Comparison of ecosystem models of the Newfoundland and Labrador Shelf and Grand Banks

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A Thesis submitted to the School of Graduate Studies in partial fulfillment of the requirements for the Degree of

Master of Fisheries Science and Technology

Center for Fisheries Ecosystem Research

Marine Institute at Memorial University of Newfoundland

July 2023

St. John’s, Newfoundland and Labrador

Abstract

Ecosystem models are tools that can provide strategic ecosystem-based fisheries management (EBFM) advice by accounting for the influence of environmental drivers and food-web interactions on fish stocks. Ecopath with Ecosim (EwE) is an ecosystem modelling platform that uses a mass-balance approach to estimate ecosystem dynamics. Existing EwE models cover the Newfoundland & Labrador Shelf and Grand Banks for 1985-1987 and 2013-2015 time periods, representing ecologically significant time periods for the region. To provide higher spatial resolution to the existing models, I separated the single model area into two for the Newfoundland & Labrador Shelf and the Grand Banks and updated the models for the 2018-2020 time period. Evidence of a strong bottom-up influence from environmental drivers demonstrated that the two model regions are distinct in ecosystem structure and function, with variable temporal dynamics. Comparisons of the system across all three time periods provided insight into ecosystem dynamics. Primary/secondary production had increased since 2013-2015 in both areas, as well as groundfish abundance, but neither were above pre-groundfish collapse (before the early 1990's) levels. Species composition and biomass was noticeably different between the northern and southern regions, as well as catch composition. Forage fish biomass did not show signs of recovery in either system, and may play key roles in predicting outcomes for the system in the near future.

Acknowledgements

I would like to start by thanking the agencies that provided funding for my research and made this thesis possible, the DFO Atlantic Fisheries Fund and the MUN School of Graduate Studies.

I would also like to express my deepest gratitude towards my supervisor Dr. Tyler Eddy, who provided me with the best academic experience of my career so far. As someone who was on the fence about pursuing a master's degree, Tyler created a very welcoming environment and encouraged me to try new things for a well-rounded degree experience. Thank you so much.

A big thank you to my committee members Jaime Tam and Paul Regular, and my thesis reviewers Alida Bundy and Maxime Geoffroy. Thank you for all of your time and feedback for my project. Your advice was invaluable to the outcome of the paper, and for that you have my sincere appreciation.

As well, a special thank you to David Belanger, Mariano Koen-Alonso, Carina Gjerdrum, and Shelley Lang, for providing data and guidance for various functional groups in the model.

Finally, I would also like to recognize the moral support provided to me throughout this experience from Reid Steele and my lab members at Team Zissou. Thank you for being such wonderful human beings.

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List of Symbols, Nomenclature, or Abbreviations

COSEWIC	Committee on the Status of Endangered Wildlife in Canada
DFO	Fisheries and Oceans Canada
EAFM	Ecosystem Approach to Fisheries Management
EBFM	Ecosystem-based Fisheries Management
EE	Ecotrophic efficiency
EPU	Ecosystem Production Unit
EwE	Ecopath with Ecosim
GOA	Gulf of Alaska
NAFO	Northwest Atlantic Fisheries Organisation
NCAM	Northern Cod Assessment Model
PA	Precautionary Approach
P/B	Production to biomass ratio
Q/B	Consumption to biomass ratio
RV	Research vessel
SST	Sea surface temperature
IUU	Illegal, unreported, and unregulated catch
2J3K	Refers to NAFO regulatory divisions 2J and 3K
3LNO	Refers to NAFO regulatory divisions 3L, 3N, and 3O.

1. **Introduction**

1.1 Ecosystem-based fisheries management and ecosystem modelling

Traditionally, fisheries stocks in the Northwest Atlantic are managed on a single species basis, meaning each species is monitored, assessed, and managed independently of each other. Recently, there has been a push to integrate an ecosystem approach to fisheries management (EAFM) into Northwest Atlantic fisheries management practices (Koen-Alonso et al. 2019), which considers how external influences such as environment or other species may influence the target species. EAFM is generally characterized as a management approach that seeks to balance multi-species fishery yield, socioeconomic wellbeing, and sustainability for all organisms living in the ecosystem as opposed to just commercially targeted stocks. This framework can be achieved by combining information from climate data, habitat type, oceanographic conditions, species ecology and physiology, and fisheries landings to capture all the complex processes that influence an ecosystem in the context of sustainable fisheries.

EAFM practices are more often being taken into account in management decisions but are usually applied in the context of single species stock assessments (Koen-Alonso et al. 2019). A step beyond EAFM is ecosystem-based fisheries management (EBFM), which seeks to integrate multiple fisheries into a comprehensive ecosystem management plan as opposed to multiple single species management plans (Link and Marshak 2022). While the benefits and drawbacks of EBFM have been heavily debated since its conception in the early 1990s (Grumbine 1994, Murawski 2007, Hilborn 2004, Hilborn 2011), many governing bodies including Canada and the United states have begun implementing EAFM practices into their stock management processes (Link and Marshak 2022). While some think there is a long road to go before EBFM practices become the norm, there has been slow but steady progress towards EBFM informed governance in developed and developing countries all over the world (Patrick and Link 2015).

