Progress on the Ecosystem Research Initiative for the Northumberland Strait since October 2012

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ABSTRACT

The Minister of Fisheries and Oceans initiated a working group in 2005 to assess the ecosystem structure and productivity of the Northumberland Strait with respect to the Confederation Bridge. Three key areas of research were proposed: 1) habitat and resource protection; 2) alternative fisheries management; and 3) economic diversification. DFO Science Gulf Region received funding under the Ecosystem Research Initiative (ERI) to address the first key area: habitat and resource protection. Studies were conducted in the Northumberland Strait (ERINS) between 2007 and 2012 focussing on three research priorities identified by stakeholders: understanding present state and development of ecosystem health indicators; assessing changes of habitat and fauna over time; and data collection, mining/rescue, accessibility and management. White et al. (2013; CSAS Research Document 2013/027) produced a national synthesis of the seven large-scale ERI programs across Canada between 2007 and 2012. We are now presenting a manuscript report showing the progress accomplished from October 2012 to September 2017 for the ERINS. In addition, published non-ERINS material relevant to the ERINS study area, and identified gaps and limitations are also presented.

RÉSUMÉ

En 2005, le ministre des Pêches et des Océans a mis sur pied un groupe de travail chargé d'évaluer la structure et la productivité de l'écosystème du détroit de Northumberland en lien avec la présence du pont de la Confédération. Trois priorités de recherche ont alors été proposés: 1) la protection de l'habitat et des ressources; 2) la gestion des pêches alternatives; et 3) la diversification économique. Afin d’adresser la première priorité, le MPO Science de la région du Golfe a reçu du financement pour mener des études dans le cadre de l'Initiative de Recherche sur les Écosystèmes (IRÉ) afin d’adresser la première priorité. Des études ont été effectuées dans le détroit de Northumberland (ERINS) entre 2007 et 2012. Les recherches ont été axées sur trois priorités identifiées par les intervenants: le développement d’indicateurs de la santé de l'écosystème et la compréhension de son état actuel; évaluer les changements de l'habitat et de la faune au fil du temps; et la collecte, l’extraction et la récupération de données, facilitant l’accessibilité et la gestion de celles-ci. White et al. (2013 ; CSAS Research Document 2013/027) a produit une synthèse nationale à grande échelle des sept programmes d'IRÉ au Canada entre 2007 et 2012. Nous présentons maintenant un rapport manuscrit montrant les progrès accomplis d'octobre 2012 à septembre 2017 pour le ERINS. En outre, des documents non-ERINS publiés concernant la zone d'étude ERINS, ainsi que certaines lacunes et limitations sont également identifiées.

EXECUTIVE SUMMARY

The Minister of Fisheries and Oceans initiated a working group in 2005 to assess the perception that ecosystem structure and productivity of the Northumberland Strait was negatively impacted by the Confederation Bridge between New Brunswick and Prince Edward Island. Following submission of a report, in April 2006 a Federal-Provincial Deputy Minister's Steering Committee was established to focus effort in three key areas: 1) habitat and resource protection; 2) alternative fisheries management; and 3) economic diversification. To address the first key area, DFO Science Gulf Region received funding under the Ecosystem Research Initiative (ERI) to carry out studies in the Strait between 2007 and 2012 focussing on three research priorities identified by stakeholders: understanding present state and development of ecosystem health indicators; assessing changes of habitat and fauna over time; and data collection, mining/rescue, accessibility and management. The ERI program originally had eight goals; however, Goal 2 (nutrient mixing) and Goal 4 (biomass size spectrum tool) were not addressed or met in the context of the Ecosystem Research Initiative for Northumberland Strait (ERINS) as they were beyond the scope of the available funding. The objective of Goal 8 was to provide structured databases of all information used or generated by this research initiative, and that was largely completed.

The objective of Goal 1 was to develop a fine-scale 3-D model of water movements. The high resolution modelling showed that the circulation in the Strait is complex due to the interaction of tides, winds, shoreline features, and remote forcing (*e.g.*, storm surge) with a general west to east circulation. There is a large seasonal cycle of water temperature in the Strait with bottom water temperatures of about -1.6°C during winter and > 23°C (> 25°C at the surface) in some places during the summer. There is no stratification in shallow areas where the mixing is strong, but a thermocline can occur in some places where the depth is > 20 m. Salinity is lower on the western side of the Strait. The high-resolution model was calibrated with micro-bead dispersion experiments and looks to be promising way to formulate and validate regional hydrodynamic models. For example, one application with American lobster larvae showed that the stock in the Strait is a largely self-contained while elsewhere there is considerable larval mixing between stocks.

The objective of Goal 3 was to examine the relationship between water masses and pelagic species (zooplankton and fishes) assemblages. There was a shallow, well-mixed, water mass in the central Strait (with a distinct zooplankton species-assemblage) while the deeper waters at the ends were separated into a warm surface layer that transitioned into a very cold bottom layer (and a different zooplankton species assemblage). Chlorophyll *a* levels in the water column have increased somewhat since the early 1990s but still are at the low end of the range and consistent with an increase of pelagic fish abundance (*i.e.*, independent from nutrient level increases). The water was clear enough that light levels required for photosynthesis reached the bottom in most of the Strait, and that primary production would contribute directly to the benthic energy cycle. Analysis of stomachs of pelagic fishes indicated that some of them were actually part of the benthic food web instead of the pelagic food web.

The objective of Goal 5 was to examine measures of ecosystem diversity and uniqueness. Pelagic fish biomass has increased and plateaued since 2001-2003 while demersal fish biomass initially decreased to 2006 and has since fluctuated. Some demersal species have undergone significant declines in abundance accompanied by distribution contraction while the abundances and areas occupied by Rainbow Smelt and Alewife (both are diadromous species) have increased. Indeed, unlike the well-studied offshore marine ecosystems, the coastal ecosystem of the Strait supports large populations of diadromous fishes, which have a strong estuary and freshwater requirement to complete their life cycles and this adds a strong terrestrial and freshwater component to energy and nutrient pathways. The central Strait acts as a major nursery for juvenile Atlantic Herring. The Winter Skate and lady crab populations almost certainly represent undescribed endemics. Unfortunately, without major intervention to reduce adult predation mortality, Winter Skate has a high likelihood of becoming extinct before description of the species can be completed.

The objectives of Goal 6 were to quantify the biomass or energy in functional groupings. Abundance indices were calculated for the main fish and large-bodied decapod species. Atlantic rock crabs play an important part of the food web both as predator and prey. In contrast, the American lobster represents an energy sink and prey mainly upon Atlantic rock crab and other American lobster. For the fishes, the low abundances and small areas of occupancy of the main piscivores indicated weak predator-prey interactions; with the American Sand Lance and Rainbow Smelt as the most commonly consumed forage fishes. This is a species-poor ecosystem and diet overlap was low to moderate with only three multi-species feeding groups: planktivores; predators on small invertebrates; and species that preyed heavily upon *Crangon* shrimp. American Plaice formed its own group and mainly ate sand dollars, sea urchins, and mysids. *Crangon* shrimp formed a key node in the food web.

The objective of Goal 7 was to assess changes of the habitat and benthic organisms since the only previous survey in 1975. Significant differences between both surveys were observed in the community analyses, even though it was restricted to presence-absence data. Nine surface dwelling and seven burrowing taxa changed significantly in occurrence from 1975 to 2009. Four surface taxa (including scallops) and five burrowing taxa decreased in occurrence while five three fish, two shrimp species, and two burrowing taxa increased in occurrence. From the quantitative analyses, sea urchins decreased in abundance by 97%, and American lobster abundance did not change - consistent with the lobster-landings pattern during the same time period. While some changes were identified between the surveys, it is difficult to infer causality with only two data points because the observed differences may be within the unknown range of natural variation of the ecosystem.

In conclusion, there is no evidence from the ERI program of a decline in the health (an undefined concept) or productivity of the Strait, indicating a fully-functioning ecosystem. The ecosystem structure and functioning is, however, in a transition state due to large changes in species abundances and changing, global scale, environmental conditions. Water quality indices (*e.g.*, water transparency, oxygen, and Chlorophyll *a* levels) are within the “excellent” range. Nutrient loading issues affecting the small adjacent estuaries are unlikely to measurably affect the marine waters of the Strait unless it can be shown that the nutrient load emptying from the estuaries is large enough to surpass the dilution capacity of the Strait. The current Chlorophyll *a* (Chl *a*) levels in the Strait are well below the level where there is concern about shading or formation of anoxic areas (dead zones). Predicted increases in bottom water temperatures due to climate change will likely result in changes to the distributions of some commercially exploited organisms (*e.g*., American lobster and Atlantic deep-sea scallop), especially in the central area and two ends of the Strait. Because the Strait is in a transition states, continued monitoring is needed. Time series data, such as annual multispecies surveys, would enable stronger inferences of ecosystem changes and might shed light on cause and effect relationships of ecosystem changes.

OVERVIEW AND TIMELINE (from White et al. 2013)

- Confederation Bridge officially opened in 1997; perception that ecosystem and productivity of the Northumberland Strait was negatively impacted by the bridge.
- September 2005; the Minister of Fisheries and Oceans instituted a Working Group on the Northumberland Strait to assess concerns over declines in productivity of the Strait ecosystem and the fisheries it supports.
- December-March 2005; public consultations, followed by report.
- April 2006; Ecosystem Overview Report (EOR).
- 2006; establishment of a Federal-Provincial Deputy Minister’s Steering Committee to focus effort in three key areas: 1) habitat and resource protection; 2) alternative fisheries management; and 3) economic diversification.
- 2007 (March); stakeholders identify working and research priorities for the Northumberland Strait.
- 2007; Science - Gulf Region receives funding under the ERI and Northumberland Strait selected as the study area (2007-2012).
- Stakeholder workshops to present results and progress were held in March 2009 and 2011 and at the end of the funding program in October 2012 (White et al. 2013).

3 overarching research priorities:

- Understanding present state and development of ecosystem health indicators.
- Assessing changes of habitat and fauna over time.
- Data collection, mining/rescue, accessibility and management.

INTRODUCTION

The coastal zone of the southern Gulf of St. Lawrence (sGSL) functions as a distinct ecosystem largely independent from the adjacent small estuaries and semi-enclosed embayments. Hereafter, the term estuary also includes the semi-enclosed embayments. The coastal zone comprises the habitat where the warm surface waters contact the substrate from the shoreline to the thermocline that, during summer, separates the warm surface waters from the very cold (<1°C) waters of the cold intermediate layer (CIL). The substrate in contact with the CIL supports a fauna distinct from that of the coastal zone and has been studied for many decades due to the important demersal fish (*e.g.*, Atlantic Cod (*Gadus morhua*), American Plaice (*Hippoglossoides platessoides*)) and snow crab (*Chionoecetes opilio*) fisheries.

Unlike the coastal zone, the estuarine ecosystems are protected from most of the effects of sea-ice and storm surges; hence, the estuaries typically support large beds of eelgrass (*Zostera marina*) and its associated flora and fauna. Most sGSL saltmarsh habitat also is found within protected estuaries. There is limited commonality in the fish and invertebrate community between the coastal and estuary/embayment ecosystems during summer months.

