2009.

Presidential Early Career Award for Scientists and Engineers (PECASE), Office of Science and Technology Policy, 2009.

Young Investigator Award, Office of Naval Research, 2008.

Frederick A. Howes Scholar in Computational Science, Department of Energy, 2003.

South Africa Teaching Fellow, Department of African and African-American Studies, Stanford University, 2002-2003.

**Bibliographical Information**

**Publications**

Author order is based on percentage of work performed or contributed, except for the PI on the project or paper who is typically listed as last author. Ph.D. student names are in bold, supervised postdoctoral researcher names are in italics.

***Refereed Journal Publications***


1. **K. S. Nelson** and O. B. Fringer, 2018, "Sediment dynamics in wind-wave dominated shallow water environments", J. Geophys. Res.-Oceans, 123, 6996-7015, doi:10.1029/2018JC013894.
2. M. Traer, A. Fildani, O. Fringer, T. McHargue, and G. Hilley, 2018, "Turbidity current dynamics: Part 1. Model formulation and identification of flow equilibrium conditions resulting from flow stripping and overspill", J. Geophysical Research - Earth Surface, 123, 501–519, doi:10.1002/2017JF004200
3. M. Traer, A. Fildani, O. Fringer, T. McHargue, and G. Hilley, 2018, "Turbidity current dynamics: Part 2. Simulating flow evolution toward equilbrium in idealized channels", Journal of Geophysical Research – Earth Surface, 123, 520–534, doi: 10.1002/2017JF004202
4. B. Wang, L. Cao, F. Micheli, R. L. Naylor, and O. B. Fringer, 2018, "The effects of intensive aquaculture on nutrient residence time and transport in a coastal embayment", Environmental Fluid Mechanics, 18 (6), 1321–1349 doi:10.1007/s10652-018-9595-7
5. **K. R. Scheu**, D. A. Fong, S. G. Monismith, and O. B. Fringer, 2018, "Modeling sedimentation dynamics of sediment-laden river intrusions in a rotationally-influenced, stratified lake", Water Resources Research, 54, 4084–4107, doi:10.1029/2017WR021533

6. Y.-J. Chou, K. S. Nelson, R. C. Holleman, O. B. Fringer, M. T. Stacey, J. R. Lacy, S. G. Monismith, and J. R. Koseff, 2018, "Three-dimensional modeling of fine sediment transport by waves and currents in a shallow estuary", J. Geophys. Res.-Oceans., 123, doi:10.1029/2017JC013064
7. M. D. Rayson, G. N. Ivey, N. L. Jones, and O. B. Fringer, 2018, "Resolving high-frequency internal waves generated at an isolated coral atoll using an unstructured grid ocean model", Ocean Model., 122, 67-84, doi:10.1016/j.ocemod.2017.12.007
8. M. D. Rayson, E. S. Gross, R. D. Hetland, and O. B. Fringer, 2017, "Using an isohaline flux analysis to predict the salt content in an unsteady estuary", J. Phys. Oceanogr., 47, 2811-2828, doi:10.1175/JPO-D-16-0134.1
9. **E. T. Mayer** and O. B. Fringer, 2017, "An unambiguous definition of the Froude number for lee waves in the deep ocean", Journal of Fluid Mechanics, 831, doi:10.1017/jfm.2017.701
10. E. Masunaga, O. B. Fringer, Y. Kitade, H. Yamazaki, and S. Gallager, 2017, "Dynamics and energetics of trapped diurnal internal Kelvin waves around a mid-latitude island", Journal of Physical Oceanography, 47, 2479-2498, doi:10.1175/JPO-D-16-0167.1
11. **R. S. Arthur**, S. K. Venayagamoorthy, J. R. Koseff, and O. B. Fringer, 2017, “How we compute N matters to estimates of mixing in stratified flows”, Journal of Fluid Mechanics, 831, doi:10.1017/jfm.2017.679
12. **K. S. Nelson** and O. B. Fringer, 2017, "Reducing spin-up time for simulations of turbulent channel flow", Physics of Fluids, 29, 105101, doi:10.1063/1.4993489
13. L. M. M. Herdman, J. L. Hench, O. Fringer, and S. G. Monismith, 2017, "Behavior of a wave-driven buoyant surface jet on a coral reef", Journal of Geophysical Research-Oceans, 122 (5), 4088-4109, doi:10.1002/2016JC011729
14. M. M. Flint, O. Fringer, S. L. Billington, D. Freyberg, and N. S. Diffenbaugh, 2017, “Historical analysis of hydraulic bridge collapses in the continental United States”, Journal of Infrastructure Systems, 23 (3), 04017005, doi:10.1061/(ASCE)IS.1943-555X.0000354
15. E. Masunaga, **R. S. Arthur**, O. B. Fringer, and H. Yamazaki, 2017, “Sediment resuspension and the generation of intermediate nepheloid layers by shoaling internal bores”, Journal of Marine Systems, 170, 31-41, doi:10.1016/j.jmarsys.2017.01.017
16. **R. S. Arthur**, J. R. Koseff, and O. B. Fringer, 2017, "Local vs. volume-integrated turbulence and mixing in breaking internal waves on slopes", Journal of Fluid Mechanics, 815, 169-198, doi:10.1017/jfm.2017.36
17. J. S. Rogers, S. G. Monismith, O. B. Fringer, D. A. Koweek, and R. B. Dunbar, 2017 ,“A coupled wave-hydrodynamic model of an atoll with high friction: Mechanisms for flow, connectivity, and ecological implications”, Ocean Modelling, 110, 66–82, doi:10.1016/j.ocemod.2016.12.012
18. *M. D. Rayson*, E. S. Gross, R. D. Hetland, and O. B. Fringer, 2016, “Time scales in Galveston Bay: An unsteady estuary”, Journal of Geophysical Research-Oceans, 121, 2268-2285, doi: 10.1002/2015JC011181
19. E. Masunaga, O. B. Fringer, H. Yamazaki, and K. Amakasu, 2016, “Strong turbulent mixing induced by internal bores interacting with internal tide-driven vertically sheared flow”, Geophysical Research Letters, 43, 2094-2101, doi:10.1002/2016GL067812

20. **R. S. Arthur** and O. B. Fringer, 2016, "Transport by breaking internal gravity waves on slopes", Journal of Fluid Mechanics, 789, 93-126, doi:10.1017/jfm.2015.723
21. **P. J. Wolfram**, O. B. Fringer, N. Monsen, K. Gleichauf, D. Fong, and S. G. Monismith, 2016, "Modeling intrajunction dispersion at a well-mixed tidal river junction", 2016, Journal of Hydraulic Engineering, 142(8), 04016019, doi:10.1061/(ASCE)HY.1943-7900.0001108
22. E. Masunaga, H. Homma, H. Yamazaki, O. B. Fringer, T. Nagai, Y. Kitade, and A. Okayasu, 2015, "Mixing and sediment resuspension associated with internal bores in a shallow bay", Continental Shelf Research, 110, 85-99, doi:10.1016/j.csr.2015.09.022
23. *Chou, Y.-J.,* Holleman, R. C., Fringer, O. B., Stacey, M. T., Monismith, S. G., and Koseff, J. R., 2015, "Three-dimensional wave-coupled hydrodynamics modeling in South San Francisco Bay", Computers and Geosciences, 85, 10-21, doi:10.1016/j.cageo.2015.08.010
24. A. Cortes, M. G. Wells, O. B. Fringer, **R. S. Arthur**, and F. J. Rueda, 2015, "Numerical investigation of split flows by gravity currents into two-layered stratified water bodies", Journal of Geophysical Research-Oceans, 120, 5254-5271, doi:10.1002/2015JC010722
25. M. H. Alford, T. Peacock, J. A. MacKinnon, J. D. Nash, M. C. Buijsman, L. R. Centuroni, S.-Y. Chao, M.-H. Chang, D. M. Farmer, O. B. Fringer, K.-H. Fu, P. C. Gallacher, H. C. Graber, K. R. Helfrich, S. M. Jachec, C. R. Jackson, J. M. Klymak, D. S. Ko, S. Jan, T. M. Shaun Johnston, S. Legg, I-H. Lee, R.-C. Lien, M. J. Mercier, J. N. Moum, R. Musgrave, J.-H. Park, A. I. Pickering, R. Pinkel, L. Rainville, S. R. Ramp, D. L. Rudnick, S. Sarkar, A. Scotti, H. L. Simmons, L. C. St Laurent, S. K. Venayagamoorthy, Y.-H. Wang, J. Wang, Y. J. Yang, T. Paluszkiewicz and T.-Y. (David) Tang, 2015, "The formation and fate of internal waves in the South China Sea", Nature, 521, 65-69, doi:10.1038/nature14399
26. **K. R. Scheu**, D. A. Fong, S. G. Monismith, and O. B. Fringer, 2015, "Sediment transport dynamics near a river inflow in a large alpine lake", Limnology and Oceanography, 60 (4), 1195-1211, doi:10.1002/lno.10089
27. *M. Rayson*, E. S. Gross, and O. B. Fringer, 2015, "Modeling the tidal and sub-tidal hydrodynamics in a shallow, micro-tidal estuary", Ocean Modelling, 89, 29-44, doi:10.1016/j.ocemod.2015.02.002
28. **R. S. Arthur** and O. B. Fringer, 2014, "The dynamics of breaking internal solitary waves on slopes", Journal of Fluid Mechanics, 761, 360-398, doi:10.1017/jfm.2014.641
29. **S. Vitousek** and O. B. Fringer, 2014, "A nonhydrostatic, isopycnal-coordinate ocean model for internal waves", Ocean Modelling, 83, 118-144, doi:10.1016/j.ocemod.2014.08.008
30. K. Gleichauf, **P. Wolfram**, N. Monsen, O. Fringer, and S. Monismith, 2014, "Dispersion Mechanisms of a Tidal River Junction in the Sacramento-San Joaquin Delta, California", San Francisco Estuary and Watershed Science, 12 (4), doi:10.15447/sfews.2014v12iss4art1
31. R. B. Zeller, J. S. Weitzman, M. E. Abbett, F. J. Zarama, O. B. Fringer, and J. R. Koseff, 2014, "Improved parameterization of seagrass blade dynamics and wave attenuation based on numerical and laboratory experiments", Limnology and Oceanography, 59(1), 251-266, doi:10.4319/lo.2014.59.1.0251
32. S. Sankaranarayanan and O. B. Fringer, 2013, "Dynamics of barotropic low-frequency fluctuations in San Francisco Bay during upwelling", Continental Shelf Research, 65, 81-96, doi:10.1016/j.csr.2013.06.006

33. **P. J. Wolfram** and O. B. Fringer, 2013, "Mitigating horizontal divergence 'checker-board' oscillations on unstructured triangular C-grids for nonlinear hydrostatic and nonhydrostatic flows", Ocean Modelling, 69, 64-78, doi:10.1016/j.ocemod.2013.05.007
34. R. Holleman, O. B. Fringer, and M. T. Stacey, 2013, "Numerical diffusion for flow-aligned unstructured grids with applications to estuarine modeling", International Journal for Numerical Methods in Fluids, 72, 1117-1145, doi:10.1002/fld.3774
35. **S. Vitousek** and O. B. Fringer, 2013, "Stability and consistency of nonhydrostatic free-surface models using the semi-implicit theta-method", International Journal for Numerical Methods in Fluids, 72, 550-582, doi:10.1002/fld.3755
36. **S. Koltakov** and O. B. Fringer, 2013, "Moving grid method for numerical simulation of stratified flows", International Journal for Numerical Methods in Fluids, 71 (12), 1524-1545, doi:10.2002/fld.3724
37. **S. K. Venayagamoorthy** and O. B. Fringer, 2012, "Examining breaking internal waves on a shelf slope using numerical simulations", Oceanography, 25(2), 132–139, doi:10.5670/oceanog.2012.48
38. G. S. Carter, O. B. Fringer, and E. D. Zaron, 2012, "Regional models of internal tides", Oceanography, 25(2):56–65, doi:10.5670/oceanog.2012.42
39. R. K. Walter, C. B. Woodson, **R. S. Arthur**, O. B. Fringer, and S. G. Monismith, 2012, "Nearshore internal bores and turbulent mixing in southern Monterey Bay", Journal of Geophysical Research-Oceans, 117, C07017, doi:10.1029/2012JC008115
40. S. N. Giddings, D.A. Fong, S.G. Monismith, C.C. Chickadel, K.A. Edwards, W.J. Plant, **B. Wang**, O.B. Fringer, A.R. Horner-Devine, and A.T. Jessup, 2012, "Frontogenesis and frontal progression of a trapping-generated estuarine convergence front and its influence on mixing and stratification", Estuaries and Coasts, 35 (2), 665-681, doi:10.1007/s12237-011-9453-z
41. **D. Kang** and O. B. Fringer, 2012, "Energetics of barotropic and baroclinic tides in the Monterey Bay area", Journal of Physical Oceanography, 42 (2), 272-290, doi:10.1175/JPO-D-11-039.1
42. R.-Q. Wang, A. W.-K. Law, E. E. Adams, and O. B. Fringer, 2011, "Large-eddy simulation of starting buoyant jets", Environmental Fluid Mechanics, 11 (6), 591-609, doi:10.1007/s10652-010-9201-0
43. Simmons, H., M.-H. Chang, Y.-T. Chang, S.-Y. Chao, O. Fringer, C.R. Jackson, and D.S. Ko. 2011, "Modeling and prediction of internal waves in the South China Sea", Oceanography, 24(4), 88-99, doi:10.5670/oceanog.2011.97
44. **S. Vitousek** and O. B. Fringer, 2011, "Physical vs. numerical dispersion in nonhydrostatic ocean modeling", Ocean Modelling, 40 (1), 72-86, doi:10.1016/j.ocemod.2011.07.002
45. **B. Wang**, G. Zhao, and O. B. Fringer, 2011, "Reconstruction of vector fields for semi-Lagrangian advection on unstructured, staggered grids", Ocean Modelling, 40 (1), 52-71, doi:10.1016/j.ocemod.2011.06.003

46. **V. Chua** and O. B. Fringer, 2011, "Sensitivity analysis of three-dimensional salinity simulations in North San Francisco Bay using the unstructured-grid SUNTANS model", Ocean Modelling, 39 (3-4), 332-350, doi:10.1016/j.ocemod.2011.05.007
47. *S. K. Venayagamoorthy*, O. B. Fringer, A. Chiu, R. L. Naylor, and J. R. Koseff, 2011, "Numerical modeling of aquaculture dissolved waste transport in a coastal embayment", Environmental Fluid Mechanics, 11 (4), 329-352, doi:10.1007/s10652-011-9209-0
48. **Z. Zhang**, O. B. Fringer, and S. R. Ramp, 2011, "Three-dimensional, nonhydrostatic numerical simulation of nonlinear internal wave generation and propagation in the South China Sea", Journal of Geophysical Research-Oceans, 116, C05022, doi:10.1029/2010JC006424
49. **B. Wang**, S. N. Giddings, O. B. Fringer, E. S. Gross, D. A. Fong, and S. G. Monismith, 2010, "Modeling and understanding turbulent mixing in a macrotidal salt wedge estuary", Journal of Geophysical Research-Oceans, 116, C02036, doi:10.1029/2010JC006135
50. K. C. Cheng, V. Acevedo-Bolton, R. T. Jiang, N. E. Klepeis, W. R. Ott, O. B. Fringer, and L. M. Hildemann, 2011. "Modeling exposure close to air pollution sources in naturally ventilated residences: Association of turbulent diffusion coefficient with air change rate", Environmental Science and Technology, 45, 4016-4022, doi:10.1021/es103080p
51. **D. Kang** and O. B. Fringer, 2010, "On the calculation of available potential energy in internal wave fields", Journal of Physical Oceanography, 40 (11), 2539-2545, doi: 10.1175/2010JPO4497.1
52. **Y.J. Chou** and O. B. Fringer, 2010, "A model for the simulation of coupled flow-bedform evolution in turbulent flows", Journal of Geophysical Research-Oceans, 115, C10041, doi:10.1029/2010JC006103
53. *M.F. Barad* and O. B. Fringer, 2010, "Simulations of shear instabilities in interfacial gravity waves", Journal of Fluid Mechanics, 644, 61-95, doi:10.1017/S0022112009992035
54. Q. Bechet, A. Shilton, O. B. Fringer, and B. Guieysse, 2010, "Mechanistic modelling of broth temperature in outdoor photobioreactors", Environmental Science and Technology, 44 (6), 2197-2203. doi: 10.1021/es903214u
55. **Y.J. Chou** and O. B. Fringer, 2010, "Consistent discretization for simulation of flows with moving generalized curvilinear coordinates", International Journal for Numerical Methods in Fluids, 62 (10), 802-826. doi:10.1002/fld.2046
56. W. J. Plant, R. Branch, G. Chatham, C. C. Chickadel, K. Hayes, B. Hayworth, A. Horner-Devine, A. Jessup, D. A. Fong, O. B. Fringer, S. N. Giddings, S. Monismith, and **B. Wang**, 2009, "Remotely sensed river surface features compared with modeling and in situ measurements", Journal of Geophysical Research-Oceans, 114, C11002, doi:10.1029/2009JC005440
57. P. Van Gastel, G. N. Ivey, M. Meuleners, J. P. Antenucci, and O. B. Fringer, 2009, "The variability of the large-amplitude internal wave field on the Australian North West Shelf", Continental Shelf Research, 29 (11-12), 1373-1383, doi:10.1016/j.csr.2009.02.006

58. **B. Wang**, O. B. Fringer, S. N. Giddings, and D. A. Fong, 2009, "High-resolution simulations of a macrotidal estuary using SUNTANS", Ocean Modelling, 28 (1-3), 167-192, doi:10.1016/j.ocemod.2008.08.006
59. R.-Q. Wang, A. Law, E. E. Adams, and O. B. Fringer, 2009, "Buoyant formation number of a starting buoyant jet", 2009, Physics of Fluids, 21, 125104, doi:10.1063/1.3275849
60. **Y. J. Chou** and O. B. Fringer, 2008, "Modeling dilute sediment suspension using large-eddy simulation with a dynamic mixed model", Physics of Fluids, 20, 115103, doi: 10.1063/1.3005863
61. **S. M. Jachec**, O. B. Fringer, R. L. Street, and M. Gerritsen, 2007, "Effects of Grid Resolution on the Simulation of Internal Tides", International Journal of Offshore and Polar Engineering, 17 (2), 105-111.
62. **S. K. Venayagamoorthy** and O. B. Fringer, 2007, "On the formation and propagation of nonlinear internal boluses across a shelf break", Journal of Fluid Mechanics, 577, 137-159. doi:10.1017/S0022112007004624
63. **S. K. Venayagamoorthy** and O. B. Fringer, 2007, "Internal wave energetics on a shelf break", International Journal of Offshore and Polar Engineering, 17 (1), 22-29.
64. **S. K. Venayagamoorthy** and O. B. Fringer, 2006, "Numerical simulations of the interaction of internal waves with a shelf break", Physics of Fluids, 18 (1), 077603, doi:10.1063/1.2221863
65. **S. M. Jachec**, O. B. Fringer, M. G. Gerritsen, and R. L. Street, 2006, "Numerical simulation of internal tides and the resulting energetics within Monterey Bay and the surrounding area", Geophysical Research Letters, 33, L12605, doi:10.1029/2006GL026314
66. O. B. Fringer, M. Gerritsen, and R. L. Street, 2006. "An unstructured-grid, finite-volume, nonhydrostatic, parallel coastal-ocean simulator", Ocean Modelling, 14 (3-4), 139-173, doi:10.1016/J.OCEMOD.2006.03.006
67. O. B. Fringer, J. C. McWilliams, and R. L. Street, 2006, "A new hybrid model for coastal simulations", Oceanography, 19 (1), 46-59, doi: 10.5670/oceanog.2006.91
68. **S. K. Venayagamoorthy** and O. B. Fringer, 2005, "Nonhydrostatic and nonlinear contributions to the energy flux budget of nonlinear internal waves", Geophysical Research Letters, 32, L15603. doi:10.1029/2005GL023432
69. O. B. Fringer, S. W. Armfield, and R. L. Street, 2005, "Reducing numerical diffusion in interfacial gravity wave simulations", International Journal for Numerical Methods in Fluids, 49 (3), 301-329. doi:10.1002/fld.993
70. O. B. Fringer and R. L. Street, 2003, "The dynamics of breaking progressive interfacial waves", Journal of Fluid Mechanics, 494, 319-353. doi:10.1017/S0022112003006189
71. O. B. Fringer and D. D. Holm, 2001, "Integrable vs. nonintegrable geodesic soliton behavior", Physica D., 150 (3-4), 237-263. doi:10.1016/S0167-2789(00)00215-3

***Refereed Conference/Symposia Proceedings***

1. **B. Wang**, O. B. Fringer, and M. T. Stacey, 2012, "Interpreting the mixing efficiency from two-equation turbulence closure models", Proceedings of the 3rd International Symposium on Shallow Flows, Iowa, USA.
2. **V. P. Chua**, and O. B. Fringer, 2012, "Impact of tidal dispersion and time scales on numerical diffusion in unstructured-grid estuarine modeling", Proceedings of the 3rd International Symposium on Shallow Flows, Iowa, USA.
3. *M. D. Rayson*, N. L. Jones, G. N. Ivey, and O. B. Fringer, 2011, "Internal hydraulic jump formation in a deep water, continuously-stratified, unsteady channel flow", 7th International Symposium on Stratified Flows, Rome.
4. O. B. Fringer and **B. Wang**, 2010, "Analysis of stratified flow and separation over complex bathymetry in a field-scale estuarine model ", Proceedings of the 2010 DoD HPCMP Users Group Conference, IEEE Computer Society, 171-176, (invited), Schaumburg, IL, USA, doi:10.1109/HPCMP-UGC.2010.14
5. *S. K. Venayagamoorthy*, O. B. Fringer, J. R. Koseff, and R. L. Naylor, 2009, "Simulations of aquaculture dissolved waste transport in near-coastal waters", Proceedings of the ASCE World Environmental and Water Resources Congress 2009: Great Rivers, 1-8. doi: 10.1061/41036(342)295, Kansas City, MO, USA.
6. R. Q. Wang, A. W. K. Law, E. E. Adams, and O. B. Fringer, 2009, "The determination of formation number for starting buoyant jet", Proceedings of the 2nd International Symposium on Computational Mechanics (ISCM II) and 12th International Conference on Enhancement and Promotion of Computational Methods in Engineering and Science, AIP Conference Proceedings, v. 1233, 1636-1641. doi: 10.1063/1.3452156, Hong Kong.
7. R. Q. Wang, A. W. K. Law, E. E. Adams and O. B. Fringer, 2009, "Large-Eddy Simulation of Starting Buoyant Jets", Proceedings of the 33rd International Association of Hydraulic Engineering and Research (IAHR) Biennial Congress, Vancouver, Canada.
8. O. B. Fringer and **Z. Zhang**, 2008, "High-Resolution Simulations of Nonlinear Internal Gravity Waves in the South China Sea", Proceedings of the DoD HPCMP Users Group Conference, 2008, DOD HPCMP, 43-46. doi: 10.1109/DoD.HPCMP.UGC.2008.46, Seattle, WA, USA.
9. **Y.-J. Chou** and O. B. Fringer, 2007, "Modeling Sediment Suspension in High Reynolds Number Flow Using Large Eddy Simulation", Proceedings of the 5th International Symposium on Environmental Hydraulics, Tempe, AZ, USA.
10. *M. F. Barad* and O. B. Fringer, 2007, "Numerical simulations of shear instabilities in open-ocean internal gravity waves", Proceedings of the 5th International Symposium on Environmental Hydraulics, Tempe, AZ, USA.
11. *S. K. Venayagamoorthy*, O. B. Fringer, J. R. Koseff, and R. L. Naylor, 2007, "Simulations of mixing and transport of dissolved wasted discharged from an aquaculture pen", Proceedings of the 5th International Symposium on Environmental Hydraulics, Tempe, AZ, USA.

12. **B. Wang** and O. B. Fringer, 2007, "Modeling the dynamics of the Snohomish River Estuary with a finite volume, unstructured-grid parallel coastal ocean simulator", Proceedings of the 5th International Symposium on Environmental Hydraulics, Tempe, AZ, USA.
13. **Z. Zhang** and O. B. Fringer, 2006, "A Numerical Study of Nonlinear Internal Wave Generation in the Luzon Strait", Proceedings of the 6th International Symposium on Stratified Flows, pp 300-305, Perth, Australia.
14. *M. F. Barad*, O. B. Fringer, and P. Colella, 2006, "Multiscale simulations of internal gravity waves", Proceedings of the 6th International Symposium on Stratified Flows, pp 722-727, Perth, Australia.
15. **S. M. Jachec**, O. B. Fringer, M. Gerritsen, and R. L. Street, 2006, "The Three-Dimensional, Time-Dependent Nature of Internal Waves Entering Monterey Submarine Canyon", Proceedings of the 6th International Symposium on Stratified Flows, pp 294-299, Perth, Australia.
16. **S. K. Venayagamoorthy** and O. B. Fringer, 2006, "The dynamics of breaking internal gravity waves over a shelf break", Proceedings of the 6th International Symposium on Stratified Flows, pp 384-389, Perth, Australia.
17. O. B. Fringer, E. S. Gross, M. Meuleners, and G. N. Ivey, 2006. "Coupled ROMS-SUNTANS simulations of highly nonlinear internal gravity waves on the Australian northwest shelf", Proceedings of the 6th International Symposium on Stratified Flows, pp 533-538, Perth, Australia.
18. **S. M. Jachec**, O. B. Fringer, M. Gerritsen, and R. L. Street, 2006. "Effects of Grid Resolution on the Simulation of Internal Tides", Proceedings of the 16th International Offshore and Polar Engineering Conference, v. III, pp 432-438, San Francisco, CA, USA.
19. **D. Kang** and O. B. Fringer, 2006. "Efficient Computation of the Nonhydrostatic Pressure", Proceedings of the 16th International Offshore and Polar Engineering Conference, v. III, pp 414-419, San Francisco, CA, USA.
20. **S. K. Venayagamoorthy** and O. B. Fringer, 2006. "Internal wave energetics on a shelf break", Proceedings of the 16th International Offshore and Polar Engineering Conference, v. III, pp 473-480, San Francisco, CA, USA.
21. **Y. Chou** and O. B. Fringer, 2005, "An unstructured immersed boundary method for simulation of flow over complex topography", Proceedings of the 9th International Conference on Estuarine and Coastal Modeling, pp. 568-584. doi: 10.1061/40876(209)33, Charleston, SC, USA.
22. **D. Kang** and O. B. Fringer, 2005, "Time accuracy for pressure methods for nonhydrostatic free-surface flows", Proceedings of the 9th International Conference on Estuarine and Coastal Modeling, pp. 419-433. doi: 10.1061/40876(209)24, Charlston, SC, USA.
23. **S. K. Venayagamoorthy** and O. B. Fringer, 2004, "Energy partitioning in breaking internal waves on slopes", In: Environmental Hydraulics and Sustainable Water Management, Proceedings of the 4th International Symposium on Environmental Hydraulics and 14th Congress of Asia and Pacific Division, International Association of Hydraulic Engineering

and Research, 15-18 December 2004, Hong Kong, v. I, Edited by J.H.W. Lee, K.M. Lam, pp. 1051-1056.

24. O. B. Fringer, M. Gerritsen, and R. L. Street, 2004, "Internal waves in Monterey Bay: An application of SUNTANS", In: Environmental Hydraulics and Sustainable Water Management, Proceedings of the 4th International Symposium on Environmental Hydraulics and 14th Congress of Asia and Pacific Division, International Association of Hydraulic Engineering and Research, 15-18 December 2004, Hong Kong, v. I, Edited by J.H.W. Lee, K.M. Lam, pp. 67-75 (invited).
25. O. B. Fringer, S. W. Armfield, and R. L. Street, 2003, "A nonstaggered curvilinear grid pressure correction method applied to interfacial waves", Proceedings of the 2nd International Conference on Heat transfer, Fluid Mechanics, and Thermodynamics (HEFAT), Victoria Falls, Zambia.
26. O. B. Fringer, S. W. Armfield, and R. L. Street, 2000, "Direct numerical simulation of unstable finite amplitude progressive interfacial waves", Proceedings of the 5th International Symposium on Stratified Flows, pp. 749-754, Vancouver, Canada.
27. O. B. Fringer and R. L. Street, 2001, "The dynamics of breaking progressive interfacial waves", Proceedings of the 3rd International Symposium on Environmental Hydraulics, Tempe, AZ, USA.

***Non-refereed Conference/Symposia Proceedings***

1. **G. T. C. Gil** and O. B. Fringer, 2016, “Particle transport due to trapped cores”, 8$^{th}$ International Symposium on Stratified Flows, San Diego, CA.
2. **R. S. Arthur,** S. K. Venayagamoorthy, J. R. Koseff, and O. B. Fringer, 2016, **“**Quantification of highly unsteady and inhomogeneous stratified turbulence in breaking internal waves on slopes”, 8$^{th}$ International Symposium on Stratified Flows, San Diego, CA.
3. O. B. Fringer, 2009, “Towards nonhydrostatic ocean modeling with large-eddy simulation”, Oceanography in 2025: Proceedings of a Workshop, pp 81-83, The National Academies Press.

***Edited Works in Print or in Press***

1. A. Desbonnet, Ed., 2008, Ecosystem-based Estuary Management: A Case Study of Narragansett Bay, Chapter 14, "Circulation and pollutant transport dynamics in Narragansett Bay", by J. Craig Swanson & Malcolm L. Spaulding, Springer Series on Environmental Management, New York: Springer.

## Presentations

### *Invited Plenary Talks and Distinguished Lectures*

1. O. B. Fringer and **Y. Zhang**, 2016, "Subgrid hydrodynamics and sediment transport modeling on unstructured grids", 15th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, September 27-29, Toulouse, France (keynote).
2. O. B. Fringer, 2016, "Numerical simulations to understand the dynamics, energetics, and mixing of breaking internal gravity waves", B'Waves 2016, June 13-17, Bergen, Norway (keynote).
3. O. B. Fringer and **R. S. Arthur**, 2016, "Transport and mixing due to breaking internal gravity waves on slopes", European Congress on Computational Methods in Applied Sciences and Engineering, June 5-10, Crete, Greece (keynote).
4. **B. Wang**, O. B. Fringer and M. Gerritsen, 2007, "Numerical techniques in a parallel, unstructured-grid, finite-volume coastal ocean simulation tool", Ninth U.S. National Congress on Computational Mechanics, San Francisco, CA (keynote).
5. O. B. Fringer, 2004, "Fluids, Math, Computers, and the Environment", Southern California Applied Mathematics Symposium (SOCAMS), Claremont, CA (keynote).

### *Other Invited Presentations*

1. O. B. Fringer, **K.R. Scheu**, D. A. Fong, and S. G. Monismith, 2017, "Modeling intrusive, sediment-laden gravity currents in a rotationally-influenced lake", IUTAM/AMERIMECH SYMPOSIUM on the Dynamics of gravity currents, September 25-27, Santa Barbara, CA.
2. O. B. Fringer and **Y. Zhang**, 2016, "Subgrid bathymetry for seamless 1d, 2d, and 3d hydrodynamics and sediment transport modeling in SUNTANS", California Water and Environmental Modeling Forum, April 11-13, Folsom, CA.
3. **Y. Zhang**, O. Fringer, I. Huang, D. Fong, and S. Monismith, 2015, "Sediment transport modeling in a San Francisco Bay salt marsh", California Water and Environmental Modeling Forum, March 11, Folsom, CA.
4. O. B. Fringer, 2015, "Three-dimensional coupled wind-wave and cohesive sediment transport modeling in South San Francisco Bay", 2015 SIAM Conference on Computational Science and Engineering, March 13-18, Salt Lake City, UT.
5. **Y. Zhang**, O. B. Fringer, I. Huang, D. A. Fong, and S. G. Monismith, 2015, "The Impact of Vegetation and Culverts on Sediment Transport in a San Francisco Bay Salt Marsh", SIAM Conference on Mathematical and Computational Issues in the Geosciences, June 29-July 2, Stanford, CA.
6. *M. Rayson*, E. Gross, and O. B. Fringer, 2015, "Challenges in three-dimensional hydrodynamic modelling of the shallow bays and estuaries along the Gulf of Mexico coast", SIAM Conference on Mathematical and Computational Issues in the Geosciences, June 29-July 2, Stanford, CA.

7. O. B. Fringer and **R. S. Arthur**, 2015, “Direct numerical simulation of transport and mixing in breaking internal waves on slopes”, 13th U.S. National Congress on Computational Mechanics, July 27-30, San Diego, CA.
8. **Y. Zhang** and O. B. Fringer, 2015, “1D, 2D, and 3D Unstructured-grid modeling of sediment transport in a salt-marsh estuary”, 13th U.S. National Congress on Computational Mechanics, July 27-30, San Diego, CA.
9. O. B. Fringer, S. Vitousek, and **Y. Zhang**, 2015, “A model to simulate nonhydrostatic internal gravity waves in the ocean”, AGU Fall Meeting Abstract NG13B-07, December 14, San Francisco, CA.
10. O. B. Fringer, 2013, “Modeling internal wave-induced transport in the coastal ocean”, Workshop on Modeling in Support of Coastal Hypoxia, Acidification and Nutrient Management in the California Current, December 10-11, Costa Mesa, California.
11. O. B. Fringer, 2013, “Towards large-eddy simulation of internal waves in the coastal ocean”, Gordon Research Conference on Coastal Ocean Circulation, Biddeford, Maine.
12. O. B. Fringer and **P. J. Wolfram**, 2013, "Dealing with divergence errors and noise in C-grid finite-volume hydrodynamic models", Advances on Computational Mechanics: A Conference Celebrating the 70th Birthday of Thomas J. R. Hughes, San Diego.
13. O. B. Fringer, **S. Vitousek**, and **P. J. Wolfram**, 2012, “Finite-volume, nonhydrostatic ocean modeling on unstructured grids”, 1st International Conference on Frontiers in Computational Physics: Modeling the Earth System, Boulder.
14. R.C. Holleman, E.S. Gross, L.J. MacVean, M.T. Stacey, and O.B. Fringer, 2012, “Modelling Hydrodynamics, Sediment Transport and Provenance in the South San Francisco Bay Salt Ponds”, AGU Fall Meeting, San Francisco, CA, Abstract OS23D-04.
15. O. B. Fringer, 2011, "Grid resolution requirements and computational overhead in nonhydrostatic coastal ocean modeling", Minisymposium "Recent advances in coastal ocean modeling", SIAM Conference on Mathematical & Computational Issues in the Geosciences, Long Beach, CA.
16. O. B. Fringer and **B. Wang**, 2010, "High-resolution numerical simulation of surface salinity variability over an abrupt sill in a salt-wedge estuary", American Geophysical Union (AGU) Fall Meeting, San Francisco, CA.
17. O. B. Fringer, 2010, "Three-Dimensional Modeling of Sediment Dynamics in San Francisco Bay Using the SUNTANS Model", The 6th Biennial Bay-Delta Science Conference, Sacramento, CA..
18. O. B. Fringer and **B. Wang**, 2010, "Analysis of Stratified Flow and Separation Over Complex Bathymetry in a Field-Scale Estuarine Model", DOD HPCMP Users Group Conference, Shaumburg, IL
19. O. B. Fringer and **B. Wang**, 2010, "Challenges in high-resolution simulations of macrotidal estuaries", American Geophysical Union (AGU) Ocean Sciences Meeting, Eos Trans. AGU, 91(26), Ocean Sci. Meet. Suppl., Abstract IT25H-04, Portland, OR.

20. **D. Kang** and O. B. Fringer, 2010, "The energetics of barotropic and baroclinic tides in the Monterey Bay area", American Geophysical Union (AGU) Ocean Sciences Meeting, Eos Trans. AGU, 91(26), Ocean Sci. Meet. Suppl., Abstract PO31C-03, Portland, OR.
21. **Z. Zhang**, O. B. Fringer, and S. R. Ramp, 2010, "Determining the phase in the tide at which internal waves are generated over ridges", American Geophysical Union (AGU) Ocean Sciences Meeting, Eos Trans. AGU, 91(26), Ocean Sci. Meet. Suppl., Abstract PO43C-02, Portland, OR.
22. O. B. Fringer, 2009, "Multi-scale numerical simulation of internal waves in the ocean", 4th Warnemunde Turbulence Days Workshop, Warnemunde, Germany.
23. O. B. Fringer, *S. K. Venayagamoorthy*, and J. R. Koseff, 2009, "Characteristics of waste plumes from aquaculture pens in the marine environment", AAAS Annual Meeting, Chicago, IL.
24. O. B. Fringer, 2009, "High-resolution 3D hydrodynamics and sediment transport modeling of San Francisco Bay", Interagency Ecological Program (IEP) "Physical Modeling and Fish Management" workshop, Sacramento, CA.
25. **B. Wang** and O. B. Fringer, 2008, "High-resolution simulations of a salinity front interacting with complex geometry and intertidal mudflats", American Geophysical Union (AGU) Ocean Sciences Meeting, Orlando, FL.
26. O. B. Fringer, 2007, "Multiscale simulations of internal waves and other coastal processes", Gordon Research Conference on Coastal Ocean Modeling, New London, NH.
27. **Z. Zhang** and O. B. Fringer, 2007, "Nonhydrostatic effects of nonlinear internal wave propagation in the South China Sea", American Geophysical Union (AGU) Joint Assembly Meeting, Eos Trans. AGU, 88 (23), Jt. Assem. Suppl., Abstract OS41A-06, Acapulco, Mexico.
28. O. B. Fringer, 2006, "Parallel performance of a nonhydrostatic, unstructured-grid coastal ocean model", National Science Foundation Petascale Computing and the Geosciences Workshop, La Jolla, CA.

### *Contributed Conference Presentations*

1. **K. Nelson** and O. B. Fringer, 2018, “Unexpected fluid and sediment transport dynamics in shallow-water wave and current driven environments”, AGU Ocean Sciences Meeting, February 11-16, Portland, OR.
2. **Y. Zhang**, S. Vitousek, and O. B. Fringer, 2018, “An adaptive vertical coordinate for unstructured-grid, nonhydrostatic ocean modeling”, AGU Ocean Sciences Meeting, February 11-16, Portland, OR.
3. O. B. Fringer and **R. S. Arthur**, 2018, “Transport and dispersion due to breaking internal gravity waves on slopes”, AGU Ocean Sciences Meeting, February 11-16, Portland, OR.
4. **E. Mayer** and O. B. Fringer, 2018, “The lee-wave Froude number and its intuition”, AGU Ocean Sciences Meeting, February 11-16, Portland, OR.

5. **J. Adelson**, R. Holleman, and O. B. Fringer, 2018, “Observations of Suspended Sediment Dynamics in San Francisco Bay using Landsat 7 Imagery”, AGU Ocean Sciences Meeting, February 11-16, Portland, OR.
6. *J. Rogers*, D. Ko, and O. B. Fringer, 2018, “A framework for seamless one-way nesting of internal wave-resolving ocean models”, AGU Ocean Sciences Meeting, February 11-16, Portland, OR.
7. **K. Scheu**, O. B. Fringer, D. Fong, and S. G. Monismith, 2018, “The role of lateral boundaries in sediment transport due to river plumes in rotational, stratified environments”, AGU Ocean Sciences Meeting, February 11-16, Portland, OR.
8. **S. White, J. Adelson**, D. Freyberg, and O. B. Fringer, 2018, “Estimating Sediment Budget in South San Francisco Bay from Limited Streamflow Data”, AGU Ocean Sciences Meeting, February 11-16, Portland, OR.
9. E. Masunaga, O. B. Fringer, H. Yamazaki, R. S. Arthur, and K. Wada, 2018, “Numerical simulations and observations of nonlinear internal tides in shallow coastal regions”, AGU Ocean Sciences Meeting, February 11-16, Portland, OR.
10. O. B. Fringer, **R. S. Arthur**, S. K. Venayagamoorthy, and J. R. Koseff, 2017, “The effect of different methods to compute N on estimates of mixing in stratified flows”, 70th Annual Meeting of the APS Division of Fluid Dynamics, November 19-21, Denver, CO.
11. **Y. Zhang**, S. Vitousek, and O.B. Fringer, 2017, “A hybrid vertical coordinate for unstructured-grid, nonhydrostatic ocean modeling”, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, August 29-September 1, Stanford, CA.
12. B. Wang, L. Cao, O.B. Fringer, F. Micheli, and R. Naylor, 2017, “Model study of the effects of intensive aquaculture on residence time and nutrient transport in a coastal embayment”, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, August 29-September 1, Stanford, CA.
13. **W. Chen**, S. L. Billington, and O. B. Fringer, 2017, “An unstructured-grid, cut-cell model for scour simulation”, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, August 29-September 1, Stanford, CA.
14. E. Masunaga, O.B. Fringer, H. Yamazaki, 2017, “Nonlinear internal wave dynamics and sediment transport processes investigated with the SUNTANS model”, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, August 29-September 1, Stanford, CA.
15. **J. H. Adelson** and O. B. Fringer, 2017, “Remote Sensing of Sediment Dynamics and Critical Shear Stress in San Francisco Bay”, Gordon Research Conference on Coastal Ocean Dynamics, June 11-16, Biddeford, ME.
16. **E. T. Mayer** and O. B. Fringer, 2017, “The dynamics of unmapped bathymetry: Lee waves”, Gordon Research Conference on Coastal Ocean Dynamics, June 11-16, Biddeford, ME.

17. E. Masunaga, G. Auger, M. Rayson, O. Fringer, Y. Uchiyama, and H. Yamazaki, 2017, "Numerical simulations of the interaction between internal waves and the Kuroshio Current over the Izu-Ogasawara Ridge", AOGS 14th Annual Meeting, August 6-11, Singapore.
18. **K. Nelson** and O. B. Fringer, 2016, "Understanding the effects of sediment stratification in shallow wave and current driven environments", AGU Fall Meeting, December 12-16, San Francisco, CA.
19. **J. Adelson**, N. Kau, and O. B. Fringer, 2016, "Remote sensing to infer surface SPM in San Francisco Bay", 9$^{th}$ Biennial Bay-Delta Science Conference, November 15-17, Sacramento, CA.
20. **J. Adelson**, R. James, V. Chirayath, and O.B. Fringer, 2016, "Calibration and Testing of an Active Multispectral Instrument for Remote Sensing Suspended Particulate Matter", Ocean Optics Conference, November 8-12, Victoria, BC, Canada.
21. **K. Nelson** and O. B. Fringer, 2016, "Reducing spin-up time for DNS and LES of turbulent channel flow", 69th Annual Meeting of the APS Division of Fluid Dynamics, 61 (20), Abstract KP1.00134, November 20-22, Portland, OR.
22. E. Masunaga, O. B. Fringer, and H. Yamazaki, 2016, "Generation mechanisms and energetics of internal waves around an island", PO33B-05, AGU Ocean Sciences Meeting Abstract MG14A-1901, February 21-26, Portland, Oregon
23. **R. S. Arthur**, J. R. Koseff, and O. B. Fringer, 2016, "Local vs. bulk measures of the mixing efficiency in breaking internal waves on slopes", AGU Ocean Sciences Meeting Abstract PO24E-2998, February 21-26, Portland, Oregon.
24. **K. R. Scheu**, D. A. Fong, S. G. Monismith, and O. B. Fringer, 2016, "Sedimentation dynamics of a sediment-laden river intrusions in a large alpine lake", AGU Ocean Sciences Meeting Abstract MG14A-1901, February 21-26, Portland, Oregon.
25. S. Y. Litvin, J. M. Beers, C. B. Woodson, P. Leary, O. B. Fringer, J. A. Goldbogen, F. Micheli, S. G. Monismith, G. N. Somero, 2016, "Quantifying physiological, behavioral and ecological consequences of hypoxic events in kelp forest", AGU Ocean Sciences Meeting Abstract ME24E-0759, February 21-26, Portland, Oregon.
26. *M. D. Rayson*, E. S. Gross, and O. B. Fringer, 2015, "Physical processes controlling tracer exchange at the mouth of Galveston Bay", Gulf of Mexico Oil Spill and Ecosystem Science Conference, February 16-19, Houston, TX.
27. **R. S. Arthur** and O. B. Fringer, 2015, "Transport by breaking internal waves on slopes", Gordon Research Conference on Coastal Ocean Modeling, June 7-12, Biddeford, ME.
28. **K. Nelson**, O. B. Fringer, and Y.J. Chou, 2015, "A three-dimensional sediment transport model and its application for studying shoal and channel sediment dynamics", Gordon Research Conference on Coastal Ocean Modeling, June 7-12, Biddeford, ME.
29. *M. Rayson*, E. Gross, R. Hetland, and O. Fringer, 2015, "Characterizing and modelling salinity variability in an estuary with transient river forcing", Gordon Research Conference on Coastal Ocean Modeling, June 7-12, Biddeford, ME.

30. **K. Scheu**, D. Fong, S. Monismith, and O. Fringer, 2015, “Modeling sedimentation dynamics of a sediment-laden river plume in a large alpine lake”, Gordon Research Conference on Coastal Ocean Modeling, June 7-12, Biddeford, ME.
31. **Y. Zhang** and O. B. Fringer, 2015, “New developments and applications of the parallel finite-volume unstructured-grid SUNTANS model for sediment transport within estuarine marshes”, Gordon Research Conference on Coastal Ocean Modeling, June 7-12, Biddeford, ME.
32. O. B. Fringer, *M. D. Rayson*, and P. J. Wolfram, 2015, “Are unstructured grids needed? Comparison of the accuracy of finite-volume unstructured to curvilinear and Cartesian grid ocean models”, 14$^{th}$ International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, September 28-30, Portland, OR.
33. O. B. Fringer and **Y. Zhang**, 2015, “Subgrid bathymetry for hydrodynamics and sediment transport in SUNTANS”, 14$^{th}$ International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, September 28-30, Portland, OR.
34. L. Zaninetta and O. B. Fringer, 2014, “New Ways to Assess Natural Recovery of Sediments in Lake Maggiore, Italy”, 30th Annual International Conference on Soils, Sediments, Water, and Energy, October 20-23, Amherst, MA.
35. **R.S. Arthur** and O. B. Fringer, 2014, “Turbulent dynamics of breaking internal gravity waves on slopes”, 67th Annual Meeting of the APS Division of Fluid Dynamics, 59 (20), Abstract BAPS.2014.DFD.R11.1, November 23-25, San Francisco, CA.
36. O. B. Fringer, **P. Wolfram**, N. Monsen, K. Gleichauf, D. Fong, and S. G. Monismith, 2014, “Comparison of mixing at a junction computed with two- and three-dimensional models to the simple flow-weighting scheme used in one-dimensional models”, 8$^{th}$ Biennial Bay-Delta Science Conference, October 28-30, Sacramento, CA.
37. M. van der Wegen, L. Lucas, N. Knowles, D. Senn, B. Jaffe, E. Elias, P. Barnard, M. Stacey, O. Fringer, E. Gross, T. Fregoso, R.C. Martyr, F. Achete, E. Melger, F. Baart, H. Los, T. Troost, J. Smits, D. Roelvink, 2014, “Building a Public Community around the D3D-FM San Francisco Bay-Delta Model”, 8$^{th}$ Biennial Bay-Delta Science Conference, October 28-30, Sacramento, CA.
38. *M. D. Rayson*, E. S. Gross, R. D. Hetland, O. B. Fringer, 2014, “Tracer age as a diagnostic for understanding the relationship between surface and boundary forcing and estuarine circulation”, Poster 3-63, Gulf of Mexico Oil Spill & Ecosystem Science Conference, January 26-28, Mobile, AL.
39. **R. S. Arthur** and O. B. Fringer, 2014, "Transport and mixing by breaking internal waves on slopes", 61st Annual Eastern Pacific Ocean Conference (EPOC). September 17-20, Mt. Hood, OR.
40. **R. S. Arthur** and O. B. Fringer, 2014, “Cross-stream variability in breaking internal waves on slopes”, Nonlinear effects in internal waves conference, June 9-12, Cornell, NY.

41. K. G. Gleichauf, **P. Wolfram**, N. Monsen, O. Fringer, and S. Monismith, 2014, "Dispersion mechanisms in a tidal river junction in the Sacremento-San Joaquin Delta, CA", AGU Ocean Sciences Meeting Abstract 14592, February 23-28, Honolulu, HI.
42. **R. S. Arthur** and O. B. Fringer, 2014, "The three-dimensional structure and energetics of breaking internal waves on slopes", AGU Ocean Sciences Meeting Abstract 13316, February 23-28, Honolulu, HI.
43. N. L. Jones, C. E. Bluteau, *M. D. Rayson*, O. B. Fringer, and G. N. Ivey, 2014, "Internal tide mixing on the Australian Northwest continental shelf and slope", AGU Ocean Sciences Meeting Abstract 15994, February 23-28, Honolulu, HI.
44. O. B. Fringer, *B. Wang*, N L. Jones, and G. N. Ivey, 2014, "Numerical modeling of nonlinear and nonhydrostatic internal waves on the Australian North West shelf", AGU Ocean Sciences Meeting Abstract 16541, February 23-28, Honolulu, HI.
45. *M. D. Rayson*, O. B. Fringer, E. S. Gross, and R. D. Hetland, 2014, "Application of a nested, unstructured mesh hydrodynamic model to a bay in the Gulf of Mexico", AGU Ocean Sciences Meeting Abstract 16922, February 23-28, Honolulu, HI.
46. **K. Scheu**, D. Fong, S. Monismith, and O. Fringer, 2014, "Seasonal variability of sediment deposition into a large alpine lake", AGU Ocean Sciences Meeting Abstract 17645, February 23-28, Honolulu, HI.
47. N. Tahvildari, T. Peacock, and O. B. Fringer, 2014, "A parametric study of nonlinear and nonhydrostatic effects on internal tide generation over a submerged ridge", AGU Ocean Sciences Meeting Abstract 16837, February 23-28, Honolulu, HI.
48. **S. Vitousek** and O. B. Fringer, 2014, "A nonhydrostatic isopycnal-coordinate ocean model", AGU Ocean Sciences Meeting Abstract 15863, February 23-28, Honolulu, HI.
49. **R. S. Arthur** and O. B. Fringer, 2013, "Dissipation and mixing in breaking internal gravity waves on slopes", Gordon Research Conference on Coastal Ocean Circulation, Biddeford, Maine.
50. N. E. Monsen, **P. Wolfram**, K. Gleichauf, O. Fringer, and S. G. Monismith, 2013, "Development of a SUNTANS model for the Sacramento-San Joaquin Delta", 2013 California Water and Environmental Modeling Forum (CWEMF) Annual Meeting, April 22-24, Folsom, California.
51. *M. Rayson*, E. Gross, and O. B. Fringer, 2013, "Residual circulation in a shallow, micro-tidal estuary: Galveston Bay, TX", Gordon Research Conference on Coastal Ocean Circulation, June 9-14, Biddeford, Maine.
52. *M. Rayson*, E. S. Gross, and O. B. Fringer, 2013, "Age as a diagnostic for understanding the link between surface and boundary forcing and estuarine circulation", The 12th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, September 16-19, Austin, Texas.
53. *M. Rayson*, E. S. Gross, and O. B. Fringer, 2013, "Development of a high-resolution, three-dimensional hydrodynamic model of Galveston Bay", Gulf of Mexico Oil Spill and Ecosystem Science Conference, January 21-23, New Orleans, Louisiana.

54. **K. R. Scheu,** O. B. Fringer, S. G. Monismith, and D. A. Fong, 2013, "Sediment transport due to river inflows into large alpine lakes", KITP Conference: Particle-Laden Flows in Nature, December 16-19, U. C. Santa Barbara.
55. **K. R. Scheu,** S. G. Monismith, D. A. Fong, and O. B. Fringer, 2013, "Seasonal variability of sediment and contaminant transport in Lake Maggiore, Italy", 16th Workshop on Physical Processes in Natural Waters, July 8-11, Queensland, Australia (awarded best presentation).
56. **S. Vitousek** and O. B. Fringer, 2013, "A Nonhydrostatic Isopycnal Model for the Simulation of Internal Gravity Waves", Gordon Research Conference on Coastal Ocean Circulation, June 9-14, Biddeford, Maine.
57. **P. Wolfram,** N. Monsen, K. Gleichauf, O. Fringer, and S. Monismith, 2013, **"**Tidal dispersion and the impact of small-scale flow features in channel junctions", Gordon Research Conference on Coastal Ocean Circulation, Biddeford, Maine.
58. **P. Wolfram,** N. E. Monsen, K. Gleichauf, O. Fringer, and S. G. Monismith, 2013, "Computing Secondary Flows in the Delta: The Problem of Noise on Unstructured C-grids", California Water and Environmental Modeling Forum (CWEMF) Annual Meeting, April 22-24, Folsom, California.
59. **Y. Zhang** and O. B. Fringer, 2013, "New developments for the parallel finite-volume unstructured-grid SUNTANS model", The 12th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, September 16-19, Austin.
60. *Y. Chou*, R. C. Holleman, S. Lee, C. Chang, O. B. Fringer, M. T. Stacey, S. G. Monismith, and J. R. Koseff, 2012, "Three-Dimensional Numerical Modeling of Sediment Suspension in San Francisco Bay", AGU Fall Meeting, San Francisco, CA, Abstract OS21C-1767.
61. **R. S. Arthur**, R.K. Walter, C.B. Woodson, O.B. Fringer, and S.G. Monismith,2012, "Field and Numerical Investigation of Nearshore Internal Bores", 59th Annual Eastern Pacific Ocean Conference (EPOC), September 22, 2012. Mt. Hood, OR.
62. **P. Wolfram** and O. Fringer, 2012, "Mitigating divergence-error oscillations in triangular C grids for nonlinear and nonhydrostatic flows", Workshop on Multiscale Modelling of Coastal, Shelf and Ocean Dynamics (IMUM), Delft, Netherlands.
63. **P. Wolfram**, N. Monsen, K. Gleichauf, O. Fringer, and S. Monismith, 2012, "Characterizing the effect of small scale flow features on dispersion within channel junctions", 7$^{th}$ Biennial Bay-Delta Science Conference, Sacramento, CA.
64. N. E. Monsen, **P. Wolfram**, K. Gleichauf, O. Fringer, and S. Monismith, 2012, "The Devil is in the details: why the representation of the flow field, especially at junctions, matters in order to simulate dispersion in the Delta", 7$^{th}$ Biennial Bay-Delta Science Conference, Sacramento, CA.
65. **S. Koltakov,** G. Iaccarrino, and O. B. Fringer, 2012, "Inferring bottom bathymetry from free-surface flow features", SIAM Conference on Uncertainty Quantification, Raleigh, North Carolina.

66. **V. P. Chua**, O. B. Fringer, D. A. Fong, S. G. Monismith, and J. R. Koseff, 2012, “Modeling the impact of sea-level rise on salinity intrusion in San Francisco Bay”, 2012 Ocean Sciences Meeting, Salt Lake City, Abstract 9460.
67. R. B. Zeller, J. S. Weitzman, M. E. Abbett, O. B. Fringer, and J. R. Koseff, 2012, “Seagrass blade dynamics in unidirectional, oscillatory, and combined flows”, 2012 Ocean Sciences Meeting, Salt Lake City, Abstract 9801.
68. **G. Trigo Cabrita Gil** and O. B. Fringer, 2012, “Lagrangian- and Eulerian-mean effects in progressive internal gravity waves”, 2012 Ocean Sciences Meeting, Salt Lake City, Abstract 10029.
69. **K. R. Scheu**, O. B. Fringer, S. G. Monismith, D. Lin, and R. G. Luthy, 2012, “Rotational effects on sediment and DDT transport within a large lake (Lake Maggiore, Italy)”, 2012 Ocean Sciences Meeting, Salt Lake City, Abstract 10877.
70. K. T. Gleichauf, **P. J. Wolfram,** S. G. Monismith, O. B. Fringer, N. E. Monsen, and A. M. Bayen, 2012, “Small-scale hydrodynamics in tidal river junctions in the Sacramento-San Joaquin River Delta”, 2012 Ocean Sciences Meeting, Salt Lake City, Abstract 12139.
71. **S. Vitousek** and O. B. Fringer, 2012, “Grid resolution requirements in modeling internal waves”, 2012 Ocean Sciences Meeting, Salt Lake City, Abstract 12494.
72. **B. Wang, P. J. Wolfram,** G. Zhao, and O. B. Fringer, 2011, “Reconstruction of vector fields for semi-Lagrangian advection on unstructured, staggered grids”, The 10th International Workshop on Multiscale (Un-)structured Mesh Numerical Modelling for coastal, shelf and global ocean dynamics, Bremerhaven, Germany, August 22-25.
73. R. Holleman, **V. Chua**, M. Stacey, and O. B. Fringer, 2011, “Numerical scalar diffusion on flow-aligned unstructured, finite-volume grids”, The 10th International Workshop on Multiscale (Un-)structured Mesh Numerical Modelling for coastal, shelf and global ocean dynamics, Bremerhaven, Germany, August 22-25.
74. O. B. Fringer and **S. Vitousek**, 2011, “Physical vs numerical dispersion in nonhydrostatic internal wave modeling”, Conference on Geophysical and Astrophysical Internal Waves, Les Houches, France.
75. S. Sankaranarayanan and O. B. Fringer, 2010, "Dynamics of Low-frequency fluctuations in San Francisco Bay due to upwelling", AGU Fall Meeting, San Francisco, CA, USA.
76. *Y. Chou* and O. B. Fringer, 2010, "Coupled Wave-Current Numerical Simulation of Cohesive Sediment Transport in San Francisco Bay using SUNTANS", AGU Fall Meeting, San Francisco, CA, USA.
77. **Gil, G. T. C.**, and O. B. Fringer, 2010, "On the potential for transport via internal tides in the coastal ocean", 63rd Annual Meeting of the APS Division of Fluid Dynamics, 55 (16), Long Beach, CA, USA.
78. O. B. Fringer and **Z. Zhang**, 2010, “Understanding internal wave generation in the South China Sea using three-dimensional numerical simulations”, BIRS Coordinated Mathematical Modeling of Internal Waves, Banff, Canada.

79. **B. Wang** and O. B. Fringer, 2010, "High-resolution simulations of stratified flow and separation over an abrupt sill in a shallow estuary", 9th International workshop on Multiscale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, MIT, Cambridge, MA, USA.
80. **V. Chua** and O. B. Fringer, 2010, "Assessing the effects of numerical diffusion in a three-dimensional unstructured-grid model of a periodically-stratified estuary", 9th International workshop on Multiscale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, MIT, Cambridge, MA, USA.
81. **Y. Chou** and O. B. Fringer, 2010, "Numerical simulation of combined wave-current flows over dynamic sand ripples", Eos Trans. AGU, 91(26), Ocean Sci. Meet. Suppl., Abstract PO15E-30, Portland, OR, USA.
82. **B. Wang**, O. B. Fringer, and E. S. Gross, 2010, "Understanding turbulent mixing in a partially stratified estuary using SUNTANS", Eos Trans. AGU, 91(26), Ocean Sci. Meet. Suppl., Abstract PO45I-10, Portland, OR, USA.
83. O. B. Fringer and *M. F. Barad*, 2009, "Numerical simulation of shear instabilities in interfacial gravity waves", 4th Warnemunde Turbulence Days Workshop, Warnemunde, Germany.
84. *M. Barad* and O. B. Fringer, 2009, "Large-eddy simulation of coherent flow structures in a river", DOD HPCMP Users Group Conference, San Diego, CA, USA.
85. **Y. Chou** and O. B. Fringer, 2009, "Numerical simulation of turbulence-induced sediment transport and the resulting bedform dynamics", Workshop on modeling of turbidity currents and related gravity currents, Santa Barbara, CA, USA.
86. **Y. Chou** and O. B. Fringer, 2009, "Numerical Simulation of Turbulence-Induced Bedform Initiation", 62nd Annual Meeting of the APS Division of Fluid Dynamics, 54 (19), Abstract BAPS.2009.DFD.AC.6, http://meetings.aps.org/link/BAPS.2009.DFD.AC.6, Chicago, IL, USA.
87. O. Fringer and *M. Barad*, 2009, "Numerical simulation of shear instabilities in interfacial gravity waves", 62nd Annual Meeting of the APS Division of Fluid Dynamics, 54 (19), Abstract BAPS.2009.DFD.HS.4, http://meetings.aps.org/link/BAPS.2009.DFD.HS.4, Chicago, IL, USA.
88. **Chou, Y.**, Fringer, O. B., and J. R. Lacy, 2008, "Numerical Study of Sediment Suspension over Bedforms in Combined Flows", Eos Trans. AGU, 89(53), Fall Meet. Suppl., Abstract OS21E-1204, San Francisco, CA, USA.
89. *S. K. Venayagamoorthy*, O. B. Fringer, R. Naylor, and J. R. Koseff, 2008, " Numerical simulations of aquaculture dissolved waste transport in a coastal embayment", 61st Annual Meeting of the APS Division of Fluid Dynamics, 53 (15), Abstract BAPS.2008.DFD.HV.9, http://meetings.aps.org/link/BAPS.2008.DFD.HV.9, San Antonio, TX, USA.
90. O. B. Fringer, 2008, "Nonhydrostatic effects of internal solitary-like waves and possible parameterizations for hydrostatic models", Eos Trans. AGU, 89(53), Fall Meet. Suppl., Abstract OS51F-08, San Francisco, CA, USA.

91. **Wang, B.**, and O. B. Fringer, 2008, "Nonhydrostatic effects in high-resolution estuarine simulations", Seventh International Workshop on Unstructured Grid Numerical Modelling of Coastal, Shelf and Ocean Flows, Halifax, Canada.
92. *M. F. Barad*, O. B. Fringer, and P. MacCready, 2008, "Surface Signatures Generated by one- and two-dimensional sinusoidal bathymetry", AGU Ocean Sciences Mtng., Orland, FL, USA.
93. **D. Kang** and O. B. Fringer, 2008, "Simulation of the interaction of mesoscale currents with internal tides", AGU Ocean Sciences Mtng., Orlando, FL, USA.
94. *S. K. Venayagamoorthy*, O. B. Fringer, J. R. Koseff, and R. L. Naylor, 2008, "Simulations of mixing and transport of dissolved wasted discharged from near-coastal aquaculture pens", AGU Ocean Sciences Mtng., Orlando, FL, USA.
95. **Z. Zhang** and O. B. Fringer, 2008, "Numerical simulation of the generation of nonlinear internal gravity waves in the South China Sea"", AGU Ocean Sciences Mtng., Orlando, FL, USA.
96. *S. K. Venayagamoorthy*, O. B. Fringer, J. R. Koseff, and R. L. Naylor, 2007, "Simulations of Mixing and Transport of Dissolved Waste Discharged From a Submerged Aquaculture pen", Eos Trans. AGU, 88 (23), Jt. Assem. Suppl., Abstract OS23G-02, Acapulco, Mexico.
97. O. B. Fringer, S. J. Macumber, and A. B. Boehm, 2007, "Transport due to Internal Waves in the San Pedro Bay Region", Eos Trans. AGU, 88 (23), Jt. Assem. Suppl., Abstract OS23G-04, Acapulco, Mexico.
98. **S. M. Jachec**, O. B. Fringer, M. Gerritsen, and R. L. Street, 2006, "Understanding Internal Tides within Monterey Bay: from Beams to Modes", Eos Trans. AGU, 87(52), Fall Meet. Suppl., Abstract OS13A-1542, San Francisco, CA.
99. **Z. Zhang** and O. B. Fringer, 2006, "Simulation of Nonlinear Internal Wave Generation in the Northeastern South China Sea", Eos Trans. AGU, 87(52), Fall Meet. Suppl., Abstract OS13A-1533, San Francisco, CA.
100. **B. Wang**, O. B. Fringer, and R. L. Street, 2006, "Application of an unstructured-grid, finite-volume parallel coastal ocean simulator to the Snohomish River Estuary", Proceedings of the fifth international workshop on unstructured mesh numerical modelling of coastal, shelf and ocean flows, Miami, FL, USA.
101. **S. K. Venayagamoorthy** and O. B. Fringer, 2006. " Dynamics of internal boluses across a shelf break", 59th Annual Meeting of the Division of Fluid Dynamics, American Physical Society, Abstract BAPS.2006.DFD.FG.3, http://meetings.aps.org/link/BAPS.2006.DFD.FG.3, Tampa Bay, FL, USA.
102. D. A. Fong and O. B. Fringer, 2006, "High-resolution, nonhydrostatic flow physics in shallow coastal and estuarine flows", Eos Trans. AGU, 87(36), Ocean Sci. Meet. Suppl., Abstract OS35D-11, Honolulu, HI, USA.
103. **S. K. Venayagamoorthy** and O. B. Fringer, 2006, "Dynamics of the interaction of breaking internal gravity waves with a shelf break", Eos Trans. AGU, 87(36), Ocean Sci. Meet. Suppl., Abstract OS12J-05, Honolulu, HI, USA.

104. J. Majkut and O. B. Fringer, 2006, `Modeling the Interaction of Internal Tides and Wind Stress Over the Bathymetry of Huntington Beach, CA", Eos Trans. AGU, 87(36), Ocean Sci. Meet. Suppl., Abstract OS26H-14, Honolulu, HI, USA.

105. **J. Wang**, R. L. Street, and O. B. Fringer, 2006, "Nonhydrostatic Numerical Simulation of Internal Solitary Waves in the South China Sea", Eos Trans. AGU, 87(36), Ocean Sci. Meet. Suppl., Abstract OS15A-2, Honolulu, HI, USA.

106. **S. M. Jachec**, O. B. Fringer, R. L. Street, and M. Gerritsen, 2006, "Tidally Partitioned Energetics for Monterey Bay Derived From Numerical Simulations", Eos Trans. AGU, 87(36), Ocean Sci. Meet. Suppl., Abstract OS26H-21, Honolulu, HI, USA.

107. A. E. Santoro, K. R. Arrigo, O. B. Fringer, and A. B. Boehm, 2006, "Physical Predictors of Biological Water Quality: Linking Ocean Temperature and Human Health Risk," Eos Trans. AGU, 87(36), Ocean Sci. Meet. Suppl., Abstract OS25M-15, Honolulu, HI, USA.

108. G. Ivey, M. Meuleners, O. Fringer, K. Winters, and E. Gross, 2006, "Regional Model of the Internal Tide Dynamics on the Australian North West Shelf", Eos Trans. AGU, 87(36), Ocean Sci. Meet. Suppl., Abstract OS24M-06, Honolulu, HI, USA.

109. **Z. Zhang** and O. B. Fringer, 2006, "Propagation and Interaction of Nonlinear Internal Solitary Waves in the South China Sea", Eos Trans. AGU, 87(36), Ocean Sci. Meet. Suppl., Abstract OS15A-15, Honolulu, HI, USA.

110. J. Warren, A. Boehm, O. Fringer, and J. Kose, 2006, "Recreational Beach Visitor Perceptions of Health Risk and Impact of Water-Borne Pathogens in Orange County, CA," Eos Trans. AGU, 87(36), Ocean Sci. Meet. Suppl., Abstract OS25M-04, Honolulu, HI, USA.

111. **D. Kang**, O. Fringer, M. Gerritsen, Y. Kanarska, J. C. McWilliams, A. Shchepetkin, and R. L. Street, 2006, "High-resolution Simulations of Upwelling and Internal Waves in Monterey Bay Using a Coupled ROMS-SUNTANS Multi-scale Simulation Tool", Eos Trans. AGU, 87(36), Ocean Sci. Meet. Suppl., Abstract OS36G-07, Honolulu, HI, USA.

112. **S. K. Venayagamoorthy** and O. B. Fringer, 2005. "Energetics of internal boluses on a shelf break", 58th Annual Meeting of the Division of Fluid Dynamics, American Physical Society, Abstract BAPS.2005.DFD.EN.7, http://meetings.aps.org/link/BAPS.2005.DFD.EN.7, Chicago, IL, USA.

113. **S. K. Venayagamoorthy** and O. B. Fringer, 2005. "Numerical simulations of internal gravity waves", Gallery of Fluid Motion Poster (#49), 58th Annual Meeting of the Division of Fluid Dynamics, American Physical Society, Chicago, IL, USA.

114. O. B. Fringer and **S. K. Venayagamoorthy**, 2005, "Modeling the generation and evolution of internal boluses on coastal slopes ", 2005, Workshop on turbidity currents and related gravity currents, UCSB, Santa Barbara, CA, USA.

115. **S. M. Jachec**, O. B. Fringer, M. Gerritsen, and R. L. Street, 2004, "Evolution of internal waves in Monterey Bay", Eos Trans. AGU, 85(47), Fall Meet. Suppl., Abstract OS21B-1230, San Francisco, CA, USA.

116. **S. K. Venayagamoorthy** and O. B. Fringer, 2004, "Generation and evolution of solibores on slopes", Eos Trans. AGU, 85(47), Fall Meet. Suppl., Abstract OS11A-0498, San Francisco, CA, USA.
117. **S. M. Jachec**, O. B. Fringer, M. Gerritsen, and R. L. Street, 2004, "SUNTANS on Monterey Bay", Eos. Trans. AGU, 85(17), Joint Assembly Suppl., Abstract OS33A-05, Montreal, Canada.
118. O. B. Fringer and A. B. Boehm, 2004, "Cross shelf transport induced by internal tides", ASLO/TOS Ocean Research Conference, Honolulu, HI, USA.
119. O. B. Fringer, M. Gerritsen, **S. Jachec**, and R. L. Street, 2002, "A new nonhydrostatic parallel coastal ocean model," Eos Transactions, AGU, 83(47): Abstract OS11C-0238, San Francisco, CA, USA.
120. O. B. Fringer, C. D. Troy, J. R. Koseff, and R. L. Street, 2002, "Laboratory and numerical experiments on breaking interfacial waves", Eos. Trans. AGU, 83(4), Ocean Sciences Meet. Suppl., Abstract OS41E-68 (Best student poster award), Honolulu, HI, USA.
121. O. B. Fringer and R. L. Street, 2001, "The dynamics of breaking progressive interfacial waves",3rd International Symposium on Environmental Hydraulics, Tempe, AZ, USA.
122. O. B. Fringer and R. L. Street. 1999. "Nonhydrostatic effects of breaking interfacial waves on a sloping boundary," 5th Workshop on Numerical Modeling of Atmospheric, Surface, and Groundwater Flows, Trento, Italy.
123. O. B. Fringer and D. D. Holm. 1998. "Integrable vs nonintegrable geodesic soliton behavior,"IGPP/NPACIWorkshop on Accurate Simulation and Modeling of Physical Systems, (Best student poster award), La Jolla, CA, USA.
124. C. J. Mikolaijczak, M. J.Wornat, F. L. Dryer, O. B. Fringer, and T. J. Held. 1996. "A flow reactor study of 1-Methylnaphthalene pyrolysis using a new condensed-species sampling probe," ESCI Fall Technical Meeting, Hilton Head, SC, USA.
125. C. J. Mikolajczak, O. B. Fringer, T. J. Held, M. J. Wornat, and F. L. Dryer. 1996. "A new condensed species sampling probe for flow reactor studies of polycyclic aromatic compounds," 26th International Symposium on Combustion, Naples, Italy.

**Former Ph.D. Students (in order of graduation year)**

1. Kurt Nelson, 2018, Thesis: "Simulating sediment dynamics in shallow-water wave- and current-driven environments"
2. Yun Zhang, 2017, Thesis: "Numerical modeling for hydrodynamics and suspended sediment transport in estuarine marshes"
3. Gonçalo Gil, 2017, Thesis: "Mass transport and shear-flow dispersion due to nonlinear internal gravity waves"
4. Kara Scheu, 2016, Thesis: "Sediment transport due to river plumes in stratified, rotationally-influenced lakes"
5. Robert Arthur, 2015, Thesis: "Numerical investigation of breaking internal waves on slopes: Dynamics, energetics, and transport"

6. Sean Vitousek, 2014, Thesis: "Towards internal wave resolving simulations of the ocean"
7. Phillip Wolfram, 2014, Thesis: "Secondary flows and dispersion in channel junctions"
8. Sergey Koltakov, 2013, Thesis: "Bathymetry inference from free-surface flow features using large-eddy simulation"
9. Bing Wang, 2012, Thesis: "Multiscale numerical simulations of a complex macrotidal tidal-river estuary"
10. Vivien Chua, 2012, Thesis: "Three-dimensional, unstructured-grid numerical simulations of hydrodynamics and scalar transport in San Francisco Bay"
11. Dujuan Kang, 2011, Thesis: "Energetics and dynamics of internal tides in Monterey Bay using numerical simulations"
12. Zhonghua Zhang, 2010, Thesis: "Numerical simulations of nonlinear internal waves in the South China Sea"
13. Yi-Ju Chou, 2009, Thesis: "Numerical study of sand ripple dynamics in turbulent flows"
14. Sheng Chen, 2009, Thesis: "Adaptive error estimators for electromagnetic field solvers"
15. Steven Jachec, 2007, Thesis: "Understanding the evolution and energetics of internal tides within Monterey Bay via numerical simulations"
16. Karan Venayagamoorthy, 2006, Thesis: "Energetics and dynamics of internal waves on a shelf break using numerical simulations"

# APPENDIX A-4

Review of near- and far-field modeling studies by Stantec Consulting for the Northern Pulp effluent treatment facility replacement project

Prepared by:
Oliver Fringer, Ph.D.
San Francisco, CA, USA

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## 1. Executive Summary

This report provides a review of computer modeling of the fate and transport of effluent from proposed discharge locations in and around Pictou Harbour and offshore of Caribou Harbour near Pictou, Nova Scotia. The modeling work was carried out by Stantec Consulting for assessment of the Replacement Effluent Treatment Facility Project registered by Northern Pulp Nova Scotia Corporation. Simulations were conducted with accepted industry-standard models including the near-field CORMIX model and the far-field MIKE 21 model.

*Owing to several problems related to the implementation of the CORMIX and MIKE 21 models, they overestimate the near- and far-field mixing and dilution of the effluent from the proposed outfalls, including the final outfall at site CH-B offshore of Caribou Harbour. This leads to the incorrect conclusion that the environmental impacts will be negligible because the effluent concentrations are predicted to be unphysically low. Instead, correct implementation of the models with more conservative and physically realistic scenarios would show that effluent concentrations in the region could be much larger and that effluent accumulation in Pictou and Caribou Harbours is likely.*

The principle problems related to the far-field MIKE 21 modeling include:

1) Agreement between the model simulated currents and water levels and observed currents and water levels in Pictou Harbour is poor. Therefore, we can have no confidence that the model accurately predicts the far-field fate and transport of the effluent at any of the proposed outfall locations.

2) Use of the two-dimensional MIKE 21 model is inappropriate given the potentially strong vertical variability of currents driven by winds and river inflows in the region. These three-dimensional effects can significantly impact the far-field transport by exaggerating accumulation in Pictou and Caribou Harbours.

3) The far-field model scenarios using MIKE 21 omit or incorrectly simulate the impacts of winds, river inflows, offshore currents in the Northumberland Strait, ice, waves, and storm surge. These processes may significantly impact far-field mixing and dilution of effluent and lead to higher effluent concentrations throughout the region.

4) The figures showing maps of low effluent concentrations offshore of Caribou Harbour are misleading because the far-field model artificially dilutes the effluent. Nevertheless, the dilution factors are reported to be over 100 in most of the region surrounding the CH-B outfall, which is an overly optimistic result.

The principle problems related to the near-field CORMIX modeling include:

1) The ambient tidal current used to drive the CORMIX model offshore of Caribou Harbour is much stronger than the expected current during a neap tidal period. Tidal currents are even weaker during winter when there is ice cover which decreases the strength of the tides. Overestimation of the tidal currents gives an unrealistic overprediction of the near-field mixing and dilution of effluent, particularly during slack tides.

2) The ambient density employed in the CORMIX model is too saline because it does not take into account potential effects of river inflows. This makes the receiving waters too dense and leads to too much buoyancy-driven mixing of the effluent plume, thus leading to an overestimate of the near-field mixing and dilution. The CORMIX modeling also ignores the effect of vertical variability in salinity, which could be strong during periods of high river inflows and reduce the near-field mixing and dilution because fresh water layers near the surface may trap the effluent beneath them.