Although Canada has not implemented a full EBFM approach, steps have been made towards it involving EAFM based policies and tools (Pepin et al. 2019). One example of a policy aligning with the principles of EAFM is the "Precautionary Approach framework (PA; DFO 2006a). The PA is intended to promote a cautious approach when there is a lack of scientific understanding in one or more aspects of a fished stock. The PA introduced the use of stock reference points, which split the target population into three zones: healthy (the stock is in good condition and low risk of collapse), cautious (the stock may be danger of collapsing, management action should be taken to reduce risk), and critical (there is a high probability of serious harm to the stock, management actions must be taken to promote stock growth). Reference points help determine the rate at which the stock may be harvested from an area. Stock reference points are usually based on the biomass and the catch removal rate of the stock and are often calculated using stock assessment models.

Ecosystem models are tools that can be used to provide strategic EBFM advice. Ecosystem models, in line with EBFM principles, seek to mathematically account for the influence of environmental drivers or stressors and food-web interactions on fish stocks. There are many types of ecosystem models that can capture a wide spectrum of ecosystem dynamics, depending on the complexity and scale of system (Fulton et al. 2003; Fulton 2010). Ecosystem models can be used on very fine, local scales to answer questions relating to species interactions and diet shifts in localized areas (Mawer et al. 2023). Alternatively, ecosystem models or a suite of ecosystem models can be combined to function on large, global scales to answer questions about the state of fisheries or biodiversity across the world, often in the context of climate change scenarios (Worm et al. 2009). Selecting the right type of model often depends on the types of questions one wishes to answer about the chosen ecosystem.

Ecopath with Ecosim and Ecospace (EwE) is a commonly used ecosystem modelling software for aquatic ecosystems, due to its ability to capture complex systems in a straightforward manner while having a user-friendly interface. EwE uses a mass-balance approach (Ecopath), for which time series analysis (Ecosim) and spatial mapping (Ecospace) can be simulated. Ecopath captures complex trophic interactions and instantaneous rates of biomass change and energy flow in an ecosystem, which are often calculated into an annual rate (Christensen and Walters, 2004). Because Ecopath provides instantaneous ‘snapshots’ of ecosystem function, its outputs are not always used for analyzing policy efficacy, but rather to refine predictions about a complex ecosystem. Ecopath models have become prolific in the aquatic ecosystem modelling world, with over 1100 publications involving an Ecopath or Ecosim model in the past 30 years, half of which have been in the past 6 years (Figure 1). Ecopath is a good tool to help describe and characterize marine ecosystems (Bentley et al. 2021) and has been successfully used to provide ecosystem level advice in identifying drivers for stock production for major commercial species such as Atlantic menhaden in Northeastern USA and food webs in the Irish Sea (Howell et al. 2021).

