force | Fundy Ocean Research Centre for Energy

Environmental Effects Monitoring Program

Quarterly Report: January-March 2023

March 31, 2023

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What’s New?

FALL 2021 LOBSTER BASELINE SURVEY REPORT

FORCE implemented a fall lobster survey in 2021 in partnership with the Fishermen and Scientists Research Society and with the help of a local lobster fisher. The survey revealed a ‘high’ catchability rate (i.e., CPUE ≥ 2.4 kg/trap haul) – consistent with a prior baseline survey at the FORCE site in 2017 and comparable to available commercial landings. read more

RAP – FISH TAGGING; OTN AND FORCE MERGE LINES OF ACOUSTIC RECEIVERS

Fish tagging commenced under the Risk Assessment Program in 2021 in partnership with Acadia University and the Mi’kmaw Conservation Group will continue in 2023, and will focus on alewife, American shad and Inner Bay of Fundy Atlantic salmon smolts. For 2023, FORCE and the Ocean Tracking Network are collaborating to merge their lines of acoustic receivers into a single array that will span the vast majority of Minas Passage, and increasing the chances of detecting tagged fish as they navigate through the area. read more

Executive Summary

Tidal stream energy devices are an emerging renewable energy technology that use the ebb and flow of the tides to generate electricity. These devices are in various stages of research, development, operation and testing in countries around the world.

FORCE was established in 2009 after undergoing a joint federal-provincial environmental assessment with the mandate to enable the testing and demonstration of tidal stream devices. Since that time, more than 100 related research studies have been completed or are underway with funding from FORCE, the Offshore Energy Research Association (OERA), and others. These studies have considered physical, biological, socioeconomic, and other research areas.

The current suite of monitoring programs implemented by FORCE build off those initiated during 2016-2020 that were conducted in anticipation of tidal stream energy device deployments at FORCE's tidal demonstration site. These efforts are divided into two components: FORCE 'site - level' monitoring activities (>100 metres from a device), and developer or 'device-specific' monitoring led by project developers (≤100 metres from a device) at the FORCE site. All monitoring plans are reviewed by FORCE's independent Environmental Monitoring Advisory Committee (EMAC) and federal and provincial regulators prior to implementation.

FORCE monitoring presently consists of monitoring for fish, marine mammals, seabirds, lobster, and marine sound. During monitoring from 2016 through 2020, FORCE completed:

- ~564 hours of hydroacoustic fish surveys;
- more than 5,083'C-POD' marine mammal monitoring days;
- bi-weekly shoreline observations;
- 49 observational seabird surveys;
- four drifting marine sound surveys and additional sound monitoring; and
- 11 days of lobster surveys

The 2021-2023 EEMP is designed to prepare for effects testing with the deployment of operational tidal stream energy devices and adheres to the principles of adaptive management by evaluating existing datasets to ensure appropriate monitoring approaches are being implemented. Moreover, the plan adopts internationally accepted standards for monitoring where possible, including feasibility assessments for new monitoring approaches that are planned to be implemented. The 2021-2023 EEMP has been implemented as designed and reviewed by FORCE's environmental monitoring advisory committee (EMAC). Device deployments are pending and there has not been an opportunity for effects testing under the 2021-2023 proposed EEMP.

Since the beginning of the 2021-2023 EEMP, FORCE has completed;

- 8 days of lobster surveys;
- a preliminary radar feasibility study to monitor for seabirds; and
- bi-weekly shoreline observations

FORCE is working with academic and Indigenous partner organizations to advance the Risk Assessment Program (RAP) for tidal stream energy. This program seeks to develop credible and statistically robust encounter rate models for migratory and resident fish species in Minas Passage with tidal stream energy devices. This will be accomplished by combining physical oceanographic data related to flow and turbulence in the Minas Passage with hydroacoustic tagging information for various fish species in the region curated by the Ocean Tracking Network at Dalhousie University. Since the start of the project, FORCE has established a high-resolution radar network in Minas Passage and has started to quantify hydrodynamic features in the region and build the tidal flow atlas required for the program. FORCE has also started modelling the spatiotemporal distributions for the nine species for which sufficient acoustic tracking data is available and is developing species distribution maps for each species. In partnership with FORCE, the Mi'kmaw Conservation Group (MCG), local fishers and Acadia University have completed the fish tagging component of the program that is required for species distribution and encounter rate model validation. The results of this work are to be shared through the development of a user-friendly graphical-user interface for non-technical stakeholders, and an R-package (or similar) for regulators and academic stakeholders. Fish tagging will continue into 2023 as part of FORCE's fish monitoring program. Ultimately, this work will contribute towards understanding the risk of tidal stream energy development for fishes in the Bay of Fundy and will assist in the development of future environmental effects monitoring programs.

This report provides a summary of monitoring activities and data analyses completed by FORCE during the first quarter of 2023. In addition, it also highlights findings from international research efforts, previous data collection periods at the FORCE site, and additional research work that is being conducted by FORCE and its partners. This includes supporting fish tagging efforts with Acadia University and the Ocean Tracking Network, radar research projects, and subsea instrumentation platform deployments through the Fundy Advanced Sensor Technology (FAST) Program. Finally, the report presents details regarding future research and monitoring efforts at the FORCE test site. This includes work in support of the 2023 EEMP and the RAP program.

All reports, including quarterly monitoring summaries, are available online at www.fundyforce.ca/document-collection.

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Appendix I	Acronyms
Appendix II	Petrichencko, J., E. Blacklock, S. Thompson, S. Scott-Tibbetts, and A. Whitney. 2023. FORCE lobster survey in Minas Passage Fall 2021. Fishermen and Scientists Research Society. 48 pp.

Introduction

This report outlines monitoring activities and results of data analyses conducted at the Fundy Ocean Research Centre for Energy test site in the Minas Passage, Bay of Fundy during January through March 2023. Specifically, this report highlights results of environmental monitoring activities conducted by FORCE and other research and development activities conducted at the FORCE site. This report also provides a summary of international research activities around tidal stream energy devices.

About FORCE

FORCE was created in 2009 to lead research, demonstration, and testing for high flow, industrial-scale tidal stream energy devices. FORCE is a not-for-profit entity that has received funding support from the Government of Canada, the Province of Nova Scotia, Encana Corporation, and participating developers.

FORCE has two central roles in relation to the demonstration of tidal stream energy converters in the Minas Passage:

1. Host: providing the technical infrastructure to allow demonstration devices to connect to the transmission grid; and
2. Steward: research and monitoring to better understand the interaction between devices and the environment.

The FORCE project currently consists of five undersea berths for subsea tidal energy device generators, four subsea power cables to connect the devices to land-based infrastructure, an onshore substation and power lines connected to the Nova Scotia Power transmission system, and a Visitor Centre that is free and open to the public from May to November annually. These onshore facilities are located approximately 10 km west of Parrsboro, Nova Scotia.

The marine portion of the project is located in a 1.6 km x 1.0 km tidal demonstration area in the Minas Passage. It is also identified as a Marine Renewable-electricity Area under the Province's Marine Renewable-energy Act. This area consists of five subsea berths that are leased to tidal energy companies[1] selected by the Nova Scotia Department of Natural Resources and Renewables. Current berth holders at FORCE are:

Berth A: Eauclaire Tidal Limited Partnership[2]
Berth B: Rio Fundo Operations Canada Limited[3]
Berth C: Sustainable Marine Energy (Canada)[4]
Berth D: Big Moon Power Canada
Berth E: Halagonia Tidal Energy Limited[5]

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[1] Further information about each company may be found at: fundyforce.ca/partners

[2] On January 16, 2023 the Department of Natural Resources and Renewables approved the transfer of the Project Agreement and FIT approvals from Minas Tidal Limited Partnership to Eauclaire Tidal Limited Partnership.

[3] On April 30, 2019 the Department of Energy and Mines approved the transfer of the Project Agreement and FIT approvals from Atlantis Operations (Canada) Ltd. to Rio Fundo Operations Canada Ltd.

[4] On May 15, 2019 the Department of Energy and Mines issued an approval for Black Rock Tidal Power to change its name to Sustainable Marine Energy (Canada) Ltd. with the transfer of assets from SCHOTTEL to Sustainable Marine Energy.

[5] Berth E does not have a subsea electrical cable provided to it.

Research, monitoring, and associated reporting is central to FORCE's steward role, to assess whether tidal stream energy devices can operate in the Minas Passage without causing significant adverse effects on the environment, electricity rates, and other users of the Bay.

As part of this mandate, FORCE has a role to play in supporting informed, evidence-based decisions by regulators, industry, rightsholders, the scientific community, and the public. As deployments of different technologies are expected to be phased in over the next several years, FORCE and regulators will have the opportunity to learn and adapt environmental monitoring approaches as lessons are learned.

Background

The FORCE demonstration project received its environmental assessment (EA) approval on September 15, 2009 from the Nova Scotia Minister of Environment. The conditions of its EA approval[6] provide for comprehensive, ongoing, and adaptive environmental management. The EA approval has been amended since it was issued to accommodate changes in technologies and inclusion of more berths to facilitate provincial demonstration goals.

In accordance with this EA approval, FORCE has been conducting an Environmental Effects Monitoring Program (EEMP) to better understand the natural environment of the Minas Passage and the potential effects of tidal stream energy devices as related to fish, seabirds, marine mammals, lobster, marine sound, benthic habitat, and other environmental variables. All reports on site monitoring are available online at: www.fundyforce.ca/document-collection.

Since 2009, more than 100 related research studies have been completed or are underway with funding from FORCE, the Offshore Energy Research Association (OERA) and others. These studies have considered socioeconomics, biological, and other research areas.[7]

Monitoring at the FORCE site is currently focused on lobster, fish, marine mammals, seabirds, and marine sound and is divided into developer (≤ 100 m from a device) and FORCE led (> 100 m from a device) monitoring. As approved by regulators, individual berth holders complete monitoring in direct vicinity of their device(s), in recognition of the unique design and operational requirements of different technologies. FORCE completes site level monitoring activities as well as supporting integration of data analysis between these monitoring zones, where applicable.

All developer and FORCE monitoring programs are reviewed by FORCE's Environmental Monitoring Advisory Committee (EMAC), which includes representatives from scientific, First Nations, and local fishing communities.[8] These programs are also reviewed by federal and provincial regulators prior to device installation. In addition, FORCE and berth holders also submit an Environmental Management Plan (EMP) to regulators for review prior to device installation. EMP's include environmental management roles and responsibilities and commitments, environmental protection plans, maintenance and inspection requirements, training and education requirements, reporting protocols, and more.

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[6] FORCE's Environmental Assessment Registration Document and conditions of approval are found online at: www.fundyforce.ca/document-collection.

[7] Net Zero Atlantic Research (formerly Offshore Energy Research Association) Portal (https://netzeroatlantic.ca/research) includes studies pertaining to infrastructure, marine life, seabed characteristics, socio-economics and traditional use, technology, and site characterization.

[8] Information about EMAC may be found online at: www.fundyforce.ca/about-us

Tidal Stream Energy Device Deployments

Since FORCE's establishment in 2009, tidal stream energy devices have been installed at the FORCE site three times: once in 2009/2010, November 2016 – June 2017, and July 2018 – present. Given the limited timescales in which a device has been present and operating at the FORCE site, environmental studies to-date have largely focused on the collection of baseline data and developing an understanding of the capabilities of monitoring devices in high flow tidal environments.

On July 22, 2018, CSTV installed a two-megawatt OpenHydro turbine at Berth D of the FORCE site and successfully connected the subsea cable to the turbine. CSTV confirmed establishment of communication with the turbine systems on July 24. On July 26, 2018, Naval Energies unexpectedly filed a petition with the High Court of Ireland for the liquidation of OpenHydro Group Limited and OpenHydro Technologies Limited.[9] For safety purposes, the turbine was isolated from the power grid that same day. On September 4, 2018, work began to re-energize the turbine, but soon afterwards it was confirmed that the turbine's rotor was not turning. It is believed that an internal component failure in the generator caused sufficient damage to the rotor to prevent its operation. Environmental sensors located on the turbine and subsea base continued to function at that time except for one hydrophone.

As a result of the status of the turbine, the monitoring requirements and reporting timelines set out in CSTV's environmental effects monitoring program were subsequently modified under CSTV's Authorization from Fisheries and Oceans Canada. The modification required that CSTV provide written confirmation to regulators monthly that the turbine was not spinning by monitoring its status during the peak tidal flow of each month. This began October 1, 2018 and was expected to continue until the removal of the turbine; however, as a result of the insolvency of OpenHydro Technology Ltd., all developer reporting activities by CSTV ceased as of March 1, 2019. FORCE subsequently provided monthly reports to regulators confirming the continued non-operational status of the CSTV turbine from March 2019 – May 2020 and received authorization from the Nova Scotia Department of Environment on June 2, 2020, to conclude these monthly reports.

In September 2020, Big Moon Canada Corporation (Big Moon) was announced as the successful applicant to fill berth D at the FORCE test site following a procurement procedure administered by Power Advisory LLC. As part of the agreement, Big Moon provided a $4.5 million security deposit to remove the non-operational CSTV turbine currently deployed at berth D, and has until December 31, 2024 to raise the turbine. The project start date for BigMoon is not known at this time, but is anticipated to commence in 2023.

Additional devices are expected to be deployed at the FORCE site in the coming years. In 2018, Sustainable Marine Energy (formerly Black Rock Tidal Power) installed a PLAT-I system in Grand Passage, Nova Scotia under a Demonstration Permit.[10] This permit allows for a demonstration of the 280 kW system to help SME and its partners learn about how the device operates in the marine environment of the Bay of Fundy. On May 11, 2022, SME announced it had successfully delivered the first floating tidal stream energy to Nova Scotia's power grid. However, on March 20, 2023, SME announced that it was withdrawing its application to Fisheries and Oceans Canada (DFO) for a Fisheries Act Authorization to deploy a PLAT-I system at FORCE, citing an unclear regulatory pathway for project build-out. The future of SME's project at FORCE is currently uncertain.

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[9] See original news report: https://www.irishexaminer.com/breakingnews/business/renewable-energy-firms-with-more-than-100-employees-to-be-wound-up-857995.html.

[10] To learn more about this project, see: https://novascotia.ca/news/release/?id=20180919002.

In 2018, Natural Resources Canada announced a $29.8 million contribution to Halagonia Tidal Energy's project at the FORCE site through its Emerging Renewable Power Program.[11] The project consists of submerged turbines for a total of nine megawatts – enough capacity to provide electricity to an estimated 2,500 homes.

Each berth holder project will be required to develop a device-specific monitoring program, which will be reviewed by FORCE's EMAC and federal and provincial regulators including Fisheries and Oceans Canada, the Nova Scotia Department of Environment and Climate Change, and the Nova Scotia Department of Natural Resources and Renewables prior to device installation.

Overall, the risks associated with single device or small array projects are anticipated to be low given the relative size/scale of devices (Copping 2018). For example, at the FORCE site a single two-megawatt OpenHydro turbine occupies ~ 1/1,000th of the cross-sectional area in the Minas Passage (Figure 1). A full evaluation of the risks of tidal stream energy devices, however, will not be possible until more are tested over a longer-term period with monitoring that documents local impacts, considers far-field and cumulative effects, and adds to the growing global knowledge base.

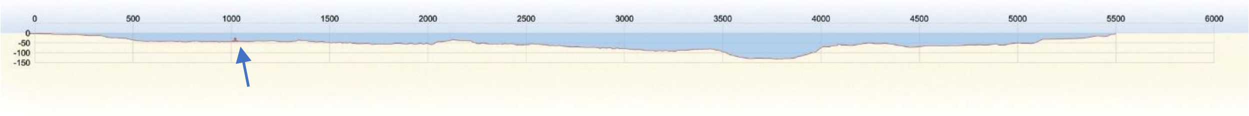

Figure 1: The scale of a single turbine (based on the dimensions of the OpenHydro turbine deployed by CSTV, indicated by the red dot and above the blue arrow) in relation to the cross-sectional area of the Minas Passage. The Passage reaches a width of ~ 5.4 km and a depth of 130 m.

International Experience & Cooperation

The research and monitoring being conducted at the FORCE test site is part of an international effort to evaluate the risks tidal energy poses to marine life (Copping 2018; Copping and Hemery 2020). Presently, countries such as China, France, Italy, the Netherlands, South Korea, the United Kingdom, and the United States (Marine Renewables Canada 2018) are exploring tidal energy, supporting environmental monitoring and innovative R&D projects. Tidal energy and other marine renewable energy (MRE) technologies such as tidal range, tidal current, wave, and ocean thermal energy offer significant opportunities to replace carbon fuel sources in a meaningful and permanent manner. Some estimates place MRE's potential as exceeding current human energy needs (Lewis et al. 2011; Gattuso et al. 2018). Recent research includes assessments of operational sounds on marine fauna (Schramm et al. 2017; Lossent et al. 2018; Robertson et al. 2018; Pine et al. 2019), the utility of PAM sensors for monitoring marine mammal interactions with turbines (Malinka et al. 2018) and collision risk (Joy et al. 2018b), demonstrated avoidance behavior by harbour porpoise around tidal turbines (Gillespie et al. 2021), a synthesis of known effects of marine renewable energy devices on fish (Copping et al. 2021), and the influence of tidal turbines on fish behavior (Fraser et al. 2018).

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[11] To learn more about this announcement, see: https://www.canada.ca/en/natural-resources-canada/news/2018/09/minister-sohi-announces-major-investment-in-renewable-tidal-energy-that-will-power-2500-homes-in-nova-scotia.html.

Through connections to groups supporting tidal energy demonstration and R&D, FORCE is working to inform the global body of knowledge pertaining to environmental effects associated with tidal power projects. This includes participation in the Bay of Fundy Ecosystem Partnership[12], TC114[13], the Atlantic Canadian-based Ocean Supercluster[14], and OES-Environmental[15].

FORCE will continue to work closely with OES-Environmental and its members to document and improve the state of knowledge about the interactions of MRE devices interactions with the marine environment. For instance, OES-Environmental is pursuing the development of new research topics for the 2024 State of the Science Report related to i) knowledge of environmental effects as the tidal energy industry scales up from single devices to arrays, ii) understanding the cumulative impacts of marine renewable energy with other anthropogenic effects, and iii) an ecosystem approach for understanding environmental effects, including interactions between trophic levels, between ecosystems and between ecosystem services. Dr. Hasselman is involved in the development of all three of these topics but is leading the effort to understand the environmental effects of 'scaling up'; this topic is currently being developed as a manuscript intended for submission to a peer-reviewed journal for publication.

FORCE Monitoring Activities

FORCE has been leading site-level monitoring for several years, focusing on a variety of valued ecosystem components. FORCE's previous environmental effects monitoring program (2016-2020) was developed in consultation with SLR Consulting (Canada)[16] and was strengthened by review and contributions by national and international experts and scientists, DFO, NSECC, and FORCE's EMAC. The most recent version of the EEMP (2021-2023) was developed in consultation with Atlantis Watershed Consultants Ltd. with input from national and international experts, including FORCE's EMAC, and was submitted to regulators for approval. The 2021-2023 EEMP was modified from the 2016-2020 EEMP based on results of previous monitoring activities, experience and lessons learned. This is consistent with the adaptive management approach inherent to the FORCE EEMP – the process of monitoring, evaluating and learning, and adapting (AECOM 2009) that has been used at the FORCE site since its establishment in 2009.[17]

FORCE's EEMP currently focuses on the impacts of operational tidal stream energy devices on lobster, fish, marine mammals, and seabirds as well as the impact of device-produced sound. Overall, these research and monitoring efforts, detailed below, were designed to test the

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[12] BoFEP is a 'virtual institute' interested in the well-being of the Bay of Fundy. To learn more, see www.bofep.org.
[13] TC114 is the Canadian Subcommittee created by the International Electrotechnical Commission (IEC) to prepare international standards for marine energy conversion systems. Learn more: tc114.oreg.ca.
[14] The OSC was established with a mandate to "better leverage science and technology in Canada's ocean sectors and to build a digitally-powered, knowledge-based ocean economy." Learn more: www.oceansupercluster.ca.
[15] OES Environmental was established by the International Energy Agency (IEA) Ocean Energy Systems (OES) in January 2010 to examine environmental effects of marine renewable energy development. Member nations include: Australia, China, Canada, Denmark, France, India, Ireland, Japan, Norway, Portugal, South Africa, Spain, Sweden, United Kingdom, and United States. Further information is available at https://tethys.pnnl.gov.
[16] This document is available online at: www.fundyforce.ca/document-collection.
[17] The adaptive management approach is necessary due to the unknowns and difficulties inherent with gathering data in tidal environments such as the Minas Passage and allows for adjustments and constant improvements to be made as knowledge about the system and environmental interactions become known. This approach has been accepted by scientists and regulators.

predictions made in the FORCE EA. Over the course of the 2016-2020 EEMP, FORCE completed approximately:

- 564 hours of hydroacoustic fish surveys;
- more than 5,083‘C-POD’ (marine mammal monitoring) days;
- bi-weekly shoreline observations;
- 49 observational seabird surveys;
- four drifting marine sound surveys and additional bottom-mounted instrument sound data collection; and
- 11 days of lobster surveys.

Since the beginning of the 2021-2023 EEMP, FORCE has undertaken:

- 8 days of lobster surveys;
- a preliminary radar feasibility study to monitor for seabirds; and
- bi-weekly shoreline observations

The following pages provide a summary of the site-level monitoring activities conducted at the FORCE site during January-March 2023, including data collection, data analyses performed, initial results, and lessons learned, that builds on activities and analyses from previous years. Where applicable, this report also presents analyses that have integrated data collected through developer and FORCE monitoring programs to provide a more complete understanding of device-marine life interactions.

Monitoring Objectives

The overarching purpose of environmental monitoring is to test the accuracy of the environmental effect predictions made in the original EA. These predictions were generated through an evaluation of existing physical, biological, and socioeconomic conditions of the study area, and an assessment of the risks the tidal energy demonstration project poses to components of the ecosystem.

A comprehensive understanding of device-marine life interactions will not be possible until device-specific and site-level monitoring efforts are integrated, and additional data is collected in relation to operating tidal stream energy devices. Further, multi-year data collection will be required to consider seasonal variability at the FORCE test site and appropriate statistical analyses of this data will help to obtain a more complete understanding of device-marine life interactions.