It should be noted that these problems are related to the implementation and choice of models, not to the models themselves. When implemented correctly, CORMIX and far-field models like MIKE 21 or its three-dimensional counterpart, MIKE 3, yield very reliable near- and far-field predictions of effluent transport.

## 2. Introduction

### *2.1. Overview*

In this report I review the near- and far-field modeling studies conducted by Stantec Consulting to understand the fate of effluent from proposed outfalls located in and around Pictou and Caribou Harbours which are connected to the Northumberland Strait in Pictou County, Nova Scotia, Canada. These studies are part of the Environmental Assessment of the Replacement Effluent Treatment Facility Project registered by Northern Pulp Nova Scotia Corporation (Northern Pulp). Specifically, in this report I analyze the modeling studies contained in the following appendices included in the Environmental Assessment:

1) Appendix E1 – Stantec final Caribou discharge receiving water study (The final study)
2) Appendix E2 – Stantec response to questions
3) Appendix E3 – Stantec receiving water study effluent treatment plant replacement (The preliminary study)

In the preliminary study (Appendix E3), scenarios were conducted to study the effluent transport from two outfalls in (sites Alt-A and Alt-B) and offshore of (sites Alt-C and Alt-D) Pictou Harbour. It was deemed that the suggested outfall location Alt-D was not appropriate because of the potential for ice scour of the outfall in the relatively shallow water (11 m). The final study (Appendix E1) was then undertaken to assess the effluent transport from outfalls located offshore of Caribou Harbour in 20 m of water at sites CH-A and CH-B. Site CH-B was recommended as the location with the least environmental impact. In what follows, I will refer to these appendices as the "final study", the "response to questions", and the "preliminary study". Collectively, they will be referred to as "the studies" or "the Stantec studies".

Simulating the transport and fate of effluent from a coastal wastewater outfall requires two kinds of models. Roughly within 100 m of the outfall, effluent is diluted relatively rapidly by mixing with ambient ocean waters. This mixing is due to strong turbulence related to jet-like flow from the outfall ports and buoyancy arising from the difference in density between relatively warm and fresh effluent and colder and saltier receiving waters. In the studies reviewed here, this dilution process is simulated with CORMIX (Jirka et al. 1996), an industry standard near-field model that takes into account diffuser geometry and properties of the effluent and receiving waters. After the near-field turbulence and buoyant mechanisms have decayed, the fate and transport of the effluent is dictated by the larger-scale circulation in the coastal region surrounding the outfall. The far-field currents, salinity, and temperature are obtained with a hydrodynamic model that computes circulation in response to winds, tides, river inflows, and other relevant coastal processes. These currents are then used to compute the far-field transport and fate of the effluent. In the studies reviewed here, the MIKE 21 model (DHI 2017) was used to compute the far-field circulation and transport. This model is also an industry standard that has been applied extensively to study circulation and transport in coastal regions. While the CORMIX model is an appropriate choice for the near-field modeling, the MIKE 21 model is not appropriate for this study because it is a two-dimensional model, as discussed in Section 3.1 below.

It is common practice to use far-field models to supply ambient currents and environmental parameters like temperature and salinity to the near-field model. The near-field dilution results including the near-field concentration and vertical distribution of the effluent plume can be supplied to the far-field model. In the Stantec studies, the ambient currents needed for the CORMIX model are taken from the MIKE 21 model, while the ambient density field for CORMIX is taken from measurements of temperature and salinity. The far-field MIKE 21 model does not use results from CORMIX. This is common given that only relative concentrations are needed to assess the far-field dilution when using a two-dimensional model like MIKE 21. As will be discussed in this report, however, a three-dimensional far-field model is needed, and this model requires information about the vertical distribution of the effluent plume from the near-field model.

*2.2. Currents and dispersion in the coastal ocean*

In coastal areas like the regions in and around Pictou and Caribou Harbours, the currents arise from a multitude of processes, although a simple categorization is to distinguish between the tides and all other non-tidal processes, such as wind-driven, river-driven, and large-scale ocean currents in the Northumberland Strait. A prevailing and misleading theme in the Stantec studies is the suggestion that, although some non-tidal processes are included in the modeling (albeit incorrectly), these non-tidal processes are not important because the tidal currents dominate the near- and far-field effluent transport. However, as discussed throughout this review, the non-tidal processes are extremely important for predicting the fate of the effluent in both the near-field and far-field.

Because of their oscillatory motion in time, tides transport effluent back and forth over an outfall, and with each oscillation the effluent is dispersed, leading to horizontal spreading of the effluent plume. This so-called tidal dispersion is strongest in regions where the tidal currents are both large and vary strongly in space, such as at the mouths of Caribou and Pictou Harbours. Although an outfall plume will spread due to tidal dispersion, there will not be much dilution of the effluent after many tidal cycles unless there are non-tidal currents that can transport the effluent away from the outfall. Without non-tidal currents, effluent would simply accumulate around outfall location CH-B and in nearby Caribou Harbour.

Accumulation of effluent in the vicinity of an outfall is strongest during slack tides, periods of low or negligible currents that occur twice during every tidal period, which is approximately 12 hours (the tidal period due to the moon is 12.42 hours and that due to the sun is 12 hours). The effects of slack tides are most pronounced during neap tides when tidal currents are weakest. For example, the maximum neap tidal current is approximately 10 cm/s at outfall location CH-B (based on the discussion presented in Section 4.2 below). With this tide, the tidal currents will be weaker than 2.5 cm/s for the one-hour period surrounding slack, or for approximately two hours (17%) of the entire tidal cycle. During each one-hour slack tide period, 173 kg[1] of suspended solids would be discharged into the ocean from outfall CH-B. The solids that were discharged 30 minutes before slack tide would find themselves just 45 meters from the outfall, only to be transported back over the outfall again at the end of the next 30 minutes to be re-entrained into the outfall plume. This demonstrates the importance of slack tide in the accumulation of effluent over an outfall diffuser due to the prolonged periods of relatively weak currents, particularly during the neap period of the spring-neap tidal cycle. Furthermore, owing to the reduction in vertical turbulent mixing because of the weak currents during slack tides, there is a strong potential for the suspended solids in the effluent to settle out of the water

[1] Based on a concentration of 48 mg/L and effluent flow rate of 1 $m^3/s$, from Table 3.2 of the final study.

column and onto the bed in the vicinity of the outfall. The effects of slack tides and the potential for settling of suspended solids is not discussed in the Stantec studies.

Fortunately for the health of coastal ecosystems, non-tidal currents exist to varying degrees in all coastal regions. In fact, the tides themselves produce non-tidal currents, much like ocean swell waves produce rip currents that have no wave-like signature. Non-tidal currents that are produced by the tides are generally smaller than other non-tidal currents in the region, such as wind-driven, river-driven, and large-scale ocean currents. While river flows and winds are included in the far-field modeling, these effects are not accurately simulated, as discussed in Section 3.1 below. There are large-scale ocean currents that are predominantly from the west to east in the Northumberland Strait at speeds ranging from 6-9 cm/s (Lauzier 1965). Another non-tidal current in the region is the counterclockwise circulation around Pictou Island that has been observed by local fisherman (MacCarthy and Egilsson 2019). This non-tidal current is likely driven by a combination of winds and tides. Although they are important in dictating the far-field transport of effluent, these non-tidal currents are regarded as not important and not included in the Stantec studies.

## 3. Review of the far-field modeling

### *3.1. Two- vs. three-dimensional modeling*

*The MIKE 21 model employed in the far-field simulations is not appropriate because it is two-dimensional and does not represent important three-dimensional processes in the region, such as wind-driven circulation and density effects arising from freshwater flows from rivers. A more appropriate model like MIKE 3 would need to be used to account for these effects.*

The MIKE 21 model employed by Stantec is a two-dimensional model in that it computes the depth-averaged currents at each grid cell in the computational domain. Therefore, it assumes that the currents are constant with height above the bed in each grid cell. The three-dimensional equivalent of MIKE 21 is the MIKE 3 model (also by DHI), which computes the variability in currents as a function of height above the bed. The principal advantage of two-dimensional, depth-averaged models is that they are computationally efficient because three-dimensional models require addition of grid cells in the vertical direction. In the case of the Stantec simulations, a three-dimensional model would require at least 20 layers in the vertical which would increase the model runtime by at least a factor of 20.

Despite its computational efficiency, a two-dimensional model is not appropriate to simulate the far-field effluent transport because of the importance of three-dimensional processes in the coastal region around Pictou and Caribou Harbours arising from variations in salinity and temperature, which affects the density stratification. Density stratification due to salinity arises along coastlines where river inflows bring fresh water into the ocean. Because the river water is fresh, it is less dense than the salty ocean, thus inducing vertical variations in the salinity field in which the denser, salty water lies beneath the lighter, fresher water above. Temperature stratification also exists throughout the oceans since the upper layers tend to be heated by the sun, leaving warmer and lighter waters above colder and denser waters. Temperature stratification is weakest in winter months when incoming heat is weakest.

Salinity stratification is more important than temperature stratification in coastal waters where river effects can be important. For example, the top and bottom salinities in the Pictou

Road region in July 1995 were 23.7 and 31.2 ppt (parts per thousand by mass), respectively, while the top and bottom temperatures were 13.5°C and 14°C, respectively (Preliminary study, p. 2.21). This translates to a top-bottom difference in density of 5.8 $kg/m^3$ due to the salinity and 0.1 $kg/m^3$ due to temperature, using the UNESCO equation of state calculator (UNESCO 1981). In December 1998, the salinity stratification at the same location was weaker (top-bottom salinity difference of 2 ppt) although the temperature stratification was slightly stronger (top-bottom temperature difference of 2°C). The salinity stratification generally increases with increasing river flow and decreases with tidal flow strength, since tidal currents generate turbulence that tends to mix the salinity and temperature field and weaken the vertical density stratification. Measurements indicate that the surface salinity near the East River in the Pictou Harbour region varied from 20 ppt during low-flow periods to just 5 ppt during high-flow periods (Preliminary study, p. 2.21).

Ocean water is generally stratified in the vertical because density increases with depth, with lighter, less dense waters overlying heavier, denser waters. However, in the coastal ocean there is also horizontal variability in the salinity-induced density. At a river mouth, the water is fresh and there is no vertical salinity stratification, while in the ocean far from the river mouth the salinity is high, yet there is also weak vertical salinity stratification. The most important effect of this horizontal variability in density is to induce a three-dimensional circulation in which fresh, river waters flow seaward over denser ocean waters which flow landward. In addition to the implications for the near-field transport (See Section 4.2 below), the implication for far-field transport is that effluent may be transported into the harbours with the landward-flowing denser currents. This effect is accentuated in deeper waters, implying that it will be stronger in Pictou Harbour (which also has higher freshwater flows), although the shipping channel in Caribou Harbour can act as a conduit to transport effluent-rich ocean waters into the harbour.

A second three-dimensional effect that cannot be captured by a two-dimensional model is related to the winds. When aligned with the main axes of Pictou or Caribou Harbours, winds will drive currents downwind along the shallow edges while the flow in the central, deeper portions will be driven upwind. Since the dominant westerly winds (August-April[2]) in the region are generally aligned with the main axes of the harbours, they have the potential to drive surface effluent seaward and that at depth into the harbours. Wind-driven circulation is typically not as strong as that driven by the rivers or tides, although it can be important during periods with neap tides and low river inflows.

A two-dimensional model also cannot capture the variability of the effluent with depth. The assumption of two-dimensionality in the effluent field is reasonable when the three-dimensional effects in the flow field are relatively weak. In fact it is possible to approximate some three-dimensional processes quite well with a two-dimensional model, such as a process known as shear-flow dispersion. Because of bottom friction, currents are slower near the bed, and if there is wind-driven circulation, the currents may be stronger near the surface. Therefore, tracers[3] that are in regions of the water column with slower-moving currents will be transported more slowly in the horizontal than those in the faster-moving regions of the water column. This process can be thought of as horizontal dispersion of the tracer field because it is spreading horizontally, and can be approximated reasonably well in a two-dimensional model with a shear-

[2] https://weatherspark.com/y/28559/Average-Weather-in-Pictou-Canada-Year-Round

[3] A tracer is a substance that is transported passively with the flow without buoyancy effects.

flow dispersion coefficient. The MIKE 21 model includes many approximations like this to account for three-dimensional effects in the two-dimensional transport module, although these were not employed in the Stantec studies (Preliminary study Table 2-1; Final study Table 2-11: "No decay and no dispersion in the particle tracking module"). Indeed, these approximations are not suitable for estuarine environments given that they work best in riverine environments that are weakly stratified, weakly wind-driven, and lack tidal influence.

Regardless of the influence of dispersion on the two-dimensional transport, the lack of vertical variability in the modeled tracer prevents simulation of an effluent that in reality can vary quite strongly in the vertical. The proposed effluent will typically be less dense than the receiving waters (it is both fresher with a total dissolved solids concentration, or salinity, of 1-4 kg/m$^3$, and warmer, with a winter temperature of 25$^o$C and summer temperature of 37$^o$C; Preliminary report p. 3.54). Therefore, if the receiving waters are sufficiently salty and cold (See Section 4.2 below) the effluent is expected to rise to the surface and propagate as a surface plume that is just 1-2 m thick based on the CORMIX near-field results in the Stantec studies. Furthermore, the depth at which the plume propagates is not necessarily at the surface, particularly under high flow conditions in which the effluent may be more dense than the receiving waters (See Section 4.2 below). Therefore, it is possible that the effluent could be driven in a direction that is opposite to that in a two-dimensional model if a three-dimensional model were used.

In summary, while three-dimensional effects may not be important during some periods of the year, such as during periods of low river flows and weak winds, in general a three-dimensional model is needed to accurately simulate the far-field fate and transport of effluent from the proposed discharge locations. Indeed, the MIKE 21 manual (Page 2 of DHI 2017) states, "In water bodies with stratification, either by density or by species (ecology), a 3D model should be used. This is also the case for enclosed or semi-enclosed waters where wind-driven circulation occurs." One might argue that three-dimensional models take too much time to run because of the need to include many grid points in the vertical. However, the Stantec final study employed a computational mesh with 24,645 grid cells (15,872 were employed in the preliminary study). Three-dimensional effects would be resolved with reasonable confidence using 20 or more grid cells in the vertical, which would result in 492,900 grid cells in three dimensions. This problem size is well within the reaches of a model like MIKE 3 using modern desktop computers and is relatively low compared to the problem size in other modeling studies in which three-dimensionality is important, both for consulting and academic projects (see, e.g. MacWilliams et al. 2008). Therefore, Stantec should have used a three-dimensional model like MIKE 3 because the circulation in the region is highly three-dimensional and the computational overhead is not restrictive.

### *3.2. Model setup and forcing*

*Although rivers and winds are included in the MIKE 21 model, these have no bearing on the far-field results because the effects of winds and rivers are not correctly reproduced with a two-dimensional model. Other processes like waves, storm surges, and large-scale currents were also not included in the MIKE 21 model even though they are important. Finally, the MIKE 21 simulations were conducted over a one-month period which is not long enough to assess the potential for effluent to accumulate in the harbours over much longer periods.*

Data from tidal, wind, and river inflow measurements were supplied to the MIKE 21 model using standard practices in coastal ocean modeling. However, owing to the two-dimensional nature of the model, the winds and river inflows have little to no bearing on the far-field results in the studies. Wind and river inflow data could be supplied to a three-dimensional model in a similar manner as it was supplied to the MIKE 21 model in the studies, although estimates for flows in all rivers and streams would need to be included (only the East River was included). As suggested in the Stantec studies, river inflows should be based on stream gauges when available, and based on approximations using the relative catchment area when unavailable (the East River inflow was inferred from measured flows in the Middle River at the Rocklin hydrometric station). With regard to tidal forcing, the standard practice was performed in which the observed tides at Wood Islands were reconstructed based on superposition of the most important components of the tides (using software such as T_TIDE; Pawlowicz 2002). However, the reduction in tidal amplitudes due to large-scale ice cover was not included in the tidal forcing (See Section 3.4 below).

The influence of wind-generated waves and swells were not included in the MIKE 21 model which is a reasonable assumption, although waves should be included during storms, as should the effect of storm surges (See Section 3.4 below). Finally, the west-to-east currents in the Northumberland Strait at speeds ranging from 6-9 cm/s (Lauzier 1965) should be included. These large-scale currents can have an important impact on transport by flushing a region that might otherwise accumulate with effluent without river flows or winds. While this will contribute to flushing of the proposed outfall at location CH-B near Caribou Harbour, it will drive the effluent southward with the potential to be entrained into Pictou and Boat Harbours. This effect is likely to be pronounced with three-dimensional modeling.

To evaluate the far-field dilution characteristics of effluent discharged from the proposed outfall locations, the MIKE 21 model was run over a total simulation time of one month during July 2016 for each outfall. This length of time is not sufficient to evaluate the effects of the effluent plumes given that the flow of effluent is not yet in equilibrium over such a short time period. The appropriate time period is dictated by the flushing time of the estuaries which can take days to months depending on the tides, river flows, winds, and large-scale circulation in Northumberland Strait. It is impossible to determine equilibrium from the spatial distributions of the effluent dilution factors (such as Figure 2.13 in the final study, showing the spatial distribution of the effluent dilution factor from the CH-B discharge location in the vicinity of Caribou Harbour after one month), since the effluent may still be accumulating in one of the harbours at the end of the month. A quantitative measure would need to be computed to demonstrate that the model is in equilibrium. For example, the total effluent mass in each harbour would need to be relatively constant in time, at least when averaged over a tidal cycle. Variations in forcing from processes that act over intervals that are longer than the tides (e.g. the spring-neap cycle, rainfall and associated river flow events, seasonal variations in winds), lead to associated slow variations in the effluent transport, and so these would need to be accounted for when assessing whether the total mass in the harbours is in equilibrium (see, e.g. Rayson et al. 2016).

In summary, the tides are the only component of the forcing in the far-field simulations that have any significant impact on the far-field dilution results. The other components of the forcing, including wind, river inflows, waves, storm surges, and large-scale currents are either not included or have little to no impact. Accurate representation of all of these effects would need a three-dimensional model that is run for much longer than one month to account for possible accumulation in the harbours.

*3.3. Model validation*

*Model validation is an important step in coastal ocean modeling because it demonstrates that the far-field model accurately predicts realistic currents, water levels, and other parameters. Not only is there no quantitative model validation in the studies, but the comparisons of water levels and currents to observations in Pictou Harbour demonstrate that the MIKE 21 model performs poorly. Therefore, the MIKE 21 model cannot be used to assess, with any level of confidence, the far-field behavior of the effluent discharged from the proposed outfall locations.*

Validation is the most important step in coastal ocean modeling because it proves that the model is a faithful representation of what is happening in the real world. This gives the user confidence to use the model to analyze results obtained during the validation period, but more importantly during periods when there is no data so that predictions under a wide variety of scenarios can be made. An important component of validation is the availability of appropriate observational datasets. For two-dimensional modeling, these datasets should include time series of observations of sea-surface height and the east and west components of depth-averaged currents. Depending on the instrument, depth-averaged currents can be computed if the instrument measures currents throughout the water column (such as an acoustic Doppler current profiler, or ADCP), since these measurements can be averaged to produce an accurate representation of the depth-averaged currents. However, it is more common to measure currents at a point above the bed. If three-dimensional effects are weak, then the depth-averaged model result can be validated with the point measurement. Strong three-dimensionality makes it difficult to compare a point measurement to the result from a two-dimensional model, which should not be expected to produce the correct currents when three-dimensional effects are important. Three-dimensional models should be validated with velocity data at different heights above the bed in the water column and with time series of salinity and temperature near the bed and free-surface (to assess model ability to reproduce the stratification). Since three-dimensional models compute the vertical distribution of turbulent mixing, then it is desirable to obtain measurements of turbulence to validate the turbulence models. Ideally, models could validate the results of effluent transport, although such observational datasets are rare and so this is not common.

A common step that is often performed in coastal ocean model validation is what is referred to as calibration, in which model parameters that cannot be measured are varied to improve the results. Despite the availability of accurate bathymetry datasets, the bed roughness is rarely measured although it plays an important role in dictating the resistance by the bed on the flow. For example, beds covered with sands or gravels are rougher than beds that are covered with silts or muds, and so the resistance over sands and gravels should be higher. Sometimes, the roughness may be very large if there are bedforms like sand ripples or dunes. Even the drag by vegetation, corals, and kelp is modeled with an effective roughness (Fringer et al. 2019). In some cases, the roughness is approximated with knowledge of the distribution of sediments (this was accounted for in the near-field CORMIX modeling). However, the bottom roughness is more commonly used as a calibration or tuning parameter and varied to give the best match between observations and simulations. In the MIKE 21 model, the roughness is represented specifically by the Manning's roughness parameter, which is used to compute the drag in flows with a free surface with given bed roughness properties.

After performing the appropriate calibration, it is standard practice to compare observations to simulations with quantitative metrics. There are many metrics available in the literature, although the most common are the mean error (also known as the bias), root-mean-square error, the coefficient of determination ("r-squared") and the lag, which is a measure of the time error between the observations and predictions. Another common metric is the skill score, which is a measure of the simulation error normalized by a measure of the spread in the observations. It is generally agreed upon in the coastal modeling community that a skill score greater than 0.65 characterizes excellent agreement between the model and observations (Allen et al. 2007). For simulations with tides, it is common to compare the amplitudes and phases of observed and modeled tidal constituents of both currents and water levels. These are particularly important to show that the model correctly captures the directions and magnitudes of the tidal currents. Examples of comprehensive validation of three-dimensional estuarine modeling studies can be found in MacWilliams et al. (2008) and Wang et al. (2011).

The MIKE 21 validation presented in the preliminary study by Stantec indicates that the model performs poorly because there is weak agreement between the simulations and observations. The validation is performed by running the model over a period in April 1990 when observations of water levels and currents in Pictou Harbour are available. Some statistics are computed, such as minimum, maximum, mean, and standard deviation, yet these statistics are computed separately for the observations and simulations and provide no objective measures for comparison like those found in the literature and discussed above. Despite a lack of quantitative comparisons, the qualitative comparisons represented by the figures in the preliminary study clearly indicate that the agreement between simulations and observations is poor. For example, Figure 1 below shows a comparison between simulated and measured water levels in Pictou Harbour (Figure 2-8 from the preliminary study). While the agreement in timing of the water level is good, most of the high- or low-water levels (indicated by the horizontal blue lines) are visibly incorrect. This lack of agreement could be due to wind and river forcing that was omitted from the model because of a "…lack of the simultaneous records of wind and river discharge during the period of model calibration in April 1990" (Preliminary study, p. 2.27). However, wind or flow events would produce disagreement in the tides over the duration of these events (over a few days each, such as during April 17-21), not throughout the entire record. Furthermore, attributing errors to incorrect forcing implies that the validation period is inappropriate because it does not allow for a demonstration of model fidelity through proper validation. Comparison of observed and simulated currents in Pictou Harbour in Figure 2-9 of the preliminary study shows that the model underpredicts the current speeds by roughly 20% at Location #1 and roughly 50% at Location #2, and in some cases by 80%. This level of disagreement is unjustifiable. Furthermore, there is no indication that the model correctly simulates the direction or timing of the currents since only current speeds are compared.

The differences between observations and simulations is attributed to "the nature of stratified currents through the water column from surface to the seabed, as well as the difference in bathymetry between the existing condition and that in 1990" (Preliminary study, p 2.28). If the difference is indeed due to stratification effects, then this justifies the need for a three-dimensional model. Differences in bathymetry would indicate that the choice of the validation period is not suitable because the circulation in the region was fundamentally different in 1990 than it was when the bathymetry datasets were collected over the past decade. Of course, it is always desirable to use more recent observations to ensure that the results are not contaminated by differences between the dates in which the bathymetry and flow measurements were made. However, a more careful validation procedure and use of an appropriate model should be able to indicate whether this is the case and if more recent data is needed. Regardless, the bottom line is that simply more observations are needed to prove that the model simulations are accurate. Even if the validation indicated that the simulations of currents and water levels in Pictou Harbour were excellent, it would be difficult to argue that the model also correctly reproduced currents in and around Caribou Harbour unless there were observations of water levels and currents from at least one station in that region.

In summary, the validation suggests that the model does not correctly predict the magnitude, direction, or timing of the currents. Therefore, in addition to a lack of validation in or near Caribou Harbour, the results provide no confidence that the model can accurately compute the currents and simulate the subsequent far-field fate and transport of the effluent from any of the proposed outfall locations. Furthermore, the validation provides no measure of confidence that can be ascribed to the predictions of ambient currents or directions at any of the six sites for use in the near-field modeling studies (See Section 4.2 below).

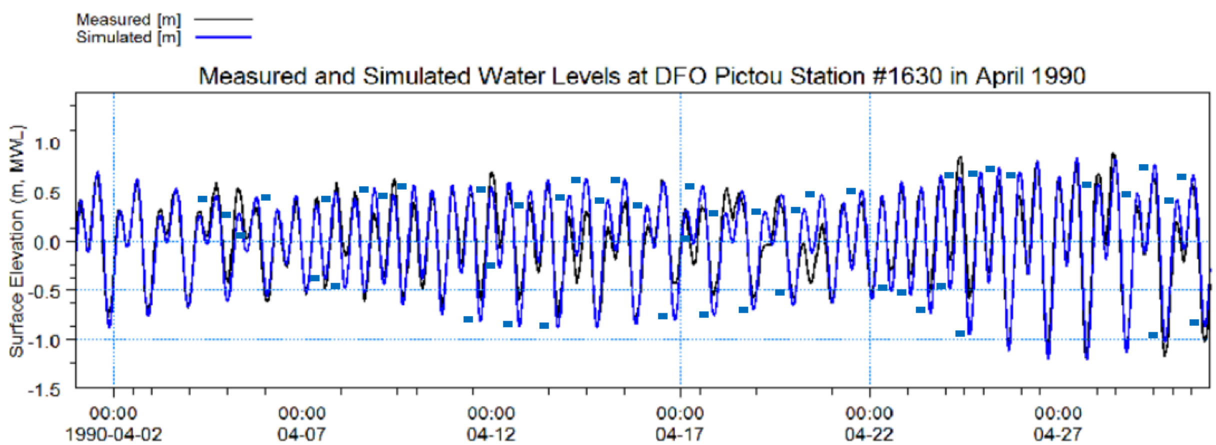


*Figure 1: (Figure 2-8 from the preliminary study): Comparison of simulated to measured water levels in Pictou Harbour during April 1990. The blue horizontal lines were added to indicate incorrectly predicted low or high water levels.*

*3.4. Model scenarios*

*The scenarios that were conducted in the studies could only evaluate (unsuccessfully) the effect of the tides in a two-dimensional model. Many more scenarios are needed using a three-dimensional model to assess the potential impacts of winds, river inflows, large-scale currents in the Northumberland Strait, waves, storm surges, and ice during winter.*

The far-field model scenarios in the studies were carried out with environmental conditions that are stated to minimize mixing of the effluent plume, thus producing conservative results. The conditions include use of "smaller tidal ranges, warmer ambient waters, less wind-driven surface currents, and lower freshwater flows from rivers" (Final report, p. 3). Warmer ambient waters during summer are conservative because, "in winter, mixing is effectively enhanced due to the larger difference in temperature and salinity (density) conditions" (Final report, p. 3). Wave and storm surge conditions are not included in the model given that "surge tides generate turbulence and ultimately provide better and faster mixing conditions" (Answer #2, Response to questions).

While some of these conditions are indeed conservative, not all are relevant or necessarily conservative, particularly in a two-dimensional model. Because the far-field model is two-dimensional and there is no vertical density stratification, the far-field plume dynamics are insensitive to the density of the effluent plume. Therefore, two-dimensional results should be the same for ambient summer or winter temperature conditions. A difference between two-dimensional effluent transport results in summer and winter could, in principle, be based on different initial effluent concentrations derived from the near-field model while taking into account the different ambient conditions from observations. However, the discharged effluent concentration in the far-field model is arbitrary because the dilution factor is a ratio of the far-field to discharged effluent concentration, and thus the actual concentration discharged from the outfall is irrelevant. A reduction in tidal and wind-driven currents reduces the vertical mixing of the plume, although again this has no bearing on the far-field results because the plume is vertically well-mixed in the two-dimensional model. However, different tidal conditions affect the tidal dispersion in the two-dimensional model and thus the tides have a significant impact on the far-field results. Wind-driven currents also affect the far-field results, but these effects are weak in a two-dimensional model since it does not account for wind-driven recirculating currents. Smaller river inflows may also be more conservative because they would be less likely to flush effluent out of the harbours. However, wind and river inflow effects can only be correctly simulated with a three-dimensional model, since both winds and river inflows can transport effluent into the harbours (See Section 3.1 above). Finally, while waves and storm surges indeed provide more mixing and dilution in the near-field, the surge has the potential to transport offshore effluent into the harbours, thus it may potentially be less conservative in terms of far-field transport.

Ice plays a significant role in the circulation and far-field effluent transport in coastal areas like Pictou and Caribou Harbours, yet its effects were not incorporated into the MIKE 21 model in the Stantec studies. While there are frameworks that can couple a model for ice formation and melting to a model like MIKE 21 (e.g. Kusahara and Hasumi 2013), it is possible to approximate the effects of ice sheets by imposing friction at the ice-water interface in the circulation model that impedes the flow of water due to the friction from the ice (Georgas 2012). In smaller domains like those in the Stantec studies, in addition to friction from the ice, the tidal boundary conditions must be altered to account for the significant reduction in tidal amplitude due to ice cover over the Gulf of St. Lawrence (Smith et al. 2006). Alternatively, these boundary conditions must be obtained from data measured during winter when there is large-scale ice cover. In shallow areas, the flow may be completely blocked when ice freezes over the entire water column, in what is referred to as "fast ice" by fishermen in the Pictou area (MacCarthy and Egilsson 2019). In the final Stantec study (p. 3), it is indicated that a winter scenario and the associated effects of ice are not considered because "the presence of ice cover would increase turbulence at the ice/water interface by providing resistance to the ambient water currents, resulting in higher mixing and dilution". Indeed, higher mixing and dilution may take place and can be modeled in the near field with CORMIX, but turbulent mixing at the ice/water interface is not accounted for in the far-field model because it is two-dimensional. Instead, the effect of ice in the far-field model is to reduce the magnitude of the currents and reduce the potential for far-field dilution. Therefore, a winter model run with extensive ice cover and appropriate boundary conditions is needed to represent a worst-case scenario for the far-field dispersion despite the substantial initial dilution of the strongly buoyant effluent during this period.

Overall, the scenarios in the Stantec reports do not reproduce the impact of different physical processes over the course of the year on the effluent transport in the region. In its current form, the far-field model can only be used to simulate the influence of tides on the far-field dispersion of the effluent plumes during low flow and low wind conditions in the absence of ice and large-scale currents. To obtain a good understanding of all of the possible scenarios that might impact the far-field transport, a three-dimensional model would need to be run under scenarios that demonstrated the effects of (1) strong/weak winds, (2) strong/weak river flows, (3) with/without ice cover (including the associated weaker tidal forcing and possibly fast ice), and (4) with/without large-scale currents through the Northumberland Strait. In each of these scenarios, the model would need to be run for at least as long as the flushing time to ensure that the far-field effluent field reaches equilibrium. If the flushing time is not much longer than a spring-neap tidal cycle, then additional scenarios would need to be run to understand the impact of strong (spring) vs. weak (neap) tides. The freshwater inflows would need to include all possible rivers and effluent from municipal wastewater treatment plants, given that the worst-case scenario may include freshening of the receiving waters to a point that significantly impacts the near-field dilution (See Section 4.2 below). Finally, storm surge scenarios would need to be studied given the possibility of strong waves and surges in the region, which could lead to significant accumulation in the harbours.

### *3.5. Results*

*The particle tracking module in MIKE 21 over-approximates the far-field mixing and dilution because of the assumption of uniformly distributed effluent mass throughout the volume of each grid cell. This gives the best-case scenario because it mixes the effluent from a point discharge completely over the water column, thus eliminating the possibility of higher concentrations confined to near-surface or mid-water layers of effluent. As a result, the assessment by Stantec that the far-field dilution factors for most of the region surrounding site CH-B are above 100 at the end of the one-month simulation period is overly optimistic. Accounting for vertical variability in the plume could lead to much smaller dilution factors but this would require a three-dimensional model. Dilution factors are also over-approximated in Caribou Harbour because the simulations are not run for long enough time to allow for accumulation of effluent in the harbour due to tidal dispersion.*

As they are presented in the reports, the far-field modeling results provide only qualitative, and in some cases misleading, information about the far-field fate and transport of effluent from the proposed outfalls. The focus of this section is on Figures 2.5-2.13 in the final study, which depict extremely low concentrations of the effluent field around site CH-B. For example, in Figure 2.5 there is a small patch of effluent located over the outfall which appears to have a concentration of 2-3 mg/L. It is hard to imagine how the concentration of the effluent from the outfall could have diluted by nearly a factor of 50 (from 100 mg/L) even though this figure depicts the concentration field at slack tide during a neap tidal cycle. As discussed in Section 2.2 above, during slack tide we expect higher concentrations due to buildup of effluent because currents are too weak to induce any significant transport away from the outfall. Higher effluent concentrations are also expected because turbulent dispersion is ignored in the particle tracking module of MIKE 21 to promote conservative dilution factors. It is possible that a diluted concentration from the outfall is imposed in the far-field model based on the near-field modeling results, although an arbitrary concentration of 100 mg/L is assumed given that the relative concentration is of interest.

The low concentrations in the figures can be explained by the particle tracking module that is used to transport effluent in MIKE 21. In the particle tracking module, the outfall is modeled as a point source from which particles with a given amount of mass are released at specified time intervals. After being released, the particles are transported by currents computed with the MIKE 21 hydrodynamic module. In the Stantec final study, the mass flow rate from the outfall is given by 0.1 kg/s, based on the assigned concentration of 100 mg/L and flow rate of 1 $m^3$/s. Therefore, if we assume that one particle is released from the outfall every hydrodynamic time step of 60 s (the details of how often particles are released are not provided, although this is a safe assumption), then it must be assigned a mass of 6 kg. It is possible to release particles at shorter intervals or multiple particles at each time step, with mass divided equally among the particles to ensure the same prescribed mass flow rate of 0.1 kg/s. However, there would be no difference between transport of a single particle and a group of particles because particles in a group do not spread over time due to a lack of turbulent dispersion, which is ignored by Stantec in the particle tracking simulations. In addition to a lack of dispersion, there is no decay assigned to the particles in the Stantec studies, and hence the mass of each particle remains fixed during the simulations.

To convert the distribution of particles to a concentration field on the hydrodynamic grid, the total mass in each grid cell (which is the sum of the masses of all of the particles in each cell) is divided by the volume of the grid cell. Assuming the grid resolution around site CH-B is approximately 25 m (based on the mesh shown in Figure 2.3 in the final study), then the volume of the prismatic grid cell containing the point release at the location of outfall CH-B is approximately 6000 $m^3$, based on a depth of 20 m and cross-sectional area of approximately 300 $m^2$. The minimum concentration in this cell can be estimated by assuming it is empty and then filled with 6 kg of effluent after one 60-s time step. Since it is assumed that this mass is uniformly distributed over the cell volume, the resulting effluent concentration will be 1 mg/L, implying a dilution factor of 100 relative to the assumed inflow concentration of 100 mg/L. This shows that conversion of the particle mass to a concentration field results in artificial mixing of the effluent, giving rise to effective mixing and dilution that depend to great extent on the mesh resolution, depth, and details of the particle release at the outfall (i.e. particle release time interval, mass per particle, number of particles per interval). Although these details are not provided in the Stantec studies, it is clear that much of the far-field dilution is an artifact of the way in which the concentration fields are calculated.

The artificial dilution arising from two-dimensional particle tracking simulations like that in the MIKE 21 model is a common feature of coastal ocean modeling. It is possible to reduce the dilution by increasing the particle release rate or by decreasing the grid size. However, decreasing the grid size is often difficult given computational constraints associated with far-field studies on grids that are finer than those in the Stantec studies. Regardless of grid resolution or the details of the particle tracking module, conclusions about far-field mixing and dilution derived from particle tracking results in a two-dimensional model should take the inherent overestimation of mixing and dilution factors into account. In this regard, Figures 2.5-2.13 in the final study cannot be used to conclude that the environmental impacts of the effluent from outfall CH-B are negligible simply because the dilution factor is at least 100 in most of the domain at the end of the 1-month period. Instead, these dilution factors represent the best-case scenario in which the effluent is mixed over the water column instantaneously upon being released from the outfall. Owing to the buoyant nature of the near-field plume and other three-dimensional effects, the effluent could be confined to a layer much smaller than the depth (as discussed in Section 3.1). As indicated by the near-field modeling results in the final study, this layer can be as small as 1-2 m, which would lead to a reduction in the dilution factor in the region surrounding the CH-B outfall by a factor of 10 or more because the effluent is not completely mixed over the water column. A three-dimensional model would be able to account for the vertical variability of the effluent plume through use of the near-field model to inform the vertical variability in the vicinity of the outfall. This would reduce the artificial dilution associated with the assumption of complete mixing over the water column in a two-dimensional model.

An additional perplexing aspect of Figures 2.5-2.13 in the final study is that they appear to depict transport of patches created by pulses of effluent discharges rather than trails of effluent emanating from the continuous-in-time discharge at outfall CH-B. Examples of such an effluent field showing trails emanating from the outfall locations are depicted in Figures 2-20 and 2-21 from the preliminary study, which show the effluent concentration field surrounding sites Alt-C and Alt-D near Pictou Harbour. Effluent trails are not visible around site CH-B in Figures 2.5-2.13 from the final study because the overestimated dilution due to the particle tracking module produces concentrations in the trails that are too low to be visible with the given color scale. Instead, higher-concentration patches (that also have artificially low concentrations) oscillate with the tides while slowly propagating away from the outfall with the weak non-tidal flow produced by the tides (see Section 2.2 for a discussion of tidal vs. non-tidal flows). While these simulations indicate that there is some dilution of the effluent patches since their concentrations decay in time, the dilution is representative of the best-case scenario when compared to the effluent concentration at the outfall of 100 mg/L.

Another process that is likely reducing dilution factors but is not represented in the simulations is accumulation in Caribou Harbour. Figure 2.11 in the final study clearly shows a patch of effluent in the harbour at slack high tide, indicating that it was transported into the harbour during the previous flood tide. Although the patch appears to be leaving the harbour during the subsequent ebb tide (Figure 2.12 in the final study), tidal dispersion is expected to transport effluent into the harbour over many tidal cycles. Furthermore, although inclusion of turbulent dispersion in the particle tracking module would act to dilute the patches, it would accentuate the tidal dispersion and promote transport into the harbour, thereby reducing the dilution in the harbour after many tidal cycles. As discussed in Section 3.4, accumulation in Caribou Harbour would need to be quantified with simulations that were run for sufficient time to demonstrate that the effluent mass in the harbour was not changing in time.

In summary, when computing concentration fields from the particle tracking results, uniform and instantaneous mixing over the grid cell volumes leads to artificially low concentrations and high dilution factors associated with far-field effluent transport from site CH-B. While it is impossible to eliminate this effect, it can be thought of as the best-case scenario in which the outfall plume is uniformly mixed over the water column. As demonstrated by the near-field modeling results in the Stantec studies, this is clearly not the case. Instead, the plume is typically confined to a smaller region in the water column, which implies a much smaller dilution factor when compared to that arising from assuming a uniform effluent concentration over the depth. The artificially low concentrations and high dilution factors produce far-field effluent concentrations in the region surrounding the CH-B outfall after a month-long simulation that are greater than 100, which is an overly optimistic result. The artificial dilution eliminates most of the visible effluent in the figures except for a few small patches that oscillate with the tides. Some of these are transported into Caribou Harbour, indicating the potential for accumulation in the harbour due to tidal dispersion, an effect that should be assessed with simulations over much longer time periods than the 31-day simulations conducted in the final study.

## 4. Review of the near-field modeling

### *4.1. Overview of CORMIX*

The CORMIX model was used to compute the three-dimensional effluent concentration field in the near-field mixing zone, which is generally defined as the region within 100 m of the outfall. Near-field mixing involves detailed flow and turbulence processes over length scales that are much smaller than the grid in the far-field model. Therefore, they cannot be simulated with MIKE 21 and must be modeled with a near-field model like CORMIX. According to the CORMIX model, the “near-field” is defined as the region between the outfall and the point at which the buoyant plume interacts with a boundary, which can be the bed, the free surface or some intermediate layer in the water column. In this near-field region, the plume dynamics are initially dictated by the high velocity flow and turbulence emanating from the outfall ports which rapidly mix the effluent with ambient waters. Once the high momentum fluid has decelerated (typically within 5-10 meters of the outfall ports), buoyancy-driven turbulence and mixing take over as the plume rises to the surface or at some point in the water column where the plume density matches the density in the water. This could be the thermocline (a point below the surface that separates the warmer, surface waters from the colder, bottom waters) or the halocline (a point at which fresher river waters are separated from the denser, saltier ocean waters below). After reaching the surface or intermediate layer, subsequent dynamics are referred to as the “far-field” zone in CORMIX. In this zone, the plume is transported by the ambient currents while spreading laterally due to weaker buoyancy effects. Once the density of the plume mixes with that of its surroundings, it propagates as a passive plume (i.e. no longer spreading due to buoyancy) with the ambient currents while spreading laterally and horizontally due to the ambient turbulence. This stage of plume development is modeled in CORMIX in a way that is similar to how it would be modeled under similar ambient conditions in a three-dimensional circulation model like MIKE 3.

The CORMIX model predicts the shape of the near-field plume in three dimensions based on the relatively complex geometry of an outfall diffuser, including the ability to specify different numbers of ports and the specific geometry of how they are attached to the diffuser pipe resting on the bed. Because CORMIX solves for the plume characteristics in a much smaller area and over much shorter time periods when compared to those in the far-field model, the characteristics of the flow needed to drive CORMIX are much simpler than the boundary conditions needed to drive the MIKE 21 model. As a result, parameters in CORMIX are generally not tuned, unlike the far-field modeling which requires tuning of, for example, the bottom roughness to improve agreement between observed and simulated currents (See Section 3.3 above). Furthermore, validation of CORMIX results is generally not required given that, at least under the scenarios that can be simulated with the CORMIX package, we expect the model to produce a good approximation of the near-field dynamics. The downside to this simplicity is that the results depend critically on choosing the effluent and ambient parameters that are representative of realistic worst-case conditions that would give the least amount of near-field dispersion and thus representative of the most conservative design scenario. As discussed in the next section, the receiving water conditions do not represent worst-case scenarios.

### *4.2. Near-field results at location CH-B*

*The receiving water current and ambient density field supplied to the CORMIX model to predict the near-field mixing and dilution at site CH-B are not representative of worst-case scenarios because the current is too strong and the ambient density is too high. This gives an over-prediction of the mixing and near-field dilution within the 100-m mixing zone surrounding site CH-B. The near-field effluent concentrations are expected to be higher, particularly during periods of high river inflows and when the tidal currents are weaker, such as during neap tides or when there is winter ice cover.*

In the final study, two scenarios for the near-field mixing at site CH-B were conducted. The only difference between the two scenarios is the use of one port in the diffuser in the first scenario and three ports in the second. The dilution factor for the three-port design was roughly twice as large as that for the one-port design 100 m from the outfall (Table 3.4 in the final study). The three-port design at site CH-B had a dilution factor that was roughly 30% larger than the six-port design at site Alt-D (Table 4.1 in the final study shows results from site CH-B obtained in the final study and results from site Alt-D, which are repeated from the preliminary study). Despite the likely increase in the dilution factor at CH-B with six ports, it was concluded that the three-port design had a favorable seabed footprint with a lower potential to interact with the seabed than the six-port design, and hence the six-port design was not evaluated at site CH-B. Given the incorrect estimates of the worst-case currents and receiving water density discussed below, studies need to be conducted with three- and six-port designs to understand their characteristics under worst-case scenarios, particularly in the presence of vertical density stratification of the water column.

The inputs to the CORMIX model that have the most significant impact on the near-field mixing in the final study are the effluent flow rate and density and the ambient tidal currents and density. The effluent flow rate was fixed at the annual average rate of 0.98 $m^3/s$, while the effluent salinity was assumed to be 4 g/L = 4 $kg/m^3$, the densest value in the reported range of 1-4 g/L. The effluent temperature was reported to be 25$^o$C in winter and 37$^o$C in summer. The summer effluent temperature was chosen under the assumption that the plume would be least buoyant in summer when the receiving waters were at their warmest. The values chosen for the effluent salinity and temperature are stated to give an upper bound for its density, thus giving a conservative estimate for the dilution because more buoyancy-driven mixing is expected to take place if the effluent is less dense than the receiving waters. Using the UNESCO equation of state (UNESCO 1981), a salinity of 4 $kg/m^3$ and temperature of 37$^o$C give an effluent density of 996 $kg/m^3$, the value used in the final study.

A key assumption in the CORMIX model is that the ambient currents are steady. Therefore, approximations are needed when applying CORMIX to tidal flows that are unsteady in that the ambient currents flowing past the outfall vary in magnitude and direction over the tidal cycle. When currents are weak, the effluent accumulates above the outfall and dilution is poor. However, the worst-case scenario occurs roughly one hour before or after slack tide when currents are weak yet sufficient to re-entrain the effluent that was recently transported away from the discharge location in the opposite direction before slack tide. CORMIX requires information about the tidal period and peak currents and the magnitude of the ambient currents one hour before or after slack tide in order to provide an estimate of the worst-case scenario. The CORMIX manual (Page 33 of Jirka et al. 1996) also recommends that additional scenarios be conducted with tidal currents at intervals of one or two hours at different stages of the tidal cycle to ensure that all possible scenarios are analyzed.

Based on the information provided in the preliminary and final studies, the ambient current supplied to the CORMIX model does not represent the worst-case mixing scenario. The preliminary report mentions the use of tidal information in the CORMIX simulations, stating that, (p. 3.54) "The results are presented for a time step corresponding to 1 hour before slack tide conditions." However, in the final report only average (10 cm/s) and maximum (27 cm/s) tidal currents are supplied based on MIKE 21 simulations in July 2016 at site CH-B. There is no mention of the tidal current speed expected within one hour of slack tide, as needed for the worst-case calculation in CORMIX. Furthermore, simulations are not conducted during different phases of the tidal cycle as suggested in the CORMIX manual. These would demonstrate the impact of current speed and direction on the dilution factor. The direction, in particular, could impact the effect of the diffuser and port alignment relative to the oscillatory flow. An important implication of the worst-case slack tide is that suspended solids may settle onto the bed within 100 m of the outfall because of the weak currents, as discussed in Section 2.2 above. This possibility is not mentioned or modeled in the Stantec studies.

Regardless of whether the details of the tide are incorporated into CORMIX, the ambient currents applied to CORMIX in the final study are too large to represent a worst-case scenario. Based on Figure 2-14 in the preliminary report, which shows the Northumberland Strait water levels over the 31-day MIKE 21 simulation period, the weakest neap tide on July 14 has a tidal range of 0.6 m, which is more than three times smaller than the strongest spring tidal range of 2 m on July 5. Therefore, the average and maximum tidal currents used in the CORMIX scenarios are much larger than they would be in the worst-case scenario because they are impacted by the large spring tides. A more conservative, worst-case tide would be given by the weakest neap tide during the period, since the weaker currents would have significantly less near-field dilution than the average tide over the 31-day period. It is important to note that, given the insufficient far-field model validation presented in Section 3.3 above, the simulations of the currents at CH-B may not be representative of the actual currents. This implies that if the currents are underpredicted in Pictou Harbour, they will not necessarily be underpredicted at site CH-B, and therefore it is not valid to justify use of inaccurate far-field model results based on the notion that the errors would lead to a more conservative worst-case scenario.

The ambient density field supplied to the CORMIX model is equally as important as the ambient currents. Estimates of the ambient density of the receiving waters were based on observations because the far-field model is two-dimensional (See Section 3.1 above). However, because observations of temperature and salinity at site CH-B were not available, the ambient density was based on observations in the Pictou Road region in August 2014 and September 2006 (Appendix B, Preliminary study). In principle, this would provide a conservative receiving water density given the likelihood that the receiving water salinity, and hence its density, was lower in this region due to more inflows into Pictou Harbour than Caribou Harbour. However, as discussed below, this is not the case. Using data from Pictou Road region, the receiving water density was calculated as 1020 kg/m$^3$ based on a temperature of 17.6$^o$C and salinity of 28 ppt, which are averages of the observations. With these salinities and temperatures, the effluent is (1020 $kg/m^3$ − 996 $kg/m^3$) = 24 $kg/m^3$ less dense than the receiving waters. According to Stantec, this provides sufficient buoyant mixing to produce far-field dilution factors computed by CORMIX that are within established water quality guidelines for the 100-m mixing zone. Owing to the strong near-field mixing by the three-port diffuser, the plume interacts with the bed up to 25 m away from the outfall. However, the dilution factor of 71 at 10 m indicates this should not be a source of concern for this value of the ambient density.

Rather than using average salinity and temperature values of observations for the ambient, a more conservative scenario for the near-field modeling would have been to use the freshest and warmest observations in the region, which should be 23 ppt instead of 28 ppt and 19.4°C instead of 17.6°C (Appendix B, Preliminary study). This would give a receiving water density that is 4 $kg/m^3$ less dense than the value used in the final study, yielding a less buoyant effluent plume and less near-field dilution. While it is unlikely that the water temperature would be much warmer than 20°C in the region, waters warmer than 20°C would contribute much less to potential reductions in ambient density than lower salinity values. This is because the density can vary by as much as 25 $kg/m^3$ due to the 0-31 ppt salinity range in the region (based on data from Galbraith et al. 2014), while it can only vary by 3 $kg/m^3$ due to the 0-20°C temperature range. In fact, the salinity value of 28 ppt that was used for the scenario is close to the maximum observed salinity in the region of 31 ppt, thus reflecting close to the best- rather than worst-case salinity for buoyancy-driven near-field dilution at site CH-B. A worst-case salinity is likely much smaller given that salinity observations in the East River range from 20 ppt during low-flow periods to as low as 5 ppt during high-flow periods (Preliminary study, p. 2.21). Lower salinity values are also likely near Caribou Harbour, although perhaps not as low given that flows into Caribou Harbour are weaker than those into Pictou Harbour. Nevertheless, all inflows in the region are expected to lower the salinity of the receiving waters surrounding the proposed outfalls in the studies.

The effect of salinity on the near-field dilution is weakest in winter when inflows are at their lowest. Combined with the colder receiving waters, winter ambient density scenarios are not needed given their potential to drive more buoyancy-driven turbulence and near-field dilution. However, given the weaker tidal currents due to ice cover in winter, scenarios would need to be conducted with worst-case winter density values for the ambient and effluent combined with model-derived worst-case weak winter tides during the period of peak ice cover.

In addition to the potential for low salinities to impact the near-field dilution by reducing the effluent buoyancy at site CH-B, low salinities indicate the existence of vertical stratification in which fresher, river water overlies saltier, denser ocean water. For example, observations in the Pictou Road region indicate a top-bottom salinity difference in July 1995 of 7.5 ppt (Preliminary study, p. 2.21), which is the dominant driver of the top-bottom density difference of 5.8 $kg/m^3$ (See Section 3.1 above). The stratification can reduce near-field dilution by trapping the effluent in a layer beneath the ocean surface where the density of the effluent matches that of the water column. Additionally, the trapping leads to far-field transport at depth rather than at the surface, thus having the potential to propagate toward the fresh water source. In the case of site CH-B, this would mean transport of the effluent into Caribou Harbour (See Section 3.1 above for a more thorough discussion of three-dimensional far-field effects). The CORMIX model has the ability to simulate near-field dilution in the presence of vertically-stratified waters, and the manual suggests including these effects when the vertical variation in density is greater than 0.1 $kg/m^3$ (Page 33 of Jirka et al. 1996), significantly smaller than the observed top-bottom density difference of 5.8 $kg/m^3$ mentioned above. Therefore, worst-case dilution scenarios at CH-B should be devised that take into account the potential for low salinity and stratification arising from high freshwater inflows in the region. These scenarios would need to be devised using results from three-dimensional, far-field modeling.

## 5. Summary

The MIKE 21 and CORMIX models were used to simulate the distribution of near- and far-field effluent discharged from proposed outfall locations in and near Pictou and Caribou Harbours. Although there are numerous metrics that are commonly used to validate far-field model results like those in the MIKE 21 simulations, these are not calculated in the study. Instead, only qualitative comparisons to observations are made, and these indicate that the far-field model is poorly reproducing the currents and water levels throughout the domain. Therefore, as it is implemented, the far-field model is inaccurate and cannot be trusted to faithfully represent actual circulation and transport dynamics in the region. Given the strong three-dimensional nature of the circulation and transport dynamics due to the winds and fresh water flows in the region, three-dimensional processes are expected to significantly impact the far-field transport. Therefore, the two-dimensional MIKE 21 model is not appropriate for use in this study.

In addition to the inaccurate nature of the far-field model, the scenarios that are presented are not representative of the multitude of processes that can impact the far-field circulation and effluent transport. While there is some qualitative evaluation of the impacts of tidal currents on the far-field fate of the effluent, the two-dimensional nature of the MIKE 21 model makes it impossible to predict the effects of strong winds or strong river inflows, effects that can significantly impact the far-field dynamics. For example, freshwater flows and wind-driven circulation can drive effluent into Caribou Harbour from site CH-B, leading to more accumulation than what might be predicted by the two-dimensional model. Furthermore, although near-field dilution may be accentuated in winter owing to the stronger temperature difference between the effluent and receiving waters, there is no assessment of the potential worst-case winter scenario in which reduced tidal currents due to ice cover may significantly reduce both near- and far-field dispersion. Similarly, while the turbulence and mixing due to storm surges and waves would likely increase near-field dilution, there are no simulations conducted to assess their impact on far-field transport, including the potential for accumulation of effluent in the harbours. Finally, the simulations are not conducted over sufficiently long time periods that are needed to ensure that the simulated far-field dilution factors are in equilibrium, making it impossible to assess the potential for accumulation of effluent in regions of the domain with weaker dispersion and flushing, such as the harbours.

Qualitative representation of the far-field dilution dynamics around site CH-B in the figures indicates fundamental inconsistencies with how the effluent concentrations are being computed and interpreted. The concentrations are unphysically low because the model assumes uniform effluent concentrations within each grid cell. This leads to an over-approximation of the far-field mixing and dilution and overly optimistic conclusions about the far-field dilution factors in the vicinity of the outfall at site CH-B, which are reported to be above 100 in most of the region after a one-month simulation. In reality, the effluent concentrations can vary significantly in the vertical, since effluent plumes can be confined to layers near the surface or mid-water, leading to higher concentrations and smaller, more realistic dilution factors. Due to the artificial dilution, trails of effluent emanating from the outfall are not visible in the figures because their concentrations are too small to appear with the given color scale. Instead, small patches of effluent oscillate with the tides, with some propagating into Caribou Harbour. These indicate the potential for accumulation of effluent in Caribou Harbour by tidal dispersion, an effect that can only be captured with simulations that are run over much longer time periods.

Based on the near-field results obtained with the CORMIX model in the final study, Stantec concluded that the dilution factors near the outfall located at site CH-B are within established water quality guidelines for the 100-m mixing zone. However, the ambient currents and densities supplied to CORMIX are not representative of worst-case near-field dilution scenarios. The currents are based on the average and peak tidal currents at site CH-B over the 31-day simulation period, which are too high because the data include two spring tides. A worst-case tidal current would be better represented by a neap tide during this period, which has smaller currents and is therefore expected to induce less near-field dilution, particularly when accounting for accumulation during slack tide. Weaker tidal currents due to winter ice cover further reduce the potential for near-field dilution, although this scenario is also not investigated. Finally, despite the potential for settling of suspended solids during slack tides within 100 m of the outfall, this is not mentioned in the Stantec studies.

In addition to the overestimated tidal currents, the ambient density supplied to CORMIX is also not representative of a potential worst-case scenario. The salinity used to compute the receiving water density is more representative of the maximum salinity in the region, which gives an effluent that is far too buoyant and thus an overprediction of the near-field buoyancy-driven mixing and dilution. The worst-case salinity, and hence receiving water density, should be much lower given the potential for high river flows to reduce the salinity in the region. Furthermore, high river flows would produce vertical salinity stratification or layering in which fresh water overlies salt water, an effect that can be included in the CORMIX model and further acts to reduce near-field dilution.

## 6. References


Allen, J., Somefield, P., and F. Gilbert, 2007, Quantifying uncertainty in high-resolution coupled hydrodynamic-ecosystem models, Journal of Marine Systems, 64, 3–14. (This paper is not freely available, although the skill score value of 0.65 is mentioned by Wang et al. 2011, which is freely available).

DHI, 2017, “MIKE 21/3 Hydrodynamic modelling (HD FM) - MIKE Powered by DHI Short description”, DHI, 14 pp., (https://www.mikepoweredbydhi.com/download/product-documentation).

Fringer, O. B., Dawson, C., He, R., Ralston, D. K., and Y. Zhang, 2019, "NSF Workshop on the future of coastal and estuarine modeling", NSF Workshop Final Report, 45 pp., (https://web.stanford.edu/~fringer/reports/nsf-workshop-final-report-2018.pdf).

Galbraith, P. S., Chassé, J., Nicot, P., Caverhill, C., Gilbert, D., Pettigrew, B., Lefaivre, D., Brickman, D., Devine, L., and C. Lafluer, 2014, Physical oceanographic conditions in the Gulf of St. Lawrence in 2014, Canadian Science Advisory Secretariat (CSAS) Research Document 2015/032, 87 pp., (http://waves-vagues.dfo-mpo.gc.ca/Library/359694.pdf).

Georgas, N., 2012: Large seasonal modulation of tides due to ice cover friction in a midlatitude estuary, Journal of Physical Oceanography, 42, 352–369, (Freely available online).

Jirka, G. H., Doneker, R. L., and S. W. Hinton, 1996, User's manual for CORMIX: A hydrodynamic mixing zone model and decision support system for pollutant discharges into surface waters, DeFrees Hydraulics Laboratory, School of Civil and Environmental Engineering Cornell University, (https://www.epa.gov/sites/production/files/2015-10/documents/cormix-users_0.pdf).

Kusahara, K., and H. Hasumi (2013), Modeling Antarctic ice shelf responses to future climate changes and impacts on the ocean, Journal of Geophysical Research - Oceans, 118, 2454–2475, (Freely available online).

Lauzier, L. M., 1965, Drift Bottle Observations in Northumberland Strait, Gulf of St. Lawrence, Journal of the Fisheries Research Board of Canada, 22 (2), 353-368, (Copy attached).

MacCarthy, A., and G. Egilsson, 2019, Caribou Harbour and Caribou Channel – dynamics, tides, ice, marine species and fisheries, Description of regional features by local fisherman.

MacWilliams, M. L., Salcedo, F. G., and E. S. Gross, 2008, San Francisco Bay-Delta UnTRIM Model Calibration Report, California Department of Water Resources Tech. Rep., 309 pp., (http://www.science.calwater.ca.gov/pdf/iep_sag/POD_UnTRIM_Calibration_Report.pdf).

Pawlowicz, R., Beardsley, B., S. Lentz, 2002, "Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE", Computers and Geosciences, 28, 929-937, (Freely downloadable software: https://www.eoas.ubc.ca/~rich/#T_Tide).

Rayson, M. D., Gross, E. S., Hetland, R. D., and O. B. Fringer, 2016, "Time scales in Galveston Bay: An unsteady estuary", Journal of Geophysical Research - Oceans, 121, 2268-2285, (Freely available online).

Smith, G.C., F.J. Saucier, and D. Straub, 2006, Response of the lower St. Lawrence Estuary to external forcing in winter, Journal of Physical Oceanography, 36, 1485–1501, (Freely available online).

UNESCO, 1981, Tenth report of the joint panel on oceanographic tables and standards, Technical Report, UNESCO Technical Papers in Marine Science, 36, Paris, 24 pp., (https://unesdoc.unesco.org/ark:/48223/pf0000046148).

Wang, B., S. N. Giddings, O. B. Fringer, E. S. Gross, D. A. Fong, and S. G. Monismith, 2011, Modeling and understanding turbulent mixing in a macrotidal salt wedge estuary, Journal of Geophysical Research - Oceans, 116, C02036, (Freely available online).

Supporting Materials to Dr. Oliver Fringer's Review of near- and far-field modeling are available at:
**https://novascotia.ca/nse/ea/Replacement_Effluent_Treatment_Facili ty _Project/comments/6-Ecojustic-comment-B-part-1.pdf**

# APPENDIX B-1

**Review of the Northern Pulp Nova Scotia Focus Report Section 6.0 and Appendix 6.2 Expanded Air Dispersion Modelling Study**

**Commentary by Elaine MacDonald, Ph.D., P.Eng., Ecojustice Senior Staff Scientist**

This commentary is provided in response to the Northern Pulp Focus Report and Stantec's Expanded Air Dispersion Modelling Study regarding the air emissions associated with the proposed Effluent Treatment Facility Project. The proposed Replacement Effluent Treatment Facility Project will produce two new sources of air emissions:

1. fugitive emissions from the replacement ETF facility; and
2. emissions of combustion gases from the burning of sludge from the replacement ETF in the power boiler.

Sections 6.1 and 9.2.7 and Appendix 6.2 of the Focus Report estimate the impacts of air pollution from the mill including the proposed new sources from the Replacement Effluent Treatment Facility.

The estimate is based on a revised emissions inventory developed "from a variety of sources and methods"[1] and emissions rates "based on a combination of site-specific data, data from alternative kraft pulp mills, and published emission estimation methods."[2] The chosen emissions inventory and emission rate data are used to drive the air dispersion model to estimate offsite ground-level concentrations.

As the inventory of emission sources and the emission rates used to conduct the air dispersion modelling come from a variety of sources and methods, many of which are not specific to the mill, the estimated ground-level concentrations are highly uncertain. Further uncertainty arises due to use of the chosen model, AERMOD. AERMOD is a simple plume dispersion model that assumes steady-state conditions.[3] However, given the coastal location of the mill and the surrounding complex terrain, a non-steady state model such as CALPUFF that contains modules for complex terrain, overwater and coastal interaction effects may be more suitable and may provide more accurate estimates.[4]

The air dispersion modelling conducted by Stantec does not take into account transitional operating conditions that occur during unit start-up, shut-down, upsets or malfunctions when air pollutant emissions often spike. The modelling appears to assume only normal operating

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[1] Focus Report, Section 6.1, page 108
[2] Focus Report, Section 6.1, page 110
[3] Focus Report, Appendix 6.2, Section 5.1, page 21.
[4] CALPUFF View
<https://www.weblakes.com/products/calpuff/resources/lakes_calpuff_view_brochure.pdf>

conditions and must, therefore, be viewed as incomplete and not representative of potential mill operations.

The estimated ground-level concentrations are compared to applicable ambient air quality criteria. Where Nova Scotia or Canadian standards, Stantec uses Ontario Reg. 419/05 standards for some contaminants.[5] The air quality analysis predicted emissions of ammonia, calcium oxide, hexavalent chromium, manganese, chloroform, benzo(a)pyrene, and total reduced sulphide above the Ontario standards.[6] Some of these contaminants, specifically hexavalent chromium (CrVI) and benzo(a)pyrene are known human carcinogens (Group 1) according to the classification by the World Health Organization International Agency for Research on Cancer.[7]

Section 6.1 of the Focus Report downplays the risk of these exceedances, stating that the frequency of the exceedances of health-based- standards occurred at discrete receptors less than 1% of the time but also notes that TRS was predicted to exceed the odour-based 10-minute standard more frequently.[8] The discrete receptors are the locations of residences near the North Pulp mill.

In terms of the amount of the exceedances and the frequency of the exceedances, total reduced sulphur (TRS) presents the greatest risk. As acknowledged on page 38 of Expanded Air Dispersion Modelling study, the effects of exposure to TRS are similar to the effects of exposure to hydrogen sulphide (e.g., irritation, respiratory and central nervous system effects). Although the TRS 10-minute standard is based on odour impacts, there have been many documented incidents of acute health effects from exposure to low concentrations of TRS, including incidents that have resulted in charges against facilities for releases of TRS compounds that have impacted neighbouring communities.[9]

The exceedances of TRS are estimated to occur frequently and at concentrations far greater than the standard at several homes (receptors). For example exceedances are noted of up to 19 percent of the time at receptor five and as much as 18 times the standard at receptor three. The most impacted home is estimated to experience an exceedance of the 10-minute odour based standard by as much as 13 times 19 percent of the time. Other receptors also have high predicted impacts from TRS either in the amount over the standard, or frequency, or both.[10]

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[5] Focus Report, Appendix 6.2, page vi and revised table 6.1 (6.1 rev.1)
[6] Focus Report, Appendix 6.2, page vi and 37
[7] <https://monographs.iarc.fr/list-of-classifications>
[8] Focus Report, p. 110.
[9] Ontario Ministry of the Environmental and Climate Change, Court Bulletin, “Refinery, Shell Canada fined $500,000 for Permitting a Discharge of Odour into the Environment”, November 27, 2015, online: <https://news.ontario.ca/ene/en/2015/11/refinery-shell-canada-fined-500000-for-permitting-a-discharge-of-odour-into-the-environment.html>. Ontario Ministry of the Environmental and Climate Change, Court Bulletin, “Pulp and Paper Mill fined $175,000 for Environmental Protection Act Violations”< https://news.ontario.ca/ene/en/2018/11/pulp-and-paper-mill-fined-175000-for-environmental-protection-act-violations.html>
[10] Focus Report, Appendix 6.2, Tables 6.2 and 7.1

Ontario also has a ten-minute odour based standard of 13 $\mu g/m^3$ for Hydrogen Sulphide ($H_2S$) that is not referred to in the report.[11] If half of the composition TRS is $H_2S$, the ten-minute $H_2S$ standard would also be exceeded at the receptors.

**Conclusion**

The air quality analysis included with the Focus Report should be considered unreliable and incomplete. The input data is not site-specific and the chosen model is not appropriate for a coastal location with complex terrain. Transitional operating conditions such as unit start-ups and shutdowns when air emissions peak were not considered. Even given these limitations the air dispersion modelling predicted exceedances of several air pollutant standards include cancer-causing substances benzo(a)pyrene and hexavalent chromium. The analysis also estimated that several residents would experience frequent and elevated concentrations of highly odorous reduced sulphur compounds resulting in an unacceptable adverse impact on the community.

November 3, 2019

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**Dr. Elaine MacDonald**
Ecojustice
Suite 1910, 777 Bay Street
Toronto Ontario, M5G 2C8

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[11] O. Reg. 419/05: Air Pollution – Local Air Quality, Schedule 3.

# APPENDIX B-2

**Dr. Elaine MacDonald**
35 Marmaduke Street
Toronto, Ontario
M6R 1T1

**Qualifications:**

- Ph.D. in Environmental Engineering (Civil Engineering Department), McGill University. 2002
- M.Eng. in Environmental Engineering (Civil Engineering Department), McGill University. 1996
- B.A.Sc. in Geotechnical Engineering, University of Toronto. 1990
- Member of Professional Engineers Ontario
- Continuing education courses in air dispersion modelling, geographic information systems and leadership

**Key Competencies**

- air and wastewater pollution emissions from municipal and industrial facilities
- environmental and human health impacts of pollution and toxic substances
- pollution and toxics law and policy

**Professional Experience**

Elaine MacDonald is a Professional Engineer with about 14 years of experience in the review and analysis of air pollution sources, dispersion modelling, environmental and human health impacts, and pollution control. Elaine MacDonald has prepared air quality reports and submissions, conducted air dispersion modelling, and analyzed numerous facility air quality reports prepared for permit applications and environmental assessments.

For over 19 years, Elaine MacDonald has been employed as a scientist at Ecojustice. Elaine MacDonald provides scientific and engineering analysis services to the environmental non-profits, community groups, and first nations through the charitable work of Ecojustice. Much of that work focuses on researching and advising on pollution-related issues, including environmental and human health impacts of emissions of pollutants to air and water from industrial and municipal facilities, and the management and regulation of toxic substances. In addition to her work as a senior scientist, in recent years Elaine MacDonald has taken on a leadership role as the Director of the Healthy Communities team.

Elaine MacDonald is a member of the Ontario government's External Working Group on O.Reg. 519/05 – Air Toxics, and the Stakeholder Advisory Council to the Federal government on the Chemicals Management Plan.

# APPENDIX C-1

**Comments on the Focus Report**

By Dr. Lynn Cameron, BSc, MSc, PhD
November 8, 2019

I am writing in relation to the Focus Report on Northern Pulp's Proposed Replacement Effluent Treatment Facility Project. My name is Lynn Cameron and I live in Three Brooks. My house is on the shore of the south gut, a tidal tributary of Caribou Harbour. Spring through fall, my dogs and I are in and on the water every day. I have a PhD in organic chemistry from the University of Victoria, an MSc in natural products synthetic chemistry from McMaster University and a BSc (Hon. Chemistry) from Saint Mary's University. Prior to my retirement in 2015, I worked at ThermoFisher Scientific (formerly known as Applied Biosystems) in the field of pharmacogenetics specializing in single nucleotide polymorphism detection and reverse transcription real time PCR (polymerase chain reaction) for gene expression analysis. Post retirement I was lucky to fish as a deck hand in the back of a boat full time during lobster season 2016 and 2017 and part time for the season of 2019.

Since I live close to the harbour and spend much of my time on or in the water I feel quite passionately against the pumping of pulp effluent into the Northumberland Strait and I urge you once again to reject the proposal.

I am writing this letter with emphasis on 3 of the terms of reference.

Term of Reference *"2.3 Submit data regarding the* ***complete physical and chemical characterization*** *of NPNS' raw wastewater (ie., influent at Point A for the Project),* ***to support the assessment of the appropriateness of the proposed treatment technology****. The influent characterization results must be compared against the proposed treatment technology specifications."*

The proposed treatment facility falls short of acceptable with respect to AOX removal (concentration measurements and lack of AOX degradation) and dangerous nitrogen and phosphorous loads that could lead to eutrophication and possible harmful algal blooms (HABs).
The proposed treatment facility is **not appropriate** because it will not sufficiently remove AOX which is composed of toxic organic chlorides including PCBs and chlorinated dioxins and furans. Nor does the facility remove excess nitrogen and phosphorous which can lead to eutrophication and ultimately harmful algal blooms (HABs).

1. **AOX Removal**

AOX is a term for a general group of organic compounds that contain 1 or more halogen atoms (in the case of bleached pulp effluent the halogen is predominately chlorine). In general, the compounds in this category are hydrophobic meaning they will adhere to fatty tissue, sediment or plant life.

Retention Time Comparison:
One of the factors affecting the amount of AOX in the water is the length of time the effluent is allowed to settle, often referred to as retention time. The authors use Point A for untreated effluent and use Point C (Boat Harbour influent) to represent the treated effluent (page 24 of the Focus Report, Figure 2.3-1).
Point C has a much longer retention time (8.5 days) which allows for the settling out of the heavier molecular weight AOX compounds compared to the proposed new ETF (less than 13 hours - Focus Report page 45). Given this fact, one can conclude that the AOX concentrations entering the marine environment from the proposed ETF will be higher than KSH predicts, and that the risk presented by such substances is greater than predicted. It is important to note that the higher the flow, the less retention time is available, which is counter to cleaning up the effluent.

Lack of AOX Degradation:
In Appendix 2.3 page 6 the authors claim the AOX is degraded into Cl- ions and carbon dioxide by photochemical and biological processes

This claim is not tenable. By the authors' own admission there can be up to 663 kg/day released into the Northumberland Strait (Focus Report, Table 2.4-3). Any AOX that can be degraded is done so during the retention time. This time is longer, as discussed above, in the current system than it will be in the proposed process. In fact, the authors show (Appendix 2.4, page 13, Table 1-5 ) that the concentration of AOX is lower in the current system (87 kg/day) than what was produced by Veolia (less than or equal to 225 kg/day). The RWS study shows 663 kg/day so the AOX released at the outfall could be more than half a metric tonne per day.

They claim that proof of the degradation is that the values for chloride ion are much greater at Point A than in the raw water (Appendix 2.3, page 6). The values for chloride are higher at Point A because chloride is produced during the bleaching process using $ClO_2$ as the bleaching agent which is what is used at Northern Pulp. The high chloride results are what we would expect based on the bleaching chemistry. Not because the AOX is degraded.

Persistent Organic Pollutants, Bioaccumulation and Biomagnification
Most AOX are toxic to marine and human health and some are considered Persistent Organic Pollutants (POPs). Persistent organic pollutants are organic compounds that do not degrade by chemical, biological, or photolytic processes.
Under the United Nations environmental program the Stockholm Convention lists 12 original, plus 16 newly classified compounds as Persistent Organic Pollutants (POPs). (1) Included in the initial 12 are hexachlorobenzene; polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans and PCBs which are also found in the pulp effluent. Because of their persistence and lipid solubility they tend to bioaccumulate. POPs have been found in the deep ocean so they do not just disappear no matter how dilute the concentration.(2)
The chlorinated dibenzo-p-dioxins (CDDs) that are eaten by marine organisms biomagnify in the food chain. The half-life in the human body for the family of

compounds known as CDD is anywhere from 5 to 15 years. (3) The ETF project entails continuous release of these harmful compounds into the Northumberland Strait. They will bioaccumulate over time and create an escalating risk as the flow continues year over year. This fact alone dictates that dilution is not the solution for pollution when it comes to chemicals that bioaccumulate.

Incorrect Sampling Technique:
The sampling reported in the Focus Report (Appendix 2.3 Pg 104 of 541 Job#B9C9662 , Pg 368 of 541 Job#B9E4451, Pg 413 of 541 Job#B9E4487, Pg 497 of 541 Job#B9E4476 , pg 541 of 541 Job# B9E4405) was done using HDPE containers. Sampling for halogenated organic compounds is typically carried out using amber glass bottles (4, 5) because the AOX molecules of interest are known to adhere to surfaces that are less hydrophilic. They stick to plastic, organic tissue (like plankton, fish and plants), sediment and HDPE. We would expect the AOX numbers to be higher if they used the proper glass bottles for sampling.

Nitrogen and Phosphorous
In Appendix 2.4 at page 10 the authors admit there is a large variation in the phosphorous content of the untreated effluent (0.12 to 5.8 mg/l) and they will not be able to attain the decreased level. Rather, they used the value from Point C (1.5 mg/L where the effluent has already settled for 8.5 days). Point C is once again not representative of actual effluent content and it is clear the phosphorous content will be variable and high.

Excessive amounts of nitrogen and phosphorous lead to algal blooms which deplete the area of oxygen and create “dead zones” in the ocean where many species can no longer live or thrive. The algal blooms can produce toxins which lead to health issues for marine life and ultimately to humans who ingest them. Algal blooms containing toxins are referred to as harmful algal blooms (HABs). Different ratios of nitrogen to phosphorous will encourage different species of algae growth. This phenomenon is not completely understood and is a current area of research. Not all algae contain toxins at all times but it is unpredictable and can change at any time. Alexandrium spp. and Pseudonitzschia spp. are both known to be present in the Northumberland Strait. (6) They have been known for producing paralytic shellfish poisoning and the neurotoxin domoic acid respectively. When conditions are not favourable for algae growth they remain in the environment as cysts. When favourable conditions arise they grow. Nitrogen and phosphorous in the effluent will surely lead to an increase in the number of blooms. With an increase in the number of blooms there is a chance that the HABs will also increase.

### 2. Baseline studies for fish and shellfish

*“9.1* ***Complete baseline studies for fish and shellfish tissue*** *(via chemical analysis) of representative key marine species important for commercial, recreational and Aboriginal fisheries in the vicinity of the proposed effluent pipeline and diffuser location.”*

It is important to note not all of the chemicals present in the effluent are tested nor are the chemical components of the effluent fully understood. The following statement is from a *Canadian Environmental Protection Act* Priority Substances List assessment report(7): *"Although approximately 250 individual compounds have been characterized in bleachery effluents, they have been estimated to represent only 10 to 40% of the total low molecular weight materials present."*
I am not confident that we truly know the effect of the chemical mixture on biological systems and therefore cannot confidently predict the risks associated with effluent exposure.