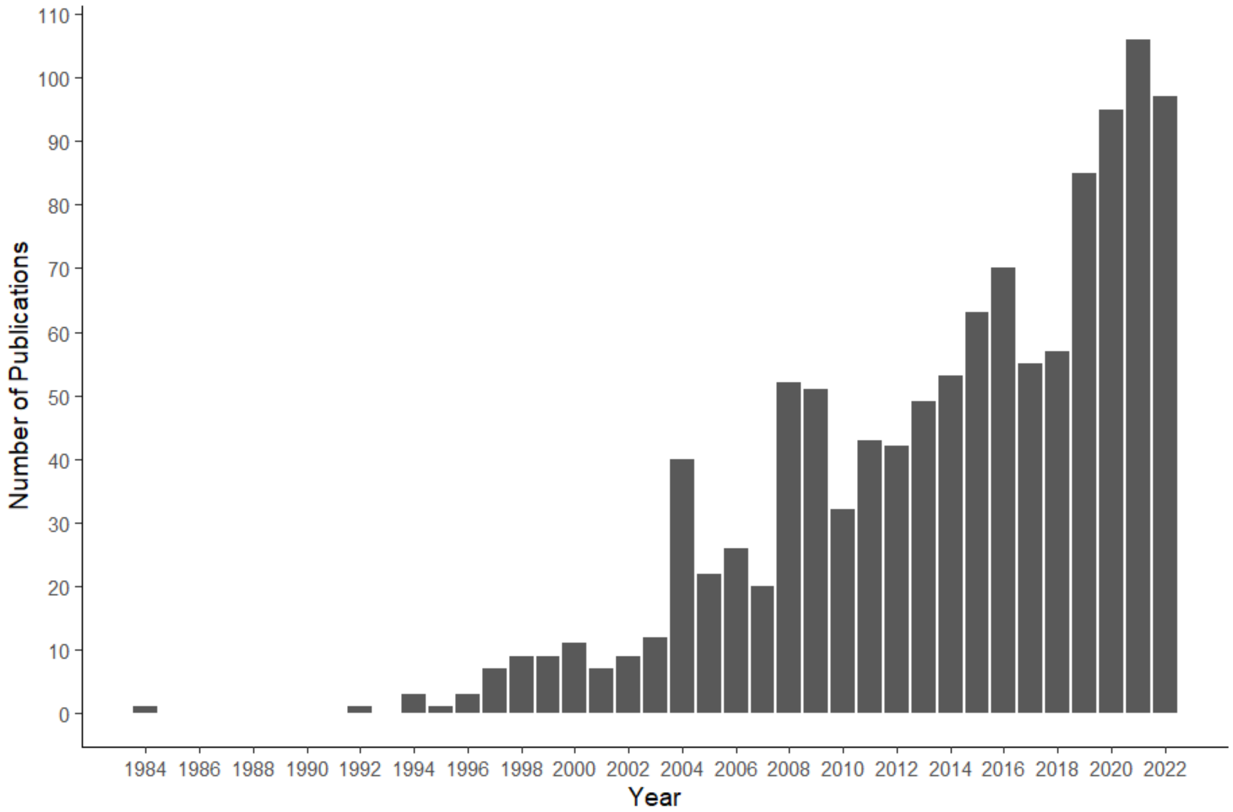

Figure 1 Number of publications using Ecopath and/or Ecosim from 1984-2022 (Source: Web of Science query made on 16/05/2023, including words "Ecopath" or "Ecosim")

In its most basic form, Ecopath inputs require estimates of biomass, diet, production to consumption ratios for each trophic group, and fishing pressure, then and outputs estimates of trophic interactions, predation mortalities and energy flow in the system. In addition to varying levels of fishing pressure, Ecopath can be used to investigate ecosystem responses to a variety of anthropogenic stressors that impact ecosystem components (Stock et al. 2023) (Table 1).

Table 1 Examples of Ecopath models involving various stressors. Adapted from Stock et al. (2023).

Stressor	How the model is impacted	Location	Reference
Climate change	Apply a forcing function based on temperature	Gulf of California (USA)	Hernández-Padilla (2021)
Climate change	Use coral bleaching as a short-term mortality event	Caribbean Reefs (Belize)	Alva-Basurto and Arias-González (2014)
Eutrophication	Impacts to primary production and bottom-up effects from plankton groups	Black Sea (Eastern Europe)	Akoglu et al. (2014)
Fishing pressure	Increasing or decreasing landings from specific groups, exploring effects such as depredation and seeing the impact on the ecosystem.	Kerguelen and Crozet Islands (French subantarctic islands)	Clavareau et al. (2020)
Invasive species	Inclusion of a new functional group, with different diet compositions	Great Lakes (Canada/USA)	Langseth et al. (2012)
Ocean acidification	Apply a forcing function to impact production and consumption of affected groups as pH changes	Puget Sound (Northeast USA)	Busch et al. (2013)
Pollution	Building four models to compare food-web dynamics before and after an oil spill	Gulf of Mexico (USA)	Lewis et al. (2021)
Underwater noise	Acoustic deterrents can correspond to loss of foraging time for mammals and seabirds	North Sea (UK)	Steenbeek et al. (2020)

In addition to including ecosystem stressors, ecosystem models can be developed in the same area at different points in history to describe changes in ecosystem structure and function across time. For example, Pitcher et al. (2002) used four Ecopath models to see how the Newfoundland and Labrador ecosystem has changed from the year 1450, 1900, 1985, and 1995, covering a large time span from pre-European colonization when cod were at an unfished biomass, to the stock collapse experienced in the early 1990's. These models contained 50 functional groups and combined scientific data with historical accounts to produce models than spanned centuries, but comparisons of the four time periods in terms of ecosystem structure and function were limited.

The 1985 model in the Pitcher et al. (2002) paper was adapted from another Ecopath model developed by Bundy et al. (2000) who modeled NAFO divisions 2J3KLNO (Figure 1) in the 1985-1987 time period, to capture the ecosystem dynamics of the Newfoundland and Labrador Shelf and Grand Banks in a pre-ground fish collapse state. Although they acknowledge that the two areas are thought to be ecologically distinct from each other, the authors mention how the choice of combining the Newfoundland and Labrador Shelf (2J3K) and Grand Banks (3LNO) as a study area was a compromise between biological homogeneity, convenience of using pre-existing NAFO boundaries, and coinciding with fish stocks within those boundaries.

In 2019 a second paper was published by Tam and Bundy (2019), who in a collaboration with the Norwegian CoArc project (A Transatlantic Innovation Anrea for Sustainable Development in the Arctic), re-developed the 1985-1987 Ecopath model, and built a new Ecopath model for the same area for the 2013-2015 time period. The goal of the project was to synthesize biomass, production, consumption and diet information for Arctic and Subarctic ecosystems to improve marine management methods for those areas. There was a slight shift of functional groups between the Bundy (2000) paper and the Tam and Bundy (2019) paper to better align with another Ecopath model that was being developed for the Barents Sea so the models could be compared for structure and function. The same study area of 2J3KLNO combined was used for the ease of translating data from the previous model, and to enable more direct comparisons between the two. However, studies that suggest 2J3K and 3LNO are distinct enough in physical and biological ecosystem characteristics that there may be justification to model the areas separately.