Table 1 outlines the objectives of the site-level monitoring activities conducted at the FORCE demonstration site. FORCE led site-level monitoring summaries will be updated as devices are scheduled for deployment at FORCE. At this time, and considering the scale of device deployments in the near-term at FORCE, it is unlikely that significant effects in the far-field will be measurable (SLR Consulting 2015). Far-field studies such as sediment dynamics will be deferred until such time they are required. However, recent discussions with scientists serving on FORCE’s EMAC suggests that the natural variability inherent to the upper Bay of Fundy ecosystem far exceeds what could be measured by far-field monitoring efforts. Moreover, the scale of tidal power development would need to surpass what is possible at the FORCE tidal demonstration site to extract sufficient energy from the system to have any measurable effects. In short, far-field monitoring would be futile unless tidal power development transitions from demonstration scale to commercial arrays. As more devices are scheduled for deployment at the FORCE site and as monitoring techniques are improved, monitoring protocols will be revised in keeping with the adaptive management approach. These studies will be developed in consultation with FORCE's EMAC, regulators, and key stakeholders.

Table 1: The objectives of each of the environmental effects monitoring activities, which consider various Valued Ecosystem Components (VECs), led by FORCE.

FORCE Environmental Effects Monitoring VEC	***Objectives***
Lobster	● to determine if the presence of a tidal stream energy device affects commercial lobster catches
Fish	● to test for indirect effects of tidal stream energy devices on water column fish density and fish vertical distribution ● to estimate probability of fish encountering a device based on fish density proportions in the water column relative to device depth in the water column
Marine Mammals	● to determine if there is permanent avoidance of the study area during device operations ● to determine if there is a change in the distribution of a portion of the population across the study area
Marine Sound (Acoustics)	● to conduct ambient sound measurements to characterize the soundscape prior to and following deployment of the tidal stream energy device
Seabirds	● to understand the occurrence and movement of bird species in the vicinity of tidal stream energy devices ● to confirm FORCE's Environmental Assessment predictions relating to the avoidance and/or attraction of birds to tidal stream energy devices

Lobster

FORCE conducted a baseline lobster catchability survey in fall 2021 (Fishermen and Scientists Research Society (FSRS), 2023) following the study design developed by TriNav Fisheries Consultants Ltd. in 2019. This study design was implemented in partnership with the FSRS (Figure 1) and with the assistance of a local lobster fisher. The catch-and-release survey included the deployment of experimental lobster traps at 18 locations distributed over three sites (i.e., 'Near-Control site', 'Far-Control site', and 'Impact site') in the vicinity of the FORCE tidal demonstration area. The baseline survey occurred prior to the fall 2021 commercial lobster fishery in Minas Passage, was conducted over two phases that coincided with neap tidal conditions, and quantified the number of lobsters captured and Catch Per Unit Effort (CPUE) for each site.

The survey captured 582 lobsters, and a subset of these (n=477) were tagged with conventional t-bar tags prior to being released to understand the extent of lobster movement in Minas Passage. Results indicated a 'high' catchability rate (i.e., CPUE ≥ 2.4 kg/trap haul) during the fall survey – consistent with a prior baseline survey at the FORCE site in 2017 (NEXUS Coastal Resource Management Ltd. 2017), and comparable to available commercial landings data provided by Fisheries and Oceans Canada (DFO). Statistical analyses revealed a marginally significant (p=0.052) difference in the number of lobsters captured among sites, with the Impact site (i.e., the intended deployment location for proposed tidal projects at FORCE) having on average fewer lobsters (6.2 lobster/trap haul) than either the Near Control site (8.46 lobster/trap haul) or Far Control site (8.92 lobster/trap haul). These differences were not reflected in the CPUE data, as non-significant differences were observed among these sites. Tagged lobsters that were recaptured during the fall commercial lobster fishery and reported to FORCE suggest wide variation in the movement of individuals over relatively short periods of time.

Commercial landings data provided by DFO revealed a marked increase in Lobster Fishing Area 35 (including grid 17 where the FORCE site is located) (Figure 2). This could be associated with a northward shift in the species distribution as a consequence of increasing water temperature in the Gulf of Maine, and its effects on lobster movement, survival and recruitment to the fishery. A repeat of this study design in the presence of an operational turbine deployed at the FORCE site is required to test whether it has an effect on lobster catchability. The 2021 baseline lobster report is provided in Appendix I.

Figure 1: Lobster scientist from the Fishermen and Scientist Research Society showing a tagged lobster prior to release.

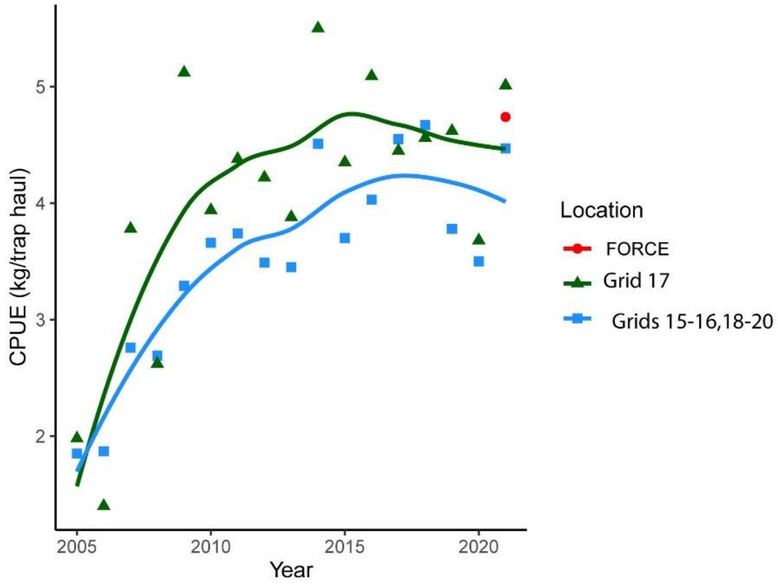

Figure 2: Scatterplot and loess (locally weighted smoothing) regression of CPUE (kg/trap haul) for the fall commercial lobster fishery (2005-2021) from LFA 35. The CPUE data from the FORCE 2021 lobster survey is consistent with existing commercial landings data collected from Grid 17 and other grids within LFA 35.

Fish

FORCE has been conducting mobile fish surveys since May 2016 to test the EA prediction that tidal stream energy devices are unlikely to cause substantial impacts to fishes at the test site (AECOM 2009). To that end, the surveys are designed to:

- test for indirect effects of tidal stream energy devices on water column fish density and fish vertical distribution; and
- estimate the probability of fish encountering a device based on any ‘co-occurrence’ relative to device depth in the water column.

Moreover, these surveys follow a ‘BACI’ (Before/After, Control/Impact) design to permit a comparison of data collected before a device is installed with data collected while a device is operational at the FORCE site, and in relation to a reference site along the south side of the Minas Passage. These 24-hour mobile surveys encompass two tidal cycles and day/night periods using a scientific echosounder, the Simrad EK80, mounted on a vessel, the Nova Endeavor (Huntley’s Sub-Aqua Construction, Wolfville, NS). This instrument is an active acoustic monitoring device and uses sonar technology to detect fish by recording reflections of a fish’s swim bladder.

Analyses of hydroacoustic fish surveys completed during baseline studies in 2011 and 2012 (Melvin and Cochrane 2014) and surveys during May 2016 – August 2017 (Daroux and Zydlewski 2017) evaluated changes in fish densities in association with diel stage (day/night), tidal stage (ebb/flood), and device presence or absence (an OpenHydro turbine was present November 2016 – June 2017). Results support the EA prediction that tidal stream devices have minimal impact on marine fishes. However, additional surveys in relation to an operating device are required to fully test this prediction.

In 2019, the University of Maine conducted a thorough analysis for 15 fish surveys conducted by FORCE from 2011-2017. The hydroacoustic data set included six 'historical' surveys conducted between August 2011 and May 2012, and nine 'contemporary' surveys conducted between May 2016 and August 2017. The analyses included comparisons of fish presence/absence and relative fish density with respect to a series of temporal (historical vs. contemporary, or by survey), spatial (CLA vs. reference study area, or by transect) and environmental (tide phase, diel state, or with/against predicted tidal flow) explanatory variables. The report identified a statistically significant difference in fish presence/absence and relative fish density between the historical and contemporary data sets that may be attributable to differences in the survey design/execution between the time periods, or could reflect changes in fish usage of the site. As such, remaining analyses were restricted to the contemporary data sets. The results revealed that: i) data collection during the ebb tide and at night are important for understanding fish presence in the CLA, ii) various explanatory variables and their additive effects should be explored further, and iii) increasing the frequency of surveys during migratory periods (consecutive days in spring/fall) may be required to understand patterns and variability of fish presence and density in Minas Passage. Importantly, the report suggested a statistically significant difference in fish presence/absence and relative density between the CL and reference site, suggesting that the reference site may not be sufficiently representative to serve as a control for the CLA, and for testing the effects of an operational device on fish density and distribution in Minas Passage. Additional work is underway using data from eight additional contemporary fish surveys (2017-2018) to determine whether this finding is biologically meaningful, or whether it is simply a statistical artefact of how the data was aggregated in the original analysis.

Because complex hydrodynamic features of the Minas Passage introduce turbulence and bubbles into the water column that interfere with the use of hydroacoustics, FORCE's mobile fish surveys have been optimized for collecting data during the best neap tidal cycle per month when turbulence is greatly reduced. However, this approach limits the number of surveys that can be conducted, and regulators have suggested that the scope of the program be expanded so that survey results are more representative of how fish use the Minas Passage. To that end, FORCE conducted multiple fish surveys during each of three neap tidal cycles in fall 2020 (i.e., September 25, 27, 29; October 7, 9, 13; and October 24, 26, 29) to determine whether variation in fish density and distribution for any given survey within a neap cycle was representative of the other surveys conducted during that same time frame. Previous work comparing stationary and mobile hydroacoustic surveys in Minas Passage found that the temporal representative range of a 24-hr mobile was approximately three days (Viehman et al. 2019).

A recent study (Viehman et al. (2022), Appendix II) examined entrained air contamination in echosounder data collected at the FORCE test site. It found that fish abundance estimates in the lower 70% of the water column and current speeds less than 3 m/s were well represented in that there was little contamination of the data set from entrained air. However, undersampling of the upper water column and faster speeds strongly affected fish abundance estimates especially during strong spring tides. This means that data collected during neap tides are more likely to yield a more accurate picture of fish abundance and distribution than those collected during spring tides. The study also highlighted how estimates of fish abundance may be affected differently depending on where fish are in the water column. For example, (hypothetical) fish located at mid-depths were omitted from the data more often as current speeds increased. These findings indicate a complex and dynamic ecosystem where the interactions of water movement and fish distribution affect our ability to infer how fish populations may interact with tidal power devices in the Minas Passage. The use of acoustic telemetry being studied under the RAP program could be used concurrently with echosounders to fill gaps in datasets and optimize what can be learned about fish abundance and distribution at tidal energy sites.

Another issue with the entrained air found in high flow environments is the need to remove the contaminated data prior to analysis which is often a tedious and time-consuming process. Existing algorithms used to identify the depth-of-penetration of entrained air are insufficient for a boundary that is discontinuous, depth-dynamic, porous, and varies with tidal flow speed. Using a case study from data obtained at the FORCE test site a recent study (Lowe et al. (2022), Appendix III) described the development and application of a deep machine learning model called Echofilter. Echofilter was found to be highly responsive to dynamic range of turbulence conditions in the data and produced an entrained-air boundary line with an average error of less than half that of the existing algorithms. The model had a high level of agreement with human data trimming. This resulted in 50% reduction in the time required for manual edits to the data set when using currently available algorithms to trim the data.

FORCE is currently working towards the development of a comprehensive fish synthesis that will bring together existing knowledge of fish distribution, abundance, and use of the Minas Passage using existing literature from stock assessments, prior hydroacoustic surveys, acoustic telemetry-based surveys, as well as other relevant sources of information. This synthesis will focus on species of conservations concern, cultural relevance, and commercial and recreational value. The results of this synthesis project will be available in 2023 and will help to determine the extent to which questions regarding fish and tidal energy project permitting have been answered and identifying remaining knowledge gaps. Dr. Graham Daborn at Acadia University is leading this work and a final report is expected in 2023.

Marine Mammals

Since 2016, FORCE has been conducting two main activities to test the EA prediction that project activities are not likely to cause significant adverse residual effects on marine mammals within the FORCE test site (AECOM 2009):

- passive acoustic monitoring (PAM) using ‘click recorders’ known as C-PODs; and
- an observation program that includes shoreline, stationary, and vessel-based observations.

Passive Acoustic Monitoring

The first component of FORCE’s marine mammal monitoring program involves the use of PAM mammal detectors known as C-PODs, which record the vocalizations of toothed whales, porpoises, and dolphins.[18] The program focuses mainly on harbour porpoise – the key marine mammal species in the Minas Passage that is known to have a small population that inhabits the inner Bay of Fundy (Gaskin 1992). The goal of this program is to understand if there is a change in marine mammal presence in proximity to a deployed tidal stream energy device and builds upon baseline C-POD data collection within the Minas Passage since 2011.

From 2011 to early 2018, more than 4,845 ‘C-POD days’[19] of data were collected in the Minas Passage. Over the study period, it was found that harbour porpoise use and movement varies over long (i.e., seasonal peaks and lunar cycles) and short (i.e., nocturnal preference and tide

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[18] The C-PODs, purchased from Chelonia Limited, are designed to passively detect marine mammal ‘clicks’ from toothed whales, dolphins, and porpoises.

[19] A ‘C-POD day’ refers to the number of total days each C-POD was deployed times the number of C-PODs deployed.

stage) timescales. This analysis, completed by Sea Mammal Research Unit (Canada) (Vancouver, BC), showed some evidence to suggest marine mammal exclusion within the vicinity of CSTV turbine when it was operational (November 2016 – June 2017) (Joy et al. 2018a). This analysis revealed that the C-PODs in closest proximity to the turbine (230 m and 210 m distance) had reduced frequency of detections, but no evidence of site avoidance with a device present and operating. These findings also revealed a decrease in detections during turbine installation activities, consistent with previous findings (Joy et al. 2017), but requiring additional data during an operational device to permit a full assessment of the EA predictions.

This monitoring program demonstrates the prevalence of harbour porpoise at FORCE, with the species being detected on 98.8% of the 1,888 calendar days since monitoring with C-PODs commenced in 2011. Harbour porpoise detections at FORCE varies seasonally, with peak activity occurring during May – August, and lowest detections during December – March. Harbour porpoise detections also vary spatially, with C-PODs deployed at locations W2 and S2 recording the greatest detection rates, and D1 values typically low. Mean lost time across C-PODs, due to ambient flow noise saturating the detection buffer on the C-POD, averaged 22.6%. Interestingly, an analysis against past datasets that controlled for time of year, indicated that the effects of the non-operational CSTV turbine structure had no detectable effect on the rate of harbour porpoise detection.

SMRU provided their 4th year final report of harbour porpoise monitoring using C-PODs at the FORCE test site (Palmer et al. 2021). The report describes the results of C-POD deployments #11-12 (i.e., 1,043 days of monitoring from August 2019 – September 2020), and places the results in the broader context of the overall marine mammal monitoring program at FORCE. The final report includes summary data that revealed that harbour porpoise was detected on a least one C-POD every day, with a median value of 11 and 17 minutes of porpoise detections per day during deployments 11 and 12, respectively. The mean percent lost time due to ambient flow and sediment noise was 19.5% and 23.8%, respectively, comparable to previous deployments. Overall, the final report supports previous findings of monitoring activities that harbour porpoise are prevalent at the FORCE test site.

The final report also reiterates that sufficient baseline data has been collected to meet the goals of the EEMP. As such, FORCE has recommended in its 2021-2023 EEMP proposal that the collection of additional baseline harbour porpoise data using C-PODs be suspended until an operational device is deployed at the FORCE site. Upon receiving confirmation that a device will be deployed at the tidal demonstration area, FORCE will deploy C-PODs prior to the construction phase to begin collecting data and assessing any changes to harbour porpoise detections in the presence of an operational device. FORCE is currently working with SMRU to continue with this monitoring program when operational devices are present.

Harbor porpoise (Phocoena phocoena) monitoring at the FORCE Test Site, Canada featured on Tethys (by FORCE and SMRU): https://tethys.pnnl.gov/stories/harbor-porpoise-phocoena-phocoena-monitoring-force-test-site-canada

Observation Program

FORCE's marine mammal observation program in 2023 includes observations made during bi-weekly shoreline surveys, stationary observations at the FORCE Visitor Centre, and marine-based observations during marine operations. All observations and sightings are recorded, along with weather data, tide state, and other environmental data. Any marine mammal observations will be shared with SMRU Consulting to support validation efforts of PAM activities when C-PODs are deployed.

FORCE uses an Unmanned Aerial Vehicle (UAV) for collecting observational data along the shoreline and over the FORCE site using transects by programming GPS waypoints in the UAV to standardize flight paths. FORCE staff received training to operate FORCE's UAV and have acquired UAV pilot certification by successfully passing the 2019 Canadian Drone Pilot Basic Operations Examination, administered by Transport Canada. These staff are now licensed to safely operate the UAV at the FORCE site. FORCE also hosts a public reporting tool that allows members of the public to report observations of marine life: mmo.fundyforce.ca

Marine Sound (Acoustics)

Marine sound – often referred to as 'acoustics' or 'noise' – monitoring efforts are designed to characterize the soundscape of the FORCE test site. Data collected from these monitoring efforts will be used to test the EA predictions that operational sounds produced from functioning tidal stream energy devices are unlikely to cause mortality, physical injury or hearing impairment to marine animals (AECOM 2009).

Results from previous acoustic analyses completed at the FORCE site indicate that the CSTV turbine was audible to marine life at varying distances from the turbine, but only exceeded the threshold for behavioural disturbance at very short ranges and during particular tide conditions (Martin et al. 2018). This is consistent with findings at the Paimpol-Bréhat site in France where an OpenHydro turbine was also deployed – data suggests that physiological trauma associated with a device is improbable, but that behavioural disturbance may occur within 400 m of a device for marine mammals and at closer distances for some fish species (Lossent et al. 2018).

In previous years, regulators have encouraged FORCE to pursue integration of results from multiple PAM instruments deployed in and around the FORCE test site. To that end, FORCE, and its partner JASCO Applied Sciences (Canada) Ltd. pursued a comparative integrated analysis of sound data collected by various hydrophones (i.e., underwater sound recorders) deployed autonomously and mounted on the CSTV turbine. That work revealed that flow noise increased with the height of the hydrophone off the seabed but had little effect on hydrophones deployed closer to the sea floor. The comparative integrated analysis provided valuable information about future marine sound monitoring technologies and protocols while building on previous acoustics analyses at the FORCE site.

In its 2021-2023 EEMP proposal, FORCE has recommended conducting a test survey in the presence of an operational device using an internationally recognized standard methodology for monitoring sound (International Electrotechnical Commission 2019). This would permit the feasibility of the approach to be tested in the Minas Passage to ensure the method can be implemented as described. This work is pending an operational device being deployed at the FORCE tidal demonstration area. FORCE will work with JASCO to collect and analyze marine sound data once a device is deployed.

Seabirds

FORCE's seabird monitoring program is designed to test the EA prediction that project activities are not likely to cause adverse residual effects on marine birds within the FORCE test area (AECOM 2009). However, there has been limited opportunity to determine potential effects of an operational device on seabirds at the FORCE test site and to test the EA predictions.

Since 2011, FORCE and Envirosphere Consultants Ltd. (Windsor, NS) have collected observational data from the deck of the FORCE Visitor Centre, documenting seabird species presence, distribution, behaviour, and seasonality throughout the FORCE site (Envirosphere Consultants Ltd. 2017). Envirosphere Consultants Ltd. recently published the results of their monitoring from 2010-2012 and demonstrated that the species and seasonal cycles of seabirds in Minas Passage reflect patterns that are typical of the inner Bay of Fundy and the northeast Atlantic coast of North American. The report also highlights the importance of the Minas Passage as a migratory pathway for black scoter (*Melanitta americana*) and Red-throated loon (*Gavia stellata*).

In 2019, FORCE commissioned Envirosphere Consultants Ltd. and Dr. Phil Taylor (Acadia University) to synthesize the results of its observational seabird surveys (2011-2018) at the FORCE test site, and to evaluate advanced statistical techniques for analysing seabird count data in relation to environmental predictor variables. The seabird count data were examined using Generalized Additive Models (GAMs) to characterize seabird abundance and to better understand the potential impacts of tidal stream energy devices on seabirds at the FORCE test site. The results of the analyses revealed that overall model fit is suitable to characterize count data for some species, and that there are clear patterns of effects of time of year, wind speed and direction, tide height and time of day on the number of seabirds observed. However, the analyses also revealed that not all species reported at FORCE have been observed frequently enough to be modelled effectively using the GAM approach. This is due in part to the variability in count data that is particularly relevant for modelling abundance of migratory species that are only present at the FORCE site for brief periods during annual migrations. This is consistent with observational data collected over the course of these surveys that have demonstrated that the FORCE site has a lower abundance of seabirds in relation to other areas of the Bay of Fundy, and even other regions of Atlantic Canada. Given these results, the report recommends that future monitoring and analyses focus on locally resident species (i.e., great black-backed gull, herring gull, black guillemot, and common eider) so that the EA predictions can be tested most effectively. This work contributes to the development of appropriate analytical methods for assessing the impacts of tidal power development in the Minas Passage on relevant seabird populations and supports the continued responsible development of tidal energy at FORCE.

In 2022 FORCE began working with Strum Consulting to test radar-based seabird monitoring capabilities and to adapt existing data processing algorithms and statistical analysis tools for quantifying seabird use of the FORCE site. Strum provided a technical report which highlights challenges and options to move forward with this approach. Challenges with the quality of the radar data limited the assessment and the full study could not be completed. This feasibility study is continuing in 2023 with FORCE providing a new radar data set to Strum to work through some of the challenges in locating avian targets.

Developer Monitoring Activities

While FORCE completes site-level monitoring activities at the FORCE site, device specific monitoring is led by individual berth holders. Like the FORCE monitoring programs, the developer monitoring plans and reports undergo review by FORCE's EMAC and regulators.

In September 2018, it was confirmed that that CSTV turbine rotor was not spinning. Since that time, CSTV had been providing written confirmation to regulators monthly that the turbine is not operational by monitoring its status during the peak tidal flow of each month. However, because of the insolvency of OpenHydro Technology Ltd., all reporting activities by CSTV ceased as of March 1, 2019. Data collection from the turbine-mounted ADCPs to confirm the turbine is no longer spinning was managed and reported by FORCE to regulators monthly from March 2019 – May 2020 but was discontinued following an amendment to this requirement.

As additional developer, device-specific environmental effects monitoring programs are required and implemented for deployed tidal stream devices, berth holder updates will be included as appendices to future reports.