It should be noted that "not detected" does not mean the substance is not present. They are known to be generated during the pulping process and the amounts of each individual substance changes based on the type of wood that is used. Some toxins are capable of accumulating in fish up to 25 000 times the concentration in water.(7) Given that the proposed treatment facility only removes about half of the organic chemicals that will be released into the Northumberland Strait, we need further investigation into the long-term health effects before the risks can be predicted accurately.

The experiments used to determine the effect of stress (toxins, temperature, salinity, pH, turbidity, etc.) on an organism have come a long way since the early 1990s. Consequently, the Acute Lethality test (LC50) should no longer be considered sufficient. Sublethal exposure may still affect the physiology and gene expression of the fish and/or shellfish and more work is required to understand this. We know many of the halogenated organic compounds affect the reproductive and immune systems, and can lead to developmental disorders or cause cancer. Gene expression experiments help gain a better understanding of the exposure effects on protein and enzyme production which gives us an idea of how the effluent will influence the function of biological processes. Popesku et al (8) look at the effects of pulp effluent (3 Kraft and 2 Thermomechanical) on gene expression of the neuroendocrine brain of fathead minnows. They conclude that pulp effluent does inhibit spawning by females by decreasing the levels of key enzymes in the hypothalamus. They conclude that effluents contain neuroactive substances that have yet to be characterized which is made more difficult because of the complex mixture that composes pulp mill effluent. The paper by Brockmeier et al (9) use gene expression to investigate exposure of mosquitofish to kraft pulp mill effluent on the Fenholloway river and demonstrates endocrine disrupting properties of the pulp mill effluent. They found 121 genes upregulated (over-expressed) and 91 genes downregulated by effluent exposure. Sixty-two of the genes are involved in metabolic pathways and are consistent with experimental results of the fish exposed to androgens. They conclude the effluent is responsible for masculinizing the female mosquitofish.
In order to understand and assess the risk presented by the effects of effluent components, further gene expression profiling experiments must be performed on fish and shellfish that are exposed to the effluent at concentrations consistent with what will exit at the diffuser as final effluent, and not once it is diluted. The results should then be compared to those from unexposed samples from the same species.
While the toxicity of each individual compound can be taken into account, as I mentioned in my comments on the EARD, the cumulative **effect of the mixture of toxins** in the

effluent on sea life and ultimately human health is unknown and the risk cannot be assessed with the information as summarized in the Focus Report and EARD. (10)

### 3. Assessment of impacts on Human Health

*9.2 Commence a Human Health Risk Assessment (HHRA) to* ***assess potential project-related impacts on human health****. The risk assessment must consider human consumption of fish and other seafood, consumption of potentially contaminated drinking water, exposure to recreational water and sediment, outdoor air inhalation, and any other potential exposure pathways. The analysis must inform the identification of contaminants of concern and updating of the receiving water study.*

In Appendix 9.2, Table A.6a the dioxin 2,3,7,8-TCDD is flagged as a contaminant of potential concern in the seafood ingestion pathway and is present in the effluent sought to be discharged at the outfall for the proposed ETF. This compound, 2,3,7,8-tetrachloro dibenzo-p-dioxin (2,3,7,8-TCDD), is the most toxic of the dioxins known. It is believed to cause liver damage, increased risk of diabetes and abnormal glucose tolerance along with possible reproductive or developmental effects as demonstrated in animal studies and may increase the risk of cancer in people. (3) As a CDD it is included in the POP as designated by the Stockholm convention mentioned above.

In Appendix 9.2, Table A-4 the authors maintain that total phosphorous is not a parameter considered to be of potential human health concern.
"Phosphorus is a required dietary mineral. Phosphorus exists in the environment as phosphate anion, where it acts as a nutrient, and has not been associated with adverse effects in humans. Human health concerns are primarily related to increased productivity (eutrophication) in aquatic systems, which is outside the scope of this human health risk assessment (CCME, 2004)."

The conclusion is not accurate: Eutrophication is an issue. Various levels of nitrogen and phosphorous will lead to algal blooms and potentially **harmful** algal blooms (HABs). (11, 12, 13, 14, 15)

### Comments on Table: Understanding Water Measurement Units

As a final point, I have attached a revision to the Table found at page xix of the Focus Report as Appendix 1 to these comments. In my view, the time analogy presented in that table is misleading and fails to properly depict the presence and significance of various compounds in the effluent. The Dillon table suggests that the presence of certain compounds is miniscule and they are therefore harmless. This is dangerous and misleading as the risks from many of these substances is very high even at extremely low concentrations. My revised table provides a better summary based on molecules per litre and molecules per day of these substances. I provide further explanatory comments following my revised table.

**Conclusion**

Thank you for taking the time to read this letter and please consider that we could potentially be destroying the sensitive aquatic ecosystem of the Northumberland Strait and rendering it uninviting for aquatic species and human recreation if the current proposal is granted. We could also be poisoning and/or killing the fish and thereby poisoning ourselves. I beg you to ensure the proper and current experiments are performed before pulp effluent is pumped into the strait. It is my opinion that the limits of allowable toxins and effects of said toxins are not well established and some risks remain unidentified, while others are much more significant than predicted in the Focus Report and EARD.

References:

1. The 12 initial POPs under the Stockholm Convention
http://chm.pops.int/TheConvention/ThePOPs/The12InitialPOPs/tabid/296/Default.aspx

2. Depth Profiles of Persistent Organic Pollutants in the North and Tropical Atlantic Ocean Environmental Science and technology, Caoxin Sun, Thomas Soltwedel, Eduard Bauerfeind, Dave A. Adelman, and Rainer Lohmann
https://pubs.acs.org/doi/pdf/10.1021/acs.est.5b05891

3. TOXICOLOGICAL PROFILE FOR CHLORINATED DIBENZO-p-DIOXINS
https://www.atsdr.cdc.gov/toxprofiles/tp104.pdf

4. from Environment Canada THE INSPECTOR'S FIELD SAMPLING MANUAL
http://publications.gc.ca/collections/Collection-R/En40-498-2005-1E.pdf

5. US EPA Sampling Guidance for Unknown Contaminants in Drinking Water
https://www.epa.gov/sites/production/files/2017-02/documents/sampling_guidance_for_unknown_contaminants_in_drinking_water_02152017_final.pdf

6. Paralytic Shellfish Poisoning (PSP) toxins in Miramichi Bay (New Brunswick, southern Gulf of St. Lawrence): Seeking the source, Claude E. Léger and Stephen S. Bates, 2012
https://waves-vagues.dfo-mpo.gc.ca/Library/346923.pdf

7. Canadian Environmental Protection Act Priority Substances List Assessment Report No. 2 Effluents from Pulp Mills Using Bleaching
https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/contaminants/psl1-lsp1/pulp_mill_effluents_pate_blanchie/pulp_bleaching-pate_blanchie-eng.pdf

8. Gene expression profiling of the fathead minnow (Pimephales promelas)

neuroendocrine brain in response to pulp and paper mill effluents, Jason T. Popeskua, Elvin Y.Z. Tana, Pierre H. Martelb, Tibor G. Kovacsb, Andrea Rowan-Carrollc, Andrew Williamsc, Carole Yaukc, Vance L. Trudeaua, Aquatic Toxicology, 99 (2010) 379–388

9. Brockmeier EK, Jayasinghe BS, Pine WE, Wilkinson KA, Denslow ND (2014) Exposure to Paper Mill Effluent at a Site in North Central Florida Elicits Molecular-Level Changes in Gene Expression Indicative of Progesterone and Androgen Exposure. PLoS ONE 9(9): e106644. doi:10.1371/journal.pone.0106644

10. DETECTION OF REPRODUCTIVE IMPACTS OF EFFLUENTS FROM PULP AND PAPER MILLS: SHIFTS IN ISSUES AND POTENTIAL CAUSES KELLY R. MUNKITTRICK, MARK E. MCMASTER, AND MARK R. SERVOS Environmental Toxicology and Chemistry, Vol. 32, No. 4, pp. 729–731, 2013 https://s3.amazonaws.com/academia.edu.documents/41222345/Detection_of_reproductive_impacts_of_eff20160115-2201-1taioh7.pdf?response-content-disposition=inline%3B%20filename%3DDetection_of_reproductive_impacts_of_eff.pdf&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Credential=AKIAIWOWYYGZ2Y53UL3A%2F20191011%2Fus-east-1%2Fs3%2Faws4_request&X-Amz-Date=20191011T005246Z&X-Amz-Expires=3600&X-Amz-SignedHeaders=host&X-Amz-Signature=8f04e71dc392e64754628c99d028463ad8ac3bad4bb831177cab01c5b2d627e6

11. US EPA The Facts about Nutrient Pollution https://nepis.epa.gov/Exe/ZyNET.exe/P100UWV3.txt?ZyActionD=ZyDocument&Client=EPA&Index=2016%20Thru%202020%7C1991%20Thru%201994%7C2011%20Thru%202015%7C1986%20Thru%201990%7C2006%20Thru%202010%7C1981%20Thru%201985%7C2000%20Thru%202005%7C1976%20Thru%201980%7C1995%20Thru%201999%7CPrior%20to%201976%7CHardcopy%20Publications&Docs=&Query=marine%20nutrient%20levels&Time=&EndTime=&SearchMethod=2&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&UseQField=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5CZYFILES%5CINDEX%20DATA%5C11THRU15%5CTXT%5C00000031%5CP100UWV3.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=15&FuzzyDegree=0&ImageQuality=r85g16/r85g16/x150y150g16/i500&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x#

12. US EPA Preventing Eutrophication: Scientific Support for Dual Nutrient Criteria https://nepis.epa.gov/Exe/ZyNET.exe/P100V89H.txt?ZyActionD=ZyDocument&Client=EPA&Index=2016%20Thru%202020%7C2011%20Thru%202015&Docs=&Query=algae%20bloom&Time=&EndTime=&SearchMethod=2&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&UseQField=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5CZYFILES%5CINDEX%20DATA%5C11THRU15%5CTXT%5C00000031%5CP100V89H.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-

&MaximumDocuments=15&FuzzyDegree=0&ImageQuality=r85g16/r85g16/x150y150g16/i500&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionE&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1

13. Harmful algal blooms and eutrophication: Examining linkages from selected coastal regions of the United States Donald M. Anderson, Joann M. Burkholder, William P. Cochlan, Patricia M. Glibert, Christopher J. Gobler, Cynthia A. Heil, Raphael M. Kudela, Michael L. Parsons, J. E. Jack Rensel, David W. Townsend, Vera L. Trainer, Gabriel A. Vargo, Harmful Algae 8 (2008) 39–53

14. Harmful Algal Blooms and Eutrophication: Nutrient Sources, Composition, and Consequences DONALD M. ANDERSON1, PATRICIA M. GLIBERT, and JOANN M. BURKHOLDER, Estuaries Vol. 25, No. 4b, p. 704–726 August 2002

15. Lucy Ngatia, Johnny M. Grace III, Daniel Moriasi and Robert Taylor (January 14th 2019). Nitrogen and Phosphorus Eutrophication in Marine Ecosystems, Monitoring of Marine Pollution, Houma Bachari Fouzia, IntechOpen, DOI: 10.5772/intechopen.81869. Available from: https://www.intechopen.com/books/monitoring-of-marine-pollution/nitrogen-and-phosphorus-eutrophication-in-marine-ecosystems

**Appendix 1**

| | Symbol | Multiplying Factor | Exponent Form | Parameter Measurements | Units | Part per | **molecules per L** (assume ave molecular weight of 300) | **molecules/day** (assume ave. molecular weight of 300 and 85 million litres per day) |
|---|---|---|---|---|---|---|---|---|
| *Base Unit* | *Base unit* | 1 | 1.00E+00 | gram/litre | g/L | 1 part per thousand | 2,047,000,000,000,000,000,000 | 174,000,000,000,000,000,000,000,000 |
| deci | d | 0.1 | 1.00E-01 | decigram/litre | dg/L | 1 part per ten thousand | 204,700,000,000,000,000,000 | 17,400,000,000,000,000,000,000,000 |
| centi | c | 0.01 | 1.00E-02 | centigram/litre | cg/L | 1 part per hundred thousand | 20,470,000,000,000,000,000 | 1,740,000,000,000,000,000,000,000 |
| milli | m | 0.001 | 1.00E-03 | milligram/litre | mg/L | 1 part per million (ppm) | 2,047,000,000,000,000,000 | 174,000,000,000,000,000,000,000 |
| micro | u | 0.000001 | 1.00E-06 | microgram/litre | ug/L | 1part per billion (ppb) | 2,047,000,000,000,000 | 174,000,000,000,000,000,000 |
| nano | n | 0.000000001 | 1.00E-09 | nanogram/litre | ng/L | 1 part per trillion (ppt) | 2,047,000,000,000 | 174,000,000,000,000,000,000 |
| pico | p | 0.000000000001 | 1.00E-12 | picogram/litre | pg/L | 1 part per quadrillion (ppq) | 2,047,000,000 | 174,000,000,000,000,000 |

For the purpose of this exercise I used an average molecular weight of 300. The calculation is shown below.

As you can see, in the mg/L range, the number of molecules per litre is in the billions of billions order of magnitude! My point is that a part per million is not as dilute a solution as the time analogy would imply. So, even if we assume the best case scenario after "cleanup" is correct, the amount of AOX is estimated to be approximately 1.02mg/L (which calculates to 87kg/day) from Table 2.3-3 we can expect somewhere around 2 billion billion halogenated molecules per litre (that is 174 trillion trillion halogenated molecules per day).

The number of molecules present in a given mass is dependent on the chemical structure (number and type of atoms that make up the molecule), therefore, an average molecular weight of 300 was used. Typically, in chemistry terms, we refer to that as 300 grams per mole (or 300g/mol).
If molecular weight is half of the assumed value, ie half of 300 is 150, the final number of molecules per litre would be doubled. Conversely, if the molecules were larger, say a MW 600, then molecules per litre would be halved.

Calculation:
Molecular weight: 300g/mole
Avogadro's number: 6.022 x $10^{23}$ molecules/mole (this is a constant)

molecules/gram: 6.022 x $10^{23}$ molecules/mole ÷ 300g/mole = 2.007 x $10^{21}$ molecules/g
molecules/mg: 2.007 x $10^{21}$ molecules/g x 0.001g/mg = 2.007 x $10^{18}$ molecules/mg
molecules/L in a 1 ppm (mg/L) solution:
2.007 x $10^{18}$ molecules/mg x 1.02 mg/L = 2.047 x $10^{18}$ molecules/L
molecules/day in a 1ppm (mg/L) solution at a flow rate of 85 million L/day (peak flow, page 38 Focus Report ):
2.047 x $10^{18}$ molecules/L x 85,000,000L/day = 1.74 x $10^{26}$ molecules/day

# APPENDIX C-2

**Lynn Michele Cameron**
84 Otter Rd
Pictou, Nova Scotia
B0K 1H0
Canada

home:(902)485-1686, cell: 360-990-0568
email: lynn@seanova.com

**Education:**

- **Doctor of Philosophy, University of Victoria** - Victoria, British Columbia
  Program in organic chemistry (synthesis of artificial ion transporters), January 1997.
- **Master of Science, McMaster University** - Hamilton, Ontario
  natural products chemistry, March 1990
- **Bachelor of Science, Saint Mary's University** - Halifax, Nova Scotia
  Honor's program in chemistry, September 1982 - April 1986

**Employment History: PEBiosystems, Applera,Applied Biosystems, Life Technologies, ThermoFisher (1999-2015)**

- **Applications Support,** ThermoFisher Scientific, November 2014- November 2015, Pharmacogenomics Support for customers in the field
- **Technical Application Specialist,** Life Technologies, 2011-2014
  Phone technical support for real time PCR including diagnostics instruments QuantStudio Dx ,7500Dx and Veriti Dx as well as support pharmacogenomics customers.
  After hours On-call phone support for Pharmacogenomic customers
- **Technical Application Specialist,** Life Technologies, January 2010- October 2014, Real time PCR and DNA Synthesis customer support
  Performed on-site customer trainings on OpenArray Genotyping System (BioTrove)
  Provide training to our technical support group
  Actively co-ordinated trainings for Support group (FAS, TS, Product Information)
  Developed and implemented online eLearning modules for internal and external customers for the NT OpenArray instrument.
  Co-developed customer training classes for Genotyping (CNV, TaqMan Genotyping, HRM)

- **Senior Technical Application Specialist,** Applied Biosystems, December 2002-2009, DNA Synthesis and Real-Time PCR applications
  Provide applications training for customers who purchase Applied Biosystems Real Time PCR Instrumentation
  Provide ongoing telephone and email application support in pre and post sale situations for all AB PCR, real-time PCR and DNA synthesis products, including software, hardware, peripheral accessories, and consumables
  Develop and maintain positive relationships with customers
  World wide support for PNA synthesis from January 2005-January 2007
  supported customers and salespeople world wide via telephone
  performed interim role of Product Specialist for 8 months
  perform role of FSTS (Field Service Technical Specialist), where I only travel to “hot” sites if the Field Service Engineers cannot solve the problem
  continued regularly scheduled on-line training sessions for customers using ABI 3900
  taught service class for ABI 3400 DNA Synthesizer
  wrote and reviewed User Bulletins for the ABI 3900 DNA Synthesizer
  continued to write Visual Basic custom programs for users of the ABI3900 DNA Synthesizer to help with the importing of sequence data
  As of March 11, 2004-present I am sole support for DNA synthesis products for North America and continue to support the world
  As of June 2004-2005 I was also supporting the Voyager MALDI via telephone queue

- **Senior Field Application Specialist,** Applied Biosystems, December 2001-2, DNA Synthesis

supported customers and salespeople in North America
developed regularly scheduled on-line training sessions for customers using ABI 3900
developed training CD for service engineers
contributed content to service class for ABI 3900 DNA Synthesizer
developed content for in-house customer class for ABI 3900 DNA Synthesizer
wrote and reviewed User Bulletins for the ABI 3900 DNA Synthesizer
wrote Visual Basic custom programs for users of the ABI3900 DNA Synthesizer to help with the importing of sequence data
on the team responsible for field laptop configuration

- **Field Application Specialist,** Applied Biosystems, March 1999-December 2001, Combinatorial Chemistry
supported customers and salespeople "west of the Mississippi",
power user responsible for training group on new customer relationship management software
assisted with ISO 9001 documentation
on the team responsible for designing an "asset tracking database" to keep track of field leased equipment
- **Scientist,** MDS Panlabs, February 1997-Feb 1999, Combinatorial Chemistry, supervise the operation of four Sciex API 150 Mass Spectrometers
helped develop a "compound tracking database" used for keeping track of compounds through the purification process
- **Part-time faculty position,** Saint Mary's University, September 1991-December 1991, supervised and marked undergraduate analytical experiments
- **Research Assistant**, for Dr. K. Vaughan, May 1991-December 1991
synthesized and characterized triazenes
- **Research and Development Chemist**, Cangene Corporation - Mississauga, Ontario, January 1990-September 1990
analytical method development and support
peptide (and substrate) synthesis and characterization, synthesized peptides and assayed as potential inhibitors for a protease
HPLC support, provided technical and theoretical support to all R and D personnel in the company
-

**Skills:**

- 14+ years of customer interaction via phone and in person
- knowledge and experience with wide range of scientific applications including real time PCR instrumentation and methods including gene expression and genotyping (High Resolution Melting, Copy number variation and SNP genotyping, digital PCR)small molecule synthesis, DNA synthesis, PNA synthesis,
- experience in DNA synthesis, purification and characterization
- experience in combinatorial chemistry synthesis, purification and characterization
- experience in both property directed and natural product synthesis as well as experience in solid phase peptide synthesis
- Experience in analytical techniques including the Mass spectrometry, chromatography, high field nmr, IR
- experience in a number of purification techniques including column chromatography, centrifugal chromatography and high speed counter current chromatography

**Publications and Patents:**

- "Purification and Analysis of Parallel Libraries", Cheryl D. Garr, Lauri Schultz, Lynn M. Cameron Chapter 7
- "Synthesis and Membrane Activity of a Bis(metacyclophane)bolaamphiphile", Lynn M. Cameron , Thomas M. Fyles , and Chi-wei Hu, *J. Org. Chem.*, 2002, *67*, 1548-1553.
- "Method of Purifying and Identifying a Large Multiplicity of Chemical Reaction Products Simultaneously", Lynn M. Cameron , Cheryl D. Garr ,David Schedin and Lauri Schultz, US Patent #5993662 (1999).
- "High Throughput Purification of Combinatorial Libraries",Lauri Schultz, Cheryl D. Garr, Lynn M. Cameron and Julie Bukowski, *Bioorganic and Medicinal Chemistry Letters*, 8 (1998) 2409-2414.
- "The Barrier to Rotation in Thioformamide: Implications for Amide Resonance", Keith E. Laidig and Lynn M. Cameron, *J. Am. Chem. Soc.*, 1996, 118, 1737.
- "What happens to formamide during C-N bond rotation? Atomic and molecular reactivity as a function of internal rotation", Keith E. Laidig and Lynn M. Cameron, *Can. J. Chem.*, 1993, 71, 872.

Lynn M.Cameron

- "Synthesis of a Series of 3-Aryl-1-methyltriazene 1-oxides with Substituents in the Ortho or Para Position in the Aryl Group." Lynn M. Cameron, Keith Vaughan and Donald L.Hooper, *Can. J. Chem.*, 1992, 70, 8, 2241.
- "Structures of the Isomeric Triazene 1-Oxides 3-(4-Ethoxycarbonylphenyl)-1-methyltriazene 1-oxide (1) and 3-(2-Ethoxycarbonylphenyl)-1-methyltriazene 1-oxide (2)." Keith Vaughan, Lynn M. Cameron, Sean Christie and Michael J. Zaworotko, *Acta. Cryst.*, 1992, C48, 1992.
- "Triazene Metabolism IV. Derivatives of Hydroxymethyltriazenes: Potential Pro-drugs for the Active Metabolites of the Anti-tumor Triazene, DTIC" L.M.Cameron, K. Vaughan, R.J.LaFrance, C.M.Hemens and R.Rajaraman, *Anti-Cancer Drug Design*, vol. 1, 1985
- "Triazene Metabolism V. Chemical and Biological Properties of N,N-bis-[(1-aryl-3-methyltriazene-3-yl-)methyl-]methylamines: Potential Pro-drugs for the Cytotoxic Monoethyltriazenes." H.W.Manning, R.J.LaFrance, L.M.Cameron and K.Vaughan, *Anti-Cancer Drug Design*, vol. 1, 1985.

**Extra Courses:**
- Computer Programming II, Visual Basic, completed April 2000 Everett Community College
- Computer Programming I, Visual Basic, completed December 2000 Everett Community College
- Project Management, completed April 1996 University of Victoria
- Decision and Risk Analysis, completed December 1995 University of Victoria

**Short Courses and Training:**
- Taqman OpenArray Genotyping System Class,Applied Biosystems; October 2008
- 7300/7500 Real Time PCR Service Class,Applied Biosystems; January 30-February 3, 2006
- 7300/7500 Real Time PCR IQ/OQ Training,Applied Biosystems; January 30-February 3, 2006
- Methods in PCR TAS/FSE,Applied Biosystems; October 3-5, 2005
- Real Time PCR Applications Training Class,Applied Biosystems; November 14-18, 2005
- Voyager – Data Explorer Course,Applied Biosystems; June 7-10, 2004
- 3400 Service Class, Applied Biosystems; October 28-30, 2003
- 392/394 Service Class, Applied Biosystems; December 3-7, 2001
- 3900 CTS Service Class, Applied Biosystems; February 21-23, 2001
- Excellence in Service, October 31- November 1, 2000
- Windows NT Fundamentals, November 13-14, 2000
- Excellence in Service, October 31- November 1, 2000
- The Counselor Salesperson, August 8-10, 2000
- Procise-HT In House Service, Applied Biosystems; July 18-21, 2000
- Versatile Salesperson, June 6-7, 2000
- Presentation Presence I, May 18, 2000
- Introduction to Programming with Visual Basic, Boston University IT Programs, April, 2000
- Short course in Visual Basic for Automating the Laboratory, Jan. 22-23, 2000
- 530 (Small Molecule Synthesizer) Service Class, Applied Biosystems; June 7-11, 1999
- Combinatorial Chemistry; Short Course offered by ASMS, June 12-13, 1999
- LC/MS: The Techniques of Electrospray and APCI, May 31-June 1, 1997

# APPENDIX D-1

Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Gulf Region

Canadian Science Advisory Secretariat
Science Advisory Report 2018/029

# ASSESSMENT OF THE SOUTHERN GULF OF ST. LAWRENCE (NAFO DIV. 4T) SPRING AND FALL SPAWNER COMPONENTS OF ATLANTIC HERRING (*CLUPEA HARENGUS*) WITH ADVICE FOR THE 2018 AND 2019 FISHERIES

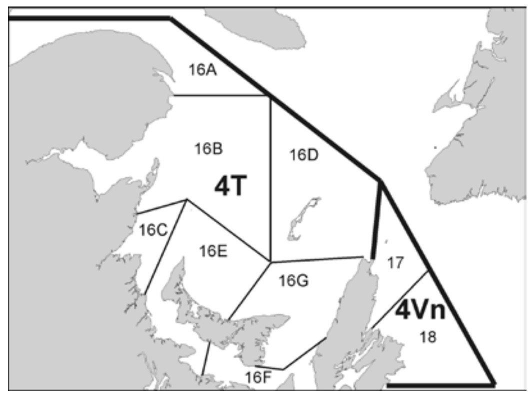


*Figure 1. NAFO Divisions 4T and 4Vn and the corresponding herring fishery management zones.*

## Context:

*The stock area for southern Gulf of St. Lawrence Atlantic Herring extends from the north shore of the Gaspe Peninsula to the northern tip of Cape Breton Island, including the Magdalen Islands (Fig. 1). Available information suggests that adults overwinter off the east coast of Cape Breton primarily in NAFO Division 4Vn. Southern Gulf of St. Lawrence herring are harvested by a fixed gear (gillnet) fleet on spawning grounds and a mobile gear (purse seine) fleet (vessels >65') in deeper water. The fixed gear fleet harvests almost exclusively the spring spawner component in the spring, except for June, and almost exclusively the fall spawner component in the fall. The mobile fleet harvests a mixture of spring and fall spawner components during their fishery. The proportions of spring and fall spawner components in the catch vary according to season. In recent years, spring herring have been sold primarily for bait but historically were also used for the bloater (smoked herring), and filet markets. Fall landings are primarily driven by the roe, bloater and filet markets. Annual quota management was initiated in 1972. In 2017, there were 2,339 fixed gear licenses and 8 seiner licenses.*

*Assessments of the spring and fall spawning herring from the southern Gulf of St. Lawrence (NAFO Div. 4T) are used to establish the total allowable catch. A meeting of the Regional Advisory Process was held March 15, 2018 in Moncton, N.B. to assess the status of the spring and fall spawner components of 4T herring and to provide advice for the 2018 and 2019 fisheries. Participants at the meeting included DFO Science (Gulf, Newfoundland and Labrador, Quebec Regions), DFO Fisheries Management (Gulf and Quebec Regions), provincial governments, the fishing industry, and aboriginal organizations.*

# SUMMARY

- Atlantic Herring in the southern Gulf of St. Lawrence are comprised of spring spawning and fall spawning components which are considered to be distinct stocks and as such are assessed separately.
- Fishery dependent indices are an important component of the assessment. Indices such as the commercial gillnet CPUE, may not be proportional to abundance due to changes in catchability over time. For example, catch rates can remain elevated despite decreases in abundance (increased catchability) due to contractions in stock distribution and targeting of aggregations by fishing fleets, as well as due to improved fishing technology and fishing practices.

### Spring Spawner Component (SS)

- The preliminary estimated landings of SS herring in 2016 and 2017 were 966 t and 1,189 t, respectively, from annual total allowable catch values of 2,000 t.
- A virtual population analysis model that incorporated changes in catchability in the fixed gear fishery has been used since the last assessment.
- The estimates of Spawning Stock Biomass (SSB) at the beginning of 2017 and 2018 were 11,744 t (95% confidence interval: 6,463 – 28,171) and 12,446 t (95% CI: 6,418 – 30,365), respectively. The SSB has been in the critical zone of the Precautionary Approach framework since 2004 and the probabilities that SSB remained in the critical zone at the beginning of 2017 and 2018 were over 90%.
- The average fishing mortality rates on ages 6 to 8 for the SS exceeded $F_{0.1}$ (the removal reference level in the healthy zone, $F = 0.35$) during 2000 to 2011. $F$ declined below $F_{0.1}$ in 2012, reaching its lowest value of 0.19. The fishing mortality rate during 2015 to 2017 averaged 0.24 (annual exploitation rate of 0.21).
- Due to variable recruitment in recent years, projections were conducted under three different recruitment scenarios during the projection period: (1) high recruitment, (2) low recruitment, and (3) mixed recruitment.
- SSB at the start of 2019 and 2020 was projected to increase slightly at annual catches less than 500 t, remain roughly stable at annual catches of 1,000 t, but decline at catches of 1,500 t or more. However, uncertainty in projected SSB is high. Even in the absence of any removals of SS herring in 2018 and 2019, the SSB is expected to only increase slightly with a high probability that the stock will remain in the critical zone.
- Since 2009, the TAC has been set to 2,000 t annually. At a catch of 2,000 t, the probability of an increase in SSB ranges from 0% (low recruitment scenario) to 19% (high recruitment scenario) with only a 10% chance of exceeding the LRP even under the high recruitment scenario.
- Elevated fishing mortality, declines in weights-at-age, and variable but low recruitment rates are further impeding the rebuilding of the stock.

### Fall Spawner Component (FS)

- The preliminary estimated landings of the FS herring component in 2016 and 2017 were 24,677 t and 20,523 t respectively, from a total allowable catch of 35,000 t annually.

- Beginning in 2015, the FS herring assessment model incorporated the dynamics of three regional sub-stocks (North, Middle, South) which jointly comprise the NAFO Div. 4T stock. The catch options are evaluated at the level of the southern Gulf of St. Lawrence.
- Catchability to the fixed gear fishery was estimated to differ between regions and to have changed over time, being lowest with little variation in the North region in contrast to increases in the Middle and South regions over the time series.
- For the southern Gulf of St. Lawrence, the median estimate of SSB at the start of 2018 is 112,000 t. The probabilities that the SSB was below the Upper Stock Reference (USR) level of 172,000 t at the beginning of 2017 and 2018 were 98% and 97%, respectively.
- The average fishing mortality rate on ages 5 to 10 for the FS exceeded $F_{0.1}$ (the removal reference level in the healthy zone, $F = 0.32$) from 1994 to 2011 except in 2004, but declined from 2012 to attain the lowest levels in 2016. $F$ averaged 0.20 during 2015 to 2017.
- Estimated abundances of age 4 herring at the start of 2017 and 2018 were very low, but with very large uncertainty.
- The median of the projected SSB at the start of 2019 and 2020 remains below the USR at all annual catch levels of 10,000 t or greater with a probability of at least 90%.
- At catches of 20,000 t (the catch in 2017) in 2018 and 2019, the probability of the SSB remaining under the USR in 2020 was estimated at 94%. At the 20,000 t catch level, the probability of the fishing mortality rate being above the removal rate reference was estimated at 46%. $F_{0.1}$ is a removal reference for when a stock is in the healthy zone of the Precautionary Approach.
- Current retrospective patterns indicate that the assessment model may overestimate the exploitable biomass. Consequently, harvest options presented may be optimistic relative to attainment of management objectives.
- When a stock is below the USR (in the cautious zone), consideration should be given to increasing the SSB. A 5% increase in SSB by 2020 would only be likely (greater than 50%) at annual catches below 16,000 t.
- Elevated fishing mortality, during the mid-1990s to 2010, declines in weights-at-age, and low recruitment rates are contributing to declines in SSB, further impeding the rebuilding of the stock.

## INTRODUCTION

The Atlantic Herring (Clupea harengus) is a schooling pelagic species. Age at first spawning is typically four years. The herring population in the sGSL consists of two spawning components: spring spawners (SS) and fall spawners (FS). Spring spawning occurs primarily in April-May at depths <10 m. Fall spawning occurs from mid-August to mid-October at depths of 5 to 20 m. Herring also show high spawning site fidelity. In recent years, the largest spring spawning areas are in the Northumberland Strait and Chaleur Bay and the largest fall spawning areas are in coastal waters off Miscou and Escuminac N.B., North Cape and Cape Bear P.E.I., and Pictou, N.S. When spawned, the eggs are attached to the sea floor.

Herring fisheries in NAFO Div. 4T of the southern Gulf of St. Lawrence (sGSL) are managed across seven herring fishing areas within area 16 (A-G; Fig. 1). The SS and FS herring of the sGSL are considered distinct stocks and are assessed separately. For the fall spawner component, a regionally-disaggregated assessment model (North, Middle, South regions) was first used to update advice for the 2015 fishery (DFO 2015).

## Fisheries

Over the period 1978 to 2017, total landings of Atlantic Herring from NAFO Div. 4T and 4Vn peaked at 93,471 t in 1995 and dropped to 20,523 t in 2017 (Fig. 2). A Total Allowable Catch (TAC) for the combined harvest of both components in 4T and 4Vn has been in place since 1972. The total landings have generally been less than the TAC since 1988. The TAC values in 2016 and 2017 were 37,000 t.

In the sGSL, herring are harvested by a gillnet fleet (referred to as “fixed” gear fleet) and a purse seine fleet (“mobile” gear fleet). The fixed gear fishery is focused in NAFO Div. 4T whereas the mobile gear fishery occurs in Div. 4T and occasionally in Div. 4Vn. As in previous years, 77% of the TAC for both seasons was allocated to the fixed gear fleet and 23% to the mobile gear fleet. The majority (73% to 97%) of the reported landings since 1981 have been from the fixed gear fleet with percentages in 2016 and 2017 of 94% and 99%, respectively (Fig. 2). Local stocks are generally targeted by the fixed gear fishery which takes place on the spawning grounds.

Separate TACs for the spring spawner component and for the fall spawner component have been established since 1985. The TACs are attributed to the fishing seasons. Reported landings from the fall season have represented the majority (65% to 98%) of the total landings of sGSL herring throughout the time series (Fig. 2). Landings in the fall fishing season were estimated to have represented 94% and 95% of the total herring harvested in 2016 and 2017, respectively.

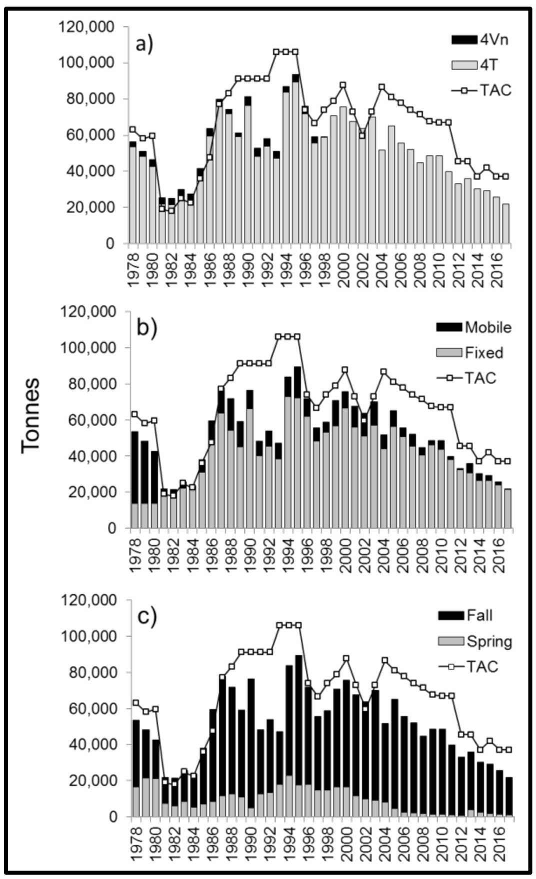


*Figure 2. Reported landings (tonnes) of southern Gulf of St. Lawrence Atlantic Herring (spring and fall spawners combined) by NAFO Division (upper panel), by gear fleet (middle panel), and by fishing season (lower panel), 1978 to 2017. In all panels, the corresponding annual total allowable catch (TAC; tonnes) is shown. For landings by season, the landings in NAFO Div. 4Vn were attributed to the fall fishing season. Data for 2016 and 2017 are preliminary.*

Spring spawners and fall spawners are not exclusively captured in their corresponding spawning seasons and the landings are attributed to spawning groups based on macroscopic characteristics of individual herring obtained from samples of the fishery catches.

### Spring spawner component (SS)

The 2016 and 2017 TAC for the SS herring was set at 2,000 t annually, the same value since 2010 (Fig. 3). The preliminary estimated landings of SS herring in 2016 and 2017 were 966 t and 1,189 t, respectively. With few exceptions, most of the SS herring were estimated to have been landed in the fixed gear fleet over the 1981 to 2017 period. In 2016 and 2017, the fixed gear fleet was estimated to have landed 82% and 96%, respectively, of the total harvests of SS herring (Fig. 3). Generally more than 90% of the SS herring landed by the fixed gear fleet is landed during the spring fishing season, whereas most (> 75%) of the SS herring landed by the mobile fleet is landed in the fall season (Fig. 3).

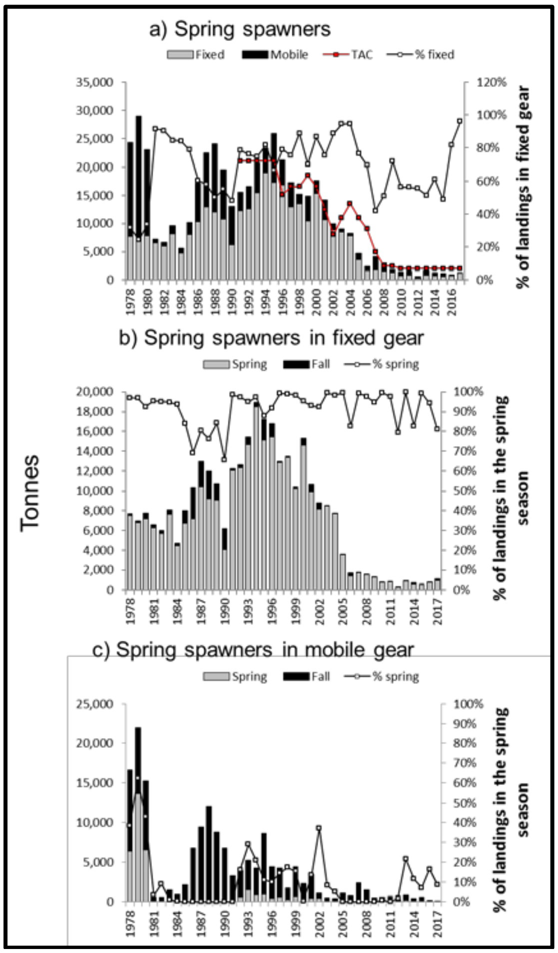


*Figure 3. Estimated landings (tonnes) of the spring spawner component (SS) of Atlantic Herring from the southern Gulf of St. Lawrence, 1978 to 2017. The upper panel shows the estimated landings by gear type and the proportion of the landings attributed to the fixed gear fleet. Also shown in the upper panel is the SS herring TAC (red symbols) for 1991 to 2017. The middle panel shows the estimated landings of SS herring in the fixed gear fleet that occurred in the spring fishery season and the fall fishery season as well as the proportion of total SS herring landed by the fixed gear fleet in the spring fishing season. The lower panel shows the estimated landings of SS herring in the mobile gear fleet that occurred in the spring fishery season and the fall fishery season as well as the proportion of the total SS herring landed by the mobile gear fleet in the spring fishing season. For landings by season, the landings in NAFO Div. 4Vn were attributed to the fall fishing season. Data for 2016 and 2017 are preliminary.*

Catch-at-age and weight-at-age

The dominant age in the 2016 SS catch was age 7 belonging to the 2009 year-class. In 2017 it was age 5, belonging to the 2012 year-class (Fig. 4).

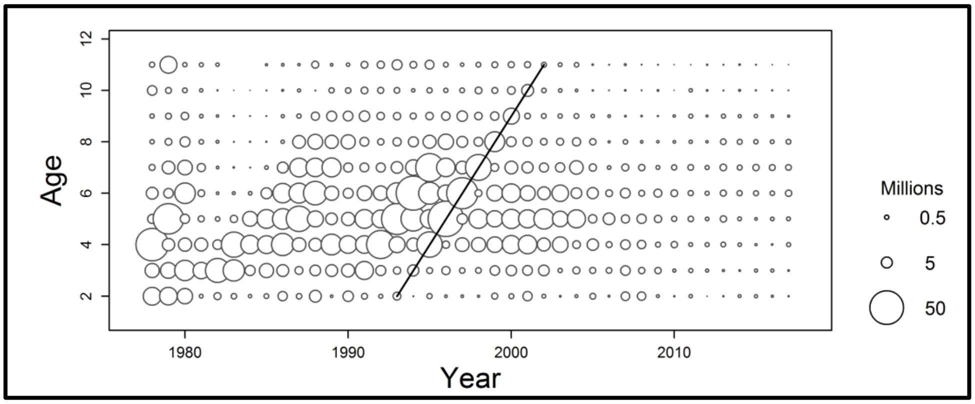


*Figure 4. Catch-at-age of the spring spawner component of Atlantic Herring from the southern Gulf of St. Lawrence fishery, all gears combined, 1978 to 2017. Size of the bubble is proportional to the catch numbers by age and year. The diagonal line tracks the most recent strong year-class (1991).*

Mean weights-at-age of the SS caught in the mobile and fixed gears in the spring season have declined since the 1990s for mobile gear, and since the mid-1980s for the fixed gear (Fig. 5).

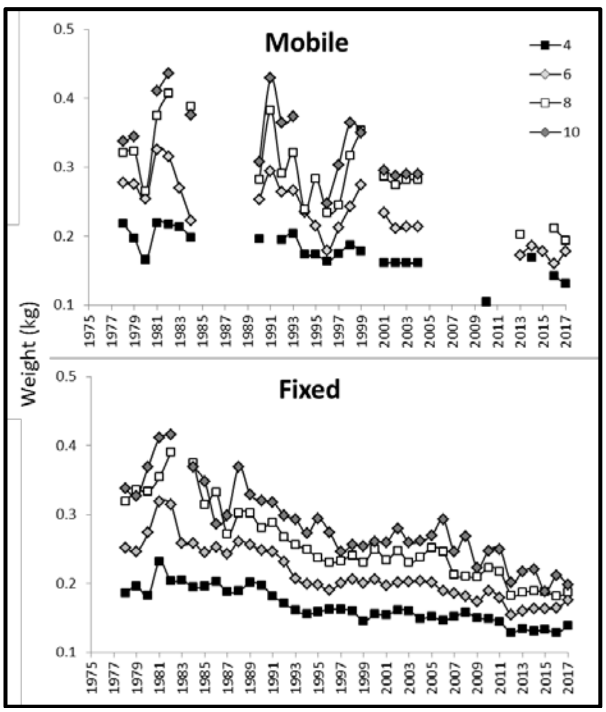


*Figure 5. Mean weight (kg) for ages 4, 6, 8 and 10 years of the spring spawner component of Atlantic Herring from the southern Gulf of St. Lawrence sampled from catches during the spring season in the mobile (upper panel) and fixed (lower panel) commercial gears, 1978 to 2017.*

### Fall spawner component (FS)

The fishery TAC for the fall spawner component is set for the NAFO Div. 4T stock unit. The preliminary estimated landings of FS herring in 2016 and 2017 were 24,677 t and 20,523 t respectively (Fig. 6). The TAC was 35,000 t in 2016 and 2017. With few exceptions, over the 1978 to 2017 period, most of the FS herring were estimated to have been landed in the fixed gear fleet. In 2016 and 2017, the fixed gear fleet was estimated to have landed 94% and 95%, respectively, of the total harvests of FS herring (Fig. 6). The majority (generally almost 100%) of the FS herring captured in the fixed gear fishery are landed during the fall fishing season. The mobile fleet has landed varying amounts of FS herring in the fall, 31% to 45% during 2016 to 2017 (Fig. 6).

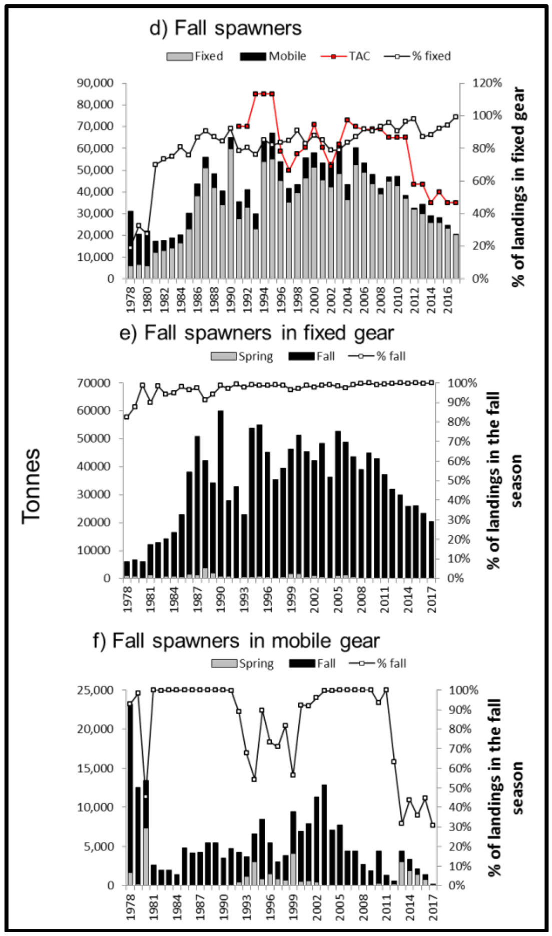


*Figure 6. Estimated landings (tonnes) of the fall spawner component (FS) of Atlantic Herring from the southern Gulf of St. Lawrence, 1978 to 2017. The upper panel shows the estimated landings by gear type and the proportion of the landings attributed to the fixed gear fleet. Also shown in the upper panel is the FS herring TAC (red symbols) for 1991 to 2017. The middle panel shows the estimated landings of FS herring in the fixed gear fleet that occurred in the spring fishery season and the fall fishery season as well as the proportion of the total FS herring landed by the fixed gear fleet in the fall fishing season. The lower panel shows the estimated landings of FS herring in the mobile gear fleet that occurred in the spring fishery season and the fall fishery season as well as the proportion of the total FS herring landed by the mobile gear fleet in the fall fishing season. For landings by season, the landings from NAFO Div. 4Vn were attributed to the fall fishing season. Data for 2016 and 2017 are preliminary.*

### Catch-at-age and weight-at-age

Catches-at-age from the fisheries were compiled by region (North, Middle, South) and year. Catches from the fixed gear fleet were attributed to the region of capture. Catches by the mobile fleet in NAFO Div. 4T were attributed to the region which is most proximate to the location of capture. Catches made in NAFO Div. 4Vn during a winter seiner fishery (prior to 1999) were attributed to each region in proportion to the other catches from each region in the same year.

Catch-at-age and weight-at-age matrices for NAFO Div. 4T FS herring include catches made by both fixed and mobile gear fleets. These were derived using age-length keys and length-weight relationships from sampling for each principal fishing area and season.

Region-specific catches-at-age used in the model fitting for both gears combined are presented in Figure 7. The catches of younger ages (less than 6 years) have recently decreased in the fisheries consistent with the estimated changes in selectivity in the fixed gear fleet and changes in size-at-age of FS herring.

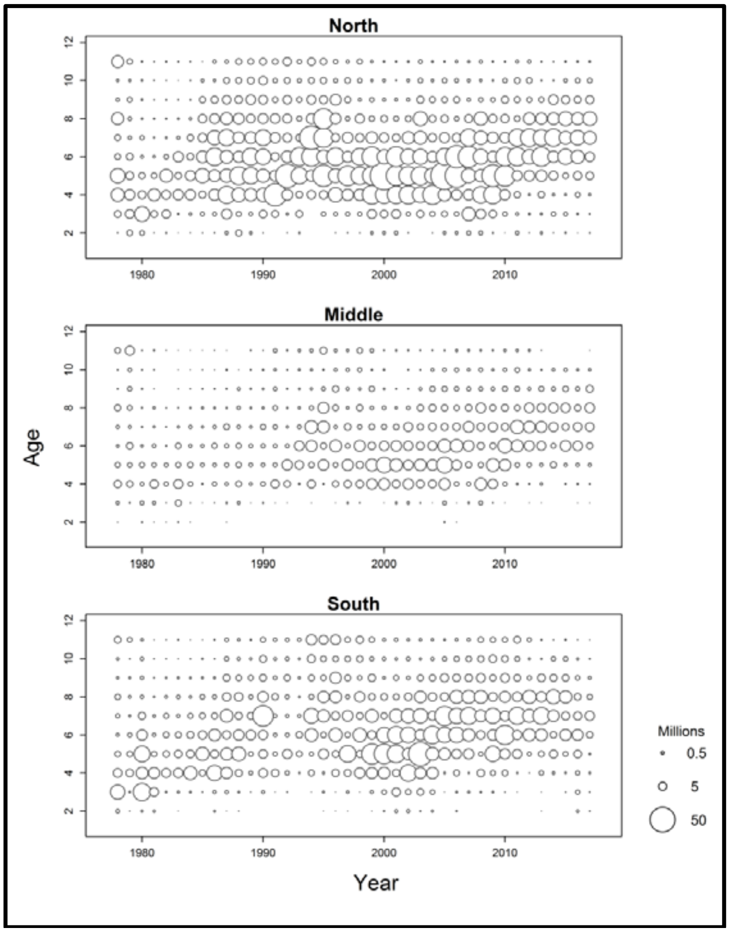


*Figure 7. Bubble plots of fishery catch-at-age (number) of the fall spawner component of Atlantic Herring from the southern Gulf of St. Lawrence by region for mobile and fixed gears combined, 1978 to 2017. The size of the bubble is proportional to the number of fish in the catch by age and year. The values indicated at age 11 represent catches for ages 11 years and older.*

Mean weights-at-age of FS herring from fixed and mobile gears have declined almost continuously over the period 1978 to 2011 and remain at low levels (Fig. 8). Lower mean weights have a consequence on the estimation of stock biomass when numbers are converted to weight.

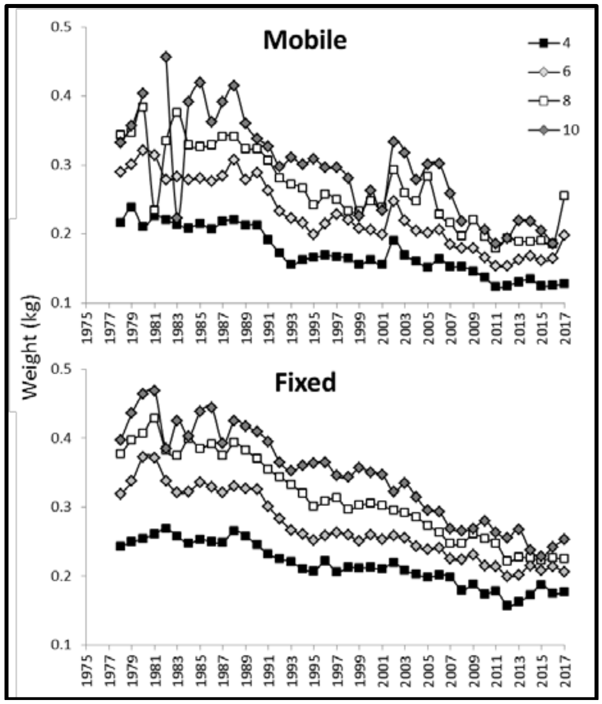


*Figure 8. Mean weight (kg) for ages 4, 6, 8 and 10 years of the fall spawner component of Atlantic Herring from the southern Gulf of St. Lawrence sampled from catches in the fall season by the mobile (upper panel) and fixed (lower panel) gear fleets, 1978 to 2017.*

# ASSESSMENT

The SS herring and FS herring of NAFO Div. 4T are considered distinct stocks and are assessed separately. The assessments of abundance are made using Virtual Population Analysis (VPA) models based on catch-at-age, fishery dependent and fishery independent indices at age. The fishery TAC, and the analysis of catch options presented in this document, are for the spring spawner component and the fall spawner component separately and at the scale of the entire southern Gulf of St. Lawrence.

## Indices of Abundance

### Telephone survey

A telephone survey has been conducted annually since 1986 to collect information on the fixed gear fishery and opinions on abundance trends. The telephone survey responses include information on fishing effort, in terms of the number of nets, number of hauls, and mesh sizes used, which is used in the derivation of the commercial catch-per-unit-effort (CPUE) indices and in modelling relative fixed gear fishery selectivity in the fall spawner assessment model. The opinion of relative abundance is not used as an index in the population model. Overall, spring fishermen felt that abundances had remained consistent with the previous assessment, however for the fall fishery there was an overall sense of decreased abundance in all regions.

### Fishery Independent Acoustic survey (SS and FS herring)

An annual fishery-independent acoustic survey of early fall (September-October) concentrations of herring in the sGSL has been conducted since 1991. The standard annual survey area occurs in the NAFO Div. 4Tmno areas (16B Fig. 1) where sGSL herring aggregate in the fall.

The 2015, 2016, and 2017 acoustic biomass indices for spawning groups combined were 169,635 t, 73,977 t, and 69,023 t, respectively. Based on biological samples, the biomasses in 2015 to 2017 were estimated to have been comprised of 19% SS and 81% FS herring.

Age-disaggregated acoustic indices for ages 4 to 8 are developed for the SS herring component. For the FS herring, the acoustic survey provides an abundance index of recruiting herring at ages 2 and 3 only.

#### Fishery Dependent Commercial Catch per Unit Effort (CPUE) (SS and FS herring)

Fixed gear catch and effort data were used to construct age-disaggregated abundance indices for SS herring and FS herring, expressed as catch per unit effort (CPUE) with values in kg/net-haul/trip. Age-specific CPUE indices for ages 4 to 10 are used in the assessments of the SS herring and FS herring stock. For the SS herring, an index is estimated for the whole stock area. For the FS herring, indices are calculated for each of the North, Middle, and South regions.

#### Fishery Independent Experimental Gillnet Indices (FS herring)

Catches from experimental nets are used to estimate the relative size-selectivity of gillnets of different mesh sizes and to produce age-disaggregated abundance indices, by region, as inputs to the fall spawner component assessment model.

Experimental gillnets, consisting of multiple panels of varying mesh size, were fished approximately weekly by fishermen during the fall fishing season. Each experimental gillnet had five panels of different mesh size, from a set of seven possible mesh sizes, ranging from 2” to 2¾” in ⅛” increments. All gillnets had panels with mesh sizes of 2½”, 2⅝”, and 2¾”, plus two smaller mesh sizes that varied among fishermen. The nets were set during the commercial fishery on the fishing grounds. The index is standardized to a one-hour soak time corresponding to the target fishing duration.

#### Fishery Independent September Bottom Trawl Survey (FS herring)

This sGSL index is used for the fall spawner population model. The annual multi-species bottom trawl survey, conducted each September since 1971, provides information on the relative abundance and distribution of NAFO Div. 4T herring throughout the sGSL. Since 1994, sampling of herring catches has been undertaken to disaggregate catches by spawner group and age. Spawning group assignment and age data were available for 1994 to 2017 for this assessment.

### Spring Spawner Component (SS)

#### Indices of abundance

Acoustic survey

The acoustic survey provides catch rates (in numbers) of SS herring for ages 4 to 8 for 1994 to 2017 (Fig. 9). The combined index was highest in the mid-1990s and subsequently declined and remained at low levels in the 2000s.

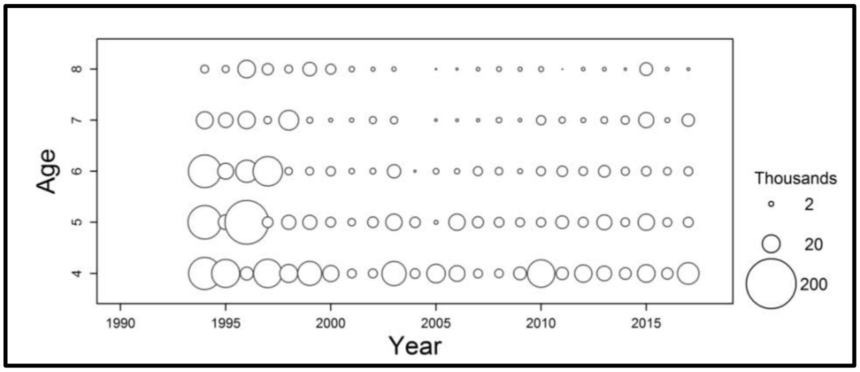


*Figure 9. Bubble plot of abundance-at-age (number) from the fisheries-independent acoustic survey for herring spring spawners (SS; ages 4 to 8) in the southern Gulf of St. Lawrence, 1994 to 2017.*

Commercial fixed gear catch per unit effort

The CPUE index for SS herring shows internal consistency as the abundance of cohorts is correlated between years, as shown for example for the sequence of catches of the 1988 year class (e.g., age 4 in 1992, age 5 in 1993, Fig. 10). Decreases in the CPUE of younger fish and increases in the CPUE of older fish are noted since 2011 (Fig. 10).

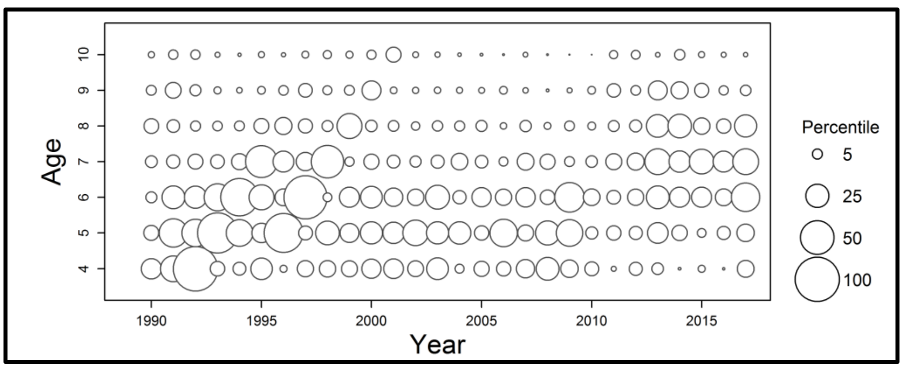


*Figure 10. Bubble plot of spring spawner Atlantic Herring fixed gear catch per unit effort values (number per net-haul per trip) at age in the southern Gulf of St. Lawrence, 1990 to 2017. The size of the bubble is proportional to the maximum CPUE index value.*

### Population model

In the previous assessment (Swain, 2016), time-varying catchability was incorporated in the virtual population analysis (VPA) to improve the residual and retrospective patterns. Fishery dependent indices are an important component of the assessment. Indices such as the commercial gillnet CPUE, may not be proportional to abundance due to changes in catchability over time. Catchability to the fishery is defined as the proportion of the stock removed by one unit of fishing effort. If catchability doubles while abundance remains the same, CPUE will increase even though abundance did not. In the absence of correcting for changes in catchability, CPUE may bias the estimate of abundance.

The VPA model inputs include a natural mortality at all ages set at 0.2, a fishery catch-at-age 2 to 11+ (in numbers), fishery CPUE in numbers at ages 4 to 10 years from 1990 to 2017, and abundance indices at ages 4 and 8 from the fall acoustic survey (1994-2017). Catchability to the fishery, defined as the proportion of the stock removed by a unit of fishing effort, averaged about 0.006 in the 1990s, increasing to a peak of 0.032 from 2007 to 2017 (Fig. 11). Estimated catchability increased as the stock declined below 60,000 t of spawner biomass (Fig. 11).

Fishery catchability has been shown to increase as population size decreases for a number of stocks including herring (Winters and Wheeler, 1985). Reasons for this include:

- The area occupied by a stock usually decreases as stock size decreases, and because fish harvesters target fish aggregations (e.g., spawning aggregations), the proportion of the stock removed by a unit of fishing effort is expected to increase.
- In a gillnet fishery, net saturation at high abundance may also contribute to reduced catchability at high population size.

Independent of changes in SSB, catchability by fisheries may increase over time due to technological improvements and changes in fishing tactics. Other factors might result in declines in catchability, for example the changes in management measures that have occurred in the spring fishery since 2010. These measures included closures of some spawning areas and a requirement that gear be in the water by 6:00 PM and not retrieved before 4:00 AM the next day (preventing the targeting of aggregations overnight).

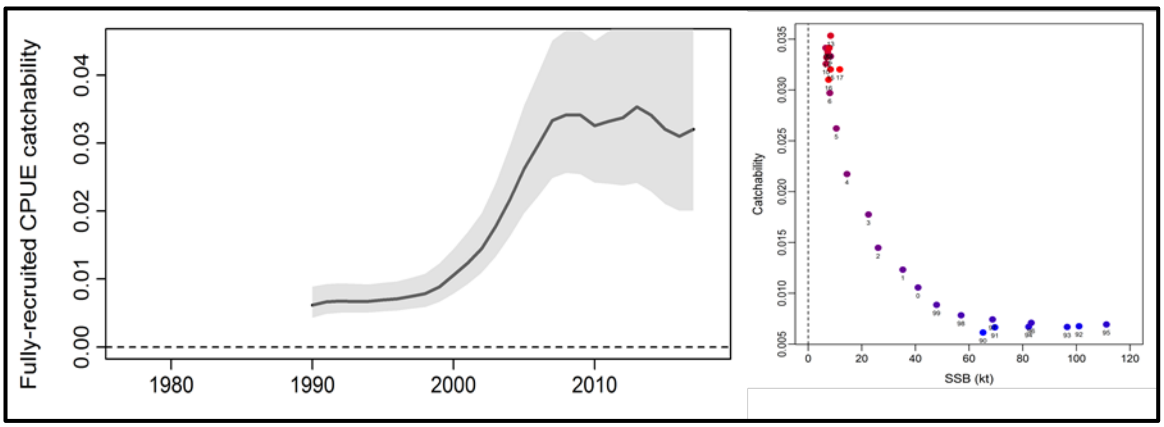


*Figure 11. Estimated fully-recruited catchability to the CPUE index of the spring spawner component of Atlantic Herring (left panel) and fully-recruited catchability to the spring spawner gillnet fishery in relation to spring spawner SSB (right panel) for the southern Gulf of St. Lawrence. In the left panel, the line shows the median estimates and shading the 95% confidence intervals.*

### Recalculating the Limit Reference Point

The limit reference point (LRP) for NAFO Div. 4T herring is based on $B_{recover}$, the lowest biomass from which the stock has been observed to readily recover, calculated as the average of the four lowest spawning stock biomass (SSB) estimates in the early 1980s (i.e., 1980-1983). Consequently, this value is model dependent. If the model changes, stock biomass may be re-scaled upwards or downwards. With the model change initiated in 2016 (DFO 2016) and retained in this assessment, there was a revised value for the biomass in the 1980s. Thus the LRP was re-calculated. The revised LRP is 19,250 t, slightly lower than the former value of 22,000 t.

### Spawning Stock Biomass and Exploitation Rate

The estimates of Spawning Stock Biomass (SSB; age 4+) at the beginning of 2017 and 2018 were 11,744 t (95% confidence interval: 6,463 – 28,171 t) and 12,446 t (95% CI: 6,418 – 30,365 t), respectively. These biomasses are higher than the SSBs in 2015 and 2016, however, the stock remains in the critical zone of the Precautionary Approach (Fig. 12). The SSB estimate for 2018 is 65% of the LRP. The probabilities that the projected SSBs were above the LRP at the start of 2017 and 2018 were <11% and 15%, respectively (Fig. 12).

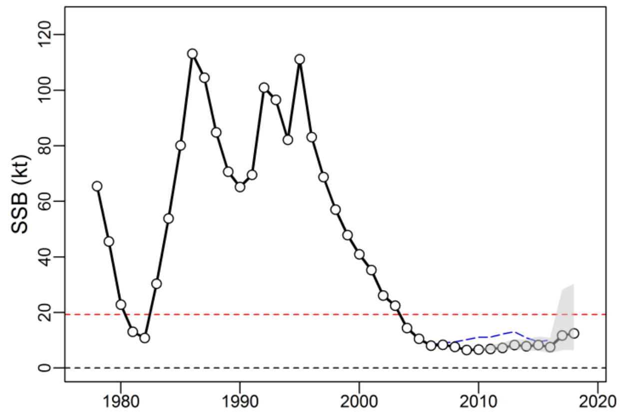


*Figure 12. Estimated beginning of the year spawning stock biomass (SSB) of the spring spawner component of Atlantic Herring in the southern Gulf of St. Lawrence, 1978 to 2018. Circles show the maximum likelihood estimates, the solid line is the median of the Monte Carlo Markov Chain (MCMC) values and shading encompasses the 95% confidence interval. The red horizontal dashed line is the Limit Reference Point (19,250 t of SSB). The blue dashed line shows the SSB estimates from the 2016 assessment (DFO 2016).*

Estimated fishing mortality rates were high in 1980 and in most years from 2000 to 2011 (Fig. 13), declined to a low value of 0.19 (annual exploitation rate of 0.16) and below the reference removal rate ($F_{0.1}$; $F$ = 0.35 corresponding to exploitation rate of 0.30) in 2012, and has remained below $F_{0.1}$ in subsequent years, with the exception of 2013. Fishing mortality rates in 2015 to 2017 averaged 0.24 (annual exploitation rate of 0.21).

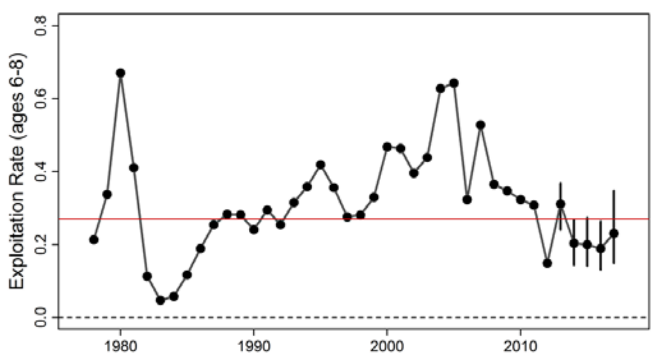


*Figure 13. Estimated annual exploitation rates of spring spawning Atlantic Herring aged 6 to 8 years in the southern Gulf of St. Lawrence, 1978 to 2017. Circles are the median estimates and vertical lines their 95% confidence intervals. The red horizontal line shows the reference level annual exploitation rate (0.295 equivalent to F = 0.35) corresponding to $F_{0.1}$.*

### Recruitment and Recruitment Rates

Recruitment rates (the number of recruits divided by the SSB that produced them) were unusually high in the early 1980s (Fig. 14). Recruitment rates have been much lower since then, though periods of moderately high recruitment rates occurred in the late 1980s and early 1990s as well as during 2005 to 2011. Recruitment rates were lower in 2012 but appear high in 2013 though the uncertainties are very high (wide confidence intervals) for that year. Estimated abundances of age 4 herring at the start of 2017 and 2018 were higher than those since 2005 (Fig. 14). The age 4 abundance in 2018 depends on the assumption that recruitment rate for this cohort equals the average rate for the preceding five cohorts. Recruitment rates and uncertainty vary among these five cohorts resulting in very high uncertainty in age 4 abundance in 2018. If the recruitment rate of the 2013 cohort was instead low, like that of the previous cohort, age 4 abundance in 2018 would be similar to the low 2016 value.

The estimate of spring spawner (4+) abundance for 2017 is 82.9 million fish (Fig.14; median value of 80.2 million with 95% CI: 42.3 – 206.5 million), about 20% of the average spawner abundance during 1985 to 1995.

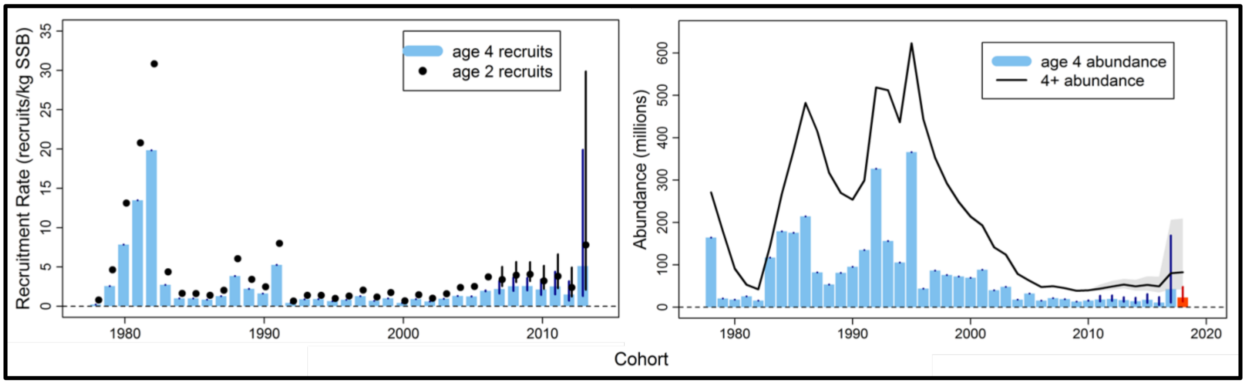


*Figure 14. Recruitment rates and beginning of year abundances of the spring spawner component of Atlantic Herring from the southern Gulf of St. Lawrence. The left panel shows recruitment rates at age 2 (circles) and at age 4 (bars) for the 1978 to 2013 cohorts with vertical lines indicating the 95% confidence intervals. The right panel shows the estimated beginning-of-year abundances of 4 year old herring (blue bars) and herring 4 years and older (line) for the spring spawner component of the southern Gulf of St. Lawrence. Bars and the line show the median estimate and vertical lines or shading the corresponding 95% confidence intervals. Age 4 abundance in 2018 (the red bar) was estimated assuming the recruitment rate for this cohort was the average of the rates of the preceding five cohorts.*

### Projections

The population model was projected forward for two years to the start of 2020 and 10 years to the start of 2027. These projections incorporated uncertainty in the estimates of abundance at age at the beginning of 2018, in the weights-at-age, partial recruitments to the fishery, and recruitment rates (to estimate ages 2 to 4). Projections were conducted at seven levels of annual catch (0 to 3,000 t in increments of 500 t) with the same catch level for the 2018 and 2019 fishing seasons. Projection results depend strongly on recruitment rates. Due to variable recruitment in recent years, projections were conducted for three recruitment scenarios during the projection period: (1) high recruitment rate scenario (2007 to 2012 cohorts), (2) low recruitment rate scenario (1999 to 2005 cohorts), and (3) mixed recruitment rate scenario (1999 to 2012 cohorts).

SSB was projected to increase slightly at annual catches of 0 and 500 t, remain roughly stable at a catch of 1,000 t, and decline at catches of 1,500 t or more (Fig. 15). However, uncertainty was high. The probability of an increase in SSB between the beginning of 2018 and the beginning of 2020 decreased from 80% at 0 t of catch to 49% at 1,000 t of catch and 11% at 2,500 t of catch under the high recruitment scenario. At the mixed and low recruitment scenarios, the probability of the SSB increasing in the absence of fishery removals (0 t) was 58% and 39%, respectively (Fig. 15; Table 1).

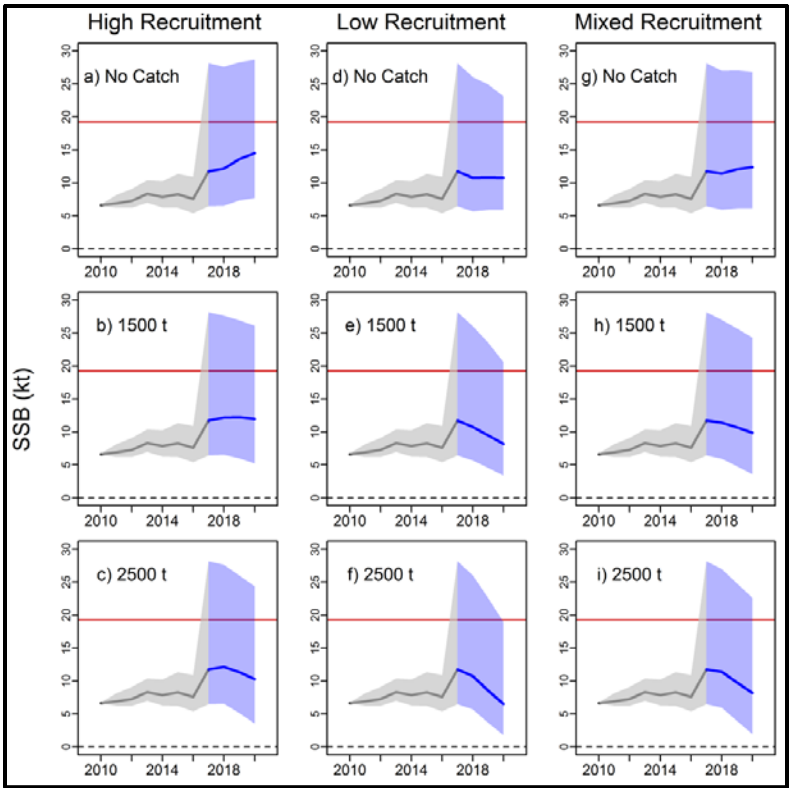


*Figure 15. Projected spawning stock biomass (SSB in kt) of spring spawning Atlantic Herring from the southern Gulf of St. Lawrence for three recruitment scenarios (columns) and at various catch levels (rows) in 2018 and 2019. Lines show the median estimates of the beginning-of-year SSB and shading the 95% confidence intervals of these estimates (based on MCMC sampling). Grey shading indicates the historical period and blue shading indicates the projection period. The red horizontal line in each panel is the limit reference point (LRP) value of 19,200 t.*

### Risk analysis of catch options

All catch levels in 2018 and 2019 (including no catch) and recruitment rate scenarios indicate little probability that SSB would exceed the LRP at the start of 2020 (for high recruitment 20% at 0 t of catch, 8% at 2,500 t of catch; at low recruitment 6% at 0 t of catch, 2% at 2,500 t of catch) (Table 1). By 2027, the probability of exceeding the LRP was most favorable (>= 50%) under the high recruitment scenarios and low catches (<1,500 t), however at the low recruitment scenarios even with no catch there was only a 13% probability of SSB exceeding the LRP (Table 1).

There is no chance that the population would be at or above the Upper Stock Reference (USR) in 2020 even with no catch regardless of the recruitment rate scenario. At the high recruitment rate scenario, there is an 11% probability of SSB exceeding the USR by 2027 with no catch whereas at the low recruitment rate there is 0% chance (Table 1).

For the low recruitment rate scenario, the probability that age 6 to 8 fully recruited *F* in 2019 would be greater than the removal rate reference level of $F_{0.1}$ (0.35) was essentially zero at 1,000 t or less of catch, increasing to 9% at 1,500 t of catch, and rising to 57% at 2,500 t of catch.

Since 2009, the TAC has been set to 2,000 t annually. At a catch of 2,000 t, the probability of an increase in SSB after 2019 ranges from 0% (low recruitment rate) to a high of 19% (high recruitment rate) depending on the recruitment rate scenario. At 2,000 t of annual catch, there is at most a 10% chance of exceeding the LRP and the probability of SSB exceeding the LRP by 2027 ranges from 2% (low recruitment) to 38% (high recruitment). Furthermore at 2,000 t there is at best a 4% chance of reaching the USR by 2027 (Table 1).