For example, Pepin et al. (2014) reported on Ecosystem Production Units (EPU) for the Northwest Atlantic and found that the bioregion of the Newfoundland and Labrador Shelves (2GHJ3KLNO) has three designatable EPU's. The Labrador Shelf (2GH), the Newfoundland Shelf (2J3K) and the the Grand Bank (3LNO). These EPU's significantly differed from each other in terms of bathymetry, primary production, chlorophyll, biodiversity, and temperature, indicating that the three ecosystems appear spatially distinct in terms of structure and function. Additionally, there has been an observable shift in fish and shellfish community structure in 2J3K and 3LNO towards the late 2010's (Koen-Alonso and Cuff 2018). Not only does this difference occur across space, but over time there appears to be a shift from invertebrate dominated biomass in the mid 2000's-2010's to an increase in benthivorous and piscivorous fish towards the late 2010's (Koen-Alonso and Cuff 2018). These observed differences in community structure and ecosystem dynamics is where my research fits in.

1.2 Study Objectives

I am seeking to answer the following questions using Ecopath models:

1) How does ecosystem structure and function differ between the Newfoundland and Labrador Shelf and the Grand Banks?
2) How has the structure and function of these ecosystems changed over time?

To answer the first question, the goal of my research is to add spatial resolution to the existing 2J3KLNO Ecopath models from Tam and Bundy (2019) by splitting it into two models at a single time period (2018-2020), one for the Newfoundland and Labrador Shelf (2J3K) and one for the Grand Banks (3LNO). Differences in substrate type, climate, primary productivity, species assemblages, and catch rates indicates that the colder Northern region may differ significantly from the warmer and more species diverse Southern region (Pepin et al. 2014). The spatially refined estimates from both models will help provide a deeper understanding of ecosystem structure and function as they relate to fisheries in the Newfoundland Shelf and Grand Banks region. Synthesis of such information will be valuable in assisting Canada's transition to EBFM practices in the Northwest Atlantic and help maintain sustainable fishery practices on an ecosystem level (Link et al. 2011).

To answer the second question, a second goal of my research will be to provide inter-model comparison of the ecosystem structure though 3 main time periods, pre-groundfish collapse (1985-1987), invertebrate dominance (2013-2015), and finally the possibility of a groundfish resurgence (2018-2020). Comparisons of the system across all three time periods provides insight into ecosystem dynamics, and how biotic factors such as secondary productivity and forage fish abundance may influence them in the future.

1.3 The Grand Banks and the Newfoundland and Labrador Shelf

The Newfoundland and Labrador Shelves are underwater continental shelves that extend out from Eastern Newfoundland and Labrador for approximately 200 nm. The benthic habitat of these shelves are characterized by a stretch of bedrock along the coast close to shore, and a series of sandy/muddy banks and channels further offshore, averaging 200-500m depth before the shelf break (Shaw et al. 2023). Oceanographically, the shelves are influenced by the cold-water flow from the Labrador current, which transports freshwater glacier melt from the Arctic south along the coast. This influx of water is known to have an influence on the abundance and distribution of zooplankton in the area and is a strong driver of the annual climate in the ecosystem (Pepin et al. 2011; DFO 2021a).

South of the Newfoundland and Labrador shelves are the Grand Banks, which are a series of submerged banks in the Southeast corner of Newfoundland widely used for fishing, gas and oil exploration / extraction, and other human activities (DFO 2007). The majority of the banks have a soft sandy or muddy substrate and are between 50-100 m in depth, with steep drops into 1000 m or deeper water along the edge of the continental slopes (Shaw et al. 2023). Flow from the Labrador current reaches the north of the Grand Banks, but it is met by a warm flow of water from the Gulf stream in the south, which influences nutrient mixing, primary and secondary productivity, and climate for the region (Anderson and Gardner 1986).

Both areas have been home of some of the highest valued fisheries in Canadian history, first the cod fishery in the 1980’s-1990’s followed by the snow crab and shrimp fishery after the cod fishery collapsed (DFO 2022a). Beyond their economic value, the Newfoundland Shelf and Grand Banks are home to a diverse array of fauna that contribute to a unique and dynamic ecosystem. Part of this study's objective is to capture the state of these unique ecosystems and compare and contrast their community structure across space and time using species biomass.

Biomass in Ecopath models is represented in terms of metric tonnes per km^2 per year, so defining the exact area of the study area is important. The previous models estimated their study area to be 495,000 km^2, based on a line drawn from shore out to the 1000 m isobath to encompass the shelf ecosystem (Figure 2). Creating a horizontal dividing line across 3K and 3L, separating the study areas into the northern 2J3K and southern 3LNO results in a study area of 257,400 km^2 for 3LNO and 237,600 km^2 for 2J3K.