Other FORCE Research Activities

Risk Assessment Program

The Risk Assessment Program (RAP) for tidal stream energy is a collaborative effort between FORCE, academic partners, First Nations, and industry to advance our understanding of the environmental risks of tidal stream energy development in Minas Passage. The greatest potential risk of tidal stream energy device operations is believed to be from collisions between marine animals and turbine blades (Copping and Hemery 2020). However, these types of interactions are difficult to observe directly due to the environmental conditions under which they would occur (i.e., fast flowing, turbulent waters) and using the suite of environmental monitoring instrumentation currently available (i.e., standard oceanographic and remote sensing instruments intended for use in more benign marine conditions) (Hasselman et al. 2020), but can be modeled using appropriate baseline data. The objective of the RAP program is to develop statistically robust encounter rate models for migratory and resident fishes with tidal stream energy devices in the Bay of Fundy using a combination of physical oceanographic data related to flow and turbulence in the Minas Passage and acoustic tag detection data for various fish species curated by the Ocean Tracking Network (OTN) at Dalhousie University.

Recent research has revealed how hydrodynamics (flow and turbulence-related features) in tidal stream environments can influence the distribution of marine animals, including fish (Lieber et al. 2018, 2019; McInturf et al. 2019). The Minas Passage is characterized by a series of turbulent hydrodynamics features (i.e., vortices, eddies, whirlpools, wakes, and shear currents) that could impact the spatiotemporal distribution of various fishes. The RAP uses ADCP data combined with data from a high-resolution radar network to create the first spatiotemporal flow atlas of the Minas Passage to understand these hydrodynamic features. Concurrently, acoustic tag detection data for various migratory and resident fish species in the Bay of Fundy that is curated by OTN was compiled and is being analysed to understand their spatiotemporal distributions. The hydrodynamic and acoustic tag detection data will be combined with information about device specific parameters (e.g., turbine blade length, swept area, turbine height off the seabed) to develop encounter rate models for various fish species. These models will then be refined and validated through a series of acoustic tagging efforts, ultimately leading to the development of a user-friendly Graphical User Interface (GUI) similar to what is available for the offshore wind energy industry in the United Kingdom (McGregor et al. 2018). Ultimately, the RAP will contribute towards improving our understanding of the risks of tidal stream energy development for fishes of commercial, cultural, and conservation importance in the Bay of Fundy, and will assist in the development of future environmental effects monitoring programs.

Since the program commenced in April 2020, OTN has facilitated access to acoustic tag detection data from 22 contributors (17 projects), covering nine fish species in the Bay of Fundy (i.e., alewife (*Alosa pseudoharengus*), American shad (*A. sapidissima*), American eel (*Anguilla rostrata*), Inner Bay of Fundy Atlantic salmon (*Salmo salar*), Atlantic sturgeon (*Acipenser oxyrhinchus oxyrhinchus*), Atlantic tomcod (*Microgadus tomcod*), spiny dogfish (*Squalus acanthias*), striped bass (*Morone saxatilis*), and white shark (*Carcharodon carcharias*)). FORCE has also established a high-resolution radar network in Minas Passage and has begun quantifying hydrodynamic features (turbulence, flow etc.) of Minas passage (Figure 3). The integration of physical habitat variables with acoustic tag detection data commenced in 2021, including the development of species distribution models for each species and species distribution maps. Fish tagging was undertaken in 2021 and 2022 in collaboration with the Mi'kmaw Conservation Group (MCG), Acadia University, and DFO Science to validate predictions of the species distribution models (Figure 4). Fish tagging efforts focused on alewife, American shad, Atlantic sturgeon, spiny dogfish, and Inner Bay of Fundy Atlantic salmon smolts. Additional tagging is planned for 2023 and will focus on alewife, American shad and Inner Bay of Fundy Atlantic salmon smolts.

In 2021 and 2022, the FORCE array of acoustic receivers consisted of 12 stations set approximately 150 metres apart, and extended from the FORCE site out towards the middle of Minas Passage. However, this resulted in incomplete coverage of Minas Passage for detecting tagged fish. For 2023, FORCE and OTN are collaborating to establish more complete coverage of the area by merging our respective lines of acoustic receivers into a 24 station array to span the vast majority of Minas Passage (Figure 5), thereby increasing the probability of detecting tagged fish as they navigate through the area. This array is planned to be deployed in spring 2023 and remain in place until the fall.

Figure 3: One of two high-resolution radars constructed near the FORCE site to be used for the Risk Assessment Program.

Figure 4: Acoustic tagging of spiny dogfish from the Minas Basin by RAP partner organization Mi'kmaw Conservation Group in 2022.

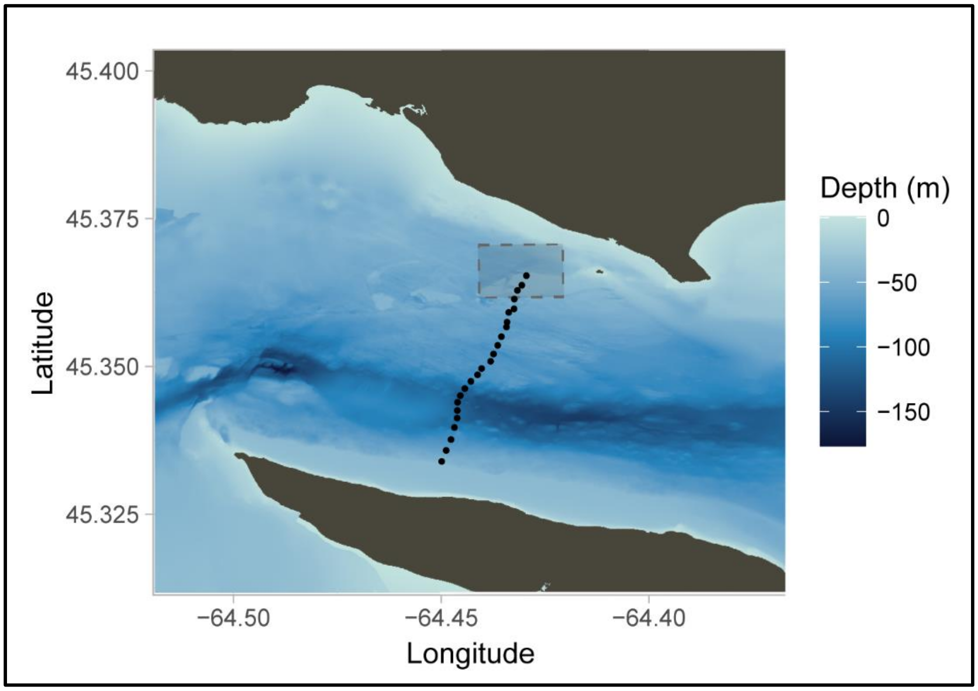

Figure 5: Planned acoustic receiver array deployment configuration (24 stations) in Minas Passage in 2023. This more thorough coverage of Minas Passage for detecting tagged fish is made possible through collaboration between FORCE and OTN.

Fundy Advanced Sensor Technology (FAST) Activities

FORCE's Fundy Advanced Sensor Technology Program is designed to advance capabilities to monitor and characterize the FORCE site. Specifically, the FAST Program was designed to achieve the following objectives:

1) To advance capabilities of site characterization;
2) To develop and refine environmental monitoring standards and technologies; and
3) To enhance marine operating methodologies.

FAST combines both onshore and offshore monitoring assets. Onshore assets include a meteorological station, video cameras, an X-band radar system, and tide gauge. Offshore assets include modular subsea platforms for both autonomous and cabled data collection and a suite of instrumentation for a variety of research purposes. Real-time data collected through FAST assets will be broadcasted through the Canadian Integrated Ocean Observing System (CIOOS) later this year. Static ADCP data is currently available on the CIOOS website.[20]

Platform Projects

The first and largest of the FAST platforms houses an instrument called the Vectron. Developed in partnership with Nortek Scientific (Halifax, NS), Memorial University (St. John's, NL), and Dalhousie University (Halifax, NS), the Vectron is the world's first stand-alone instrument to remotely measure, in high resolution, turbulence in the mid-water column. Measurements and analysis from the Vectron will help tidal energy companies to better design devices, plan marine operations, and characterize the tidal energy resource.

A smaller platform called FAST-3 was equipped with an upward looking echosounder and deployed during 2017-2018 to monitor fish densities at the FORCE site. FORCE and its partners, including Echoview Software completed data processing and analysis in 2019. This data was integrated with the mobile hydroacoustic surveys that FORCE conducts as part of its EEMP to evaluate the temporal and spatial representativeness of each method and to determine the degree to which results were corroborative (Figure 6). Although the spatial representative range of the stationary results could not be determined from the mobile data, it did reveal strong tidal and diel periods in fish density estimates at the site, with greater variation over shorter time frames than over the course of a year. These findings reinforce the importance of 24-hr data collection periods in ongoing monitoring efforts. The report reveals that collecting 24 hours of data allows the tidal and diel variability to be quantified and isolated from the longer-term trends in fish density and distribution that need to be monitored for testing the EA predictions. This project was funded by Natural Resources Canada (NRCan), the NSNRR, and the Offshore Energy Research Association (now Net Zero Atlantic).

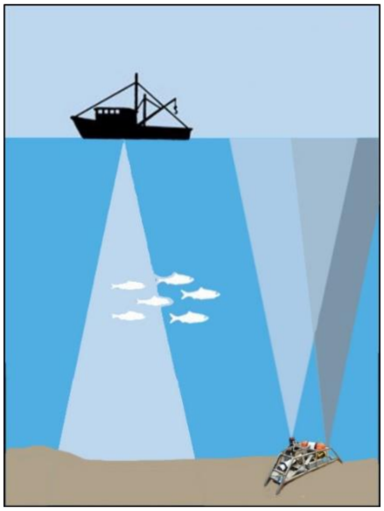

Figure 6: A representation of the data collection methods of the FORCE site-level fish EEMP and the FAST-3 platform.

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[20] This is available online at: https://catalogue.cioosatlantic.ca/dataset/ca-cioos_db15458d-df2c-4efb-b5a0-791e7561a0cb

Fish Tracking

To enhance fish monitoring and to expand its data collection capacity, FORCE partnered with the Ocean Tracking Network (OTN)[21] and attached one VEMCO[22] fish tag receiver (a VR2W receiver) to each C-POD mooring/SUBS (Streamlined Underwater Buoyancy System) package (see above). These receivers are used to supplement OTN's ongoing data collection program within the Minas Passage and are referred to as 'Buoys of Opportunity.' Upon retrieval of the C-PODs and receivers, instruments are shared with OTN where data is offloaded prior to redeployment. This effort will support increased knowledge of fish movement within the Minas Passage, which has applicability beyond tidal energy demonstration, as well as complement FORCE's hydroacoustic data collection efforts that do not allow for species identification. No C-POD mooring/SUBS have been deployed since 2020, however ongoing data collection for fish monitoring is occurring through the RAP acoustic receiver line.

OTN data managers are in the process of acquiring information, including species identification, and sharing this with FORCE. Initial results show that the OTN receivers deployed by FORCE have detected tags from the following projects:

- Maritimes Region Atlantic salmon marine survival and migration (Hardie, D.C., 2017);
- Quebec MDDEFP Atlantic Sturgeon Tagging (Verreault, G., Dussureault, J., 2013);
- Gulf of Maine Sturgeon (Zydlewski, G., Wippelhauser, G. Sulikowski, J., Kieffer, M., Kinnison, M., 2006);
- OTN Canada Atlantic Sturgeon Tracking (Dadswell, M., Litvak, M., Stokesbury, M., Bradford, R., Karsten, R., Redden, A., Sheng, J., Smith, P.C., 2010);
- Darren Porter Bay of Fundy Weir Fishing (Porter, D., Whoriskey, F., 2017);
- Movement patterns of American lobsters in the Minas Basin, Minas Passage, and Bay of Fundy Canada (2017);
- Shubenacadie River Monitoring Project: Tomcod (Marshall, J., Fleming, C., Hunt, A., and Beland, J., 2017);
- MA Marine Fisheries Shark Research Program (Skomal, G.B., Chisholm, J., 2009);
- UNB Atlantic Sturgeon and Striped Bass tracking (Curry, A., Linnansaari, T., Gautreau, M., 2010);
- Inner Bay of Fundy Striped Bass (Bradford, R., LeBlanc, P., 2012);
- Minas Basin Salmon Kelt (McLean, M., Hardie, D., Reader, J., Stokesbury, M.J.W., 2019);
- New York Juvenile White Shark Study (Tobey Curtis)
- Massachusetts White Shark Research Program (Greg Skomal); and
- St. Lawrence River Fish Monitoring (Valiquette, E., Légaré, J., Soulard, Y. 2020)

Further information about these Buoys of Opportunity, and the projects listed above, can be found on OTN's website: https://members.oceantrack.org/project?ccode=BOOFORCE

Starting in 2018, FORCE has worked in collaboration with Dr. Mike Stokesbury at Acadia University to install additional VEMCO receivers of a new design on FORCE's C-POD moorings/SUBS packages. These new receivers are expected to be even more effective in picking up acoustic detections in high flow environments, where tag signals can be obscured by noise. This partnership will contribute additional information regarding movement patterns of Atlantic salmon, sturgeon, striped bass, and alewife in Minas Passage and Basin. This work is

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[21] Ocean Tracking Network's website: www.oceantrackingnetwork.org.

[22] VEMCO is "the world leader in the design and manufacture of acoustic telemetry equipment used by researchers worldwide to study behaviour and migration patterns of a wide variety of aquatic animals." Learn more: www.vemco.com.

sponsored by the OERA, NRCan, NSNRR, the Natural Sciences and Engineering Research Council of Canada (NSERC), and the Canadian Foundation for Innovation (CFI).[23]

Discussion

The 2021-2023 EEMP represents a strategic opportunity for FORCE and its partners to learn from previous experiences, incorporate regulatory advice, and to re-evaluate approaches to research and monitoring in the high flows of the Minas Passage. The EEMP is designed to prepare for effects testing with the deployment of operational devices, and adheres to the principles of adaptive management by evaluating existing datasets to ensure appropriate monitoring approaches are being implemented. Moreover, the plan adopts internationally accepted standards for monitoring where possible, including feasibility assessments for new monitoring approaches that are planned to be implemented.

Advances in monitoring capabilities made possible through programs like FORCE's Risk Assessment Program enhance our ability to understand how animals use Minas Passage, and contribute towards a better understanding of risk from the development of tidal stream power in the Upper Bay of Fundy. Ongoing research and the development of peer-reviewed publications add credibility to the innovative science activities that FORCE continues to undertake in support of its role as environmental steward. Post COVID19, FORCE and its partners have resumed conducting monitoring, engaging in meaningful assessments of monitoring technology capabilities, and providing data analyses and interpretation that advance our ability to effectively monitor the effects of tidal stream energy devices in high flow environments, and specifically at the FORCE test site. Reports from FORCE's partners and updates are routinely subjected to review by FORCE's EMAC and regulators, along with continued results from FORCE's ongoing monitoring efforts.

FORCE continues to implement lessons learned from the experiences of local and international partners, build local capacity, and enhance skills development, test new sensor capabilities, and integrate results from various instruments. Cumulatively, these efforts provide an opportunity for adaptive management and the advancement and refinement of scientific approaches, tools, and techniques required for effectively monitoring the device and site-level areas of tidal stream energy devices in dynamic, high-flow marine environments.

Ongoing monitoring efforts will continue to build on the present body of knowledge of marine life-device interactions. While it is still early to draw conclusions, initial findings internationally and at the FORCE test site have documented some disturbance of marine mammals primarily during marine operations associated with device installation/removal activities, but otherwise have not observed significant effects.

FORCE will continue to conduct environmental research and monitoring to increase our understanding of the natural conditions within the Minas Passage and, when the next device(s) are deployed and operating, test the EA prediction that tidal energy is unlikely to cause significant harm to marine life. In the longer-term, monitoring will need to be conducted over the full seasonal

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[23] Information about this project, and others funded through this program, is available online at: https://netzeroatlantic.ca/sites/default/files/2020-04/2020-04-09%20NRCan%20Public%20Report%20Final%20-%20Resize.pdf

cycle and in association with multiple different device technologies to understand if tidal energy can be a safe and responsibly produced energy source. FORCE will continue to report on progress and release results and lessons learned in keeping with its mandate to inform decisions regarding future tidal energy projects.

References

AECOM. 2009. Environmental Assessment Registration Document - Fundy Tidal Energy Demonstration Project Volume I: Environmental Assessment. Available from Available at www.fundyforce.ca.

Bangley, C.W., Hasselman, D.J., Flemming, J.M., Whoriskey, F.G., Culina, J., Enders, L., and Bradford, R.G. 2022. Modeling the probability of overlap between marine fish distributions and marine renewable energy infrastructure using acoustic telemetry data. Front. Mar. Sci. **9**: 851757. doi:10.3389/fmars.2022.851757.

Copping, A.E. 2018. The State of knowledge for environmental effects - driving consenting/permitting for the marine renewable energy industry. Available from https://tethys.pnnl.gov/sites/default/files/publications/The State of Knowledge Driving Consenting Permiting for the MRE.pdf.

Copping, A.E., and Hemery, L.G. 2020. OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES). *In* State Sci. Rep. doi:10.2172/1632878.

Copping, A.E., Hemery, L.G., Viehman, H., Seitz, A.C., Staines, G.J., and Hasselman, D.J. 2021. Are fish in danger ? A review of environmental effects of marine renewable energy on fishes. Biol. Conserv. **262**: 109297. Elsevier Ltd. doi:10.1016/j.biocon.2021.109297.

Daroux, A., and Zydlewski, G. 2017. Marine fish monitoring program tidal energy demonstration site – Minas Passage. : 34. Orono, ME.

Envirosphere Consultants Ltd. 2017. Marine seabirds monitoring program – tidal energy demonstration site – Minas Passage, 2016-2017.

Fraser, S., Williamson, B.J., Nikora, V., and Scott, B.E. 2018. Fish distributions in a tidal channel indicate the behavioural impact of a marine renewable energy installation. Energy Reports **4**: 65–69. Elsevier Ltd. doi:10.1016/j.egyr.2018.01.008.

Gaskin, D.E. 1992. Status of the harbour porpoise, Phocoena phocoena, in Canada. Can. F. Nat. **106**(1): 36–54.

Gattuso, J.P., Magnan, A.K., Bopp, L., Cheung, W.W.L., Duarte, C.M., Hinkel, J., Mcleod, E., Micheli, F., Oschlies, A., Williamson, P., Billé, R., Chalastani, V.I., Gates, R.D., Irisson, J.O., Middelburg, J.J., Pörtner, H.O., and Rau, G.H. 2018. Ocean solutions to address climate change and its effects on marine ecosystems. Front. Mar. Sci. **5**(OCT). doi:10.3389/fmars.2018.00337.

Gillespie, D., Hastie, G., Palmer, L., Macaulay, J., and Sparling, C. 2021. Harbour porpoises exhibit localized evasion of a tidal turbine. Aquat. Conserv. Freshw. Ecosyst.: 1–10. doi:10.1002/aqc.3660.

Hasselman, D.J., Barclay, D.R., Cavagnaro, R., Chandler, C., Cotter, E., Gillespie, D.M., Hastie, G.D., Horne, J.K., Joslin, J., Long, C., McGarry, L.P., Mueller, R.P., Sparling, C.E., Williamson, B.J., and Staines, G.J. 2020. Environmental monitoring technologies and techniques for detecting interactions of marine animals with turbines. *In* Report for Ocean Energy Systems (OES).

Hasselman, D.J., Li, H., Cotter, E., and Joslin, J. 2022. Editorial: Novel technologies for assessing the environmental and ecological impacts of marine renewable energy systems. Front. Mar. Sci. **9**: 990327. doi:10.3389/fmars.2022.990327.

International Electrotechnical Commission. 2019. Marine Energy - Wave, tidal and other water current converters - Part 40: Acoustic characterization of marine energy converter.

Joy, R., Robertson, F., and Tollit, D. 2017. FORCE Marine Mammal Environmental Effects Monitoing Program - 1st Year (2017) Monitoring Report.

Joy, R., Wood, J., and Tollit, D. 2018a. FORCE echolocating marine mammal environmental effects monitoring program - 2nd year (2018) monitoring report.

Joy, R., Wood, J.D., Sparling, C.E., Tollit, D.J., Copping, A.E., and McConnell, B.J. 2018b. Empirical measures of harbor seal behavior and avoidance of an operational tidal turbine. Mar. Pollut. Bull. **136**: 92–106. Elsevier. doi:10.1016/j.marpolbul.2018.08.052.

Lewis, A., Estefen, S., Huckerby, J., Musial, W., Pontes, T., and Torres-Martinez, J. 2011. Ocean Energy. *In* Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change. *Edited by* O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, and S. Kadner. Cambridge University Press, Cambridge, Massachusetts. pp. 497–534.

Lieber, L., Nimmo-Smith, W.A.M., Waggitt, J.J., and Kregting, L. 2018. Fine-scale hydrodynamic metrics underlying predator occupancy patterns in tidal stream environments. Ecol. Indic. **94**: 397–408. Elsevier. doi:10.1016/j.ecolind.2018.06.071.

Lieber, L., Nimmo-Smith, W.A.M., Waggitt, J.J., and Kregting, L. 2019. Localised anthropogenic wake generates a predictable foraging hotspot for top predators. Commun. Biol. **2**(1): 1–8. Springer US. doi:10.1038/s42003-019-0364-z.

Lossent, J., Lejart, M., Folegot, T., Clorennec, D., Di Iorio, L., and Gervaise, C. 2018. Underwater operational noise level emitted by a tidal current turbine and its potential impact on marine fauna. Mar. Pollut. Bull. **131**(May 2017): 323–334. Elsevier. doi:10.1016/j.marpolbul.2018.03.024.

Lowe, S.C., McGarry, L.P., Douglas, J., Newport, J., Oore, S., Whidden, C., and Hasselman, D.J. 2022. Echofilter: A deep learning segmentation model improves the automation, standardization, and timeliness for post-processing echosounder data in tidal energy streams. Front. Mar. Sci. **9**: 867857. doi:10.3389/fmars.2022.867857.

Malinka, C.E., Gillespie, D.M., Macaulay, J.D.J., Joy, R., and Sparling, C.E. 2018. First in situ passive acoustic monitoring for marine mammals during operation of a tidal turbine in Ramsey Sound, Wales. Mar. Ecol. Prog. Ser. **590**: 247–266. doi:10.3354/meps12467.

Marine Renewables Canada. 2018. State of the Sector Report: Marine Renewable Energy in Canada.

Martin, B., Whitt, C., and Horwich, L. 2018. Acoustic data analysis of the OpenHydro opencentre turbine at FORCE: final report.

McGregor, R.M., King, S., Donovan, C.R., Caneco, B., and Webb, A. 2018. A Stochastic Collision Risk Model for Seabirds in Flight. Available from https://www2.gov.scot/Resource/0053/00536606.pdf.