*Table 1. Risk analysis table of probabilities (%) of increases in SSB, of SSB being greater than the LRP (i.e., the SSB not in the critical zone), of SSB being greater than the USR (i.e., the SSB in the healthy zone), and of fully-recruited fishing mortality rate ($F_{6-8}$) being above $F_{0.1}$ for differing fixed catch options in 2018, 2019, and 2027 for the spring spawner component of Atlantic Herring from the southern Gulf of St. Lawrence according to three recruitment rate scenarios. The recruitment rate scenarios are: A) High recruitment rate scenario (2007-2012 cohorts), B) low recruitment rate scenario (1999-2005 cohorts), and C) mixed recruitment rate scenario (1999-2012 cohorts). nd means not considered.*

| | | | Catch option (t) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Scenario | State of stock | Year | 0 | 500 | 1,000 | 1,500 | 2,000 | 2,500 | 3,000 |
| A | SSB increasing | 2018 | 91% | 80% | 63% | 44% | 28% | 16% | nd |
| | | 2019 | 80% | 66% | 49% | 32% | 19% | 11% | nd |
| | SSB > LRP | 2019 | 16% | 15% | 13% | 12% | 11% | 10% | nd |
| | | 2020 | 20% | 17% | 14% | 11% | 10% | 8% | nd |
| | | 2027 | 87% | 76% | 63% | 50% | 38% | 29% | 21% |
| | SSB > USR | 2019 | 0% | 0% | 0% | 0% | 0% | 0% | nd |
| | | 2020 | 0% | 0% | 0% | 0% | 0% | 0% | nd |
| | | 2027 | 11% | 9% | 6% | 5% | 4% | 3% | 2% |
| | $F_{6-8}$ > 0.35 | 2018 | 0% | 0% | 0% | 4% | 22% | 48% | 71% |
| | | 2019 | 0% | 0% | 0% | 3% | 18% | 39% | 60% |
| | | 2027 | 0% | 0% | 1% | 10% | 30% | 51% | 69% |
| B | SSB increasing | 2018 | 53% | 25% | 8% | 1% | 0% | 0% | nd |
| | | 2019 | 39% | 18% | 5% | 1% | 0% | 0% | nd |
| | SSB > LRP | 2019 | 7% | 6% | 6% | 5% | 5% | 5% | nd |
| | | 2020 | 6% | 5% | 4% | 3% | 3% | 2% | nd |
| | | 2027 | 13% | 7% | 4% | 3% | 2% | 1% | 1% |
| | SSB > USR | 2019 | 0% | 0% | 0% | 0% | 0% | 0% | nd |
| | | 2020 | 0% | 0% | 0% | 0% | 0% | 0% | nd |
| | | 2027 | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| | $F_{6-8}$ > 0.35 | 2018 | 0% | 0% | 0% | 6% | 31% | 58% | 78% |
| | | 2019 | 0% | 0% | 0% | 9% | 33% | 57% | 74% |
| | | 2027 | 0% | 0% | 29% | 73% | 91% | 96% | 98% |
| C | SSB increasing | 2018 | 68% | 52% | 37% | 23% | 13% | 7% | nd |
| | | 2019 | 58% | 43% | 28% | 17% | 10% | 5% | nd |
| | SSB > LRP | 2019 | 11% | 10% | 9% | 8% | 7% | 7% | nd |
| | | 2020 | 12% | 10% | 8% | 7% | 6% | 5% | nd |
| | | 2027 | 54% | 40% | 28% | 19% | 12% | 9% | 6% |
| | SSB > USR | 2019 | 0% | 0% | 0% | 0% | 0% | 0% | nd |
| | | 2020 | 0% | 0% | 0% | 0% | 0% | 0% | nd |
| | | 2027 | 2% | 1% | 1% | 1% | 1% | 0% | 0% |
| | $F_{6-8}$ > 0.35 | 2018 | 0% | 0% | 0% | 5% | 26% | 53% | 75% |
| | | 2019 | 0% | 0% | 0% | 6% | 26% | 49% | 68% |
| | | 2027 | 0% | 0% | 7% | 35% | 62% | 79% | 90% |

## Fall Spawner Component (FS)

The FS herring assessment considers three regions (North, Middle, South) which cover the entire NAFO Div. 4T area as three independent populations. The regions are defined on the basis of traditional herring spawning beds and fishing areas: North (Gaspe and Miscou; 4Tmnopq), Middle (Escuminac-Richibucto and west Prince Edward Island; 4Tkl) and South (east Prince Edward Island and Pictou; 4Tfghj) (Fig. 16). The choice of three regions was dictated by geographic proximity of spawning beds and is the finest level of disaggregation that can presently be supported by the available data.

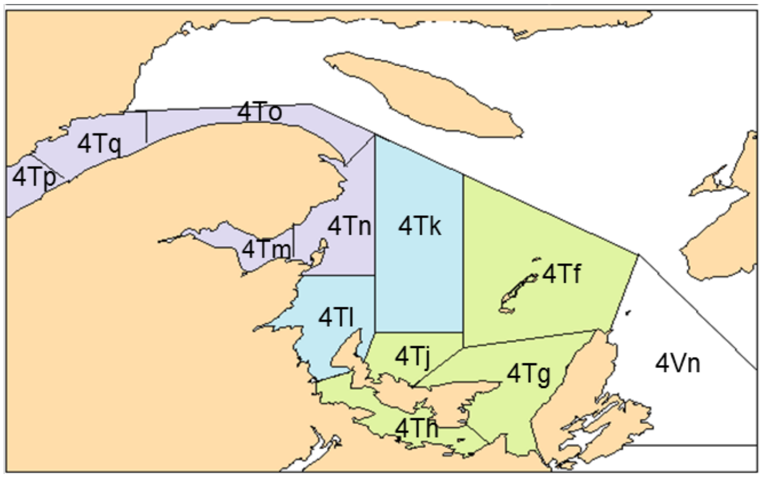


*Figure 16. Correspondence between the herring fishing areas and the three regional groups (by colour shading) used in the assessment of the fall spawner component of Atlantic herring from the southern Gulf of St. Lawrence. Fishing areas in each region are described in the text above.*

## Indices of abundance

### Acoustic survey

For the FS assessment model, the acoustic survey provides a useful abundance index of recruiting herring (ages 2 and 3) for the entire NAFO Div. 4T stock unit (LeBlanc et al. 2015). It is not considered a useful abundance index for older ages given that the survey is limited to a restricted portion of the sGSL at a time when older herring are distributed and spawning in areas throughout the sGSL. The index of three year olds was relatively high in 2015, with relatively smaller abundances for both age classes in 2016 and 2017 (Fig. 17).

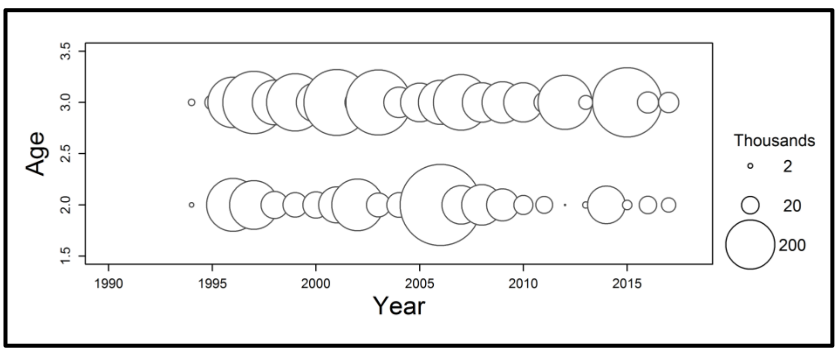


*Figure 17. Bubble plot of the index of abundance (number of fish) of fall spawning herring at age 2 and 3, from the fisheries-independent acoustic survey for fall spawners, 1994 to 2017.*

### Commercial fixed gear catch per unit effort

Decreases in the CPUE of younger fish and increases in the CPUE of older fish were noted for the FS herring (Fig. 18). In the North region, CPUE indices for ages 6 to 8 in 2016 and 2017 were lower than in previous recent years. CPUE values in the Middle region were higher in 2016 than in the previous recent years but declined in 2017. CPUE values in the South region were higher in 2017 than in 2016 but both years were lower than most of the previous years.

In the North and Middle regions, catches of FS in 2016 were dominated by age 6 and 7 and in 2017 by ages 7 and 8 (2009 and 2010 year-classes). In the South region, catches of FS in 2016 and 2017 were dominated by age 7 and 8 respectively (2009 year-class).

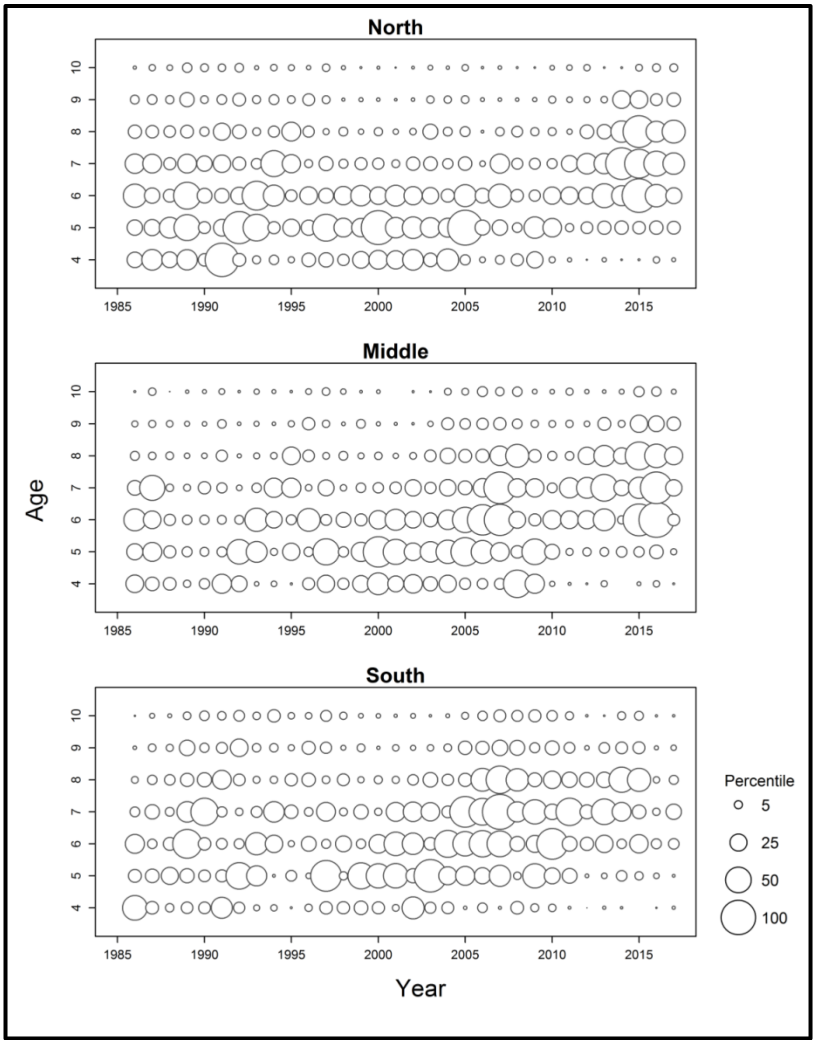


*Figure 18. Fall spawner (FS) herring fixed gear age-disaggregated catch per unit effort values (number per net-haul per trip) by region (upper panel North, middle panel Middle, and lower panel South) in the southern Gulf of St. Lawrence, 1986 to 2017. The size of the bubble is proportional to the CPUE index value.*

### Experimental gillnet indices

The experimental gillnet indices suggest an increase in young herring (ages 2 to 4) until 2009, after which the numbers declined, with proportional catches of herring 5 to 9 generally increasing from 2010 to 2017, in all regions (Fig. 19).

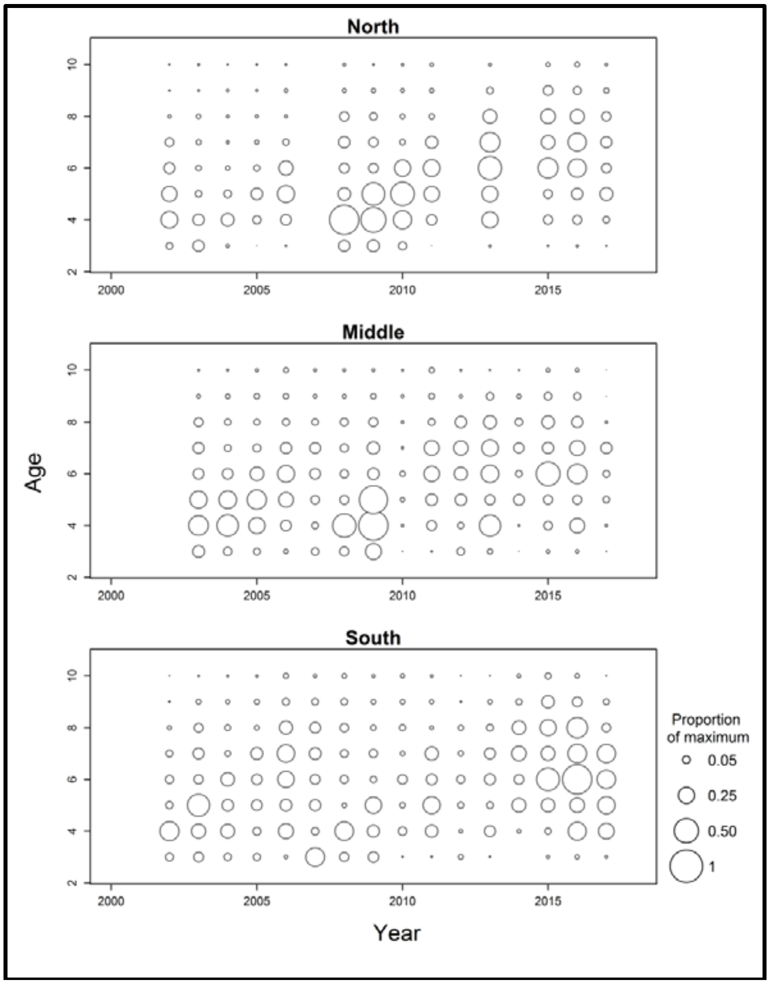


*Figure 19. Bubble plots of catch-at-age indices (number) of fall spawner herring from the experimental gillnets by region (upper panel North, middle panel Middle, and lower panel South) in the southern Gulf of St. Lawrence, 2002 to 2017. The size of the bubble is proportional to the index value.*

### Fishery Independent September Bottom Trawl Survey

The index suggests an increasing trend in four year old FS herring from the mid-1990s to 2011, and generally higher abundance of six year old FS herring in the 2000s compared to the 1990s (Fig. 20).

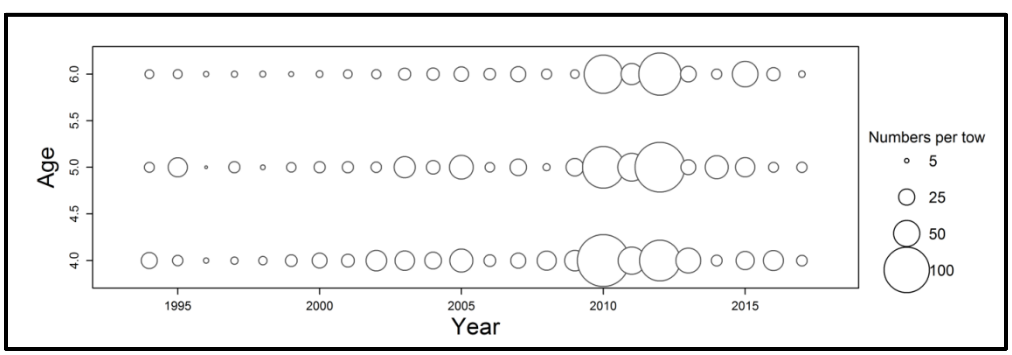


*Figure 20. Multispecies bottom trawl survey abundance index (number of fish per standardized tow) for fall spawning herring ages 4 to 6 years in the southern Gulf of St. Lawrence, 1994 to 2017.*

### Population model

A virtual population analysis (VPA) as described in DFO (2015) was conducted for three regions and then combined to estimate the overall FS herring abundance in NAFO Div. 4T. Natural mortality at all ages and in all regions was set at 0.2. Data inputs were fishery catches at ages 2 to 11+ (in numbers), fishery CPUE in numbers at ages 4 to 10 years from 1986 to 2017, catch rates at age in experimental nets (ages 3 to 9 or 10, 2002 or 2003 to 2017, with indices missing in some years in some regions), abundance indices at ages 2 and 3 from the fall acoustic survey (1994 to 2017), and catch rates at ages 4 to 6 in the September bottom trawl survey. Separate fishery catch-at-age, CPUE indices from the gillnet fishery, and indices from the experimental nets were derived for each of the three regions. The acoustic and bottom trawl survey indices were considered abundance indices for the sum of the three regions.

Additional inputs included the proportion of gillnets with 2 $^{5}/_{8}$ inch mesh in each region in each year (Fig. 21) and relative selectivity to the gillnet fishery by age, year, and mesh size (Fig. 22). As a result of the changes in size at age over time, the relative selectivities in the two main gillnet mesh sizes used in the fixed gear fishery have also changed over time, generally declining over the time series for ages 4 to 6 and declining since the late 1990s for ages 8 and 10 in the 2 ¾ inch mesh gear (Fig. 22).

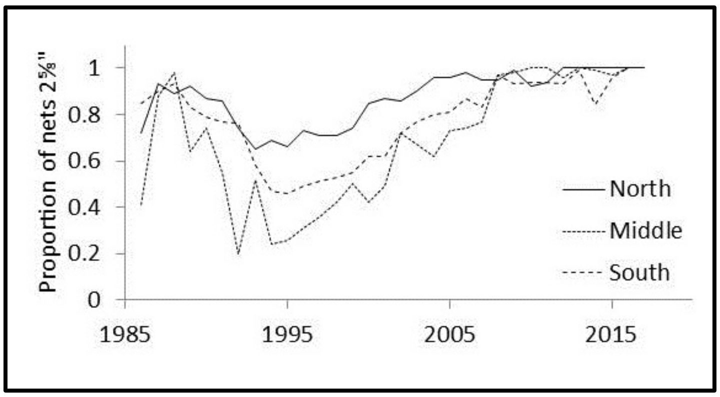


*Figure 21. Variations by region in the proportions of gillnets with mesh sizes 2 $^{5}/_{8}$ inches used in the fall herring fishery season in the southern Gulf of St. Lawrence, 1986 to 2017. It is assumed that all other nets used were of mesh size 2 ¾.*

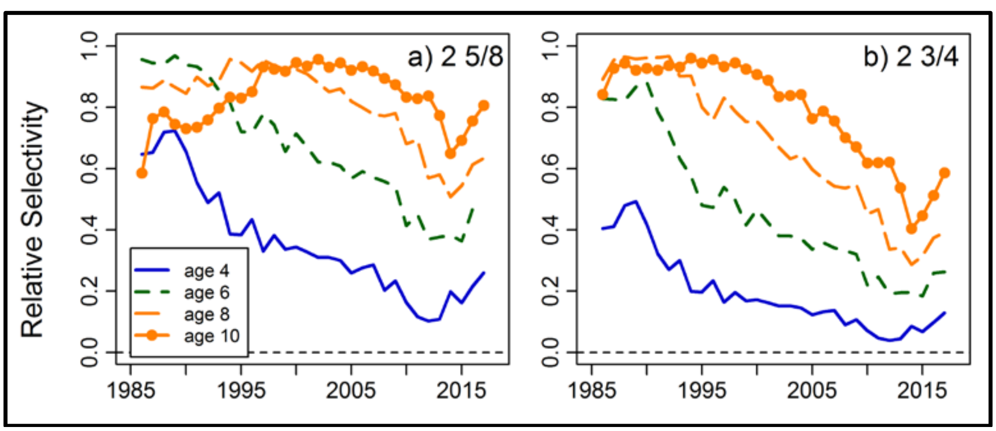


*Figure 22. Changes in relative selectivity of fall spawning herring aged 4, 6, 8 and 10 years to gillnets with mesh sizes of 2 $^{5}/_{8}$ inches (left panel) or 2 ¾ inches (right panel) in the fall herring fishery of the southern Gulf of St. Lawrence, 1986 to 2017.*

Similar to the results for 2016 (DFO 2016), the model diagnostics indicated an adequate fit to the observations. There was no severe blocking of residuals for the commercial CPUE indices. Fits to the CPUE indices were reasonably good, with predicted values consistent with the general trends in the indices. Retrospective patterns were present but negligible for the Middle region and greatest for the North region, though not in a consistent direction.

Estimated changes in catchability (*q*) to the gillnet fishery differed between regions (Fig. 23). Catchability was lowest and varied little over time in the North region. Catchability in the South region increased over time, primarily between 1995 and 2010 but has decreased recently. Estimated catchability was greatest in the Middle region except for a brief period in the mid-2000s.

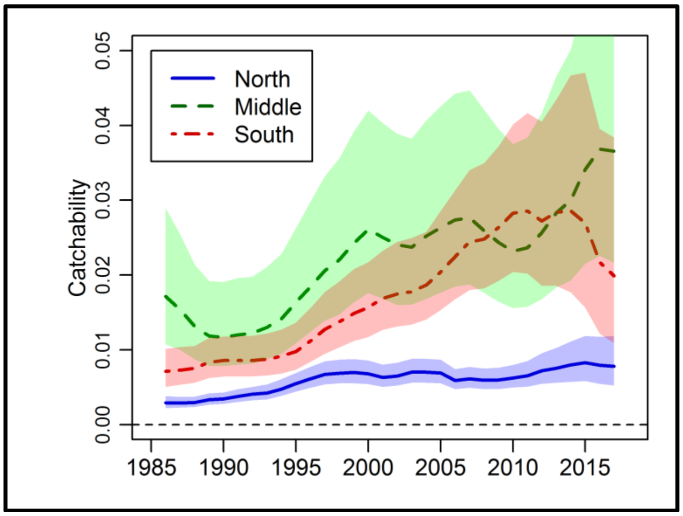


*Figure 23. Estimated fully-recruited catchability (q) of fall spawner herring to the fall gillnet fishery in three regions (North, Middle and South) of the southern Gulf of St. Lawrence, 1986 to 2017.*

Catchability to fisheries is expected to change over time for a number of reasons including a common inverse relationship between catchability and population size, and improvements in fishing technology and tactics. Variation in *q* within the Middle and South regions was independent of variations in stock biomass suggesting that much of the increase in *q* in these two regions is related to technological improvements and changes in fishing tactics.

### Recalculating the Limit Reference Point

The limit reference point (LRP) in 4T herring is $B_{recover}$, the lowest biomass from which the stock has been observed to readily recover, and it is calculated as the average of the four lowest spawning stock biomass (SSB) estimates during the early 1980s (i.e., 1980-1983). Consequently, this value is model dependent. If the model changes, stock biomass may be re-scaled upwards or downwards. With the model change initiated in 2015 (DFO 2015) and retained in this assessment, there was a revised value for the biomass in the 1980s. Thus the LRP was re-calculated and the revised LRP is 58,000 t, slightly greater than the former value of 51,000 t.

### Spawning Stock Biomass and Exploitation Rate

Estimated SSB in the North region was at a high level from the mid-1980s to the early 1990s and declined to a moderate level from the mid-1990s to the late 2000s (Fig. 24). Estimated SSB in this region declined continuously during 2012 to 2018, with the median estimate reaching low levels not observed since the early-1980s. In the Middle region, estimated SSB increased gradually from 1980 to the late 2000s, but declined by about 60% during 2009 to 2018. SSB in the South region was at a relatively high level from about the mid-1980s to the late 2000s, however, estimated SSB declined during 2009 to 2015. In 2016, SSB began to increase in the South region, however, the estimate has very high uncertainty in this region. Summed over the three regions, the median estimate of total SSB at the start of 2018 is 112,000 t. The estimated probabilities that total SSB was below the USR of 172,000 t at the beginning of 2017 and 2018 are 98% and 97%, respectively.

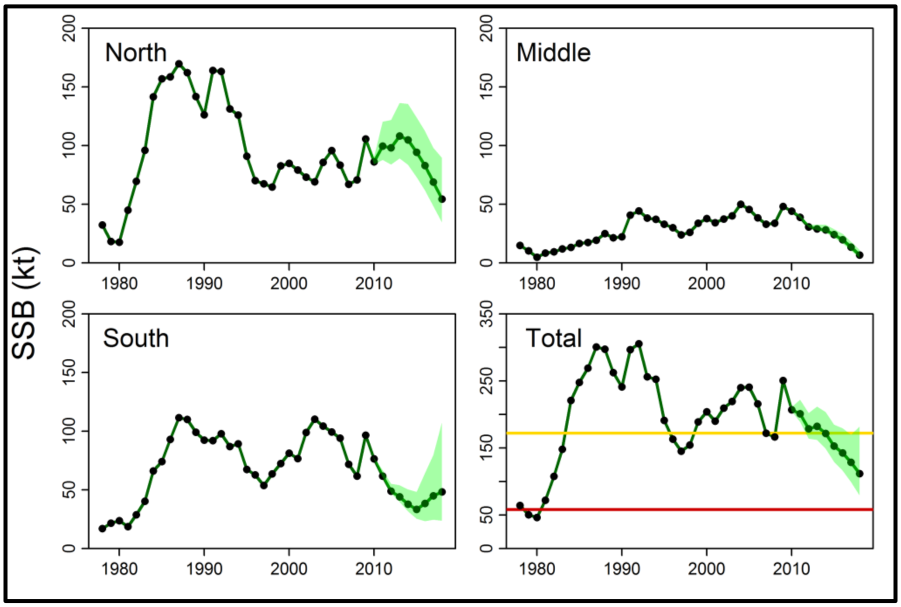


*Figure 24. Estimated spawning stock biomass (SSB) of fall spawning herring by region and overall (Total) for the southern Gulf of St. Lawrence, at the beginning of the year 1978 to 2018. The line and circles show the median estimates and the shading their 95% confidence intervals. In the bottom right panel for Total, the yellow horizontal line is the upper stock reference level (USR) and the lower red horizontal line is the limit reference point (LRP).*

Estimated fishing mortality rates (*F*; ages 5 to 10) declined to a relatively low level in the North (0.22 in 2017) region but in the Middle and South regions they remained relatively high and consistent until 2017 (Fig. 25). In the Middle region, *F* increased sharply to 0.95 in 2017, whereas in the South region it decreased to 0.10 in 2017 (Fig. 25). The average fishing mortality rate on ages 5 to 10 over all three regions (weighted by region-specific abundances of 5 to 10 year olds) exceeded $F_{0.1}$ (F = 0.32; the reference level in the healthy zone) during 1994 to 2011, except in 2004, but declined after 2011 to attain its lowest levels in 2016 (F = 0.18; Fig. 25). The probability that the overall *F* for ages 5 to 10 exceeded the $F_{0.1}$ value in 2017 was 20%.

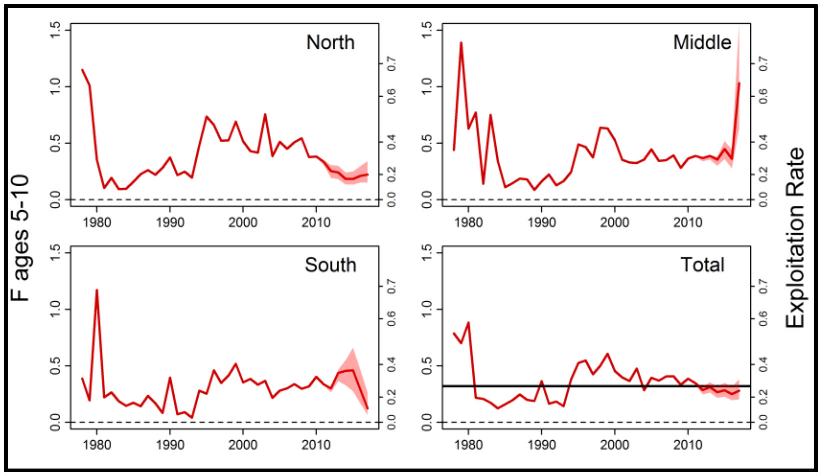


*Figure 25. Estimated age 5 to 10 fishing mortality rates (instantaneous rate F in left axes and as annual exploitation rate in right axes) of fall spawning herring by region and averaged over regions (weighted by region-specific abundance at ages 5 to 10 years) in the southern Gulf of St Lawrence, 1978 to 2017. Lines show the median estimates and shading their 95% confidence intervals. The horizontal line in the bottom right panel (Total) shows the reference removal rate level of $F_{0.1}$ (F = 0.32, an exploitation rate of 27% annually) applicable in the healthy zone.*

### Recruitment and Recruitment Rates

The three most recent estimates of recruitment rate (2012 to 2014 cohorts; recruit abundance divided by the SSB producing them) were among the lowest observed in the North and Middle regions. The estimates for these three cohorts were average in the South region, though the estimates were extremely uncertain (Fig. 26). Summed over all three regions, total recruitment rates for the 2012 to 2014 cohorts were among the lowest observed.

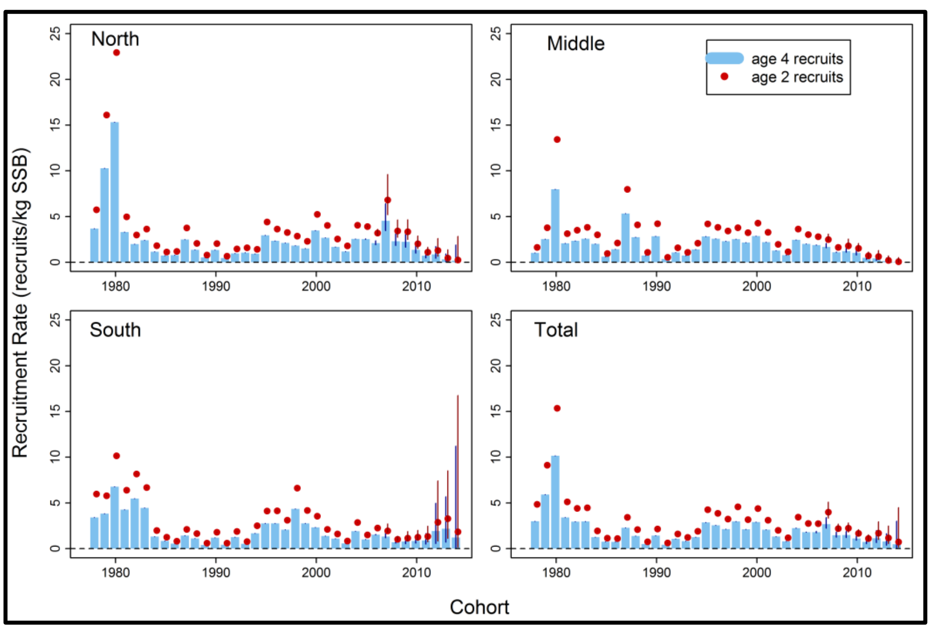


*Figure 26. Estimated recruitment rates to age 2 (circles) and age 4 (bars) for fall spawning herring by region and summed (Total) over regions in the southern Gulf of St. Lawrence, for the 1978 to 2014 cohorts. Vertical lines are the 95% confidence intervals.*

Estimated abundances of FS age 4 and older have declined in the North and Middle regions since 2013 and 2009, respectively (Fig. 27). In the South region, the abundances declined during 2004 to 2015 but increased recently, however, the estimates have very high uncertainty in this region since 2015 (Fig. 27).To a large extent, this reflects reductions in the recruitment of 4-year-old herring. In all three regions, estimated abundances of age 4 herring for the last three years (2016 to 2018) are among the lowest observed and comparable to the low levels estimated for the late 1970s.

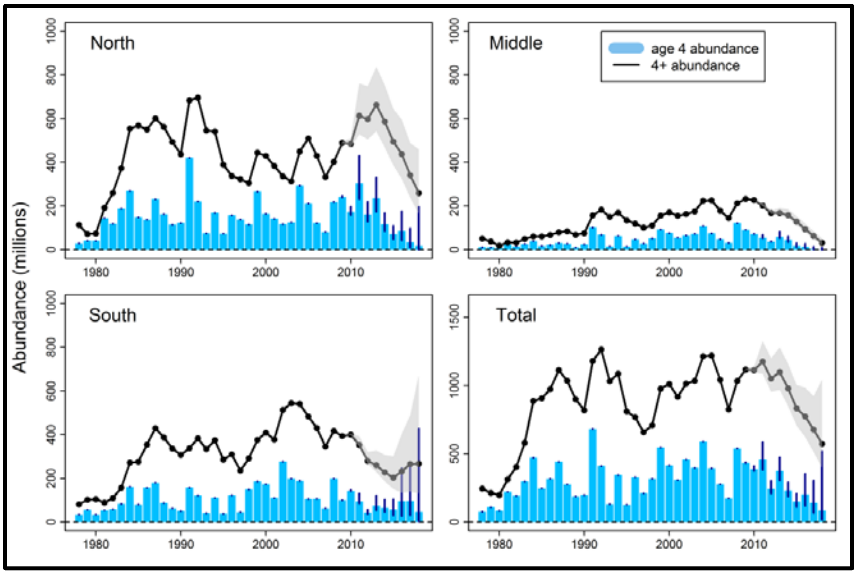


*Figure 27. Estimated abundances of fall spawning herring at ages 4 and for ages 4+ by region and for the entire (Total) southern Gulf of St. Lawrence at the beginning of the year, 1978 to 2018. Line and circles (age 4+) and bars (age 4) show the median estimates and shading or vertical lines show the 95% confidence intervals.*

### Projections

The fishery TAC for the fall spawner component is set at the level of the entire NAFO Div. 4T stock unit. The three region-specific models were projected forward to the start of 2020. Uncertainties incorporated in projections included estimates of abundance at age at the beginning of 2018, weights-at-age, partial recruitment to the fishery, and recruitment rates (to estimate age 2 abundance). Summed over all three regions, the median estimate of SSB at the start of 2020 was projected to be below the USR at all catch levels between 10,000 and 50,000 t (Fig. 28).

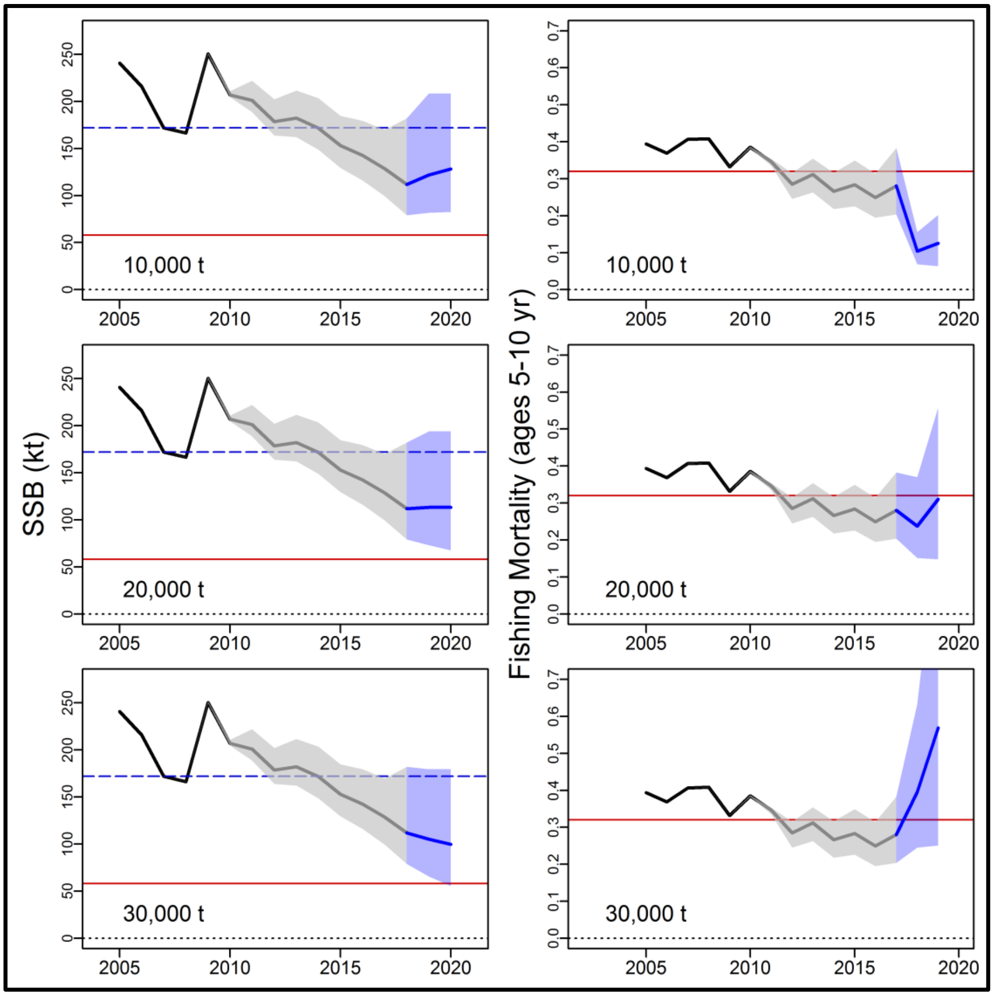


*Figure 28. Spawning stock biomass (SSB in kt; left panels) and ages 5 to 10 fishing mortality rates (F; right panels) of fall spawner Atlantic herring from the southern Gulf of St. Lawrence for three catch levels in 2018 and in 2019. In all panels, lines show the median estimates and shading the 95% confidence intervals of these estimates (based on MCMC sampling). Black lines and grey shading indicate the historical period whereas blue lines and shading show the projection period, respectively. In the left panels, the blue dashed line is the upper stock reference (USR) and the red horizontal line is the limit reference point (LRP). In the right panels, the red horizontal line is the removal rate reference level ($F_{0.1}$; F = 0.32).*

### Risk analysis of catch options

The probability that SSB would be below the USR at the start of 2020 increases from 90% at 10,000 t of catch to 99% at 50,000 t of catch. At a catch of 20,000 t (the catch in 2017) in 2018 and 2019, this probability would be 94% (Fig. 29). At catch levels from 10,000 to 20,000 t in 2018 and 2019, the median value of weighted average *F* for ages 5 to 10 over all regions in 2019 was less than 0.32, i.e. the probability that F would exceed $F_{0.1}$ < 50%.

The probability that SSB would be below the LRP in 2020 ranged from 0% at 10,000 t to 17% at 50,000 t. A 5% increase in SSB by 2020 would only be likely at catches below 16,000 t whereas a decrease in SSB is probable at catches of 24,000 t and above.

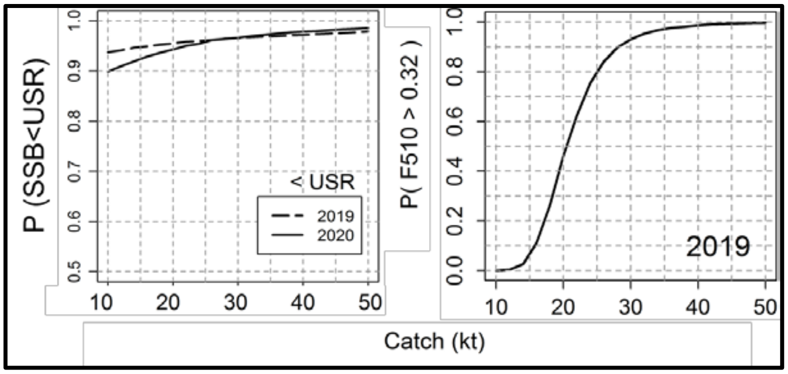


*Figure 29. Risk analysis of annual fixed catch options for 2018 and 2019 for the FS herring component of the southern Gulf of St. Lawrence. The left panel shows probabilities that total SSB at the start of 2019 and 2020 will be below the USR. The right panel shows probability profile of average F for ages 5 to 10 in 2019 being greater than the reference level F = 0.32 ($F_{0.1}$).*

## Sources of Uncertainty

Fishery dependent indices, such as the commercial gillnet CPUE indices, may not be proportional to abundance due to changes in catchability over time. On one hand, catch rates can remain elevated despite decreases in abundance (increased catchability) due to contractions in stock distribution and targeting of aggregations by fishing fleets, as well as due to improved fishing technology and fishing practices. On the other hand, catch rates can be negatively affected by boat limits, saturation of nets at high abundance, and closure of prime fishing areas that redirect fishing effort to other locations. Catch rates calculated on the basis of realized landings and available fishing effort information would be subject to such effects. The estimation of time-varying catchabilities in the SS and FS assessments accounts for some of the effects listed above.

The commercial CPUE calculations are subject to uncertainty. The estimates are based on regional average seasonal values of fishing effort data (number of nets, number of hauls, and net length of gillnets) from the telephone survey rather than trip specific information. Trips with no catch were not documented prior to 2006 and therefore are not incorporated in the effort data. No information is collected on the soak time of nets. There are also potential inconsistencies in the reporting of effort data within and among regions and seasons.

The new modelling approach considers the dynamics of fall spawning herring in three regions. The dynamics are modelled independently among regions and assume closed populations after recruitment at age 2. This is a strong assumption that can have consequences on region-specific estimates of abundance and dynamics. Empirical evidence for spawning bed fidelity has been documented in fall spawning herring based on tagging studies. Nevertheless, elemental analyses of otolith structures did not detect region-specific differences among fall spawners despite showing distinct differences between spring spawners and fall spawners in the sGSL. Genetic research has been unable to identify population-level differences between regions for fall spawners.

The weight-at-age of herring has declined and remains at near record low levels. The causes of these declines in weight-at-age and the consequences to recruitment rate are unknown.

Catches of herring in bait fisheries are presently not accounted for in the assessments of either spring or fall spawner components. Catches in these fisheries are meant to be recorded in harvester logbooks but compliance with the requirement to complete and return logbooks is low. Catches of herring in the bait fishery are expected to be much lower than landings in the commercial fishery, nonetheless this unaccounted fishing mortality constitutes a source of uncertainty in the total fishing mortality.

Uncertainty in recruitment rate in both the SS and FS leads to uncertainty in projections as these are heavily reliant on the recruitment rate selected. In this assessment, three recruitment scenarios were used for the SS assessment to account for variation in recruitment rates among years. In the FS assessment, an intermediate recruitment rate value was used as it appears that the most recent estimates of recruitment rate were biased low and would result in overly pessimistic projections.

The model assumes that natural mortality was constant over time. Retrospective patterns from previous assessments indicated a change in dynamics over time which could be associated with changes in catchability of the commercial cpue index (q) or natural mortality (M). A model that incorporated time varying change in q rather than M resolved the non-stationarity problem. This does not mean that M did not change but the current data and information used in the model only resolve one or the other. Future research should also consider whether M has changed in this ecosystem and what information could be used to incorporate this dynamic in the population model.

In the previous assessment, the fall spawner abundances were declining with the estimate at the end of 2015 just below the USR. In this assessment, the median of the 2014 and 2015 estimates are below the USR. The declining trend in status has continued into 2018. Given this decline in absolute level of abundance from the previous assessment, it is possible that the current biomass values from the model are overestimated. This overestimation of the biomass will result in an underestimate of the risk of failing to achieve defined management objectives for different catch options for 2018 and 2019 although the extent of the bias is not known.

# CONCLUSIONS AND ADVICE

## Spring Spawner Component (SS)

The spring spawner component trajectory with respect to spawning stock biomass and fishing mortality levels is shown in Figure 30. The stock has been in the critical zone (SSB < LRP = 19,250 t) since 2004 with fishing mortalities above the $F_{0.1}$ level until 2010. Since 2010 $F$ has decreased and remained at levels below $F_{0.1}$.

SSB at the start of 2019 and 2020 was projected to increase slightly at annual catches less than 500 t, remain roughly stable at annual catches of 1,000 t, but decline at catches of 1,500 t or more. However, uncertainty in projected SSB is high. Even in the absence of any removals of SS herring in 2018 and 2019, the SSB is expected to only increase slightly with a very high probability (90%) that the stock will remain in the critical zone.

Fishing mortality on the SS herring in recent years was estimated at 0.24, low relative to the history of the fishery but still high for a stock in the critical zone. Elevated fishing mortality and declines in weight-at-age are also exacerbating the reductions in SSB.

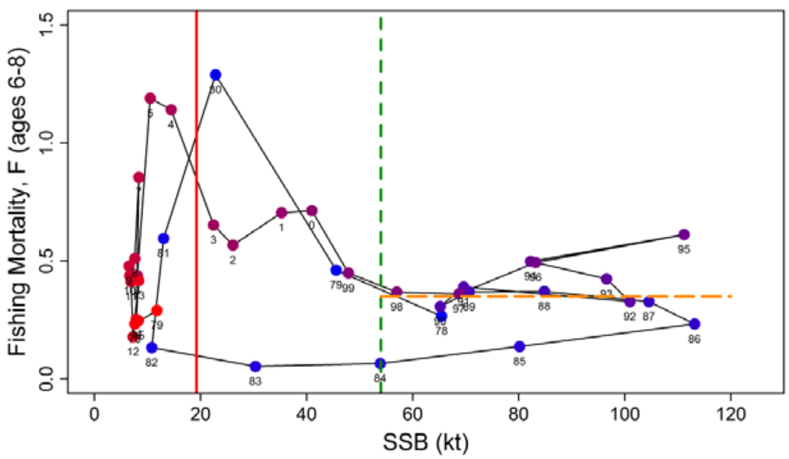


*Figure 30. The southern Gulf of St. Lawrence Atlantic Herring spring spawner component trajectory in relation to spawning stock biomass (SSB, kt = thousand t) and fishing mortality rates for ages 6 to 8 years. The solid red vertical line is the LRP (19,250 t), the green dashed vertical line is the Upper Stock Reference (USR = 54,000 t), and the dashed horizontal line is the removal rate reference value ($F_{0.1}$ = 0.35). Point labels are years (83 = 1983, 0 = 2000). Colour coding is from blue in the 1970s and early 1980s to red in the 2000s.*

## Fall Spawner Component (FS)

The fall spawner component trajectory with respect to spawning stock biomass and fishing mortality levels is shown in Figure 31. The median estimate of the SSB has generally been in the healthy zone (SSB > 172,000 t) over its history with few exceptions but the median estimate of SSB has been in the cautious zone since 2015. Fishing mortality rates generally exceeded the removal rate reference from the mid-1990s to 2011 but were below the reference level from the early 1980s to the mid-1990s and since 2011.

The median SSB estimate at the start of 2019 and 2020 was projected to remain in the cautions zone (below the USR) even at catch levels of 10,000 t. At a catch of 20,000 t (the catch in 2017) in 2018 and 2019, the probability of the SSB being in the cautious zone in 2020 was estimated at 94%, and the probability of the fishing mortality rate being above the removal rate reference was estimated at 46%.

Fishing mortality on the FS herring averaged 0.20 since 2012, just over half of the $F_{0.1}$ removal reference level.

Declining abundance at age 4 in recent years, resulting from declining recruitment rates, has contributed to the decline in SSB for this stock. The causes of the low recruitment rates for the FS herring component are unknown. Declines in weight-at-age are also exacerbating the reductions in SSB. Fishing mortality rates in excess of $F_{0.1}$ from the mid 1990’s to 2010 have also contributed to reductions in SSB.

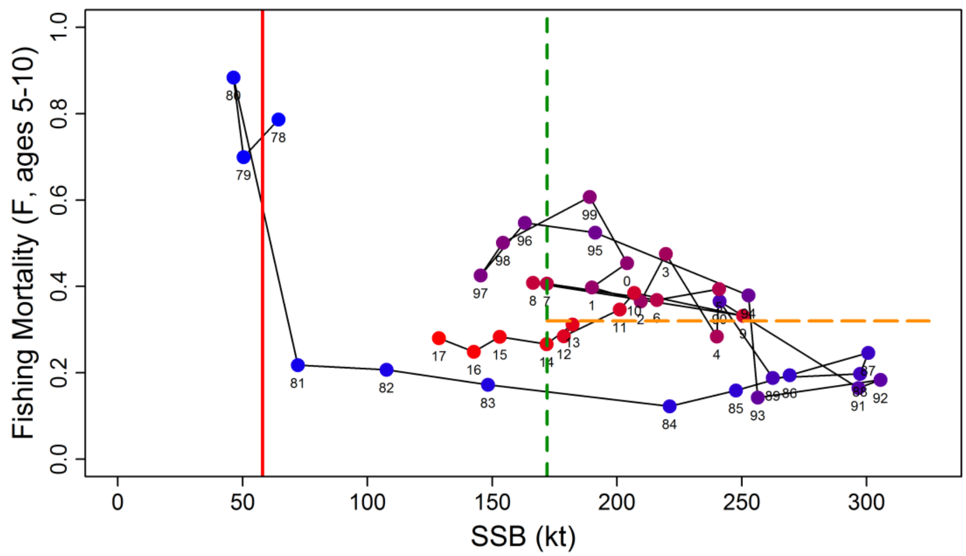


*Figure 31. The southern Gulf of St. Lawrence Atlantic Herring fall spawner component trajectory in relation to spawning stock biomass (SSB, kt = thousand t) and fishing mortality reference levels. The solid red vertical line is the LRP (58,000 t), the green dashed vertical line is the Upper Stock Reference (USR = 172,000 t), and the dashed horizontal line is the removal rate reference value ($F_{0.1}$ = 0.32). Point labels are years (83 = 1983, 0 = 2000). Colour coding is from blue in the 1970s and early 1980s to red in the 2000s.*

## SOURCES OF INFORMATION

This Science Advisory Report is from the March 15, 2018 regional science peer review meeting on the Assessment of stock status of Atlantic herring (*Clupea harengus*) from the southern Gulf of St. Lawrence (NAFO Div. 4T-4Vn) to 2017 and advice for the 2018 and 2019 fisheries. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule] as they become available.


Bourne, C., Mowbray, F., Squires, B., and Croft, J. 2015. 2014 Assessment of Newfoundland East and South Coast Atlantic Herring (*Clupea harengus*). DFO Can. Sci. Advis. Sec. Res. Doc. 2015/055. v + 61 p.

DFO. 2005. Spawning Stock Biomass Reference Points for Southern Gulf of St. Lawrence Herring. DFO Can. Sci. Advis. Sec. Advis. Rep. 2005/070.

DFO. 2007. Size at 50% maturity for southern Gulf of St. Lawrence herring (NAFO 4T). DFO Can. Sci. Advis. Sec. Sci. Resp. 2007/019.

DFO. 2009. [A fishery decision-making framework incorporating the Precautionary Approach].

DFO. 2014. Assessment of Atlantic herring in the southern Gulf of St. Lawrence (NAFO Div. 4T) to 2013. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/040.

DFO. 2015. Updated assessment to 2014 of the fall spawning component of Atlantic Herring (*Clupea harengus*) in the southern Gulf of St. Lawrence (NAFO Div. 4T) and advice for the 2015 fishery. DFO Can. Sci. Advis. Sec. Sci. Resp. 2015/033.

DFO. 2016. Assessment of the southern Gulf of St. Lawrence (NAFO Div. 4T) spring and fall spawner components of Atlantic herring (*Clupea harengus*) with advice for the 2016 and 2017 fisheries. DFO Can. Sci. Advis. Sec. Sci. Resp. 2016/036.

LeBlanc, C.H., Mallet, A., Surette, T., and Swain, D. 2015. Assessment of the NAFO Division 4T southern Gulf of St. Lawrence herring stocks in 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/025. vi + 133 p.

McDermid, J.L., Mallet, A., and Surette, T. 2016. Fishery performance and status indicators for the assessment of the NAFO Division 4T southern Gulf of St. Lawrence Atlantic herring (*Clupea harengus*) to 2014 and 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/060. ix + 62 p.

Melvin, G.D., Stephenson, R.L., and Power, M.J. 2009. Oscillating reproductive strategies of herring in the western Atlantic in response to changing environmental conditions. ICES J. Mar. Sci. 66: 1784-1792.

Paloheimo, J.E., and Dickie, L.M.1964. Abundance and fishing success. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 155: 152-143.

Swain, D.P. 2016. Population modelling results for the assessment of Atlantic herring (*Clupea harengus*) stocks in the southern Gulf of St. Lawrence (NAFO Division 4T) for 2014-2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/061. xi + 53 p.

Winters, G.H., and Wheeler, J.P. 1985. Interaction between stock area, stock abundance, and catchability coefficient. Can. J. Fish. Aquat. Sci. 42: 989-998.

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*Aussi disponible en français :*

*MPO. 2018. Évaluation du hareng de l'Atlantique (Clupea harengus), composantes des reproducteurs de printemps et d'automne, du sud du golfe du Saint-Laurent (division 4T de l'OPANO) et avis pour les pêches de 2018 et de 2019. Secr. can. de consult. sci. du MPO, Avis. Sci. 2018/029.*

# APPENDIX D-2

Fisheries and Oceans Canada    Pêches et Océans Canada
Ecosystems and Oceans Science    Sciences des écosystèmes et des océans

**Canadian Science Advisory Secretariat (CSAS)**

**Research Document 2016/097**

**Gulf Region**

# Estimation of local spawning biomass of Atlantic Herring from acoustic data collected during fall commercial gillnet fishing activities in the southern Gulf of St. Lawrence (NAFO Div. 4T)

Tobie Surette, Claude LeBlanc, Ross Claytor and Jenni McDermid

Fisheries and Oceans Canada
Gulf Fisheries Centre
343 University Avenue
Moncton, New Brunswick, E1C 9B6)

November 2016

## Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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## ABSTRACT

In partnership with Fisheries and Oceans Canada (DFO), fish harvesters participating in the Atlantic herring (*Clupea harengus*) fall fishery in NAFO Div. 4T surveyed five spawning grounds in the southern Gulf of St. Lawrence using acoustic sounders over the course of their regular fishing activities from 2002 to 2012. Using a statistical method developed for Fisherman's Bank, seasonal biomass was estimated for all five spawning grounds. Acoustic data from each area was processed and analyzed to produce nightly biomass estimates for a subset of days over the season. Missing biomass values were simulated using a Bayesian time-series model, then grouped by spawning aggregation using a spatial-temporal clustering model. Seasonal biomass estimates were then produced by year and region. While this approach showed some promise, the model did not provide realistic results for two of the five regions. Furthermore, there are also underlying methodological and biological issues which raise significant doubts as to the comparability of results among regions. Given the inconsistencies in model performance and the underlying issues with the data it was decided that these data could not be used to develop a time series of local abundance indices for herring as part of the fall herring stock assessment. Recommendations are made to aid in future spawning bed specific acoustic surveys.

**Estimation de la biomasse du stock de reproducteurs de harengs de l'Atlantique à l'échelle locale à partir des données acoustiques recueillies au cours des activités de pêche commerciale au filet maillant d'automne dans le sud du golfe du Saint-Laurent (division 4T de l'Organisation des pêches de l'Atlantique Nord-Ouest (OPANO))**

## RÉSUMÉ

En partenariat avec Pêches et Océans Canada (MPO), les pêcheurs participant à la pêche d'automne du hareng de l'Atlantique (*Clupea harengus*) dans la division 4T de l'OPANO ont effectué des relevés dans cinq frayères du sud du golfe du Saint-Laurent en utilisant des sondeurs acoustiques pendant leurs activités de pêche courantes entre 2002 et 2012. À l'aide d'une méthode statistique conçue pour le Fisherman's Bank, on a estimé la biomasse saisonnière pour les cinq lieux de frai. Des données acoustiques de chaque zone ont été traitées et analysées afin de produire des estimations de la biomasse chaque nuit pour un sous-ensemble de jours au cours de la saison. Les valeurs de la biomasse manquantes ont été simulées à l'aide d'un modèle bayésien d'ajustement des séries chronologiques puis classées par groupement de poissons en frai à l'aide d'un modèle de regroupement spatiotemporel. Les estimations de la biomasse saisonnière ont ensuite été produites par année et par région. Bien que cette méthode se soit révélée assez prometteuse, le modèle n'a pas fourni des résultats réalistes pour deux des cinq régions. De plus, il y a aussi des problèmes méthodologiques et biologiques sous-jacents qui soulèvent de sérieux doutes quant à la comparabilité des résultats entre les régions. Compte tenu des irrégularités dans le rendement du modèle et des problèmes sous-jacents liés aux données, il a été décidé que ces données ne pouvaient pas être utilisées pour élaborer une série chronologique d'indices de l'abondance locale du hareng dans le cadre de l'évaluation du stock de reproducteurs d'automne de hareng. Des recommandations sont formulées pour faciliter les relevés acoustiques propres aux frayères à venir.

# INTRODUCTION

Population biomass and fishing mortality estimates are key components of fishery management decision frameworks, and are necessary for developing harvest control rules based on defined reference points (DFO 2006). The risk of not achieving sustainability objectives when fisheries occur on discrete spawning grounds increases when information is only obtained for large scale processes. Managing diverse herring spawning grounds for sustainability is important for conserving intraspecific biodiversity and adaptive potential (Sinclair 1988; Stephenson et al. 2001).

Until 2014, the stock assessment for the southern Gulf of St. Lawrence (sGSL) fall Atlantic herring (*Clupea harengus*) stock used a population model adjusted to annual gillnet catch-per-unit-effort (CPUE) from all spawning grounds combined and management provides Total Allowable Catch (TAC) advice based on the overall sGSL biomass (LeBlanc et al. 2015). There are concerns that gillnet CPUE does not track population biomass well, because fisheries that target spawning aggregations often exhibit hyperstability, where CPUEs remain elevated even as stock abundance declines (Erisman et al. 2011; Swain 2016).

Acoustic data from fishing vessels have been used to analyze school morphology characteristics, spatial patterns, relative changes in school density (Shen et al. 2008) and to develop estimates of abundance (Melvin et al. 2002; Honkalehto et al. 2011). Derivation of an annual seasonal index of biomass of herring from fishery acoustic data have been problematic for two reasons (Claytor and Clay 2001). First, the behaviour of herring gradually accumulating on spawning grounds prior to spawning, if not accounted for, can lead to multiple counts of the same fish which leads to over-estimation of biomass. Second, missing data created by weather, equipment malfunction, fishery closures, and other reasons create a source of uncertainty and potential biases in biomass and exploitation rate estimates.

From 2002 to 2012, acoustic data were collected from commercial gill netting vessels while fishing on the five major Atlantic herring fall spawning areas located within the coastal waters of the sGSL. The fall spawning areas were Miscou (NB), Escuminac and Richibucto (NB), Fisherman’s Bank (PEI), West PEI, and Pictou (NS) (Fig. 1). Acoustic data were to be collected according to a protocol described in Claytor and Allard (2001) for the purpose of developing a time series of local abundance indices for herring as part of the fall herring stock assessment. The objectives of this research document were to analyze the collected acoustic data and determine whether they could be used to derive an index of local abundance. Nightly biomass estimates were derived following a defined protocol (Claytor and Clay 2001) and an analytical method (Surette et al. 2015) was applied to estimate spawning bed specific estimates of annual abundance and area-specific estimates of exploitation rates for five sGSL fall spawning grounds. This novel method was developed to account for some aspects of herring spawning behaviour and includes many sources of uncertainty in its final inferences.

# METHODS

Atlantic herring from the sGSL are comprised of two spawning components, a spring spawning component and a fall spawning component (Scott and Scott 1988; Messieh 1988). Both spawning components have preferred spawning seasons and specific grounds. Herring show a high degree of fidelity to a specific spawning season and spawning ground once they have spawned (Wheeler and Winters 1984; McQuinn 1997; Brophy et al. 2006). Herring spawn in temporally discrete groups, separated by several days to weeks in a single spawning season (Ware and Tanasichuk 1989). Genetic and morphometric differences found in spawning herring were consistent with a replacement period of 6 days or less (McPherson et al. 2003). Fall spawning occurs from mid-August to mid-October, at depths of 5 to 25 m (Messieh and MacDougall 1984). The fall spawning component is the focus of this study.

Fisherman's Bank has been the focus of numerous prior studies on herring spawning behaviour. In situ observations showed that a spawning event and the creation of the associated spawning bed took place over the course of a single day (Messieh 1988). Between 1985 and 1995 the number of spawning beds surveyed on Fisherman's Bank per season varied from a minimum of 1 to a maximum of 7, with few cases of simultaneous spawning events (Table 1). Spawning season length (i.e., between the first and last spawning event) varied from 6 to 29 days (Cairns et al. 1996).

Herring spawn in multiple waves during the course of the season. Incoming schools of herring create spawning aggregations over spawning beds, and may be joined by further schools accumulating over several days. Herring subsequently dissipate after spawning, as evidenced by the low frequency of spawned herring in fishery catches. To avoid double-counting of fish during the accumulation phase, observations need to be partitioned by spawning waves. The method previously applied to Fisherman's Bank (Surette et al. 2015) is applied in this study to the other four spawning areas surveyed.

## OVERVIEW OF ANALYSIS

The goal of the analysis is to estimate the total fall spawning biomass from a set of nightly acoustic observations. Seasonal biomass requires a daily tally of all incoming or outgoing fish over spawning grounds for each region. The data presents two difficulties. Firstly, biomass estimates are only available for nights where the participating fish harvester was active. Secondly, spawning aggregations contain a mixture of fish which entered the grounds during the previous 24 hours and those from days prior.

The analysis proceeds in three steps. The first is to process and analyze the nightly acoustic data for each region in order to obtain a nightly biomass estimate. The method is described in Claytor and Clay (2001). The second step is to use a model to simulate values for nights with missing observations. The third step is to partition nightly biomass into distinct spawning waves using a spatial-temporal model. This step provides estimates of recruitment and escape biomasses which are then summed into a seasonal estimate. Uncertainty due to missing observations and clustering were incorporated in each step of the analysis.

## ACOUSTIC DATA ANALYSIS

Two data sources were used in the following model: region-specific landings from the sGSL fall gillnet fishery and region-specific acoustic data from participating fishing vessels. Nightly landings were obtained from dockside monitoring data compiled and archived by the Department of Fisheries and Oceans Statistics Branch. The acoustic data was obtained from one or two fishing vessels per night from each spawning ground (Fig. 2). Acoustic calibration, data collection and processing, as well as the method for calculating nightly biomass, are described in Claytor and Clay (2001).

### Nightly biomass model

Observations from each day of the spawning season are required for calculating the seasonal biomass. Missing observations occurred due to logistical problems (e.g., equipment failure, vessel electrical problems), weekend fishery closures, inclement weather or the fishery attaining its quota before the end of the spawning season. Missing nightly biomass values were inferred using a time-series model.

Let $b_{ijk}$ be the nightly biomass estimate for day *i*, year *j* and region *k*. Zero values and positive values of $b_{ijk}$ were modeled separately. Let $z_{ijk} \sim Bern(\pi_{jk})$ be a binary random variable indicating whether $b_{ijk}$ is zero ($z_{ijk} = 1$) or one ($z_{ijk} = 0$). For each year and region, positive values of $b_{ijk}$ are assumed to be log-normally distributed realisations from a first order autoregressive process (AR(1)):

$$\varepsilon_{ijk} \sim N(\phi_k \varepsilon_{i-1,jk},\ \sigma_\varepsilon^2)$$

$$\mu_{ijk} = \alpha_{jk} + \varepsilon_{ijk}$$

$$b_{ijk} \mid z_{ijk} = 0 \sim LN(\mu_{ijk}, \sigma^2)$$

where the log-linear annual means $\alpha_{jk} \sim N(\mu_{\alpha,}\sigma_\alpha^2)$ were given a hierarchical prior, with $\mu_\alpha \sim N(0, 10^4)$ and $\sigma_\alpha^2 \sim InvGam(10^{-4}, 10^{-4})$, the AR(1) process error was given a prior of $\sigma_\varepsilon^2 \sim InvGam(10^{-4}, 10^{-4})$, the AR(1) autocorrelation parameter a prior of $\phi_k \sim U(0, 1)$, the nightly observation error parameter was given a prior of $\sigma^2 \sim InvGam(10^{-4}, 10^{-4})$ and the prior probability of observing a zero was given a hierarchical prior of $\pi_{jk} \sim Beta(a, b)$ with $a \sim Exp(1)$ and $b \sim Exp(1)$. An error (CV = 0.15), based on empirical considerations (Claytor and Allard 2001) was added to each nightly biomass as a proxy for estimation error. If landings were reported for a given night, missing observations were assumed to be drawn from a truncated distribution and these were used to inform missing observations by serving as lower bound in a censored log-normal distribution. When landings exceeded nightly biomass estimates, the latter were treated as missing values. The above model differed slightly from the one presented in Surette et al. (2015) which made no provision for autocorrelation between observations and had no inter-regional hierarchical priors as it was applied to Fisherman's Bank region only. The OpenBUGS code for this model is found in Appendix A.

For the purposes of this study, the fishing season was defined as a period of 28 days starting at the opening date of the fishery. The sampling period by participating vessels covers the potential spawning period of herring for each spawning area. The seasonal distribution of acoustic data samples for each region is shown in Figure 2.

## Spatial-temporal clustering model

The locations of nightly aggregations were calculated directly from acoustic density data, as a density-weighted average of GPS coordinates. These coordinates were used as inputs in a spatial-temporal clustering model, used for partitioning observed spawning aggregations by spawning wave. Under this model, a temporal sequence of spatially proximate aggregations would likely be grouped together as a single spawning wave, while those which are spatially distant would not. Such structural features in the data aid in probabilistically inferring the spawning wave with which missing observations are associated. The model formulation is as follows.

Let $x_{ijk}$ and $y_{ijk}$ represent the horizontal and vertical coordinates (in UTM projection, NAD83, zone 20, scaled to kilometers) of the aggregation locations for day *i* of the fishing season at year *j* within spawning region *k*. The coordinates were modeled as random walks with heterogeneous variances:

$$x_{ijk} = x_{i-1,jk} + \varepsilon_{ijk}^x, \text{ with } \varepsilon_{ijk}^x \sim \mathrm{N}(0, \sigma_{s_{ijk}}^2)$$

$$y_{ijk} = y_{i-1,jk} + \varepsilon_{ijk}^y, \text{ with } \varepsilon_{ijk}^y \sim \mathrm{N}(0, \sigma_{s_{ijk}}^2)$$

where $\varepsilon_{ijk}^{x}$ and $\varepsilon_{ijk}^{y}$ are independent normal random variables, each with two variance parameters $\sigma_0^2 < \sigma_1^2$ which were given uninformative priors of $\mathrm{InvGam}(10^{-4}, 10^{-4})$. The choice of variance parameter used is controlled by a binary random variable $s_{ijk}$, modeled as a 2-state Markov chain $s_{ijk}$. Formally,

$$s_{ijk}|s_{i-1,jk} = 0 \sim \mathrm{Bern}(\pi_{0\mathrm{k}})$$

$$s_{ijk}|s_{i-1,jk} = 1 \sim \mathrm{Bern}(\pi_{1\mathrm{k}})$$

where state 0 indicates that the aggregation location from day *i* belongs to the same spawning wave as that of previous day and state 1 indicates that it belongs to a new spawning wave. The transition probabilities were given hierarchical priors of $\pi_{0k} \sim \mathrm{Beta}(a_0, b_0)$ and $\pi_{1k} \sim \mathrm{Beta}(a_1, b_1)$ with $a_0 \sim \mathrm{Exp}(1)$, $a_1 \sim \mathrm{Exp}(1)$, $b_0 \sim \mathrm{Exp}(1)$ and $b_1 \sim \mathrm{Exp}(1)$. The probability parameter $\pi_{0\mathrm{k}}$ controls the residence time of sequences within spawning events while $\pi_{1\mathrm{k}}$ controls how often an aggregation will be remain within the current spawning event, given that a new spawning event has just occurred. The spawning event to which an observation from day *i*, year *j* and region *k* belongs, labelled $c_{ijk}$, is the cumulative sum of the corresponding elements of $s_{ijk}$ over the season:

$$c_{ijk} = \sum_{m=1}^{i} s_{mjk} \; + \; 1$$

This model was nearly identical to that presented in Surette et al. (2015), except for the hyperpriors placed on the transition probabilities and variance parameters, to allow for some pooling of information across regions.

For both the nightly biomass and spatial clustering model, posterior samples were drawn via Monte Carlo Markov Chain (MCMC), with a burn-in sample of 5,000 iterations, plus a further draw of 100,000 samples which were thinned to one out of every twenty samples, for a total of 5,000 posterior samples. The OpenBUGS code (Lunn et al. 2000) for this model is found in Appendix B.

## Seasonal biomass calculation

Simulations of nightly biomasses for each night of the season and their corresponding spawning wave identifications provided the input for calculating a seasonal spawning biomass. Each day of an event was assumed to be either a recruitment day, whereby a quantity of fish enter the aggregation, or an escape day, where fish exit the aggregation. For the first day of the event, biomass was considered to be recruitment. For subsequent days, recruitment and escape days were determined by comparing the biomass from day *i+1* ($b_{i+1}$) with the residual biomass of the day *i*, expressed as the difference of the biomass from day *i* ($b_i$) and the landings ($l_i$). If $b_{i+1}$ was larger, it was interpreted as a recruitment day, otherwise it was an escape day. This recruitment was calculated as the difference between the biomass $b_{i+1}$ and the residual biomass $r_i$. The seasonal biomass is defined as the sum of the recruitment biomasses.

A minimum sequence of three days was imposed for a simulated spawning event to be considered valid in the summation of seasonal spawning biomass. Sequences less than three days were ignored in the summation, and were considered as roaming fish not actively participating in a spawning event.

## RESULTS

A log-scale scatterplot of landings versus estimated nightly biomass is shown in Figure 3. The correlation between the two values is weak; high biomass estimates do not imply high landings. Despite efforts to have good coverage of the spawning aggregation by the participating fish harvesters, 22% of nightly biomass estimates were less than the reported nightly landings. In the most severe cases, the biomass estimates were 10 to 50 times less than the landings. Estimates of biomass from the Miscou spawning area showed the largest discrepancies between biomass and landings.

The spatial distributions of spawning aggregations used in the spatial-temporal clustering model are shown in Figure 4 for each spawning region. Each region has its particular characteristics. Where Fisherman's Bank has clusters of locations strongly associated with a submerged ridge, Miscou has a more diffuse distribution across a large area. The distribution in Pictou is stretched out along the coast, and the fleet tends to move as schools of herring migrate through the region during the season. The distribution in the Escuminac region is composed of a northern and southern component. West PEI shows a more complex distribution of scattered locations and a small patch to the Northwest.

Summary statistics for the main model parameters are shown in Table 2.

For the nightly biomass model, credibility intervals showed that the auto-correlation parameter $\phi$ was not significant for Escuminac, Fisherman's Bank and West PEI, while it was marginally significant for Pictou and significant for Miscou. Variation in the biomass estimates was high and this was reflected in the posterior credibility intervals of missing observations. As an example, boxplots of posterior estimates for Miscou in 2006 are shown in Figure 5. The auto-correlation in the posterior simulations aided in the interpolation of missing values for Miscou. For other regions, the simulations for missing observations are nearly independent (i.e., their posterior means and variances are similar). Actual observations, shaded in grey, had the assumed baseline CV of 0.15.

For the spatial-temporal model, the error parameters $\sigma_0$ and $\sigma_1$ indicate the amount of distance change (in kilometers) between adjacent pairs of nightly spawning aggregations. Since the coordinates are modelled as a Gaussian random walk, the values of $\sigma_0$ and $\sigma_1$ are estimates which indicate that points along the walk will occur within $\sigma_0$ (intra-aggregation) and $\sigma_1$ (new aggregation) kilometers of the previous coordinate in 68% of cases. The intra-event distance parameter $\sigma_0$ was 0.53 km in Fisherman's Bank. In terms of surface area, this corresponds roughly to 0.88 km² at 68% areal coverage or 3.52 km² at 95% coverage, assuming a circular distribution of points. These values correspond well with spawning bed surface area estimates from previous studies (Table 1), which ranged from 0.36 km² to 1.44 km². We expect the spatial distribution of aggregations over and around spawning beds to be larger in extent than that of the spawning beds themselves. The $\sigma_0$ values for other regions were somewhat larger, from 0.68 km in West PEI to 1.46 km in Pictou. The extra-event distance parameter $\sigma_1$ showed more variability, going from 4.39 km in Fisherman's Bank to 24.0 km in Pictou. This parameter reflects the regional extent of coverage, with fish harvesters travelling significantly more during the season in some regions than in others.

The intra-event transition probability $\pi_0$ controls the residence time of aggregations within spawning events while the transition probability $\pi_1$ controls how often sequences of new spawning aggregations occur. Mean intra-event transition probabilities $\pi_0$ were generally high, from 0.81 for Fisherman's Bank, 0.87 for Escuminac and 0.88 for West PEI. The probability value for Miscou was exceptionally high at 0.97, while Pictou was very low with 0.55. The transition probabilities $\pi_1$ were more consistent between regions, ranging from 0.41 for Pictou to 0.65 in West PEI (Table 2).

The estimated number of spawning events for each spawning region by year is shown in Table 3. In general, the number of events was 3 or 4 events per 28-day period, the exception being Miscou, with generally one or two spawning events per period, owing to its high intra-event transition probability of 0.97.

Combining the nightly biomass and the spawning event inferences, seasonal biomass estimates for each region and year were obtained. Boxplots of seasonal estimates by spawning region by year are shown in Figure 6. Escuminac shows a downward trend in abundance during 2002 to 2010, with a slight increase in the last years. The estimates for Pictou fluctuate during the first half of the series and have increased in the past four years. Fisherman's Bank shows no overall trend but the last two years show low values with respect to the rest of the series. Estimates for West PEI are fairly stable, but show a slight decreasing trend across the series. Estimates for Miscou varied in the first half of the series, were low in 2008 and 2009, rose in 2010 and 2011, and then was reached a minimum in 2012. Given the variability in the inferred missing nightly biomasses (Fig. 5), the variability of the seasonal biomasses is correspondingly high. For comparison, the means of observed nightly biomass estimates, unadjusted for spawning events are shown in Figure 7. These trends are broadly similar to those of estimated seasonal biomasses.

The exploitation rate was calculated by dividing the total seasonal landings (for the same 28 day period as used in the model) by the seasonal biomass estimate. Boxplots of the exploitation rates by spawning area are presented in Figure 8. The scale of exploitation rates estimates varies among regions, with Escuminac and West PEI being somewhat lower than in other regions. Exploitation rate estimates in West PEI show an increasing trend. Escuminac, Fisherman's Bank, and Pictou show low rates for the last two years.

There are a number of caveats to consider in the interpretation of these results (both seasonal biomass and exploitation rates).

## DISCUSSION

Science advice should be tailored to the management strategy. Currently, a reference removal rate is applied to a NAFO 4T Atlantic herring biomass estimate and a historical sharing formula is used to partition the TAC among the fleets from different regions. In this study, we evaluated the possibility of including spawning ground acoustic biomass indices as an additional element to the fall herring stock assessment and the subsequent science advice that could aid in partitioning the TAC. For the presented method to play such a role, seasonal biomass estimates must be comparable and be on the same scale among regions. How these estimates would actually be used to partition the TAC is beyond the scope of this review. We have thus restricted our discussion to the robustness of the science advice that could be provided using this model.

For seasonal biomass estimates to be valid and comparable across spawning areas, underlying assumptions of the model must be respected. The main assumptions are:

- nightly landings are accurate,
- nightly biomass estimates are unbiased estimators of true biomass in each spawning area,
- the models used are an adequate representation of the processes (e.g., spawning behaviour, fishing fleet dynamics, etc.) generating the observations and adequately account for double-counting, missing observations, and other potential sources of error,
- the study period captures the majority of spawning activity, and

- sampling methods and biological processes are sufficiently similar across regions that meaningful comparisons can be made.

For the fall herring fishery, there is little concern of bias in landings as there is 100% dockside monitoring, documented conversion factors, and controls on catch recording because nightly or weekly quotas are used to manage the fishery.

A working hypothesis for calculating the seasonal biomass is that nightly biomass estimates are on the same scale as landings. However, comparison of nightly biomass values with landings showed that these were underestimated in at least 22% of cases. These discrepancies were more prevalent in Miscou than in other regions. This percentage is probably higher given that nightly exploitation rates of 80% or larger are probably unreasonable in most regions.

Participating fish harvesters were to follow to a protocol for a complete fishery survey over each night of scanning, as defined in Claytor and Allard (2001). This protocol called for sampling vessels to collect acoustic data before and after a management-imposed nightly boat limit was caught. An incomplete survey was said to occur if the data collection was terminated when the boat limit was caught. If this protocol was properly adhered to, nightly biomass could be estimated from acoustic data before any fishing has occurred followed by a removal estimate after fishing activity has ceased. However, timing of data collection and discussions with fish harvesters indicated that acoustic scanning of spawning aggregations was generally performed during fishing activities, rather than before and after as the original protocol stated. Thus the data collection occurs as fish are actively being exploited, rather than in the pre- and post-fishing condition. Nightly biomass estimates were calculated using all validated acoustic data, irrespective of the time it was gathered or with reference to fleet fishing activities. Also, scanning during peak fishing activities is problematic because placement of gillnets over concentrations inhibits the ability of the sampling vessel to scan over the whole concentration. Thus the exploited spawning aggregation may be inadequately covered by the acoustic vessel, which may result in an underestimation of nightly biomass. In addition to possible bias in observed spawning aggregations, the presence of unobserved aggregations would also lead to underestimates of nightly biomass. This would be an issue where herring schools are more fragmented and spread out over spawning grounds. This would also have implications for fishing fleets which exploit them, in that these would also tend be more fragmented and widely distributed over spawning grounds. The sampling vessel in such cases would have had limited ability to cover the entire fleet activities. It is also possible that some spawning aggregations remain undetected by any portion of the fleet during a night of fishing in each region.