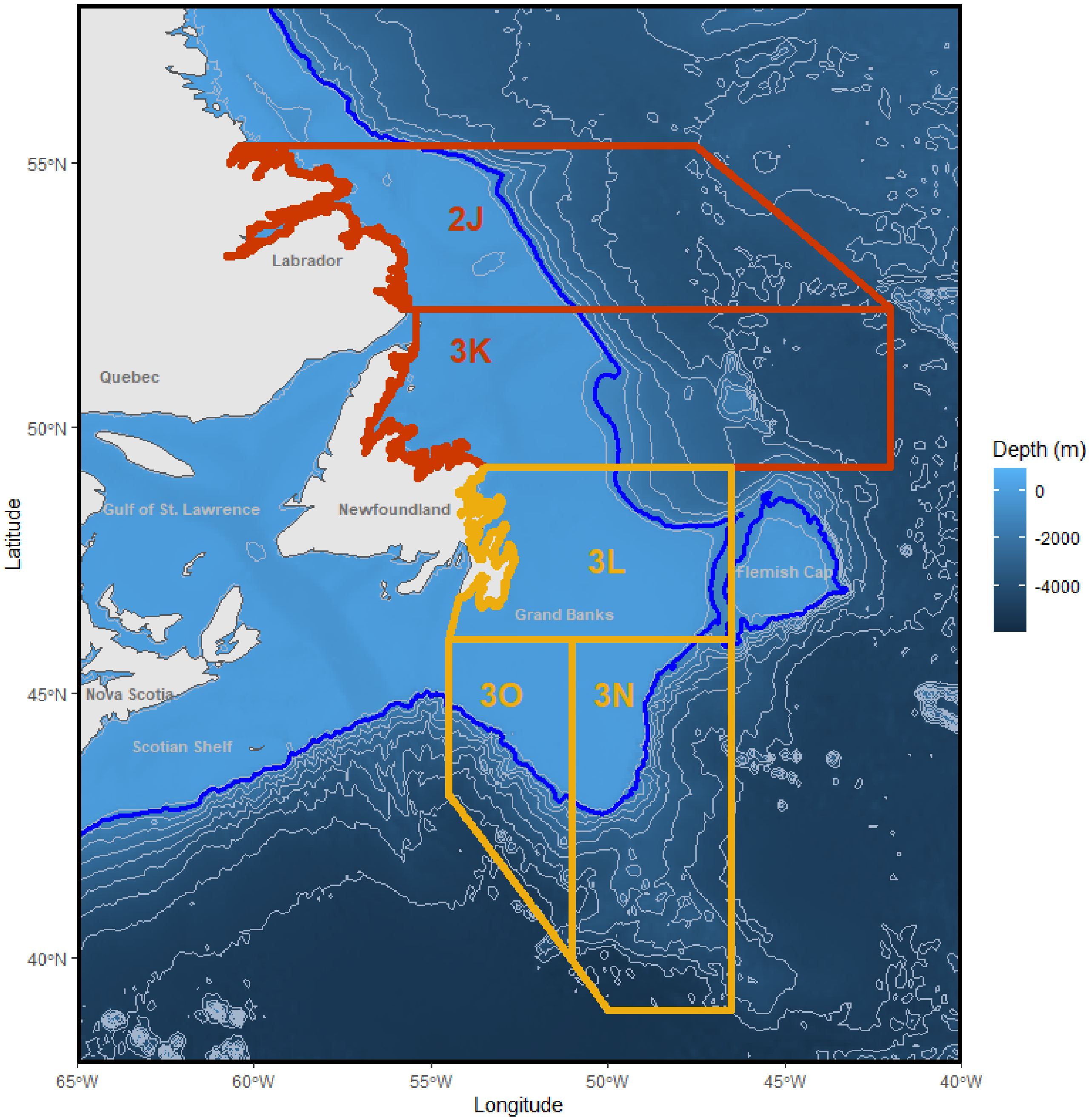

Figure 2 Map of the Grand Banks (yellow) and Newfoundland and Labrador Shelf (red) NAFO divisions 3LNO and 2J3K respectively. The area included in model extends from shore to the 1000m isobath (blue line).

1.4 Methods

1.4.1 Equations including multi-stanza routine

The core Ecopath routine is based on a series of linear equations that help solve for one unknown. Often this unknown is the Ecotrophic Efficiency or *EE*, which is the proportion of biomass of any given prey that is consumed by higher trophic levels. Sometimes, in the case of forage fish that are common prey items, *EE* can be set to near 1 and biomass can be estimated. This can be useful in the cases of small pelagic fish, who often are underrepresented in RV surveys such as Arctic cod or Atlantic herring. The first equation describes the production term for each group. Production is defined as the total amount of tissue elaborated in the population in the study area during a given time period, which in this case is annual or per one year, and is measured by accounting for the total biomass lost by death (Christensen and Pauly 1993). In Ecopath it is mathematically described as:

Production = catch + predation mortality + net migration + biomass accumulation + other mortality

Or:

$$P_i = Y_i + B_i M2_i + E_i + BA_i + M0_i$$

[Eq 1]

Where:

P_i = Production rate of species *i*

Y_i = Total fishery catch rate of species *i*

B_i = Total biomass of species *i*

$M2_i$ = Predation mortality on species *i*

E_i = Net migration (emigration - immigration) of species *i*

BA_i = Biomass accumulation rate for species *i*

$M0_i$ = All other mortality that isn't predation or catch of species *i*

It should be noted that in this case, all rates are averaged annual rates. The Ecopath master equations have terms for biomass accumulation (*BA*) and net migration (*E*), which describe the change in biomass over time (e.g., noticeable changes over the year your model captures) and the emigration rate minus the immigration rate respectively. However, these terms were not included in either model. (i.e., any accumulation of biomass was assumed to be consumed and net migration was assumed to be 0). Therefore, in order for the models to be in mass balance, the following condition must be met based on Equation 1:

$$P_i - M0_i - M2_i - Y_i = 0$$

[Eq 2]

$M0_i$ can be expressed as ($1-EE_i$), or, the proportion of biomass not consumed by higher trophic levels.

$M2_i$ is calculated by summing the annual consumption of species *i* by all *j* predator groups:

$$M2_i = \Sigma\, p_{ij}\, Q_j$$

[Eq 3]

Where:

p_{ij} = Proportion by mass of predators *j*'s diet that is comprised of prey *i*

Q_j = Annual consumption of biomass by predator *j*

Annual consumption (Q_i) can be calculated by:

Consumption = production + respiration + unassimilated food

Or:

$$Q_i = P_i + R_i + U_i$$

[Eq 4]

Where:

P_i = Production rate of species *i*

R_i = Respiration rate of species i

U_i = Proportion of food not assimilated into body tissue

Equations [1] and [4] are scaled by biomass, so they are expressed a biomass ratios (P/B and Q/B) when parameterizing the model.

Multi-stanza groups are age structured, with parameters from the leading group (the older, larger group) estimating the parameters in the secondary groups. Multi-stanza groups have two main assumptions:

1) The growth of a species follows a von Bertalanffy growth curve (Weight is proportional to length cubed).
2) The population has a relatively stable mortality and recruitment rate. (Christensen and Pauly 1992)

Multi-stanza groups are useful in situations where predation mortality and/or catch differs significantly between life stages of the same species, and therefore can be split into numerous groups. This work best with species that are well studied and have known life history parameters (Christensen and Walters 2004). In my models, Atlantic cod and American plaice are both multi-stanza groups.

Ecopath can also calculate trophic level for each functional group based on the number of predator/prey linkages in the food web.

1.4.2 Model parameterization methods

Species in Ecopath are represented as functional groups. A functional group can be comprised of a single species, a collection of species, or in the case of multi-stanza groups, a life stage. A total of 45 functional groups were defined for the 3LNO model and 42 functional groups for the 2J3K model (Table 2), as 2J3K is beyond the habitat range of some functional groups found in 3LNO such as haddock, yellowtail flounder, and silver hake/pollock. Functional groups are based on size and diet similarity across fish, mammals, seals, seabirds, invertebrates, and plankton. Where applicable, groups were kept as close as possible to the Tam and Bundy (2019) models for purposes of inter-model comparisons. The most notable changes was the removal of the microbial loop due to data limitations, and the combining the minke whale group into the fish eating whales group. For ease of comparison, in the results functional groups are aggregated into larger groups (called 'aggregated groups') based on organism type and feeding type. Aggregated groups can be viewed in Table 2.

Table 2 Functional groups and aggregated present in both models. Species unique to the model are highlighted.

	3LNO Aggregated Groups	3LNO Model Functional Groups		2J3K Aggregated Groups	2J3K Model Functional Groups
1	Whales	Whale fish eater	1	Whales	Whale fish eater
2		Whale zooplankton eater	2		Whale zooplankton eater
3		Whale squid eater	3		Whale squid eater
4		Whale mammal eater	4		Whale mammal eater
5	Seals	Seal harp	5	Seals	Seal harp
6		Seal hooded	6		Seal hooded
7		Seal other	7		Seal other
8	Seabirds	Seabird piscivore	8	Seabirds	Seabird piscivore
9		Seabird planktivore	9		Seabird planktivore
10		Seabird benthivore	10		Seabird benthivore
11	Piscivorous fish	Greenland shark	11	Piscivorous fish	Greenland shark
12		Atlantic cod > 35cm	12		Atlantic cod > 35cm
13		Atlantic cod ≤ 35cm	13		Atlantic cod ≤ 35cm
14		Greenland halibut	14		Greenland halibut
15		Silver hake / pollock	15		Other piscivorous fish
16		Other piscivorous fish	16	Plank-Piscivorous fish	Redfish
17	Plank-Piscivorous fish	Redfish	17		Arctic cod
18		Arctic cod	18		Other plank-piscivorous fish
19		Other plank-piscivorous fish	19	Large benthivorous fish	American plaice >35cm
20	Large benthivorous fish	American plaice >35cm	20		American plaice ≤ 35cm
21		American plaice ≤ 35cm	21		Thorny skate
22		Thorny skate	22		Other large benthivorous fish
23		Haddock	23	Medium benthivorous fish	Witch flounder
24		Other large benthivorous fish	24		Other medium benthivorous fish
25	Medium benthivorous fish	Yellowtail flounder	25	Small benthivorous fish	Small benthivorous fish
26		Witch flounder	26	Planktivorous fish	Herring
27		Other medium benthivorous fish	27		Sandlance
28	Small benthivorous fish	Small benthivorous fish	28		Capelin
29	Planktivorous fish	Herring	29		Other planktivorous fish
30		Sandlance	30	Exploitable invertebrates	Squid
31		Capelin	31		Shrimp