McInturf, A.G., Steel, A.E., Buckhorn, M., Sandstrom, P., Slager, C.J., Fangue, N.A., Klimley, A.P., and Caillaud, D. 2019. Use of a hydrodynamic model to examine behavioral response of broadnose sevengill sharks (Notorynchus cepedianus) to estuarine tidal flow. Environ. Biol. Fishes **102**(9): 1149–1159. Environmental Biology of Fishes. doi:10.1007/s10641-019-00894-3.

Melvin, G.D., and Cochrane, N.A. 2014. Investigation of the vertical distribution, movement and abundance of fish in the vicinity of proposed tidal power energy conversion devices. Final Report for the Offshore Energy Research Association. Research Project 300-170-09-12.

NEXUS Coastal Resource Management Ltd. 2017. Lobster Catchability Study Report.

Palmer, K.J., Wood, J., and Tollit, D.J. 2021. FORCE Marine Mammal EEMP - Yer 4 Final Report.

Pine, M.K., Schmitt, P., Culloch, R.M., Lieber, L., and Kregting, L.T. 2019. Providing ecological context to anthropogenic subsea noise: Assessing listening space reductions of marine mammals from tidal energy devices. Renew. Sustain. Energy Rev. **103**(July 2018): 49–57. Elsevier Ltd. doi:10.1016/j.rser.2018.12.024.

Robertson, F., Wood, J., Joslin, J., Joy, R., and Polagye, B. 2018. Marine Mammal Behavioral Response to Tidal Turbine Sound. (206). doi:10.2172/1458457.

Schramm, M.P., Bevelhimer, M., and Scherelis, C. 2017. Effects of hydrokinetic turbine sound on the behavior of four species of fish within an experimental mesocosm. Fish. Res. **190**:

1–14. Elsevier B.V. doi:10.1016/j.fishres.2017.01.012.

SLR Consulting. 2015. Proposed Environmental Effects Monitoring Programs 2015-2020 for Fundy Ocean Research Center for Energy (FORCE).

Viehman, H., Hasselman, D., Boucher, T., Douglas, J., and Bennett, L. 2019. Integrating hydroacoustic approaches to predict fish interactions with in-stream tidal turbines. Available from https://netzeroatlantic.ca/sites/default/files/2020-04/FISH FINDER Final Report 31-03-2020_0.pdf.

Viehman, H.A., Hasselman, D.J., Douglas, J., and Boucher, T. 2022. The ups and downs of using active acoustic technologies to study fish at tidal energy sites. Front. Mar. Sci. **9**: 851400. doi:10.3389/fmars.2022.851400.

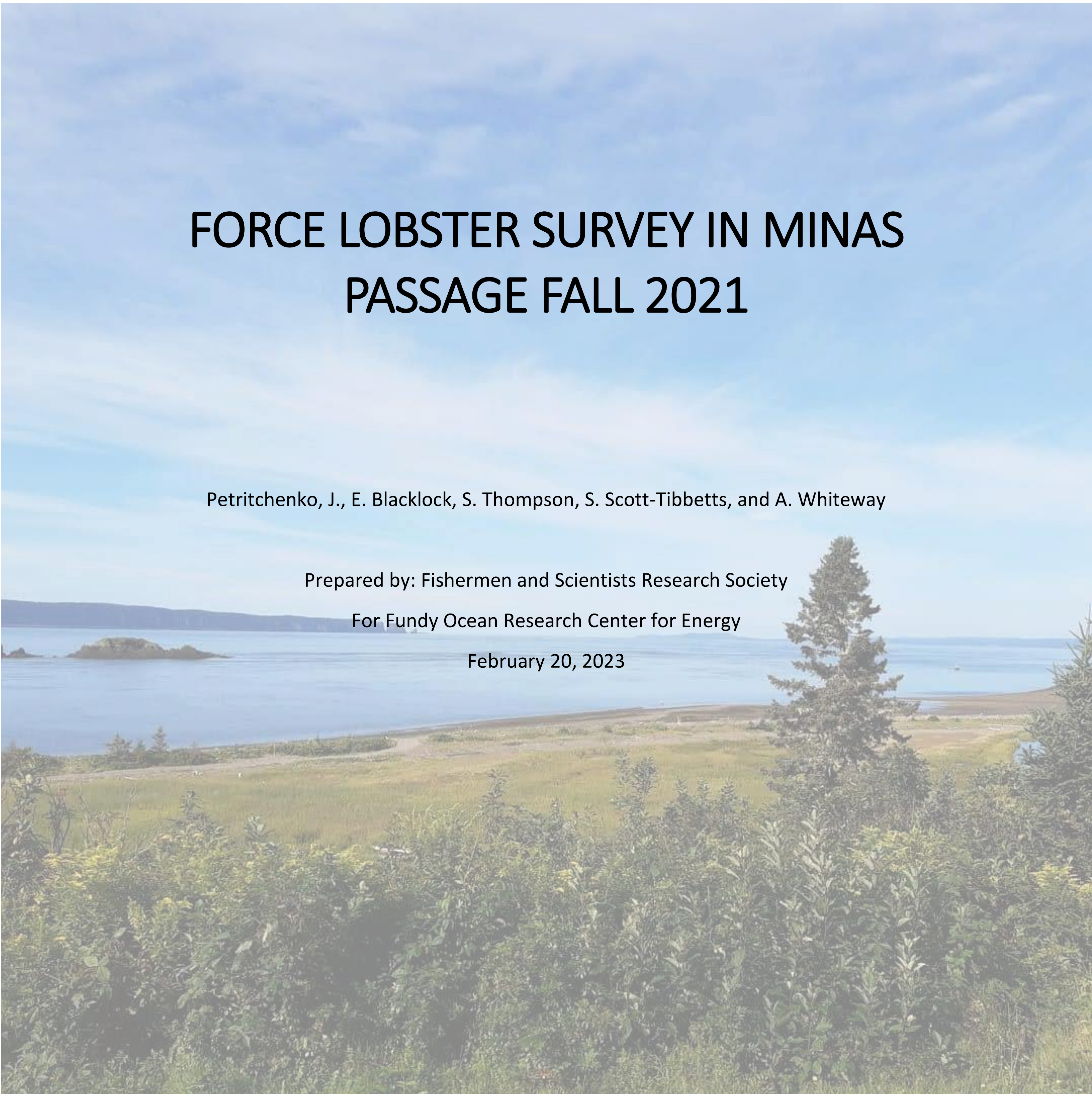
Appendix I

Acronyms

AAM	Active Acoustic Monitoring
ADCP	Acoustic Doppler Current Profiler
AMAR	Autonomous Multichannel Acoustic Recorder
BACI	Before/After, Control/Impact
BC	British Columbia
BoFEP	Bay of Fundy Ecosystem Partnership
CFI	Canadian Foundation for Innovation
CIOOS	Canadian Integrated Ocean Observing System
CLA	Crown Lease Area
cm	Centimetre(s)
CPUE	Catch Per Unit Effort
CSTV	Cape Sharp Tidal Venture
DFO	Department of Fisheries and Oceans (Canada)
DEM	Department of Energy and Mines (Nova Scotia)
EA	Environmental Assessment
EEMP	Environmental Effects Monitoring Program
EMAC	Environmental Monitoring Advisory Committee
EMP	Environmental Management Plan
FAD	Fish Aggregation Device
FAST	Fundy Advanced Sensor Technology
FAST-EMS	Fundy Advanced Sensor Technology – Environmental Monitoring System
FERN	Fundy Energy Research Network
FORCE	Fundy Ocean Research Center for Energy
GPS	Global Positioning System
hr	Hour(s)
IEA	International Energy Agency
kg	Kilogram(s)
km	Kilometre(s)
kW	Kilowatt(s)
m	Metre(s)
MET	Meteorological
MRE	Marine Renewable Energy
MREA	Marine Renewable-electricity Area
NL	Newfoundland and Labrador
NRCan	Natural Resources Canada
NS	Nova Scotia
NSDEM	Nova Scotia Department of Energy and Mines
NSE	Nova Scotia Department of Environment
NSERC	Natural Sciences and Engineering Research Council
NSPI	Nova Scotia Power Inc.
OERA	Offshore Energy Research Association of Nova Scotia
OES	Ocean Energy Systems
ONC	Ocean Networks Canada
ORJIP	Offshore Renewables Joint Industry Programme
OSC	Ocean Supercluster
OTN	Ocean Tracking Network
PAM	Passive Acoustic Monitoring
Q1/2/3	Quarter (1, 2, 3), based on a quarterly reporting schedule

R&D	Research and Development
TC114	Technical Committee 114
SUBS	Streamlined Underwater Buoyancy System
SME	Sustainable Marine Energy (Canada)
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
VEC(s)	Valuable Ecosystem Component(s)

Appendix II



FORCE LOBSTER SURVEY IN MINAS PASSAGE FALL 2021

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For Fundy Ocean Research Center for Energy

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Executive Summary

As part of its Environmental Effects Monitoring Program (EEMP), the Fundy Ocean Research Centre for Energy (FORCE) commissioned a lobster survey in fall 2021 to establish baseline data on lobster catchability by quantifying the number of lobsters captured and Catch Per Unit Effort (CPUE) in the vicinity of the FORCE tidal demonstration site. The survey design followed that developed by TriNav Fisheries Consultants Ltd. in 2019, and included the deployment of experimental lobster traps at 18 locations distributed over three sites ('Near-Control site', 'Far-Control site', and 'Impact site'). The survey occurred prior to the commencement of the fall 2021 commercial lobster fishery in Minas Passage and was conducted over two sampling phases that coincided with neap tidal conditions (Phase I: August 29 – September 3, and Phase II: September 27 – October 1). Prior to their release, biological data collected from captured lobsters included carapace length, sex, shell hardness, and reproductive stage (females). Lobster weight was estimated from a previously documented polynomial length-weight regression for lobster in the region, and was used for estimating CPUE (kg/trap haul). A subset of individuals were tagged with conventional t-bar tags prior to being released. A total of 582 lobsters were caught and released over the course of the survey, with 477 being tagged. Approximately 5% of tagged lobsters were recaptured and reported by local fishers during the fall 2021 commercial lobster fishing season; providing important information about the short term (approximately 1-2 months) movements of lobster in Minas Passage. Statistical analyses were conducted to determine if there was a significant ($p < 0.05$) difference in the abundance of lobster and CPUE between survey phases and sample sites, and if water temperature influenced the abundance of lobster captured and CPUE.

We detected no significant difference in lobster abundance or CPUE between Phases I and II of the survey. However, we observed marginally significant ($p=0.052$) differences in the abundance of lobster captured among sites, with the Impact Site having on average fewer lobster (6.2 lobster/trap haul) than either the Near Control Site (8.46 lobster/trap haul) or Far Control Site (8.92 lobster/trap haul). These differences were not reflected in the CPUE data, as non-significant differences in CPUE were observed among the sites. We observed a significant decrease in water temperature over the course of the survey, and observed a statistically significant, but weak negative correlation between water temperature and lobster abundance and CPUE during Phase II of the survey. However, we cannot draw any conclusions about the influence of water temperature on lobster catchability due to the protracted time frame over which data was collected during Phase II of the survey (i.e., limited sample sizes and reduced statistical power).

Commercial landings data provided by Fisheries and Oceans Canada (2005-2021) revealed a marked increase in lobster CPUE in LFA 35, including grid 17 where the FORCE tidal demonstration site is located. This may be associated with a northward shift in the distribution of lobster associated with increasing water temperatures in the Gulf of Maine and it effects on lobster movement, survival and recruitment to the fishery. These data provide important context for the interpretation of the results from the 2021 fall lobster survey.

Contents

Introduction

Objectives

The primary objective of FORCE's American lobster (*Homarus americanus*) monitoring program is to determine whether the presence of a tidal stream energy turbine affects commercial lobster catches ('catchability') (AECOM 2009). This objective is intended to be met by determining whether turbine operations result in a statistical change in commercial lobster catchability. There is a need for statistically robust baseline data about lobster presence and movement in the vicinity of the FORCE tidal demonstration site to quantify any changes after tidal energy devices have been deployed. Therefore, the objective of the Fall 2021 FORCE lobster survey was to improve the quality of baseline catchability data for lobster at the FORCE tidal demonstration site so that a meaningful comparison could be made once operational turbines are deployed.

Background

In fall 2017, FORCE commissioned a baseline lobster catchability survey (NEXUS Coastal Resource Management Ltd., 2017) that involved a catch-and-release BACI (Before-After-Control-impact) survey design conducted over 11 days and consisting of commercial traps deployed in two concentric rings around the future location of the Cape Sharp Tidal Venture (CSTV) turbine deployment planned for 2018. Captured lobsters were measured (carapace length (mm)), had their sex and reproductive stage determined (male, female, and berried female), and shell condition evaluated. This baseline survey captured 351 lobsters and reported a 'high' Catch Per Unit Effort (CPUE) (> 2.7 kg/trap) following established criteria (Serdynska and Coffen-Smout, 2017) (Table 1). Preliminary analyses indicated that catch rates declined during the survey and was associated with increasing tidal velocities (i.e., a statistically significant negative correlation between catch rates and maximum tidal range was reported). No significant differences in catch rates were observed between trap deployment locations (either within or between concentric rings or quadrants of that survey design), suggesting a uniformly high density of lobster in the survey area. A repeat of the survey in the presence of an operational turbine is required to determine whether turbine operations have an impact on lobster catchability. Although a repeat of the catchability survey was planned for fall 2018 following the deployment of the CSTV turbine, that device ceased working shortly after installation, and its non-operational status necessitated a postponement of the survey until an operational device could be installed. Additionally, Fisheries and Oceans Canada (DFO) provided feedback on the design of the lobster survey, advocating for the incorporation of a tagging component to account for variability in lobster behavior and its influence on catchability (DFO, 2016); something that was not included in the 2017 survey design.

In 2019, FORCE commissioned TriNav Fisheries Consultants Ltd. ('TriNav Fisheries') to redesign the lobster monitoring program based on the feedback from regulators to include a more statistically robust survey design. TriNav Fisheries evaluated the efficacy of a variety of methods and identified the combination of a modified catchability survey design with a mark-recapture component using conventional tags as the best approach. This new survey design included the use of an impact site (i.e., where turbines are intended to be deployed), and a near-, and far-control site for lobster trap deployment, and was implemented in fall 2021 in partnership with the Fishermen and Scientists Research Society (FSRS) and with the assistance of a local lobster fisher. The survey design also included comparisons of lobster abundance and CPUE to water temperature to determine whether this environmental variable influenced lobster catchability. Historical commercial catch (landings) data from Minas Passage and the surrounding region (Lobster Fishing Area (LFA) 35) was made available by DFO and provides additional information to help contextualize baseline lobster catchability over time, and is considered herein.

Table 1. An index of lobster catchability indicators in terms of Catch Per Unit Effort (CPUE) (kg/trap haul) (modified from Serdynska and Coffen-Smout, 2017).

CPUE (kg/trap haul)	Lobster Catchability
0-0.7	Low
0.8-1.1	Moderately low
1.2-1.7	Moderate
1.8-2.3	Moderately high
2.4-10.7	High

The Minas Basin lobster fishery and the value of local ecological knowledge

The FORCE tidal demonstration site is located in LFA 35 (Figure 1). Based on the 2021 Science Advisory Report (DFO 2021) for LFAs 35-38, the abundance of lobster and the CPUE trend indicate an increase in lobster stock biomass in LFA 35. The lobster fishery in LFA 35 is an effort-controlled fishery, with effort limited by season, minimum legal size, number of licenses, and number of traps per license. LFA 35 has two fishing seasons annually: i) spring (March 31st to July 31st) and ii) fall (Oct 15th to December 31st). The FORCE fall lobster survey (late August to early October) precedes the fall lobster fishing season and does not interfere with the commercial fishery, but does permit tagged lobster to be capture during the fall fishing season and reported to FORCE.

The inclusion of local stakeholders in fisheries research is imperative for assisting with positive perceptions of projects related to marine industries (Bundy et al., 2017; Cooke et al., 2017; Fujitani et al., 2017). Engaging community members in scientific monitoring activities promotes a willingness to share information and increased support for marine science and conservation (Martin et al., 2016; Fujitani et al., 2017; Dean et al., 2018). In LFA 35, fishers actively participate in scientific data collection through participating in scientific sampling of lobster at sea and maintaining catch logbooks and field notebooks (This Fish, 2021). For the purposes of the FORCE fall lobster survey, lobster traps were rented from a local fisher and a fishing vessel was used for trap deployment/retrieval and the collection of biological data. Beyond this, the incorporation of local and traditional ecological knowledge acquired from extensive experience is invaluable for assisting with the planning and execution of fisheries related research (Childress et al., 2010; Farr et al., 2018). To that end, a local fisher was employed during the 2021 fall lobster survey to share insights about sampling locations and how to deploy and retrieve lobster traps in the Minas Passage safely and efficiently (Figure 2). Following completion of trap deployments, retrievals and tagging activities, the survey also partially relied on fishers notifying FORCE of any tagged lobsters that were captured during the fall 2021 commercial fishery including the date of capture and approximate coordinates (i.e., latitude and longitude).

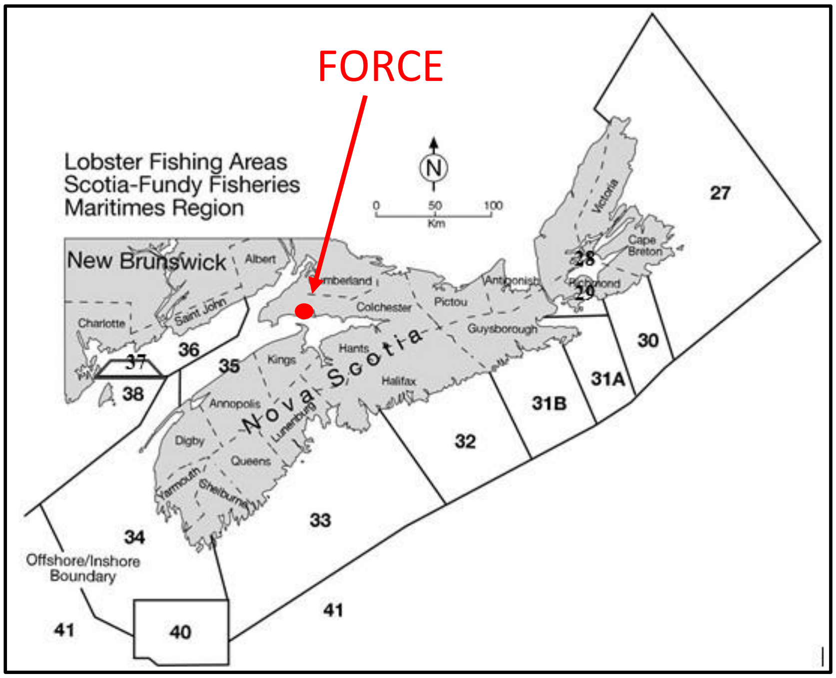


Figure 1: Map of lobster fishing areas in the DFO ‘Maritimes Region’. (Source: https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/maritimes/2019/inshore-lobster-eng.html)

Figure 2: A local lobster fisher (right) oversees the deployment and retrieval of lobster traps during the FORCE fall lobster survey 2021.

American Lobster biology and distribution

Lobster life history and habitat

The life history of the American lobster is divided into pelagic and benthic stages (Cobb and Wahle, 1994; Lillis and Snelgrove, 2010). The larvae first exists as pelagic zoea, and the post-larval stage settles to a benthic environment, where the juvenile lobster matures in sheltered nursery habitat (Cobb and Wahle, 1994; Wahle and Incze, 1997; Barret et al., 2017). FORCE's monitoring objective focuses on assessing the effects of operational turbines on lobster that have already undergone this transition and are susceptible to capture in commercial lobster fishing gear. Temperature influences the moult cycle and size at maturity of lobster (Watson et al., 2013). In this survey, sex was recorded for each lobster, and moult stage was recorded for two lobsters from each trap haul. Clutch maturity and percent coverage were noted for egg-bearing (i.e., 'berried') female lobsters.

Lobster spatial distribution is largely habitat dependent. Juvenile lobsters are more at risk of predation and are largely restricted to habitats that provide shelter. Shelter-restricted juveniles depend on cobble and eelgrass meadow habitats where there are plenty of spaces to escape from predators (Factor, 1995). However, all lobster life stages can be found on mud or clay where they can form depressions or burrows, or on a more heterogenous substrate of sand and rock where lobster can make shallow burrows under rock (Factor, 1995). Scoured bedrock habitat, which is characteristic of the FORCE tidal demonstration site, tends to have reduced habitat complexity for burrowing, but lobster can be found where boulders or other complex habitat features are present (Factor, 1995). Figure 3 provides a heatmap of bathymetry around the FORCE tidal demonstration site. The impact site has scoured bedrock as a substrate, with more heterogenous benthic habitats in the near and far control sites (Figure 4).

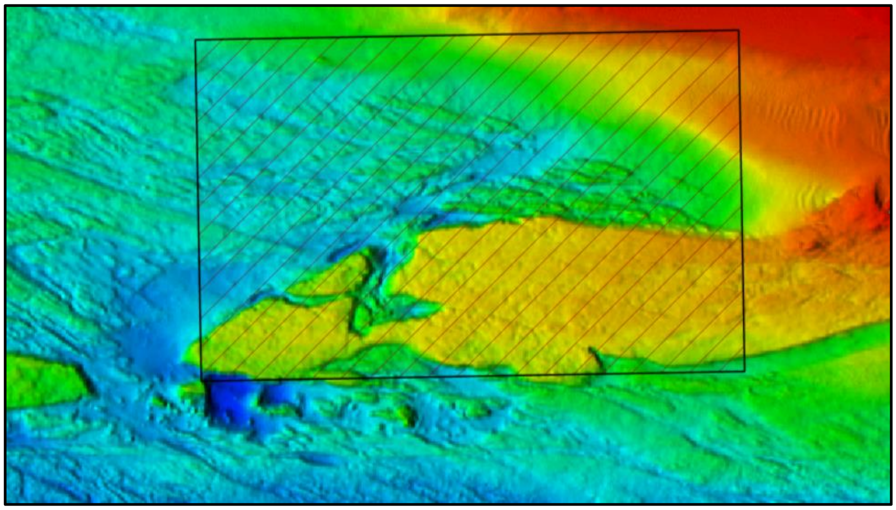


Figure 3: Heat map of bathymetry of the FORCE tidal demonstration site (shaded black square). ‘Warmer’ colours indicate more shallow locations, and the impact site (future site of tidal turbine deployments) shown in Figure 4 is located on the relatively shallow volcanic plateau.

Figure 4: Map showing the 18 deployment locations for lobster traps in the Impact Site (IMP1-6), Near Control Site (NC1-6), and Far Control Site (FC1-6) in the Minas Passage. Note: the Near Control Site and Impact Site are located within the FORCE tidal demonstration site.