Biases could arise from the acoustic data itself, such as variability in backscattering in high target concentrations, the relationship between target strength and fish size, and acoustic extinction from near surface reverberation (Fréon and Misund 1999; Simmonds and MacLennan 2005; Brehmer et al. 2006; Boswell et al. 2008). Variability arising from these factors are minimized because the 28-day study period is relatively short, we are dealing with a single species in a well-defined phase of its life history (spawning) with a relatively restricted size-distribution, and the equipment is calibrated against objects of known target strength.

## BIOMASS MODEL

The biomass model was developed as a way of inferring nightly biomass over the study period. However, there are two issues with the approach. The first is a potential sampling bias and the second is a lack of structure in the observations by which to make strong inferences.

The variability in nightly biomass estimates is very high with estimates ranging from 0 to over 33,000 tons. There was little evidence of temporal trends or autocorrelation in nightly biomass estimates making it difficult to infer missing biomass values. This may have some implications with respect to the assumed process of accumulating waves of herring into spawning aggregations, in that residence times of herring within an aggregation may be relatively short, though uncertainties in the nightly biomass estimates as discussed above prohibit a strong conclusion.

Given that fishing is not independent of the quantity of fish, biases may arise through temporal sampling biases, given that sampling is not randomly distributed throughout the season. Such biases may be minimized by high sampling rates (i.e., most every weekday throughout the season) but the temporal pattern of coverage varies from year to year and by region. There is little indication that the survey season was cut short by attainment of the quota. Only West PEI showed a lower sampling density during the last week of the study period. Ideally, surveys would have been conducted daily or randomly within the potential spawning period of herring.

The length of the 28-day period is supported by the spawning event study on Fisherman's Bank (Cairns et al. 1996) and average length of recent fishing seasons. Biases may occur if the start date of the fishery is offset from major waves of spawning activity or if major spawning waves occur after the study period. Given the general absence of trends in the nightly biomass values, we are unable to comment on whether the study period encompasses the majority of spawning activity within each region. A strong economic argument could be made that the fishery depends on a fishing season that is timed with spawning activity, and after 28 days fishing activity has generally tapered to low levels.

## SPATIAL-TEMPORAL MODEL

The spatial-temporal model was developed to identify local spawning aggregations as a precursor to assessing fish which are present in aggregations over multiple days (i.e., double-counting). The spawning behaviour assumptions in the model are justified in Fisherman's Bank (Cairns et al. 1993, 1996), however these biological assumptions have not been independently confirmed.

For a modelling perspective, spawning events in Escuminac, West PEI and Fisherman's Bank have similar spatial extents and residence times (Table 2). As a consequence, the relative scaling between the observations and the estimated seasonal biomass is expected to be similar. The spatial extent between spawning event aggregations in Fisherman's Bank of 0.53 km (or 1.06 km at two standard deviations) are consistent with previous estimates of spawning bed size, 0.92 (+/- 0.65) $km^2$ (Cairns et al. 1996). Cairns et al. (1993, 1996) also found that the observed number of spawning beds per season was between 1 and 7 from 1985 to 1995 on Fisherman's Bank. These values are consistent with our annual average of 3.7 spawning events over the 28 day estimation period. West PEI and Escuminac produced results that were within the expectations from model assumptions.

In Miscou, the model was deemed inconsistent with biological knowledge as the fitted parameters implied long, protracted spawning events spanning large spatial areas. As a consequence, seasonal estimates were essentially the sum of recruitment days over each 28 day sampling season. The distribution of sampling and fishing effort at Miscou shows little clustering of fishing aggregations, which are otherwise present in other regions (Fig. 4). The presence of such spatial features is assumed by the model. This suggests that spawning aggregations in Miscou may follow different spatial dynamics than in other regions. Miscou also had a lower sampling density than other regions (Fig. 2), so that the seasonal estimates for certain years (e.g., 2007 with no observations, 2010 and 2011 with three observations each) are more a reflection of the hierarchical prior for the mean nightly biomass values rather than actual observations. Furthermore, Miscou landings surpassed nightly biomass estimates more frequently than in other regions. Consequently, the data collected from Miscou do not satisfy the model assumptions.

Pictou fishing locations were spread out along the coast and around Pictou Island (Fig. 4). While this data set is richer, spatial clusters and therefore spawning aggregations, were found to be of short duration resulting in approximately half of the schools being classified as roaming, non-spawning fish. These in turn were not considered in the biomass summation, implying that the downward scaling between observed nightly biomass and seasonal biomass was more severe in Pictou than in other areas. Whether this is due to true differences in herring reproductive behaviour, or that the sampling fish harvester is simply more apt to change locations over such a wide area, remains unclear.

These results suggest that seasonal biomass estimates for Miscou and Pictou are not on the same scale as other regions. The model does not appear to produce valid results in these regions.

Given the inconsistencies in model performance and the underlying issues with the data, this project could not be used to develop a time series of local abundance indices for herring as part of the fall herring stock assessment.

## SUMMARY AND RECOMMENDATIONS

Summary of results

- Results for Fisherman's Bank, Escuminac, and West PEI are comparable. Seasonal biomass estimates are comparable if sampling methods and biological processes are also comparable.
- Results for Miscou and Pictou spawning components indicate a mismatch between model output and known spawning biology and behaviour.

Recommendations for future analyses

- Possible biases in nightly biomass estimates need to be assessed.
- Observed aggregations need to be well covered by the sampling vessel to ensure edges of observed schools are well defined in the available acoustic data sets, and determine if spatial structure of available data shows evidence of partial coverage or differences between years or regions.
- Some effort must be made to verify that there are no other spawning aggregations in the area which are unaccounted for. The existence of such unobserved aggregations might be inferred from local fleet dynamics, i.e., logbooks or VMS data.
- Uncertainty in the seasonal biomass is in large part driven by variability in observations. An experiment could be conducted where the sampling vessel is active over as many nights as possible over the season. This data set could then be used to test the robustness of the model at varying proportions of missing observations.
- Nightly spawning aggregations may be better characterized by multiple rather than a single coordinate point, to account for more complex local spatial distributions such as when multiple schools are present in an area.

Recommendations for improving the data collection protocols

- Develop clear protocols for ensuring that fishing surveys are complete and that a method for evaluating this completeness is identified.
- Two possibilities for obtaining these data are noting fishing location in logbooks and by VMS recording.

- This protocol will include comments on the number of vessels required and fishery reporting that includes location of catch.
- Strict adherence to protocols in particular that acoustic surveys should be completed prior to conducting the nightly fishing activity.
- Periodic structured surveys might be undertaken over the entire potential spawning area during the spawning season. It is recommended that it be performed once a week on each spawning bed during weekend fishery closures, and also one week prior and two weeks after end of fishing season, assuming a seven day turnover rate.

## REFERENCES CITED


Boswell, K.M, Kaller, M.D., Cowan jr., J.H., and Wilson, C.A. 2008. Evaluation of target strength–fish length equation choices for estimating estuarine fish biomass. Hydrobiologia (2008) 610: 113-123.

Brehmer, P., Thang, D.C., and Mouillot, D. 2006. Amphidromous fish school migration revealed by combining fixed sonar monitoring (horizontal beaming) with fishing data. J. Exp. Mar. Biol. Ecol. 334 (2006): 139–150.

Brophy, D., Danilowicz, B.S., and King, P.A. 2006. Spawning season fidelity in sympatric populations of Atlantic herring (*Clupea harengus*). Can. J. Fish. Aquat. Sci. 63: 607-616.

Cairns, D.K., LeBlanc, C., and MacDougall, C. 1996. Herring spawn volume and progenitor biomass at Fisherman's Bank, Prince Edward Island, in 1995. DFO Atl. Fish. Res. Doc. 96/121: 12 p.

Cairns, D.K., Messieh, S.N., Wade, E., MacPherson, P.A., and Bourque, G.C.J. 1993. Timing, location, and volume of herring spawn deposition at Fishermen's Bank, Prince Edward Island, 1987-1990. Can. Tech. Rep. Fish. Aquat. Sci. No. 1928: 60 p.

Claytor, R.R., and Allard, J. 2001. Properties of abundance indices obtained from acoustic data collected by inshore herring gillnet boats. Can. J. Fish. Aquat. Sci. 58: 2502-2512.

Claytor, R., and Clay, A. 2001. Distributing fishing mortality in time and space to prevent overfishing. In Spatial processes and management of marine populations. Edited by G.H. Kruse, A.B.N. Bez, M. Dorn, S. Hills, R. Lipcius, D. Pelletier, C. Roy, S.J. Smith, and D. Witherell. University of Alaska Sea Grant, AK-SG-00-04, Fairbanks, Alaska. pp. 543–558.

DFO. 2006. A Harvest Strategy Compliant with the Precautionary Approach. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/023.

Erisman, B.E., Allen, L.G., Claisse, J.T., Pondella II, D.J., Miller, E.F., and Murray, J.H. 2011. The illusion of plenty: hyperstability masks collapses in two recreational fisheries that target fish spawning aggregations. Can. J. Fish. Aquat. Sci. 68: 1705-1716.

Fréon, P., and Misund, O.A. 1999. Dynamics of pelagic fish distribution and behaviour: effects on fisheries and stock assessment. Fishing News Books, Oxford.

Honkalehto, T., Ressler, P.H., Towler, R.H., and Wilson, C.D. 2011. Using acoustic data from fishing vessels to estimate walleye pollock (*Theragra chalcogramma*) abundance in the eastern Bering Sea. Can. J. Fish. Aquat. Sci. 68: 1231–1242.

LeBlanc, C.H., Mallet, A., Surette, T., and Swain, D. 2015. Assessment of the NAFO Division 4T southern Gulf of St. Lawrence herring stocks in 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/025. vi + 142 p.

Lunn, D.J., Thomas, A., Best, N., and Spiegelhalter, D. 2000. WinBUGS -- A Bayesian modelling framework: concepts, structure, and extensibility. Statistics and Computing, 10: 325-337.

McQuinn, I.H. 1997. Metapopulations and the Atlantic herring. Rev. Fish Biol. Fish. 7: 297-329.

McPherson, A.A., Stephenson, R.L., and Taggart, C.T. 2003. Genetically different Atlantic herring *Clupea harengus* spawning waves. Mar. Ecol. Prog. Ser. 247: 303–309.

Melvin, G.D., Li, Y., Mayer, L., and Clay, A. 2002. Commercial fishing vessels, automatic acoustic logging systems and 3D data visualization. ICES J. Mar. Sci. 59: 179-189.

Messieh, S. 1988. Spawning of Atlantic Herring in the Gulf of St. Lawrence. American Fisheries Society Symposium 5: 31-48.

Messieh, S.N., and MacDougall, C. 1984. Spawning groups of Atlantic herring in the southern Gulf of St. Lawrence. CAFSAC Res. Doc. 84/74: 28 p.

Scott, W.B., and Scott, M.G. 1988. Atlantic fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219. 731 pp.

Simmonds, E.J., and MacLennan, D.N. 2005. Fisheries Acoustics, Theory and Practice. Second Edition. Blackwell Science, Oxford UK.

Sinclair, M. 1988. Marine populations: An essay on population regulation and speciation. Washington Sea Grant Program, University of Washington Press, Seattle, USA.

Shen, H., Quinn, T.J. II, Wespestad, V., Dorn, M.W., and Kookesh, M. 2008. Using acoustics to evaluate the effect of fishing on school characteristics of walleye pollock. pp. 125–140. In Resiliency of Gadid Stocks to Fishing and Climate Change, Alaska Sea Grant College Program, AK-SG-08-01, Fairbanks AK.

Stephenson, R.L., Clark, K.J., Power, M.J., Fife, F.J., and Melvin, G.D. 2001. Herring stock structure, stock discreteness and biodiversity. pp. 559-572. In: Herring 2000: Expectations for a New Millennium. Edited by F. Funk, J. Blackburn, D. Hay, A. J. Paul, R. Stephenson, R. Toreson, and D. Witherell. 18th Lowell Wakefield Fisheries Symposium, Anchorage, Alaska, 23–26 February 2000. University of Alaska Sea Grant, AK-SG-01-04, Fairbanks. 800 pp.

Surette, T., LeBlanc, C.H., Claytor, R.R., and Loots, C. 2015. Using inshore fishery acoustic data on Atlantic herring (*Clupea harengus*) spawning aggregations to derive annual stock abundance indices. Fish. Res. 164: 266-277.

Swain, D.P. 2016. Assessment framework for fall-spawning Atlantic herring (*Clupea harengus*) in the southern Gulf of St. Lawrence (NAFO Div. 4T): Population models and status in 2014. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/066. x + 59 p.

Ware D.M., and Tanasichuck, R.W. 1989 Biological basis of maturation and wave spawning in Pacific herring (*Clupea harengus pallasi*). Can. J. Fish. Aquat. Sci. 46: 1776-1784.

Wheeler, J.P., and Winters, G.H. 1984. Homing of Atlantic herring (*Clupea harengus harengus*) in Newfoundland waters as indicated by tagging data. Can. J. Fish. Aquat. Sci. 41: 108-117.

# TABLES

*Table 1. The number and mean surface area of spawning beds detected from Fisherman's Bank spawning bed surveys (Cairns et al. 1996).*

| Year | Number | Area ($km^2$) |
|---|---|---|
| 1985 | 5 | 0.36 |
| 1986 | 1 | 1.10 |
| 1987 | 4 | 0.52 |
| 1988 | 4 | 0.84 |
| 1989 | 5 | 0.81 |
| 1990 | 7 | 0.70 |
| 1991 | 5 | 1.08 |
| 1992 | 4 | 1.44 |
| 1993 | 5 | 1.22 |
| 1994 | 6 | 1.26 |
| 1995 | 2 | 0.64 |

*Table 2. Posterior means (95% credibility intervals in parentheses) for selected nightly biomass and spatial-temporal model parameters.*

| Region | $\phi$ | $\sigma_0$ | $\sigma_1$ | $\pi_0$ | $\pi_1$ |
|---|---|---|---|---|---|
| Escuminac | 0.24<br>(-0.16 ,0.66) | 0.98<br>(0.85 ,1.12) | 16.08<br>(12.93 ,20.06) | 0.87<br>(0.81 ,0.93) | 0.45<br>(0.27 ,0.65) |
| Fisherman's Bank | 0.01<br>(-0.44 ,0.49) | 0.53<br>(0.41 ,0.68) | 4.39<br>(3.6 ,5.45) | 0.81<br>(0.71 ,0.9) | 0.52<br>(0.31 ,0.74) |
| Miscou | 0.61<br>(0.25 ,0.85) | 1.46<br>(1.29 ,1.65) | 24.0<br>(16.45 ,36.27) | 0.97<br>(0.94 ,0.99) | 0.48<br>(0.16 ,0.86) |
| Pictou | 0.48<br>(0.1 ,0.76) | 0.86<br>(0.66 ,1.12) | 8.32<br>(7.28 ,9.53) | 0.55<br>(0.39 ,0.7) | 0.41<br>(0.26 ,0.58) |
| West PEI | 0.45<br>(-0.07 ,0.79) | 0.68<br>(0.56 ,0.83) | 13.67<br>(10.59 ,18.2) | 0.88<br>(0.82 ,0.93) | 0.65<br>(0.45 ,0.85) |

*Table 3. Estimated number (standard error in parentheses) of spawning events for each spawning region by year.*

| Year | Miscou | Escuminac | West PEI | Fisherman's Bank | Pictou |
|---|---|---|---|---|---|
| 2002 | 2.5 (0.7) | 3.0 (1.0) | 3.2 (1.1) | 2.6 (0.8) | 3.8 (1.1) |
| 2003 | 1.1 (0.2) | 3.9 (0.5) | 2.7 (0.8) | 3.7 (1.0) | 3.9 (1.0) |
| 2004 | 1.6 (0.7) | 1.6 (0.7) | 4.3 (0.5) | 3.5 (0.9) | 4.2 (1.1) |
| 2005 | 1.1 (0.3) | 3.7 (0.7) | 2.5 (1.0) | 3.1 (1.1) | 3.2 (0.9) |
| 2006 | 1.0 (0.1) | 3.2 (0.8) | 3.0 (0.2) | 4.1 (1.0) | 3.7 (1.0) |
| 2007 | 1.1 (0.3) | 1.4 (0.6) | 2.9 (1.0) | 4.3 (0.9) | 3.3 (1.0) |
| 2008 | 2.0 (0.3) | 3.7 (0.7) | 4.1 (0.9) | 3.8 (0.8) | 4.2 (1.0) |
| 2009 | 1.0 (0.2) | 3.5 (0.6) | 3.8 (0.5) | 4.1 (1.0) | 4.4 (1.0) |
| 2010 | 1.3 (0.5) | 3.5 (0.8) | 2.4 (0.6) | 3.4 (1.0) | 3.9 (1.2) |
| 2011 | 2.0 (0.3) | 4.0 (0.7) | 3.0 (0.9) | 4.0 (0.9) | 3.4 (0.7) |
| 2012 | 2.3 (0.6) | 2.7 (0.7) | 3.2 (0.8) | 4.0 (1.0) | 4.2 (1.1) |

## FIGURES

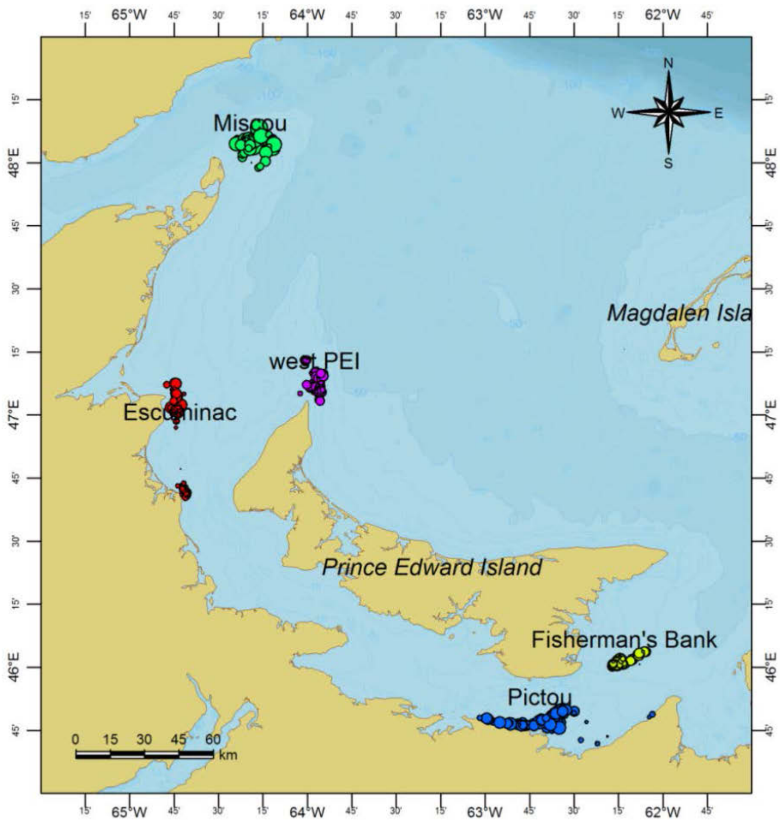


*Figure 1. Herring fall spawning locations in NAFO 4T.*

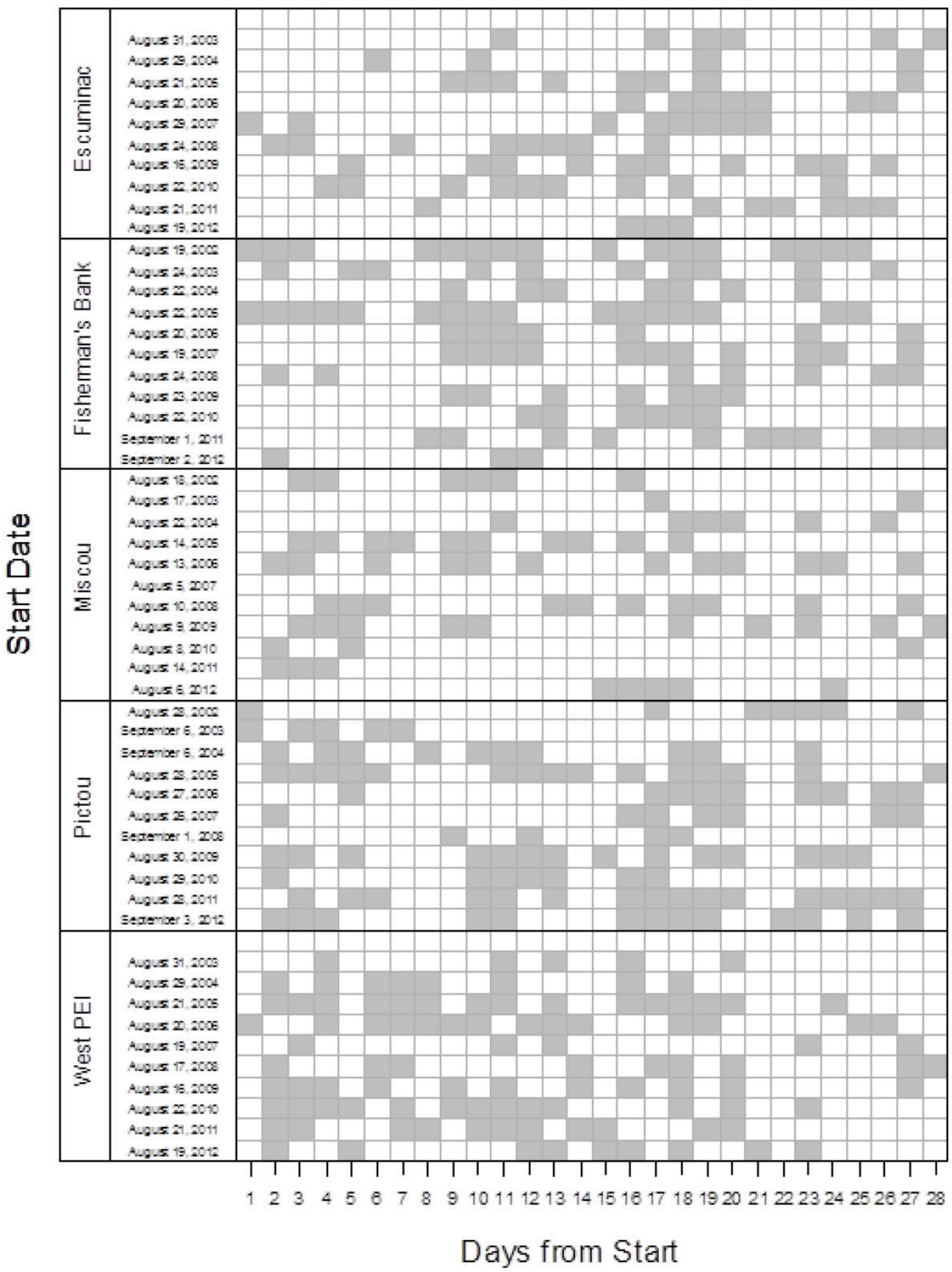


*Figure 2. Seasonal pattern of nightly observations (grey squares) used for the analysis for each 28-day period by year and spawning region.*

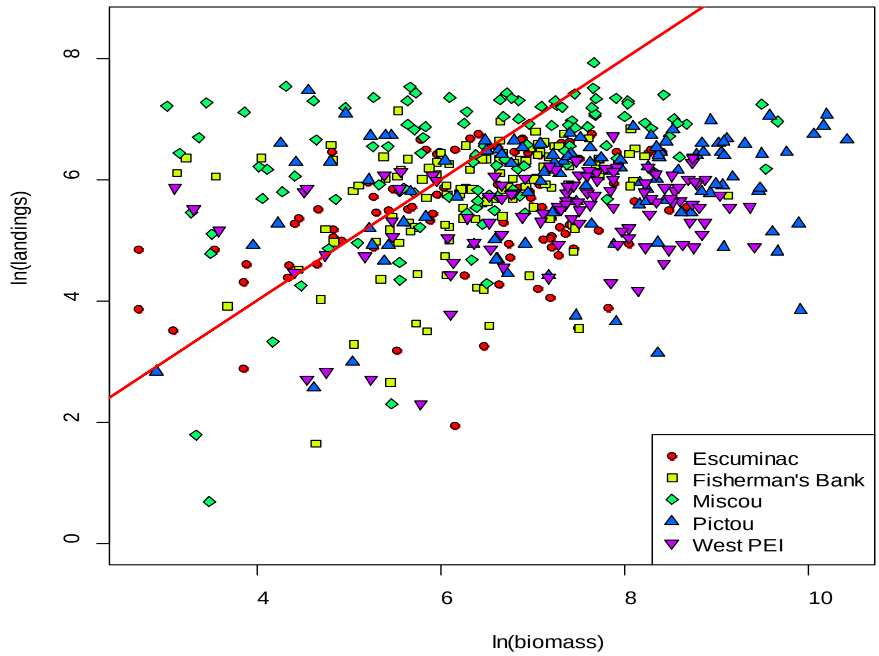


*Figure 3. Nightly landings versus nightly biomass estimates for each spawning region for all years combined on the log-scale. The red line is the boundary where nightly landings equal nightly biomass estimates. For points above the line, the nighty landings are greater than the nightly biomass estimates and for points below the line the nightly landings are less than the nightly biomass estimates.*

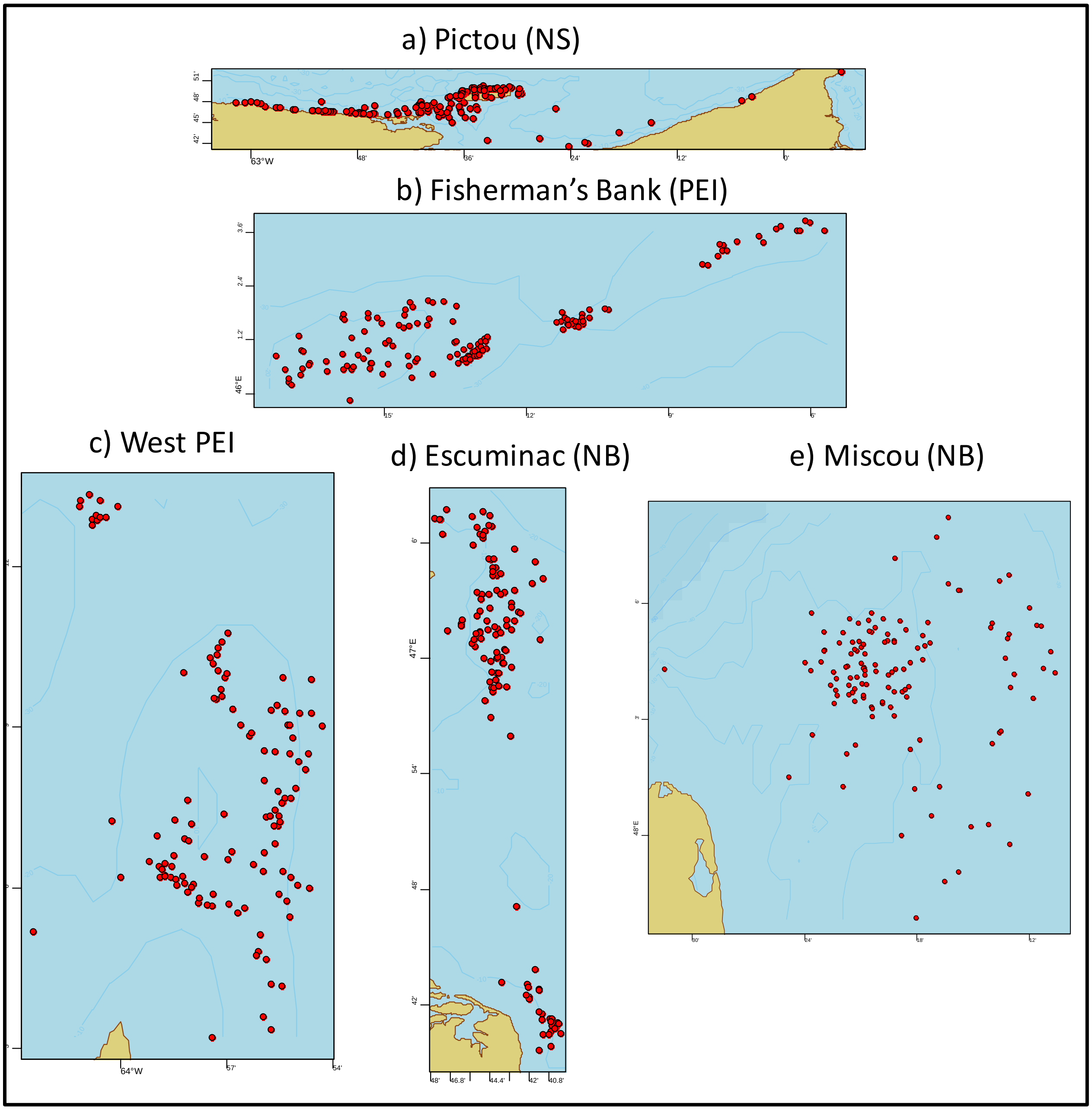


*Figure 4. Distribution maps of estimated nightly school locations for each spawning area for all years combined.*

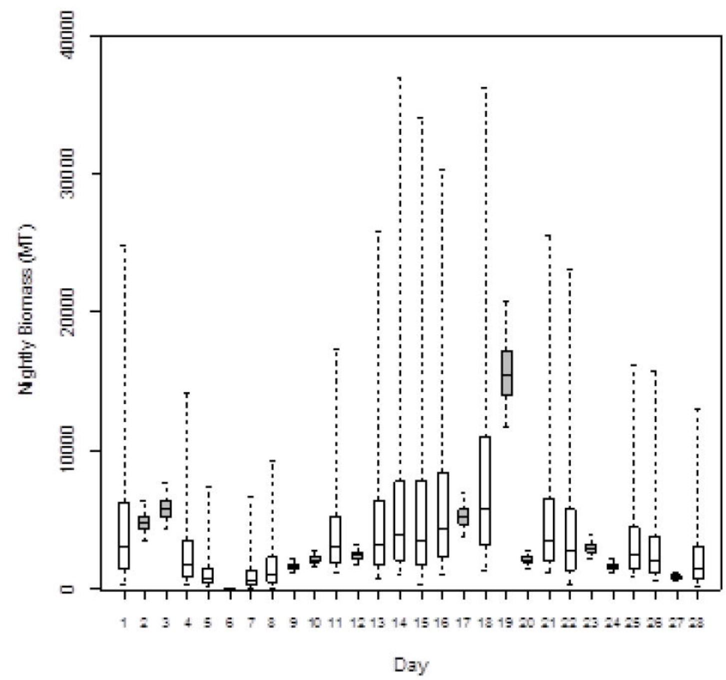


*Figure 5. Boxplot of posterior MCMC simulated nightly biomass observations (in grey) and missing values (in white) for Miscou in 2006. Boxplots indicate the median, interquartile range (box) and 95% credibility intervals (whiskers).*

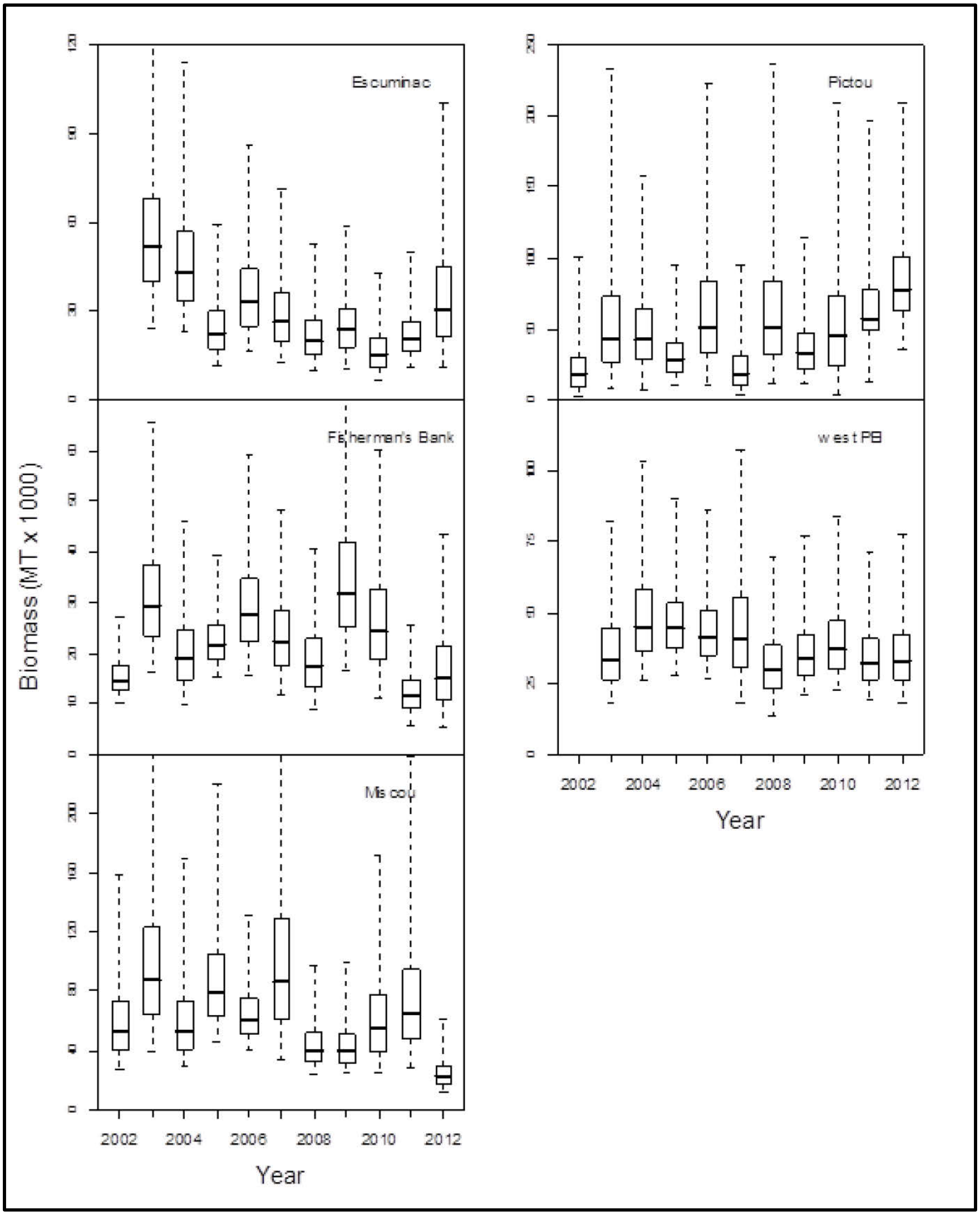


*Figure 6. Seasonal biomass estimates by year obtained from MCMC posterior simulations (n = 5,000) for the five spawning areas. Boxplots indicate the median, interquartile range (box) and 95% credibility intervals (whiskers).*

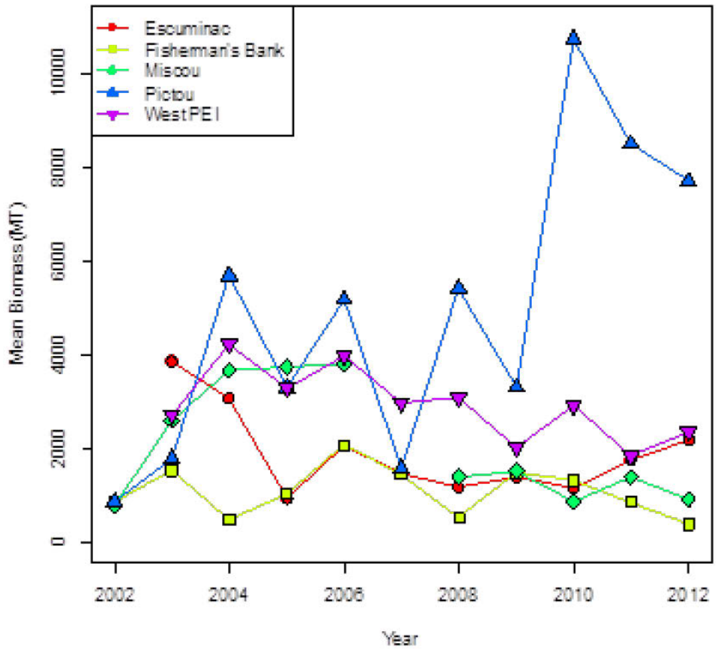


*Figure 7. Mean observed nightly biomass for each spawning area by year.*

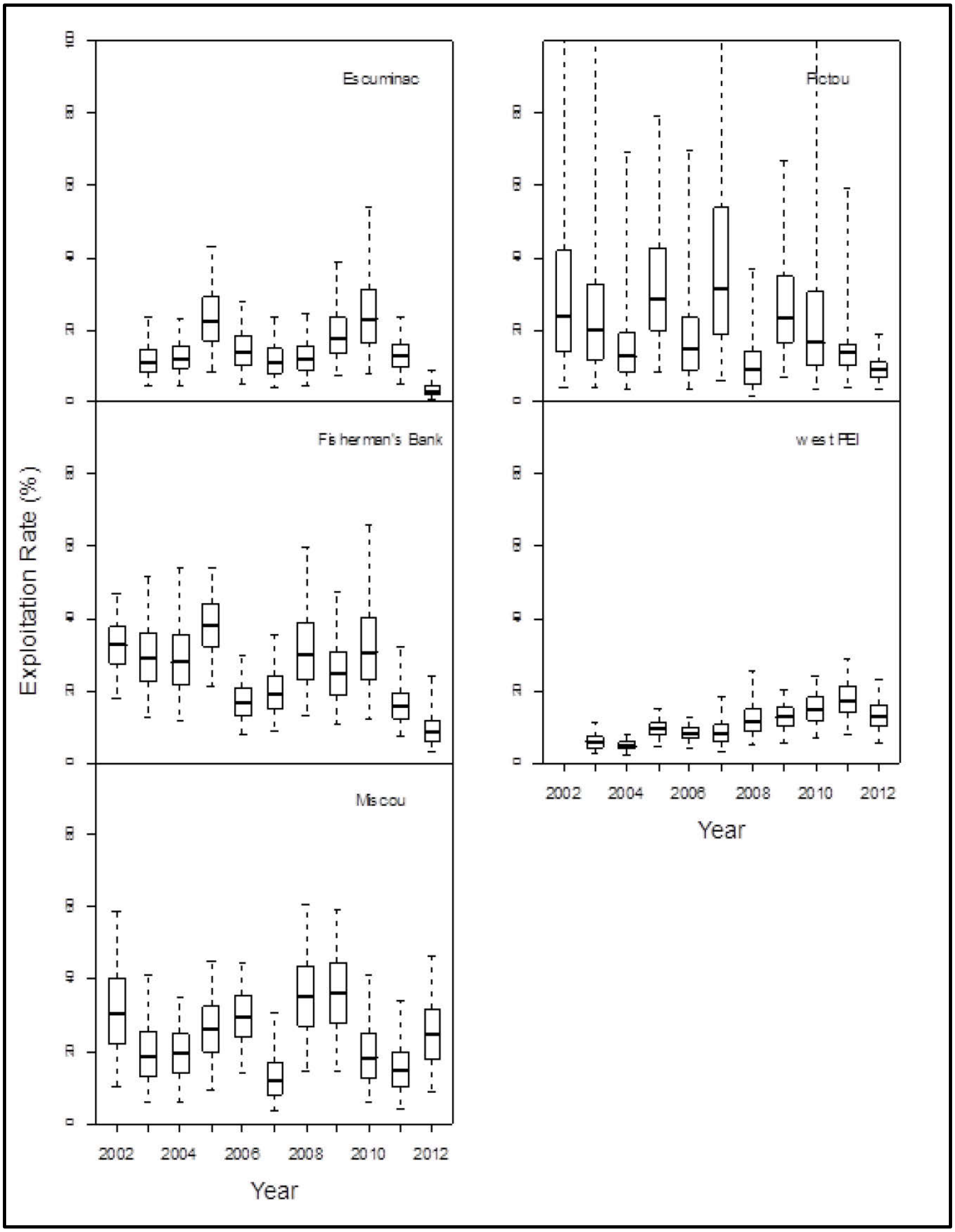


*Figure 8. Exploitation rates by year obtained from MCMC posterior simulations (n = 5,000) for the five spawning areas. Boxplots indicate the median, interquartile range (box) and 95% credibility intervals (whiskers).*

# APPENDICES

## APPENDIX A. OPENBUGS CODE FOR THE NIGHTLY BIOMASS MODEL.

```
# Prior over zero proportions:
alpha.pi ~ dexp(1)
beta.pi ~ dexp(1)
for (i in 1:n.region){
    for (j in 1:n.year){
        pi[i,j] ~ dbeta(alpha.pi, beta.pi) } }
# Hierarchical mean prior
mu.mu ~ dnorm(0, 0.01)
tau.mu ~ dgamma(0.1, 0.1)
sigma.mu <- pow(tau.mu, -2)
for (i in 1:n.region){
        phi[i] ~ dunif(-1,1)
        tau.eps[i] ~ dgamma(1,1)
        tau.eps.global[i] <- (1-pow(phi[i], 2)) * tau.eps[i] }
for (i in 1:n.region){
    for (j in 1:n.year){
        mu.year[i,j] ~ dnorm(mu.mu, tau.mu)
        eps[i,j,1] ~ dnorm(0, tau.eps.global[i])
        for (k in 2:n.day){
        mu.eps[i,j,k] <- phi[i] * eps[i,j,k-1]
        eps[i,j,k] ~ dnorm(mu.eps[i,j,k], tau.eps[i]) }
        for (k in 1:n.day){
        mu[i,j,k] <- mu.year[i,j] + eps[i,j,k] } } }
# Prior observation error
tau.b ~ dgamma(0.1, 0.1)
var.b <- 1 / tau.b
sigma.b <- sqrt(var.b)
# Additional observation error parameters
cv.mu <- -log(pow(0.15,2) + 1) / 2
cv.tau <- 1 / log(pow(0.15,2) + 1)
# Observation error model
for (i in 1:n){
        b[i]  ~ dlnorm(mu[region[i], year[i], day[i]], tau.b) I(L[i], )
        z[i]  ~ dbern(pi[region[i], year[i]])
        cv[i] ~ dlnorm(cv.mu, cv.tau)
        biomass[day[i], year[i], region[i]] <- (1-z[i]) * b[i] * cv[i] }
```

## APPENDIX B. OPENBUGS CODE FOR THE SPATIAL-TEMPORAL CLUSTERING MODEL.

```
# Prior over transition probabilities
for (i in 1:2){
        alpha.p[i] ~ dexp(1)
        beta.p[i] ~ dexp(1)
    for (k in 1:n.region){
        P[k,i] ~ dbeta(alpha.p[i], beta.p[i]) } }
# Define Markov probability transition matrix
for (k in 1:n.region){
        T[k,1,1] <- P[k,1]
        T[k,1,2] <- 1 - P[k,1]
        T[k,2,1] <- P[k,2]
        T[k,2,2] <- 1 - P[k,2]}
# Define state of initial distance observation
for (j in 1:n.year){
    for (k in 1:n.region){
        S[1,j,k] <- 1
        C[1,j,k] <- 1 } }
# Define the Markovian state vector of observations
for (i in 2:n.day){
    for (j in 1:n.year){
        for (k in 1:n.region){
        S[i,j,k] ~ dcat(T[k, S[i-1,j,k],1:2])
        C[i,j,k] <- C[i-1,j,k] + (S[i,j,k]-1) } } }
# Spatial extent of spawning event
for (m in 1:2){
        alpha.tau[m] ~ dexp(1)
        beta.tau[m] ~ dexp(1)
    for (k in 1:n.region){
        tau[k,m] ~ dgamma(alpha.tau[m], beta.tau[m])
        sigma[k,m] <- pow(tau[k,m], -0.5) } }
# Coordinate random walk
for (j in 1:n.year){
    for (k in 1:n.region){
        x[(j-1)*n.day*n.region + (k-1)*n.day + 1] ~ dnorm(0, 0.001)
        y[(j-1)*n.day*n.region + (k-1)*n.day + 1] ~ dnorm(0, 0.001) } }
for (i in 2:n.day){
    for (j in 1:n.year){
        for (k in 1:n.region){
        x[(j-1)*n.day*n.region + (k-1)*n.day + i] ~
        dnorm(x[(j-1)*n.day*n.region + (k-1)*n.day + i - 1], tau[k,S[i,j,k]])
        y[(j-1)*n.day*n.region + (k-1)*n.day + i] ~
        dnorm(y[(j-1)*n.day*n.region + (k-1)*n.day + i - 1], tau[k,S[i,j,k]]) } } }
```

# APPENDIX D-3

# DIOXINS AND FURANS

## The Issue

Dioxins and furans are common names for toxic chemicals that are found in very small amounts in the environment, including air, water and soil. As a result of their presence in the environment, they are also present in some foods.

Exposure to dioxins and furans has been associated with a wide range of adverse health effects in laboratory animals and humans. The type and occurrence of these effects typically depend on the level and duration of exposure.

## Background

There are 210 different dioxins and furans. All dioxins have the same basic chemical "skeleton," and they all have chlorine atoms as part of their make-up. Furans are similar, but have a different “skeleton”. These substances vary widely in toxicity. The one considered most toxic is referred to as 2,3,7,8-tetra-chlorodibenzo-p-dioxin, or simply TCDD.

The biggest source of dioxins and furans in Canada is the large-scale burning of municipal and medical waste. Other major sources include:

- the production of iron and steel
- backyard burning of household waste, especially plastics
- fuel burning, including diesel fuel and fuel for agricultural purposes and home heating
- wood burning, especially if the wood has been chemically treated
- electrical power generation
- tobacco smoke

Dioxins can also be produced from natural processes, such as forest fires and volcanic eruptions. Most dioxins are introduced to the environment through the air. The airborne chemical can attach to small particles that can travel long distances in the atmosphere, which means that Canadians may also be exposed to dioxins and furans created in other countries.

These substances work their way up the food chain by moving into and remaining stored in body fat. Because of this, people actually take more dioxins and furans into their bodies through food than through air, water or soil. Ninety per cent of people's overall exposure to dioxins is estimated to be from the diet. Meat, milk products and fish have higher levels of dioxins and furans than fruit, vegetables and grains.

## The Health Effects of Dioxins and Furans

Scientists have studied the effects of dioxins and furans on laboratory animals. They have also researched the health effects on people exposed to dioxins through industrial accidents, contaminated food, and occupational exposure to certain herbicides prior to improved manufacturing processes that have reduced these contaminants.

The studies show that dioxins and furans have the potential to produce a range of effects on animals and humans. Health effects associated with human exposure to dioxins include:

- skin disorders, such as chloracne
- liver problems
- impairment of the immune system, the endocrine system and reproductive functions
- effects on the developing nervous system and other developmental events
- certain types of cancers

It is important to remember that with all toxic substances, including dioxins, the risk of health effects depends on many factors, including:

- the way a person is exposed (e.g., through food, air, water, etc.)
- how much a person is exposed to, and when (e.g., whether it is a large amount on one occasion, or daily exposure to small amounts, etc.)
- individual susceptibility, including general state of health
- whether the person is also exposed to other substances that may be associated with health effects

These issues are very complex. Scientists do not have all of the answers, but they agree that exposures to dioxins and furans should be kept as low as possible.

## Dietary Exposure to Dioxins and Furans

For most people, about 90% of overall exposure to dioxins comes through diet. The Joint Expert Committee on Food Additives, an expert group of the World Health Organization and the Food and Agriculture Organization of the United Nations, has set a "tolerable monthly intake" level for dioxins, furans and similar substances.

The "tolerable" level (meaning no serious health effects are expected) is 70 picograms per kilogram of body weight / month. This is roughly 2.3 picograms per kilogram of body weight / day. A picogram is one-trillionth of a gram.

Studies done between 1998 and 1999 in two Canadian cities showed that the average dietary intake of dioxins, furans and similar substances was 0.62 picograms per kilogram of body weight /day. This is well within the level considered tolerable by Joint Expert Committee on Food Additives.

## Minimizing Your Risk

If you are concerned about exposure to dioxins and furans, consider taking the following steps:

- Prepare meat and fish in a way that minimizes your exposure by trimming visible fat from food. Bake, broil, roast, barbecue or microwave instead of frying, and drain off extra fat after cooking.
- Follow the advice in Canada's Food Guide to Healthy Eating, and enjoy a variety of foods. Vegetables, fruit and grains contain fewer dioxins and furans than meat, milk products and fish.
- Follow provincial/territorial government advisories about eating certain types of fish.
- Do not burn garbage, especially construction materials that might contain wood preservatives or plastic.
- Limit the amount of wood you burn in your fireplace or stove, and learn about wood-burning techniques that release fewer dioxins. For more information about safer wood burning techniques go to the Need More Info section below.
- Do not smoke, and keep your family away from second-hand smoke as much as possible.

By taking these steps, you can reduce your family's exposure to dioxins and furans, and help to limit the overall release of these substances into the environment.

## The Government of Canada's Role

The Government of Canada is working to control, and if possible eliminate, releases of these substances into the environment to help protect Canadians against harm from dioxins and furans. Actions to date include:

- Guidelines to minimize the release of dioxins and furans from municipal solid waste and hazardous waste incinerators.

- Regulations requiring the virtual elimination of dioxin and furan releases from pulp mills.
- Virtual elimination of dioxins and furans from pest control products used in Canada.
- Active support for international agreements to reduce releases of these substances on a global basis.

These efforts are working. The latest inventory shows a 60 percent decrease since 1990 in the overall release of dioxins and furans from sources within Canada. Also, the levels of dioxins and furans in Canadian human milk, which were already low, went down by roughly 50 percent between the 1980s and the 1990s. It is expected that levels of dioxins in various sources in Canada will continue to decline in conjunction with ongoing pollution prevention and control activities.

The Government's work to control sources of dioxins and furans in Canada continues. A federal-provincial task force has updated the inventory of sources for these substances, and Canada-wide standards are being established to address releases from remaining manufactured sources. In addition, the Government is continuing to carry out food monitoring activities to identify, control and if possible, eliminate previously unknown sources of dioxin contamination.

Also, Health Canada is doing a comprehensive reassessment of the risks posed by dioxins. In the meantime, Health Canada has adopted the Joint Expert Committee on Food Additives’ tolerable monthly intake for dioxins as a guideline for Canadians.

## Need More Info?

For more information, contact:
Health Canada's Management of Toxic Substances Division
Room A724,
Jeanne Mance Building #19
Tunney's Pasture Ottawa, ON
K1A 0K9 (613) 957-3127

Health Canada's Food Program Web site at:
http://www.hc-sc.gc.ca/fn-an/index_e.html

Canada’s Food Guide to Healthy Eating at:
http://www.hc-sc.gc.ca/fn-an/food-guide-aliment/index_e.html

Environment Canada, Persistent Organic Pollutants - POPs at:
http://www.ec.gc.ca/pops/index_e.htm

For tips on safer ways to burn wood, visit Natural Resources Canada, Burn it Smart at:
http://www.burnitsmart.org/

For more on the health effects associated with exposure to dioxins, see the following:

The World Health Organization’s “Safety Evaluation of Certain Food Additives and Contaminants” at
http://www.inchem.org/documents/jecfa/jecmono/v48je20.htm

The World Health Organization’s “ Dioxins and their effects on human health”
http://www.who.int/mediacentre/factsheets/fs225/en/index.html

The U.S. Environmental Protection Agency’s “Draft Dioxin Reassessment”at:
http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=55265

United States National Academy of Sciences Report, Dioxins and Dioxin-like Compounds in the Food Supply: Strategies to Decrease Exposure at:
http://www.iom.edu/report.asp?id=13097

For information on herbicide use at National Defence, see the National Defence Web site at:
http://www.forces.gc.ca/site/Reports/defoliant/index_e.asp

For additional articles on health and safety issues go to the It’s Your Health Web site at:
www.healthcanada.ca/iyh
You can also call toll free at
1-866-225-0709
or TTY at 1-800-267-1245*

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# APPENDIX D-4

Fisheries and Oceans Canada
Pêches et Océans Canada

Ecosystems and Oceans Science
Sciences des écosystèmes et des océans

**Canadian Science Advisory Secretariat (CSAS)**

**Research Document 2016/044**

**Gulf Region**

# Identification and Characterization of Important Areas based on Fish and Invertebrate Species in the Coastal Waters of the Southern Gulf of St. Lawrence

A. Rondeau, J.M. Hanson, M. Comeau, and T. Surette

Gulf Fisheries Centre
Department of Fisheries and Oceans
P.O. Box 5030
Moncton, N.B.  E1C 9B6

May 2016

Canada

**Foreword**

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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## ABSTRACT

Identification and designation of Ecologically and Biologically Significant Areas (EBSA) is recognized both nationally and internationally as a useful tool for aquatic resource conservation, management, and planning. In eastern Canada, previous work focused on offshore waters with the highly productive coastal areas intentionally excluded. The aim of this study was to apply the EBSA criteria of uniqueness, aggregation, and fitness consequences to the coastal area of the southern Gulf of St. Lawrence. The criteria were applied to 32 fish and 23 benthic invertebrate taxa to identify important areas (IA). Based on data from multi-species surveys and literature reviews, three IA were identified in order of precedence: Northumberland Strait, St. George's Bay, and water at the eastern end of Prince Edward Island. These IA stood out primarily due to the presence of likely-endemic species (i.e. lady crab and winter skate), and all three IA had previously been identified as EBSA. Although not identified as IA, special consideration could be assigned to Chaleur Bay and the Shediac Valley for their importance in the migration of several anadromous species.

**Identification et caractérisation de zones d'intérêt basées sur les espèces de poissons et d'invertébrés dans les eaux côtières du sud du golfe du Saint-Laurent**

## RÉSUMÉ

L'identification et la désignation des zones d'importance écologiques et biologiques (ZIEB) est reconnu nationalement et internationalement comme étant un outil efficace pour la conservation des ressources aquatiques de même que pour la gestion et la planification. Dans l'est du Canada, les travaux antérieurs portaient principalement sur le milieu hauturier alors que le milieu côtier hautement productif avait été intentionnellement mis de côté. L'objectif de cette étude visait à appliquer les critères d'unicité, d'agrégation et de conséquences sur la valeur adaptative des ZIEB dans la zone côtière du sud du golfe du Saint-Laurent. Ces critères ont été considérés en lien avec 32 espèces de poissons et 23 espèces d'invertébrés benthiques afin d'identifier les aires d'importance (AI). Selon les données des relevés de recherche plurispécifique et d'une revue de la littérature, trois AI ont été identifiées en ordre de précédence : le détroit de Northumberland, la baie St. George et les eaux de l'extrémité est de l'Île-du-Prince-Édouard. Ces trois AI se démarquent principalement par la présence d'espèces présumées endémiques (c.-à.-d. le crabe calicot et la raie tachetée) et toutes les trois ont précédemment été identifiées à titre de ZIEB. Bien qu'elles ne sont pas identifiées comme AI, la baie des Chaleurs de même que la vallée de Shédiac pourraient bénéficier d'une considération particulière pour leur importance lors de la migration de plusieurs espèces anadromes.

# INTRODUCTION

Canada's Oceans Act (1997) authorizes the Department of Fisheries and Oceans (DFO) to provide enhanced protection to areas of the oceans and coasts that are ecologically or biologically significant through mechanisms such as Marine Protected Areas. Ocean areas can be ecologically or biologically "significant" because of the functions that they serve in the ecosystem and/or because of structural properties (DFO 2004). Identifying Ecologically and Biologically Significant Areas (EBSA) is not a general strategy for protecting all habitats and marine communities that have some ecological significance. Rather, it is a tool for calling attention to an area that has particularly high ecological or biological significance, to facilitate provision of a greater-than-usual degree of risk aversion in management of activities in these areas (DFO 2004).

DFO established criteria to identify EBSA (DFO 2004) and applied these to features in the Gulf of St. Lawrence (DFO 2006). Ten EBSA were identified, all offshore (DFO 2007, Savenkoff et al. 2007). There were many discussions during the 2006 meeting regarding the inclusion of coastal areas in the EBSA evaluation for the Gulf but no consensus was reached on how to consider the ecological and biological significance of coastal and estuarine areas within a classification system that is based primarily upon the relationship with large scale oceanographic features or processes (DFO 2006). The review at that time excluded coastal features such as barachois, salt marshes, and eel grass beds on the premise that they may have a high local significance but they likely do not have a substantive effect on the functioning of the much larger oceanic ecosystem (DFO 2006).

Following several EBSA exercises within Canadian waters, a reflection was made on the overall efficiency of the EBSA process and to provide guidance in future application its criteria (DFO 2011). It was recognized that the three primary criteria (aggregation, uniqueness, and fitness consequences) were applicable to coastal habitat with the acknowledgment that some ecological functions and processes in these systems differ from comparable ones in marine systems (DFO 2011). It was also proposed to use heat maps to illustrate the different criteria when possible.

The identification of EBSAs in the coastal zone is necessary to complete the ecological profile of the estuary and the Gulf of St. Lawrence and for the planning of the network of marine protected areas. In order to determine if the coastal zone meets the EBSA criteria, a zonal peer review meeting was held in Mont-Joli, Quebec in December 2014 (DFO 2015). A two-step approach was considered during the meeting. The first step was to agree on a definition of the coastal zone and to identify and describe the data sets that could be used to apply the EBSA criteria to the coastal zone. The second step was a formal review process of the data and information applied to the EBSA criteria to yield a number of important areas (IA). This study presents the information, data, and analyses considered for the identification of IA in the southern Gulf of St. Lawrence (sGSL) based upon invertebrates and fishes.

# MATERIALS AND METHODS

## STUDY AREA

Standardized data from three surveys were used for modeling to predict the probability of detecting the presence of a taxon in a standardized tow. Survey data and environmental variables were defined for the same 2.5 x 2.5 km (6.25 km2) grid derived by Dutil et al. (2012) for the entire sGSL. The study area was defined as waters between 0 and 40 m deep (mean value of the cell) within the sGSL but excluded estuaries and semi-enclosed embayments. The estuary/coastal area boundaries were determined by the presence of barrier islands or peninsulas, and cells with centroids inside of those features were removed. Also, cells east of New Carlisle along the Gaspé Peninsula and east of Cape North in Cape Breton (i.e., outside the sGSL) were removed. The final grid for the sGSL coastal study area was comprised of 4,486 cells (Fig. 1).

## DATA SOURCES

Quantitative data were retrieved from three surveys:

- the annual September bottom trawl survey in the sGSL (RV survey);
- the annual Northumberland Strait bottom trawl survey (NS survey); and
- two recent scallop-dredge surveys.

These surveys record data on most of the animal species captured and have substantial sampling effort within the coastal waters of the sGSL. The shallow-water depth threshold (roughly 4 m chart datum) for the small-boat surveys (NS, scallop-dredge) was determined by the draft of the survey ships. The RV survey was designed to survey waters deeper than ~20 m. The survey catch data were transformed to presence-absence for modeling purposes. The annual snow crab survey was not considered for this study because nearly all stations are in water >40 m deep.

### Annual September bottom trawl survey in the sGSL (RV survey)

A bottom-trawl survey of the sGSL has been conducted in September since 1971 and provides the longest time-series of distributions and relative abundances for fishes and invertebrates in the sGSL. The RV survey follows a stratified random design, with stratification based on depth and geographic area. Twenty-four strata have been fished since 1971 and three inshore strata were added in 1984.

The RV survey uses the same standardized fishing procedures each year: a 30-minute tow at a speed of 6.5 km/h. Five ships using two types of trawls (“Yankee-36” and “Western IIA”) have been used during the time series. Corrections and adjustments for net efficiency, net swept area, and vessel effects are described by Hurlbut and Clay (1990), Benoît and Swain (2003a), and Benoît (2006). The difference in catchability of certain species based on the time of day was assessed by Benoît and Swain (2003b).

Between 100 and 200 tows were attempted during the RV survey each year (Fig. 2). Because of issues with data quality and accuracy in the identification of some species, only data collected between 1976 and 2013 were used in this study.

### Northumberland Strait bottom trawl survey (NS survey)

Between July and August, the demersal community of the Northumberland Strait was sampled annually since 2000. Two bottom trawls were used, depending upon the survey’s goals. For all years except 2010 and 2011, when a Nephrops trawl was used, the survey gear was a number 286 bottom trawl equipped with rockhopper footgear (rockhopper trawl). The NS survey area (Fig. 3) was overlain with a 3.7 x 3.7 km grid (starting point 46°30’ N; 64°00’ W), establishing over 1,100 possible sampling stations (Voutier and Hanson 2008; Bosman et al. 2011; Kelly and Hanson 2013a, b). The study area was originally divided into nine strata, based on bottom composition and water mass characteristics, and surveys followed a random block sampling design. Starting in 2010, some strata were dropped and stations were randomly selected (at a reduced sampling intensity) from within the original grid (see Rondeau et al. 2014 for details).

During the NS survey, the rockhopper trawl was towed for 15 minutes at a speed of 4.6 km/h. However, because of the gap under the rollers, the net was inefficient at catching Atlantic rock crab (*Cancer irroratus*), a species that plays an important role in the coastal ecosystem in terms of energy cycling (Hanson et al. 2014; Rondeau et al. 2014). To address this shortcoming, a Nephrops trawl that digs into the bottom (Conan et al. 1994), and is more efficient at capturing crabs, lobster, and many other benthic organisms, was used in 2010 and 2011 (Hanson *et al.* 2014; Hanson and Wilson 2014). The Nephrops trawl was towed at a speed of 3.7 km/h for only 5 minutes because large amounts of sediment and debris were retained. Between 101 and 255 valid tows were done per survey from 2000 to 2013 (Fig. 3).

### Scallop-dredge survey

A scallop-dredge survey was conducted in 2012 and 2013 to gather information on the distribution and abundance of adult and juvenile sea scallop (*Placopecten magellanicus*) within the sGSL. The survey gear was an 8 bucket Digby-type dredge (total length of 3.3 m) fitted with a Vexar® mesh liner (mesh size of 12-14 mm) to retain scallop recruits and small benthic species. The dredge was towed for 2 minutes at a speed of 3.7 to 4.6 km/h at 67 randomly selected stations in Northumberland Strait (2012) and at 87 stations in Chaleur Bay (2013) (Fig. 4).

## SPECIES SELECTION

Sampling protocols for multi-species surveys specified that all organisms encountered be identified to the lowest practical taxon (typically species). Unfortunately, identification effort and taxonomic expertise has not been constant throughout the RV survey time series. Nevertheless, with a few exceptions, most fish species encountered are thought to have been accurately identified to species level over the years and as such were considered as the primary source of information. One exception is the combination of blueback herring and alewife to match commercial catch recordings (where they are called “gaspereau”). Some deep-water species were eliminated from the analysis even if they were caught at the margin of the study area to minimize their influence on the modelling predictions. Hereafter, fish and invertebrate species or taxa were identified by their common names. Based on the three benthic surveys, there were usable data for 32 fish taxa (Table 1). The final species selection was done after consultation with peers following a CSAS meeting on the application of EBSA criteria to the coastal area (DFO 2015).

The list of invertebrates was more difficult to establish. For the RV survey, a consistent effort to identify and record catch information on invertebrate taxa only started in 1989. Hence, invertebrate data prior to 1989 were not considered. In the NS survey, most of the sampling in the early years was focusing at large decapod crustaceans and fishes. Data from American lobster, Atlantic rock crab, snow crab, lady crab, and toad crab sampled in 2003, and between 2005 and 2013, were used. For small-bodied taxa, only data starting in 2010 were considered reliable. Invertebrate data from both years of the scallop-dredge survey were retained. Furthermore, some species or taxa still needed to be removed from the potential data set because of uncertainties in their identification. In some instances, species were only identified to a higher taxonomic level (e.g., sponges, sea anemones) which most likely includes both coastal and deep water taxa. Since the latter was not considered in our analysis, species identified at high taxonomic levels (i.e., above genus level, excepting mussels) were not selected. As for fish species, recognized deep water invertebrate species were excluded from the analysis (e.g., sea potato *Boltenia ovifera*, Iceland scallop *Chlamys islandica*) and the final list of species retained was vetted by peers. For this study, 23 invertebrate species and/or taxa (Table 2) were included. Over 18 shrimp species can be found in the sGSL, and some (especially *Crangon* *septemspinosa*) are known to play an important role in the coastal-ecosystem food web (Hanson 2011; Kelly and Hanson 2013a; Hanson and Wilson 2014; Hanson et al. 2014;). Unfortunately, because of data availability issues, it was not possible to incorporate the information on shrimp in the analysis.

Information on the selected species of fish and invertebrate from the three surveys was transformed into presence-absence data and a minimum of ten occurrences was arbitrarily selected as the threshold for a taxon to be retained for modeling.

## DATA PROCESSING AND MODELING

The presence-absence data were modeled to predict the probability (0 to 1) of detecting a taxon in a standardized tow within a grid location. In addition to environmental variables, spatial and gear effects were included as predictors. Five environmental variables from Dutil et al. (2012) known to or are presumed to affect species distributions were included in the model testing:

- mean water depth in the grid cell,
- mean bottom temperature at the mean water depth within the grid cell,
- mean bottom salinity at the mean water depth within the grid cell,
- mean tidal current (cm/sec) associated with the “principal lunar semi-diurnal” component of the tide (M2), and
- mean annual wind speed (m/sec).

Generalized Additive Models (GAM) were used to model binary presence-absence data. Using a forward stepwise approach, the model having the lowest total Akaike information criterion (AIC, Burnham and Anderson 2002) value over the 14 selected taxa (Table 3) was selected and used for spatial predictions.

Smoothing terms over space (i.e. latitude and longitude coordinates converted into UTM), water depth, bottom temperature, bottom salinity, tidal current and annual wind speed were included were added one by one, choosing the smoothing term which contributed to the largest decrease in AIC value at each step or until the total AIC increased. The selected model was:

Presence ~ s(T_BOT_MEAN) + s(DEPTHMEAN) + s(x, y) + gear

where s(T_BOT_MEAN) is an additive smoothing term for mean bottom water temperature, s(DEPTHMEAN) is a smoothing term over water depth, s(x,y) is a spatial smoothing term and gear is an additive term denoting the type of gear used. The data from each survey is not on the same scale, the gear effects correct for (logit) linear differences in scale, such that any linear transform of data observations applied to surveys other than the reference survey leave the end result unaffected, as the gear effect parameters will scale accordingly in the estimation.

The selected model was applied to all data available from the coastline up to the 60 m isobaths, the data between 40 m and 60 m were included so as to obtain a better adjustment at the margins of the study area (i.e. near 40 m). Contour maps of the restricted study area (0-40 m) were then produced using the predicted probability of capturing a given taxon for a standard tow of 1.75 nautical miles (nm) with a Western IIA trawl (as used in the RV survey) for each grid cell. Since lady crab and mud crab were not caught in the RV survey, their predictions were based on Nephrops trawl of standard tow length 0.125 nm from the NS survey rather than the Western IIA trawl.

The predicted species distribution from the model depended on the spatial and temporal occurrence of the survey sampling stations; therefore, the predicted species distribution could be misleading if sampling was limited or absent (i.e., upper Chaleur Bay, western Cape Breton and a caution for the northern part of Magdalen Islands). Sampling gear can also affect the catchability, therefore, the observed species occurrences can be affected by the spatial distributions of the gear used. Contour maps for all species and taxa were either presented in the analysis section of this document or in Appendix 1.

Biodiversity contour maps were produced separately for fish and invertebrate taxa by summing single-taxon predictions by grid cell, which yielded the number of taxa expected to be captured in a grid cell. For invertebrates, since many different species were encompassed within a single taxon (e.g., toad crab includes *Hyas araneus* and *H. coarctatus*; Table 2), and many groups were not included (e.g., shrimps, polychaetes), the biodiversity indicator displayed on the map is severely underestimated and should be interpreted as a “pseudo-diversity” map. This is also true to a lesser extent for the fish “pseudo-diversity” map because only a few fish taxa were comprised of more than one species (Table 1).

When considering 55 species or taxa for the identification and characterization of potential IA in the coastal zone of the sGSL, special considerations must be made for the species-at-risk. However, the EBSA process is separated from the one dealing with critical habitat designation under the Species at Risk Act (SARA). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has already evaluated twelve fish species identified in this IA process and are suspected of being at risk of extinction or extirpation (Table 4). However, at the moment only three species are assigned a status under SARA, one has been rejected (winter skate; Canada Gazette 2010), and the others are still under consideration. Data on five of the twelve species evaluated by COSEWIC were available from our trawl surveys; for the remaining seven, capturability was very low or nil (e.g., bluefin tuna *Thunnus thynnus* and white shark *Carcharodon carcharias* are fast-swimming pelagic species that have never been captured in our survey trawls).

## EVALUATION CRITERIA

To identify important areas (IA), the evaluation of the coastal waters in the sGSL was based on the same three criteria or dimensions proposed for EBSA (DFO, 2004): uniqueness, aggregation, and fitness consequences. These criteria have already been used for the identification of mid-shore and offshore EBSAs, and they could be equally applied to coastal waters (DFO, 2011). It must be recognized that to identify IA, the ecological consequences of a severe perturbation in that area would be greater than an equal perturbation of most other areas in the region. An IA should be different from unexceptional areas; in the latter case, this does not make the area an unimportant area.

Based on the uniqueness criterion, an area would be deemed important if it contains unique, rare, or distinct characteristics when compared to other areas in the region. Either the biological processes that are taking place in such an area, or the species that are present, should reveal some uniqueness. Special considerations at the species level were given to rare and/or potential endemic species as well as species evaluated under COSEWIC or SARA.

For the aggregation criterion, the species as well as the pseudo-diversity contour maps were used to identify areas of high abundance (concentrations), and where the greatest number of species occurred. These observations, however, only reflect the period when the data were collected, i.e., during the summer months. Additional information from the literature (Appendix 2), commercial landings, traditional ecological knowledge and expert opinion were considered to fill the gaps and increase the reliability of the overall evaluation.

The fitness consequences criterion was used to identify key or important areas where crucial life history activities are undertaken. The criterion was divided into five ecological functions:

- feeding,
- reproduction,
- nursery area,
- migration, and
- seasonal refugia.

Based on the available literature, the connectivity among the areas where these ecological functions were observed was also discussed. Fishes are mobile and several areas can serve as locations for different ecological functions. In contrast, the majority of the invertebrate species are either sessile or are benthic with minimal seasonal movements (i.e., can be considered sedentary), and a single site serves for most fitness functions. Information on invertebrates was mainly considered for the aggregation criterion (the pseudo-diversity contour maps); however, uniqueness was applicable for the lady crab, a likely undescribed endemic whose entire distribution is within Northumberland Strait (Voutier and Hanson 2008).

# ANALYSIS

## GENERAL CHARACTERISTICS OF THE STUDY AREA

The coastal zone was defined as the area with waters ≤40 m deep (DFO 2015). Consequently, this coastal zone actually comprises areas where the warm surface waters contact the bottom (typically ≤30 m) and includes much of the transition zone between the surface layer and the cold intermediate layer (CIL; Gilbert and Pettigrew 1997). Hence, fish species that prefer cold and tolerate low temperatures occur at the shallow edge of their distributions in the coastal zone but most of the population is located in or below the CIL. In contrast, the species that prefer warm waters have the deep-water boundary of their distribution within the transition zone. Finally, diadromous species are a major component of the warm-water fish community, and are all but absent from the cold-water community. The study area, except for the Magdalen Islands (Fig. 5), includes rivers large enough for spawning by anadromous fishes and there is relatively little difference in species diversity of anadromous species. A major exception is the Miramichi River, which is the only known spawning area for striped bass and American shad.

The shallow coastal zone is characterized by seasonal extremes in environmental conditions. During summer months, bottom-water temperatures can exceed 21°C in many areas (often >25°C in embayments and estuaries) while there is an extended period of land-fast and sea ice during winter with bottom water temperatures as low as ca. -1.7°C. The areas exposed to sea ice are subjected to moving ice and ice ridges that can cause bottom scouring down to 20 m depths (Brown et al. 2001; Forbes et al. 2004; Prisenberg et al. 2006). In addition, there is extensive down-welling of ice crystals during storms. Contact with ice or exposure to water below the freezing point of fish tissue can be fatal and consequently most fishes migrate out of the danger zone for the winter months (Clay 1991) often following well-defined migration corridors.

The sGSL is characterized by an array of different environments and habitats but some features of its coastal zone need to be emphasized. Within the study area, Northumberland Strait (Fig. 5) is the only area bounded by land on two sides and it is characterized by almost 100% warm and shallow (<30 m) habitat. There is a prominent cool-water (10-12°C during summer) upwelling area near Wood Island that corresponds to the end of a narrow channel running along the southeastern shore of Prince Edward Island (PEI). Part of that trench is deeper than 40m and has been excluded from the study area (Fig. 1). The blocking in 1954 of the Canso Strait by a causeway created a major disruption in St. George's Bay (Fig. 5) as it closed an important migration route for many long-distance migrants (e.g., the three *Alosa* species, Atlantic saury, butterfish, and perhaps bluefin tuna). The coastal area west of Cape Breton is limited to a narrow band with limited presence of shallow water (Fig. 1). One distinctive feature of the Magdalen Islands is the near-absence of freshwater input in the coastal habitat resulting in the near absence of anadromous species.

## ECOLOGICAL PROPERTIES

### Uniqueness

White hake (Fig. 6) and winter skate (Fig. 7), two suspected undescribed endemics, now occur at very low abundance, and there has been severe range compression to small areas where the population remnants are concentrated (COSEWIC 2005, 2013; Kelly and Hanson 2013a, 2013b). The areas occupied by those two species are therefore unique as they represent their last stronghold.

St. George's Bay and the eastern end of Northumberland Strait constitute the only remaining spawning area for white hake (Fig. 6) as well as a critical summer feeding area (COSEWIC 2013). When migrating out to the Laurentian Channel and Cabot Strait for the winter, adults go through the Northumberland Strait and then follow the west coast of Cape Breton.

While formerly widespread, winter skate is now mainly restricted to the western half of Northumberland Strait (Fig. 7) where they feed and release most of their eggs. In late autumn, they spread from the shallow waters of Northumberland Strait out into the deeper waters of the sGSL; however, some remain in waters ≤ 40 m deep.

The sGSL also shelters a lady crab that is likely an undescribed endemic species (Voutier and Hanson 2008; J.-M. Gagnon, Canadian Museum of Nature, Ottawa) (Fig. 8). Should there be a negative effect that eliminates the lady crab population in the Strait, this would represent a species extinction. The lady crab population from the Northumberland Strait has not been assessed by COSEWIC.

### Aggregation

Given the endangered status of white hake population (COSEWIC 2013), concentrations of this species, especially the juveniles, in Northumberland Strait, St. George's Bay and east of PEI (Fig. 6) increase the importance of these areas. The species also formerly occupied the Shediac Valley (Fig. 5), which is no longer the case (Benoit et al. 2003; Swain et al. 2012).

Juvenile Atlantic cod occur at the shallow edge of the CIL and well into the transition zone waters (Fig. 9), and large numbers of age-0 (semi-pelagic) individuals occur in warm waters such as Northumberland Strait. Aggregations of juvenile Atlantic cod occur east of PEI but that is only one of many areas of aggregation (Hanson 1996; Benoit et al. 2003; Darbyson and Benoit 2003). In autumn, juvenile Atlantic cod follow after the adults and they appear to concentrate north of the Magdalen Islands and along the edge of the Laurentian Channel for the winter. Mixed groups of adult and juvenile Atlantic cod return to the sGSL in spring, shortly after the ice melts.