Within decapod crustaceans, the seven-spine bay shrimp (*Crangon septemspinosa*) is common to both ecosystem types but species such as grass shrimps (*Palaemon* spp.), Harris mud crab (*Rhithropanopeus harrisii*), and the alien green crab (*Carcinus maenus*) almost never occur in the coastal zone. The Atlantic rock crab (*Cancer irroratus*; hereafter refer as rock crab) occurs in most estuaries but the bulk of the population occurs in the coastal zone along with nearly all American lobster (*Homarus americanus*; hereafter refer as lobster) and all northern lady crab (*Ovalipes c.f. ocellatus*). For most of the coastal zone, the only shrimp species present is *Crangon*.

The fish community within the sGSL estuaries is characterized by species rarely found in the coastal zone, including: Smooth Flounder (*Pleuronectes putnami*), Mummichog (*Fundulus heteroclitus*), Atlantic Silversides (*Menidia menidia*), Four-spine Stickleback (*Apeltes quadracus*), White Perch (*Morone americana*), American Eel (*Anguilla rostrata*), and Northern Pipefish (*Syngnathus fuscus*). During early summer, the juveniles stages of Striped Bass (*Morone saxatilis*), Blueback Herring (*Alosa aestivalis*), Alewife (*Alosa pseudoharengus*), American Shad (*Alosa sapidissima*), Atlantic Tomcod (*Microgadus Tomcod*), and Rainbow Smelt (*Osmerus mordax*) move out of estuaries and into the coastal zone. Moreover, nearly all of the adults of these species feed in the coastal zone during summer months. During autumn, winter, and spring, there are potentially important exchanges between the coastal zone and the estuaries: diadromous fishes move in to estuaries and freshwater to spawn during winter (Atlantic Tomcod) or spring (Rainbow Smelt, the three *Alosa* species, Sea Lamprey (*Petromyzon marinus*), sticklebacks, and Striped Bass). As well, substantial numbers of Rainbow Smelt, Atlantic Tomcod, Winter Flounder (*Pseudopleuronectes americanus*), Striped Bass, Shorthorn Sculpin (*Myoxocephalus scorpius*), juvenile Atlantic Herring (*Clupea harengus*; hereafter refer as Herring), and Greenland Cod (*Gadus ogac*) overwinter in the estuaries (some feeding; some not). The three *Alosa* species leave the sGSL for the winter months and return during spring to spawn in freshwater. Also, large numbers of juvenile White Hake (*Urophycis tenuis*) make a short feeding foray during autumn prior to migrating out of sGSL (Hanson and Courtenay 1995; Bradford et al. 1997). Finally, while there are Sea-run Brook Trout (*Salvelinus fontinalis*) in nearly all rivers emptying into the Ecosystems Research Initiative in Northumberland Strait (ERINS) study area, where they spend their marine life, and its duration, is unknown.

Mass-balance type ecosystem models are becoming commonplace for ecosystem-based management of fisheries resources in mid-water zones including several on the east coast of Canada (Morissette et al. 2009; Link et al. 2011; Araújo and Bundy 2012). In contrast, only a few, greatly simplified, mass-balance type models have been formulated for small coastal zone areas (*e.g.*, Byron et al. 2011; Zhang et al. 2012), largely because most of the required input data are lacking. Nevertheless, the mass-balance approach should be amenable to well-defined areas like the Strait where the requisite information can, in principle, be collected. Mandatory data requirements include realistic population estimates for the major biomass components, fisheries removals, and representative feeding information (preferably by biologically relevant size classes) for as many taxa as possible. Obtaining much of this mandatory baseline information was one goal of the ERINS program.

A project-end meeting for the ERINS was held 24 October 2012 in which work completed to date was summarized (White et al. 2013). The goals of this report are to summarize subsequent progress on the eight original goals (Section 1); provide a literature review of selected work that may be relevant to the ERINS study area (Section 2); and identified some knowledge gaps and caveats (Section 3).

SECTION I. Progress since Stakeholder Meeting Summary (October 24, 2012)

This section reproduces the descriptions of the eight original goals of the ERINS, the work completed as of 24 October 2012, and adds a summary of any progress since that date. Some of this information is expanded upon in subsequent sections of this report.

Goal #1. Fine-scale 3-D model of water movements in the Strait itself with inputs from inflowing estuaries.

The initial 3-D model of water movements in the Strait required deployment of 4 Doppler current meters in 2008 and field validation of this model and the mixing model between the Strait and inflowing estuaries occurring in 2010/11and 2011/12 (micro-bead technology). The required modeling computer support and expertise was provided in part by the Centre for Ocean Model Development and Application.

Results to October 2012

- Refinement of the 3-D model was done from CTD surveys and current-meter data;
- Further refinement and calibration of the 3-D model of water movement will be done immediately after the micro-bead data are fully analyzed.

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- One paper, based on experiments using micro-bead technology, designed to refine model parameters was completed (Hrycik et al. 2013);
- Versions of the water-movement model have been used for purposes such as invasive species work in an estuary (Kanary et al. 2011), larval lobster transport in the Strait (Chassé and Miller 2010), and sediment transport at the ends of the Strait (Shaw et al. 2008);
- The four current meters deployed during the ERI have been use to calibrate another 3-D model to investigate larval dispersal in St. Georges Bay (Daigle et al. 2016).

Synopsis

The high resolution modelling showed that the circulation in the Strait is rather complex due to the interaction of tides, winds, shoreline features, and remote forcing (*e.g.*, storm surge). While, the residual circulation is generally from west to east, certain conditions cause east-west residual currents that can last for days to weeks. The west side of the Strait typically showed a diurnal tidal cycle, while the east side exhibited a mixture of diurnal and semi-diurnal components. The tidal currents are stronger in constrictions off West Point, Wood Islands, and around Pictou Island – reaching speeds of up to 1.5 m/s. Bottom water temperature seasonally ranges from near freezing (-1.7 °C) to about 23 °C with surface and near shore water temperatures occasionally > 25 °C during mid-summer. The central part of the Strait is well-mixed and stratification often occurs in waters > 25 m deep (Debertin et al., in press). Salinity is typically lower on the western side of the Strait because of the influence of the Miramichi River.

A high-resolution model was calibrated with micro-bead dispersion experiments (Hyrcik et al. 2013) and used to model larval drift of some important marine species. For example, modelling lobster larvae drift showed that the lobster stock in the Strait is essentially self-sustained while other stocks (Atlantic coast-wide) exhibit considerable mixing from adjacent stock areas (e.g., Chasse and Miller 2010; Benestan et al. 2016). A study on dispersal of larvae of benthic invertebrates in St. Georges Bay showed that release site had the strongest effect of all factors affecting dispersal metrics (Daigle et al. 2016). Also, regional variations in coastal sediment transport around Prince Edward Island (PEI) using results of the modeling system and the role of Milne Bank, a submarine bank at East Point, was studied (Manson et al. 2016). It was found that the disturbing effect of East Point on the hydrodynamic regime controls sediment transport in the area. Sand from the north coast of PEI enters Milne Bank and is carried south in a field of migrating sand waves. Milne Bank was shown to be a major sediment sink rather than a link between the eroding north coast and the sediment-rich south facing coast of PEI.

Goal #2. Quantification of the source, pool size, and mixing of nutrients and small particles between the southern Gulf, Northumberland Strait, and inflowing estuaries.

Quantify movement of nutrients, zooplankton, and possible invasive species propagules such as green crab and tunicates were in the original ERINS research plan. In addition to its use in the various biomass black box models there is an application to integrated management plans. Many estuaries are highly nutrient enriched from various land uses, and it is assumed that large amounts are exported to the Strait. It also follows that, if this is a significant portion of the nutrient pool of the Strait, any changes (improvements or further degradation) will propagate into the Strait itself. There currently is no information to judge one way or the other – the volume of water moving through the Strait likely so dwarfs that of inflowing estuaries that no increase or decrease in land-based nutrient loading would noticeably alter the nutrient budget of the main Strait. The second part, movement of small particles into the Strait, where they are dispersed, is a real concern as several recently colonizing alien invasive species can release propagules into the Strait and the models (and field tests) are needed to evaluate the risks to systems currently devoid of the invaders.

Results to October 2012

- It was realized early that to address nutrients from estuaries (also from all land-based sources) within the ERINS, a larger integrated network with the proper expertise and added funding would be needed; hence this project was not done within the ERINS.

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- Nil.

Goal #3. Structure and energy transfer in the pelagic food loop.

This aspect will quantify the distribution and abundance of plankton, pelagic predators and their feeding selectivity and identify species associations as controlled by water masses that were identified in Goal 1. In addition to the sampling described in this project, there is heavy reliance on samples collected in the multispecies trawl survey conducted annually (July-August) on CCGS Opilio since 2001 and this will be part of a graduate student's thesis work (University of New Brunswick).

For data collected between 2009 and 2011, and in collaboration with Dr. C. T. Taggart (Oceanography Department, Dalhousie University, Halifax, NS), a V-fin (with Optical Particle Counter and CTD built in) and a BIONESS sampler to quantify the 200 to 3,000 micron-size groups of the pelagic energy (and nutrient) loop was used. These data are then used in "black box" models (dynamic and static), biomass spectra, formulation of an index of biotic integrity, and are required for any mass-balance modeling (Ecopath/Ecosim; inverse models) that may be formulated for the Strait.

Results to October 2012

- As part of a M. Sc. Thesis (Debertin 2011), snap shot contour maps were derived of physical characteristics, salinity, oxygen, Chl *a*, zooplankton, and light penetration;
- The M. Sc. Thesis identified major water masses (zones) and tested whether locations of the zooplankton species assemblages matched the three oceanic zones;
- The M. Sc. Thesis project collected data needed to estimate survey biomasses, distribution, and size frequencies of planktivorous fishes;
- As part of the M. Sc. project, stomach contents for pelagic fishes collected in 2008 and 2009 were analyzed, which represents the data needed to quantify diets, feeding selectivity, and diet overlap.

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- While the M. Sc. Thesis of Alan Debertin (2011) was completed, the contents were not as originally proposed. The University graduate thesis committee changed the focus of the thesis to remove the feeding study
- A manuscript describing the major water masses and the zooplankton taxon assemblages has been accepted for publication (Debertin et al., in press);
- Spatially explicit feeding data of planktivorous fishes and concurrent prey fields were collected during the 2008 and 2009 surveys in the ERINS study area; all samples were processed and entered into a database; and statistical analysis of diet overlap and selectivity are in progress (Debertin and Hanson, in prep.);
- As a compromise, diet and diet overlap assessment was done for pelagic fishes >15 cm total length (TL) for the period 2000 to 2003 (when pelagic fish abundance was much lower than in 2008-2009) (Hanson, in press).

Synopsis

There was a shallow, well-mixed, water mass in the central Strait (with a distinct zooplankton species-assemblage) while the deeper waters at the ends were separated into a warm surface layer that transitioned into a very cold bottom layer (and a different zooplankton species assemblage). The zooplankton community composition reflected these water masses. Chl *a* levels in the water column have increased slightly since the early 1990s but in a manner consistent with the observed increased pelagic fish abundance. By reducing zooplankton numbers, consumption of phytoplankton was reduced, resulting in increased phytoplankton abundance (a small-scale trophic cascade. The Chl *a* levels measured during the study are at the low end (oligotrophic) of the range; consequently, the water was clear enough that light levels required for photosynthesis reached the bottom in most of the Strait, and that primary production would contribute directly to the benthic energy cycle.