Lobster moult stage and tagging

Observations made from lobster hemolymph (blood) and pleopods can be used to predict the likelihood that a lobster will moult; information that is relevant to tag retention (i.e., a lobster close to moulting may lose its tag). Therefore, pleopod and hemolymph samples were taken to predict moult stage and to assess the likelihood that t-bar tags would be retained by sampled lobster (Haakonsen & Anoruo, 1994). From the hemolymph, degree's brix (°Bx) is a metric that is used as an indicator of pre-moult, inter-moult, and post-moult stages (Battison, 2018). Pleopod samples can be taken and examined at 40x magnification with a compound light microscope to also determine moulting stage (Aiken, 1973). When used in combination, these metrics can account for confounding variables (e.g., scarring which alters the edge of the pleopod, injury or illness that lower degrees brix). For more information see Appendix A.

Lobsters were tagged with individually numbered Hallprint t-bar tags that are inserted in the soft tissue of the lobster where the carapace meets the first somite. Tagged lobster with moult stage 'D0' were susceptible to recapture in the Fall 2021 commercial lobster season, while intermoult lobster were expected to retain their tags until the spring 2022 commercial season. T-bar tags are cost-effective, easy to insert and have a low risk of mortality (Comeau et al., 2003). While mortality associated with tagging occurs most often in lobster that are two weeks pre- or post-moult, little mortality is associated with tagging intermoult lobster (Comeau et al., 2003). Injury during the tagging process can occur using t-bar tags, but can be mitigated by tagging intermoult lobster, tagging larger lobster, and tagging to the lateral portion of the carapace to avoid piercing organs (Comeau et al., 2003).

Influence of water temperature on lobster physiology, behaviour, and epidemiology

Water temperature influences many physiological and behavioural parameters in marine animals (Nielson and McGaw, 2016) and can influence the seasonal distribution of lobster (Jury and Watson (2013). Lobster have different optimal temperature ranges at different life history stages (Annis, 2005; Quinn 2016); juveniles avoid water temperatures below 8°C and above 20°C (Nielson and McGaw, 2016). Water temperature at the sea floor stimulates lobster egg development, hatching and larval settlement (Cobb and Wahle, 1994; Annis, 2005). Water temperature also determines the duration of the pelagic larval phase, affecting settlement and distribution, which are relevant to fisheries management (Cobb and Wahle, 1994; Annis, 2005). Water temperature at the sea floor was collected at each trap deployment site using a temperature logger deployed in each trap and was used to better understand lobster distribution and catch data.

Elevated water temperatures can result in shell disease (Wahle et al., 2013; Nielson and McGaw, 2016; Quinn, 2016) that can influence the distribution of larval settlement and recruitment to the commercial fishery (Wahle et al., 2015; Le Bris et al., 2017). Lobster shell disease is an 'catch-all' term for a variety of pathogens and parasites, including bacteria, protozoans and nematodes, that create lesions on lobster shells (NOAA, 2018). An increase in water temperature in southern New England led to increased prevalence of shell disease and recruitment failure that culminated in the collapse of the lobster fishery in that region (Wahle et al., 2015; Le Bris et al., 2017). Instances of shell disease were noted during the FORCE Fall 2021 lobster survey.

Water temperature at the seafloor also influences lobster growth and moult cycles (Annis, 2005; Wahle et al., 2013). Lobster require four to nine years of growth before being recruited to the fishery (Wahle et al., 2004), and the collection of life history data over multiple years is important for understanding lobster population dynamics (Phillips, 1986; Li et al., 2015). Many research projects last only three to five years, but in the context of long-lived crustaceans, longer time series data are required (Phillips, 1986; Caputi et al., 1995; Wahle et al., 2004; Star, 2010). To that end, the results of the 2021 fall lobster survey were compared to historic CPUE data for lobster in the Minas Passage area to provide added context on lobster population dynamics in the region.

Quantifying lobster catchability

CPUE is a standardized unit of measurement for assessing lobster catchability and is commonly used to measure relative population abundance (Appleman, 2015). The unit of measurement for catch and the effort indicated in CPUE are fishery-dependent; catch can be measured by weight or number of individuals (Appleman, 2015). Effort must be measured in a way that is relevant to the fishery, and the number of trap hauls is the standard unit of effort for the lobster fishery (Tremblay et al., 2009). CPUE is often overestimated for migratory species (Appleman, 2015) and can be different for lobster populations during spring and fall due to lobster migration (Tremblay et al., 2009; Haakonsen and Anoruo, 1994). For the purposes of this survey, CPUE is expressed as the number of lobster caught per trap haul, and weight of lobster caught per trap haul. A scale for lobster CPUE (kg/ trap haul) for the Minas Passage is provided in Table 1 (Serdynska and Coffen-Smout, 2017).

Materials and Methods

Sampling schedule

Consultations with local lobster fishers suggested that tidal flow conditions in Minas Passage would place logistical constraints on the survey design due to the influence of strong currents on vessel mobility, timing of buoy resurfacing, and the operational window for successfully recovering and re-deploying 18 traps during low water slack conditions. To optimize the survey design within these operational constraints, the survey was scheduled around two neap tide phases (Phase I: August 29 – September 3; Phase II: September 27 – October 1) so that nine traps could be recovered and deployed during each survey phase around the low water slack portion of the tidal cycle. This required 10 marine operational days (five days for each phase of the survey) to ensure a minimum 24-hour soak period for each trap between deployment and recovery.

This survey was conducted under DFO Scientific Licence #347451. A total of six traps were deployed in each of the Impact Site, Near Control Site and Far Control Site over the course of the survey; three traps within each site in Phase I and Phase II (Figure 4; Table 2). Trap deployment locations within each of these sites was selected using a random number generator assigned to unique combinations of latitude and longitude within the geographic boundaries of each site; these locations were maintained throughout the duration of the survey phase (Table 2). Traps were deployed at each location and retrieved four times on subsequent days throughout each survey phase for a total of 72 trap hauls over the course of the survey.

Captured lobster were measured (i.e., carapace length (mm)), assessed (i.e., sex, reproductive stage for females, moult staging – hemolymph and pleopod assessment) and tagged before being released back to the area from which they were captured.

During Phase I, traps were deployed on August 29 and hauled daily from August 30 through September 1, with the final haul delayed to September 3 due to inclement weather that prevented marine operations on September 2. During Phase II, trap deployment was delayed by one day due to inclement weather, and traps were deployed on September 27, with trap hauls occurring daily from September 28 through October 1.

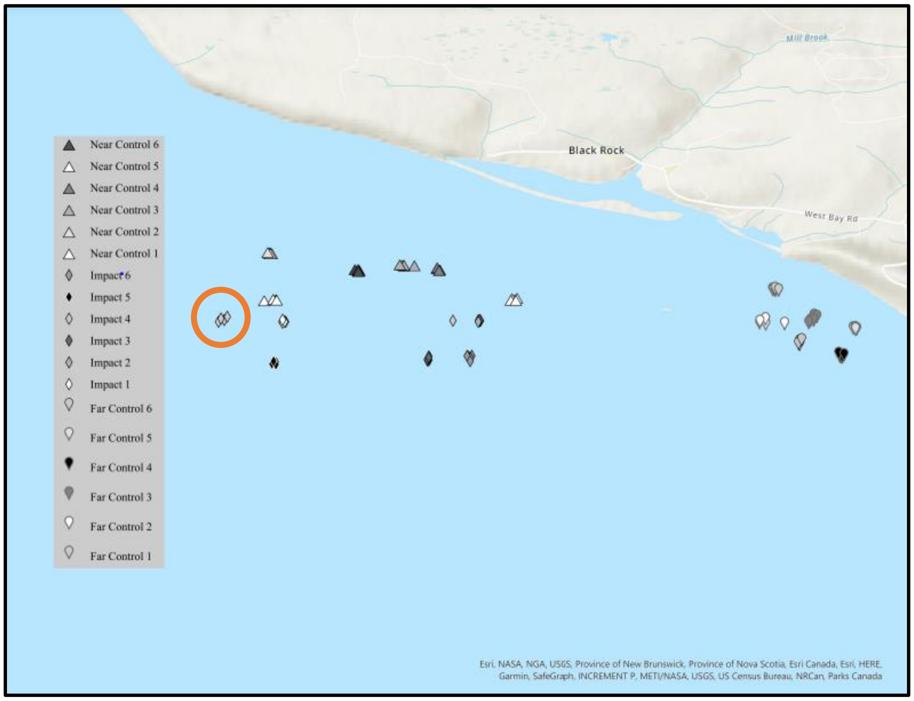
During Phase II of the survey, the trap that was intended to be deployed at site IMP4 was deployed at incorrect coordinates due to a data entry error in the vessel GPS. Given that the traps were deployed outside of the Impact Site, the data collected from these traps were excluded from analyses. Trap deployment locations during Phase I and Phase II of the survey, including incorrect deployment location for IMP4 are shown in Figure 5.

Sampling equipment and trap deployment

Due to the elevated tidal current speeds in Minas Passage (up to 5 m/s), the commercial wire lobster traps (dimensions: 1.21m x .038m x 0.61m) used in this survey were modified to include 150 kg of ballast (concrete) to ensure traps remained in place following deployment; this is common practice among commercial lobster fishers in Minas Passage. Each trap was affixed with a DFO-approved identification tag and was connected to a 100 m buoy line with a corresponding marked buoy. The traps also had their escape vents blocked to permit full enumeration of lobster and the collection of size distribution data for Minas Passage. Traps were baited using 1.5 kg of redfish (*Sebastes spp.*) heads impaled on a bait spike and were deployed from a commercial vessel (the Nova Endeavor) using the planned deployment coordinates (Figure 6).

Table 2: Lobster trap deployment coordinates during the 2021 fall lobster survey.

	Near Control Site			Impact Site			Far Control Site		
Survey phase	Site	Latitude	Longitude	Site	Latitude	Longitude	Site	Latitude	Longitude
Phase I	**NC1**	45°21.599	-64°26.240	**IMP1**	45°21.540	-64°26.214	**FC1**	45°22.008	-64°24.144
Phase I	**NC2**	45°22.120	-64°26.258	**IMP2**	45°21.543	-64°25.307	**FC2**	45°21.518	-64°24.162
Phase I	**NC3**	45°22.089	-64°25.510	**IMP3**	45°21.441	-64°26.441	**FC3**	45°21.540	-64°24.036
Phase II	**NC4**	45°22.075	-64°25.415	**IMP4**	45°21.542	-64°25.379	**FC4**	45°21.432	-64°23.564
Phase II	**NC5**	45°21.599	-64°25.219	**IMP5**	45°21.432	-64°26.240	**FC5**	45°21.504	-64°23.528
Phase II	**NC6**	45°22.074	-64°26.027	**IMP6**	45°21.448	-64°25.336	**FC6**	45°21.468	-64°24.072



Esri, NASA, NGA, USGS, Province of New Brunswick, Province of Nova Scotia, Esri Canada, Esri, HERE, Garmin, SafeGraph, INCREMENT P, METI/NASA, USGS, US Census Bureau, NRCan, Parks Canada

Figure 5: Map of the trap deployment locations during Phases I and II of the lobster survey. The incorrect deployment location for IMP4 are marked with an orange circle.

Figure 6: Photo of trap retrieval (left) and deployment (right) aboard the Nova Endeavor.

Data collection

The biological sampling procedure followed the standardized protocol for lobster assessment developed by DFO (2019a) and applied broadly across the DFO Maritimes Region (LFA 27-38; Figure 1). Following trap recovery, lobsters were removed from the trap and placed in individually labelled totes so they could be processed (Figure 7). Carapace length for each lobster was measured using 8” vernier calipers held parallel to the carapace from the eye socket to the posterior edge of the carapace (Figure 8) and rounded down to the nearest millimetre. Sex was determined by inspection of secondary sexual characteristics (i.e., pleopods). While males have rigid modified pleopods where the tail meets the body, females have soft reduced pleopods (Figure 9). Sex was recorded as 1-males, 2-females, and 3-egg bearing (berried) females. For berried females, the egg maturity stage (Table 3) and the density of their clutch (%) (Table 4) was recorded. Lobster condition as a result of the fishing activity was recorded on a scale from 0-no damage to 4-dead or dying (Table 5). Shell hardness and moult stage was recorded on a scale from (1) to (7) (Table 6) and was assessed by gently pressing on three regions of the carapace. When a lobster moults, the shell hardens sequentially from the anterior region of the carapace to the ventral region of the carapace (Figure 10). The presence of a v-notch in one of the uropods (a conservation measure used to mark reproductive females to prevent them from being retained in the fishery) was recorded as present or absent (Figure 11).

Moult stage determination

To understand the likelihood that tagged lobster would retain their tags, we assessed their molt stage through a combination of hemolymph examination and pleopod inspection. Hemolymph was extracted from two lobster per trap per day from a sinus in the underside of the tail using a syringe. A brix refractometer was used to quantify the amount of protein in the hemolymph and was used to determine degrees brix (°Bx) – an indicator of lobster moult stage (Battison 2018). Values of °Bx < 7 typically indicate that a lobster is post-moult or is suffering from disease or injury, °Bx between 8-16 indicate an intermoult stage, and °Bx values > 16 are indicative of lobster that are actively preparing to moult (Battison 2018). In addition to determining °Bx, the anterior right pleopod was excised and subsequently examined using a compound light microscope under 40x and 100x magnification to help determine moult stage (Appendix A). When a lobster is in active pre-moult a separation can be observed at the edge of the pleopod.

Figure 7: Following trap recovery, lobsters were placed in individually labelled totes until they could be processed.

Figure 8: Measurement of lobster carapace length.

Figure 9: Female (left) and male (right) secondary sexual characteristics (i.e., modified pleopods) used to determine lobster sex. Source: DFO (2019a).

Table 3: Egg stage codes adapted from DFO (2019a).

Egg stage	Description
0	No eggs
1	Newly deposited eggs, which are shiny and dark green or black.
2	Older eggs lose their luster and may be larger and brown or orange.
3	Mature eggs are bulky, orange and less loosely packed. You will see eyespots of the larval lobster. These eggs are partially hatched or hatching soon.
4	Eggs hatching or hatched (mossy), empty egg casings become opaque, the “glue” that adheres eggs to the tail becomes visible as well as the long hairs on the egg-bearing pleopods.

Table 4: Percent clutch coverage codes adapted from DFO (2019a).

Percent Clutch Coverage	Description
0	No clutch
1	Full clutch, 100% coverage
2	Partial clutch, 10%- 50% coverage
3	Small clutch, >10% coverage

Table 5. Lobster condition adapted from DFO (2019a).

Lobster condition	Description
0	No injury
1	Minor damage, such as a broken rostrum or missing leg
2	Multiple minor damages
3	Severe damage, such as crushed carapace or tail
4	Dead or dying

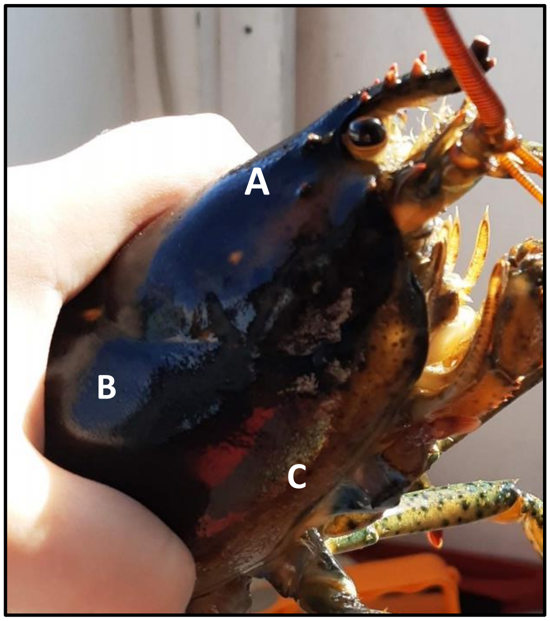


Figure 10: Lobster carapace hardens sequentially from the anterior portion of the carapace (A) to the posterior portion of the carapace (B), and to the lateral portion of the carapace (C).

Table 6: Descriptions of moult stages adapted from DFO (2019a).

Moult Stage	Description
1	Recent moult, firm gelatin texture
2	Soft shell compressible
3	Hardened in the anterior portion of carapace only
4	Dorsal anterior and posterior portions of carapace hardened
5	Dorsal anterior, posterior, and lateral portions of the carapace are hardened
6	Hard shell with epiphytic growth
7	Hard carapace split bilaterally, a lobster actively moulting

Figure 11: A V-notched female lobster. The v-notch is cut in the tail on the uropod to the right of the telson when observing the dorsal side of the lobster (indicated by a circle).

Lobster tagging

Lobsters with a minimum carapace length of 80 mm were tagged with uniquely numbered t-bar tags inserted under the posterior portion of the carapace using a tagging gun (Figure 12). Lobster with a carapace length < 80 mm, those with moult condition 3 or 4 (Table 5) and berried females were not tagged due to the increased risk of injury, reduced probability of tag retention, and out of conservation concern for the local commercial fishery, respectively. Tags were also labelled ‘FORCE’ and ‘REWARD’ with an associated phone number to increase the chances that tagged lobster captured during the fall commercial fishery would be reported. The duration of time between release and recapture and the distance between the release and recapture location were calculated in R (R Development Core Team 2021) using the ‘geosphere’ package.

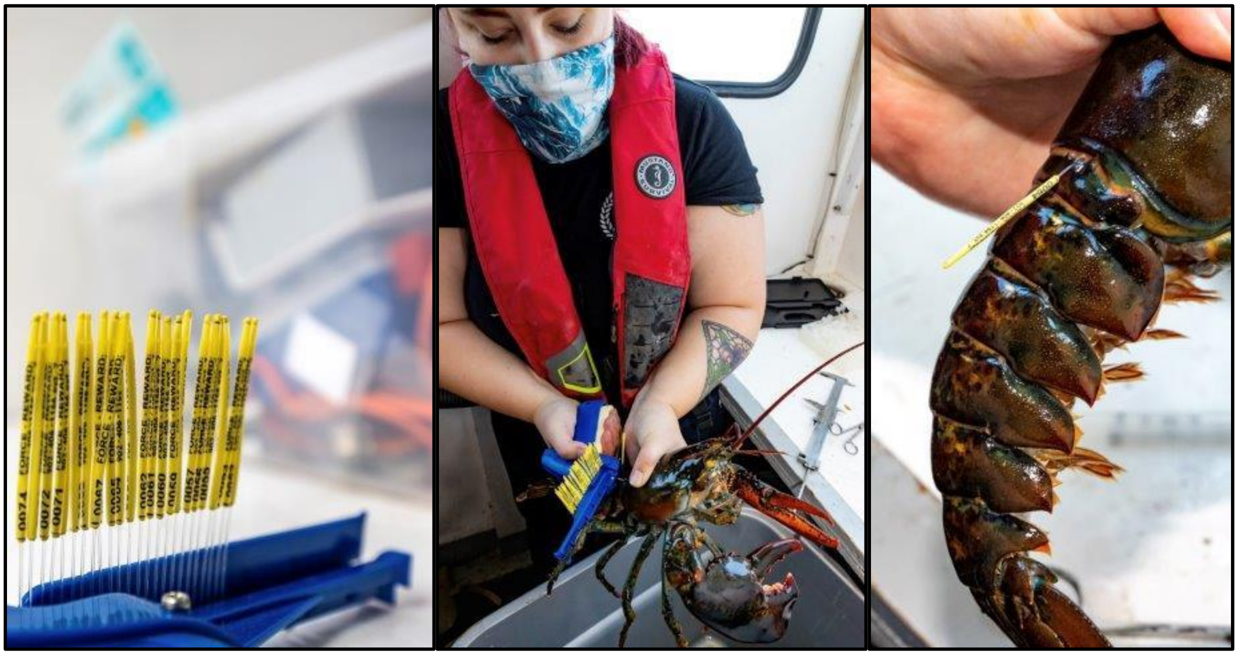


Figure 12: Photographs of lobster tagging during the lobster survey. Individually numbered Hallprint t-bar tags (left), tagging process (center), position of inserted tag (right).

Water temperature data

Water temperature near the sea floor was recorded using HOBO tidbit V2 temperature loggers (Figure 13) attached to each trap. Following each phase of the survey, the data from the temperature loggers were downloaded using the HOBO Optic USB Base Station. Lobster CPUE data was compared with these abiotic variables to identify whether any correlations could be detected that might shed light on environmental factors that could influence lobster catchability.

Figure 13: HOBO tidbit V2 temperature logger and Optic base station.

Data analyses

Raw data was recorded in the field on a standardized data sheet developed for lobster (Appendix B) and was transferred to an electronic format (Microsoft Excel) at the end of each field day. Data analyses were conducted in R (R Development Core Team 2021) to determine the extent to which lobster abundance and CPUE (kg/trap haul) varied among survey phases, among sites (i.e., Impact Site, Near-Control Site and Far-Control Site), and to understand correlations with water temperature. Statistical analyses included standard tests for data normality and equal variance, correlations, and univariate statistics (detailed below).

CPUE calculation

To estimate CPUE (kg/trap haul), lobster weight (Wt) (lbs) was estimated from carapace length (CL) (mm) using a documented polynomial length-weight regression for female American lobster in the region (MacDonald and Scott, 2000) (Figure 14):

$$\text{Wt (lbs)} = 1.492 - 0.04037(\text{CL}) + 0.000444(\text{CL})^2$$

Estimated weight was then converted to kilograms prior to statistical analyses. Individuals below the legal commercial harvest size (i.e., < 82.5 mm CL), berried females and v-notched individuals were omitted from CPUE calculation for making comparisons with historical commercial landings data from LFA 35 provided by DFO (see below).

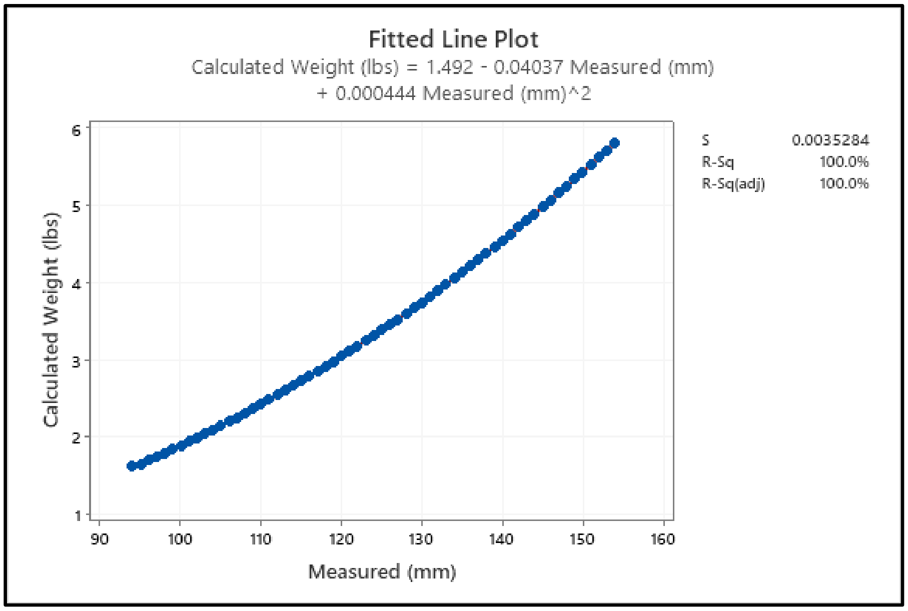


Figure 14: A fitted line plot of the measured carapace length (mm) to the calculated weight (lbs) based on a polynomial regression (MacDonald and Scott, 2000).