Atlantic halibut is not a coastal species per se; however, part of the population occurs closer to shore in the Gaspe and Cheticamp troughs during summer and early autumn (Benoit et al. 2003; Darbyson and Benoit 2003). Based on our data, the Atlantic halibut was mostly observed in the waters from northeastern New Brunswick (NB), on the north side of PEI, and east of the Magdalen Islands (Fig. 10).

Most individuals from the Atlantic salmon, alewife, and American eel populations that migrate into the Restigouche River, to either spawn (anadromous) or feed (catadromous), must congregate, even temporarily, in Chaleur Bay and this area would be important for their fitness. Unfortunately, the map generated from our alewife data (Fig. 11) does not reflect this expectation because data were collected mostly in the summer months. The aggregation of alewife occurs in a brief period during spring and is limited geographically; hence, it is unlikely that it could be observed in the traditional bottom trawl surveys, i.e., illustrating data limitation. Similarly, the entire breeding population of American shad and striped bass must cross the eastern NB area to access their single spawning site in the Miramichi River (Chaput and Bradford 2003; Douglas et al. 2009; COSEWIC 2012b; DFO 2014a), so this transition area is important in terms of the aggregation of those species.

Although our contour map for butterfish (Fig. 12) suggests a single aggregation within Northumberland Strait, they also occupied several other areas in the summer and the fall. However, other than occasional captures in the Miramichi Estuary (Hanson and Courtenay 1995), they have not been captured in areas west of North Point, PEI (Benoit et al. 2003; Darbyson and Benoit 2003).

The pseudo-diversity contour map for fish (Fig. 13) indicated the greatest numbers of species were captured in the Northumberland Strait, St. George's Bay, and Chaleur Bay. Based on the available data, numerous species found in these areas were indeed very abundant (e.g. Atlantic herring, longhorn sculpin, rainbow smelt, alewife, winter flounder) and therefore had a very high predicted probability of capture. Aggregation of fish species was less important around the Magdalen Islands mostly because of the absence of anadromous species. Coastal waters west of Cape Breton are restricted to a very narrow band and limited data were available from our surveys to generate the model's predictions which could explain why fewer species seemed to be present in that area.

The pseudo-diversity contour map for invertebrates suggests that relatively high numbers of species occur in the Shediac Valley, Chaleur Bay, and just south of the Magdalen Islands; and that lower numbers of species are present in the Northumberland Strait, St. George's Bay, and eastern PEI (Fig. 14). This is quite the opposite of the results based on fish species (Fig. 13). The invertebrate pseudo-diversity contour map seems to be driven by the high number of echinoderm species in our database, and transient invertebrate species (i.e., at the upper limit of the CIL). Sea stars, sea cucumbers, and sea urchins are easy to identify compared to many other taxa that were not included in this evaluation, such as shrimps, polychaetes, small crustaceans (i.e., mysids, cumaceans, and amphipods), sponges, sea anemones, tunicates, and small mollusks. Thus, the pseudo-diversity contour map for invertebrates based on the available information is a biased representation of the coastal invertebrate community and is a severely biased indicator of the aggregation criterion. Consequently, it should not be considered in the identification and characterization of coastal IA.

## Fitness consequences

### Feeding

The majority of the research trawl surveys occur between early July and late September. Thus, summer species' distributions represent areas where fishes are observed actively feeding and growing. With a few exceptions, fishes that remain in the sGSL during winter do not feed or feed at greatly reduced levels.

Adult white hake currently only feed in St. George's Bay and the eastern end of Northumberland Strait (Fig. 6) so key food source for that species might only be available there; however, their main prey are Atlantic herring and Atlantic mackerel, two widespread species (Hanson 2011). It is recognized that there are high concentrations of forage fish in St. George's Bay such as juvenile and adult Atlantic herring, Atlantic saury, and juvenile alosids in autumn and spring. This area along with the eastern end of Northumberland Strait is critical to the fitness of the white hake population since the remnant of the adult population feeds there and it is two of the three locations, along with Shediac Valley, where juveniles feed. There is an October feeding migration of juvenile white hake into estuaries of Northumberland Strait and up to at least the Miramichi Estuary (Hanson and Courtenay 1995; Bardford et al. 1997; Swain et al. 2012) adjacent to the Shediac Valley (Fig. 5).

The western end of Northumberland Strait is the only feeding area for the lady crab (Voutier and Hanson 2008) and the summer feeding area for the remnant population of winter skate (Kelly and Hanson 2013a, 2013b), both species having a high likelihood to be undescribed endemics. The warm water (probably too warm for most of the transition water/CIL species), sand substrate, and currents result in Northumberland Strait being the only area suitable for lady crabs north of the United States eastern seaboard (with the exception of a small population in Minas Basin) (Voutier and Hanson 2008).

Large proportions of the alewife (Fig. 11), windowpane flounder (Fig. 15), rainbow smelt (Fig. 16), and American shad populations also feed within Northumberland Strait, where there also are high concentrations of forage fish such as juvenile Atlantic herring (McQuinn et al. 2012). The area is also used consistently for feeding by most anadromous species. Rainbow smelt are very common in the <35 m depths in bottom trawl surveys and occur along all the shoreline of the sGSL except the Magdalen Islands (Fig. 16) during the ice-free season. Typically, there are large concentrations of rainbow smelt feeding in waters <30 m deep in Chaleur Bay, eastern NB, and throughout Northumberland Strait (Benoit et al. 2003; Bosman et al. 2011; Savoie 2014a). Juvenile rainbow smelt have the same general distribution of adults once they enter full salt water, but the juveniles tend to be closer to shore.

There are at least four marine fish species (transient marine species) that enter the sGSL coastal waters to feed during summer months: bluefin tuna, butterfish, Atlantic saury, and spiny dogfish (Appendix 2). The bluefin tuna and Atlantic saury are pelagic species and not captured in DFO trawl surveys but based on commercial and reported commercial fisheries landings (DFO 2010; Vanderlaan et al. 2014) feeding aggregation information could be deduced. The largest numbers of bluefin tuna occur along the north coast of PEI and at the eastern end of the Strait where they feed actively. The Shediac Valley is the third high-density feeding areas for bluefin tuna (based on landings) within the sGSL making those areas rather important for the fitness of that species. Atlantic saury is noteworthy for its feeding concentrations during autumn in a small area of St. George's Bay (Chaput and Hurlbut 2010; DFO 2010) - they presumably enter and exit along the west coast of Cape Breton. Butterfish enter the sGSL sometime during summer with very small numbers caught in the NS survey, and from central Strait to St. George's Bay (Fig. 12) in September and October. Large incursions of spiny dogfish occur when its population in adjacent ecosystems is at high levels (COSEWIC 2010b). Spiny dogfish mainly occur during late summer and autumn in coastal waters from Miscou Island through Northumberland Strait and the north Shore of PEI to eastern PEI, with a concentration on the east side of the Magdalen Islands (Benoit et al. 2003; COSEWIC 2010b) (Fig. 17). During autumn, these aggregations of spiny dogfish likely are concentrating on spawning aggregations of Atlantic herring.

A group of anadromous species does not leave the sGSL and uses the coastal zone as their primary open-water feeding area. Some species tend to stay very close to shore (e.g., striped bass and brook trout) and others are simply poorly sampled (e.g., Atlantic tomcod and threespine stickleback), because much of the population occurs, again, close to shore or is pelagic (not mutually exclusive mechanisms), resulting in the absence or quasi-absence of these species in our research trawl surveys.

**Migration corridors**

Of the fish species that show significant seasonal movements, most appear to undergo diffuse migration between summer feeding areas and overwinter refuges. There are notable exceptions. The entire near-shore area from Gaspé to roughly the Margaree Estuary in Cape Breton represents the seasonal migration corridor for striped bass (Robinson et al. 2004; Douglas et al. 2009; S. Douglas, Gulf Fisheries Centre, pers. comm.) (Fig. 18); however, this species does not move out of the sGSL. American eel, the three alosid species, butterfish, Atlantic saury, and spiny dogfish, all are thought to migrate along the coast, and especially in Northumberland Strait, to the west coast of Cape Breton and then out along the northern tip of Cape Breton. Atlantic cod shows a similar migration pattern in and out of the sGSL (Hanson 1996; Campana et al. 1999; Comeau et al. 2001). While Atlantic mackerel and bluefin tuna do not necessarily stay in coastal waters when feeding, they mostly pass along the north tip of Cape Breton as they enter and exit the sGSL. White hake also migrate along the west coast of Cape Breton (current low population pattern) and showed a similar migration along the coastal areas of both sides of PEI when population numbers were higher. Thus there clearly is a major migration corridor primarily through Northumberland Strait (and to a lesser degree along the north shore of PEI), along the west coast of Cape Breton, and then a highly significant choke point at the northern tip of Cape Breton Island (Fig. 18).

The three alosid species (alewife, blueback herring, and American shad) undergo long-distance migrations to overwinter well outside the sGSL (Chaput and Bradford 2003; Darbyson and Benoit 2003; McQuinn et al. 2012). The three species spawn in rivers during spring or early summer; the young-of-the-year move down the estuary as they grow; they join the large juveniles and adults in coastal waters (especially in Northumberland Strait) during late summer or early fall, and all sizes leave the sGSL before ice formation. The migration appears to run along the shoreline of the mainland (mainly Northumberland Strait) and, for a while, there can be large numbers concentrated at the eastern end of St. George's Bay. Eventually, all the migrants exit along the west coast of Cape Breton, leaving the sGSL completely during winter. All sizes of alosids return to the sGSL as the ice melts, adults enter freshwater to spawn, and the post-spawners move back down to coastal waters to feed for the summer – along with the immature fishes (Hanson and Courtenay 1995; Bosman et al. 2011; J.M. Hanson, unpublished data). A very large proportion of the populations of the three alosid species, butterfish, striped bass (in the Miramichi River and a few nearby rivers), and adult American eels migrate through the Northumberland Strait in autumn to overwinter or to breeding sites (reverse migrations in spring for diadromous species). For species entering rivers within the Strait, there is no other route so the area is an obligatory passage. Winter skate migrate into the Strait from overwinter areas to feed and breed. As an obligatory passage to local end points (either to breeding, feeding, or overwinter sites), this area is critical for the fitness of many anadromous species, such as striped bass and American shad, and for winter skate.

Atlantic mackerel is also a long distance migrant. They migrate to US coastal shelf region to overwinter, returning in spring to spawn, and both adults and juveniles feed pelagically in the coastal zone all summer (McQuinn et al. 2012; DFO 2014b). Like the three alosid species, the migrants must pass through the choke point at northern tip of Cape Breton (Fig. 18) during both migrations.

As a deep-water species, adult Atlantic cod mainly occur in the cold waters of the CIL although, when population numbers were high, some occurred in the transition waters. The migration path of Atlantic cod is well-known (Swain et al. 1998; Campana et al. 1999; Comeau et al. 2001); the western group moves in waters offshore from the north shore of PEI in October, joins up with eastern group along west coast of Cape Breton, and move to the edge of the Cape Breton Trough up to the north tip Cape Breton in November. The adults migrate ahead of the ice-edge in Cabot Strait as winter progresses and ultimately out onto the Scotian Shelf.

As described earlier, bluefin tuna, butterfish, Atlantic saury, and spiny dogfish are known to enter the sGSL to feed. Presumably, all enter and exit via the passage at the tip of Cape Breton and pass along the west coast of Cape Breton, presumably between the shore and edge of the Laurentian Channel.

Anadromous species spawn in freshwater and have migrations of varying lengths. Corridors leading to those freshwater spawning locations are therefore important for the fitness of the anadromous species in the sGSL. Chaleur Bay is an obligatory passage for salmon, alewife, and American eels going into rivers like the Restigouche, and likely for striped bass during its feeding migrations. Similarly, eastern NB (coastal Shediac Valley) is also an obligatory passage for these species going into other rivers. Furthermore, the Miramichi River is the only known spawning site for striped bass and American shad so the entire population funnels through the area coming either from the northern and southern route (Fig. 18) before entering the river. Young-of-the-year striped bass and American shad move down the river and into the estuary as they grow and then disperse all along the coast in mid-summer (Chaput and Bradford 2003; Robinson et al. 2004). Finally, most of the juvenile and adult alewife and rainbow smelt go through the Miramichi Estuary to migrate into Northumberland Strait to feed during the summer months.

There is an October feeding migration of juveniles of white hake from the Shediac Valley into the Miramichi Estuary (eastern NB) where fish aggregate for a month or so before leaving to overwintering locations (Hanson and Courtenay 1995; Bradford et al. 1997; Swain et al. 2012; COSEWIC 2013). Eastern NB is therefore important for the fitness of this endangered species. Since there is also a feeding migration of juvenile white hake in rivers of Northumberland Strait, that area must also be of some importance.

Atlantic salmon undertakes a long feeding migration. Small juvenile Atlantic salmon (smolts) migrate down the estuaries of their natal rivers during spring. The pelagic smolts from several major rivers apparently congregate for a short time in the Miramichi “outer-bay” area and move as a group across the Magdalen Shallows, crossing to the Strait of Belle Isle, and ending up near Greenland (COSEWIC 2010c). The return migration is not synchronous with fish fresh from the ocean appearing in fresh waters from late June through October. Locations of the adults in transit are poorly understood, and they are all but immune to our survey gears because they are pelagic and fast-moving; hence, possible migration corridors (if any) cannot be inferred. The adults spawn during autumn and the surviving spent fish move back down the estuary during spring (feeding as they go) and out to sea. Some of the spent fish that migrate back to the ocean sea will return to spawn in subsequent years.

Longhorn sculpin, sea raven, yellowtail flounder, windowpane, and ocean pout are widely distributed and most individuals appear to leave the <30 m waters occupied during summer and move to the deeper waters within the sGSL to overwinter with no specific migration corridor (Bosman et al. 2011; Hanson and Wilson 2014). Similarly, the almost ubiquitous winter flounder shows two types of migration to overwinter refuges. Some individuals move to the edge of the Laurentian Channel while others enter estuaries during autumn and exit shortly after ice-melt (Hanson and Courtenay 1995, 1996; Darbyson and Benoit 2003).

Some warm-water coastal-zone species do not appear to migrate (see Appendix 2). Cunner hides under rocks or buries in sediment and enters a state of torpor as water temperatures drop below 5 to 8 °C (Johansen 1925; Dew et al. 1976; Green et al. 1984). Rock gunnel mainly lives under rocks close to shore and inside estuaries (Scott and Scott 1988). Wrymouth live in deep burrows (Scott and Scott 1988). Presumably these species remain in their preferred habitat year-round. Grubby (almost exclusively close to shore and in estuaries) and northern sand lance are not well sampled and their seasonal movements cannot be discerned.

The Canso Strait was most likely an important passageway for many species (e.g., Atlantic herring, Atlantic saury, and *Alosa* spp.) but since its blockage, each side now acts as a retention area (depending on the season) where migratory fish species are caught up until they take an alternative route out and around Cape Breton, i.e., along the west coast of Cape Breton in the sGSL. A significant proportion of the migratory species populations pass along the west coast of Cape Breton. Atlantic salmon populations using the rivers in the area must migrate through St. George's Bay to access spawning endpoints. St. George's Bay formerly was very important for the fitness of species migrating through the Canso Strait but now marine fish are going around Cape Breton following the shore west of Cape Breton or a bit offshore.

Invertebrate species do not show much in the way of seasonal movements although some adult American lobsters do make short seasonal movements to slightly deeper water if cover is not available in the <30 m depths (Bowlby et al. 2007, 2008). Consequently, no area can be identified as being important for the fitness of invertebrate species based on migration.

### Spawning locations

Fish populations in the sGSL can be classed in four guilds by spawning behavior; anadromous species, those that do not spawn in the sGSL, species with known spawning beds, and species where no spawning area has been located (the vast majority of species). Anadromous, catadromous, and transient species do not spawn in the sGSL marine coastal habitat and therefore their spawning grounds can be ignored for the purpose of this report. With few exceptions (e.g., Atlantic herring, white hake, winter skate), distinct spawning areas are unknown for most marine resident species.

The St. George's Bay is unique as it is the only remaining breeding location for coastal white hake (Swain et al. 2012; COSEWIC 2013); the entire breeding population is present and the loss of this location would most likely result in the extirpation or extinction of white hake. As the only breeding area for lady crab (Fig. 8) and most of the remnant winter skate population (Fig. 7), the western half of Northumberland Strait is critical for these species. The loss of this breeding area would most likely result in the extinction of lady crab and winter skate. Baie Verte located in central Northumberland Strait (Fig. 5) used to be one of the two known spawning location for white hake (with St. George's Bay) but this function is now lost (Swain et al. 2012).

Atlantic herring (spring and fall spawners) have many spawning beds (e.g., Miscou Island, both ends of Northumberland Strait, Chaleur Bay) (Messieh 1987) but usage is not consistent from year to year. Historically, there have been spring and fall herring spawning beds for the entire sGSL but some of them seem to have disappeared (McQuinn et al. 2012).

Capelin probably spawns on offshore banks and perhaps beaches from Miscou Island to roughly Gaspé Bay; however, actual locations have not been documented.

Winter sampling in the lower Miramichi Estuary has detected Greenland cod and shorthorn sculpin in spawning condition (ripe and running and newly spent; Hanson and Courtenay 1995) but whether winter spawning in the lower section of estuaries is the rule for sGSL populations is unknown.

Beside St. George's Bay and Northumberland Strait, no other areas can be identified as being important for the reproductive fitness of fish species. As for the invertebrate species, very little information on breeding grounds is available. As said previously, most species are sessile or sedentary and will complete their whole life cycle within the same area.

#### Nursery areas

The possibility of distinct nursery areas has not been investigated for most marine species. Estuaries, for varying lengths of time, represent important nursery areas for all of the diadromous fishes except Atlantic salmon and sea lamprey (whose young pass quickly through the zone en route to marine feeding areas). There are very few juveniles of diadromous species in shallows of St. George's Bay and the Magdalen Islands because of the small number and the total absence of inflowing rivers, respectively. For most species, the juvenile fish essentially share the same locations as the adults although there is a moderate tendency for the juveniles to be in shallower waters.

Distinct nursery areas are known for Atlantic herring, and are located within Northumberland Strait and the end of Chaleur Bay (LeBlanc et al. 1998; Bosman et al. 2011). There are also some concentrations of juvenile herring in St. George's Bay (McQuinn et al. 2012).

For Atlantic cod, the major concentrations of juveniles occur around the north point of PEI, immediately west of the Magdalen Islands, and along the north and east coasts of PEI. Some concentrations of age-0 and small juveniles occur within Northumberland Strait during summer (Bosman et al. 2011).

Juvenile white hake are now only found in three locations: St. George's Bay, Northumberland Strait, and eastern PEI (Hanson and Courtenay 1995; Swain et al. 2012; COSEWIC 2013) with no area being more important than the others for the fitness of the remnant population. The western half and central Northumberland Strait is also the only nursery area for lady crab and remnant winter skate population; meaning it is critical for the fitness of both species. In addition to those two likely-endemic species, there are large concentrations of age-0 and juveniles of the three alosid species and striped bass. High concentrations of adult windowpane (Fig. 15) and winter flounder probably indicate that the area is used as a breeding and nursery area as well as for feeding.

#### Seasonal refuge

With one exception, there is no significant winter refuge in the coastal zone of the sGSL. Most strictly warm-water coastal fishes migrate to deeper waters outside the coastal area or enter estuaries for the winter, including all of the rare (COSEWIC ranked) or suspected endemic fishes (winter skate and white hake). A few widely-distributed warm-water fishes (e.g., wrymouth, cunner, and rock gunnel) remain in their burrows, hide under rocks, or bury in the sediments to overwinter. Furthermore, seasonal migrations by benthic invertebrate species, including the likely undescribed endemic population of lady crab, are minimal or non-existent. The whole population of lady crab is restricted to the western half of Northumberland Strait year-round so the area is its sole refuge. The fitness (i.e., continued survival) of this species depends on this area.

## DISCUSSION

In contrast with the identification and characterization of important areas (IA) in the coastal waters, the workshop held in 2006 (DFO 2007) was not limited by depth, per se. The focus of the 2006 workshop was more "offshore" largely because the RV survey typically has very few sets in water <25 m deep. Nevertheless, two of the ten identified EBSAs (St. George's Bay and the western Northumberland Strait; DFO 2007) occur entirely in waters ≤40 m deep (Table 5). Furthermore, two other EBSA (Western Cape Breton and southwestern coast of the Gulf; DFO

2007) were very large areas that covered much deeper waters (>40 m) but included large portions of coastal waters (Table 5).

Based on the information available, the Northumberland Strait area is the highest ranked IA. Its importance is paramount considering the three evaluation criteria; uniqueness, aggregation and fitness consequences. The high importance in terms of these three criteria is mainly driven by the presence of two likely-endemic species (lady crab and winter skate) in the center and western half of the Strait, and by its being the only remaining spawning location for the coastal white hake (eastern half). Moreover, the only other known spawning location for these white hake was within the Strait in Baie Verte (Swain et al. 2012). In addition, the Northumberland Strait is a major migration corridor for fishes (butterfish, striped bass, *Alosa* spp. and adult American eels) with a bottleneck at both ends. The western part of the Strait was identified as an EBSA (see Table 5) in the 2006 workshop (DFO 2007) mainly because of the presence of the lady crab (Chabot et al. 2007) and remnant winter skate population (Swain and Benoît 2007), and more recently for its importance for small pelagic fishes in the eastern half (McQuinn et al. 2012). However, given the similarity of the oceanographic processes within Northumberland Strait (Chassé et al. 2014), the entire area could be characterized as a single unit.

St. George’s Bay was previously identified as an EBSA (St. George’s Bay EBSA 2; DFO 2007), and since the entire bay is <40 m, and the same dataset was used, we could also consider it as a coastal IA (Table 5), and de facto as a coastal EBSA. St. George’s Bay ranked high because it is part of the only remaining breeding location for white hake, and losing this area would result in its extirpation or extinction (Swain and Benoît 2007). Additionally, concentrations of juvenile white hake are found there. St. George’s Bay is an important feeding area for many fishes (e.g., juvenile and adult Atlantic herring, juvenile *Alosa* spp., white hake and Atlantic saury) and many fish species aggregate there during part of their migration in and out the sGSL. The area was designated as an EBSA in 2006 mostly for its major role for meroplankton (largest array and abundance in the sGSL) as well as for its usage by groundfish and pelagic fish (DFO 2007).

The coastal areas at the eastern end of PEI and along the western shore of Cape Breton are encompassed by a much larger area that was identified and characterized as an EBSA (DFO, 2007). At the 2006 EBSA meeting, western Cape Breton was designated as an EBSA (EBSA 1; DFO 2007) because of its major role for meroplankton (with a large array of species), high biomasses and large concentrations of small (<1 mm) and large (>1 mm) meso-zooplankton and its importance to groundfish (Swain and Benoît 2007). The Cape Breton Channel serves as a migration corridor (spring and fall) for many fishes but especially for Atlantic cod and white hake (Swain and Benoît 2007). However, the main ecological functions are more important in the offshore portion of the western Cape Breton EBSA. Indeed, the EBSA is mostly comprised of the deep waters (>40 m) that occur between PEI and Cape Breton rather than coastal waters. Within the context of the current study, the coastal zone (<40 m) along the western coast of Cape Breton is a narrow band, and does not appear to be of critical importance to any of the species considered in the present evaluation; therefore, it would not be designated as IA (Table 5). In contrast, the coastal zone at the eastern end of PEI is wider and is directly connected to the adjacent IAs (i.e., Northumberland Strait and St. George’s Bay). Thus, it should be considered an IA (Table 5), mainly because of the presence of white hake, but also due to its importance to pelagic fishes (McQuinn et al. 2012).

Chaleur Bay and the coastal waters west of the Shediac Valley (i.e., eastern NB) should not be considered an IA; however, the deeper waters adjacent to these coastal areas have been identified as EBSA (Table 5) and might warrant special consideration. The relative importance of these areas refers mainly to migratory anadromous species (e.g., Atlantic salmon, alewife, and American eels) going into the Restigouche river and with American shad and striped bass (their only spawning locations in the sGSL) going into the Miramichi River (which also supports much larger populations of salmon, alewife, and American eels than the Restigouche River). These two areas are comprised within the southwestern coast of the Gulf EBSA identified during the 2006 workshop and represent most of its coastal portion (<40 m). The discrepancy between the two evaluations seems to be the depth restriction and additional layers of information. First, the southwestern coast of the Gulf EBSA is influenced by the Gaspé current and both the Miramichi and Restigouche rivers empty into the area creating special physical processes including retention potential, resurgence, and important tidal mixing (DFO 2007). Consequently, with the influence of the Gaspé current carrying nutrients and phytoplankton cells, high phytoplankton concentrations can be observed in the area. That would explain the importance of that area for pelagic fishes (DFO 2007; McQuinn et al. 2012). Second, fishes and invertebrates are high in numbers but the species listed is indicative of species that prefer lower temperatures and thus more abundant, or present, at depth >40 m. Furthermore, Chaleur Bay represents one of the principal wintering areas for juvenile Atlantic herring (DFO 2007; McQuinn et al. 2012), but this occurs in waters >40 m and hence was not considered in our identification for coastal IA (Table 5). Also, the southwestern coast of the Gulf was identified as an EBSA because of a significant feeding area for several marine mammal species, but offshore from Gaspé (DFO 2007), not in the coastal area. Finally, Swain and Benoît (2007) indicated the importance of Chaleur Bay (their IA-7) as low and Shediac Valley (their IA-5) as moderate (Table 5) based on information for demersal fishes.

Finally, coastal areas north of PEI and around Magdalen Islands ranked the lowest as IA based on the three evaluation criteria and all the ecological functions. These locations have no distinctive features and do not seem to be essential for any of the fish or invertebrate species accounted for this evaluation of coastal IA. Similarly, they were not given any special consideration during the identification and characterization process to established EBSA in 2006 (Table 5).

## DATA AND RESEARCH LIMITATIONS

The framework and concepts for the identification of IA rely on data availability and quality. Our evaluation had limitations due to gaps in survey coverage in shallow waters of the coastal habitat. For waters < 25 m deep, only Northumberland Strait was well-surveyed; with reasonably good coverage in the eastern half of the Strait only starting in 2005. Waters of Northumberland Strait < 4 m deep could not be sampled due to the draft of the survey trawlers; consequently, distributions of many species described within this study are truncated. Elsewhere in the sGSL (including St. Georges Bay), there is little information for depths < 25 m, and extrapolating the results from this study to the entire coastal zone should be done with caution.

Lack of sampling in the coastal habitat also reflects, among other things, heterogeneous rough bottoms in some areas which prevent sampling by bottom trawls during some surveys. Rocky hard bottoms (e.g., boulder, reefs) in the sGSL are largely located in ≤ 40 m depths. Also, some areas, specifically the western half of Northumberland Strait, could not be sampled during the annual RV survey due to ongoing fishing activities (i.e., the large numbers of lobster traps). Hence, the only information available for this area comes from the NS survey that began in 2000, reflecting inconsistencies in the sampling coverage and sampling gears for the data considered. Filling the data gap in these areas would be difficult for many species.

Trawl efficiency is also an issue for many fish and invertebrate species, especially small bodied species but also for epibenthic (including demersal fishes such as flatfishes) and endobenthic species which are not well-sampled with the trawls used in most multispecies surveys. This is problematic for species such as the sevenspine bay shrimp (*Crangon septemspinosa*) and the Atlantic rock crab that play a critical role in the coastal zone food web (Hanson 2011; Kelly and Hanson 2013a; Hanson and Wilson 2014;Hanson et al. 2014). However, basic information such as abundance and distribution is lacking for these species for most of the sGSL. Information on buried invertebrates (e.g., small and large bivalves, polychaetes, some tunicates, some echinoderms) is also lacking or with very limited spatial coverage even if it is recognized that species of the endobenthos are an important link within ecosystem food webs.

Correct species identification in the different surveys continues to be an issue. Species diversity, even for fishes in our study, is affected by taxonomic shortcomings such as pooling two species for alewife and blueback herring (similar to commercial landings) or the separation of small stichaeids (daubed shanny, stout eel blenny; slender eel blenny, juvenile snakeblenny) that has not been done consistently in the surveys' time series. The issue with the invertebrate data availability bears repeating. Many groups, including higher taxa, are pooled to class or phylum level in the database. In some cases, species-level identification work has been done (e.g., shrimps since 2002) following surveys but their entry into the database has been slow and this information was not available for the present study. With only one shrimp species in the warm-water part of the coastal zone versus at least 14 species occurring in the transition waters and CIL, the difference in biodiversity between the two depth zones is greatly underestimated.

Data-rich areas are more likely to be considered as important, creating a bias compare to data-poor areas. Unique characteristics, evidence of aggregations of some species, and the functionality of an area are easier to identify with a wealth of data and information. Also, the large amount of data on commercial species could predispose the identification of IA to those species and not for whole ecosystem processes.

## CONCLUSION

The process for identification and characterization of coastal important areas (IA) reveals three locations that rank high based on fish species and one crab species: Northumberland Strait, St George's Bay, and eastern coast of PEI. These areas stand out primarily because of the presence of likely-endemic species. Chaleur Bay and coastal Shediac Valley are important mainly for the migration of several anadromous species and may warrant some special consideration. The area along the west coast of Cape Breton has a major role as a migration corridor, but more so in the > 40 m deep portion of the area and especially at the "choke point" for many fish species. Finally, there is no evidence to consider northern PEI and Magdalen Islands as IA, as per the previous EBSA identification and characterization meeting in 2006 (DFO 2007).

## REFERENCES CITED


Benoît, H.P. 2006. Standardizing the southern Gulf of St. Lawrence bottom-trawl survey time series: Results of the 2004-2005 comparative fishing experiments and other recommendations for the analysis of the survey data. DFO Can. Sci. Adv. Secr. Res. Doc. 2006/008. iii+127 p.

Benoît, H.P., and Swain, D.P. 2003a. Standardizing the southern Gulf of St. Lawrence bottom-trawl survey time series: adjusting for changes in research vessels, gear and survey protocol. Can. Tech. Rep. Fish. Aqua. Sci. 2505. 95 p.

Benoît, H.P., and Swain, D.P. 2003b. Accounting for length and depth-dependent diel variation in catchability of fish and invertebrate in an annual bottom-trawl survey. ICES J. Mar. Sci. 60: 1297–1316.

Benoit, H.P., Darbyson, E., and Swain, D.P. 2003. An atlas of the geographic distribution of marine fish and invertebrates in the southern Gulf of St. Lawrence based on annual bottom trawl surveys (1971-2002). Can. Data Rep. Fish. Aquat. Sci. 1112. 185 p.

Bosman, S.H., Methven, D.A., Courtenay, S.C., and Hanson, J.M. 2011. Fish assemblages in a north Atlantic coastal ecosystem: Spatial patterns and Environmental correlates. Estuar. Coast. Shelf S. 92: 232-245.

Bowlby, H.D., Hanson, J.M., and Hutchings, J.A. 2008. Stock structure and seasonal distribution pattern of American lobster, *Homarus americanus*, inferred through movement analysis. Fish. Res. 90: 279-288.

Bowlby, H.D., Hanson, J.M., and Hutchings, J.A. 2007. Resident and dispersal behavior among individuals within a population of American lobster, *Homarus americanus*. Mar. Ecol. Progr. Ser. 331: 207-218.

Bradford, R.G., Chaput, G., and Hurlbut, T., and Morin, R. 1997. Bycatch of striped bass, white hake, winter flounder and Atlantic tomcod in the autumn open-water smelt fishery of the Miramichi River estuary. Can. Tech. Rep. Fish. Aquat. Sci. 2195: 43p.

Brown, T.G., Jordan, I.J., and Croasdale, K.R. 2001. A probabilistic approach to analysis of ice loads for the Confederation Bridge. Can. J. Civil Eng. 28: 562–573.

Burnham, K.P., and Anderson, D.R. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretical Approach. 2d ed Springer-Verlag. New York. 488 p.

Cairns, D.K. 1997. A biological review of commercial diadromous fishes of Prince Edward Island. DFO Can. Stock Assess. Sec. Res. Doc. 97/74. iii + 53 p.

Campana, S.E., Chouinard, G.A., Hanson, J.M., and Frechet, A. 1999. Mixing and migration of overwintering cod stocks near the mouth of the Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 56: 1873-1881.

Canada Gazette. 2010. Order amending schedule 1 to the Species at Risk Act. Canada Gazette 144 Part II: 240-247.

Chabot, D., Rondeau, A., Surette, T., Sainte-Marie, B., and Archambault, P., 2007. Ecologically and biologically significant areas in the Estuary and the Gulf of St. Lawrence: Benthic invertebrates (molluscs, crustaceans). DFO Can. Sci. Advis. Sec. Res. Doc. 2007/018

Chaput, G., and Bradford, R.G. 2003. American shad (*Alosa sapidissima*) in Atlantic Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/009. iv + 71 p.

Chaput, G. and Hurlbut, T. 2010. Opportunity for a fishery for Atlantic Saury (*Scomberesox saurus*) in the Nova Scotia portion of the southern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/051. iv + 41 p.

Chassé, J., Lambert, N., Comeau, M., Galbraith, P.S., Larouche, P., and Pettipas, R.G. 2014. Environmental conditions in the southern Gulf of St. Lawrence relevant to lobster. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/031. v + 25 p.

Clay, D. 1991. Seasonal distribution of demersal fish (Osteichthyes) and skates (Chondrichthyes) in the southeastern Gulf of St. Lawrence. Can. Spec. Publ. Fish. Aquat. Sci. 113: 241-259.

Comeau, L.A., Campana, S.E., Chouinard, G.A., and Hanson, J.M. 2001. Timing of Atlantic cod (*Gadus morhua* L.) seasonal migrations in relation to serum levels of gonadal and thyroidal hormones. Mar. Ecol. Progr. Ser. 221: 245-253.

Conan, G.Y., Comeau, M., Gosset, C., Robichaud, G., and Garaicoechea, C. 1994. The Bigouden Nephrops trawl, and the Devismes trawl, two otter trawls efficiently catching benthic stages of snow crab (*Chionoecetes opilio*) and American lobster (*Homarus americanus*). DFO Can. Tech. Rep. Fish. Aquat. Sci. 1992. 27 p.

COSEWIC. 2005. COSEWIC assessment and status report on the winter skate *Leucoraja ocellatus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 41 p.

COSEWIC. 2009. COSEWIC assessment and status report on the American plaice *Hippoglossoides platessoides* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. x + 74 p.

COSEWIC. 2010a. COSEWIC assessment and status report on the Atlantic cod *Gadus morhua* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xiii + 105 p.

COSEWIC. 2010b. COSEWIC assessment and status report on the Spiny Dogfish *Squalus acanthias*, Atlantic population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 50 p.

COSEWIC. 2010c. COSEWIC assessment and status report on the Atlantic Salmon *Salmo salar* (Nunavik population, Labrador population, Northeast Newfoundland population, South Newfoundland population, Southwest Newfoundland population, Northwest Newfoundland population, Quebec Eastern North Shore population, Quebec Western North Shore population, Anticosti Island population, Inner St. Lawrence population, Lake Ontario population, Gaspé-Southern Gulf of St. Lawrence population, Eastern Cape Breton population, Nova Scotia Southern Upland population, Inner Bay of Fundy population, Outer Bay of Fundy population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xvii + 136 p.

COSEWIC. 2011. COSEWIC assessment and status report on the Atlantic bluefin tuna *Thunnus thynnus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. ix + 30 p.

COSEWIC. 2012a. COSEWIC assessment and status report on the American Eel *Anguilla rostrata* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xii + 109 p.

COSEWIC. 2012b. COSEWIC assessment and status report on the Striped Bass *Morone saxatilis* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. iv + 82 p.

COSEWIC. 2013. COSEWIC assessment and status report on the white hake *Urophycis tenuis* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xiii + 45 p.

Darbyson, E., and Benoit, H.P. 2003. An atlas of the seasonal distribution of marine fish and invertebrates in the southern Gulf of St. Lawrence. Can. Data Rep. Fish. Aquat. Sci. 1113. iii + 294 p.

Dew, C.B. 1976. A contribution to the life history of the cunner, *Tautogolabrus adspersus*, in Fishers Island Sound, Connecticut. Chesapeake Science 17: 101-113.

DFO. 2004. Identification of Ecologically and Biologically Significant Areas. DFO Can. Sci. Advis. Sec. Ecosystem Status Rep. 2004/006.

DFO. 2006. Zonal workshop report on Ecologically and Biologically Significant Areas (EBSA) in the Estuary and Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Ecosystem Status Rep. 2006/011.

DFO. 2007. Ecologically and Biologically Significant Areas (EBSA) in the Estuary and Gulf of St. Lawrence: identification and characterization. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/016.

DFO. 2010. Opportunity for Atlantic silverside and Atlantic saury fisheries in the Nova Scotia portion of the southern Gulf of St. Lawrence. DFO Can. Sci. Advis. Secr. Sci. Advis. Rep. 2009/081.

DFO. 2011. Ecologically and Biologically Significant Areas – Lessons Learned. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/049.

DFO. 2013a. Recovery potential assessment of American eel (*Anguilla rostrata*) in eastern Canada. DFO Can. Sci. Advis. Secr. Sci. Advis. Rep. 2013/078.

DFO. 2013b. Stock assessment of Atlantic halibut of the Gulf of St. Lawrence (NAFO Divisions 4RST) for 2011 and 2012. DFO Can. Sci. Advis. Secr. Sci. Advis. Rep. 2013/033.

DFO. 2014a. Recreational fishery catches, spawner abundance, and biological characteristics of striped bass (*Morone saxatilis*) in the southern Gulf of St. Lawrence in 2013. DFO Can. Sci. Advis. Secr. Sci. Resp. 2014/015.

DFO. 2014b. Assessment of the Atlantic Mackerel stock for the Northwest Atlantic (Subareas 3 and 4) in 2013. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/030.

DFO. 2015. Proceedings of the zonal peer review meeting on the identification of Ecologically and Biologically Significant Areas (EBSAs) in the coastal zone of the Estuary and Gulf of St. Lawrence, December 16-17, 2014. DFO Can. Sci. Advis. Sec., Proceed. Ser. 2015/053.

Douglas, S.G., Chaput, G., Hayward, J., and Sheasgreen, J. 2009. Prespawning, spawning, and postspawning behavior of Striped Bass in the Miramichi River. T. Am. Fish. Soc. 138: 121-134.

Dutil, J.-D., Proulx, S.P. Galbraith, S., Chassé, J., Lambert, N., and Laurian, C. 2012. Coastal and epipelagic habitats of the Gulf of St. Lawrence. Can. Tech. Rep. Fish. Aquat. Sci. 3009: ix + 87 p.

Forbes, D.L., Parkes, G.S., Manson, G.K., and Ketch, L.A. 2004. Storms and shoreline retreat in the southern Gulf of St. Lawrence. Mar. Geol. 210: 169-204.

Gilbert, D., and Pettigrew, B. 1997. Interannual variability (1984-1994) of the CIL core temperature in the Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 54 (Suppl. 1): 57–67.

Green J.M., Martel G., and Martin, D.W. 1984. Comparisons of the feeding activity and diets of male and female cunners *Tautogolabrus adspersus* (Pisces: Labridae). Marine Biology 84: 7-11.

Hanson, J.M. 1996. Seasonal distribution of juvenile Atlantic cod in the southern Gulf of St. Lawrence. J. Fish Biol. 49: 1138-1152.

Hanson, J.M. 2011. Ontogenetic diet comparison of Atlantic cod and white hake during a period of historically low population abundances. Trans. Am. Fish. Soc. 140:1070-1077.

Hanson, J.M., and Courtenay, S.C. 1995. Seasonal abundance and distribution of fishes in the Miramichi Estuary. p. 141-160. In E. M. P. Chadwick [ed.]. Water, science, and the public: the Miramichi ecosystem. Can. Spec. Publ. Fish. Aquat. Sci. 123.

Hanson, J.M., and Courtenay, S.C. 1996. Seasonal use of estuaries by winter flounder in the southern Gulf of St. Lawrence. Trans. Am. Fish. Soc. 125: 705-718.

Hanson, J.M., and Wilson, T. 2014. Abundance, distribution, and diet of a small-bodied ecotype of windowpane flounder. Trans. Am. Fish. Soc. 143: 650-659.

Hanson, J.M., Comeau, M., and Rondeau, A. 2014. Atlantic rock crab, unlike American lobster, is important to ecosystem functioning in Northumberland Strait. Trans. Am. Fish. Soc. 143: 1266-1279.

Hurlbut, T., and Clay, D. 1990 Protocols for research vessel cruises within the Gulf Region (demersal fish) (1970-1987). Can. Man. Rep. Fish. Aquat. Sci. 2082: 1–143.

Johansen, F. 1925. Natural history of the cunner. Contributions to Canadian Biology and Fisheries 17: 425-467.

Kelly, J.T., and Hanson, J.M. 2013a. Maturity, size-at-age, and predator-prey relationships of winter skate (*Leucoraja ocellata*) in the southern Gulf of St. Lawrence: potentially an undescribed endemic species facing extinction. J. Fish Biol. 82: 959-978.

Kelly, J.T., and Hanson, J.M. 2013b. Abundance, distribution, and habitat characteristics of winter skate (*Leucoraja ocellata*) in the southern Gulf of St. Lawrence: a population on the brink of extirpation? J. Fish Biol. 82: 877-892.

LeBlanc, C.H., Mello, L., and Dupuis, H.M.C. 1998. Juvenile Atlantic herring 1991 to 1995 December bottom-trawl survey results in the southern Gulf of St. Lawrence. Can. Tech. Rep. Fish. Aquat. Sci. 2244. iv + 45 p.

McQuinn, I.H., Bourassa, M.-N., Tounois, C., Gregoire, F., and Baril, D. 2012. Ecologically and biologically significant areas in the Estuary and Gulf of St. Lawrence: small pelagic fishes. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/087.

Messieh, S.N. 1987. Some characteristics of Atlantic herring (*Clupea harengus*) spawning in the southern Gulf of St. Lawrence. NAFO Science Council Studies 11: 53-61.

Prinsenberg, S.J., van der Baaren, A., and Peterson, I.K. 2006. Ice ridging and ice drift in southern Gulf of St. Lawrence, Canada, during winter storms. Annals of Glaciology 44: 411-417.

Robinson, M., Courtenay, S., Benfey, T., Maceda, L., and Wirgin, I. 2004. Origin and movements of young-of-the-year striped bass in the southern Gulf of St. Lawrence, New Brunswick. Trans. Am. Fish. Soc. 133: 412-426.

Rondeau, A., Hanson, J.M., and Comeau, M. 2014. Rock crab, *Cancer irroratus*, fishery and stock status in the southern Gulf of St. Lawrence: LFA 23, 24, 25, 26A and 26B. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/032. vi + 52 p.

Savenkoff, C., Bourassa, M.-N., Baril, D., and Benoît, H.P. 2007. Identification of Ecologically and Biologically Significant Areas in the Estuary and Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec., Res. Doc. 2007/015.

Savoie, L. 2014a. Preliminary results from the September 2012 and 2013 bottom-trawl surveys of the southern Gulf of St. Lawrence and comparisons with previous 1971 to 2011 surveys. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/053. v + 127 p.

Savoie, L. 2014b. Results from the 2012 and 2013 sentinel bottom-trawl surveys in the southern Gulf of St. Lawrence and comparisons with previous 2003 to 2011 surveys. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/054: v + 63 p.

Scott, W.B., and Scott, M.G. 1988. Atlantic Fishes of Canada. Canadian Bulletin of Fisheries and Aquatic Sciences 219.

Swain, D.P., and Benoît, H.P. 2007. Ecologically and biologically significant areas for demersal fishes in the southern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/012.

Swain, D.P., Chouinard, G.A., Morin, R., and Drinkwater, K.F. 1998. Seasonal variation in the habitat associayions of Atlantic cod (*Gadus morhua*) and American plaice (*Hippoglossoides platessoides*) from the southern Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 55: 2548-2561.

Swain, D.P., Hurlbut, T.R., and Benoît, H.P. 2012. Pre-COSEWIC review of variation in the abundance, distribution and productivity of white hake (*Urophycis tenuis*) in the southern Gulf of St. Lawrence, 1971-2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/066.

Vanderlaan, A.S.M., Hanke, A.R., Chasse, J., and Neilson, J.D. 2014. Environmental influences on Atlantic bluefin tuna (*Thunnus thynnus*) catch per unit effort in the southern Gulf of St. Lawrence. Fish. Oceanogr. 23: 83-100.

Voutier, J.L., and Hanson, J.M. 2008. Abundance, distribution, and feeding of a disjunct population of lady crab in the southern Gulf of St. Lawrence. Aquat. Ecol. 42: 43-60.

## TABLES

*Table 1. Fish species or group of species considered for modeling.*

| Common name | Scientific name |
|---|---|
| Gaspereau | *Alosa pseudoharengus, A. aestivalis* |
| American plaice | *Hippoglossoides platessoides* |
| American shad | *Alosa sapidissima* |
| Atlantic cod | *Gadus morhua* |
| Atlantic halibut | *Hippoglossus hippoglossus* |
| Atlantic herring | *Clupea harengus* |
| Atlantic mackerel | *Scomber scombrus* |
| Atlantic tomcod | *Microgadus tomcod* |
| Butterfish | *Peprilus triacanthus* |
| Capelin | *Mallotus villosus* |
| Cunner | *Tautoglabrus adspersus* |
| Daubed shanny | *Leptoclinus maculatus* |
| Fourbeard rockling | *Enchelyopus cimbrius* |
| Greenland cod | *Gadus ogac* |
| Grubby | *Myoxocephalus aenaeus* |
| Longhorn sculpin | *Myoxocephalus octodecemspinosus* |
| Lumpfish | *Cyclopterus lumpus* |
| Northern sandlance | *Ammodytes sp.* |
| Ocean pout | *Zoarces americanus* |
| Rainbow smelt | *Osmerus mordax* |
| Rock gunnel | *Pholis gunnelus* |
| Sea raven | *Hemitripterus americanus* |
| Shorthorn sculpin | *Myoxocephalus scorpius* |
| Snakeblenny | *Lumpenus lampretaeformis* |
| Spiny dogfish | *Squalus acanthias* |
| Threespine stickleback | *Gasterosteus aculeatus* |
| White hake | *Urophycis tenuis* |
| Windowpane | *Scophthalmus aquosus* |
| Winter flounder | *Pseudopleuronectes americanus* |
| Winter skate | *Leucoraja c.f. ocellata* |
| Wrymouth | *Cryptacanthodes maculatus* |
| Yellowtail flounder | *Limanda ferruginea* |

*Table 2. Invertebrate species and taxa considered for modeling.*

| Taxon or species | Scientific name | Phylum | RV data |
|---|---|---|---|
| American lobster | *Homarus americanus* | Arthropoda | 1989-2013 |
| Atlantic rock crab | *Cancer irroratus* | Arthropoda | 1989-2013 |
| Lady crab | *Ovalipes c.f. ocellatus* | Arthropoda | NA |
| Mud crab | *Dyspanopeus sayi* | Arthropoda | NA |
| *Pagurus* | *Pagurus sp.* | Arthropoda | 1989-2013 |
| Toad crab | *Hyas sp.* | Arthropoda | 1989-2013 |
| Sea strawberries | *Gersemia sp.* | Cnidaria | 2003-2013 |
| *Asterias* | *Asterias sp.* | Echinodermata | 2004-2013 |
| Blood star | *Henricia sp.* | Echinodermata | 1989-2013 |
| Brittle star | *Ophiuroidea* | Echinodermata | 1989-2013 |
| *Leptasterias polaris* | *Leptasterias polaris* | Echinodermata | 2004-2013 |
| Purple sunstar | *Solaster endeca* | Echinodermata | 2005-2013 |
| Sand dollars | *Echinarachnius parma* | Echinodermata | 1989-2013 |
| Scarlet psolus | *Psolus fabricii* | Echinodermata | 1995-2013 |
| Sea cucumber | *Cucumaria frondosa* | Echinodermata | 1989-2013 |
| Sea urchins | *Strongylocantrotus sp.* | Echinodermata | 1989-2013 |
| Spiny sunstar | *Crossaster papposus* | Echinodermata | 2005-2013 |
| Mussels | *Mytilus edulis* | Mollusca | 1989-2013 |
| Northern moonsnail | *Euspira eros* | Mollusca | 1989-2013 |
| Ocean quahaug | *Arctica islandica* | Mollusca | 1989-2013 |
| Sea scallop | *Placopecten magellanicus* | Mollusca | 1989-2013 |
| Sea slugs | *Nudibranchia* | Mollusca | 2002-2013 |
| Whelks | *Buccinum sp.* | Mollusca | 1989-2013 |

*Table 3. Test taxa included in the model selection process for selecting the most common best fitting model to be applied to the whole taxa list.*

| Fish species | Invertebrates species |
|---|---|
| Alewife | American lobster |
| American plaice | Atlantic rock crab |
| Atlantic cod | Lady crab |
| Atlantic herring | Sea scallop |
| Rainbow smelt | Snow crab |
| Winter flounder | Toad crab |
| Winter skate | |
| Yellowtail flounder | |

*Table 4. List of species that have been evaluated by the Committee on the Status of Endangered Wildlife in Canada with their status and year of assessment. Species and populations listed under the Species At Risk Act (SARA) are identified. Species for which trawl-survey data were available to this study are underlined.*

| Common name | Scientific name | Status | Year of assessment |
|---|---|---|---|
| American eel | *Anguilla rostrata* | Threatened | 2012 |
| <u>American plaice</u> | *Hippoglossoides platessoides* | Threatened | 2009 |
| <u>Atlantic cod</u> | *Gadus morhua* | Endangered | 2010 |
| Atlantic salmon | *Salmo salar* | Special concern | 2010 |
| Atlantic wolffish | *Anarhichas lupus* | SARA - Special concern | 2003 |
| Bluefin tuna | *Thunnus thynnus* | Endangered | 2011 |
| <u>Spiny dogfish</u> | *Squalus acanthias* | Special concern | 2010 |
| Striped bass | *Morone saxatilis* | Special concern | 2012 |
| Thorny skate | *Amblyraja radiata* | Special concern | 2012 |
| <u>White hake</u> | *Urophycis tenuis* | Endangered | 2013 |
| White shark | *Carcharodon carcharias* | SARA – Endangered<br>Atlantic population | 2006 |
| <u>Winter skate</u> | *Leucoraja ocellata* | Endangered | 2005 |

*Table 5. Comparison of the Ecologically and Biologically Significant Areas (EBSA) and important areas (IA) within the southern Gulf of St. Lawrence (sGSL). EBSA locations (as indicated in Figure 5) are based on DFO (CSAS 2007/016), Swain and Benoît (CSAS 2007/012) and McQuinn et al. (CSAS 2012/087), and possible coastal IA based on fish and invertebrate species are from the present study. NB = New Brunswick; PEI = Prince Edward Island.*

| Locations | Coastal IA | CSAS 2007/016 | status | CSAS 2007/012 | status | CSAS 2012/087 | status |
|---|---|---|---|---|---|---|---|
| Northumberland Strait | yes | part of EBSA 3 | High | IA 3 (part) | High | IA 7, 9, 24 | High |
| St. George’s Bay | yes | EBSA 2 | High | IA 2 | High | IA 7, 9, 24 | High |
| East PEI | yes | Part of EBSA 1 | High | None | Low | IA 9, 24 (part) | High |
| West of Cape Breton | no | Part of EBSA 1 | High | IA 1 (part) | High | None | Low |
| Coastal Shediac Valley | no | Part of EBSA 5 | High | IA 5 | Moderate | IA 8, 23 and 1 (part) | High |
| Chaleurs Bay | no | Part of EBSA 5 | High | IA 7 | Low | IA 3, 12, 1 (part) | High |
| North PEI | no | None | Low | None | Low | IA 13 | Moderate |
| Magdalen Islands | no | None | Low | None | Low | None | Low |

# FIGURES

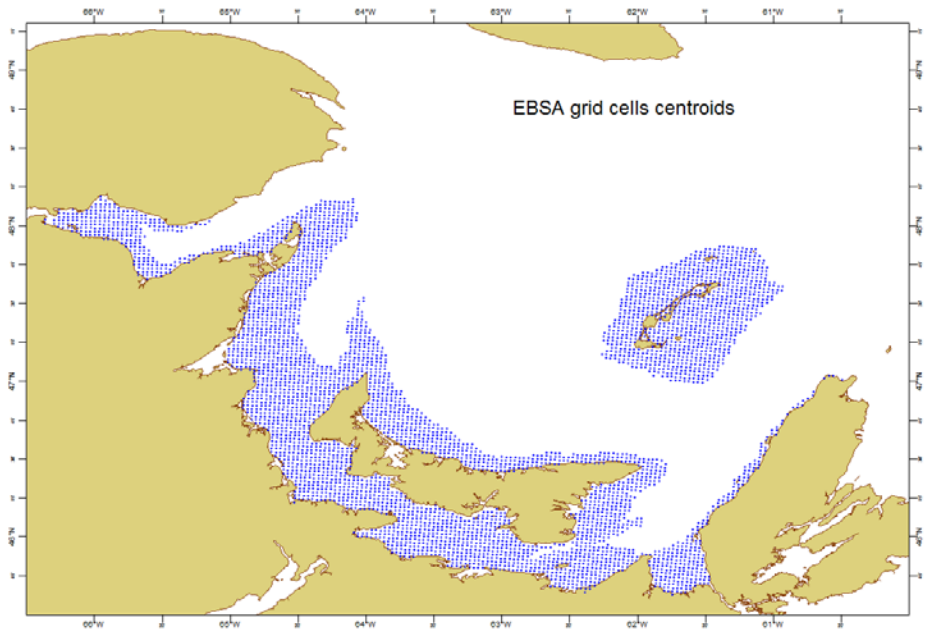



*Figure 1. Map of the southern Gulf of St. Lawrence with the cell grid centroids between 0 and 40 m water depth, excluding cells within estuaries and semi-enclosed embayments.*

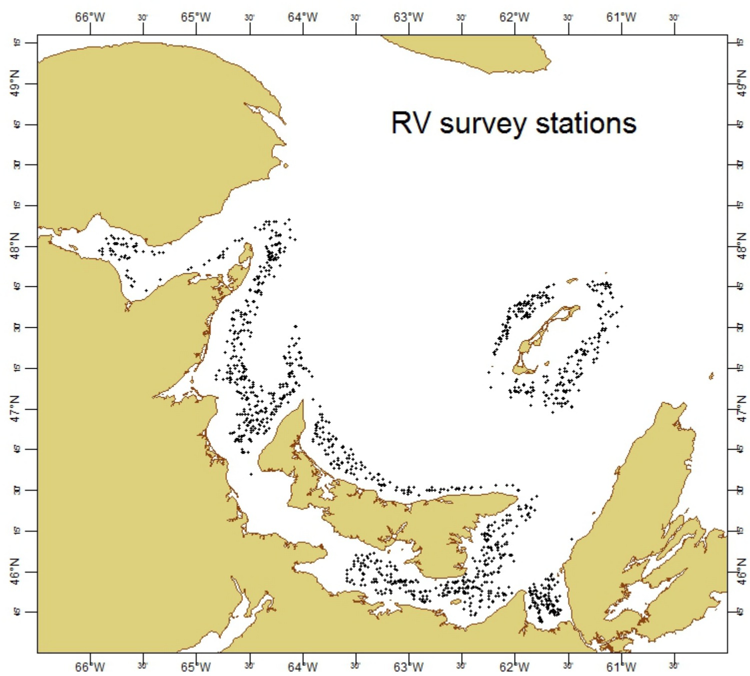



*Figure 2. Map of the southern Gulf of St. Lawrence with the annual September bottom trawl survey (RV survey) sampling stations between 0 and 40 m deep, 1976 - 2013. Mid-tow locations were used for plotting the stations.*

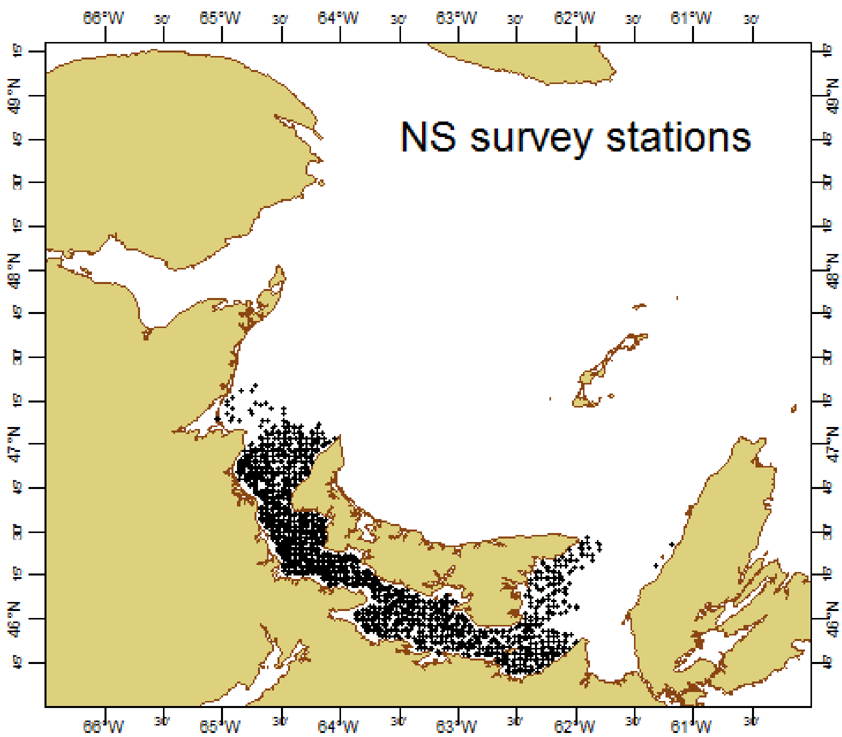



*Figure 3. Map of the southern Gulf of St. Lawrence with the annual Northumberland Strait bottom trawl survey (NS survey) sampling stations between 0 and 40 m deep, 2000 - 2013. Mid-tow locations were used for plotting the stations.*

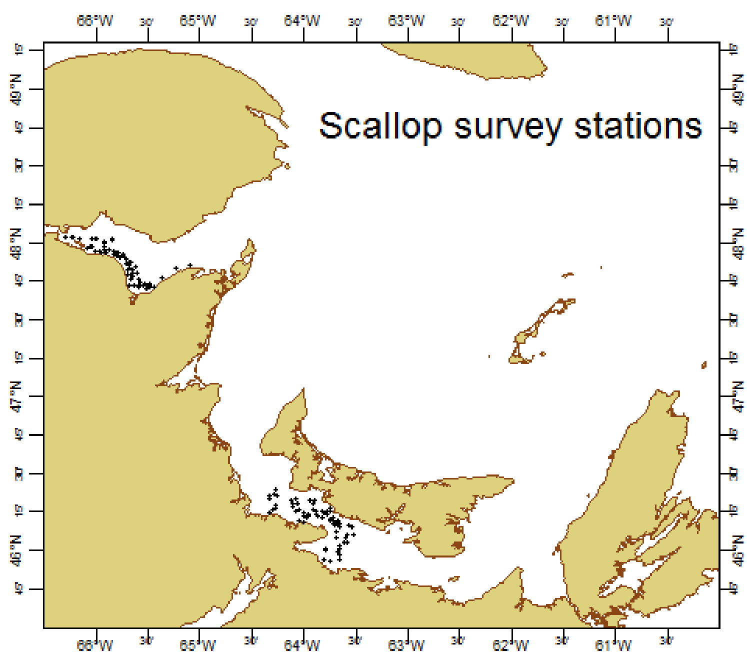



*Figure 4. Map of the southern Gulf of St. Lawrence with the scallop survey sampling stations between 0 and 40 m deep in 2012 and 2013. Mid-tow locations were used for plotting the stations.*

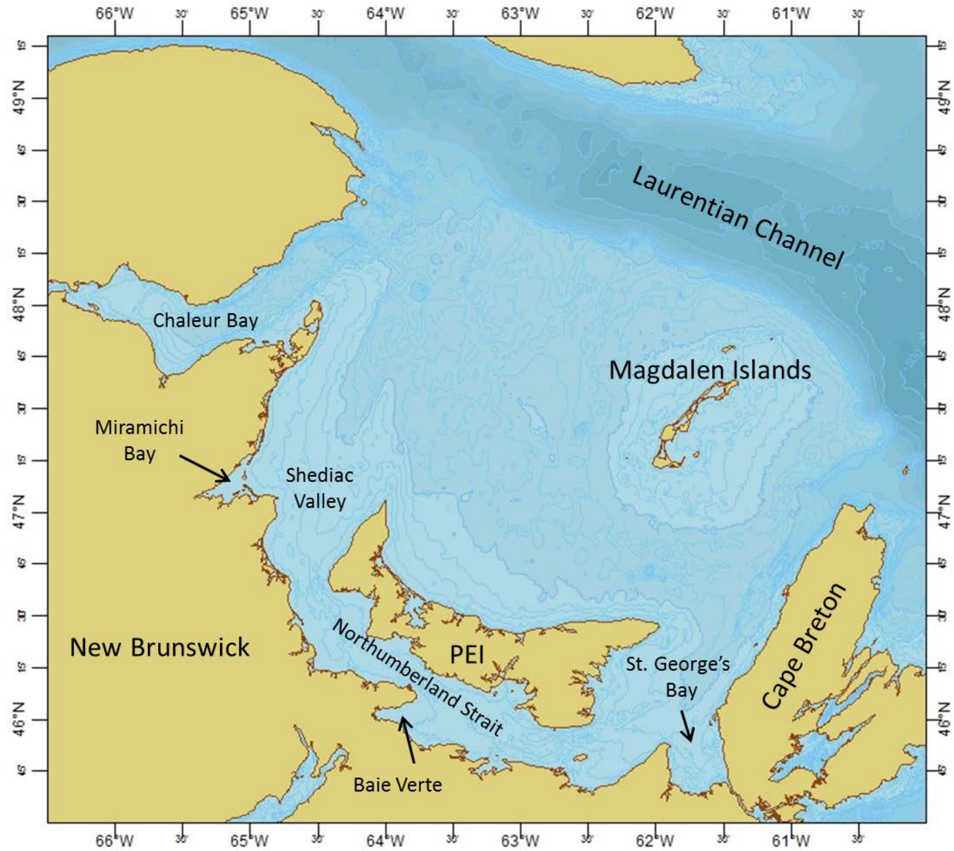



*Figure 5. Map of the southern Gulf of St. Lawrence with place names identified. (Prince Edward Island = PEI).*

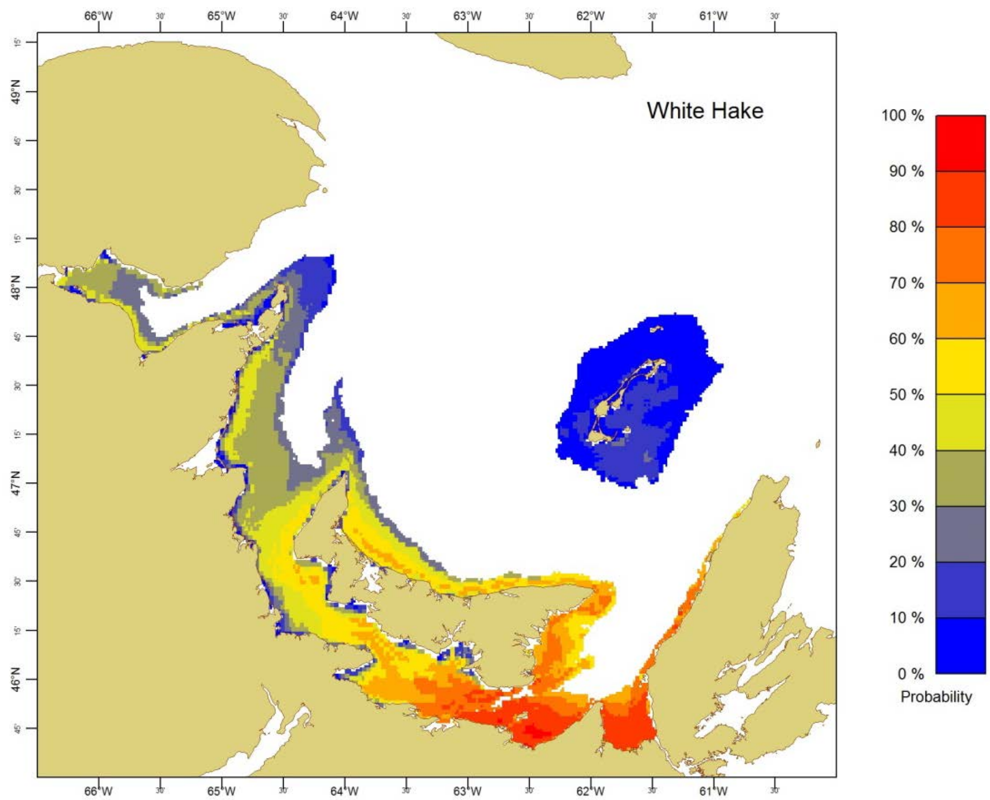



*Figure 6. Contour map showing the predicted probabilities of capturing white hake (Urophycis tenuis) during a standard tow, using a Western IIA bottom trawl.*

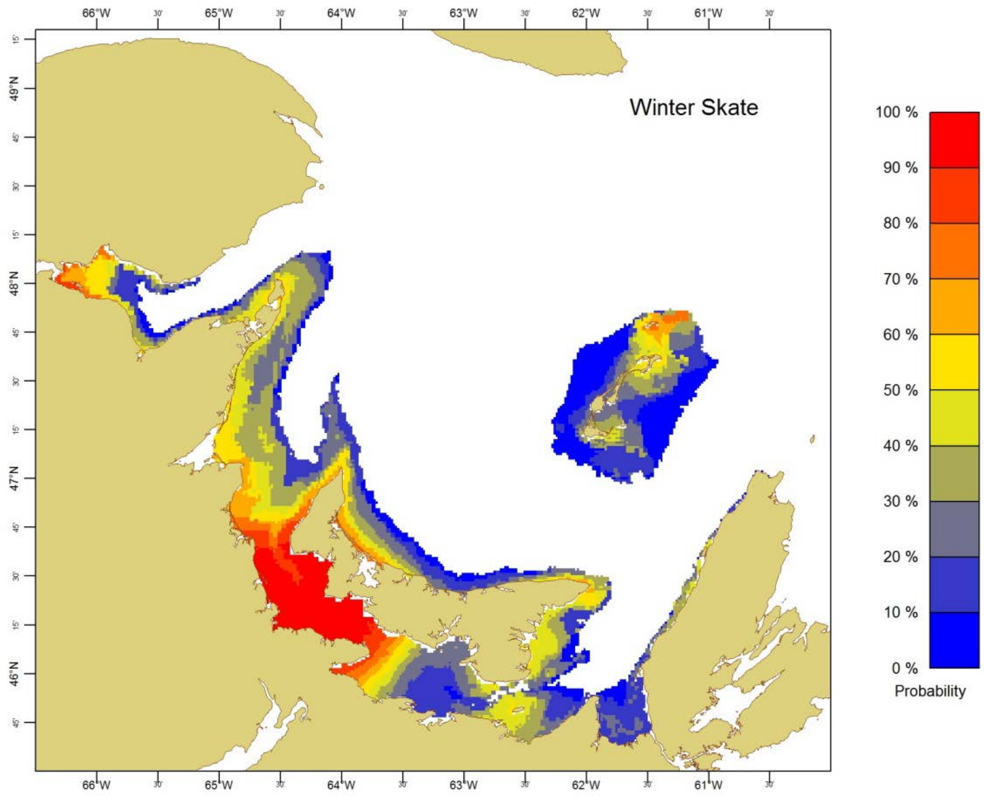



*Figure 7. Contour map showing the predicted probabilities of capturing winter skate (Leucoraja ocellata) during a standard tow, using a Western IIA bottom trawl.*

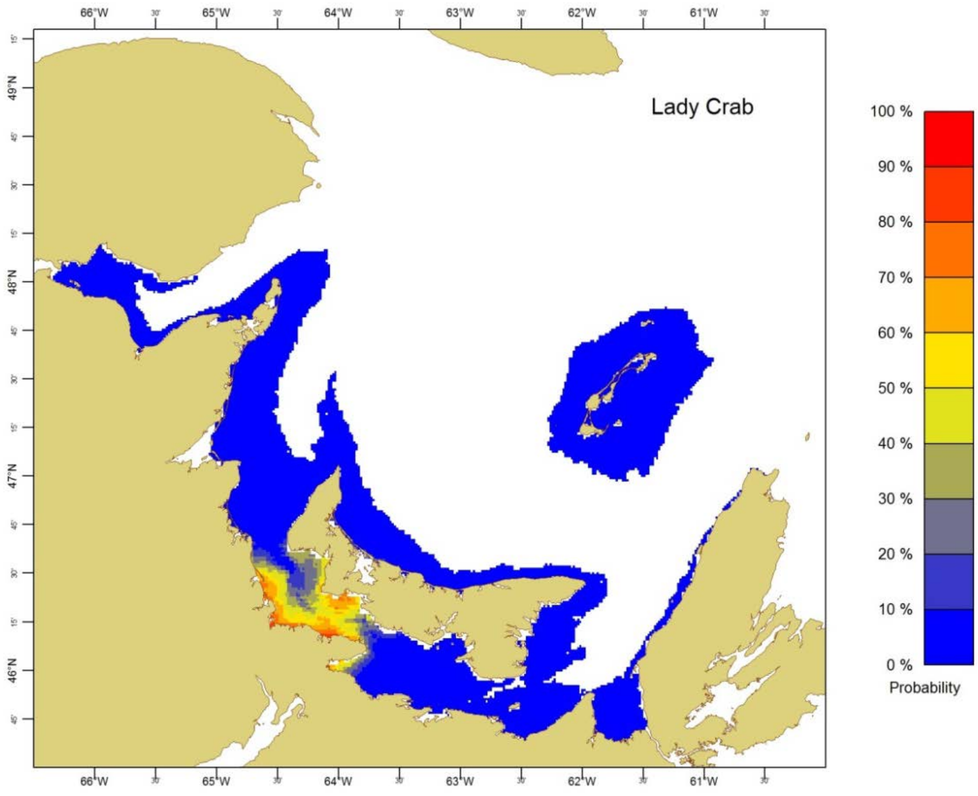



*Figure 8. Contour map showing the predicted probabilities of capturing lady crab (Ovalipes ocellatus) during a standard tow, using a Nephrops trawl.*

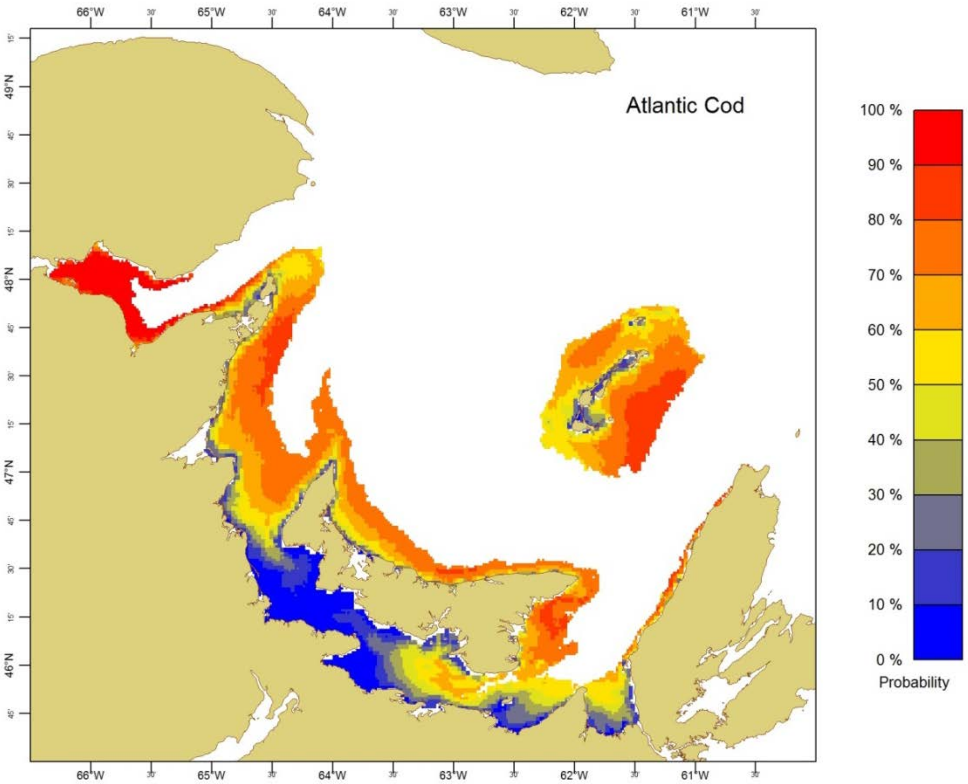



*Figure 9. Contour map showing the predicted probabilities of capturing Atlantic cod (Gadus morhua) during a standard tow, using a Western IIA bottom trawl.*

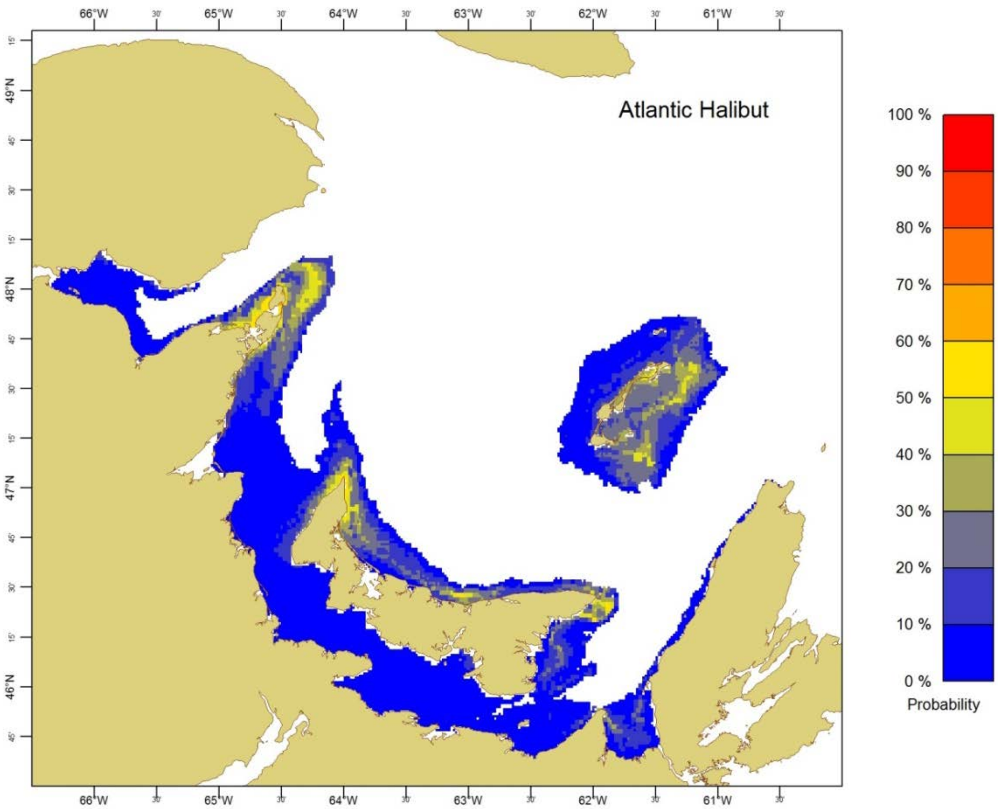



*Figure 10. Contour map showing the predicted probabilities of capturing Atlantic halibut (Hippoglossus hippoglossus) during a standard tow, using a Western IIA bottom trawl.*