Analysis of stomachs of pelagic fishes indicated that Atlantic Mackerel (*Scomber scombrus;* hereafter refer as mackerel), herring, Alewife, and American Shad fed mainly upon copepods (large and small sizes) and crab zoea. Rainbow Smelt mainly ate *Crangon* shrimp, polychaetes, and small amounts of fish. Alewife also included substantial amounts of *Crangon* shrimp in their diet, and mackerel consumed substantial amounts of Rainbow Smelt and American Sand Lance (*Ammodytes americanus*). Hence, some of the pelagic fishes actually were part of the benthic food web instead of the pelagic food web.

Goal # 4. The biomass size spectrum tool.

Pelagic and combined pelagic/demersal models will be formulated as a species independent measure of ecosystem structure and functioning for the various water masses of the Strait and compared and contrasted with key inflowing estuaries (Goal 5). Complementary species-based analyses (tools) involve calculating indices of species diversity and evenness. Both tools are accepted measures of degree of disturbance and are sensitive to both improvements and degradation of ecosystem health (including effects of overexploitation, habitat degradation, and establishment of alien species). Data collection, as indicated in Goal 3, was done in collaboration with Dr. C. T. Taggart.

Results to October 2012

- Optical counter transects were done in June and September 2008 – whole Strait;
- BIONESS sampling done at > 40 stations; some samples processed and the rest were stored when DFO funding shortfall occurred, resulting in project staff being laid off.

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- Dr. Taggart has continued to work on this project using Natural Sciences and Engineering Research Council funding and the optical counter data were analyzed as part of an honors thesis (Pagniello 2015)
- There has been no progress in the study using the BIONESS samples.

Goal # 5. Formulating an Index of Biotic Integrity.

The index of biotic integrity is another commonly used tool that has yet to be used for coastal waters. It combines measures of physical, chemical, and biological characteristics of a water body (or location) and, where gradients have been studied, is used as another index of whether a system is judged to be relatively unperturbed or degraded. By comparing and contrasting with past and planned studies in key inflowing estuaries, useful interpretation of patterns will be possible. The estuary studies will follow the methods developed during the Green Crab Strategic Fund Program, providing a limited historical comparison (ten years) of estuary structure and biomass levels (nutrients, Chl *a*, eelgrass abundance and distribution, zooplankton, benthos, large decapods, and fish).

Results to October 2012

- The formulation of an Index of Biotic Integrity based on estuary data was not addressed or met in the context of the ERINS as it was beyond the scope of the funding request;
- Data have been used for identification and status (Committee on the Status of Endangered Wildlife in Canada, *i.e.*, COSEWIC) of possible unique or endemic species;
- Quantification of makeup and location of fish species assemblages in part of ERINS study area was completed (Bosman et al. 2011).

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- Substantial work related to identifying coastal Ecologically and Biologically Significant Areas in the sGSL was initiated in 2014 (Rondeau et al. 2016) and the ERINS study area represented the highest-ranked important area;
- COSEWIC assessed White Hake as "Threatened" (COSEWIC 2013);
- COSEWIC status assessment for Winter Skate (*Leucoraja ocellata*) was done (endangered) but it is still not included under the Species at Risk Act schedule 1 (Canada Gazette 2010);
- With regards to extending the 2000–2006 time series (Bosman et al. 2011) to 2009 for pelagic to benthic fish ratios and changes in makeup and location of fish species assemblages, there has been no progress (Figure 1);
- Recent work demonstrates there is a high likelihood that the Winter Skate in the sGSL is an undescribed endemic (Kelly and Hanson 2013a, b, Lighten et al. 2016). Furthermore, there is a risk that this species will become extinct (Swain

et al 2009, 2013; Swain and Benoît 2016) before it is described;

- Taxonomic studies to assess potential endemism of lady crab in the ERINS study area are underway (Johari 2015), with a manuscript to describe the results expected in the near future (J.-M. Gagnon, personal communication, Curator of Invertebrates, Canadian National Museum of Nature, 240 Rue McLeod, Ottawa, ON, K2P 2R1).

Synopsis

Preliminary analyses suggest pelagic fish biomass has increased and plateaued since 2005 (Figure 1) while demersal fish biomass initially decreased in 2004-2005 and has since fluctuated, almost solely due to small Winter Flounder numbers (Figure 1). Some demersal species (*e.g*., Yellowtail Flounder (*Limanda ferruginea*), Longhorn Sculpin (*Myoxocephalus octodecemspinosus*), Cunner (*Tautogolabrus adspersus*), and Winter Skate) have undergone dramatic declines in abundance accompanied by distribution contraction while areas occupied by Rainbow Smelt and Alewife have increased (see also Savoie 2014). There is substantial separation in areas occupied by adult and juvenile Herring; *i.e*., the central part of the Strait functions as a nursery zone. Importance Areas analysis identifies the Strait as highly ranked compared to the rest of the coastal zone of the sGSL. There is a high likelihood that the "Winter Skate" and lady crab populations, both restricted to a small area of the west-central Strait, are undescribed endemics. The Winter Skate could well become extinct before description of the species is completed. Windowpane Flounder (*Scophthalmus aquosus*) seem to represent a small bodied, short-lived, form of the species but no evaluation regarding genetic or morphological uniqueness has been undertaken.

Goal # 6. Black box models for the Strait and key inflowing estuaries.

The estuaries aspect of the program was deleted shortly after the ERINS program began. In principle, the goal was to quantify the amount of nutrients or energy in functional groupings such as nutrient levels (not done), Chl *a* (a proxy for phytoplankton biomass), major zooplankton groups, pelagic fishes, demersal fishes, rock crab, lobster, other decapods, and grey seals (*Halichoerus grypus*) as bins. Aside from stratum- specific means (and measure of dispersion) for each desired group, one can also obtain global estimates and contours (using kriging) of distribution.

Results to October 2012

- Major pools identified, *i.e.*, biomass or biomass indices;
- Samples needed for most tasks (exception, nutrient levels were not quantified) were collected, most sorted, and some analyses initiated;
- A conceptual model was developed;
- Linkages with estuaries and land outside the scope of ERINS.

Status September 2017

- Abundance estimates and feeding data for rock crab with subsequent comparison to lobster have been completed (Hanson et al. 2014);
- Most of the stomach data have been published (Voutier and Hanson 2008; Hanson 2009, 2011; Kelly and Hanson 2013b; Hanson and Wilson 2014; Hanson et al. 2014; Hanson, in press);
- While the rockhopper trawl used in most July-August surveys of the ERINS study area since 2001 provide an index of abundance for many fishes and some decapods, the capture efficiency of the net is highly variable between species and simple trawlable biomass estimates will not suffice for quantitative work. For example, the *Nephrops* trawl has ~ 2- to 12-fold higher catches per unit area for lobster and Windowpane Flounder, respectively, than the rockhopper trawl. Capture efficiency for rock crab with the rockhopper trawl is so low that it is unreliable as an abundance index (Hanson and Wilson 2014; Hanson et al. 2014). Similar between-net comparisons need to be done for most of the species included in the ERINS area. Subject to resource availability, additional analysis may be done in the upcoming years.

Synopsis

Abundance indices (not calibrated for fishing efficiency of the net) have been calculated for the main fish and large-bodied decapod species; however, realistic biomass estimates are not available to date. There are large populations of rock crab and lobster, with rock crabs being an important part of the food web both as predator and prey. In contrast, lobster represents an energy sink and prey mainly upon rock crab and other lobster. For the fishes, the low abundances and small areas of occupancy of the main piscivores (*e.g*., White Hake, Winter Skate, Sea Raven (*Hemitripterus americanus*), and small Shorthorn Sculpin) indicated that predator-prey interactions were weak, and there was little diet overlap between the strongly piscivorous species. Overall, the American Sand Lance and Rainbow

Smelt were the most commonly consumed forage fishes. This is a species-poor ecosystem and diet overlap was low to moderate. There were three multi-species feeding groups (≥40% diet similarity): planktivores (*e.g*., Mackerel, Herring, Alewife, and American Shad); predators on small invertebrates such as amphipods, polychaetes, and small molluscs (*e.g*., Cunner, Winter Flounder, Yellowtail Flounder); and species that preyed heavily upon *Crangon* shrimp (*e.g*., Windowpane Flounder, Longhorn Sculpin, Rainbow Smelt, small White Hake, small Winter Skate). American Plaice formed its own group and mainly ate sand dollars (*Echinarachnius parma*), sea urchins (*Strongylocentrus droebachiensis*), and mysids. *Crangon* shrimp formed a key node in the food web; however, it is premature to designate them as a keystone species.

<u>Goal # 7. Assessment of habitat and benthic organisms changes in the last 30 years.</u>

In 1975 a survey was conducted in the Strait to gather baseline information on the state of the ecosystem (Caddy et al. 1977). Ninety six stations distributed evenly in four areas (A, B in western Strait, *i.e*., Lobster Fishing Area (LFA) 25, and C, D in eastern Strait, *i.e*., LFA 26A) were sampled using a benthic grab to quantify the infauna and a combination of a scallop dredge and a beam trawl to quantify the epifauna. The same stations using similar sampling gear were re-sampled in 2009-2010 to gather data for comparison with the earlier survey and possibly identify changes in the ecosystem.

<u>Results to October 2012</u>

- All field samples have been collected; however, laboratory processing of samples has not been fully completed;
- Data were partially entered, but the quality control and the merging with the 1975 data in a standard format for statistical analysis was not done.

<u>Status September 2017</u>

- All samples have been sorted, organisms identified to lowest practical taxonomic level, and data entered into a Department of Fisheries and Oceans (DFO)-Science database;
- Some preliminary quality control of data completed but an analyzable database that can be compared to the 1975 data is not yet available. The merging of data files will be done in 2018, and with additional resources, analysis may be done in 2018/2019 to complete the temporal comparison.

<u>Synopsis</u>

Most of the data from 1975 are species presence/absence, with the exception of quantitative information for lobster and sea urchin. A data screening was done prior to the individual taxa and community analyses to remove rare taxa from the analyses, since they contribute little information. The screening involved removing taxa with fewer than 20 occurrences for both survey combined. Nine epifauna and seven infauna taxa changed significantly in occurrence from 1975 to 2009-2010. Four epifauna taxa, all bivalves (horse mussel (*Modiolus modiolus*), blue mussel (*Mytilus edulis*), Atlantic deep-sea scallop (*Placopecten magellanicus*; hereafter refer as scallop), Icelandic scallop (*Chlamys islandica*) and ocean quahog (*Arctica islandica*)), decreased in occurrence by between 64% and 89% and five epifauna taxa: three fish (Windowpane Flounder, Winter Flounder and Grubby (*Myoxocephalus aenaeus*)) and two shrimp species increased in occurrence between 12- and 44-fold. Four infauna taxa (3 polychaetes and 1 bivalve) decreased in occurrence between 78% and 98% and two infauna taxa (1 polychaetes and hydrozoans) increased in occurrence between 5- and 9-fold. In the epifauna and infauna community analyses, significant differences between both surveys were observed. Significant spatial effects among areas were common and of larger size compared to the temporal changes between surveys. For the quantitative analyses, sea urchins decreased significantly in abundance by about 97% and the increase in lobster was not significant. However, when lobsters were divided into commercial size observed in 1975 (short; <63.5 mm of carapace length (CL): canner; ≥63.5 and ≤80.0 mm CL: market; ≥81.0 mm CL), market size lobsters increased significantly in abundance by about 3.5-fold. While some changes were identified between both surveys in the individual taxa and community analyse and quantitative analyses for sea urchin and lobster, it is difficult to infer ecological changes using only two data point. Hence, it is speculative to conclude that the observed differences are within the range of natural variation of the ecosystem or outside that range due to anthropogenic effects. Time series data, such as annual multispecies surveys, would enable stronger inferences of ecosystem changes and might shed light on cause and effect relationships of ecosystem changes.