Comparison among survey phases

Lobster abundance and CPUE data were compared between the two phases of the survey to determine whether the data from each phase could be combined for analyses. A Shapiro-Wilks test was conducted in R to determine if the data collected in Phase I and Phase II of the survey were normally distributed. If the data from the two survey phases approximated normality and had equal variance, a two-sample t-test was conducted to determine if there was a statistically significant difference (i.e., $p < 0.05$) in lobster abundance and CPUE between the phases of the survey. If the data was non-normal, a two-sample Wilcoxon rank test was conducted (suitable for non-parametric data).

Comparison among sites

A Shapiro-Wilks test was conducted in R to determine if the data collected among the sites were normally distributed. A one-way Analysis of Variance (ANOVA) and a Tukey Honest Significant Differences (HSD) test was conducted in R to determine if there was a statistically significant difference between the Impact Site, Near Control Site and Far Control Site for i) the abundance of lobster and, ii) CPUE.

Influence of water temperature on lobster abundance and CPUE

Water temperature data collected during both survey phases was checked for normality (Shapiro-Wilks test) and then subjected to a two-sample Wilcoxon rank test to determine if there was a statistically significant differences in water temperature between survey phases. Correlations between water temperature and lobster abundance and CPUE were then investigated.

Historical Commercial Landings Data

Commercial landings data (i.e., lobster weight and trap haul data for 2005-2021) was requested from DFO for LFA 35 (grids 15-20) as part of a data sharing agreement established in August 2021 (Appendix C). The FORCE tidal demonstration site is located in grid 17 (Figure 15), and commercial landings data from all grids in LFA 35 were examined for temporal trends in CPUE, including comparisons with CPUE from grid 17. The commercial landings data (Appendix C) only includes lobster that were recruited to the fishery and eligible for commercial harvest (i.e., does not include individuals <82.5 mm carapace length, berried females, of v-notched individuals).

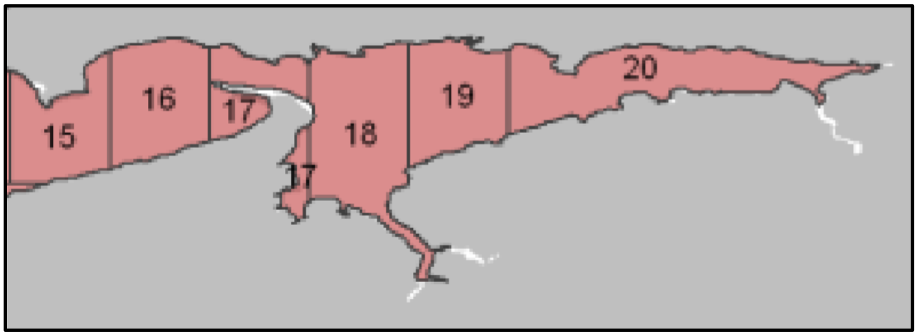


Figure 15: Grids 15-20 for LFA 35; adapted from Coffen-Smout et al. (2013).

Results

Lobster abundance and sex distribution

Over the course of the fall 2021 survey, 582 lobster were captured across all sites; Phase I (n=277), Phase II (n=305) (Table 7). This total includes 40 individuals that were captured from traps deployed at the incorrect deployment coordinates for IMP4 during Phase II of the survey, and that are excluded from analyses below. Males and females comprised 57% and 43% of the total catch, respectively (Table 7; Figure 16). The number of male and female lobster captured for each site is provided in Table 8. Across the survey, one lobster exhibit no external secondary sexual characteristics and could not be assigned to sex, 17 females (~6%) were berried, and 30 females exhibited signs of having recently released their eggs (i.e., 'mossy' condition).

Table 7: Number of lobsters caught over the course of the fall 2021 lobster survey.

	Male	Female	Total
Phase I	165	112	277
Phase II	166	138	305*
Total	331	250	582*

* Includes one lobster that did not display secondary sex characteristics

Table 8: Number of lobsters caught at each site during the fall 2021 lobster survey.

	Male	Female	Total
Impact Site	85	79	165*
Far Control	131	83	214
Near Control	115	88	203

* Includes one lobster that showed no secondary sex characteristics

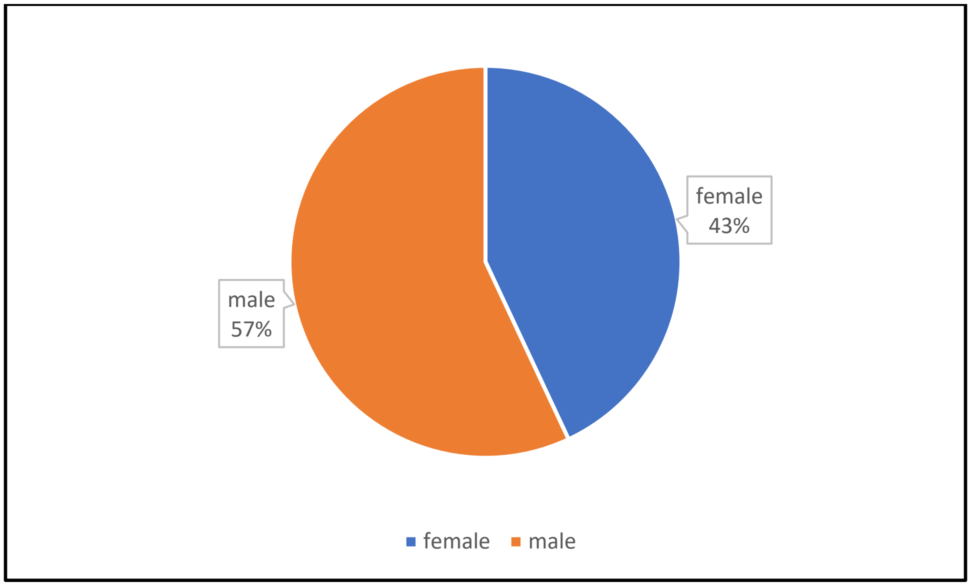


Figure 16: Percent male and female lobster captured during the fall 2021 lobster survey (N=582).

Shell hardness, moult stage and presence of shell disease

Over the course of the fall 2021 lobster survey, 15 individuals had shell hardness stage 3 (i.e., soft, but hardening shells), 65 were in stage 4 (i.e., medium hard shells), and 502 were in stage 5 (i.e., hard shells) (Figure 17). During the survey, pleopods and hemolymph were taken from 145 lobster. The distribution of pleopod stages observed during the survey are shown in Figure 18, and indicated that most of the sampled lobster had experienced a recent moult. The mean °Bx value for sampled lobster was 8.4 (range: 5.6 – 15.4) and supported results of pleopod inspection (Figure 19). Severe shell disease was observed for ~3% (n=18) of the lobsters captured during the fall 2021 survey (Figure 20).

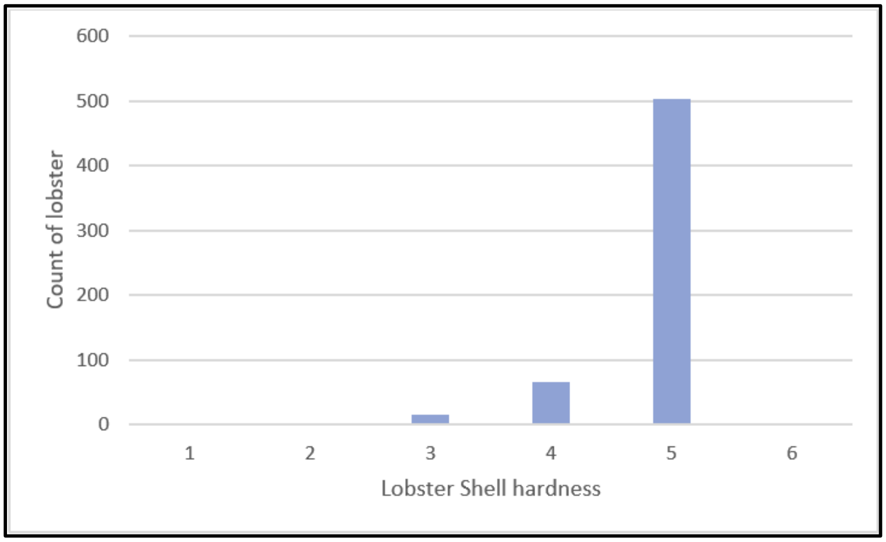


Figure 17: Shell hardness for lobster sampled during the fall 2021 survey (N = 582). See Table 6 for descriptions of shell hardness.

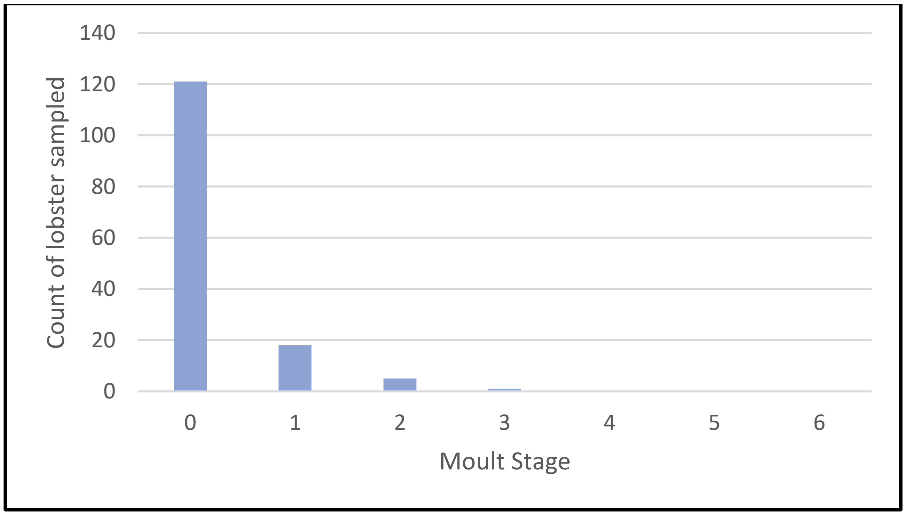


Figure 18: Moult stage determined by pleopod samples for lobster sampled during the fall 2021 survey (n=145) (see Appendix A).

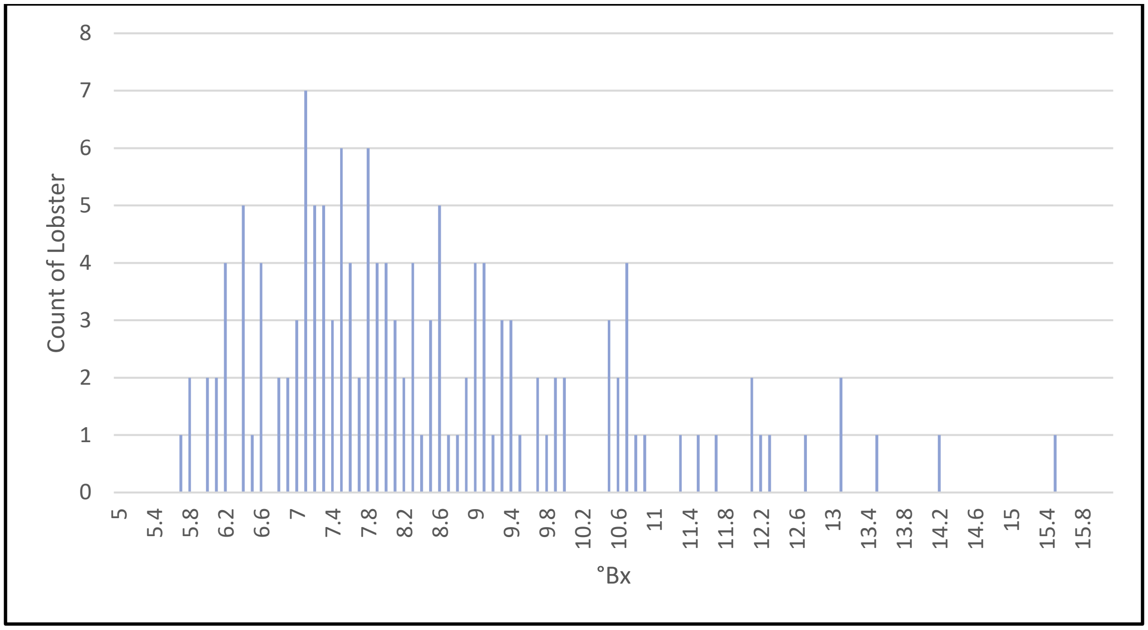


Figure 19: Distribution of °Bx from hemolymph samples taken during the fall 2021 lobster survey (n=145).

Figure 20: Examples of shell disease observed during the fall 2021 lobster survey.

Lobster size distribution and CPUE estimation

Over the course of the fall 2021 lobster survey, the carapace length of lobster ranged from 52mm – 136 mm (Figure 21). The average carapace length during Phase I and Phase II of the survey was 88.28 mm and 94.48 mm, respectively. Across all sites, 68 trap hauls were conducted and the average number of lobsters captured per trap haul during Phase I and Phase II of the survey was 7.69 and 8.25, respectively. On average, fewer lobster were captured at the Impact site (6.20) than either the Near Control site (8.46) or Far control site (8.92) (Table 9). Across all sites, CPUE was 5.72 kg/trap haul. However, this includes all lobster captured during the survey, including those that were < 82.5 mm CL that could not be legally harvested. When undersized lobster, berried females, and v-notched individuals were omitted, CPUE across all sites was 4.74 kg/trap haul. CPUE was lower at the Impact site (4.58 kg/trap haul) than either the Near Control site (6.07 kg/trap haul) or Far Control site (6.02 kg/trap haul) (Table 10).

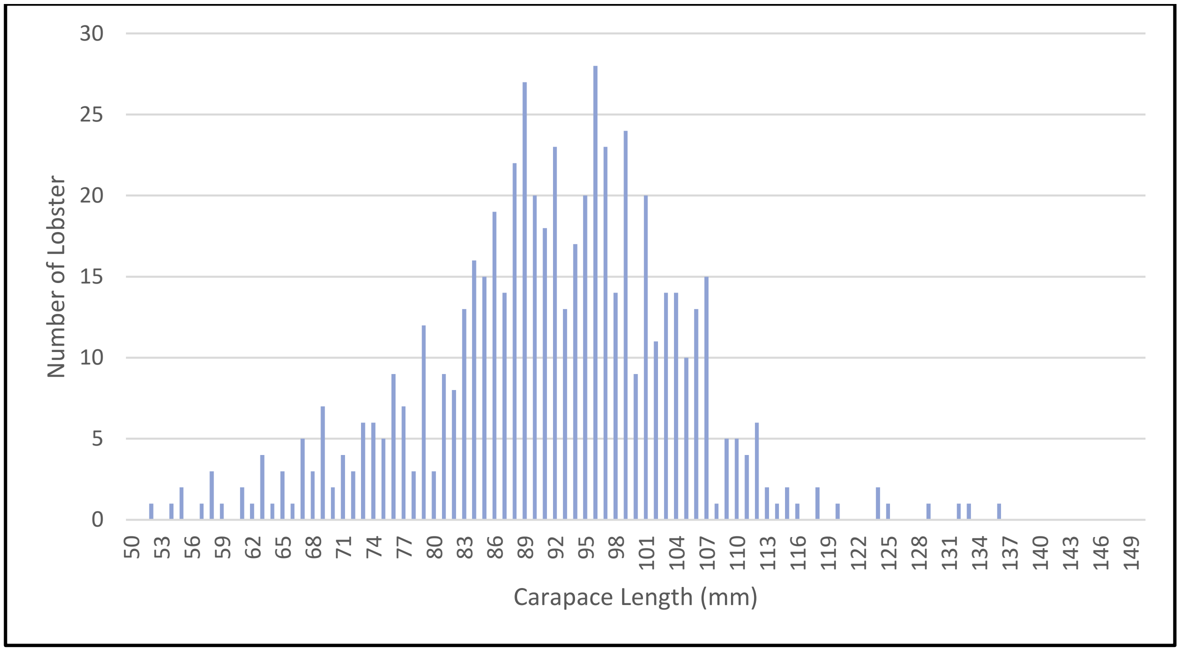


Figure 21: Size distribution of lobster during the fall 2021 lobster survey (N=582).

Table 9: Summary statistics for number of lobsters captured by site during the fall 2021 survey.

Site	Traps Hauled	# Lobster Caught	Mean lobsters/trap haul	SD lobsters/trap haul
Impact	20*	125	6.20	3.69
Far Control	24	214	8.92	4.55
Near Control	24	203	8.46	2.99
All sites	68	542	7.97	3.92

*Excludes data collected from IMP4 deployed at incorrect coordinates during Phase II

Table 10: Summary statistics for weight and CPUE of lobsters captured by site during the fall 2021 survey.

Site	Traps Hauled	Total Weight (lbs)	Total Weight (kg)	Mean CPUE (kg/trap haul)	SD CPUE (kg/trap haul)
Impact	20*	201.72	91.55	4.58	2.74
Far Control	24	318.26	144.36	6.02	2.97
Near Control	24	320.95	145.58	6.07	2.30
All sites	68	841.04	381.49	5.66	2.73

*Excludes data collected from IMP4 deployed at incorrect coordinates during Phase II

Comparison of lobster catchability among survey phases

A Shapiro-Wilks test indicated that lobster abundance during Phase I of the survey was not normally distributed (p=0.017), whereas lobster abundance during Phase II was normally distributed (p=0.528). A two-sample Wilcoxon rank test indicated that the median lobster catch between Phase I and II was not significantly different (p=0.427) (Table 11), and catch data from each phase was subsequently combined for further analyses.

A Shapiro-Wilks test confirmed that lobster CPUE data collected during Phases I and II of the survey were both normally distributed (p > 0.05), and an F-test confirmed equal variance in CPUE between both survey phases (p=0.637). A two-sample t-test confirmed no significant difference in CPUE (Table 12) between Phase I and II (p=0.081) (Table 12), and CPUE data from both survey phases were combined for further analysis.

Table 11: Summary statistics and results of two-sample Wilcoxon rank test for lobster catch data (abundance) collected during the fall 2021 lobster survey excluding data collected at IMP4 during Phase II (deployed outside of Impact Site).

Sample	**N**	**Median**	**IQR**	**p-value**
Phase I	36	7.00	6.50	0.427
Phase II	32	8.50	4.25	

Table 12: Summary statistics and results of a two-sample t-test for lobster CPUE data collected during the fall 2021 lobster survey excluding data collected at IMP4 during Phase II (deployed outside of Impact Site).

Sample	**N**	**Mean**	**SD**	**T-value**	**DF**	**p-value**
Phase I	36	5.07	2.79	-1.77	66	0.081
Phase II	32	6.22	2.56			

Comparisons of lobster catchability among sites

A one-way ANOVA revealed a marginally significant difference (p=0.052) in the abundance of lobster captured between the sites (Table 13). A Tukey HSD test revealed that this was attributable to more lobster being captured at the Far Control Site relative to the Impact Site; however, this result was also only marginally significant (p=0.055) (Figure 22).

Table 13: Summary statistics from ANOVA and a Tukey HSD test for abundance data between the Impact site, Near Control site and Far Control site.

Source	DF	Sum Sq	Mean Sq	F-value	p-value
Site	2	89.9	44.94	3.104	0.052
Residuals	65	941	14.48		

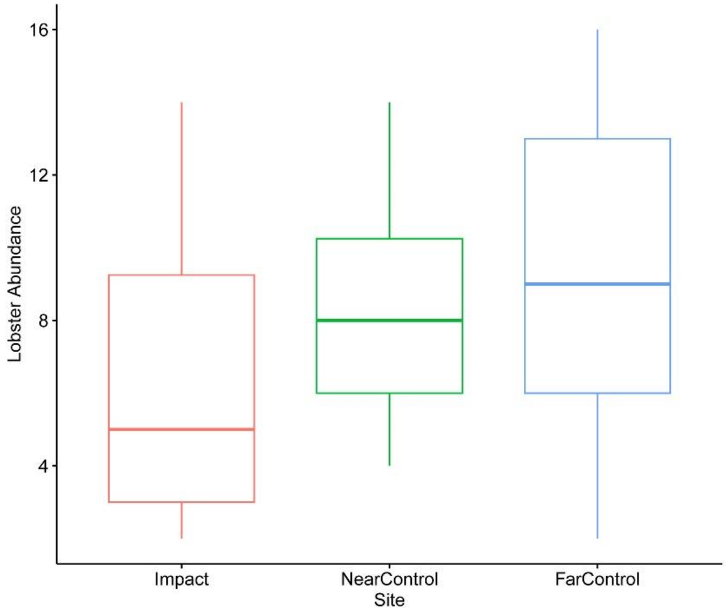


Figure 22: Boxplot displaying the abundance of lobster captured at each site over the course of the fall 2021 lobster survey. A marginally significant difference was observed in the number of lobster captured across sites and was attributed to a greater number of lobster captured at the Far Control site relative to the Impact site.

Although greater CPUE was observed for both the Near Control site and Far Control site relative to the Impact Site (Table 10), a one-way ANOVA revealed this difference to be statistically non-significant (p=0.13) (Table 14). The similarities in CPUE by site are shown in Figure 23.

Table 14: Summary statistics from ANOVA and a Tukey HSD test for CPUE data between the Impact site, Near Control site and Far Control site.