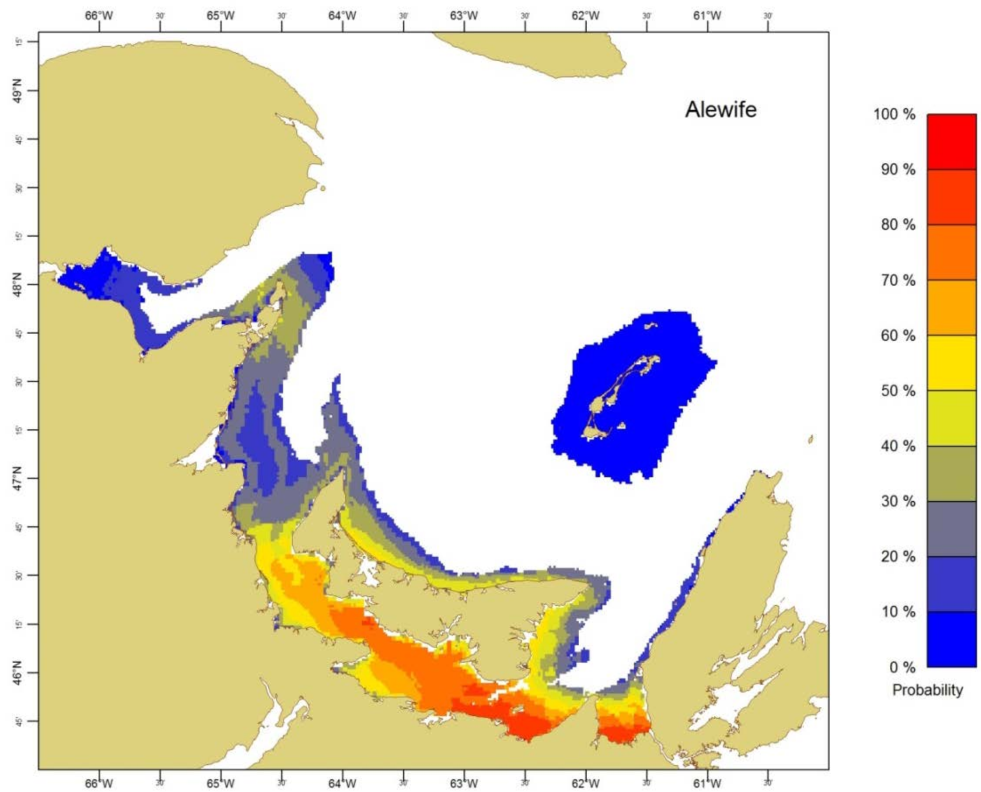



*Figure 11. Contour map showing the predicted probabilities of capturing Alewife (Alosa pseudoharengus) during a standard tow, using a Western IIA bottom trawl.*

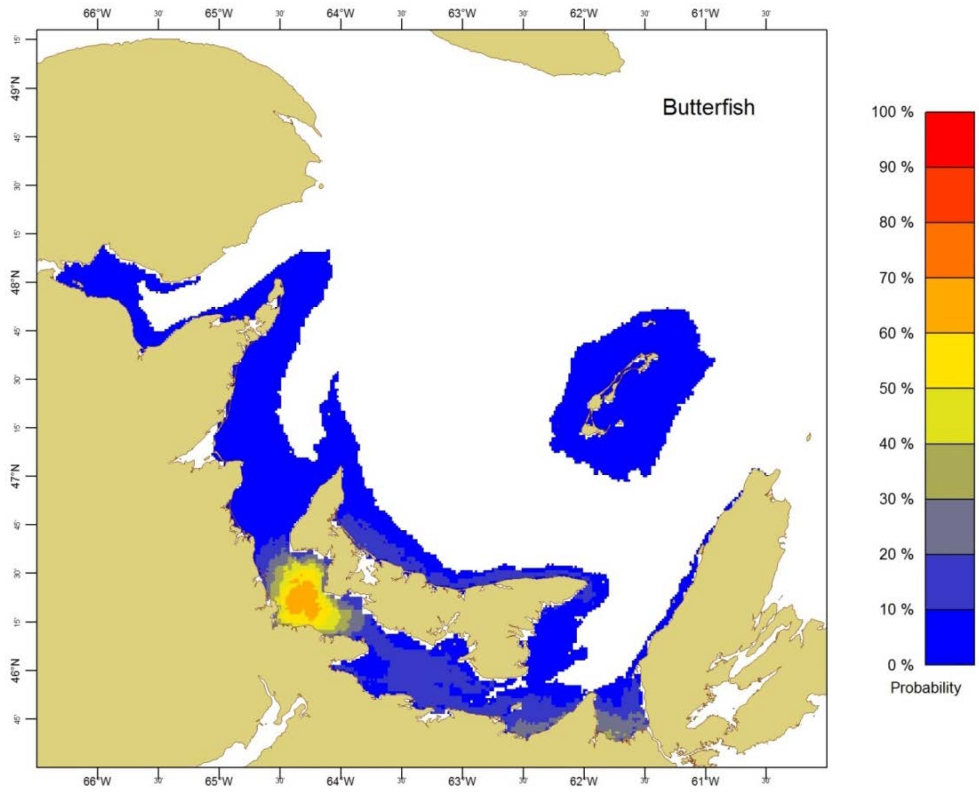



*Figure 12. Contour map showing the predicted probabilities of capturing Butterfish (Peprilus triacanthus) during a standard tow, using a Western IIA bottom trawl.*

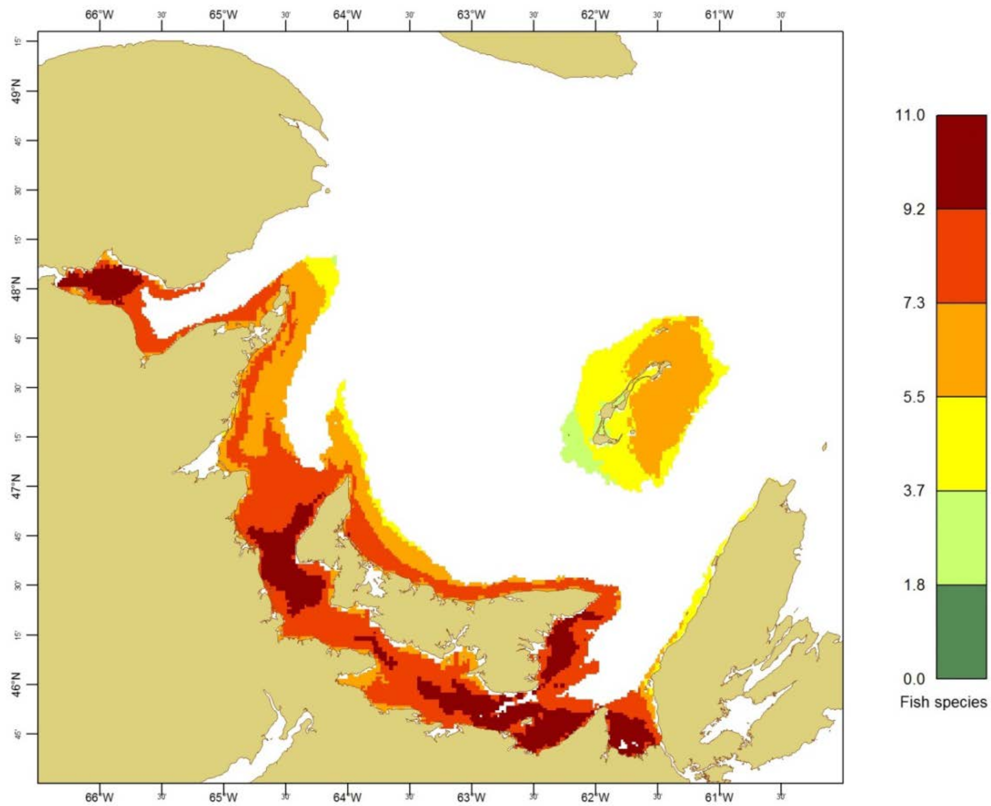



*Figure 13. Pseudo-diversity contour map based on the 32 fish species examined.*

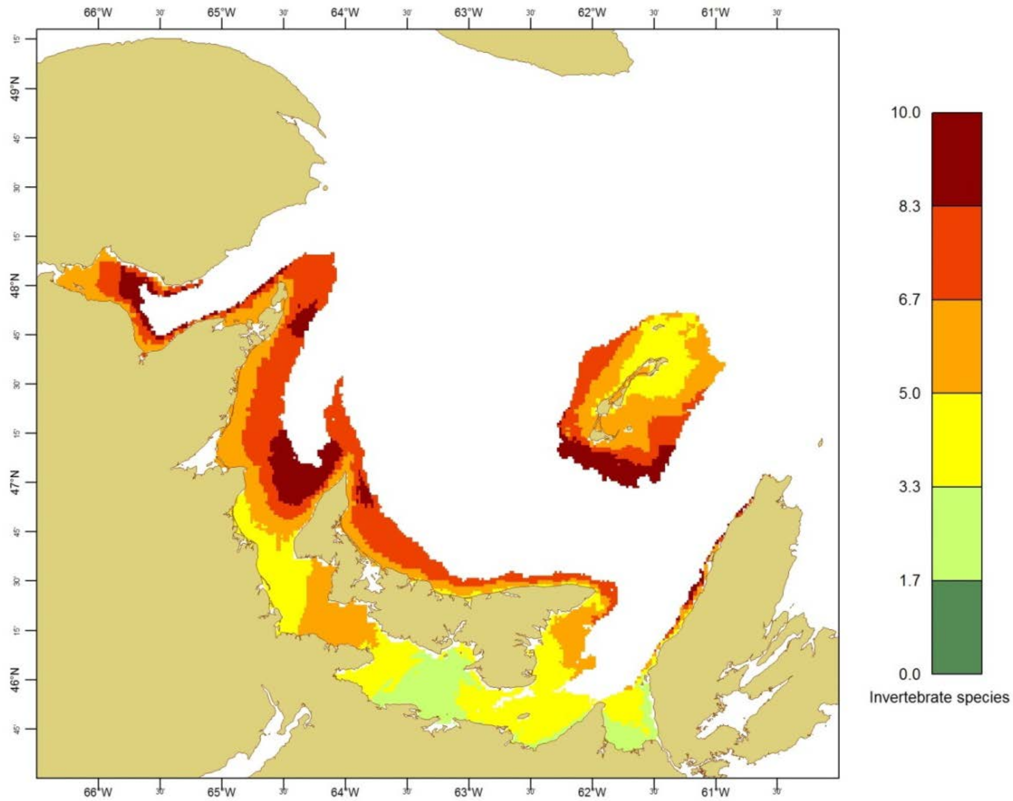



*Figure 14. Pseudo-diversity contour map based on the 23 invertebrate species examined.*

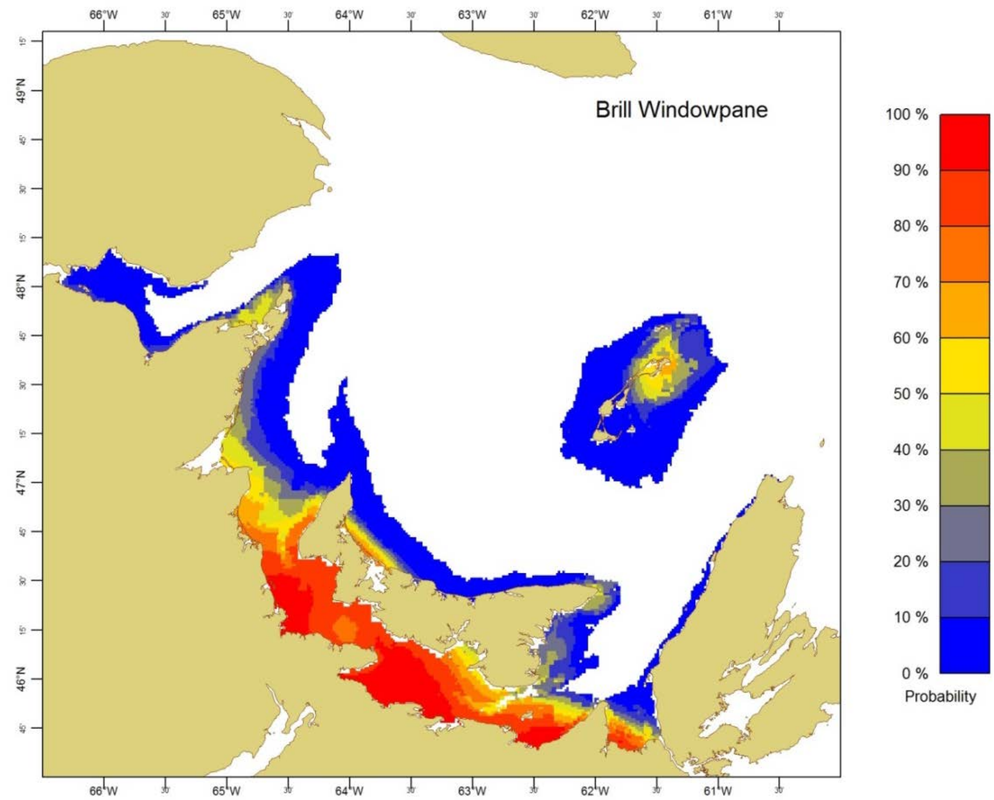



*Figure 15. Contour map showing the predicted probabilities of capturing windowpane (Scophthalmus aquosus) during a standard tow, using a Western IIA bottom trawl.*

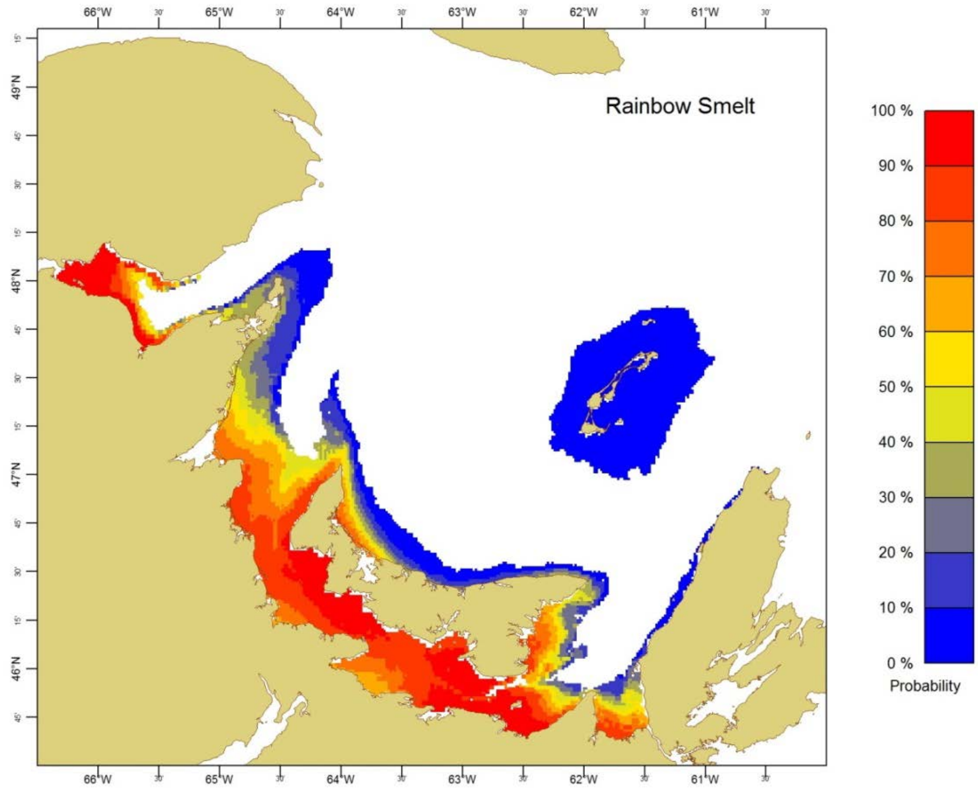



*Figure 16. Contour map showing the predicted probabilities of capturing rainbow smelt (Osmerus mordax) during a standard tow, using a Western IIA bottom trawl.*

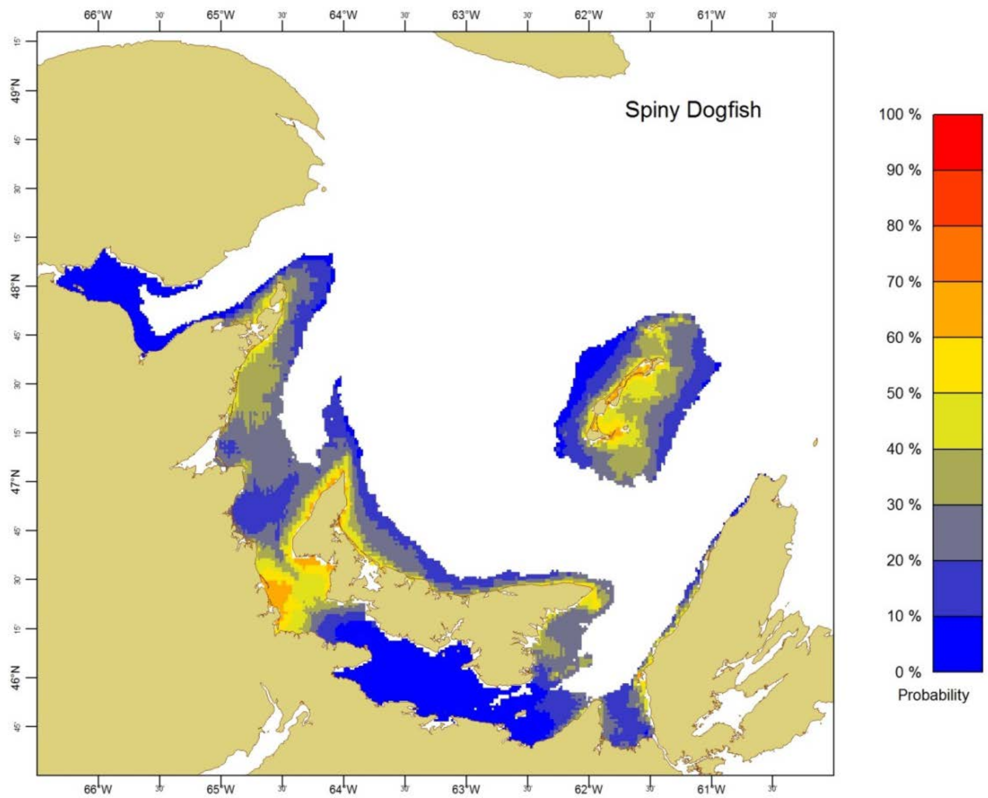



*Figure 17. Contour map showing the predicted probabilities of capturing spiny dogfish (Squalus acanthias) during a standard tow, using a Western IIA bottom trawl.*

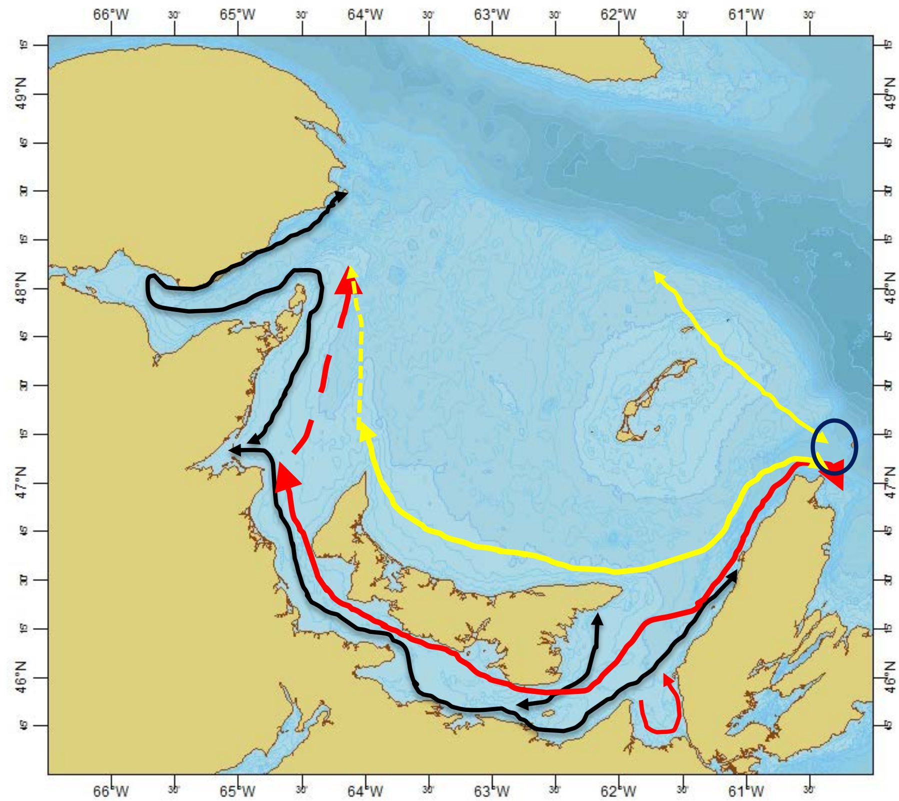
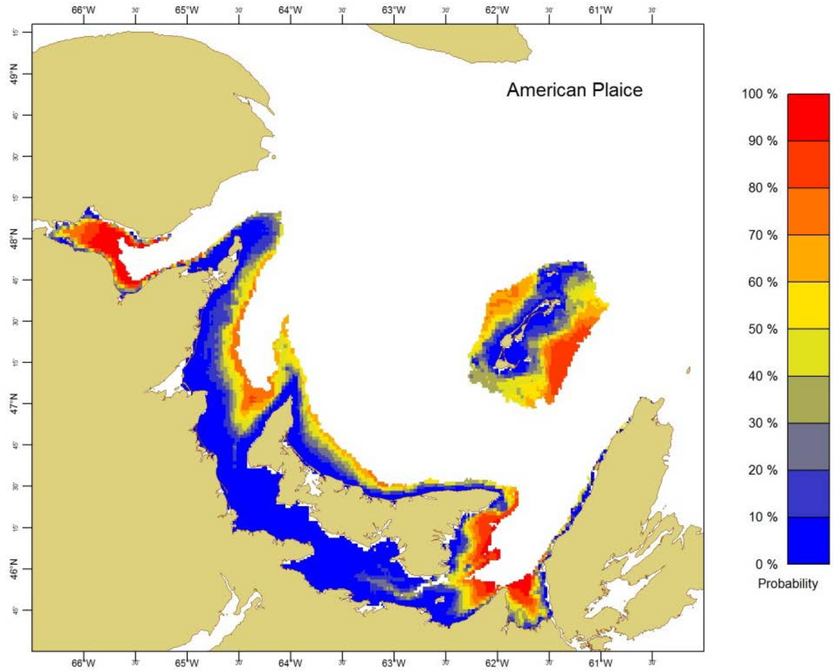


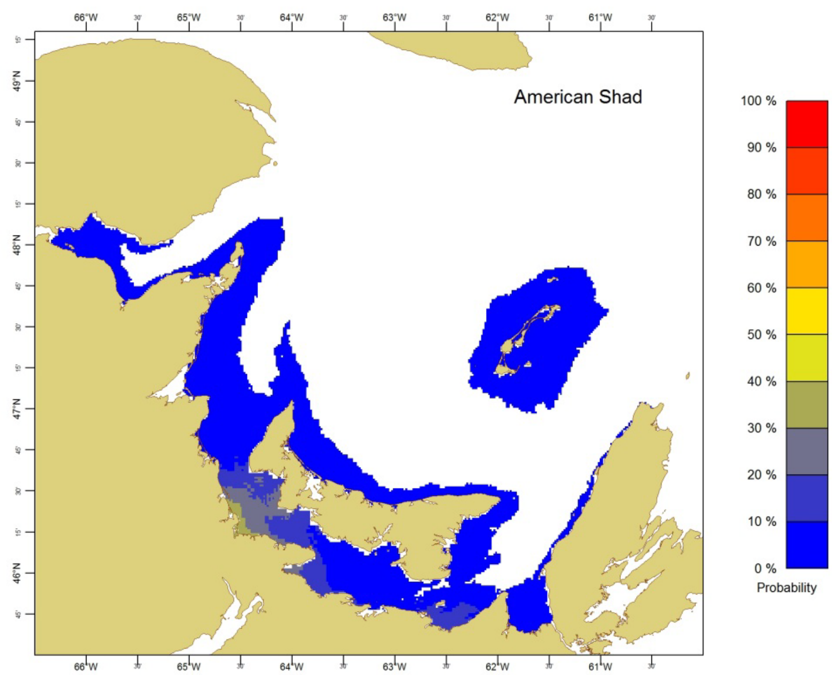

*Figure 18. Major migration corridors for striped bass (black) and long distance migrants (red and yellow) with the most important route for anadromous species shown in red. The choke point through which most species presumably pass to exit the Gulf of St. Lawrence (southern route) is indicated by a dark blue circle between the tip of Cape Breton and St. Paul Island. NB. Striped bass migrate very close to shore, usually within several hundred meters, but this could not be shown to scale.*

# APPENDICES

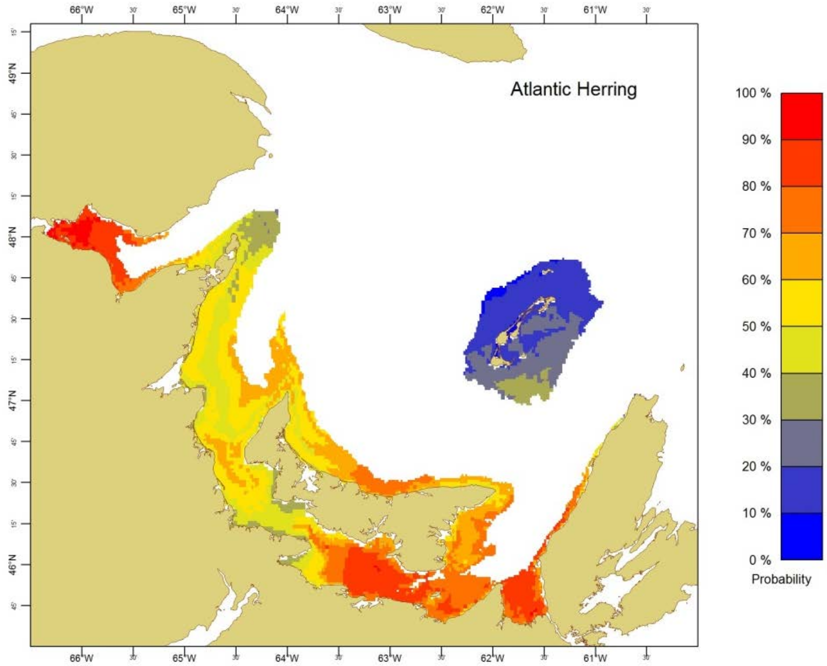
## APPENDIX 1: CONTOUR MAPS OF DISTRIBUTION OF FISH AND INVERTEBRATES SPECIES



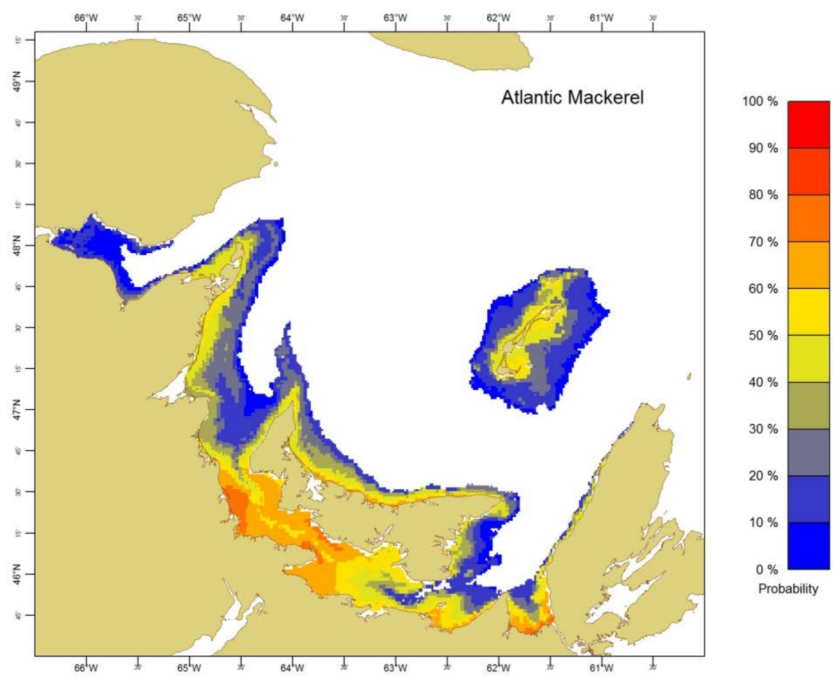

*Map 1. Contour map showing the predicted probabilities of capturing American plaice (Hippogloissoides platessoides) during a standard tow, using a Western IIA bottom trawl.*



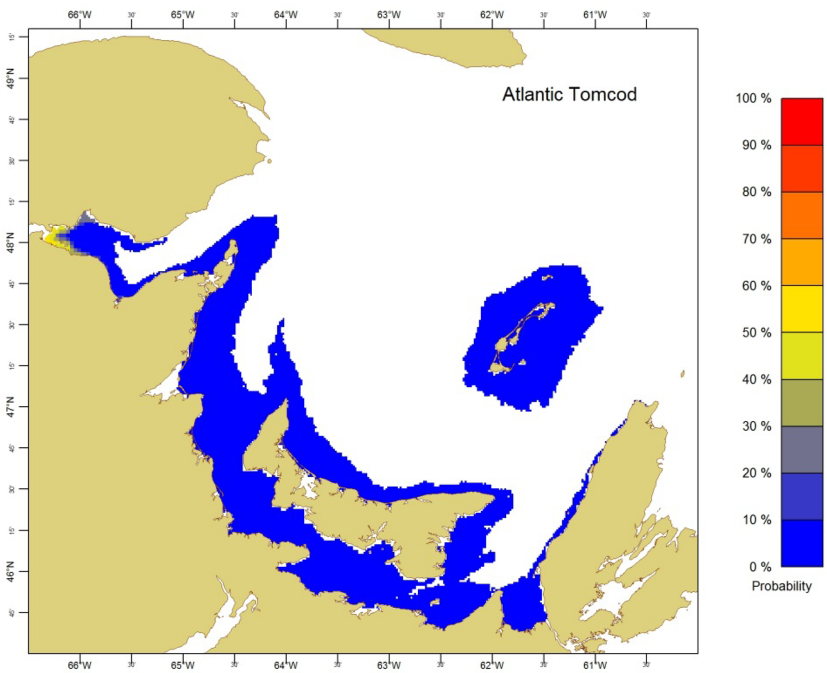

*Map 2. Contour map showing the predicted probabilities of capturing American shad (Alosa sapidissima) during a standard tow, using a Western IIA bottom trawl.*



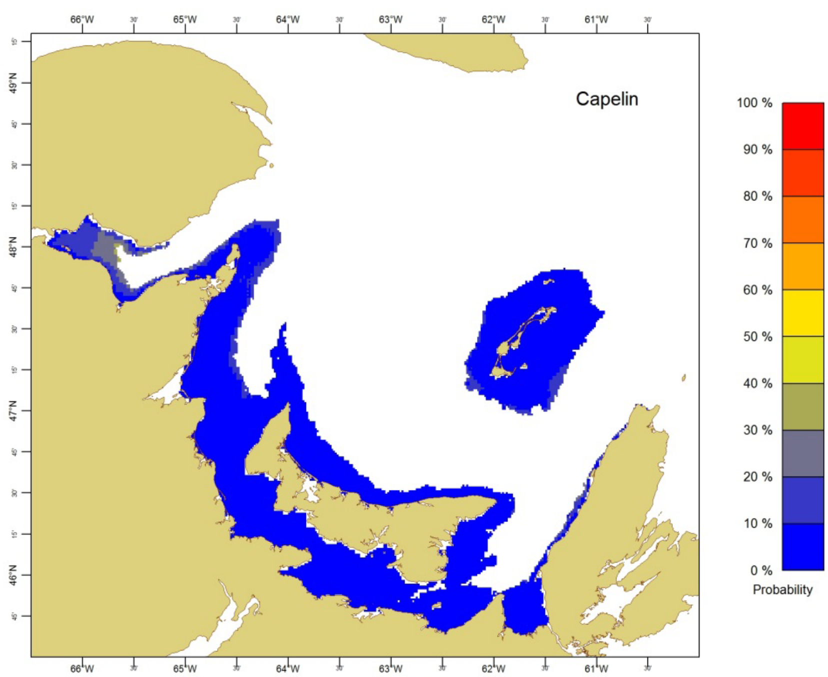

*Map 3. Contour map showing the predicted probabilities of capturing Atlantic herring (Clupea harengus) during a standard tow, using a Western IIA bottom trawl.*



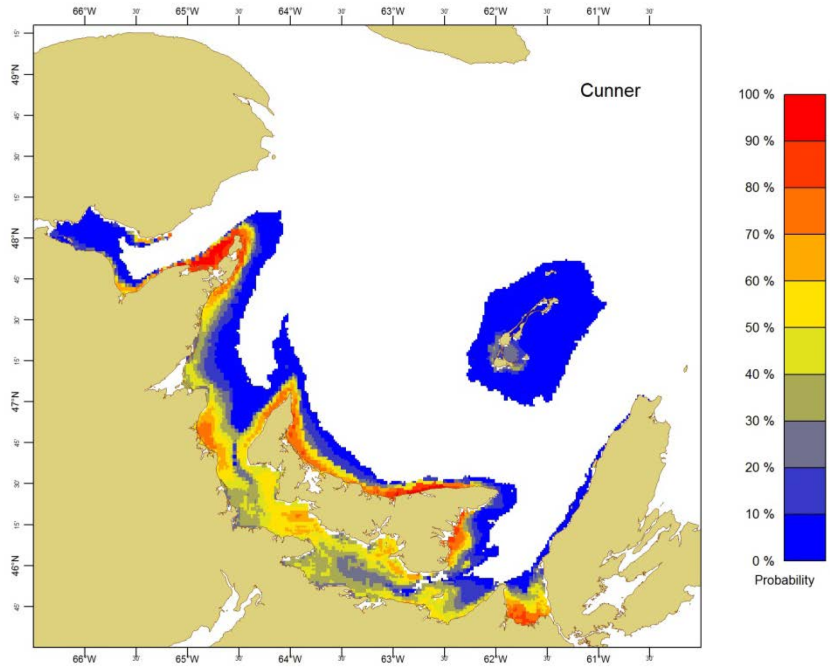

*Map 4. Contour map showing the predicted probabilities of capturing Atlantic mackerel (Scomber scombrus) during a standard tow, using a Western IIA bottom trawl.*



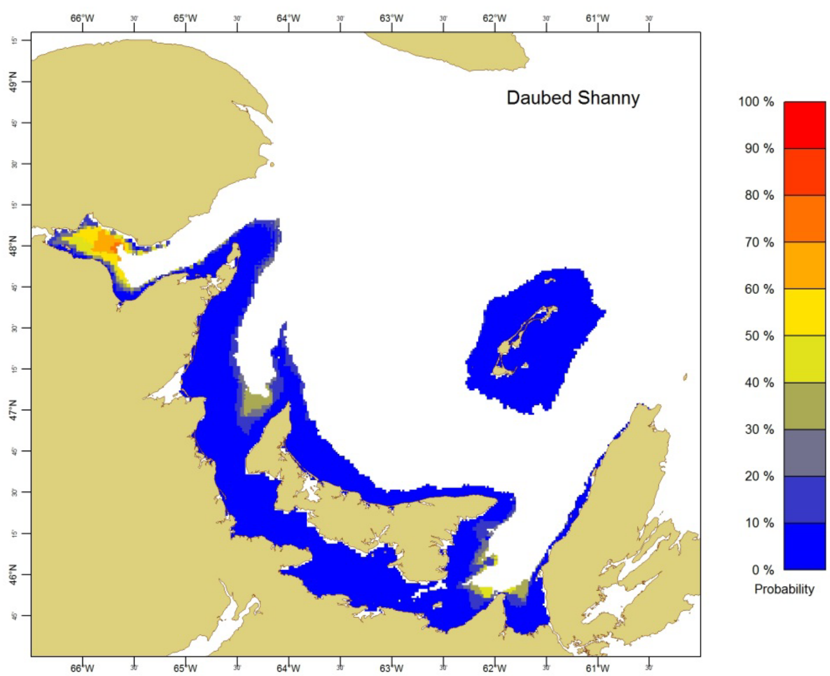

*Map 5. Contour map showing the predicted probabilities of capturing Atlantic tomcod (Microgadus tomcod) during a standard tow, using a Western IIA bottom trawl.*



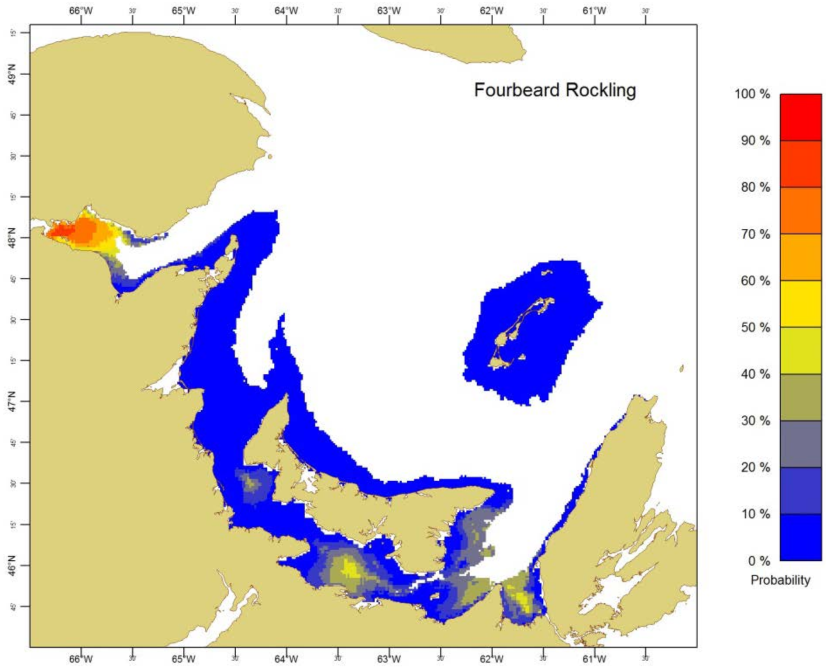

*Map 6. Contour map showing the predicted probabilities of capturing capelin (Mallotus villosus) during a standard tow, using a Western IIA bottom trawl.*



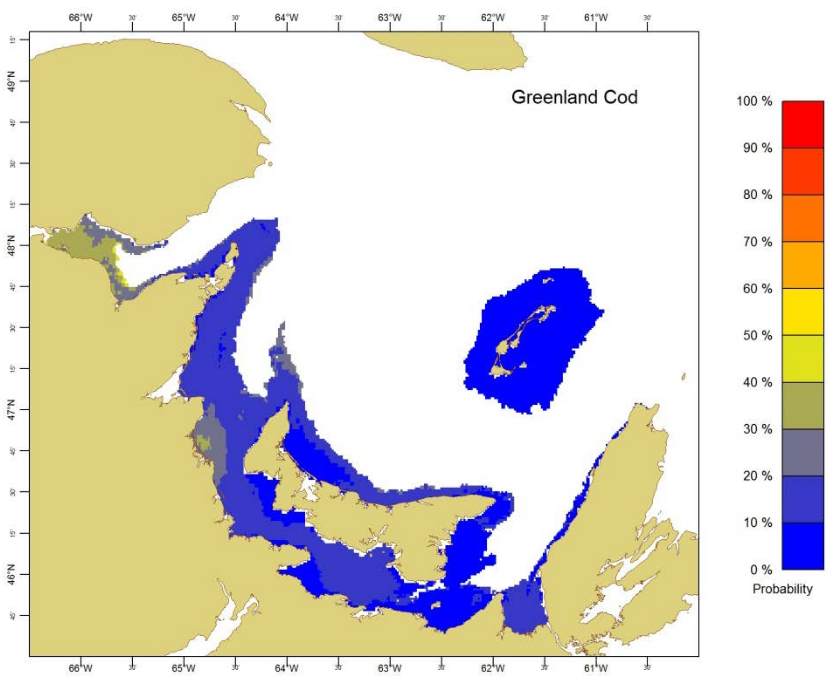

*Map 7. Contour map showing the predicted probabilities of capturing cunner (Tautoglabrus adspersus) during a standard tow, using a Western IIA bottom trawl.*



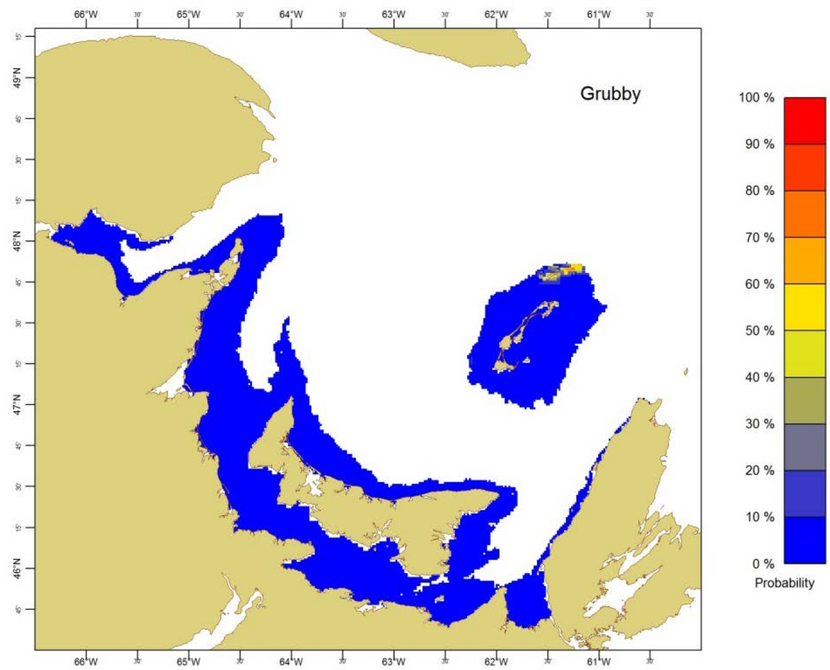

*Map 8. Contour map showing the predicted probabilities of capturing daubed shanny (Leptoclinus maculatus) during a standard tow, using a Western IIA bottom trawl.*



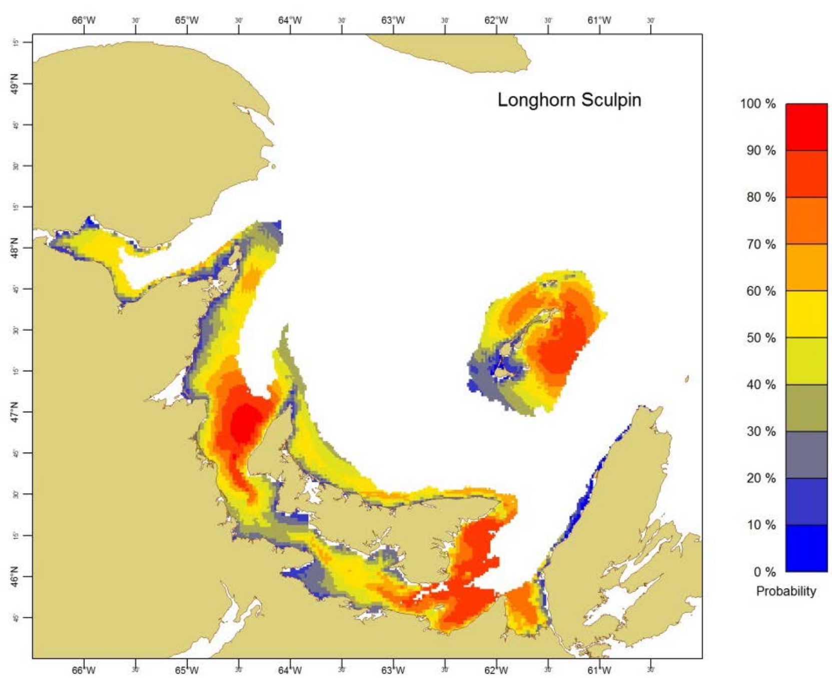

*Map 9. Contour map showing the predicted probabilities of capturing fourbeard rockling (Enchelyopus cimbrius) during a standard tow, using a Western IIA bottom trawl.*



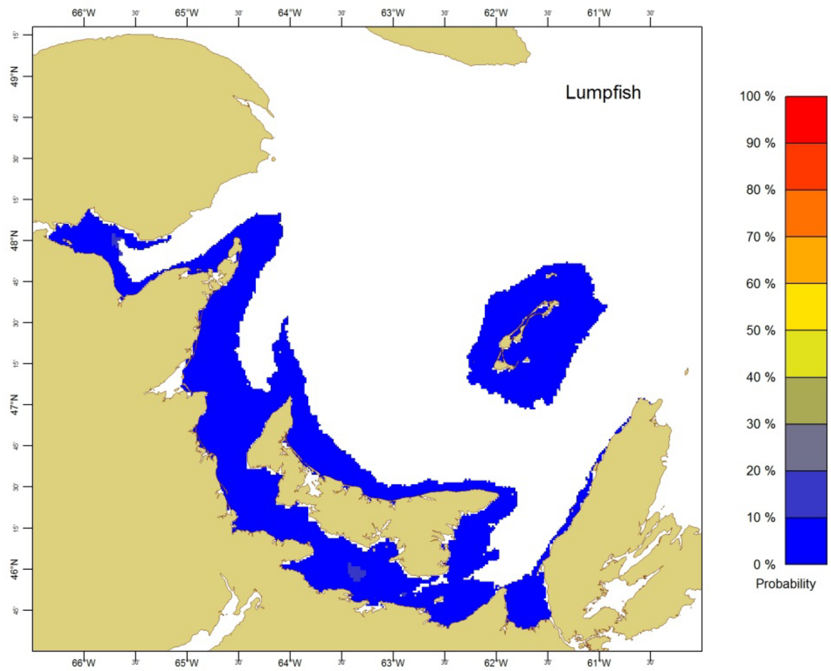

*Map 10. Contour map showing the predicted probabilities of capturing Greenland cod (Gadus ogac) during a standard tow, using a Western IIA bottom trawl.*



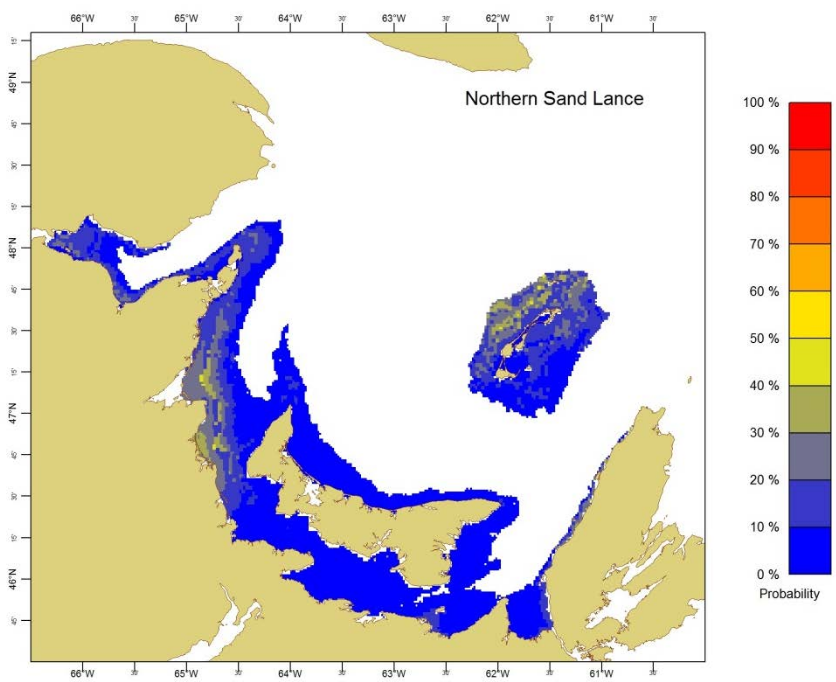

*Map 11. Contour map showing the predicted probabilities of capturing grubby (Myoxocephalus aenaeus) during a standard tow, using a Western IIA bottom trawl.*



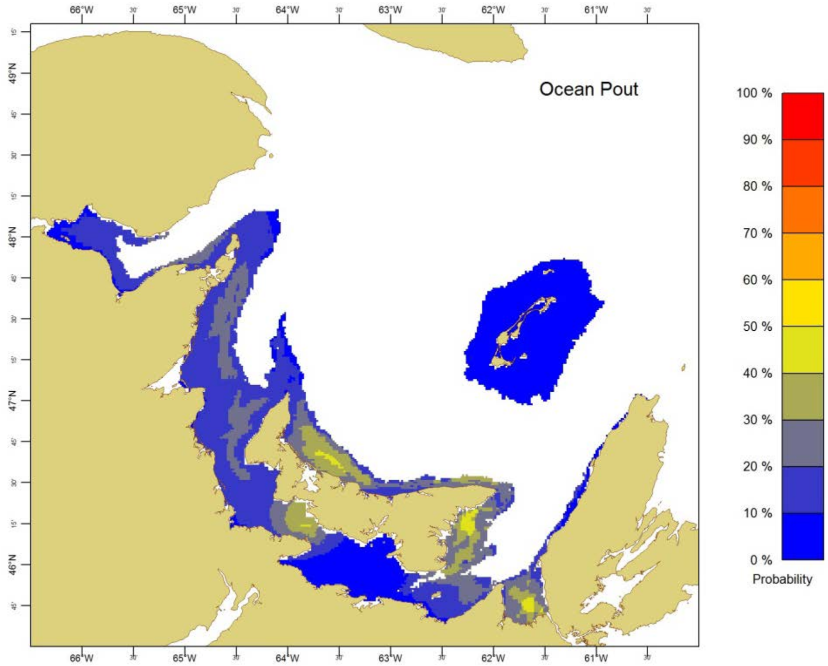

*Map 12. Contour map showing the predicted probabilities of capturing longhorn sculpin (Myoxocephalus octodecemspinosus) during a standard tow, using a Western IIA bottom trawl.*



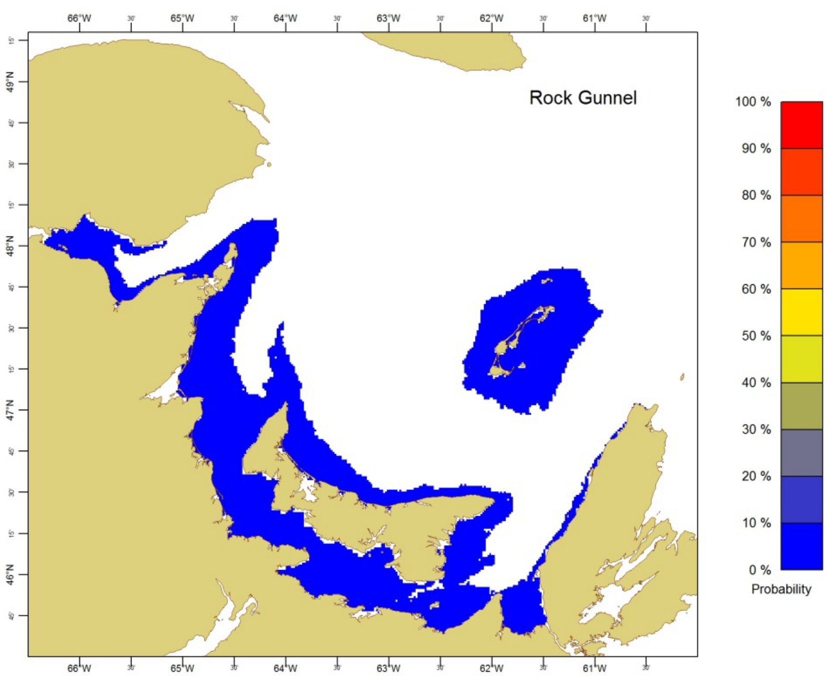

*Map 13. Contour map showing the predicted probabilities of capturing lumpfish (Cyclopterus lumpus) during a standard tow, using a Western IIA bottom trawl.*



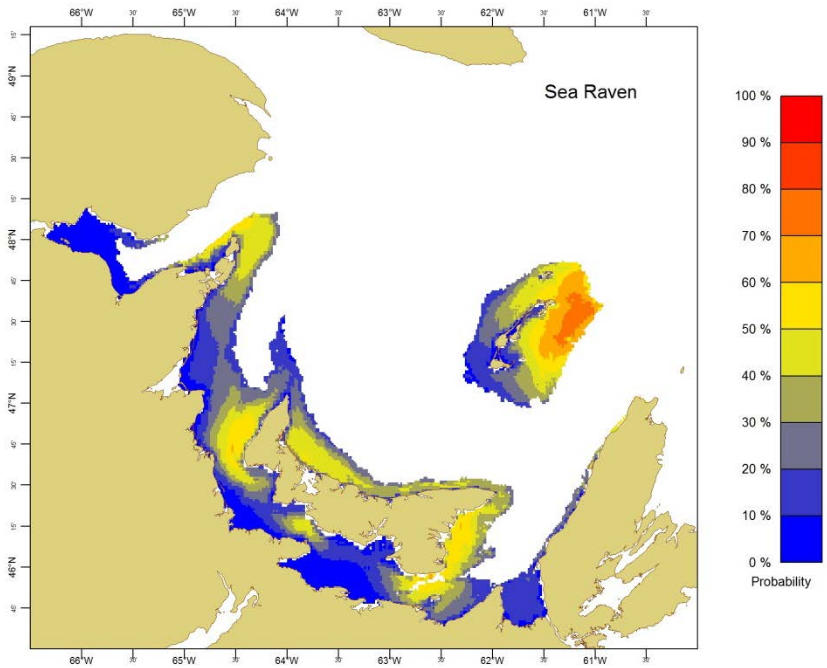

*Map 14. Contour map showing the predicted probabilities of capturing northern sand lance (Ammodytes sp.) during a standard tow, using a Western IIA bottom trawl.*



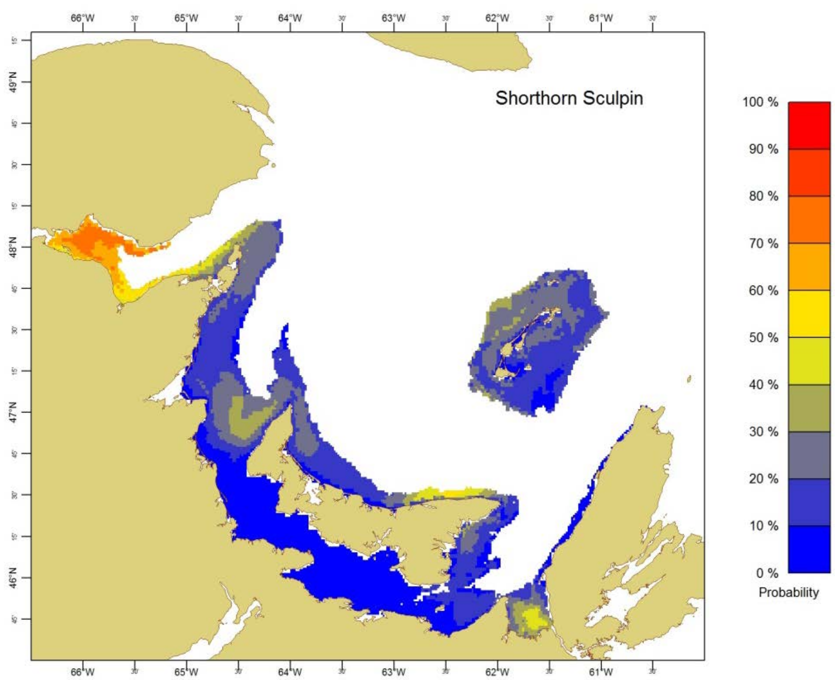

*Map 15. Contour map showing the predicted probabilities of capturing ocean pout (Zoarces americanus) during a standard tow, using a Western IIA bottom trawl.*



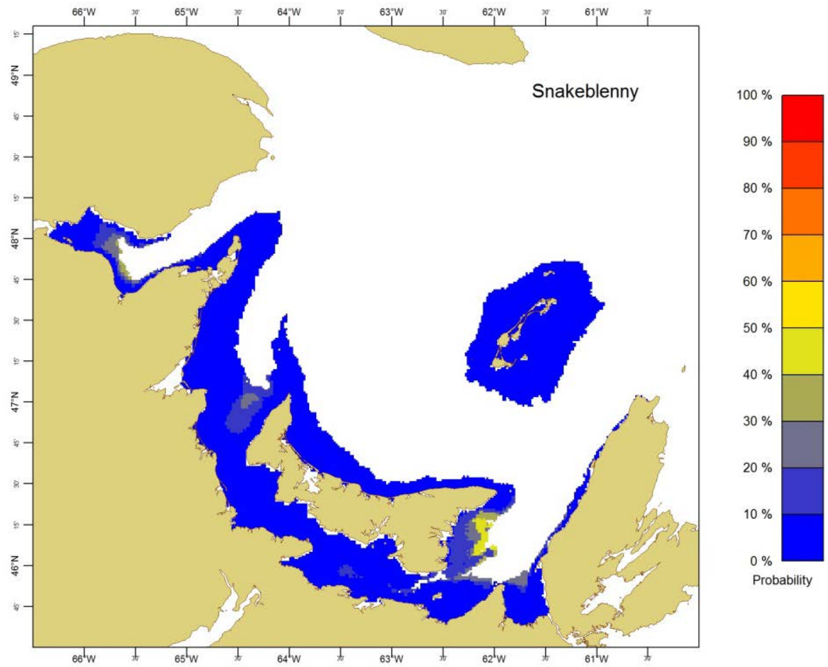

*Map 16. Contour map showing the predicted probabilities of capturing rock gunnel (Pholis gunnelus) during a standard tow, using a Western IIA bottom trawl.*



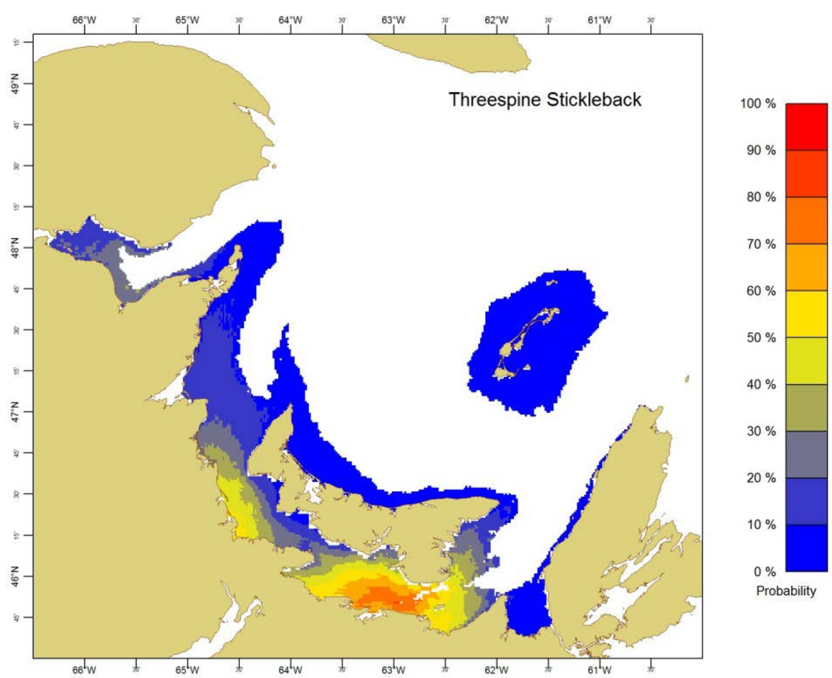

*Map 17. Contour map showing the predicted probabilities of capturing sea raven (Hemitripterus americanus) during a standard tow, using a Western IIA bottom trawl.*



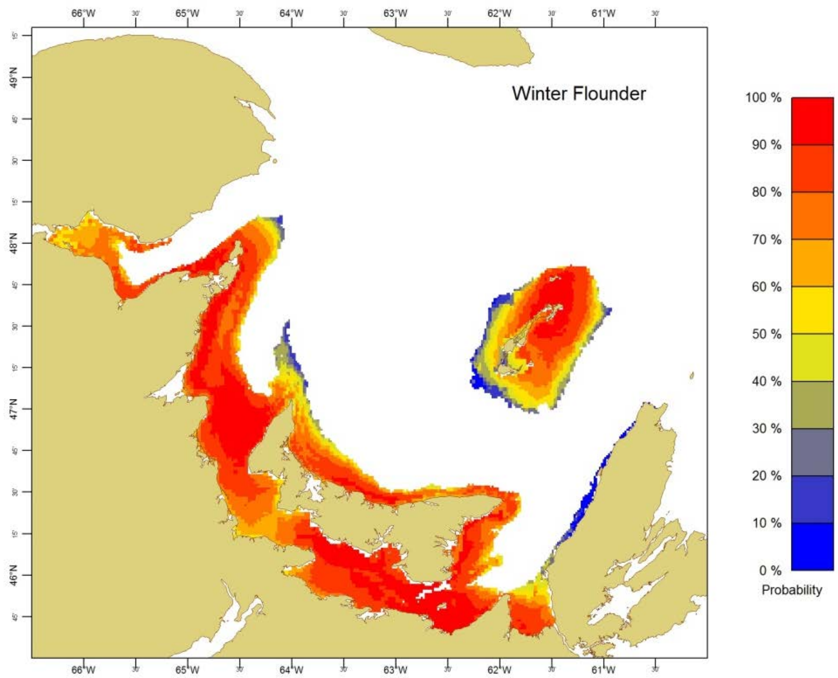

*Map 18. Contour map showing the predicted probabilities of capturing shorthorn sculpin (Myoxocephalus scorpius) during a standard tow, using a Western IIA bottom trawl.*



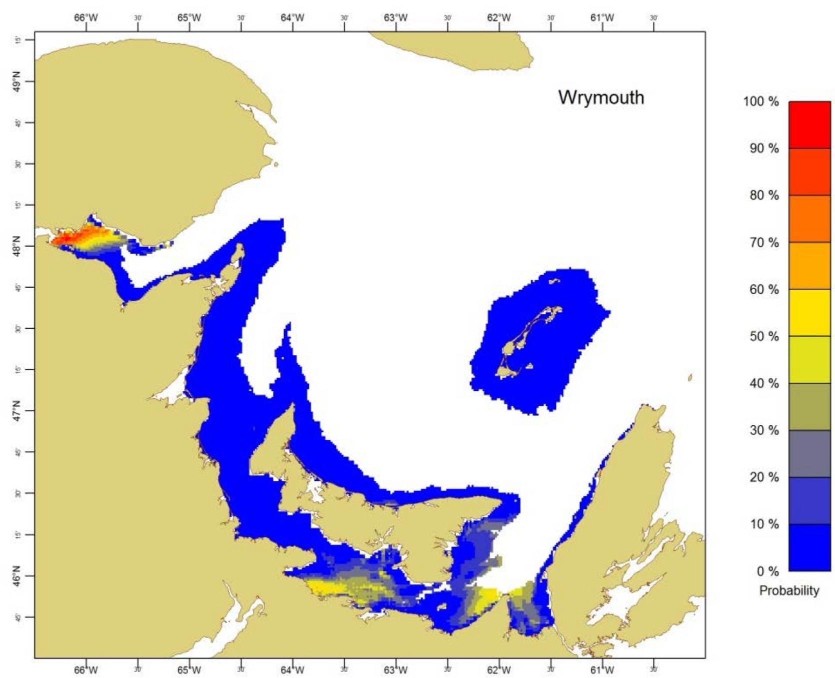

*Map 19. Contour map showing the predicted probabilities of capturing snakeblenny (Lumpenus lampretaeformis) during a standard tow, using a Western IIA bottom trawl.*



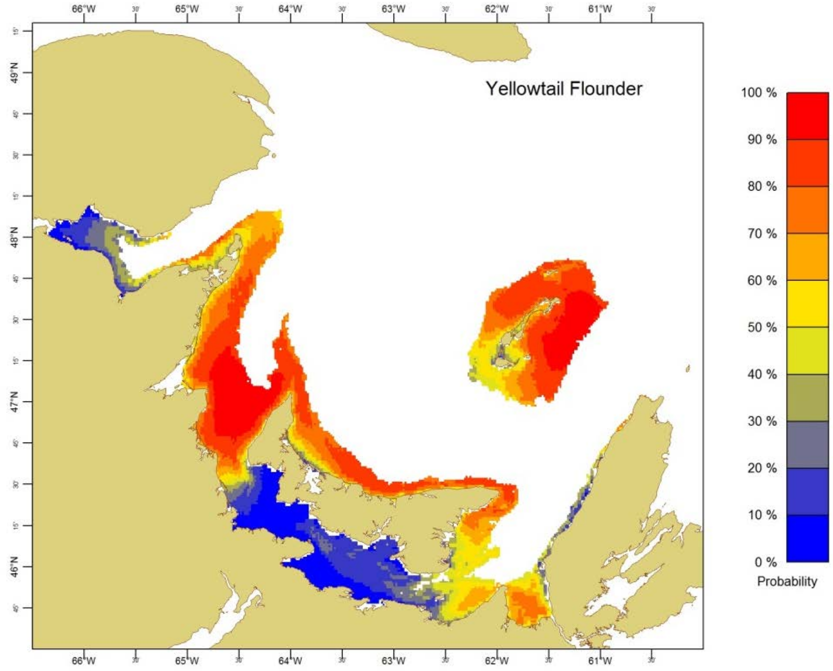

*Map 20. Contour map showing the predicted probabilities of capturing threespine stickleback (Gasterosteus aculeatus) during a standard tow, using a Western IIA bottom trawl.*



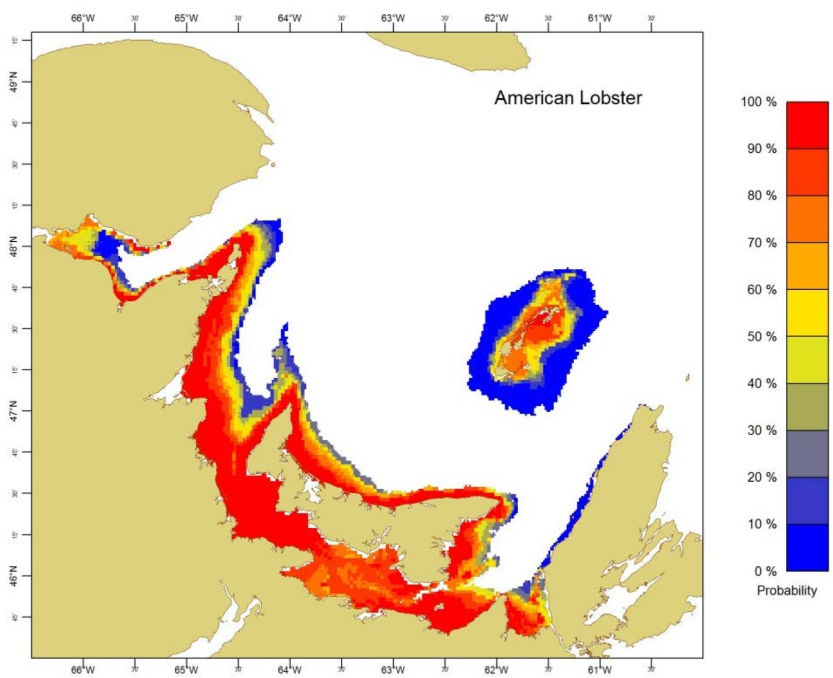

*Map 21. Contour map showing the predicted probabilities of capturing winter flounder (Pseudopleuronectes americanus) during a standard tow, using a Western IIA bottom trawl.*



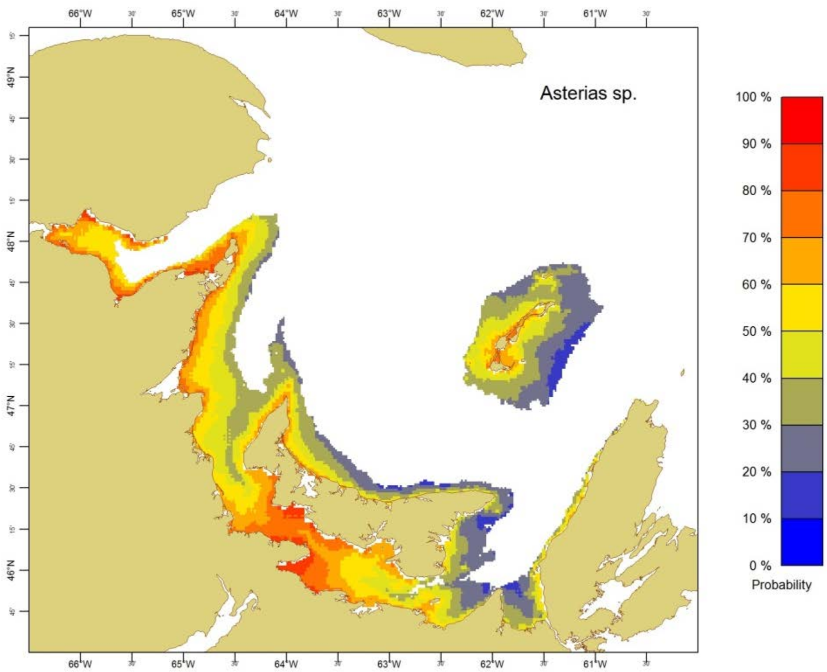

*Map 22. Contour map showing the predicted probabilities of capturing wrymouth (Cryptacanthodes maculatus) during a standard tow, using a Western IIA bottom trawl.*



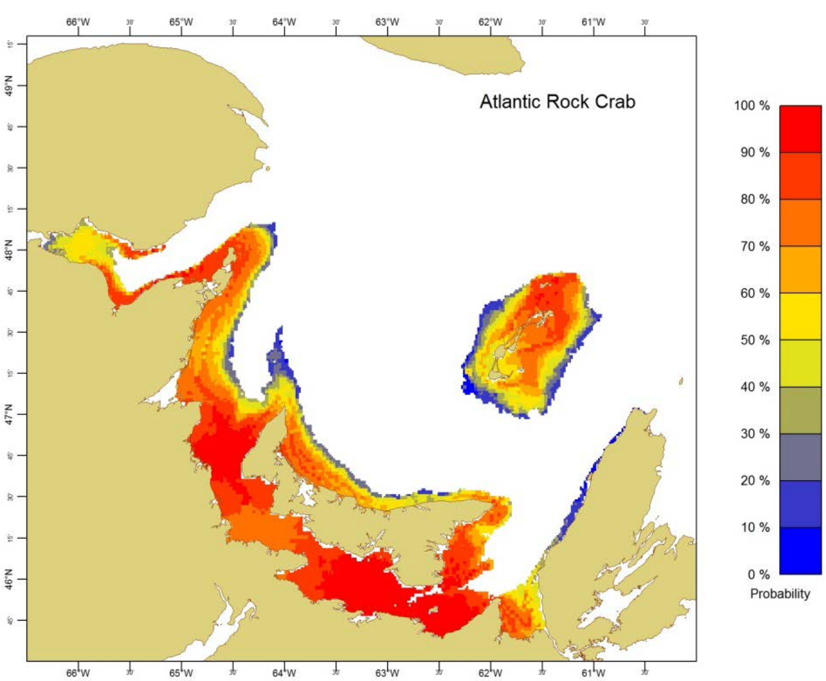

*Map 23. Contour map showing the predicted probabilities of capturing yellowtail flounder (Limanda ferruginea) during a standard tow, using a Western IIA bottom trawl.*



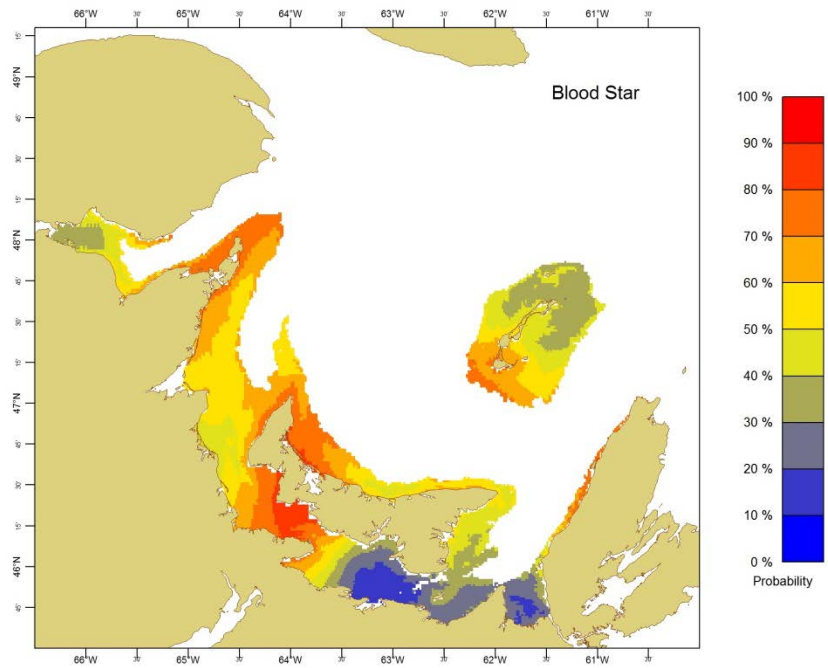

*Map 24. Contour map showing the predicted probabilities of capturing American lobster (Homarus americanus) during a standard tow, using a Western IIA bottom trawl.*



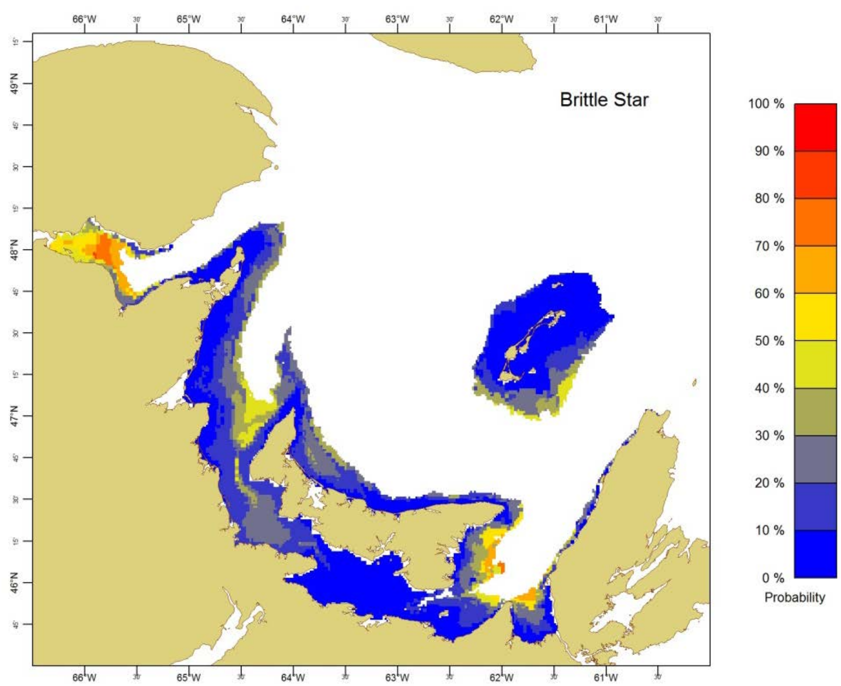

*Map 25. Contour map showing the predicted probabilities of capturing asterias (Asterias sp.) during a standard tow, using a Western IIA bottom trawl.*



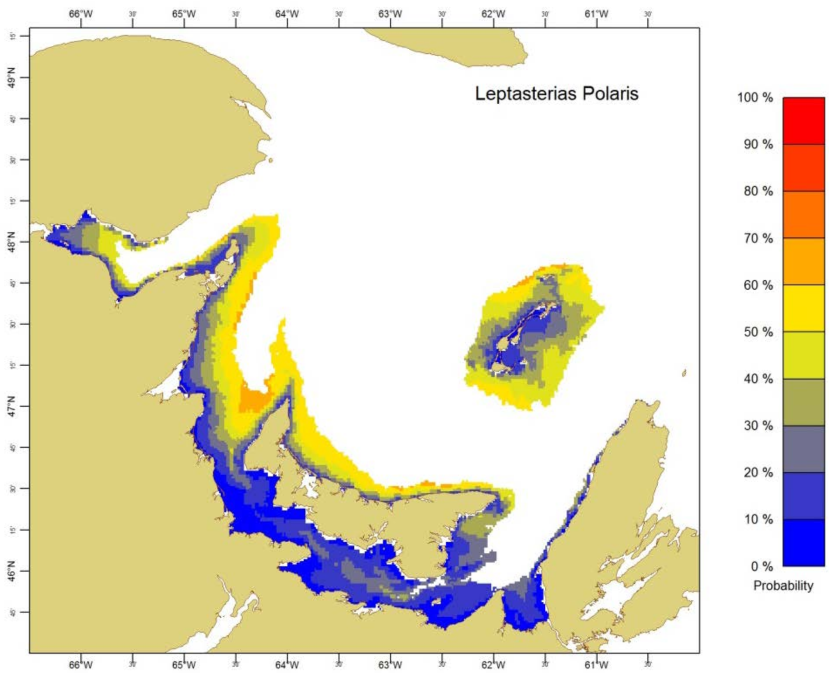

*Map 26. Contour map showing the predicted probabilities of capturing Atlantic rock crab (Cancer irroratus) during a standard tow, using a Western IIA bottom trawl.*