<u>Goal # 8. Provide structured databases and access to all information used and generated by this research initiative.</u>

Results to October 2012

- Largely completed (see the exception below).

Status September 2017

- Datasets derived from Goal 7 have yet to be merged with the 1975 data into a standard format. Merging the different datasets could be done during the statistical analysis planned for 2018/2019.

SECTION II. Published non-ERINS Material Relevant to the ERINS Study Area.

2.1 Potentially Invasive Species

It is a misconception that only non-native species can become invasive. An invasive species is one that: can change habitats, alter ecosystem structure and function, and affect ecosystem services; crowds out or replaces existing species (including naturalized non-native species); and disturbs human activities. Cases of a native species becoming invasive can include: (1) when a natural range extension permits colonization of a region previously devoid of them; (2) reduction in predation or competition permits a species to increase substantially in abundance and results in increasing its area of occupancy; or (3) a species native to an adjacent region (perhaps separated by mountains or a watershed divide) is introduced outside of its natural range. In contrast, alien or non-native species by definition do not occur naturally in an area – usually transported by human vectors from another continent but sometimes by massive natural phenomena (e.g., Carlton et al. 2017). The vast majority of introduced, alien, species never show invasive tendencies (Pysek et al. 2012; Gaither et al. 2013). There are many naturalized species and cryptic alien species in Canada, meaning many alien species have come into some sort of balance in the receiving location and may not ever have been invasive.

With the exception of the four macroalgae species, nearly all established alien species in the sGSL are restricted to estuarine locations (Benoît et al. 2012 and references within). Indeed, the sGSL coastal zone is surprisingly devoid of recently-arrived alien species. The same cannot be said for estuaries adjacent to the ERINS study area.

(2.1.1) Crustaceans

Green crab: There is a continuing evolution of studies on effects (positive and negative) of green crab on community structure and functioning (Therriault et al. 2008). Every time green crab is found in a new location, there are alarmist claims of pending ecosystem destruction (*e.g.*, see http://www.fishaq.gov.nl.ca/education/pdf/The%20Invasion...European%20Green%20Crab.pdf accessed 22 August 2017) that contain serious misinformation. (1) Green crabs are eaten by many Atlantic Canada species, including: lobsters, rock crab, Jonah crab (*Cancer borealis*), Striped Bass, and many birds. With regards to fish predators, the limiting factor is lack of overlap in distribution between green crab and large fishes in Canadian waters. In US waters, many large fishes eat green crabs. (2) Eelgrass is not a significant nursery area for lobster or Atlantic Cod – even in Newfoundland and certainly not in the sGSL or waters to the south. That green crabs are solely responsible for observed changes in eelgrass beds (positive and negative), is dubious. (3) Green crabs can prey upon small-sized crabs (regardless of species), which would be a predator-prey interaction, not competition. There is no evidence of a negative effect of green crab on any crab species due to joint use of a resource in short supply, which is required by definition for competition to occur (Andrewartha and Birch 1984).

Green crab continues to spread in estuaries of the Strait and beyond. As with any other specie's introduction, the ecosystem quickly reaches a new "stable" state. Indeed, green crab became an important link in non-native ecosystems and an important prey item for birds, fishes, and other invertebrates (Jones and Shulman 2008; Carlsson et al. 2009; Estelle and Grosholz 2012; Wong and Dowd 2014) such that removal of a large part of the green crab population has significant negative effects on the predator community. Initially, green crabs were expected to become numerous and widespread in subtidal waters of the sGSL; however, this has not happened. To date, no green crab has been captured by trawling activities in the Strait nor have there been any reports of green crab occurring in lobster or rock crab traps set within the Strait. Thus, the weight of evidence indicates green crab is of trivial concern to the waters contained of the ERINS study area.

While green crab and lobster distributions overlap somewhat in the Bay of Fundy (Lynch and Rochette 2009), outside of a few large semi-enclosed estuaries, there is almost no distribution overlap between these species in the sGSL. In the Gulf of Maine, most green crab are restricted to inter-tidal habitat due to predation; those occurring subtidally are heavily preyed upon by lobster and large *Cancer* crabs (*e.g.*, see Jones and Shulman 2008; League-Pike and Shulman 2009). Rock crab, which attains much larger body size than green crab, is the main prey of lobster

(Hanson 2009; Hanson et al. 2014), and it should not have been a surprise that green crab are readily eaten by lobster. Green crab have a much smaller maximum size, and a thinner, less domed, carapace compared to rock crab of the same size. Behaviourally, green crab often exhibit aggression towards (as opposed to trying to flee or bury), which makes it easier for lobster to capture, handle, and consume the green crab compared to rock crab of the same size.

Lobster remains have not been recovered from stomachs of wild-caught green crab. Nevertheless, a lot of laboratory-based work has been done to try and show there is the potential for a major negative effect of colonization by green crab on lobster populations (*e.g*., Rossong et al. 2006; Williams et al. 2006, 2009; Haarr and Rochette 2012). For large juvenile- and adult-size lobster (> about 50 mm CL), the most common interaction is for lobster to either ignore or eat the green crab (Lynch and Rochette 2009; League-Pike and Shulman 2009; Haarr and Rochette 2012). Under some conditions, large green crab can displace very small lobster from bivalve prey (Rossong et al. 2006; Williams et al. 2009) but that interaction is reversed once lobsters attain a size of ~70 mm CL. If the lobsters are very small (newly settled to about 35 mm CL) and without adequate shelter, then and only then can green crab can kill and eat the lobster.

Take away message: green-crab ecosystem effects may be an issue for places adjacent to the Strait; however, no assessment of total ecosystem effect or ecological services analysis has ever been done. Within the coastal zone, green crab is largely irrelevant to ecosystem functioning and warrants no further research efforts in the short term (i.e., until large numbers are detected in coastal waters).

Baltic prawn: Egg-bearing specimens of the Baltic prawn (*Palaemon adspersus*) were recently identified in eelgrass beds in the Magdalen Islands (Gonzalez-Ortegon et al. 2015). It can be distinguished from the two native grass shrimps (*Palaemon vulgaris* and *P. pugio)* by the band of red spots on the lower half of the rostrum. So far, the Baltic prawn has not appeared in any location in the Strait. Other than displacement of some or all of the native grass shrimp population, it is unknown how the establishment of this species may affect the structure and functioning of eelgrass habitat in estuaries adjacent to the Strait. It is unlikely to become an issue in the coastal zone due to the limited distribution of eelgrass beds.

(2.1.2) Non-native Tunicates

As with green crab, nearly all issues regarding non-native tunicates involve semi-enclosed embayments and estuaries, and mainly man-made structures (*e.g*., see Therriault and Herborg 2008; Locke et al. 2009; Kanary et al. 2011). While invasive alien tunicates have been observed as epibionts of lobster and rock crab, this only occurred within estuaries on the north shore of PEI (Bernier et al. 2009), and the lobster and crabs examined in the ERINS study area only carried small numbers of native tunicates Most of the invasive tunicate species present in sGSL estuaries and on the invasive species watch list are not likely to establish outside of the protected waters of estuaries and semi-enclosed embayments and thus are largely irrelevant to the ERINS study area, with one exception.

The tunicate that could become an issue in the ERINS study area is the carpet sea squirt (*Didemnum vexillum*), which has colonized off shore waters on George’s Bank and Minas Basin, Bay of Fundy (Moore et al. 2014). Once it arrives at a new location, it quickly forms large, thick, mats over a wide range of natural and artificial substrates. With a water temperature tolerance of -2°C to >24°C, and a broad salinity range, there are no physiological limits to where this species can spread within the coastal zones of Quebec and the Atlantic Provinces (Daniel and Therriault 2007). This species represents a serious threat to the estuaries and coastal zone of the sGSL and prevention of colonization is the only real option. Eradication is unlikely to succeed except under very restrictive conditions.

(2.1.3) Alien Seaweeds

While colonization by tunicates is a recent phenomenon in the sGSL, colonization by seaweeds has been ongoing since the first ships arrived from Europe. There are at least four alien seaweed species established in estuaries and shallow waters (intertidal and shallow subtidal zones not covered by ERINS surveys) of the Strait. They are: European rockweed (*Fucus serratus*, first detected in Pictou in 1860s); oyster thief (*Codium fragile*; first detected near Pictou area in 1997); forked claw weed or black carrageen (*Furcellaria lumbricalis*, first detected in the Strait in 1931); and Bonnemaison’s hookweed (*Bonnemaisonia hemifera*, first detected in Souris, PEI, in 1948) (Chapman et al. 2002; Johnson et al. 2012). *Fucus*, *Fucellaria*, and *Codium* mainly occur attached to objects in the intertidal and shallow subtidal zone; *Codium* also is widespread in estuaries. *Codium* is a species initially thought to decrease faunal abundance and diversity when it colonizes a new location but one recent study showed faunal abundance and diversity is actually higher in invaded sites than in monospecific stands of native eelgrass (Drouin et al. 2011). In contrast, to most non-native macrophyte species, *Bonnemaisonia* is more of an epiphyte and does not require a fixed surface. It is often collected during trawling activities in the Strait (J.M. Hanson, personal observation), but its occurrence has not been quantified.

There could well be additional non-native macroalgae in the Strait. A recent study indicates at least 7 additional species of introduced seaweeds either occur just south of the sGSL or bracket it with colonies being found in rocky-intertidal sites in Newfoundland water (Mathieson et al. 2008). These seven species can be viewed as an imminent watch list, assuming these species simply have not simply gone undetected in the sGSL.

While the rocky subtidal zone in the Strait was the focus of a variety of surveys between 1930 and 1985 (*e.g*., see Bell and MacFarlane 1933; Stephenson and Stephenson 1952; Edelstein et al. 1971; Novaczek and McLachlan 1989), relatively little has been done in the >4 m depth zone. The most recent systematic survey that reported macroalgae species occurrence in that depth zone of the Strait was Caddy et al. (1977), and although one ERI goal was to repeat that study, the expertise required to identify marine algae to species was not available.