32		Other planktivorous fish	32		Snow crab
33	Exploitable invertebrates	Squid	33	Invertebrates	Predatory invertebrates
34		Shrimp	34		Deposit feeing invertebrates
35		Snow crab	35		Suspension feeding invertebrates
36	Invertebrates	Predatory invertebrates	36	Zooplankton	Macrozooplankton
37		Deposit feeing invertebrates	37		Large mesozooplankton
38		Suspension feeding invertebrates	38		Small mesozooplankton
39	Zooplankton	Macrozooplankton	39		Microzooplankton
40		Large mesozooplankton	40	Phytoplankton	Large phytoplankton
41		Small mesozooplankton	41		Small phytoplankton
42		Microzooplankton	42	Detritus	Detritus
43	Phytoplankton	Large phytoplankton			
44		Small phytoplankton			
45	Detritus	Detritus			

Biomass estimates were often obtained from either stock assessment documents published by DFO or NAFO, or were obtained from the research vessel (RV) stratified random sampling survey data. The RV stratified survey data was accessed using a local DFO R package called 'Rstrap', developed by Brian Healey, Danny Ings, and Paul Regular at DFO Canada (Regular et al. 2020) based on methodology from Smith and Somerton (1981). In cases where neither was used, such as for the whale groups, more information is provided in the functional group parameterization sections.

Production to biomass ratios and consumption to biomass ratios were obtained from the literature. In cases where information was not available, estimates were made based on values used in Tam and Bundy (2019) or Bundy (2000). P/B ratios can be estimated by assuming $P/B = Z = F + M$. Where:

Z = Total mortality
F = Fishing mortality
M = Natural mortality

Fishing mortality can be calculated as the proportion of biomass that is caught in a year, and natural mortality can be obtained from stock assessment models or, in some cases, estimated using the Hoenig (1983) equation for mortality.

For fish groups:

$$\ln(M) = 1.46 - 1.01 * \ln(Age_{\mathrm{max}})$$

[Eq 5]

For marine mammals:

$$\ln(M) = 0.941 - 0.873 * \ln(Age_{\mathrm{max}})$$

[Eq 6]

Where:

M = Natural mortality

Age_{max} = Maximum age for a given species or average maximum age for a group.

In areas where consumption rates were not available for species in the area, an assumption of a production to consumption ratio, P/Q (also known as 'Growth Efficiency') of 0.15 was used based on Christensen (1995). Diet compositions for both models were adapted from the 2013-2015 model in Tam and Bundy (2019), and modified to account for prey availability in each area. Changes were supported from data in RV diet surveys and relevant literature. Catch data for commercial finfish and shellfish fisheries were obtained from the NAFO STATLANT 21A database. Any catch of species not in the NAFO STATLANT 21A database is detailed in the 'catch' section of that species parameterization section. Bycatch statistics, if available, were also added if bycatch was greater than 0.001 t/km² for the functional group.

Because the NAFO STATLANT 21A database has historical catch records by area dating back to the 1980s, catch comparisons were made across the three time periods (1985-1987, 2013-2015, and 2018-2020) AND both geographic areas (2J3K and 3LNO). Because biomass data was not easily available in the same way, biomass comparisons were made in two different ways. 1) Comparing 2J3K and 3LNO to each other at the 2018-2020 time period 2) Comparing 2J3KLNO combined at all three time periods (1985-1987, 2013-2015, and 2018-2020). This was achieved by combining each groups biomass estimate in tonnes, then dividing by total 2K3LNO area to get an estimate in t/km².

1.4.3 Balancing methods

While balancing the model, the pedigree function in Ecopath was used. The pedigree chart allows data sources to be tracked for each parameter and associated certainty levels that range from high-precision local sampling (low uncertainty), to 'guestimates' (high uncertainty). These uncertainties become important when using the Ecosim function in Ecopath, as it is used to build probability distributions for parameter selection in dynamic modeling. In the context of my models, they demonstrate the areas of the ecosystem that are well studied and documented versus groups and areas where data is poor. For example, you can reference the pedigree chart to see which parameters have high uncertainty, and therefore may have better justification to alter to achieve mass-balance. Sometimes the *P/B* ratio was increased for certain groups to decrease the EE, following the guidelines that the production to consumption ratio should be between 0.1 and 0.3 (Heymans et. al 2016).