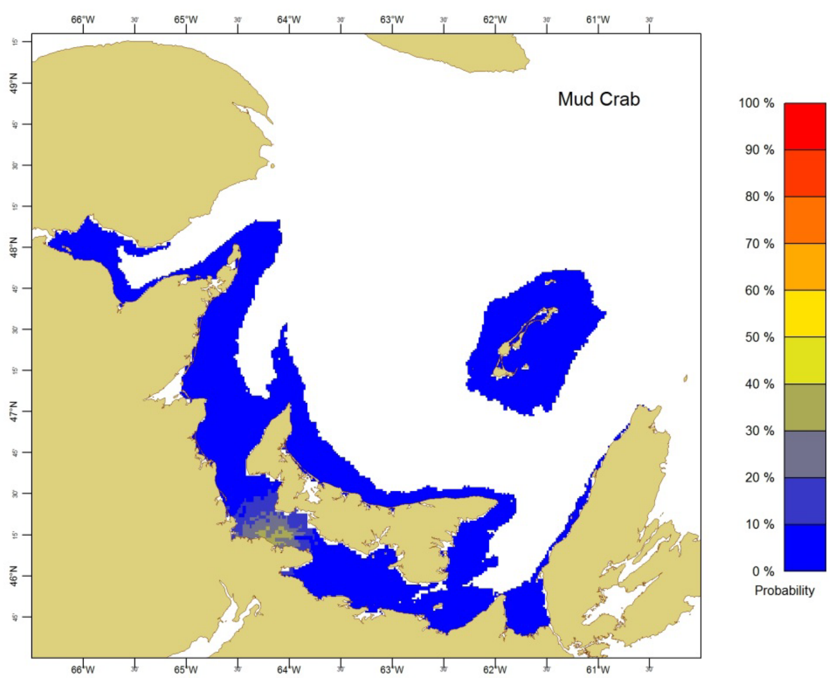

*Map 27. Contour map showing the predicted probabilities of capturing blood star (Henricia sp.) during a standard tow, using a Western IIA bottom trawl.*



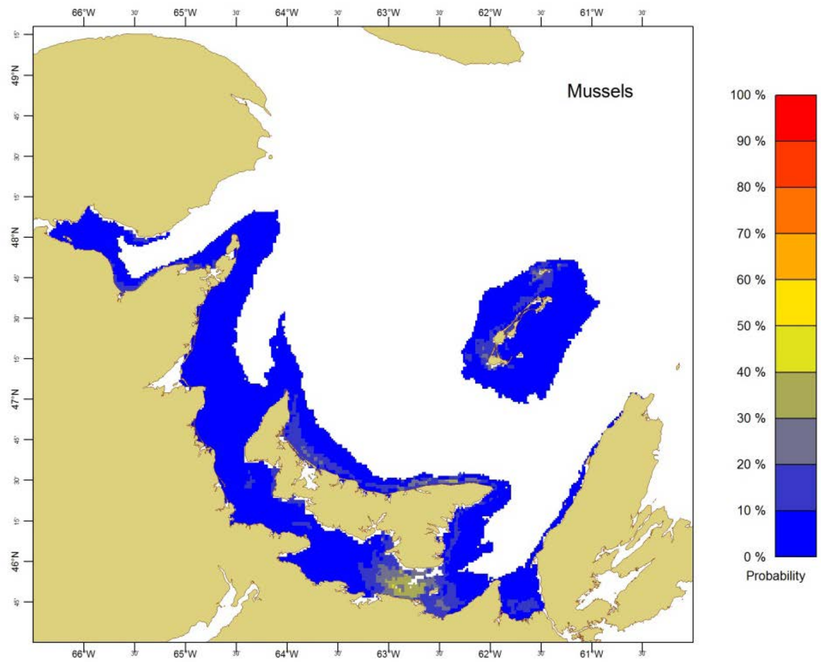

*Map 28. Contour map showing the predicted probabilities of capturing brittle star (Ophiuroidea) during a standard tow, using a Western IIA bottom trawl.*



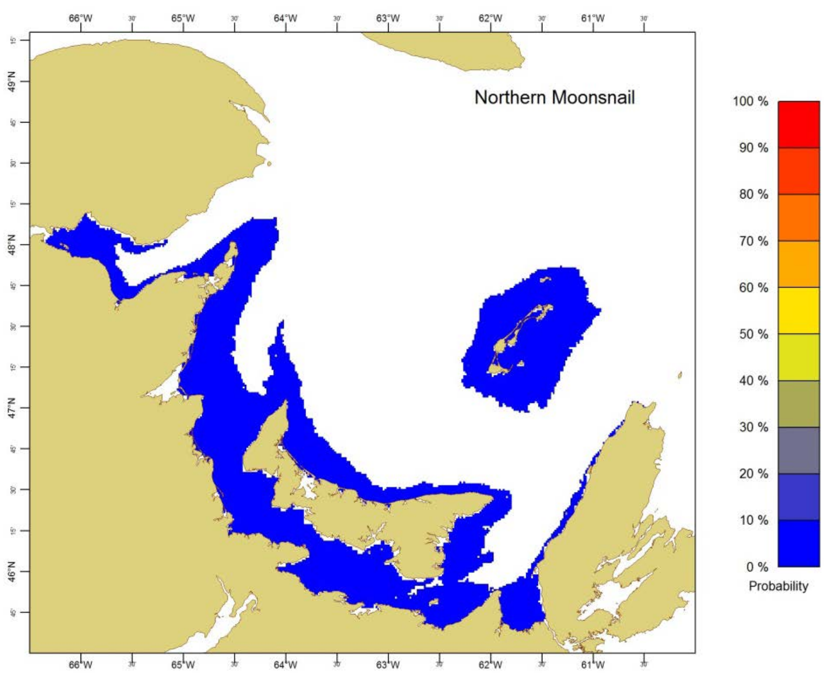

*Map 29. Contour map showing the predicted probabilities of capturing polar sea star (Leptasterias polaris) during a standard tow, using a Western IIA bottom trawl.*



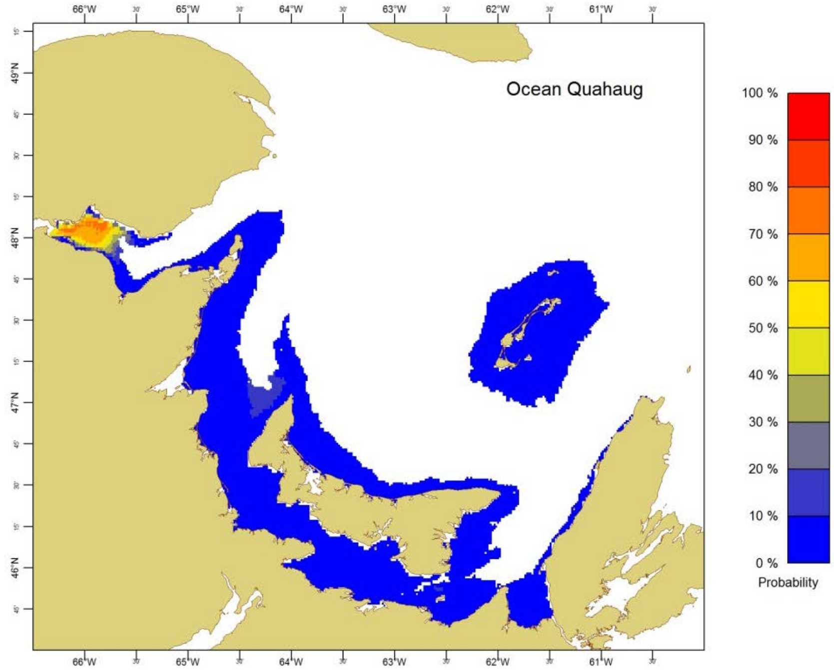

*Map 30. Contour map showing the predicted probabilities of capturing mud crab (Dyspanopeus sayi) during a standard tow, using a* Nephrops *trawl.*



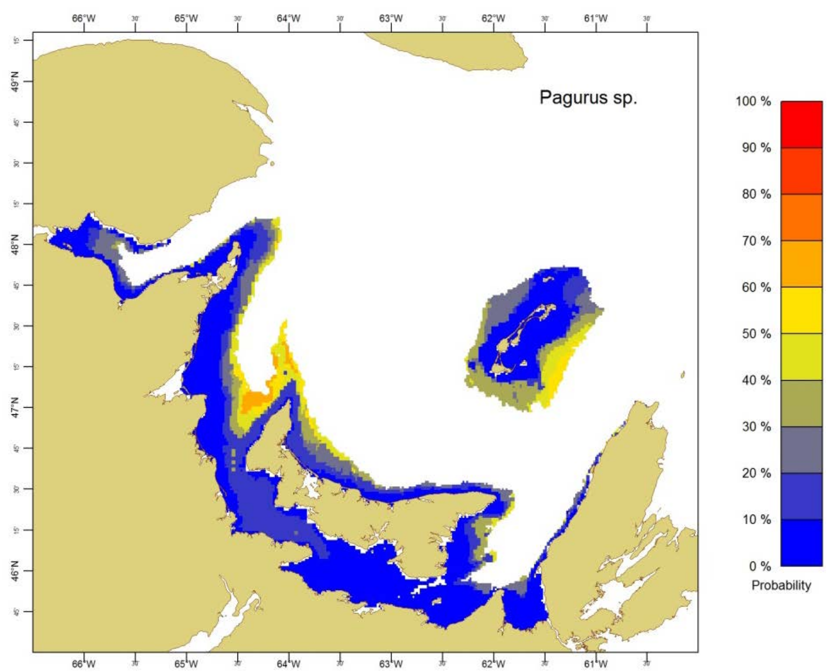

*Map 31. Contour map showing the predicted probabilities of capturing mussels (includes Mytilus edulis, Musculus niger and Modiolus modiolus) during a standard tow, using a Western IIA bottom trawl.*



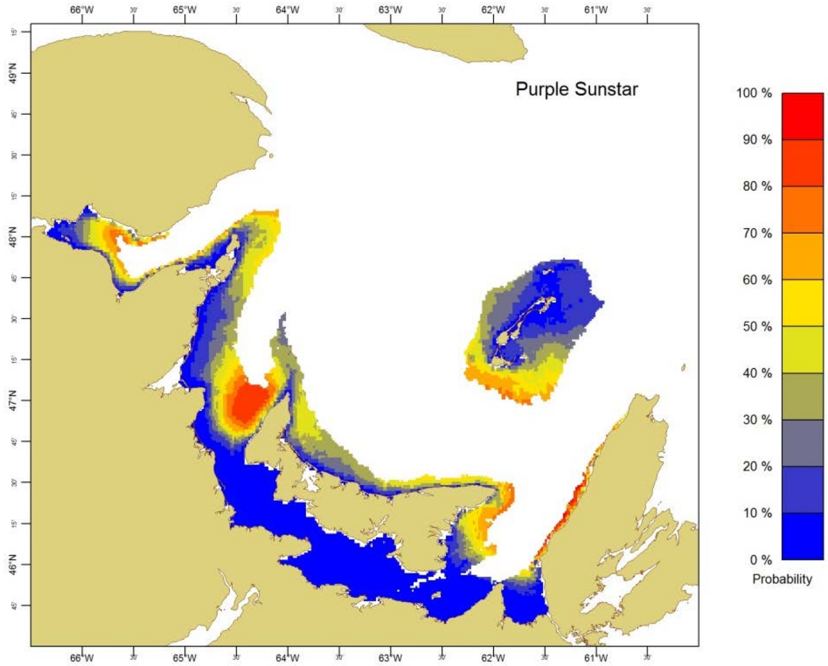

*Map 32. Contour map showing the predicted probabilities of capturing northern moonsnail (Euspira eros) during a standard tow, using a Western IIA bottom trawl.*



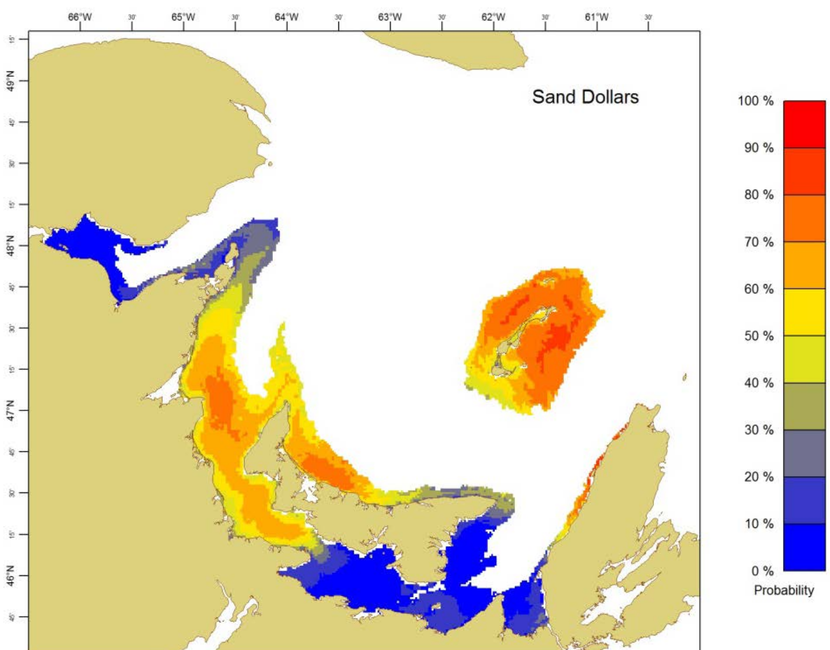

*Map 33. Contour map showing the predicted probabilities of capturing ocean quahaug (Arctica islandica) during a standard tow, using a Western IIA bottom trawl.*



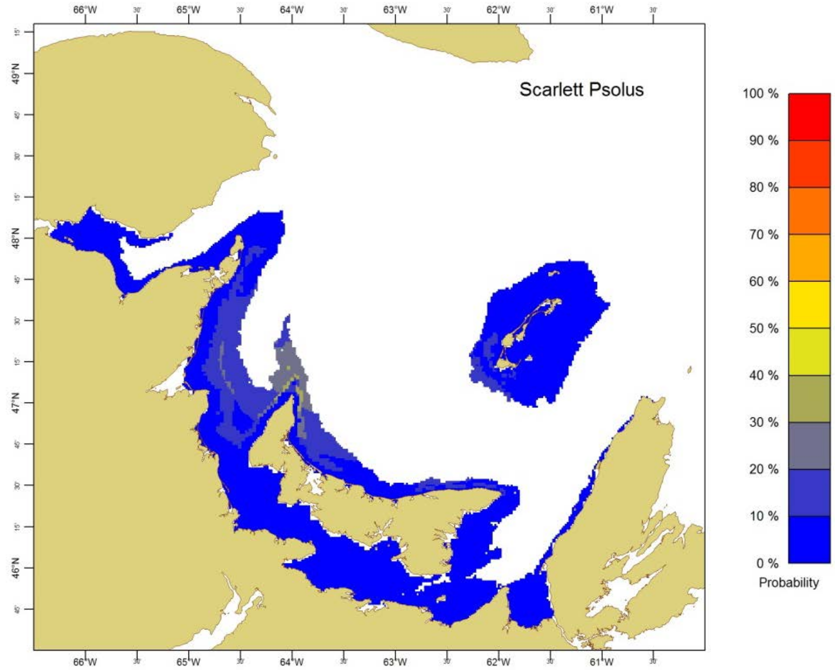

*Map 34. Contour map showing the predicted probabilities of capturing hermit crab (Pagurus sp.) during a standard tow, using a Western IIA bottom trawl.*



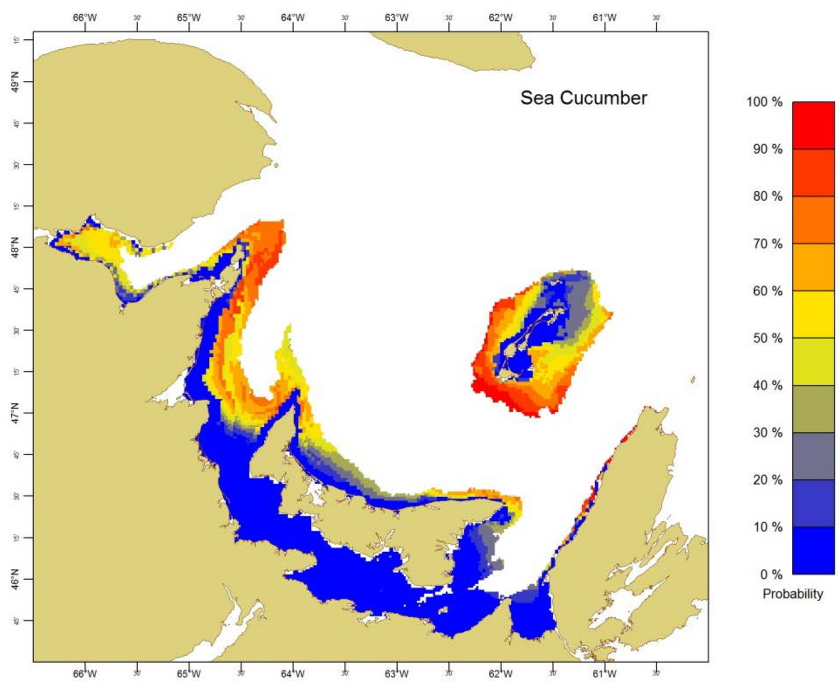

*Map 35. Contour map showing the predicted probabilities of capturing purple sunstar (Solaster endeca) during a standard tow, using a Western IIA bottom trawl.*



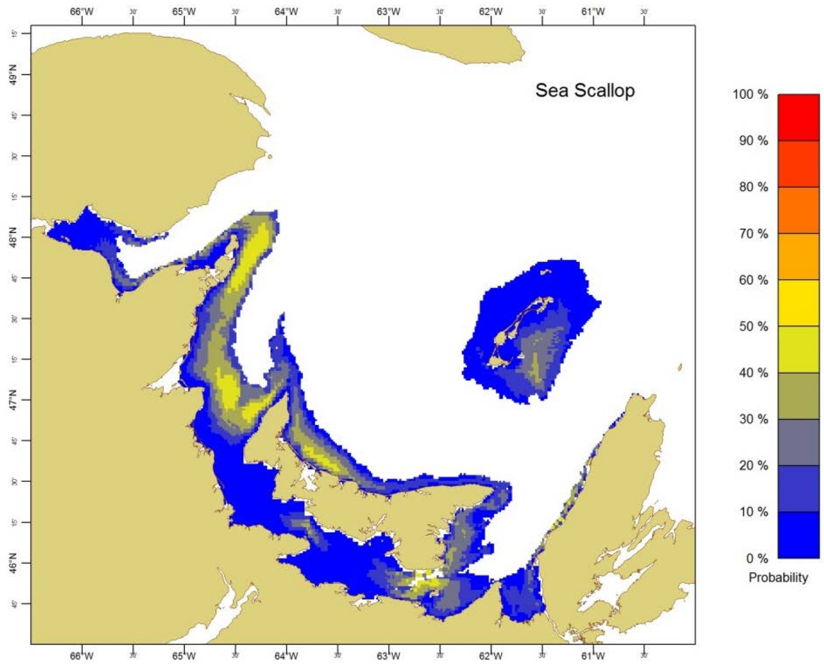

*Map 36. Contour map showing the predicted probabilities of capturing sand dollars (Echinarachnius parma) during a standard tow, using a Western IIA bottom trawl.*



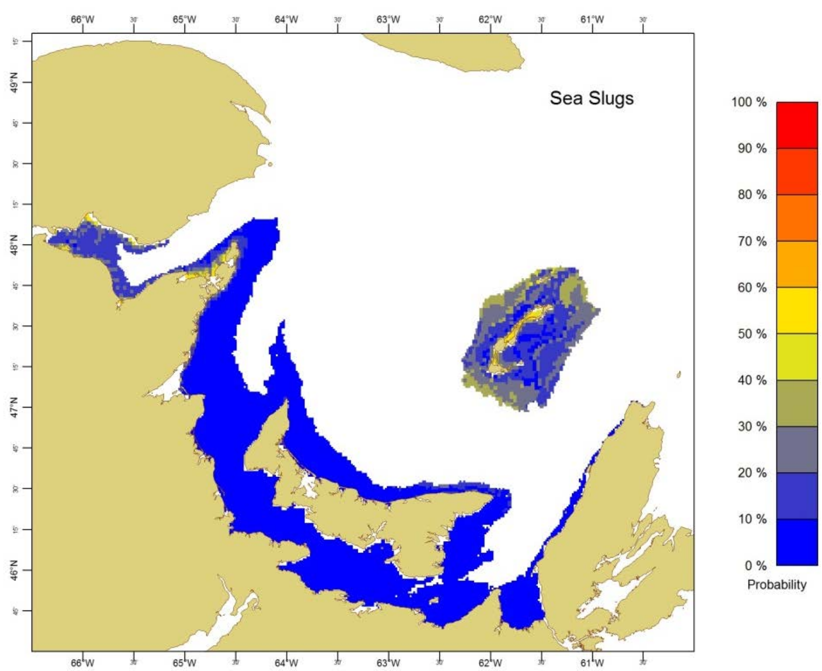

*Map 37. Contour map showing the predicted probabilities of capturing scarlet psolus (Psolus fabricii) during a standard tow, using a Western IIA bottom trawl.*



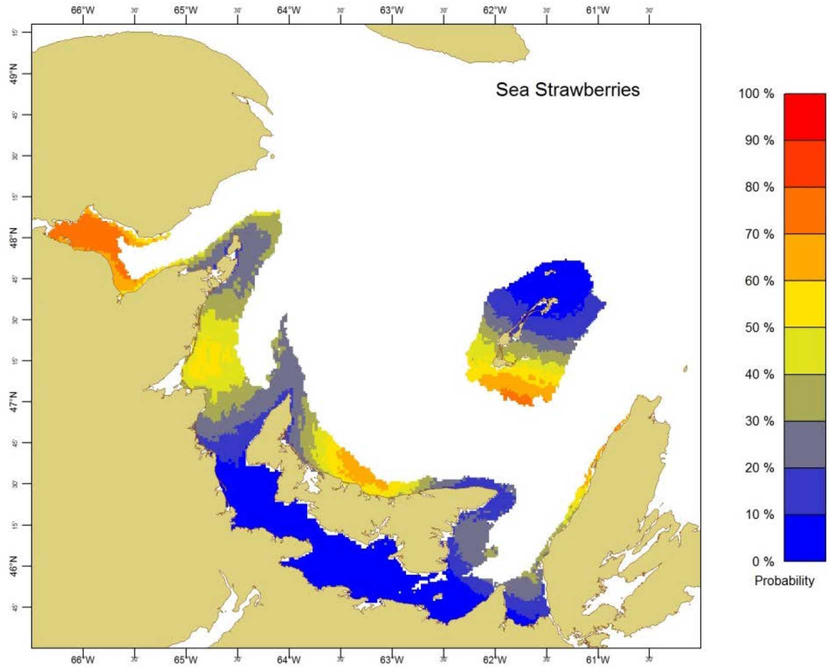

*Map 38. Contour map showing the predicted probabilities of capturing sea cucumber (Cucumaria frondosa) during a standard tow, using a Western IIA bottom trawl.*



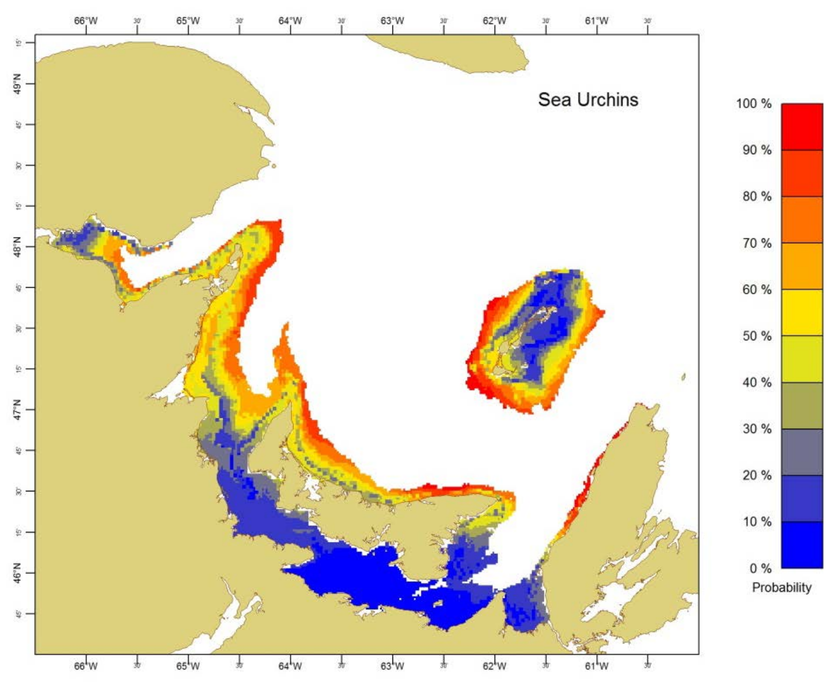

*Map 39. Contour map showing the predicted probabilities of capturing sea scallop (Placopecten magellanicus) during a standard tow, using a Western IIA bottom trawl.*



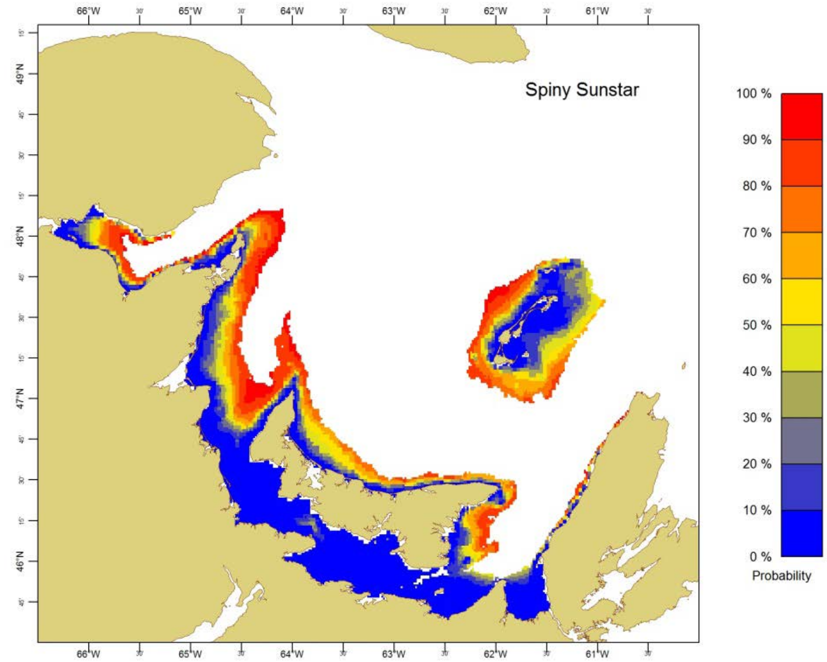

*Map 40. Contour map showing the predicted probabilities of capturing sea slugs (Nudibranchia) during a standard tow, using a Western IIA bottom trawl.*



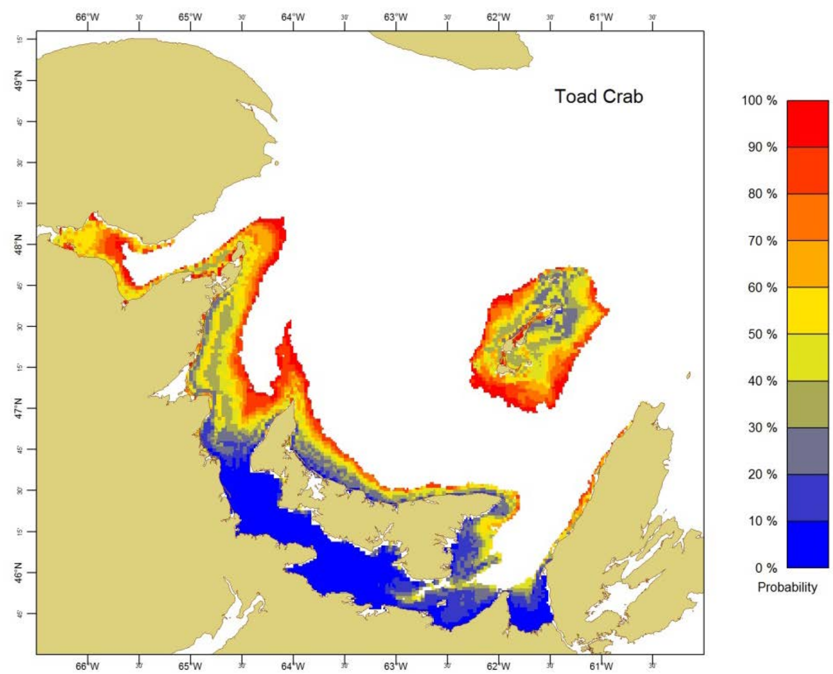

*Map 41. Contour map showing the predicted probabilities of capturing sea strawberries (Gersemia sp.) during a standard tow, using a Western IIA bottom trawl.*




*Map 42. Contour map showing the predicted probabilities of capturing sea urchins (Strongylocentrotus sp.) during a standard tow, using a Western IIA bottom trawl.*




*Map 43. Contour map showing the predicted probabilities of capturing spriny sunstar (Crossaster papposus) during a standard tow, using a Western IIA bottom trawl.*




*Map 44. Contour map showing the predicted probabilities of capturing toad crab (Hyas sp.) during a standard tow, using a Western IIA bottom trawl.*

## Appendix 2. Summary of the available distribution and major habitat information[1] for the fish community (plus lady crab) found in the ≤40 m depth (coastal and upper part of the transition zone) within the southern Gulf of St. Lawrence (sGSL).

| Species (reference)[1] | Guild | Portion used | Presence/ Area used |
|---|---|---|---|
| American eel (COSEWIC 2012a; DFO 2013a) | Catadromous<br>Long-distance migrant<br>Adults leave sGSL to breed | Both juveniles and adults transit through the study area on their migrations between oceanic spawning grounds and continental growth areas. Juveniles feed during these migrations but adults do not. | Just passing through<br>Absent around Magdalen Islands |
| Atlantic salmon (COSEWIC 2010c) | Anadromous<br>Long-distance migrant<br>Juveniles and adults leave sGSL to feed | Pelagic<br>Brief feeding while in transit | Just passing through |
| Alewife / blueback herring (Bosman et al. 2011; Cairns 1997; Darbyson and Benoît 2003; Hanson and Courtenay 1995; McQuinn et al. 2012) | Anadromous<br>Long-distance migrant<br>Feeding/nursery<br>Leaves sGSL for winter | Shallow warm waters | High concentration in Northumberland Strait<br>Absent around Magdalen Islands<br>Leaves sGSL for winter |
| American shad (Bosman et al. 2011; Cairns 1997; Chaput and Bradford 2003; Hanson and Courtenay 1995; McQuinn et al. 2012) | Anadromous<br>Long-distance migrant<br>Feeding/nursery | Shallow warm waters | Mainly in East NB and Northumberland Strait<br>Absent around Magdalen Islands<br>Leaves sGSL for winter |
| Striped bass (Cairns 1997; COSEWIC 2012b; DFO 2014a; Douglas et al. 2009; Robinson et al. 2004) | Anadromous<br>Resident<br>Feeding/nursery. | Very shallow, close to shore | Absent around Magdalen Islands and north of PEI |
| Threespine stickleback (Bosman et al. 2011; Cairns 1997; Hanson and Courtenay 1995) | Anadromous<br>Resident<br>Feeding/nursery | Very shallow, close to shore | Probably ubiquitous |
| Atlantic tomcod (Bosman et al. 2011; Cairns 1997; Hanson and Courtenay 1995) | Anadromous<br>Resident<br>Feeding/nursery | Very shallow, close to shore | Absent around Magdalen Islands |
| Rainbow smelt (Bosman et al. 2011; Cairns 1997; Hanson and Courtenay 1995; LeBlanc et al. 1998; McQuinn et al. 2012) | Anadromous<br>Resident<br>Feeding/nursery | Shallow warm waters | Absent around Magdalen Islands |

| Species (reference)[1] | Guild | Portion used | Presence/ Area used |
|---|---|---|---|
| Butterfish (McQuinn et al. 2012) | Transient marine species<br>Feeding only | Very shallow and estuaries<br>Pelagic | Mainly around PEI<br>Absent around Magdalen Islands and in Chaleur Bay<br>Leaves sGSL for winter |
| Atlantic saury (Chaput and Hurlbut 2010; DFO 2010) | Transient marine species<br>Feeding only | Poorly sampled<br>Pelagic | Only in St. George's Bay<br>Leaves sGSL for winter |
| Spiny dogfish (COSEWIC 2010b) | Transient marine species<br>Feeding only<br>Periodic outbursts | Shallow warm waters<br>Semi-pelagic | Rare in Chaleur Bay<br>Leaves sGSL for winter |
| Bluefin tuna (COSEWIC 2011; Vanderlaan et al. 2014) | Transient marine species<br>Feeding only | Warm waters<br>Pelagic | Not in Chaleur Bay<br>Leaves sGSL for winter |
| Atlantic mackerel (DFO 2014b; McQuinn et al. 2012) | Marine resident<br>Long-distance migrant | Warm waters<br>Pelagic | Ubiquitous<br>Leaves sGSL for winter |
| Juvenile white hake (Bradford et al. 1997; COSEWIC 2013; Hanson and Courtenay 1995; Swain et al. 2012) | Marine resident<br>Winter migration to deeper waters<br>Unique autumn feeding migration into estuaries<br>Possible endemic | Warm waters | Currently, "high" juvenile numbers in St. George's Bay, Northumberland Strait, and east of PEI |
| White hake (COSEWIC 2013; Hanson and Courtenay 1995; Swain et al. 2012) | Marine resident<br>Winter migration to deeper waters<br>Possible endemic | Warm waters | Formerly ubiquitous. Only spawning site is in St. George's Bay |
| Winter skate (Clay 1991; COSEWIC 2005; Kelly and Hanson 2013a, 2013b) | Marine resident<br>Spreads to deeper waters for winter but some stay in ≤ 40 m depths<br>Highly likely an endemic | Warm waters | Formerly ubiquitous<br>Now almost exclusively in Northumberland Strait (the only known breeding area) |
| Lady crab (Voutier and Hanson 2008) | Marine resident<br>No seasonal movement<br>Highly likely an endemic | Warm waters – sand | Entire lifecycle in Northumberland Strait |
| Cunner (Bosman et al. 2011; Dew 1976; Green et al. 1984; Johansen 1925) | Marine resident<br>No seasonal migration | Warm waters | Ubiquitous |
| Rock gunnel (Scott and Scott 1988) | Marine resident<br>No seasonal migration | Warm waters, lives under rocks | Likely ubiquitous |
| Wrymouth (Scott and Scott 1988) | Marine resident<br>No seasonal migration | Warm waters, lives in burrows (need mud) | Found in Chaleur Bay, Northumberland Strait, east of PEI and St. George's Bay |
| Greenland cod (Bosman et al. 2011; Hanson and Courtenay 1995) | Marine resident<br>No clear seasonal migration | May occur at all depths | Ubiquitous but scarce; may spawn in estuaries during winter |

| Species (reference)[1] | Guild | Portion used | Presence/ Area used |
|---|---|---|---|
| Windowpane flounder (Hanson and Wilson 2014) | Marine resident<br>Winter migration to deeper waters<br>Small-bodied ecotype | Warm waters | Widely distributed but scarce in Chaleur Bay, north of PEI and west of Cape Breton |
| Atlantic herring (Bosman et al. 2011; LeBlanc et al. 1998; McQuinn et al. 2012; Messieh 1987) | Marine resident<br>Winter migration to deeper waters | Warm waters to transition zone | Ubiquitous<br>Spawning rare or absent in St. George's Bay, west of Cape Breton and around Magdalen Islands |
| Juvenile Atlantic herring (LeBlanc et al. 1998; McQuinn et al. 2012; Messieh 1987) | Marine resident<br>Winter migration to deeper waters | Warm waters | Rare or absent in St. George's Bay, west of Cape Breton and around Magdalen Islands |
| Sea raven (Bosman et al. 2011) | Marine resident<br>Winter migration to deeper waters | Warm waters to transition waters<br>(rare in CIL) | Ubiquitous |
| Longhorn sculpin (Bosman et al. 2011) | Marine resident<br>Winter migration to deeper waters | Warm waters to transition waters<br>Rare in <15 m depths | Ubiquitous |
| Winter flounder (Bosman et al. 2011; Clay 1991; Hanson and Courtenay 1995, 1996)] | Marine resident<br>Winter migration into estuaries and to deeper waters | Warm waters to transition waters | Ubiquitous |
| Yellowtail flounder (Bosman et al. 2011) | Marine resident<br>Winter migration to deeper waters | Warm waters to transition waters<br>Rare <15 m depths | Ubiquitous |
| Atlantic halibut (DFO 2013b; Savoie 2014a) | Marine resident<br>Winter migration to deeper waters | Warm waters to deep waters<br>Rare <15 m depths | Rare species<br>Absent from central part of Northumberland Strait |
| Atlantic cod juveniles (Bosman et al. 2011; Hanson 1996, 2011) | Marine resident<br>Winter migration to deeper waters | Cooler waters – some in CIL | 0+ in Northumberland Strait and most places; larger juveniles in most places |
| Ocean pout (Bosman et al. 2011) | Marine resident<br>Winter migration to deeper waters | Cooler waters – some in CIL | Ubiquitous but rare in Northumberland Strait |
| Shorthorn sculpin (Hanson and Courtenay 1995) | Marine resident<br>No clear seasonal migration | Found in warm and cooler waters | Ubiquitous |
| Atlantic cod adults (Campana et al. 1999; Comeau et al. 2001; COSEWIC 2010a; Hanson 2011; Swain et al. 1998) | Marine resident<br>Migratory; leave sGSL for winter | Mainly a cold-water species | Ubiquitous in deepest fringe (absent from Northumberland Strait) |
| American plaice (COSEWIC 2009; Swain et al. 1998) | Marine resident<br>Migratory; move to deeper waters | Mainly a cold-water species | Low numbers in Northumberland Strait |

| Species (reference)[1] | Guild | Portion used | Presence/ Area used |
|---|---|---|---|
| Capelin (McQuinn et al. 2012) | Marine resident No clear seasonal migration | Mainly a cold-water species | Deepest margins, not in Northumberland Strait |

[1] Most of the species listed have substantial use of coastal waters except for the adult Atlantic cod, American plaice and capelin, which are mainly cold-water species. Most distribution data come from the probability maps generated for this study and atlases or survey documents derived from the September trawl surveys and sentinel surveys (Benoît 2006; Benoît et al. 2003; Benoît and Swain 2003a, 2003b; Darbyson and Benoît 2003; Savoie 2014a, 2014b). Supplemental references are provided below the species name. CIL refers to the Cold Intermediate Layer.

# APPENDIX E-1

VANCOUVER CALGARY TORONTO OTTAWA HALIFAX

James Gunvaldsen Klaassen
jgunvaldsenklaassen@ecojustice.ca
Sarah McDonald
smcdonald@ecojustice.ca
520-1801 Hollis St
Halifax, NS B3J 3N4
902-417-1700, ext 642/643
File No: 1003

October 10, 2019

The Honourable Minister Gordon Wilson
Department of Environment
Barrington Tower
1894 Barrington Street, Suite 1800
P.O. Box 442
Halifax, NS B3J 2P8
*Minister.Environment@novascotia.ca*

Environmental Assessment Branch
Nova Scotia Environment
PO Box 442
Halifax, NS B3J 2P8
*EA@novascotia.ca*

***Sent via Electronic Mail***

Dear Minister Wilson:

**Re:** Replacement Effluent Treatment Facility Project – Northern Pulp Nova Scotia Environmental Assessment – Focus Report

We write as counsel for Friends of the Northumberland Strait to request that you grant additional time within the above-captioned environmental assessment process currently underway. Specifically, we request that you:

1. Grant additional time for the submission of public comments, with a new deadline of Monday December 9, 2019; and
2. Add 30 more days to the 25-day period within which the Administrator must submit all comments and a recommendation to you, following close of the public comment period.

As Minister, you may increase the time allotted for public comments, pursuant to section 16(2) of the *Environmental Assessment Regulations*, if the default 30 day period for review is insufficient in a particular case. Likewise, Section 17(2) of the *Regulations* empowers you to allow more time for the Administrator's review of focus reports, when the default regulatory timeframe is insufficient.

In the present case, due to the volume, complexity and highly technical nature of the Focus Report materials submitted by Northern Pulp, more time is clearly required to permit a sufficient and reasonable opportunity for the public to review and comment on the submission, and for those comments to be given serious and fair consideration by the Administrator, and ultimately by yourself.

The Focus Report and supporting materials submitted on behalf of Northern Pulp Nova Scotia amount to well over two and a half thousand pages. The materials involve many scientific disciplines and are not readily accessible or easily understandable by laypeople. Further, the Focus Report, and some of the supporting materials refer the reader back to the original materials filed within Northern Pulp's Environmental Assessment Registration Document (EARD) package submitted in February 2019. As you will be aware, that submission was also very large and consisted of many other scientific reports and technical materials. It is unfair and counterproductive to require the general public to address all of this material within the short time currently allowed.

The Focus Report was made available to the public on the Nova Scotia Environment website on October 3, 2019 at 2:32 pm. The announcement indicates that comments are due on November 8, 2019. It will be essentially impossible for people to fit a comprehensive review of all this material into their daily lives, without more time. As well, while paper copies of the Focus Report package were made available at the New Glasgow and Pictou Libraries, these are available for review only by a few people at a time, and only when the library is open.

Northern Pulp Nova Scotia has had several years to prepare these materials, and was given a second chance in April 2019, via this Focus Report, to attempt to fix all the omissions in its original submission. It is noted that most, if not all, of these materials were prepared with taxpayer monies, yet the average taxpaying resident of Pictou and area will be given almost no time to review them.

As per NSE's "Citizen's Guide to Environmental Assessment," "[p]ublic participation is vital to the success of environmental assessment."[1] In respect of Northern Pulp's original EARD, then Minister Miller acknowledged that it was very difficult for the public to address a submission of this nature, within a short timeframe. She said "I don't know that the public is really going to be able to fully digest everything that's been submitted."[2]

It is clear that this project is highly controversial and has generated a very high level of public interest and concern, within the Pictou area and across Nova Scotia. Serious concerns have also been raised by residents and officials in Prince Edward Island. Appropriately, the Terms of Reference for the Focus Report recommended that Northern Pulp Nova Scotia engage with relevant stakeholders and the Mi'kmaq including Pictou Landing First Nation, and to share relevant studies and reports, in the process of preparing its focus report. However, Northern Pulp has shared nothing with our clients or many other affected groups who have taken a consistent and active involvement in this project and the Environmental Assessment process. Instead, its materials were submitted *en masse* all at once, creating barriers for our clients and for the general public which prevent a thorough and thoughtful review. This approach has also made it very difficult for our clients to receive timely and comprehensive advice from experts in the many fields covered by this submission.

[1] Nova Scotia Environment, *A Citizen's Guide to Environmental Assessment* (Halifax, NS: Nova Scotia Environment, 2017) at p 4. Link to: https://novascotia.ca/nse/ea/docs/EA.Guide-Citizens.pdf

[2] Jean Laroche, "Northern Pulp's plans for pipeline, effluent treatment plant now public," CBC, February 7, 2019.

The additional time requested herein is also appropriate as there are materials promised, but not included in the Focus Report package. For example, it appears that the following materials are to be considered by NSE and Minister but are not included in the package:

1. Appendix 7.2 – states it includes as Appendix A an "Underwater Benthic Habitat Survey Video". However, no such video or link to any such video is included in the package.
2. Appendices 10.1 and 10.2 both refer to reports which are not provided.
3. Appendix 11.1 refers to a Mi'kmaq Ecological Knowledge Study but no such study is included in the package.

We hereby request that all these documents be posted on the NSE website forthwith, and that our clients, and all other affected groups, are given a sufficient opportunity to comment on them, and the public comment period be lengthened as requested.

As well it is unclear as to whether reports are intended to be included, or submitted late, under Appendices 3.3, 3.5, 5.2, 6.1 and 7.5 of the Focus Report. If any such report will be submitted for your consideration, it must also be made available for public comment prior to any decisions being made by you as Minister.

We make these submissions in the alternative to, and without prejudice to, our submissions dated February 12, 2019 and March 8, 2019, and our client's submission of September 27, 2018, in respect of our position that you, as Minister of Environment within the government of Nova Scotia and as a member of cabinet, have shown that a reasonable apprehension of bias exists in relation to this project and that you must recuse yourself from any further decision-making in relation to this environmental assessment process.

On behalf of the Friends of the Northumberland Strait, we therefore ask that you:

1. Provide additional time for the public comment period under section 16 of the *Regulations* such that comments may be submitted no later than Monday, December 9, 2019; and
2. Likewise, under s 17 of the *Regulations*, give the Administrator an additional 30 days, beyond the 25 day period default set out therein, to summarize all comments submitted and provide recommendations to you as Minister of Environment;

Thank you for considering these submissions and we look forward to hearing from you. As time is of the essence in this matter, we ask for a response no later than Tuesday October 15, 2019.

Sincerely,

James Gunvaldsen Klaassen
Barrister & Solicitor

For Sarah McDonald
Barrister & Solicitor

c. Friends of the Northumberland Strait, by electronic mail



ecojustice

# APPENDIX E-2

Royal Gazette
Part I
Volume 228, No. 41
October 9, 2019
Halifax, Nova Scotia
Published by Authority

## Index of Notices



IN THE MATTER OF: The *Change of Name Act*, R.S.N.S. 1989, c. 66

This is to certify that on August 2, 2019 at 11:56 in the forenoon change(s) was/were made under the provisions of the *Change of Name Act* for the following individual(s):

From: CAMERON JENAY MULLEN
To: CAMRYN JENAY MULLEN
Year of Birth: 2002, born: HALIFAX, NOVA SCOTIA

This is to certify that on August 2, 2019 at 15:55 in the afternoon change(s) was/were made under the provisions of the *Change of Name Act* for the following individual(s):

From: SAMANTHA NICOLE PRINCE
To: RYLAND DEXTER MALACHAI PRINCE
Year of Birth: 1994, born: WESTMORLAND, NEW BRUNSWICK

This is to certify that on August 9, 2019 at 13:33 in the afternoon change(s) was/were made under the provisions of the *Change of Name Act* for the following individual(s):

From: SHANE PORTER RALPH THOMAS PAUL
To: SHANE PORTER JAMES PAUL
Year of Birth: 2005, born: FREDERICTON, NEW BRUNSWICK

This is to certify that on August 12, 2019 at 14:40 in the afternoon change(s) was/were made under the provisions of the *Change of Name Act* for the following individual(s):

From: NEVILLE CARL TIDD
To: NEVILLE CARL TYR
Year of Birth: 1989, born: HALIFAX, NOVA SCOTIA

This is to certify that on August 12, 2019 at 14:40 in the afternoon change(s) was/were made under the provisions of the *Change of Name Act* for the following individual(s):

From: NORAH ANNETTE CYR
To: NORAH ANNETTE TYR
Year of Birth: 1983, born: MUSQUODOBOIT HARBOUR, NOVA SCOTIA

This is to certify that on August 12, 2019 at 14:40 in the afternoon change(s) was/were made under the provisions of the *Change of Name Act* for the following individual(s):

From: LILITH ILARIA TYR
To: OCTAVIA LILITH ILARIA TYR
Year of Birth: 2016, born: HALIFAX, NOVA SCOTIA

SOUL REAL ESTATE INC.
SPAMADAD CLEANING INC.
SPRING GARDEN CONVENIENCE LTD.
STATE FARM INVESTOR SERVICES (CANADA) INC.
STELLAR LIGHTING (2011) LIMITED
STONE-BURKE CONSULTING GROUP INC.
STONY HOLDINGS INC.
SUBTLE PROPERTIES LTD.
SUNKISSED TANNING LTD.
SUSHI WAY JAPANESE RESTAURANT INCORPORATED
SWEPT TECHNOLOGIES INC.
SYNERGY AEROSPACE CANADA LIMITED
SYNERGY AGRI GROUP INC.
TAP PROJECTS CANADA, INC.
THE FAMILY KNIFE MARKETING CONSULTANCY INC.
THE GAVIN GROUP INC.
THE HILL'S AND BRAS D'OR LAKE VIEW EXPERIENCE LIMITED
THE HIVE HAIR SALON INCORPORATED
THE HOUSE WHISPERER HOME IMPROVEMENT LTD.
THE INQUISITIVE TOY COMPANY INC.
THE KINDER GARDEN PRESCHOOL INCORPORATED
THE PETERSON GROUP INCORPORATED
THE SOCIAL REALTY INC.
TIAZ HOLDINGS INC.
TMG THE METLEJ GROUP, PROJECT MANAGEMENT INC.
TOMBOY RENOVATION & DESIGN LTD.
TOTAL PLUMBING INC.
TOULON NB INC.
TRAMPOLINE CREATIVE INC.
TROD HOLDINGS LIMITED
TROY BOWERS INSTALLS INC.
TROY RESTAURANT INC.
TUCKER LAKE PROPERTIES LIMITED
UNIA DEVELOPMENTS LIMITED
VALUE CONVENIENCE STORES INC.
VICTORIA CROSSING LIMITED
VINLAND FARMS LTD.
WALLWRIGHT BUILDERS INC.
WANTECH LIMITED
WCHC HOLDINGS INCORPORATED
WHITE RHINO INC.
WILSON & LOHNES CONSTRUCTION INCORPORATED
WINDSOR CURLING CLUB LIMITED
WORLD SEAFOOD INTERNATIONAL LTD.
WYE ENTERPRISES LIMITED
ZZAP CONSULTING INC.

Dated at Halifax, Province of Nova Scotia, on October 4, 2019.

Registry of Joint Stock Companies
Hayley Clarke, Registrar

October 9, 2019

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IN THE MATTER OF: The *Environment Act*, S.N.S. 1994-95, c. 1

Release of Focus Report Pursuant to
the Nova Scotia *Environment Act*

This is to advise that on October 2, 2019, the Minister of Environment received the Focus Report for the Replacement Effluent Treatment Facility Project proposed by Northern Pulp Nova Scotia Corporation in accordance with Part IV of the *Environment Act*.

The Northern Pulp Nova Scotia Corporation Northern Bleached Softwood Kraft pulp mill is located at Abercrombie Point adjacent to Pictou Harbour in Pictou County, Nova Scotia. The proposed project will consist of the development of a new effluent (wastewater) treatment facility (ETF) constructed on Northern Pulp property, and a transmission pipeline that will carry treated effluent overland and in the marine environment and discharge via an engineered diffuser (marine outfall).

The new ETF will employ the AnoxKaldnes BAS™ Biological Activated Sludge process purchased from Veolia Water Technologies, which combines Moving Bed Biofilm Reactor (MBBR) technology with conventional activated sludge. Once treated onsite at Northern Pulp's facility, effluent will be sent through an approximately 15 km long pipeline. The pipeline will enter the south side of Pictou Harbour and make landfall on the north side of the harbour roughly following Highway 106 right-of-way to Caribou, and then re-enters the marine environment adjacent to the Northumberland Ferries marine terminal and continues for approximately 4.0 km through Caribou Harbour to the Northumberland Strait, terminating at an engineered marine outfall.

Copies of the Focus Report may be examined at the following locations:

- Pictou Library, 40 Water Street, Pictou, NS
- New Glasgow Library, 182 Dalhousie Street, New Glasgow NS
- EA website https://www.novascotia.ca/nse/ea/

The public is invited to submit written comments to:

Environmental Assessment Branch
Nova Scotia Environment
P.O. Box 442, Halifax, Nova Scotia B3J 2P8

on or before November 8, 2019, or contact the Department via Fax at (902) 424-6925 or e-mail at EA@novascotia.ca. If you have any EA process questions, please contact us at our Toll-free phone number: 833-424-8694.

All comments received from the public consultation will be posted on the department's website for public viewing. In the case of an individual, the address, email and contact information will be removed before being placed on the website. By submitting your comments, you are consenting to the posting of your comments on the department's website.

October 9-2019

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# APPENDIX E-3

CBC

## Nova Scotia

# Minister not considering extension to comment period on Northern Pulp report

Environmental group says volume of documents warrants more time

Michael Gorman · CBC News · Posted: Oct 10, 2019 4:28 PM AT | Last Updated: October 10

The pubic has until 11:59 p.m. on Nov. 8 to submit comments on the Northern Pulp focus report. (David Gutnick/CBC)

comments

Nova Scotia Environment Minister Gordon Wilson is not considering a request to extend the public comment period on the Northern Pulp focus report or the amount of time his department staff has to review people's submissions.

Lawyers for Ecojustice, on behalf of the group Friends of the Northumberland Strait, wrote to Wilson on Thursday requesting 30 additional days for the public comment period and 30 more days for department staff to review submissions.

"It is clear that this project is highly controversial and has generated a very high level of public interest and concern, within the Pictou area and across Nova Scotia," lawyers write in the letter, which was released publicly.

Northern Pulp is seeking approval to build a new effluent treatment facility at its Pictou County mill site, a proposal that includes using a pipeline to move treated effluent to the Northumberland Strait.

The lawyers for the environmental groups say the volume of documents involved — in the range of 2,500 pages — and technical nature of much of the material is cause to give the public more time.

But Wilson noted the public comment period for the mill's previous submission, which his predecessor deemed to be insufficient and thus ordered the focus report, was for 30 days and received about 4,000 submissions.

"We want to hear from Nova Scotians," Wilson told reporters at Province House.

"Thirty days has always been adequate in the past; it's worked very well and I certainly feel that it should meet the requirements this time also."

Environment Minister Gordon Wilson says he thinks 30 days is enough time for people to file comments on the proposal. (Craig Paisley/CBC)

Wilson said the 30-day comment period for a Class 1 environmental assessment is the standard used in the province.

But NDP Leader Gary Burrill said that's precisely the problem.

"This is a major, major project with many, many sides," he said.

"We said from the beginning that a Class 1 assessment will not work to establish the kind of public confidence that you need to get out of an environmental assessment and that's plainly the case now."

Tory Leader Tim Houston agreed, and said it's reasonable for the minister to consider the group's request.

"There's no room for error on this file," he said. "Thirty days is a short time for a document of this significance and this volume."

With no changes to the timeline, the public has until 11:59 p.m. on Nov. 8 to submit comments and Wilson must deliver his decision by Dec. 17.

**MORE TOP STORIES**

- **Officer hurt trying to stop fleeing offender at Halifax courthouse, police say**
- **N.S. changing law to force MLAs to resign if they run for another office**

- **Criminal charges being pursued against three Halifax police officers, says chief**

# APPENDIX E-4

HALIFAX

# More time needed for review of N Pulp pipeline proposal: communit

By **Taryn Grant** Star Halifax
Thu., Oct. 10, 2019 | 3 min. read

HALIFAX—A community group opposed to Northern Pulp's plan to pump treated effluent into the Northumberland Strait is pressing the Nova Scotia government to give more time for the review of a report that claims there won't be any significant, adverse environmental impacts.

Friends of the Northumberland Strait submitted a letter to Environment Minster Gordon Wilson Thursday morning requesting that he add another 30 days to the public consultation period for thousands of pages of new documents from Paper Excellence, the owners of the Northern Pulp kraft mill in Abercrombie, N.S. The letter also requests an extension to the internal review period.

The documents in question were submitted to the department of environment on Oct. 2 as a supplement to a submission from January. The public currently have until Nov. 8 to submit comments and the minister must announce a decision on the project by Dec. 17.

treatment facility and pipeline without more information. She told Paper Excellence to complete a focus report on the potential environmental and human health impacts of the project.

The public were given 36 days to consult on the focus report, which Wilson said should be enough. It’s six days longer than he’s legally required to give.

“I feel comfortable that we are giving Nova Scotians an opportunity to reply,” he said in an interview at Province House.

Wilson said he expects the planned time-frame “to work for us very well.”



James Gunvaldsen Klaassen, a lawyer for the environmental law firm Ecojustice that’s representing Friends of the Northumberland Strait, said the window for consultation is more of an issue with the focus report than it was with the initial environmental assessment submission from January.



Paper Excellence released some pieces of the initial submission to the public months before they were formally submitted to the government, giving extra time for review. In an interview, "This time, everything has been (released) in one big blast, and so it's very difficult to process the entire scope of it in a very short time."

Gunvaldsen Klaassen said his firm is currently recruiting experts to review the focus report "to make sure (the data) is reliable and that the conclusions that are drawn from the data are also accurate and reasonable."

"It's very scientifically complex," he said. "It requires a lot of thought and considered response, and it's very difficult to do that in the short time that's been permitted thus far."

"I just think this extra time is vital to deal with a submission of this nature, and because of what's at stake for the strait and for the people that live in that area," Gunvaldsen Klaassen said.

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**Scheer campaign faces leadership speculation as election day nears**

Paper Excellence is required, by law, to close Northern Pulp's current effluent treatment facility in Boat Harbour by Jan. 31, 2020. The now-polluted lagoon has significant cultural importance to the Pictou Landing First Nation, and the Mi'kmaw people of that community have been calling for it to be cleaned up for decades.

The proposed alternative would treat effluent on-site at the mill and transport millions of litres of treated wastewater daily through a 15-kilometre pipeline into the Northumberland Strait — a plan that's opposed by environmentalists, fishers and the Pictou Landing First Nation for fear of environmental and human health risks.

Without an effluent treatment facility, the mill — a keystone of the province's forestry industry — cannot operate. According to the focus report, the new effluent treatment facility and pipeline would take 21 months to construct. By that timeline, and with the deadline for closing Boat Harbour about three months away, the closure of the mill, at least temporarily, is an almost certain eventuality.

**Taryn Grant** *is a Halifax-based reporter focusing on the Nova Scotia legislature. Follow her on Twitter: @tarynalgrant*

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## MORE HALIFAX

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## New rules on the way for Nova Scotia politicians looking to jump between levels of government

## Halifax police chief on three officers arrested in one month: 'There will be consequences'

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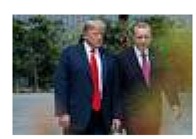

## Soufi’s restaurant to reopen Friday, refusing to give in to hate in wake of death threats

## ‘Why can’t there be a written apology?’ Community seeks action after trustee calls Peel school ‘McCriminal’



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# APPENDIX E-5

VANCOUVER CALGARY TORONTO OTTAWA HALIFAX

James Gunvaldsen Klaassen
jgunvaldsenklaassen@ecojustice.ca
Sarah McDonald
smcdonald@ecojustice.ca
520-1801 Hollis St
Halifax, NS B3J 3N4
902-417-1700, ext 642/643
File No: 1003

October 23, 2019

The Honourable Minister Gordon Wilson
Department of Environment
Barrington Tower
1894 Barrington Street, Suite 1800
P.O. Box 442
Halifax, NS B3J 2P8
*Minister.Environment@novascotia.ca*

Environmental Assessment Branch
Nova Scotia Environment
PO Box 442
Halifax, NS B3J 2P8
*EA@novascotia.ca*

***Sent via Electronic Mail***

Dear Minister Wilson:

**Re:** Replacement Effluent Treatment Facility Project – Northern Pulp Nova Scotia Environmental Assessment – Focus Report

We write further to our letter of October 10, 2019 on behalf of our client, the Friends of the Northumberland Strait in relation to the Northern Pulp focus report. In that letter we asked that you:

1. provide additional time for the public comment period on the focus report, pursuant to section 16 of the *Environmental Assessment Regulations*; and
2. give the Administrator an additional 30 days pursuant to section 17 of the *Environmental Assessment Regulations*, to summarize all comments submitted during the comment period.

Our letter explained why, in our clients' view, more time was essential in the circumstances of this environmental assessment process. We also noted that several documents were missing from the public comment package, making it impossible to comment on such materials within the existing timeframe. Finally, we asked that we receive a response to our letter by October 15, 2019, but none has been received to date.

There is very little time remaining to complete a review of this complex package given the short timeframe you have imposed, and there is insufficient time to fully appreciate and address the multitude of issues that are raised in this complex package. We therefore ask for your response forthwith and without further delay.

Sincerely,

James Gunvaldsen Klaassen
Barrister & Solicitor

Sarah McDonald
Barrister & Solicitor

c. Friends of the Northumberland Strait, by electronic mail



ecojustice

# APPENDIX E-6

NOVA SCOTIA
**Environment**
**Office of the Minister**

PO Box 442, Halifax, Nova Scotia, Canada B3J 2P8 • www.novascotia.ca/nse

Our File number:
10700-40-55257

OCT 23 2019

James Gunvaldsen Klsassen
Ecojustice
jgunvaldsenklaassen@ecojustice.ca

Dear James Gunvaldsen Klaassen:

On behalf of Premier McNeil, I am responding to your e-mail of October 3, 2019, regarding Northern Pulp's proposal.

Protecting the environment is my first priority. Northern Pulp registered the Effluent Treatment Facility Project for Class I Environmental Assessment (EA) on February 7, 2019, as required under the EA Regulations. On March 29, 2019, Margaret Miller, Minister of Environment at the time, released a decision concerning this review. The Minister determined that the registration information was insufficient to make a decision on the project, and that a focus report was required.

Public input is a key component in decision making. The public comment period as outlined in the EA Regulations is for 30 days. The department posted the Focus Report documents online on October 3, 2019, and Nova Scotians will have until November 8, 2019, to provide comments. That is 7 days longer than required. We started the comment period early because of Nova Scotians' considerable interest in the project. I appreciate your concerns and look forward to receiving your comments. This input will be considered when decisions are made.

Copies of the Focus Report may be examined at the following locations:

- Pictou Library, 40 Water Street, Pictou, NS
- New Glasgow Library, 182 Dalhousie Street, New Glasgow NS
- EA website at http://www.novascotia.ca/nse/ea

The public is invited to submit written comments to:

Environmental Assessment Branch
Nova Scotia Environment
P.O. Box 442, Halifax, Nova Scotia B3J 2P8

on or before November 8, 2019, or contact the Department via Fax at (902) 424-6925 or e-mail at EA@novascotia.ca.

Your concerns regarding the proposed project are acknowledged and have been included as part of the EA review. Please note that all comments received from the public consultation will be posted on the department's website for public viewing. In the case of an individual, the address, email and contact information will be removed before being placed on the website. On or before December 17, 2019, I will make a decision regarding the proposed project. By submitting your comments, you are consenting to the posting of your comments on the department's website.

Thank you for bringing your views forward. I appreciate your interest in this project.

Sincerely,

Gordon Wilson, MLA
Minister of Environment

# APPENDIX E-7

CBC

# Northern Pulp's plans for pipeline, effluent treatment plant now public

Environment minister has until March 29 to decide whether plan is acceptable

Jean Laroche · CBC News · Posted: Feb 07, 2019 1:15 PM AT | Last Updated: February 7

Northern Pulp has released details of its plan to build a new effluent treatment plant and discharge pipe. (Jeorge Sadi/CBC)

Nova Scotians now have access to the details of Northern Pulp's controversial plan to build a new effluent treatment plant and discharge pipeline that will empty into the Northumberland Strait.

The Pictou County pulp mill's 614-page document, including 18 appendices, was filed with Nova Scotia's Environment Department a week ago and was posted Thursday on the department's website.

The plan put forward to the Environment Department is to build a "biological activated sludge" treatment facility purchased from a Paris-based multinational corporation called Veolia Water Technologies.

The corporate website says Veolia Water "specializes in water treatment solutions and provides the complete range of services required to design, build, maintain and upgrade water and wastewater treatment facilities for industrial clients and public authorities."

Nova Scotia Environment Minister Margaret Miller said the nearly 2,000-page submission was not a surprise.

"I think it's pretty much what the department was expecting," she said.

## Safe drinking water a concern

The treatment facility would be located on Northern Pulp property not far from the existing plant.

The 15.5-kilometre pipeline would run from the new facility along the shoulder of Highway 106 to Caribou before entering Caribou harbour next to the Northumberland Ferries terminal. From there, it would discharge roughly four kilometres into the Northumberland Strait.

A boat doing survey work for the proposed Northern Pulp effluent pipe is tied to the wharf in Pictou, N.S. (Submitted by Ben Anderson)

That route is a concern for the town of Pictou. Mayor Jim Ryan said it means wastewater will be piped over the town's main watershed.

"This particular issue is about safe drinking water," he said in a telephone interview Thursday.

Ryan said he told Northern Pulp general manager Bruce Chapman in November that any plans for a pipe that carries treated or untreated effluent through the watershed would be unacceptable to the town.

## Work would take 21 months

Northern Pulp's plan to discharge treated effluent into the strait has also been controversial.

Thousands protested last July over concerns it would hurt the environment. Fishermen had also prevented a survey crew from doing work for the company, but agreed last month to a court injunction ordering them not interfere.

Northern Pulp protesters outside a Supreme Court injunction hearing late last year. (Preston Mulligan/CBC)

Company owners have also sought a one-year extension of the provincial law requiring the mill's current treatment facility in Boat Harbour to close in January 2020. The company has argued it needs more time to build a replacement, but Premier Stephen McNeil has refused to extend the deadline.

According to company documents, the plan is to complete the work within 21 months, starting this spring. That means a working system would not be in place until 11 months — at the earliest — after the provincial government is legally mandated to turn off the tap to the provincially owned treatment plant.

## Pipe would mostly be buried

The company has proposed using a polyethylene pipe that's 90 centimetres in diameter to carry the treated effluent from the plant to the dispersal site.

"The terminus of the effluent pipe consists of an outfall location with the three-port diffuser, situated at the depth of approximately 20 [metres]," says the project description.

The plan is to bury the pipe along most of the route, but the company is proposing suspending it to the exterior of the bridge that crosses the Pictou Causeway "due to the limited roadway width."

"The exposed area will be protected from damage by existing guard rails," says the document.

Northern Pulp's proposed route for the effluent pipe would go from a new treatment plant into the Northumberland Strait. (Nic Meloney/CBC)

The company has promised to mark the pipeline location with signs and post markings at public and private roads and water crossings. The system will also need a pumping station which the company states "will operate in a similar manner to municipal pumping station."

## Serious impact on lobster 'highly unlikely'

The company said it looked at alternatives to the plan it has submitted for provincial approval, including simply shutting down or creating a closed wastewater recovery system, but none was feasible.

An indication of how much the company wants an extension is the people it has hired to lobby the governing Liberals on its behalf: Kirby McVicar, McNeil's former chief of staff; Stephen Moore, McNeil's former director of communications; and Trevor Floyd, a one-time executive assistant to Health Minister Randy Delorey when he held the environment portfolio.

- **Premier unmoved by Northern Pulp's ask for more time to close waste water facility**

As for concerns expressed by opponents to the plan, the company has included a response to 38 questions or comments, ranging from the possible harm to lobster stocks to heavy metal contamination and the environmental review process.

The company stated "it is highly unlikely that there will be serious impact on lobster," and that heavy metals occurred naturally in the environment "and are released to the environment from a range of human and natural sources."

## Public invited to submit comments

As for the review process, Northern Pulp noted it was a provincial process but the Canadian Environmental Assessment Agency would review the company's application to determine whether a federal environmental assessment was necessary.

Nova Scotia Environment Minister Margaret Miller has until March 29 to make a decision on Northern Pulp's plan. (CBC)

The public now has until March 9 to digest the information and submit their comments, either by mail or using an online form.

Miller has until March 29 to decide if the project will be granted conditional environmental assessment approval. Officials in her department will sift through the material to ensure it provides a complete picture of the plan and its potential impact on the environment.

If additional work is needed, they can ask the company to provide it. But Miller said the consultation period would not be extended beyond the 30 days if that were to happen.

She acknowledged the existing file could be a challenge for Nova Scotians to assess.

"I don't know that the public is really going to be able to fully digest everything that's been submitted."

# APPENDIX E-8

**Jill Graham Scanlan**

**From:** "Environment Assessment Web Account" <EA@novascotia.ca>
**To:** <sgslaw@ns.sympatico.ca>
**Sent:** Wednesday, October 23, 2019 1:35 PM
**Subject:** RE: Northern Pulp - Additional Information Requested

Good afternoon,

The Focus Report and Appendices for the project are posted on our website with the content that was submitted to NSE by the company. The NS EA process does not include a conformity review or other check that the Focus Report contains all of the items listed in the Terms of Reference. Copies of the Focus Report may be examined at the following locations:

- Pictou Library, 40 Water Street, Pictou, NS
- New Glasgow Library, 182 Dalhousie Street, New Glasgow NS

Thank you

**From:** Jill Graham Scanlan <sgslaw@ns.sympatico.ca>
**Sent:** October 16, 2019 12:04 PM
**To:** Environment Assessment Web Account <EA@novascotia.ca>
**Subject:** Northern Pulp - Additional Information Requested

Hi: I am a member of Friends of the Northumberland Strait and am writing to you on their behalf. When reviewing the Terms of Reference for the Focus Report to be filed by Northern Pulp, I noted the following requirements:

7.1 Conduct fish and fish habitat baseline surveys for the freshwater environment, **to the satisfaction of Fisheries and Oceans Canada**.

7.2 Conduct fish habitat baseline surveys for the marine environment, **to the satisfaction of Fisheries and Oceans Canada**.

The Focus Report filed by Northern Pulp does not appear to include any information to determine the criteria for the surveys established by Fisheries and Oceans Canada, nor any report from Fisheries and Oceans Canada indicating whether or not the surveys were completed to their satisfaction. This information is important for the public to have in order to conduct a proper review and response to the Focus Report. Where do I obtain this information?

The Terms of Reference also set out the following requirement:

7.3 Conduct additional impact assessment of treated effluent on representative key marine fish species important for commercial, recreational and Aboriginal fisheries. This must be based upon updated information, additional studies and/or an understanding of expected movement of contaminants. **Assessment methodology must first be agreed upon by NSE in consultation with relevant federal departments**.

The Focus Report filed by Northern Pulp does not appear to include details of the assessment methodology agreed upon by NSE in consultation with relevant federal departments. This information is important for the public to have in order to conduct a proper review and response to the Focus Report.

Where do I obtain this information?

I look forward to your reply.

Jill Graham-Scanlan
94 Water Street, PO Box 1720
Pictou, NS B0K 1H0
(902) 485-4313 telephone
(902) 485-5083 fax

# APPENDIX E-9

## Jill Graham Scanlan

**From:** "Jill Graham Scanlan" <sgslaw@ns.sympatico.ca>
**Date:** October 24, 2019 11:30 AM
**To:** "Environment Assessment Web Account" <EA@novascotia.ca>
**Subject:** Re: Northern Pulp

Thank you for your reply. I wish to advise that I reviewed the Focus Report at the Pictou Library and found that the Figures were blurry and I was not able to read them in their entirety. This will impact the ability of the public to properly respond to the Focus Report. It will impact the ability of the various government departments to respond to the Focus Report as well, including Nova Scotia Environment, if the quality of the Figures in the Focus Report provided for review are similarly blurry.

Please note my concerns for the record.

Thank you,
~Jill

**From:** Environment Assessment Web Account
**Sent:** Wednesday, October 23, 2019 1:35 PM
**To:** sgslaw@ns.sympatico.ca
**Subject:** RE: Northern Pulp

Good afternoon,
The Focus Report and Appendices for the project are posted on our website in the manner that they were submitted to NSE by the company. Copies of the Focus Report may be examined at the following locations:
• Pictou Library, 40 Water Street, Pictou, NS
• New Glasgow Library, 182 Dalhousie Street, New Glasgow NS
Thank you

**From:** Jill Graham Scanlan <sgslaw@ns.sympatico.ca>
**Sent:** October 23, 2019 11:29 AM
**To:** Environment Assessment Web Account <EA@novascotia.ca>
**Subject:** Fw: Northern Pulp

I am forwarding an email I sent to you on October 16, 2019 to which I have received no response. Kindly advise where I can obtain clear copies of the Figures. The deadline for public response to Northern Pulp's Focus Report is fast approaching and it is very important that the requested information is provided so that the public has the opportunity to review it and reply appropriately.

Thank you,
~Jill

**From:** Jill Graham Scanlan
**Sent:** Wednesday, October 16, 2019 11:24 AM
**To:** EA@novascotia.ca
**Subject:** Northern Pulp

Hi: I am a member of Friends of the Northumberland Strait and am writing to you on their behalf. When reviewing the Focus Report filed by Northern Pulp, I noted that some of the Figures were blurry and I was not able to read them, particularly the key / legend. See Figure 7.3-1 found on page 124 for one example, but there are others. The Figures are blurry when viewed online and when printed.

Where do I obtain clear copies of these Figures?

~Jill
Jill Graham-Scanlan
94 Water Street, PO Box 1720
Pictou, NS B0K 1H0
(902) 485-4313 telephone
(902) 485-5083 fax

# APPENDIX E-10

News release

# Northern Pulp Focus Report Submitted

Environment (../search?dept=124)
October 2, 2019 - 11:57 AM

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Northern Pulp submitted a focus report for its proposed effluent treatment plant in Pictou County to the Environment Department today, Wednesday, Oct. 2.

The report will be available online within 14 days once department staff have done a preliminary check to confirm it is complete.

Once it is posted online, Nova Scotians will have 30 days to share their comments as part of the environmental assessment process. A decision on the proposed effluent treatment plant will be made within 39 days after the public comment period ends.

## Quick Facts:

-- the environment minister directed Northern Pulp to submit a focus report on March 29.

-30-

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## Media Contact:

Rachel Boomer
Cell: 902-478-9865 (tel:+19024789865)
Email: rachel.boomer@novascotia.ca (mailto:rachel.boomer@novascotia.ca)

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All government social media accounts (/connect/)

## Related information

- Media enquiries (https://beta.novascotia.ca/media-contacts)
- Search news releases (/news/)
- Archive: news releases from 1995-97 (/news/archive.asp)

# APPENDIX E-11

# Profile

Printer Version

Profile Info People Info Activites Info Related Reg's Info

**PROFILE** - FRIENDS OF THE NORTHUMBERLAND STRAIT - as of: 2018-09-06 11:00 AM

| | |
|---|---|
| **Business/Organization Name:** | FRIENDS OF THE NORTHUMBERLAND STRAIT |
| **Registry ID:** | 3320210 |
| **Type:** | Society |
| **Nature of Business:** | |
| **Status:** | Active |
| **Jurisdiction:** | Nova Scotia |
| **Registered Office:** | 94 WATER STREET<br>PICTOU NS Canada B0K 1H0 |
| **Mailing Address:** | PO BOX 1720<br>PICTOU NS Canada B0K 1H0 |

## PEOPLE

| **Name** | **Position** | **Civic Address** | **Mailing Address** |
|---|---|---|---|
| NICOLE MACKENZIE | Director | 613 CENTRAL CARIBOU ROAD<br>PICTOU NS B0K 1H0 | |
| KRISTA FULTON | Director | 63 JAMES STREET<br>PICTOU NS B0K 1H0 | |
| LINDA TOWNSEND | Director | 1114 HIGHWAY 14<br>GREENFIELD NS B0N 1N0 | |
| CORINNE MACKEIL | Director | 2 BROOK AVENUE<br>LYONS BROOK NS B0K 1H0 | |
| JILL GRAHAM-SCANLAN | Director | 388 ELMFIELD ROAD<br>SCOTSBURN NS B0K 1R0 | |
| JILL GRAHAM-SCANLAN | Recognized Agent | 388 ELMFIELD ROAD<br>SCOTSBURN NS B0K 1R0 | PO BOX 1720<br>PICTOU NS B0K 1H0 |

## ACTIVITIES

| Activity | Date |
|---|---|
| Incorporated | 2018-08-23 |
| Filed Document | 2018-08-23 |

## RELATED REGISTRATIONS

There are no related registrations on file for this company.