2.2 Climate Change Past and Future

Between 1928 and 1950, there were as many as 9 major mass-mortality events of scallop in the Strait (Dickie and Medcof 1963), which were attributed to exposure to water temperatures >23°C (maximum tolerance if acclimated). Some mass-mortalities were caused by high temperatures alone while others seem to have been due to rapid temperature shifts during strong seiche events in which very warm surface waters were down-welled over scallop beds. Bottom water temperatures >23°C have been observed several times in the central Strait during recent surveys, and this area could become permanently devoid of scallops if the predicted warming of the Strait occurs. However, this same warming should create additional habitat for some species (e.g., lobster, rock crab, sea scallops) in the deeper water at the ends of the Strait.

Because they are mobile and already show seasonal movements in response to changing water temperatures (Bowlby et al. 2007, 2008; den Heyer et al. 2009), lobster are not likely to be killed by increasing water temperature (Chassé et al. 2014). The most likely scenario is for lobsters to begin their spring migrations into shallower waters earlier in the year and then begin moving away from warm-water areas as bottom waters warm during summer months. As mentioned for scallops, warmer water conditions will likely result in creation of additional lobster habitat in the deeper waters at both ends of the Strait – possibly a net gain in habitat.

Fishes are mobile and most species found in the Strait already undergo seasonal migrations in response to impending winter conditions (Rondeau et al. 2016). It is clear from survey data that the various fishes in the coastal area have their own preferred temperature-of-occupation ranges and their spatial distributions will change to as the distributions of preferred bottom temperatures change.

Regardless of effects of current climate change, ongoing subsidence of the sGSL and adjacent landmasses means water level will continue to rise. The construction of the Confederation Bridge provided incentive to study a wide range of physical characteristics of the central Strait area, especially in relation to sea ice (*e.g*., see Brown et al. 2001; Frederking et al. 2007; Obert and Brown 2011) The ERINS study area continues to be a focal site for studies of changes in sea level, storm surges, coastal erosion, and sea ice effects (*e.g*., see Obert and Brown 2011; Zhang and Sheng 2012; Bernier and Thompson 2007, 2010, 2015a,b; Craik et al. 2015). The people living on or near the shore will need to continuously adapt to these changing conditions (Chouinard et al. 2008).

2.3 Stock Assessments

Information on commercially-fished species is updated periodically through scientific advice on stock status and research documents posted on the Canadian Science Advisory Secretariat (CSAS) website. Several exploited species status reports in which a substantial part of a stock is or was found within the ERINS are published at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm accessed 22 August 2017.

Atlantic Cod (Savoie 2014; DFO 2015; Swain et al. 2015a)

Formerly abundant at both ends of the Strait, fish >20 cm TL now are seldom caught at both ends of Strait based on the September and July-August surveys. All abundance indices are at or near lowest values in the various time series especially for fish

>42 cm TL. Natural mortality of these larger Atlantic Cod has increased to very high levels. Predation by grey seals is thought to be an important component of this elevated natural mortality (*e.g.*, Swain and Benoît 2015). A shift in the distribution of Atlantic Cod out of shallow inshore waters where predation risk is high also contributes to the absence of Atlantic Cod from areas of the Strait where they were once common (Swain et al. 2015b).

<u>White Hake</u> (COSEWIC 2013; DFO 2015; Swain et al. 2016)

A recovery assessment for COSEWIC was completed (Swain et al. 2016). There are two White Hake components: a coastal component found in shallow waters in summer and a deep-water component found along the southern slope of the Laurentian channel and in the Cape Breton Trough. The coastal component also overwinters in these deep waters. The coastal component shows both morphometric and genetic separation from the deep-water component (Roy et al. 2010). The index for commercial-sized fish is at the lowest level ever recorded, and there has been no sign of a recovery despite a moratorium since 1995. Natural mortality of adult fish has increased to very high levels. Predation by grey seals is thought to be an important component of this elevated natural mortality (*e.g.*, Swain and Benoît 2015). Formerly common, fish >60 cm TL have disappeared from the population. The only remaining spawning area for the coastal population is at the St. Georges Bay edge of the ERINS study area. After spawning, White Hake used to forage in the shallow waters of the Strait and St. Georges Bay, but now appear to move back into deeper water immediately after spawning (Swain et al. 2015b).

<u>Winter Flounder</u> (DFO 2012; Savoie 2014; DFO 2015; DFO 2017a)

All abundance indices were at or near the lowest in time series with fish <20 cm TL dominating catches. Strong, almost linear, decrease in size at age (*e.g.*, for age 8) from 1971 to 2011 has been demonstrated. Based on a population model, the estimates of natural mortality have recently increased for young fish (ages 2 to 4) and continually increased for older fish (aged 5+). The rates are high for ages 5+ and increasing from 0.68 at the start of the time series in 1973 to greater than 1 (63% annual mortality) recently. Overall, the fishing mortality rate is very low compared to the estimated natural mortality rate. Hence it was concluded at the last stock assessment that the contraction in size structure of Winter Flounder, the decline in the estimated size at 50% maturity, and the decline in abundance indices of the previously abundant commercial-size group are consistent with stock experiencing very high levels of mortality.

<u>Yellowtail Flounder</u> (DFO 2015; Savoie 2014; DFO 2016a; Surette and Swain 2016)

The natural mortality on larger and older animals is estimated to have increased from 22% annual mortality during 1985 to 1990 to 86% in 2009 to 2015. In contrast, natural mortality on small and young animals is estimated to have declined from 53% annually in 1985 to 1990 to 16% to 21% since 1997. The spawning stock biomass is estimated to be higher than in the past decade, however, it is now composed primarily of fish <25 cm (72 %). As observed with the Winter Flounder, the contraction in size structure of Yellowtail Flounder and the decline in abundance indices of the previously abundant commercial sized group are consistent with a stock experiencing very high levels of mortality.

<u>Winter Skate</u> (DFO 2017b)

The sGSL population is unique and likely represents an undescribed endemic species (Kelly and Hanson 2013a,b; Lighten et al. 2016). Its abundance has declined to extremely low levels. Its distribution, once widespread throughout shallow inshore areas of the sGSL now appears to be restricted to part of the central Strait. Its extreme decline is due to unsustainably high natural mortality of adult skate. If current conditions persist it is expected to soon be extinct (Swain and Benoît 2017).

<u>Herring</u> (DFO 2014a, DFO 2016b)

There are two spawning components, and both have spawning beds within the ERINS study area. Abundance indices for the spring component are very low (in the critical zone) and show no signs of improving; however, spawning biomass is not declining. The assessment for the fall spawning fish shows a continuing decline is spawning biomass and the most recent estimates are in the caution zone. A troubling observation is that weights-at-age have declined substantially since the early 1990s and are at the lowest values ever observed.

<u>Mackerel</u> (DFO 2014b, DFO 2017c)

The stock status for the Mackerel is based on the egg-survey index and spawning biomass index from the analytical assessment. The spawning biomass estimates based on the analytical assessment from the Quebec Region indicate that the Mackerel stock for the NAFO sub-areas 3 and 4 was at its historical lowest level in 2012 and is still in the critical zone. It’s the same situation for the abundance index from the egg survey in the sGSL.

Rock crab (DFO 2013a; Rondeau et al. 2014; DFO 2017d)

There are no fishery-independent indices for this species and catch rates are affected by the market price and demand, and limits imposed by individual allocations. Landings from the directed fishery have been relatively stable between 2006 and 2011 but have slightly declined since then. Trawls used in the July-August and September surveys have very low efficiencies for catching rock crab and do not provide reliable fishery-independent indices. Rock crab plays a major role in ecosystem structure and functioning (Hanson et al. 2014; Hanson, in press), both as predator and prey (including a high level of cannibalism). Indeed, they are an important food resource for lobster during the molt process.

Lobster (DFO 2013b; DFO 2016c)

The lobster fishery is managed by effort controls and restrictions on sizes and sex of lobster that can be landed. Exploitation rates for the sizes landed are very high (at least 60%). Landings for Lobster Fishing Areas in the Strait were diminishing from the early-1990s to the late 2000s, followed by an increasing trend in the last 5 years. There is no real trend in catch-per-unit-effort from the July-August trawl surveys from 2001 to 2012 with increasing numbers in 2015 and 2016. While lobster may form a large biomass in the ERINS study area, they have few predators other than harvesters, other lobsters, and the Shorthorn Sculpin (whose abundance is currently very low). The lobster diet consists mainly of rock crab, old rock crab carapaces, and other lobster; therefore, lobster functions mainly as an energy sink in the Strait (Hanson 2009; Hanson et al. 2014).

Sea scallop (Davidson et al. 2012)

The only abundance index for scallop in the ERINS study area comes from landings and catch-per-unit-effort in the fishery. A research trawl survey in the western half of the ERINS study area was conducted in 1997 (Hanson 1998), but it was never repeated. In general, scallop landings in both Scallop Fishing Areas encompassed by the ERINS study area were high in the 1960s and early 1970s, were stable at a lower level until 1999 and have decreased substantially to very low levels since then. While there is a lot of bycatch, the proportion of fishes and crustaceans severely injured were only high for Yellowtail Flounder, American Sand Lance, rock crab and toad crab (*Hyas sp.)* (Benoît 2011). Moreover, when the experiment's mortality estimates were extrapolated to the entire landings of the scallop fishery and compared to the survey biomass estimates, the scallop dredge mortality represents a trivial fraction of the main (September) trawl survey population estimates.

Oceanographic conditions

DFO annually evaluates oceanographic conditions Atlantic-wide; however, the modelled results do not capture the unique conditions within the ERINS study area. A separate evaluation, based on profiles collected with a CTD sampler (roughly 110 stations per survey), is at a scale more appropriate to meet the needs of the ERINS program (Chassé et al. 2014). In addition, there is a coastal water temperature monitoring program run by the Lobster Section that has roughly 16 stations relevant to the ERINS study area (Paulin et al. 2014).

Ecologically and Biologically Significant Areas (EBSA)

There has been interest in EBSA and potential Marine Protected Areas-related work in the coastal zone since the mid-2000s (*e.g*., Savenkoff et al. 2007; Swain and Benoit 2007). The most recent exercise to identify candidates of ecologically significant areas is ongoing; however, work to date identifies the ERINS study area as the highest ranked coastal area in the entire sGSL. The two likely endemics are presently restricted to the western end of the Strait and that drives the very high uniqueness score (Rondeau et al. 2016).

2.4 Grey Seal

It is impossible to talk about ecosystem structure and functioning in any part of the sGSL without including the effects of the extraordinary, in terms of a wildlife population restoration effort, increase in grey seal abundance from a few thousand animals in the 1960s to >500,000 in Canadian waters alone in 2015. The population is still increasing exponentially and expanding its distribution (DFO 2014c), including south into US waters where no reliable estimate of numbers exist. Counts of >15,000 animals in Massachusetts waters alone indicate the numbers feeding and breeding in US waters (to at least Cape Cod) are not trivial (Waring et al. 2015).

The sGSL population, much of which breeds and feed in the ERINS study area, increased from very low numbers to >100,000 with substantial seasonal immigrants, mainly from the Sable Island herd, feeding in the sGSL (for a total of > 140,000 animals) (Swain et al. 2015). With each seal consuming 1,600-2,200 kg of food per year (Kastelein et al. 1990; Hammill and Stenson 2000; Trzcinski et al. 2006), they are a major source of mortality for the species that they consume, a prey list that encompasses nearly every fish species that grows >15 cm TL (Swain and Benoit 2015; Swain et al. 2015). It is, however, very difficult to obtain grey seal diet information representative of a specific study area and that for the ERINS coastal zone is particularly poorly studied (Benoît et al. 2011a, b). No credible ecosystem-based model for any ecosystem where grey seal occurs (or may spread to) can ignore this increasingly abundant, very large, predator.