Source	DF	Sum Sq	Mean Sq	F-value	p-value
Site	2	30.3	15.152	2.107	0.13
Residuals	65	467.4	7.191		

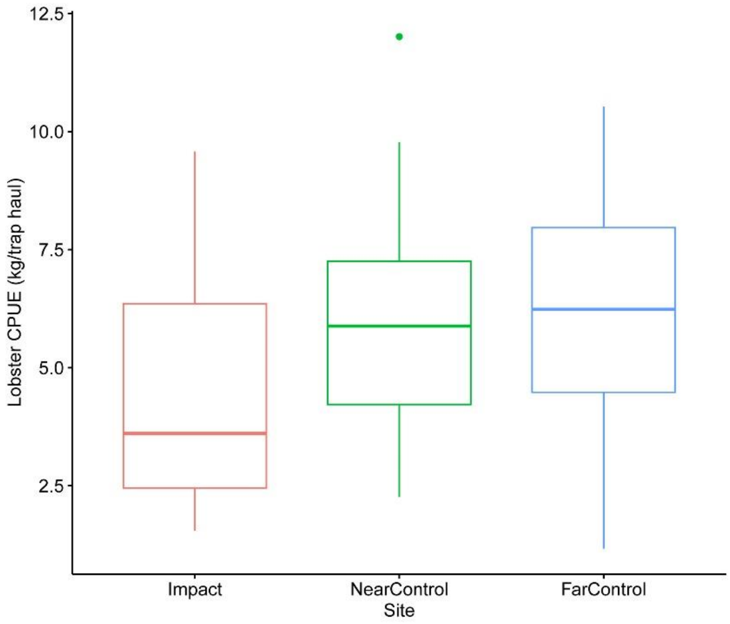


Figure 23: Boxplot displaying lobster CPUE at each site over the course of the fall 2021 lobster survey.

Lobster tagging

Over the course of the fall 2021 survey, 477 lobster were tagged and released (Phase I: n=203; Phase II: n=274). Of those tagged lobster, n=24 (i.e., 5% of those tagged) were subsequently captured during the fall 2021 commercial lobster fishery and had their tags returned to FORCE; 20 with accompanying data on coordinates and date of capture. Based on moult stage assessment for tagged individuals it is unlikely that many lobsters lost their tags. However, there is no way to know how many tagged lobsters may have been captured during the fall 2021 commercial fishery but not reported.

The original release and subsequent recapture location for tagged lobster are visualized in Figures 24-26 and data summarized in Table 15. The greatest distance traversed between release and recapture was approximately 10.8 KM during 63 days at large (tag# 0214), while the shortest was 0.42 KM during 30 days at large (tag# 0374) (Table 16). There was no correlation between the amount of time between release and recapture (i.e., 'days at large') and distance between these locations (Pearson correlation = -0.003) (data not shown) and may be due to the relatively small sample size included in the analysis (n=20).

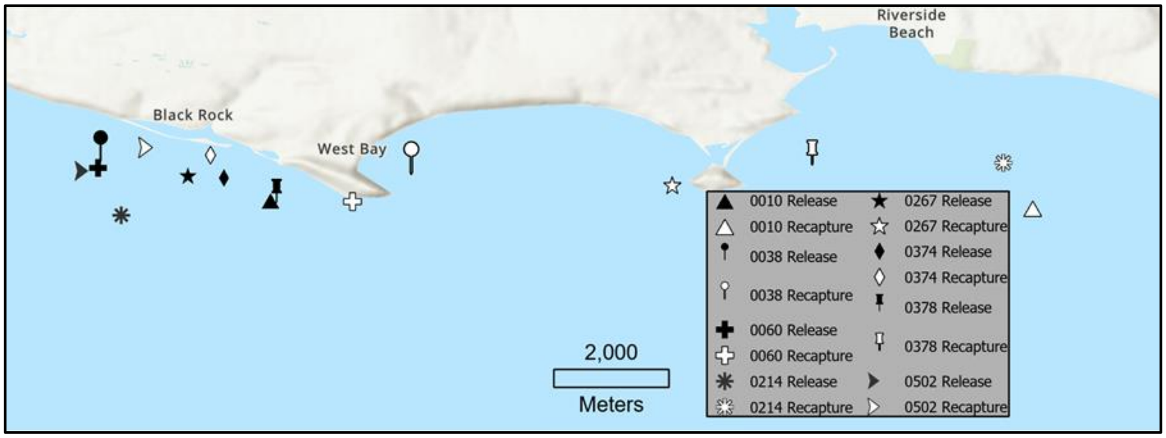


Figure 24: Release and recapture locations for lobsters with tag IDs 0010, 0038, 0060, 0214, 0267, 0374, 0378, and 0502 sampled during 2021 fall survey.

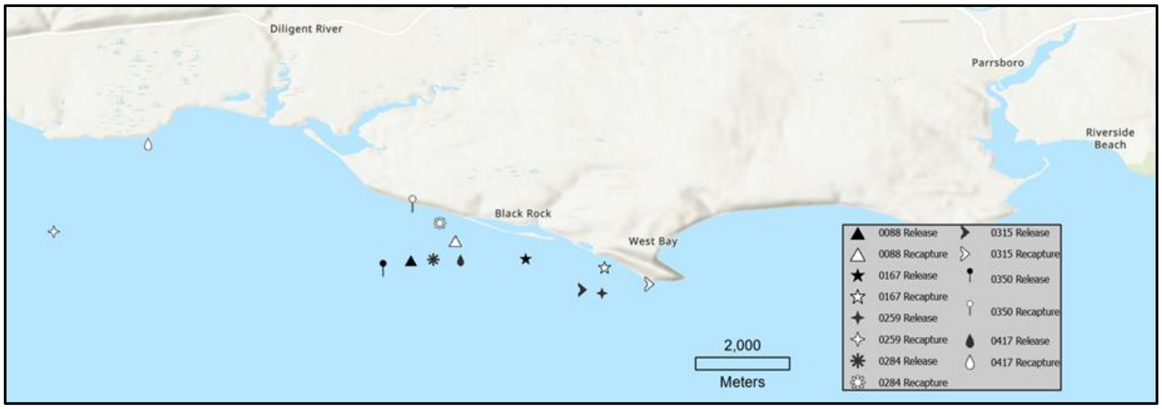


Figure 25: Release and recapture locations for lobsters with tag IDs 0088, 0167, 0259, 0284, 0315, 0350, and 0417 sampled during 2021 fall survey.

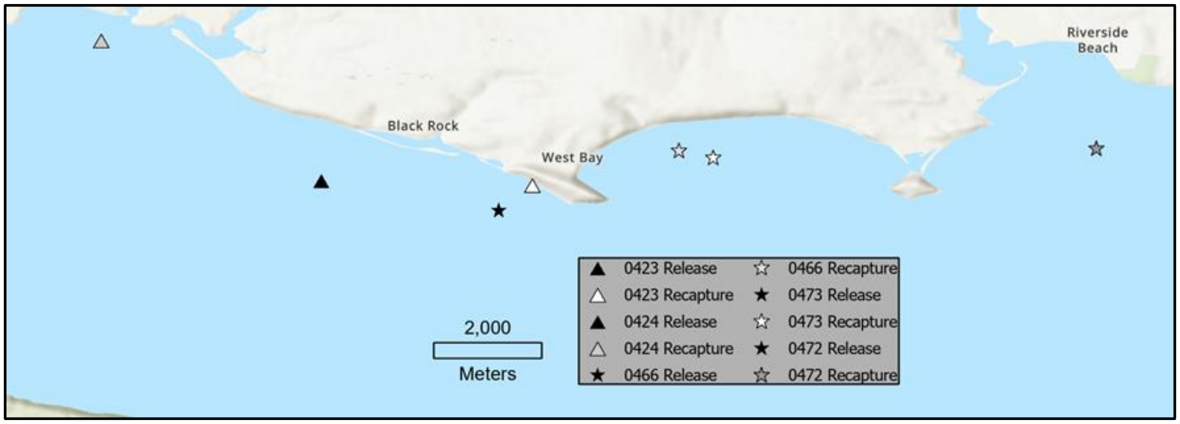


Figure 26: Release and recapture locations for lobsters with tag IDs 0423, 0424, 0466, 0473, and 0472 sampled during 2021 fall survey. Note: the release location for tag IDs 0423 and 0424 are the same, as are those with tag IDs 466, 472, 473.

Table 15: Summary information for tagged lobster (n=20) including date and coordinates for release and recapture during the fall 2021 commercial lobster fishery in LFA 35.

Tag ID	Release Location		Recapture Location		Release Date	Recapture Date	Linear Distance Travelled (m)	Days at Large
	Latitude	Longitude	Latitude	Longitude				
0010	45°21.848	-64°24.276	45°21.766	-64°17.131	08-30-2021	10-29-2021	9,316	60
0038	45°22.192	-64°25.868	45°22.084	-64°22.956	08-30-2021	11-01-2021	3,798	63
0060	45°22.147	-64°25.892	45°21.832	-64°23.507	08-31-2021	10-21-2021	3,158	51
0088	45°22.111	-64°26.288	45°22.334	-64°25.778	08-31-2021	11-24-2021	782	85
0167	45°22.123	-64°26.971	45°22.024	-64°24.067	09-03-2021	10-21-2021	3,789	48
0214	45°21.704	-64°25.673	45°22.194	-64°17.406	09-03-2021	11-05-2021	10,816	63
0259	45°21.728	-64°24.097	45°22.433	-64°30.384	09-28-2021	11-01-2021	8,301	34
0267	45°22.074	-64°25.049	45°21.985	-64°20.589	09-28-2021	10-15-2021	5,821	17
0284	45°22.114	-64°26.031	45°22.530	-64°25.957	09-28-2021	11-01-2021	774	34
0315	45°21.768	-64°24.267	45°21.832	-64°23.499	09-29-2021	10-15-2021	1,009	16
0350	45°21.913	-64°26.607	45°22.650	-64°26.270	09-29-2021	11-28-2021	1,438	61
0374	45°22.053	-64°24.712	45°22.266	-64°24.838	09-29-2021	10-29-2021	423	30
0378	45°21.813	-64°24.219	45°22.172	-64°19.198	09-30-2021	11-01-2021	6,571	33
0417	45°22.108	-64°25.719	45°23.433	-64°29.302	09-30-2021	11-12-2021	5,284	45
0423	45°22.100	-64°26.017	45°22.054	-64°23.910	09-30-2021	11-11-2021	2,746	43
0424	45°22.100	-64°26.017	45°23.498	-64°28.214	09-30-2021	10-16-2021	3,862	16
0466	45°21.801	-64°24.245	45°22.396	-64°22.446	10-01-2021	10-29-2021	2,592	28
0472	45°21.801	-64°24.245	45°22.418	-64°18.279	10-01-2021	10-21-2021	7,864	20
0473	45°21.801	-64°24.245	45°22.326	-64°22.104	10-01-2021	11-11-2021	2,955	42
0502	45°22.118	-64°25.982	45°25.982	-64°25.381	10-01-2021	11-01-2021	7,211	31

Water temperature and associations with lobster abundance and CPUE

We observed a subtle, but statistically significant ($p <0.001$), decrease in water temperature at the sea floor over the course of the survey (Table 16; Figure 27). During Phase I, the mean water temperature at the sea floor was 17.2°C (range: 16.6°C – 19.6°C); whereas, during Phase II, the mean water temperature at the sea floor was 16.7°C (range: 16.3°C – 17.8°C). This was not unexpected given the time frames for the different phases of the survey (i.e., early vs. late September).

Table 16: Summary statistics for bottom temperature (C°) during both phases of the survey for the Far Control (FC), Near Control (NC) and Impact (IMP) sites.

Water Temperature (°C)	Phase I			Phase II		
	Far Control	Near Control	Impact	Far Control	Near Control	Impact
Mean	17.15	17.18	17.35	16.65	16.73	16.75
Min	16.61	16.63	17.03	16.32	16.39	16.39
Max	19.58	17.77	17.92	17.03	17.15	17.18

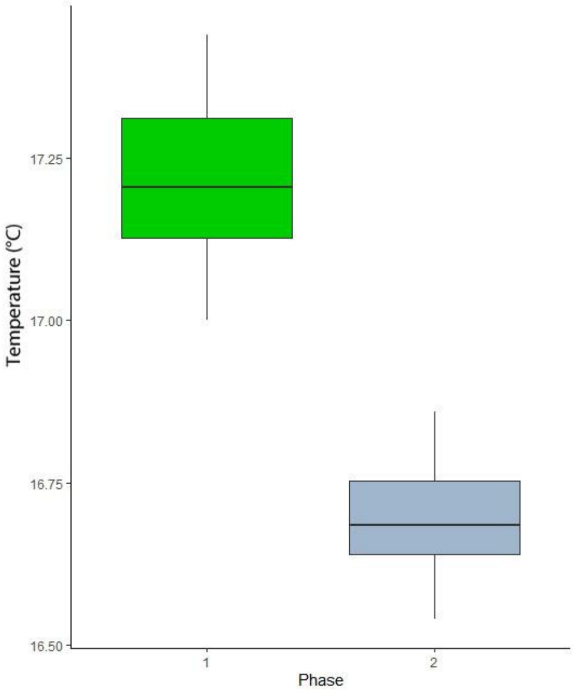


Figure 27: Boxplot displaying water temperature data collected during Phase I and II of the survey. Water temperature was significantly ($p < 0.001$) lower during Phase II of the survey.

A Shapiro-Wilks test confirmed that water temperature data collected within each phase of the survey was normally distributed. However, when combined these data significantly departed from normality ($p < 0.001$) and had significantly different variance ($p = 0.044$). As such, examination of the influence of temperature on lobster abundance and CPUE was conducted separately for each phase of the survey. During Phase I, we detected a non-significant ($p < 0.05$) and weak negative correlations between water temperature and lobster abundance ($r = -0.193$; $p = 0.259$) and CPUE (kg/haul) ($r = -0.170$; $p = 0.321$). However, during Phase II, we observed a statistically significant but weak negative relationship between water temperature and lobster abundance ($r = -0.362$; $p = 0.042$) and CPUE (kg/haul) ($r = -0.403$; $p = 0.022$).

Historical Commercial Landings Data

We observed a marked increase in commercial landings data (CPUE) for the fall lobster fishery from LFA 35 since at least 2005 (Figure 28). This pattern was observed for commercial landings reported from Grids 15-16 and 18-20, and from Grid 17 where the FORCE tidal demonstration site is located. Interestingly, CPUE from Grid 17 is generally higher than that reported from the remaining grids in LFA 35 (Appendix C). The CPUE data generated from the fall 2021 lobster survey is consistent with the CPUE reported from the other grids in LFA 35.

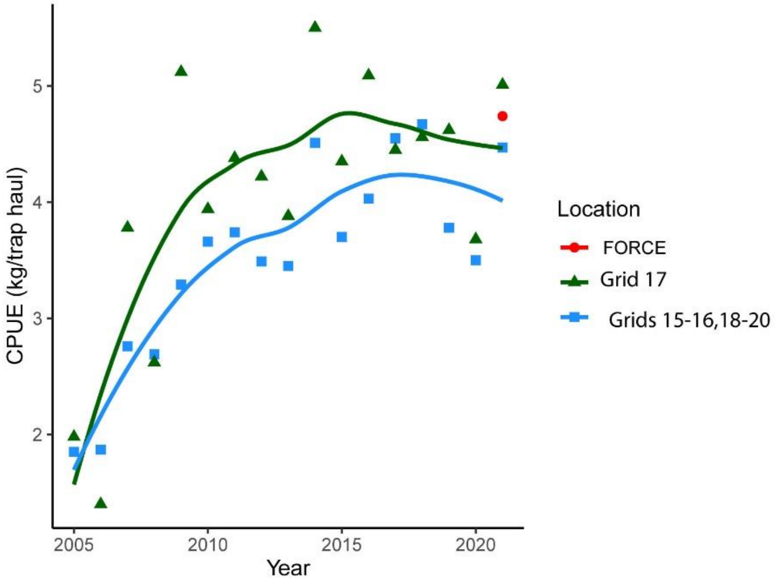


Figure 28: Scatterplot and loess regression of CPUE (kg/trap haul) for the fall commercial lobster fishery (2005-2021) from LFA 35. The CPUE data from the FORCE 2021 lobster survey is consistent with existing commercial landings data collected from Grid 17 and other grids within LFA 35.

Discussion

The objective of FORCE's lobster monitoring program is to determine whether operational tidal stream turbines have an effect on the catchability of lobster at the tidal demonstration site. The fall 2021 lobster survey followed the survey design developed by TriNav Fisheries to provide a statistically robust baseline dataset on lobster catchability in the vicinity of the FORCE tidal demonstration site, and incorporated a tagging component to understand the extent of lobster movement over relatively short time frames (approximately 1-2 months). A total of 582 lobsters were captured, assessed and released over the course of the survey, with 477 being tagged with conventional t-bar tags prior to release. We observed a nearly 1:1 sex ratio and few instances of shell disease (~3%), with 97.4% of assessed lobsters exhibiting moult stages 4 or 5 (i.e., 'hard shells'). Moult stage determination was supported by hemolymph and pleopod assessment which indicated that the majority of lobster were at the intermoult stage and had a high likelihood of retaining their tags. Over the course of the survey, carapace length ranged from 52-136 mm (mean: 92 mm CL), with average size during Phase I (88.28 mm CL) being slightly smaller than that during Phase II (94.48 mm CL). The minimum legal harvest size for lobster in LFA 35 is 82.5 mm CL.

Statistical analyses revealed non-significant differences in lobster abundance (lobster/trap haul) or CPUE (kg/trap haul) between Phase I (early September) and Phase II (late September) of the survey. However, we detected a marginally significant (p=0.052) difference in the abundance of lobster captured among sites, with the Impact Site having on average fewer lobster (6.2 lobster/trap haul) than either the Near Control Site (8.46 lobster/trap haul) or Far Control Site (8.92 lobster/trap haul) (Table 13; Figure 22). While we also observed lower CPUE at the Impact Site (4.58 kg/trap haul) relative to the Near Control site (6.07 kg/trap haul) or Far Control Site (6.02 kg/trap haul), this difference was non-significant (Table 14; Figure 23). Nonetheless, results of this survey reveal a 'high' catchability (i.e., 2.4 – 10.7 kg/trap haul; Table 1) of lobster in the vicinity of the FORCE tidal demonstration site, and is consistent with the findings of the 2017 lobster survey (Nexus Coastal Resource Management Ltd., 2017). Although the exclusion of data from Impact Site 4 (i.e., due to trap deployment at incorrect coordinates) reduced the sample size for comparison among sites, this was mitigated through examination of lobster abundance and CPUE through scaling the data by the number of trap hauls. The Impact Site constitutes the southern portion of the FORCE tidal demonstration site, and is located on an elevated volcanic plateau that is relatively flat with benthic habitat comprised of scoured bedrock (Figure 3, 4) (AECOM, 2009). These conditions may not provide optimal habitat for lobster (preferring habitats with boulders and rocks that provide shelter; Cobb, 1976) and may explain why catch rates and CPUE were lower relative to the control sites.

A slight (~0.5 °C) but statistically significant decrease in water temperature was detected at the seafloor over the course of the survey (Figure 27); consistent with survey time frame (Phase I: early September; Phase II: late September). We detected statistically significant, albeit weak negative correlations between water temperature and both lobster abundance and CPUE during Phase II of the survey. However, we cannot draw any conclusions about the influence of water temperature on lobster catchability due to the protracted time frame over which data was collected during Phase II of the survey (September 27 – October 1). A considerably longer time series, including continuous data collection to increase sample sizes and improve statistical power, would be required to conduct a more meaningful analysis. Unfortunately, the high tidal flow rates and turbulent conditions of the Minas Passage impose operational limitations on the implementation of the lobster survey that necessitate trap deployments and recoveries around neap tides to increase operational windows around 'slack water' conditions (i.e., the period of transition from flood to ebb tidal phase). In a more benign marine environment, it would be possible to extend the duration of the survey, deploy all 18 trap simultaneously, maintain 24-hour soak periods for data collection, and complete the survey in a single phase. This is simply not feasible in Minas Passage, and the advice of local lobster fishers proved invaluable in fine-tuning the approach to be taken during this survey. While the 2017 lobster survey was able to recover and deploy eight lobster traps per day (Nexus Coastal Resource Management Ltd., 2017), this survey was only able to increase that to nine traps per day.

Approximately 5% of tagged lobsters were recaptured and reported by local fishers during the fall 2021 commercial lobster fishing season and provided important information about the short term (approximately 1-2 months) movements of lobster in Minas Passage. Lobster movement was highly variable (0.42-10.8 KM; Table 15), and there was no correlation between the number of days an individual was at large and the distance travelled, and may be due to the relatively small sample size (n=20).

The marked increase in commercial landings data provided by Fisheries and Oceans Canada for the fall lobster fishery in LFA 35 for 2005-2021, including for grid 17 where the FORCE tidal demonstration site is located (Figure 28), is consistent with a northward shift in the distribution of lobster associated with climate change. Sea surface temperatures in the Gulf of Maine have increased faster than 99% of the global ocean, and is related to a northward shift in the Gulf Stream and changes to the global ocean circulation patterns (Pershing et al. 2015). Increasing water temperature can impact lobster movement, susceptibility to disease, survival and recruitment to the fishery (Wahle et al. 2009; Mills et al. 2013). It is possible that a combination of these and other factors are contributing to the increased abundance of lobster being captured by the fall commercial lobster fishery in LFA 35.

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FORCE is located in Mi’kma’ki, the ancestral and unceded territory of the Mi’kmaq, covered by the “Treaties of Peace and Friendship” which Mi’kmaq and Wolastoqiyik (Maliseet) People first signed with the British Crown in 1725. Mi’kmaw Peoples have lived on and cared for this land for over 13,500 years.

We would also like to acknowledge Bliss Walton, a local lobster harvester who devoted his time and local ecological knowledge to this project. Local ecological knowledge includes perceptions about an environment formed by consistent interaction with an environment, and cultural knowledge about an environment passed down generations. Fish harvesters like Mr. Walton are stewards of their resource, and their contributions to surveys like this provide a perspective that is invaluable to research. We would like to thank Mr. Walton for making marine operations a safe and efficient experience, and for bringing a positive outlook onboard the vessel each day.

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References

AECOM. 2009. Environmental assessment registration document – Fundy tidal energy demonstration project. Volume 1: environmental assessment. Fundy Ocean Research Centre for Energy Pro. # 107405.

Aiken, D. E. (1973). Proecdysis, Setal Development, and Molt Prediction in the American Lobster *Homarus americanus.* Journal of the Fisheries Research Board of Canada, 30(9), 1337–1344. Doi:10.1139/f73-214

Ainsworth, C.H. (2011) Quantifying species abundance trends in the Northern Gulf of California using local ecological knowledge. *Marine and Coastal Fisheries*, 3(1), 190-218. Doi: 10.1080/19425120.2010.549047

Annis, E. R. (2005). Temperature effects on the vertical distribution of lobster postlarvae *(Homarus americanus*). *Limnology and Oceanography*, 50, 1972–1982.

Appelman, M. (2015). A Catch Per Unit Effort (CPUE) Spatial Metric with Respect to the Western North Atlantic Pelagic Longline Fishery. Master's thesis. Nova Southeastern University. Retrieved from NSUWorks, Oceanographic Center.