SECTION III. Some Gaps and Limitations

3.1 Shifting Baselines

Assessments of most fisheries and aquatic ecosystems began well after the ecosystems were being subjected to human perturbation. Abundances of many native species had declined, including lobster in the late 1890s due to overexploitation (Wilder 1965; DeWolf 1974; Chaussade 1983), or were driven to extinction; and many non-native species had become naturalized (Pauly 1995; Carlton 1998; Pinnegar and Engelhard 2008; Lotze and Worm 2009). Thus, it is risky to accept conditions observed at the beginning of a study as the "true" baseline and assume inadequate data were collected in earlier periods. Moreover, the design of studies (large sampling areas with many stations) means well-conducted studies that do not cover the same area are ignored as they do not contain all of the required data.

In fisheries

First, nearly all of our fish assessment data series in the sGSL begin with the trawl survey initiated in 1971. Nevertheless, the use of earlier data shows the size at 50% maturity of sGSL Atlantic Cod is much smaller for the 1971-present period compared to the 1950s and 1960s (Swain 2011). The same paper shows that the estimate of instantaneous natural mortality almost universally used in stock assessments (M = 0.20 or about 17% per year) tripled between the late 1970s and 2005 for this population.

Second, caution is needed in interpreting published studies. For example, often in the literature it is stated unequivocally that predation by Atlantic Cod, and to a lesser degree other groundfish, is the major controlling factor of lobster abundance. This fact is mentioned in many articles or books published over the last 110+ years with no empirical evidence, but rather a compilation of local traditional ecological knowledge or based on a citation (sometime to a second degree or more) of a previous study (e.g., papers citing Bigelow and Schroeder 1953). The original source for this belief is two papers by Herrick (1895, 1909) where the only supporting evidence is an anecdote that one harvester found >100 lobsters in a single Atlantic Cod stomach. Regardless of the facts, some papers mentioned that any period of inverse variation in fish and lobster abundances proves a predator-prey effect (*e.g.*, see Acheson and Steneck 1997; Worm and Myers 2003; Boudreau and Worm 2010), despite that there is no empirical evidence supporting this supposed causal relationship (*i.e.*, occurrence of large numbers of lobsters in fish stomachs; Hanson 2009; Hanson et al. 2014). Moreover, and never mentioned in these studies, an inverse abundance relationship between two species could equally describe a competitive interaction (competitive exclusion) or an inverse response to environmental variables (*e.g.*, temperature). It also may be a mere coincidence that does not apply when the full time series is examined (*e.g.*, Boudreau and Worm 2010 arbitrarily truncate the available lobster and groundfish abundance time series). This information is presented to resource managers as a fact, and it is firmly believed by many harvesters (the sociology term is availability heuristic, Davis and Wagner 2003; Davis et al 2004; Ruddle and Davis 2011). Harvesters, in the sGSL at least, were willing to accept the contrary, empirical, evidence when they were directly involved in projects designed to test the validity of their traditional ecological knowledge on the subject (Hanson and Lanteigne 2000; Davis et al. 2004).

Water temperatures and climate modelling

When the time series begins is important to interpret the size of observed and predicted climate change and can lead to different conclusions on what is "normal" variation. To illustrate, we can compare water temperature data in the ERINS study area from 1921-1969 (Lauzier and Hull 1969) to 1980-2012 (Chassé et al. 2014). Taking two sites (Borden versus the entire Lobster Fishing Area 25 south), the average surface-water temperature for the 1921-1969 period was ~1 °C warmer in the July-August period than the 1980-2012 period, which accounts for much of the predicted surface-water temperature increase for 2040-2069 versus 1980-2012 (Long et al. 2016).

Station	Period	Mean T °C July	Mean T °C Aug
Borden	1921-1969	17.32	18.56
LFA 25 south	1980-2012	16.37	17.44
Difference		**+0.95**	**+1.12**

Staying with the pre-1971 theme, earlier work using annual mean surface-water temperatures (e.g., Lauzier and Marcotte 1965), shows lower water temperatures from 1885 to1950, an increase with a spike in the 1950s, followed by a steep decreasing trend in the early 1960s.

Regime shifts

Other changes to baselines are the regime shift, which may also involve a trophic cascade (sensu Carpenter and Kitchell 1996). A non-reversible regime shift would be one where species become locally extirpated/extinct (*e.g*., sGSL Thorny Skate (*Amblyraja radiate*), Atlantic Cod, coastal White Hake, Winter Skate) or there is naturalization of a non-native species. Physical changes, *e.g*., increase in minimum water temperatures to >2 °C would also change many aspects of ecosystem functioning, allow colonization by organisms presently excluded because they cannot tolerate below freezing water temperatures, and likely would be permanent, at least for several life spans.

Some regime shifts trigger a trophic cascade. A trophic cascade is defined as alternating peaks and valleys in biomass of trophic levels, usually due to changes in predator abundance (Pace et al 1999; Shears and Babcock 2003; Steneck 2012). It need not be permanent. The simplest, and best understood examples, occur when planktivore abundance increases substantially (usually due to overexploitation of their predators), which allows them to crop down the zooplankton biomass, and that leads to increased biomass of phytoplankton.

A regime shift most certainly is underway in the sGSL because the grey seal population has been increasing exponentially since the 1960s, there has been a major decrease in abundance of all medium to large bodied demersal fishes in the sGSL (Benoît and Swain 2008; Savoie 2014), and the increase in the abundance of small demersal fishes, shrimps, and small pelagic fishes (*e.g*., Capelin *Mallotus villosus*) have increased markedly. It is impossible to test for a trophic cascade in the demersal energy loop because there is no means to assess whether the food base (largely benthic invertebrates) has decreased and the amount of detritus has increased.

There is preliminary evidence of a trophic cascade within the ERINS study area: the biomass of pelagic species increased markedly between 2000 and 2009 (Figure 1) and that was accompanied by a substantial decrease in biomass of most species of medium to large-bodied demersal fishes. There has been an almost complete disappearance of large predators (Atlantic Cod and White Hake) from both ends of the Strait. While there are no quantitative estimates of zooplankton abundance within the ERINS study area prior to 2008-2009, the mean concentration of Chl *a* increased threefold between 1990-95 and 2008-2009, which is consistent with a trophic cascade (Debertin 2011; Debertin et al. in press). However, there is a caveat: this could be related to an increase in nutrient loading from rivers flowing into the Strait (these hypotheses are not mutually exclusive). There certainly have been many issues with nutrient excesses causing fish kills in rivers and upper-most extent of estuaries in PEI. However, the volume of water provided annually by all the rivers adjacent to the Strait is tiny compared to the volume of water in the Strait and any possible effect would be diluted further by movements of water through the Strait. Finally, unlike species losses or establishment of non-native species, nutrient loading problems can be reversed.

For much of the information collected during the ERINS program, this is the first time quantitative measures were attempted for many ecosystem characteristics; therefore, this program becomes the *de facto* baseline representing a period when we know the structure and function of the ecosystem is changing. Moreover, there is the very real possibility that some components (*e.g*., skates, White Hake) will disappear permanently, and establishment of non-native species is always a threat.

3.2 Data Void: The Shallow Subtidal and Intertidal Zone

A technical limitation in the ERINS program was that data and samples collected were restricted to waters >4 m deep due to the draft of the main survey vessel used for most projects. Consequently, near-shore fish species either have never been captured (*e.g*., Striped Bass and Sea-run Brook Trout) or were captured in small numbers (Atlantic Tomcod) during trawl surveys. For instance, it is well-known that Striped Bass make long feeding migrations from their main spawning/nursery area along the coast of much of the sGSL. Atlantic Tomcod either mostly feed close to shore or live sufficiently high off the bottom to avoid being captured by bottom trawls. Relatively few Atlantic Tomcod are captured during the July-August survey and almost always at the shallowest stations. The Atlantic Tomcod represents an important bycatch, often greater than Rainbow Smelt landings, in the estuarine Rainbow Smelt fishery suggesting that the numbers of Atlantic Tomcod present in the ERINS study area could be quite large. Rainbow Smelt are the most commonly captured fish species in the July-August trawl surveys (Bosman et al. 2011) while tomcod are seldom captured.

It has been decades since any attempt was made to evaluate the biomass, species composition, or distribution of macrophytes in the <4 m depth zone in the Strait, despite several species having been harvested for commercial purposes. There is no monitoring of the harvest of marine seaweeds in the ERINS study area.

3.3 Benthic Photosynthesis

At the bottom of the food web, there is a, as yet unquantified, similarity that separates the coastal and estuary-embayment zones from the better-studied offshore zone, which is benthic photosynthesis. The photic zone (conservatively estimated as depth of 1% surface level of photosynthetically active radiation, PAR) extends to the bottom in nearly all estuaries and embayments; shading by phytoplankton in severely nutrient-enriched estuaries is the exception. The percentage of PAR reaching the bottom is ≥1% for at least 50% of the ERINS study area (Debertin et al., in press). The proximity to land also brings with it the potential for substantial direct deposition of land-derived carbon-based materials, sediment, and anthropogenic nutrient enrichment.

Emergent and canopy forming macrophytes (algae, eelgrass, and all marsh plants) fix carbon from both dissolved and gaseous CO_2 pools (*e.g.*, see Watanabe and Kuwae 2015). Macrophytes also act as a trap for particulate carbon (and nutrients) of terrestrial and freshwater origin. Consequently, it is not unusual for seagrasses to attain standing biomasses and annual turnover of >1.5 kg/m^2 dry weight at temperate latitudes (McRoy 1970; Sand-Jensen 1975; Jacobs 1979) while macroalgae such as kelps, *Fucus*, and rockweeds can substantially exceed these biomasses. There are a limited number of estuaries adjacent to the ERINS study area where eelgrass abundance has been measured and tracked for a limited number of years. Many of these data were collected by DFO Gulf Region, however, the status of these data and the monitoring program is unknown. The state of the eelgrass beds outside of estuaries (*e.g.*, in Baie Verte) is unknown.

Benthic microalgae also are highly productive in shallow waters (estuaries and coastal zone) where their biomass and annual production often are several times that of the pelagic phytoplankton (*e.g.*, see Cahoon et al. 1990; Pinckney and Zingmark 1993; Lukatelich and McComb 1986). When added to the estimates for macrophytes, the main route of primary production in the coastal and estuary habitats it is almost certain to be much greater than that of the pelagic zone meaning the formulation of mass-balance models for these two ecosystems will be dominated by the detrital/benthic pathway. Benthic photosynthesis in general is poorly sampled in Canadian marine waters, and no information or quantitative estimates of benthic photosynthesis by microalgae in the ERINS coastal zone or any adjacent estuary is available.