Barret, L., Miron, G., Ouellet, P., & Tremblay R. (2017). Settlement behaviour of American lobster (*Homarus Americanus)*: effect of female origin and developmental temperature. *Fisheries Oceanography*, 26(1), 69-82.

Battison, A. L. (2018). Use of the Brix value with cuticle indices to describe haemolymph biochemistry parameters in Homarus americanus H. Milne Edwards, 1837 (Decapoda: Malacostraca: Nephropidae). Journal of Crustacean Biology, Volume 38, Issue 5, September 2018, Pages 625–634, https://academic.oup.com/jcb/article/38/5/625/5087934

Boudreau, S. A., & Worm, B. (2010). Top-down control of lobster in the Gulf of Maine: insights from local ecological knowledge and research surveys. *Marine Ecology Progress Series,* 403, 181-191.

Brennan, C. E., Blanchard, H. & Fennel, K. (2016). Putting Temperature and Oxygen Thresholds of Marine Animals in Context of Environmental Change: A Regional Perspective for the Scotian Shelf and Gulf of St. Lawrence*. PLOS ONE,* 11(12), 1-27 https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0167411

Brewin, R. J. W., Smale, D. A., Moore, P. J., Dall'Olmo, G., Miller, P. I., Taylor, B. H., Smyth, T. J., 38tlantic, J. R., & Yang, M. (2018). Evaluating operational AVHRR sea surface temperature data at the coastline using benthic temperature loggers. *Remote Sensing,* 10, 1-23. https://www.mdpi.com/2072-4292/10/6/925

Bundy, A., Chuenpagdee, R., Boldt, J. L., de Fatima Borges, M., Camara, M. L. Coll, M., Diallo, I., Fox, C., Fulton, E. A., Gazihan, A., Jarre, A., Jouffre, D., Kneisner, K., M., Knight, B., Link, J., Matiku, P. P., Masski, H., Moutopoulos, D. K., Piroddi, C., Raid, T., Sobrino, I., Tam, J., Thiao, D., Torres, M. A., Tsagarakis, K., van der Meeren, G.I, & Shin, Y. (2017). Strong fisheries management and governance positively impact ecosystem status. *Fish and Fisheries,* 18, 412-439.

Caputi, N., Brown, R. S., & Chubb, C.F. (1995). Regional prediction of the western rock lobster, *Panulirus Cygnus*, commercial catch in Western Australia. *Crustaceana,* 68(2), 245-256.

CEF Consultants Ltd. (2010). Fundy Tidal Energy Demonstration Project Lobster Catch Monitoring. FORCE.

CEF Consultants (2011) Fundy Tidal Energy Demonstration Project Lobster Catch Monitoring: Summary of Results from Three Surveys with Recommendations for a Revised Survey Design. FORCE.

Chang, Y., Sun, C., Chen, Y., Zhang, Y., & Yeh S. (2011). Incorporating climate changes into population modelling: an individual-based modelling approach for lobster. *Canadian Journal of Fisheries and Aquatic Sciences,* 68, 122-136. https://cdnsciencepub.com/doi/abs/10.1139/F10-148

Childress, J. L., Shearman, R. K., & Harte, M. (2010). Evaluation of 39tlantic39 crab pots as platforms of opportunity for ocean-observing research. Presented at Oceans 2010, Seattle, WA, USA. Doi: 10.1109/OCEANS.2010.5664269

Cigliano, J. A., Meyer, R., Ballard, H. L. Frietag, A., Phillips, T. B., & Wasser, A. (2015). Making marine and coastal citizen science matter. *Ocean and Coastal Management*, 115, 77-87.

Cobb, J.S. 1976. The American lobster: the biology of Homarus americanus. University of Rhode Island, Marine Technical Report 49.

Cobb, J. S., & Wahle, R. A. (1994). Early Life History and Recruitment Processes of Clawed Lobsters. *Crustaceana,* 67(1), 1-25.

Coffen-Smout, C., D. Shervill, D. Sam, C. Denton, and J. Tremblay. 2013. Mapping Inshore Lobster Landings and Fishing Effort on a Maritimes Region Modified Grid System. Can. Tech. Rep. Fish. Aquat. Sci. 3024; 33 pp.

Comeau, Michel; Mallet, Manon. (2003). The effect of timing of tagging on streamer-tag recapture rates for American lobster (Homarus americanus). The Free Library (July, 1), https://www.thefreelibrary.com/The%20effect%20of%20timing%20of%20tagging%20on%20streamer-tag%20recapture%20rates%20for...-a0107524523

Cooke, S. J., Wesch, S., Donaldson, L. A., Wilson, A. D. M., & Haddaway, N. R. (2017). A call for evidence-based conservation and management of fisheries and aquatic resources. *Fisheries,*42(3), 143-149.

DFO (Fisheries and Oceans Canada). 2016. Review of Environmental Effects Monitoring Program for the Fundy Tidal Energy Project. DFO Can. Sci. Advis. Sec. Sci. Resp. 2016/022.

DFO. 2019a. At-sea sampling protocol for American Lobster. Lobster Unit, Population Ecology Division Department of Fisheries and Oceans.

DFO. 2019b. Assessment of Lobster (*Homarus Americanus*) in Lobster Fishing Areas 27-32. DFO Canadian Science Advisory Secretariat Science Advisory Report 2019

DFO. 2021. Science Advisory Report 2021/020 Assessment of American Lobster (Homarus americanus) in Lobster Fishing Areas 35–38. Retrieved January 2 from dfo-mpo.gc.ca/csas-sccs/Publications/SAR-AS/2021/2021_020-eng.html

Factor, J. R. (Ed). (1995). Biology of the Lobster *Homarus americanus.* Academic Press Inc.

Farr, E. R., Stoll, J. S., & Beitl, C. M. (2018). Effects of fisheries management on local ecological knowledge. *Ecology and Society,* 23(3), 1-9.

FORCE. (2021) Operational safety plan: Lobster survey Minas Basin

FORCE. (2019). Renewable and predictable: Our purpose. Retrieved January 17, 2022 from fundyforce.ca/about-us

Freer, J. J., Partridge, J. C., Tarling, G. A., Collincs, M. J. (2018). Predicting ecological responses in a changing ocean: the effects of cimate uncertainty. *Marine Biology,* 165(7), 1-19.

FSRS (2022). About the FSRS. Retrieved January 17, 2022 from https://fsrsns.ca/objectives//

Fujitani, M., McFall, A., Randler, C., & Arlinghaus, R. (2017). Participatory adaptive management leads to environmental learning outcomes extending beyond the sphere of science. *Science Advances,* 3, 1-11.

Haakonsen, H. O.; Anoruo, A. O. (1994). Tagging and migration of the American lobster Homarus americanus. Reviews in Fisheries Science, 2(1), 79–93. https://www.tandfonline.com/doi/abs/10.1080/10641269409388553

Jury, S. H., & Watson, W. H. (2013). Seasonal and sexual differences in the thermal preferences and movements of American lobsters. *Journal of Fisheries and Aquatic Sciences,* 70(11), 1650-1657. https://doi-org.qe2a-proxy.mun.ca/10.1139/cjfas-2013-0061

Lavalli, K.L., & Lawton P. (1996). Historical Review of Lobster Life History Terminology and Proposed Modifications to Current Schemes. *Crustaceana,* 69, 594-609.

Le Bris, A., Mills, K. E., Wahle, R. A., Chen, Y., Alexander, M. A., Allyn, A. J., Shuetz, J.G., Scott, J.D. & Pershing, A. J. (2017). Climate vulnerability and resilience in the most valuable North American fishery. *PNAS,* 115(8), 1831-1836.

Li, B., Cao, J., Chang, J., Wilson, C., & Chen, Y. (2015). Evaluation of effectiveness of fixed-station sampling for monitoring American lobster settlement. *North American Journal of Fisheries Management,* 35, 942–957. https://www.tandfonline.com/doi/abs/10.1080/02755947.2015.1074961

Li, B., Tanaka, K.R., Chen, Y., Brady, D. C., & Thomas, A.C. (2017). Assessing the quality of bottom water temperatures from the Finite-Volume Community Ocean Model (FVCOM) in the Northwest Atlantic Shelf region. *Journal of Marine Systems,* 173, 21–30.

Lillis, A., & Snelgrove, P. V. R. (2010). Near-bottom hydrodynamic effects on postlarval settlement in the American lobster *Homarus americanus. Marine Ecology Progress Series,* 401, 161-172.

MacDonald, C. and Scott, S. 2000. Lobster v-notch conservation program for LFA 32 and 31B, Fishermen and Scientists Research Society, 19 p.

Medeiros, M. C., Barboza, R. R. D., Martel, G. & da Silva Mourao, J (2018). Combining local fishers' and scientific ecological knowledge: Implications for comanagement. Ocean and Coastal Management, 158, 1-10.

Medley, A. H., & Ninnes, C. H. (1997). A recruitment index and population model for spiny lobster (*Panulirus argus)* using catch and effort data. *Canadian Journal of Fisheries and Aquatic Sciences,* 54, 1414-1421.

Mills, K.E., A.J. Pershing, C.J. Brown, Y. Chen, F.-S. Chiang, D.S. Holland, S. Lehuta, J.A. Nye, J.C. Sun, A.C. Thomas, and R.A. Wahle. 2013. Fisheries management in a changing climate: Lessons from the 2012 ocean heat wave in the Northwest Atlantic. Oceanography 26(2):191–195, http://dx.doi.org/10.5670/oceanog.2013.27.

Morrison, K., Broome, J., and Redden, A.M. (2014). Minas Passage Lobster Tracking Study. Acadia University. FORCE.

NEXUS Coastal Resource Management Ltd. (2017). Lobster Catchability Study Report. FORCE

Nielsen, T. V., & McGaw, I. J. (2016). Behavioural thermoregulation and trade-offs in juvenile

NOAA (2018). Lobster shell disease. Retrieved January 19, 2022, from https://www.fisheries.noaa.gov/science-blog/lobster-shell-disease

Pershing, A. J., Alexander, M. A., Christina, M., Kerr, L. A., Bris, A. Le, Mills, K. E., Nye, J. A., Record, N. R., Scannell, H. A., Scott, D., Sherwood, G. D., & Thomas, A. C. (2015). Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery. *Science*, *October*, 1–8.

Phillips, B. F. (1986). Prediction of commercial catches of the western rock lobster *Panulirus Cygnus. Canadian Journal of Fisheries and Aquatic Sciences,* 43, 2126-2130.

Quackenbush, L. S. (1994). Lobster reproduction: a review. *Crustaceana,* 67(1), 82-94.

Quinn, B. K. (20167). Threshold temperatures for performance and survival of American lobster larvae : A review of current knowledge and implications to modeling impacts of climate change. *Fisheries Research*, 186, 383-396. http://dx.doi.org/10.1016/j.fishres.2016.09.022.

R Development Core Team (2021) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, ISBN 3-9000051-07-0, URL http://www.R-project.org.

Roman, S., Jacobson, N., & Cadrin, S. X. (2011). Assessing the Reliability of Fisher Self-Sampling Programs. *North American Journal of Fisheries Management,* 31, 165–175., 2011. https://www.tandfonline.com/doi/abs/10.1080/02755947.2011.562798

Serdynska, A., and Coffen-Smout, S. (2014). Mapping Inshore Lobster Landings and Fishing Effort on a Maritimes Region Statistical Grid. Fisheries and Oceans Canada Maritimes Region.

Serdynska, A., & Coffen-Smout, S. (2017). Mapping inshore lobster landings and fishing effort on a Maritimes Regional statistical grid (2012-2014). Dartmouth, NS: Fisheries and Oceans Canada.

Shearman, R. K., & Childress, J. L. (2012). Deploying dissolved oxygen sensors on crab pots for ocean observations. *Sea Technology*, 53(6), 25-30.

Sobral, A., La Torre-Cuadros, M., Alves, R. R. N. & Albuquerque, U. P. (2017). Conservation efforts based on local ecological 42tlantic42 : The role of social variables in identifying environmental indicators. *Ecological Indicators,* 81, 171-181

Starr, P. J., & Vignaux, M. (1997). Comparison of data from voluntary logbook and research catch-sampling programmes in the New Zealand lobster fishery. *Marine and Freshwater Research*, 48, 1075-1080

Starr, P. (2010). Fisher-Collected Sampling Data: Lessons from the New Zealand Experience. *Marine and Coastal Fisheries*, 2(1), 47-59, DOI: 10.1577/C08-030.1

Tremblay, M. J., Macdonald C., and Claytor, R. R. (2009) Indicators of abundance and spatial distribution of lobsters (Homarus americanus) from standard traps, New Zealand Journal of Marine and Freshwater Research, 43:1, 387-399, DOI: 10.1080/00288330909510008

This Fish (2021). Fishery Profile: Bay of Fundy Nova Scotia Lobster Fishing Area 35. Retrieved Jan 2 from https://thisfish.info/fishery/43tlantic-lobster-canada-lfa35

Van-Sander, S., Clifton, J., & Harvey, E. (2016). Can citizen science work? Perceptions of the role and utility of citizen science in a marine policy and management context. *Marine Policy,* 72, 82-93.

Waddy, S. L., Feindel, N. Hamilton-Gibson, N., Aiken, D. E., Merrit, V., & Leavitt, N. (2017). Reproductive cycles and mating capacity in male American Lobsters (*Homarus americanus). Fisheries Research,* 186, 358-366. https://www.sciencedirect.com/science/article/abs/pii/S0165783616303277?via%3Dihub

Wahle, R. A., Battison, A., Bernatchez, L., Boudreau, S., Castro, K., Grabowski, J. H., Greenwood, C. G., Rochette, R., & Wilson, J. (2013). The American lobster in a changing ecosystem: a US-Canada Science Symposium. *Canadian Journal of Fisheries and Aquatic Science,* 70, 1571-1575. https://cdnsciencepub.com/doi/10.1139/cjfas-2013-0465

Wahle, R. A., Cobb, J. S., Incze, L. S., Lawton, P. Gibson, M., Glenn, R., Wilson, C., & Tremblay, J. (2010). The American lobster settlement index at 20 years: looking back – looking ahead. *Journal of the Marine Biological Association of India,* 52, 180-188.

Wahle, R. A., Dellinger, L., Olszewski, S., & Jekielek, P. (2015). American lobster nurseries of southern New England receding in the face of climate change. *ICES Journal of Marine Science*, 72(Supplement 1), i69-i78. https://academic.oup.com/icesjms/article/72/suppl_1/i69/622623

Wahle, R. A., & Incze, L. S. (1997). Pre- and post-settlement processes in recruitment of the American Lobster. *Journal of Experimental Marine Biology and Ecology,* 217, 179-207.

Wahle, R. A., Incze, L. S., & Fogarty, M. J. (2004). First projections of American lobster fishery recruitment using a settlement index and variable growth. *Bulletin of Marine Science,* 74(1), 101–114.

Watson, F. L., Miller, R. J., & Stewart, S. A. Spatial and temporal variation in size at maturity for female American lobster in Nova Scotia. *Canadian Journal of Fisheries and Aquatic Sciences,* 70, 1240–1251. Dxdoi.org/10.1139/cjfas-2012-0480

Xu C., & Scneider, D. C. (2012). Efficacy of conservation measures for the A,erican lobster: reproduction value as a criterion. *ICES Journal of Marine Science,* 69(10), 1831-1839. https://academic.oup.com/icesjms/article/69/10/1831/622515

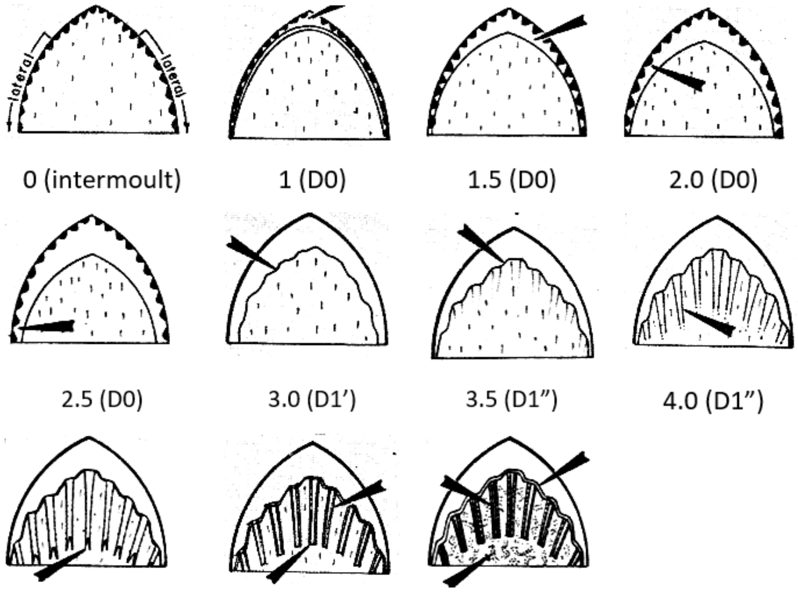
Zhang, Y., Chen, Y., & Wilson, C. (2011). Developing and evaluating harvest control rules with different biological reference points for the American lobster (*Homarus americanus*) fishery in the Gulf of Maine. *ICES Journal of Marine Science,* 68(7): 1511-1524. https://academic.oup.com/icesjms/article/68/7/1511/656815

Appendices

Appendix A: Moult Staging in American Lobster

A brix refractometer is used to quantify solute in liquids, which is primarily protein in lobster hemolymph (Battison 2018). Degrees brix (°Bx) can be used as an indicator of pre-moult, inter-moult and post-moult stages of the lobster moult cycle (Battison 2018). Less than 7 °Bx could indicate a lobster is recovering from moult or is suffering from disease or injury (Battison 2018). An intermoult lobster provides hemolymph with greater than 8 °Bx (Battison 2018). A lobster with near 16 °Bx is actively preparing to moult (Battison 2018).

Pleopod samples can be taken and examined at 40x magnification using a compound light microscope to determine whether a lobster is preparing to moult or is in the intermoult stage (Aiken 1973). The figure below shows indicators a technician would observe to establish whether a lobster is preparing to moult. The table describes moult and pleopod stages shown in the figure. Pleopod stage 0 is seen in intermoult lobster that are not preparing to moult (Aiken 1973). Pleopod stages 1 through 2.5 are described as moult stage D0, where it will still be several months before the lobster moults (Aiken 1973). Lobster with pleopods stages 4.5 to 5 are in moult stage D2 and will moult in under two weeks (Aiken 1973). Lobster with pleopods in stage 5.5 or moult stage D3 will moult within several days (Aiken 1973).



0 (intermoult) 1 (D0) 1.5 (D0) 2.0 (D0)

2.5 (D0) 3.0 (D1’) 3.5 (D1”) 4.0 (D1”)

4.5 (D2’) 5.0 (D2”) 5.5 (D3)

Pleopod moult stages as observed through a compound light microscope. Modified from Aiken (1973).

Moult and pleopod staging in American lobster. Modified from Aiken (1973).

Moult Stage	Pleopod Stage	Description
C4	0	Epidermis closely applied to cuticular nodes at tip of pleopod; no amber zone or epidermal retraction at pleopod tip
D0	1	First indication of apolysis - amber or double-bordered region forms at the pleopod tip. Chromatophores often show signs of reorganization but there is no epidermal retraction from the cuticle
D0	1.5	Epidermis retracting from terminal cuticular nodes; may have double-bordered appearance
D0	2.0	Epidermal line clearly formed and retracting from lateral cuticular nodes
D0	2.5	5 Maximum epidermal retraction - not touching any lateral cuticular nodes
D1’	3.0	Invagination papillae form at site of future setae; epidermis becomes scalloped
D1”	3.5	Invagination papillae clearly formed but shafts of new setae not well defined
D1”’	4.0	Shafts of developing setae visible but proximal ends not clearly defined. Shafts now invaginated to maximum length.
D2’	4.5	Shafts visible full length but proximal ends are bifurcate instead of blunt (Fig. 4N, O). Barbules becoming visible on setal shafts.
D2”	5.0	0 Shafts of developing setae thick, proximal ends blunt
D3	5.5	Shafts of setae very thick and dark, proximal ends blunt. Classify as Ds" if folds or ripples are visible in cuticle on upper surface of pleopod

Appendix B: Sample Data Sheet

FORCE FALL LOBSTER SURVEY 2021

Date	
Lat	
Long	
Trap ID	
Temp logger	
Sampler	
Release coordinates	

Length	Sex	Clutch stage	Clutch %	Shell Hardness	Condition	V-notch	Tag no.	Moult Stage	Blood Protein	Comments

Appendix C: DFO Historic Landings Data

CPUE calculated as weight (lbs) per trap haul and weight (kg) per trap haul for LFA 35 grids 15, 16, 18, 19, and 20 in the Minas Basin during the fall fishing season from 2005 to 2021. N is the number of trips sampled each year used to calculate CPUE.

Year	N	Weight (kg)	Number of trap hauls	CPUE (kg/trap haul)
2005	192	35,122.00	18,970	1.85
2006	316	59,510.88	31,891	1.87
2007	469	134,628.80	48,851	2.76
2008	476	154,862.81	57,661	2.69
2009	530	165,584.13	50,310	3.29
2010	557	191,163.27	52,222	3.66
2011	642	195,429.93	52,314	3.74
2012	575	192,284.35	55,069	3.49
2013	430	144,655.78	41,986	3.45
2014	488	216,613.15	48,016	4.51
2015	300	143,446.71	38,728	3.70
2016	418	176,088.62	43,693	4.03
2017	315	167,320.18	36,810	4.55
2018	228	116,031.97	24,854	4.67
2019	265	104,219.50	27,572	3.78
2020	252	99,543.31	28,412	3.50
2021	151	82,956.92	18,579	4.47

CPUE calculated as weight (lbs) per trap haul and weight (kg) per trap haul for LFA 35 grid 17 in the Minas Basin during the fall fishing season from 2005 to 2021. N is the number of trips sampled each year used to calculate CPUE.

Year	N	Weight (kg)	Number of Trap hauls	CPUE (kg/trap haul)
2005	5	467.12	236	1.98
2006	49	4,150.11	2,965	1.40
2007	42	16,217.69	4,294	3.78
2008	108	25,643.99	9,789	2.62
2009	99	49,231.29	9,617	5.12
2010	85	23,793.65	6,044	3.94
2011	139	50,917.91	11,627	4.38
2012	164	75,192.74	17,810	4.22
2013	112	42,834.47	11,027	3.88
2014	149	76,883.90	13,972	5.50
2015	72	46,877.10	10,776	4.35
2016	120	58,564.63	11,507	5.09
2017	73	25,013.61	5,623	4.45
2018	67	30,226.76	6,623	4.56
2019	88	44,154.20	9,552	4.62
2020	82	38,272.56	10,388	3.68
2021	49	36,947.85	7,377	5.01