While pelagic primary production can be estimated fairly well from measured Chl *a* profiles and water temperatures, it is labor intensive. For pelagic photosynthesis, it is tempting to use satellite estimates based on colour; however, the depth of the Chl *a* maximum is not constant, ranging between 3 and 17 m in ERINS (Debertin et al., in press). The Chl *a* values were also highly patchy in space and the pattern and maximum values of measured Chl *a* differed substantially between the two survey years. How well satellite images capture the amount of Chl *a* in the photic zone needs to be carefully assessed and likely would need annual ground truthing. Moreover, satellites cannot be expected to capture benthic Chl *a*, which is a problem because it occurs in >50% of the ERINS study area (Debertin et al., in press). Returning to pelagic primary production, fairly small errors in phytoplankton biomass can have very large effects on annual primary production estimated by models due to the multiplicative nature of terms in the models.

3.4 Ecosystem Degradation

A small, partially anoxic, area was detected in the ERINS study area. The 2008 and 2009 July-August trawl surveys had high levels of oceanographic data sampling through CTD casts and that of 2008 (Debertin et al., in press) detected a small area of low oxygen concentrations off the mouth of Hillsborough Bay, PEI. Oxygen concentration data are available from subsequent surveys but have yet to be examined or mapped. It would seem appropriate to monitor this area annually or alternatively place a series of oxygen probes in the area. Finally, across from the Strait from Hillsborough Bay, near the mouth of the River John in Nova Scotia, an area that could be described as essentially a dead zone (undetermined size) has been observed, and could be related to low oxygen concentrations. This area is visited and sampled (targeting lobsters but also recording occurrence of rock crab, *Crangon sp.*, and fish species) regularly by divers and the latest observations are consistent: there is still next to nothing living in this area (M. Comeau, unpublished data).

3.5 Fisheries Effects

Scallop dragging certainly perturbs the bottom but its effect on the ecosystem is unknown. A recent study included central Strait as one of two study locations and looked at short-term effects of the scallop dragging on sediment-dwelling organisms (LeBlanc et al. 2015), but unfortunately results were ambiguous, partly due to low statistical power. This aside, conducting a short-term study (1 year) in an area that has been perturbed by scallop dredging for many decades (another shifting baseline issue) is unlikely to be of long enough duration for a site to revert to an unknown previous condition. Moreover, beyond bycatch issues, scallop dredging affects bottom topography by smoothing out features and removing inert and living structure-forming species (*e.g*., rocks, sea anemones, colonial polychaetes). The new baseline, however, is that the ERINS study area is a coastal zone heavily perturbed annually by scallop dredging (Davidson et al. 2012) and by various environmental conditions such as ice-scouring.

With the severely depressed status of most demersal fish stocks, effects of bottom trawls and seines on the coastal ecosystem are now minimal. There are, however, Herring and Mackerel gillnet fisheries. There are no studies on discard practices, bycatch, the quantity of fish lost through falling out of net; and the extent of ghost fishing by lost or abandoned gillnets. There are some estimates of bycatch in lobster-trap and rock-crab pot fisheries and despite there being hundreds of thousands of traps and pots fished annually, bycatch is returned alive and in good condition, and the gear footprint on the bottom is thought to be minimal.

3.6 Relevant Metabolic Rates

The ERINS study area is characterized by high summertime bottom water temperatures. Any attempt at mass-balance modelling will require use of a consumption model in which basal metabolic rate and prey evacuation rates play a large role. Metabolic rates and consumption rates for most of the coastal species, especially for the high water temperatures characteristic of ERINS study area, are missing. For example, based on studies in freshwater, information on metabolic rates shows that Rainbow Smelt is a cool-water fish (prefers to be below the thermocline and avoids waters >14°C) while alewives are a warm-water fish with preferences in the 24 to 28°C range (Coutant 1977; Brandt et al. 1980; Rooney and Paterson 2009; Simonin et al. 2012). However in the ERINS (*i.e*., in saltwater), both species are most abundant in the center of the Strait (Bosman et al. 2011) where bottom waters often exceed 21°C – well above the avoidance temperature of Rainbow Smelt in freshwater. Furthermore, when temperature-distributions are plotted, Alewife avoided temperatures <10°C while Rainbow Smelt were evenly distributed between 5 and 22°C but avoiding temperatures <5°C. The 50% occupancy temperature of Rainbow Smelt was 15.5°C, which is above its published avoidance temperature. This is important because Rainbow Smelt is one of the dominant species in the Strait. A similar problem exists for the possible endemic skate: Winter Skate elsewhere prefer water temperatures <10°C while the skates in the ERINS study area prefer temperatures >12°C and do not occur, during summer months, in waters <10°C (Kelly and Hanson 2013a). Where literature values do not exist, realistic metabolic rates at ambient summer temperatures will need to be determined if a realistic mass-balance model is desired for ERINS study area.

3.7 Ecosystem Hysteresis

Whether a new stable alternate state develops or not, is it even possible to revert to something like that which was formerly present, and what is the target period – assuming it is known (*e.g*., in the 1800s or even 1960s)? In many cases, the newest stable state resists efforts to return to a former state such that the degree of change needed to go back is greater than that required to drive it to the recent stable state (phenomenon of hysteresis). Some changes are irreversible; *e.g*., the possible extinction of Winter Skate; naturalization of a non-native species; loss of the last coastal White Hake spawning group (the Baie Verte component is already gone); new temperature regime; water level changes due to isostatic post-glacial rebound, etc.

3.8 Birds and Marine Mammals (other than seals)

Several bird species such as the northern gannet (*Morus bassanus*), the double-crested cormorant (*Phalacrocorax auritus*), the common tern (*Sterna hirundo*), osprey (*Pandion halieatus)*, bald eagle (*Haliaeetus leucocephalus*), and great blue heron (*Ardea herotius*) feed in coastal waters, estuaries, and shallow embayments. Programs to obtain population estimates or to evaluate prey consumption by birds or any other relevant type of research on birds would have to be initiated and led by Environment Canada, which has the mandate and the expertise for research on this topic within the Federal Government. Within estuaries, the effect of bird predation might be important on the overall ecosystem.

Large sea mammals other than grey seals do feed in the ERINS study area but population sizes, duration of residence, diets, and feeding rates are unknown.

3.9 Pelagic Species

The main survey gear in the Strait is a bottom trawl; consequently, pelagic and semi-pelagic species (*e.g*., mackerel, herring) and even some burying fishes (*e.g*., Northern Sand Lance *Ammodytes dubius*, Wrymouth *Cryptacanthodes maculatus*) are poorly sampled. In the case of herring and mackerel, there are dedicated surveys used in stock assessments; however, there is no reliable estimate for either burying species, which would not matter if the Northern Sand Lance was not an important forage species.

In addition to the species above, some marine pelagic species (*e.g*., Bluefin Tuna *Thunnus thynnus*, Banded Rudderfish *Seriola zonata*, Atlantic Saury *Scomberesox saurus*, Ocean Sunfish *Mola mola*, leatherback sea turtle *Dermochelys coriacea*) undergo feeding migrations into the coastal waters of the Strait, sometimes in commercially exploitable numbers (*e.g*., Atlantic Leatherback Turtle Recovery Team 2006; Chaput and Hurlbut 2010; DFO 2011), yet these species have seldom, if ever, been captured in any sGSL research surveys. In most cases, our inability to capture these pelagic species would not matter as only Bluefin Tuna is widespread and, potentially, abundant.

Bluefin Tuna is an apex predator, currently at a low, but slowly increasing, abundance level, and it is impossible to predict the ecosystem level effects of the present and future population without knowing population size, duration of residence, and diet. Presumably, each Bluefin Tuna landed are sampled to obtain detailed feeding information; however, the only publication available describes stomach contents of 23 fish captured from a single location (Port Hood) and in one year (Pleizer et al. 2012). Hence, from the several hundred Bluefin Tuna fished every year stomach samples could be retained by harvesters and handed over to DFO personnel with the species' mandate for diet analysis. Reliable and quantitative feeding information, preferably concurrent with grey seal feeding information, is critical because the structure and functioning of the entire sGSL ecosystem is changing rapidly as the grey seal population continues its exponential increase. If they are not at present, at some point, these two apex predators will almost certainly become competitors for the food supply in the ERINS study area and the sGSL as a whole.

3.10 Poorly Sampled Invertebrates

<u>Seven-spine bay shrimp</u>

The role of *Crangon* shrimp in ecosystem functioning is poorly understood. Clearly it is important in the sGSL because it is the only shrimp species occurring in the coastal zone (<30 m depths), and it is the main shrimp species found in estuaries and very shallow waters along the coastline (Hanson and Lanteigne 1999; Locke et al. 2005). Even in the eelgrass beds, *Crangon* catches far exceed those of grass shrimps *Palaemon* (= *Palaemonetes*) spp. (Joseph et al. 2006). In the sGSL, *Crangon* species may play a keystone-species role due to: omnivorous diet (detritus, plant material, meiofauna, and macroinvertebrates ; Taylor and Peck 2004; Feller 2006; Antonio et al. 2011); predation on newly settled fish, crab, and lobsters (Olmi III and Lipcius 1991; Keefe and Able 1994; Taylor 2003; Sigurdsson and Rochette 2013); and presence in diets of many coastal and estuarine fishes and large decapods (Robichaud-LeBlanc et al. 1997; St-Hilaire et al. 2002; Hanson 2011; Kelly and Hanson 2013b; Hanson and Wilson 2014; Hanson et al. 2014; Hanson, in press). Bringing together all available feeding information (Table 1), *Crangon* was an important prey (>10% prey biomass) for of 9 of 18 most commonly captured species or groups in the ERINS study area and of moderate importance (5% to 10%) to another four groups.

Substantial numbers of coastal fishes enter estuaries during autumn (Hanson and Courtenay 1995, 1996). We sampled diets of 13 predator groups on a seasonal basis although most were only present during autumn and winter (Table 2). *Crangon* were an important prey (21%-95% of prey biomass) of all but small Winter Flounder and the two size-classes of Smooth Flounder. One omission from this study, we did not sample Rainbow Smelt during the 1991-1993 surveys, Rainbow Smelt preyed heavily on *Crangon* in the Strait (Hanson, in press) and likely did the same in the estuary location.

A major information gap is the lack of quantitative estimates of *Crangon* abundance and production in estuaries, the near shore, and coastal zones. As a key prey species, this lack of abundance data (or even a single baseline estimate) will affect the performance of most mass-balance type ecosystem-based models for the coastal zone

<u>Mysids</u>

While not as important in the food web as *Crangon* shrimp, mysids are an important prey (>10% of prey biomass) of demersal fishes in the ERINS study area and adjacent estuaries, including: Windowpane Flounder (Hanson and Wilson 2014); juvenile Atlantic Cod (Hanson 2011); juvenile Striped Bass (Robichaud-LeBlanc et al. 1997); White Perch (St-Hilaire et al. 2002); and Longhorn Sculpin and American Plaice (J.M. Hanson, in press). Because they migrate vertically from bottom sediments during the day to well up into the water column at night, mysids are a link between the benthic algae, detritus, meiofauna eaten during daylight hours, and the zooplankton plus phytoplankton consumed at night. This diel vertical migration can be a challenge for studying mysids.

Diet sampling was conducted during daylight hours when mysids are closely associated with the bottom, making them largely unavailable to pelagic predators and our plankton nets. While it is not as important to obtain realistic abundance estimates for mysids as it is for *Crangon* shrimp (juvenile shrimp can substitute for mysids in the diets and *vice versa*), it also is not a trivial information gap.

Jellyfishes

Jellyfishes, both the small forms such as *Aglantha* and large forms such as *Aurelia aurita* and *Cyanea capillata* have long existed as prominent parts of the estuarine and marine ecosystems in the entire GSL. All jellyfishes eat pelagic prey such as small zooplankton, larval fishes and other jellyfishes. Other than annual newspaper reports of very large numbers of large jellyfish in shallow areas (especially beaches), information on abundance, distribution, population size structure, etc., is lacking.

3.11 Two-Way Subsidies

Large concentrations of diadromous fish feed in the ERINS study area both as adults and juveniles (Hanson, in press). *Crangon* may or may not move between estuaries and the coastal zone. While only a small fraction of lobster and rock crab population lives in larger estuaries or embayments of the sGSL, they still support locally important fisheries (*e.g*., in Miramichi Bay and Malpeque Bay). The better known phenomenon is nutrient (or carbon) subsidies to freshwater and estuarine areas due to spawning runs of diadromous fishes. The situation on the east coast of North America is less-well studied than on the west coast and the very depressed population sizes of many diadromous species, and especially Atlantic Salmon, in USA and other waters has been an issue in calculating present versus past importance of this phenomenon (baseline has changed) and the marine derived nutrient inputs at present are likely much less than in the past (Nislow et al. 2004; Saunders et al. 2006; Jardine et al.2009; Limburg and Waldman 2009; Samways and Cunjak 2015). Nevertheless, using carcass analogs to enhance juvenile Atlantic salmon production is proving to be a fruitful line of research in some severely degraded watersheds (Guyette et al. 2013, 2014).

While Atlantic Salmon numbers currently are much lower than in the past 30 years in major salmon rivers and at minimal levels in many smaller rivers of the sGSL (DFO 2017e) and ERINS study area, there are many species of diadromous fishes that can contribute to marine subsidies to freshwater and estuarine locations; *e.g*., Sea Lamprey, Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*), the three *Alosa* species, Atlantic Tomcod, Rainbow Smelt, Sea-run Brook Trout, and even sticklebacks. While run sizes may not be healthy in every river, overall there was a dramatic increase in Alewife and Rainbow Smelt catches in July-August trawl surveys between 2001-2009 (Bosman et al. 2011; A. J. Debertin and J. M. Hanson, unpublished data) The majority of the Alewife and Rainbow Smelt populations occur shallower than the depths covered by the September trawl survey; nevertheless, abundance indices of both taxa have increased markedly since the early 1980s as has the area of occurrence (Savoie 2014). Incorporating the subsidies by spawning diadromous fishes is not a major issue for any attempt to formulate mass-balance or food-web type models for the ERINS study area, other than as a loss to the system, but is important for those working in the adjacent rivers and estuaries.

CONCLUSION

Based on the ERINS program, there is no evidence of a decline in the state or productivity of the Strait or that it is not a fully-functioning ecosystem. The ecosystem structure and functioning is, however, in a transition state because abundances of small fishes and invertebrates, lobster, and grey seal are increasing while populations of medium and large, mainly predatory, fishes are at very low abundance levels and still declining. Unlike the well-studied offshore marine ecosystems, the coastal ecosystem of the Strait supports large populations of diadromous fishes, which have a strong estuary and freshwater requirement to complete their life cycles. There likely is sufficient species redundancy present in the strictly marine fish community (e.g., mackerel, herring, sand lance) to compensate for ecosystem functioning should diadromous-fish population sizes change. Water quality indices (*e.g.*, water transparency, oxygen levels, and Chl *a* levels) are within the "excellent" range, unlike the case in some adjacent, semi-enclosed, estuaries. Nutrient loading issues affecting the adjacent estuaries are unlikely to noticeably affect the marine waters of the Strait unless it can be shown that the amount of water (and its nutrient load) emptying from the estuaries is large enough to surpass the dilution capacity of the amount of water present in and passing through the Strait. However, there has been a small increase in Chl *a* levels in the Strait since the 1990s, but the current levels are well below the level where there is concern about shading or the formation of zero-oxygen dead zones. Lobster landings are at the highest level in the >120 year time series. Predicted increases in bottom water temperatures due to climate change will result in changes in distributions of some commercially exploited organisms (*e.g*., lobster and scallop), especially in the central area and two ends of the Strait. Because the Strait is transitioning between regimes, or states, continued monitoring is needed. Time series data, such as annual multispecies surveys, would enable stronger inferences of ecosystem changes and might shed light on cause and effect relationships of ecosystem changes.

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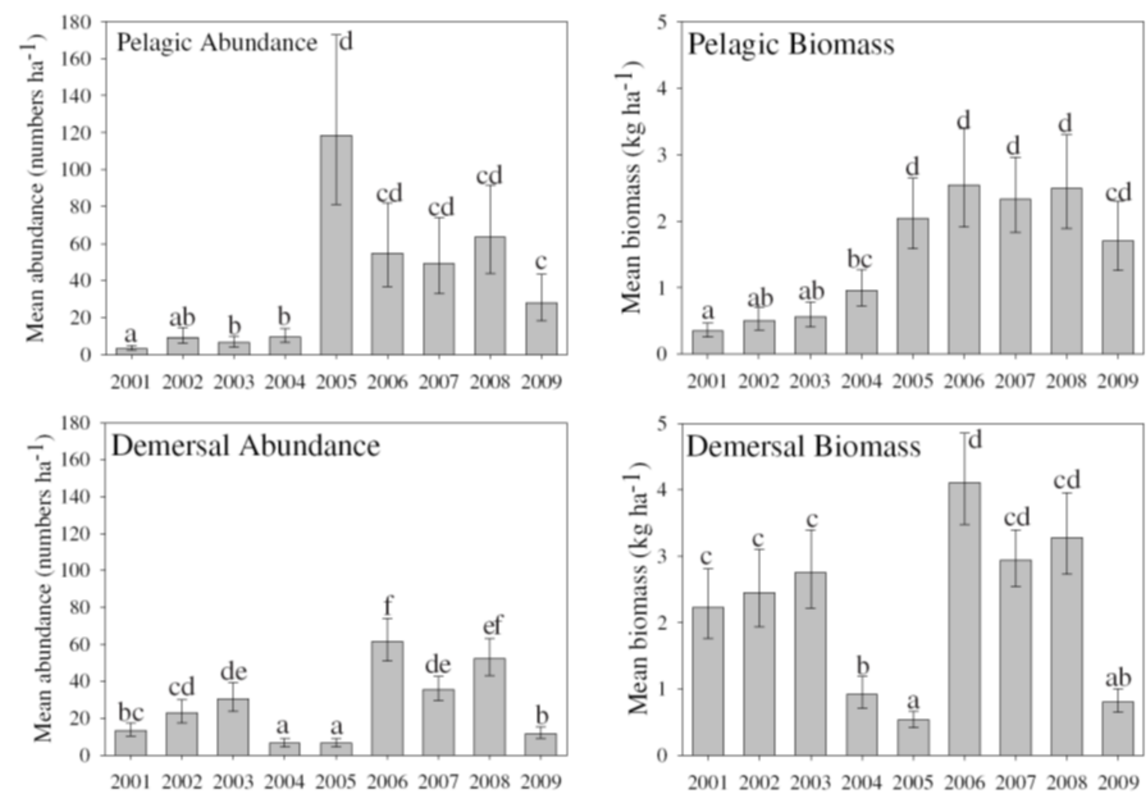

Figure 1. Geometric mean abundance and biomass (±95% confident interval) of pelagic and demersal fish within Northumberland Strait (A.J. Debertin and J. M. Hanson, unpublished data). Years with letters in common are not significantly different from each other ($p = 0.05$; Tukey test).

Table 1. Contribution of the seven-spine bay shrimp (*Crangon septemspinosa*) to the diets of fishes in Northumberland Strait during the July-August bottom trawl surveys (from Hanson, in press). Important diet component (>10% prey weight) is indicated in bold and moderate importance (>5%) is underlined. Total Length = TL.

Predator	TL (cm)	% biomass	N (%empty)
Cunner	< 15	**25.3**	297 (3.4)
Cunner	≥ 15	<u>5.4</u>	454 (2.9)
Winter Flounder	< 20	<u>6.8</u>	396 (9.1)
Winter Flounder	≥ 20	2.8	466 (6.2)
Windowpane Flounder	< 20	**71.6**	314 (9.2)
Windowpane Flounder	≥ 20	**85.4**	144 (8.3)
Yellowtail Flounder	All	3.0	287 (14.6)
American Plaice	< 30	<0.1	353 (24.6)
Longhorn Sculpin	< 20	**26.5**	259 (18.1)
Longhorn Sculpin	≥ 20	**14.9**	643 (14.5)
Shorthorn Sculpin	All	< 0.1	148 (28.4)
Sea Raven	All	< 1.0	175 (45.1)
White Hake	< 35	**66.7**	247 (5.3)
White Hake	≥ 35	< 0.1	2869 (38.6)
Winter Skate	< 40	**70.1**	571 (4.0)
Winter Skate	≥ 40	<u>5.9</u>	408 (3.2)
Rainbow Smelt	All	**53.6**	2236 (31.4)
Alewife	All	<u>7.2</u>	507 (3.0)
Herring	All	1.2	377 (7.7)
Mackerel	All	2.7	368 (4.1)
Shad	All	1.0	394 ((0.5)
Rock crab	All	**15.8**	1166 (31.8)
Lady crab	All	0.4	976 (36.6)
Lobster	All	0.3	1931 (6.8)

Table 2. Importance (% total prey biomass) of seven-spine bay shrimp (*Crangon septemspinosa*) in diets of demersal fishes collected in the Miramichi River Estuary. Data (as percentage total prey biomass) were collected by trawling and sampling bycatch (rainbow smelt traps), 1991 to 1993. Important diet component (>10% prey weight) is indicated in bold. The White Perch (*Morone americana*) were captured in the Richibucto River (St.-Hilaire et al. 2002).

Predator (total length)	period	N (% empty)	% biomass
Winter Flounder <20 cm	Autumn	1,365 (79)	5.0
Winter Flounder ≥20 cm	Autumn	118 (83)	**27.3**
Smooth Flounder <20 cm	May-Oct	1216 (45)	0.7
Smooth Flounder ≥20 cm	May-Oct	187 (20)	3.0
White Perch 5-17 cm	Summer	67 (0)	**87.9**
Striped Bass (<30 cm)	Autumn	192 (80)	**59.9**
Shorthorn Sculpin (6-19 cm)	Winter	285 (26)	**36.2**
Ocean Pout (17-45 cm)	Winter	34 (44)	**21.2**
Greenland Cod <15 cm	Oct-May	107 (29)	**95.0**
Greenland Cod ≥15 cm	Oct-May	250 (8)	**29.6**
Atlantic Tomcod <15 cm	Oct-May	702 (47)	**70.0**
Atlantic Tomcod ≥15 cm	Oct-May	1017 (6)	**77.7**
White Hake <35 cm	Autumn	515 (24)	**48.6**