2. Model Parameterization

2.1 Cetacean groups

Cetaceans are a group of marine mammals that include whales, porpoises, and dolphins. There are 89 species of cetaceans worldwide, with over 13 of them distributed in 2J3K and/or 3LNO (Fordyce and Perrin 2023; Lawson and Gosselin 2009). Cetaceans are often high in marine ecosystem food webs with diets that range from plankton, fish, and even other mammals. Whales play a key role in nutrient cycling across marine ecosystems through ingestion and excretion, particularly of iron (Doughty et al. 2015; Ratnarajah et al. 2014). When large cetaceans die and their bodies sink to the sea floor (known as 'whale fall'), they provide an invaluable source of organic matter and nutrients to the benthic community (Li et al. 2022).

The cetaceans in the study area were divided into four functional groups based on primary prey type: fish eaters, zooplankton eaters, squid eaters, or mammal eaters. All baleen whales in the model such as humpback whales, minke whales, fin whales, blue whales, and sei whales are transient and will seasonally migrate into the study area to feed and leave the study area to breed at lower latitudes (Lien 1985). Other cetaceans such as the Northern bottlenose whale or Long-finned pilot whale do not exhibit this north-south migration and tend to stay within their home range for their entire lives (Reeves et al. 1993; Nelson and Lien 1996). Where applicable, biomass estimates for each cetacean group were scaled with a residency time based on the number of days a year each species is present in the study area.

Commercial whaling was banned in Canada in 1972, so no commercial catch of cetaceans occurs within the study area. Some species such as narwal and beluga are still hunted by indigenous groups for food, social, and ceremonial purposes, but no harvesting occurs in the study area.

2.1.1 Whale fish eater

Whale fish eaters are defined as cetaceans whose diet is primarily composed of fish and may be supplemented with small invertebrates. The cetaceans included in this group are listed in Table 3.

Table 3 List of piscivorous cetacean species included in both models.

Common name	Species
Common dolphin	*Delphinus delphis*
Fin whale	*Balaenoptera physalus*
Harbour porpoise	*Phocoena phocoena*
Humpback whale	*Megaptera noveangliae*
Minke whale	*Balenoptera acutorostrata*
White-beaked dolphin	*Lagenorhynchus albitrosis*
White-sided dolphin	*Lagenorhynchus acutus*

Biomass

Of the species within the whale fish eater group, fin whales, minke whales, and humpback whales are known to have seasonal north-south migrations where they enter the study area every year to feed (Risch et al. 2014; Johnson and Davoren 2021). Common dolphins, harbour porpoise, white beaked dolphin and white sided dolphins are less known to migrate longitudinally but do move on and off the Shelf seasonally (Sergeant and Fisher 1957). Tam and Bundy (2019) used a residency time to scale biomass estimates for piscivorous whales, by multiplying the estimated abundance by mean body weight, then multiplying the percentage of days out of 365 they are present in the study area. Residency times for migratory species was set at 180 days to incorporate the spring and summer seasons when the sightings occur most frequently (DFO 2022b). Residency time for non-migratory species was set at 270 days (DFO 2022b). The biomass of each species was averaged to create a mean biomass per km^2 for each study area (Table 4 and 5).

Population estimates for each species were obtained from Tam and Bundy (2019), based on estimates from the NAISS marine mammal census survey, as well as the National Oceanic and

Atmospheric Administration (NOAA) stock assessment report for minke whales (NOAA 2022a). Mean body weights for each species were adapted from Bundy et al. (2000) using averaged estimates across several literature sources.

Table 4 Whale fish eater biomass calculations for the 2J3K 2018-2020 model. *Note: Final biomass was decreased by 0.09 in balancing phase.

Species	Number of individuals	Mean body weight (t)	Biomass (t/km^2)	~Days spent in 2J3K	Biomass adjustment for time spent in 2J3K (t/km^2)
Common dolphin	349721	0.125	0.1840	270	0.0907
Fin whale	1567	38.5	0.2539	180	0.1252
Harbour porpoise	35081	0.05	0.0074	180	0.0036
Humpback whale	6076	31	0.7927	180	0.3909
Minke whale	7154	5.6	0.3066	180	0.1512
White beaked dolphin	381987	0.04	0.0643	270	0.0317
White sided dolphin	2430	0.2	0.0020	270	0.0010
Estimated Average Biomass					**0.79**

Table 5 Whale fish eater biomass calculations for the 3LNO 2018-2020 model.

Species	Number of individuals	Mean body weight (t)	Biomass (t/km^2)	~Days spent in 3LNO	Biomass adjustment for time spent in 3LNO (t/km^2)
Common dolphin	349721	0.125	0.1698	270	0.0838
Fin whale	1567	38.5	0.2344	180	0.1156
Harbour porpoise	35081	0.05	0.0068	180	0.0034
Humpback whale	6076	31	0.7318	180	0.3609
Minke whale	7154	5.6	0.2830	180	0.1396
White beaked dolphin	381987	0.04	0.0594	270	0.0293
White sided dolphin	2430	0.2	0.0019	270	0.0009
Estimated Average Biomass					**0.73**

Production: Biomass

P/B ratios for whale fish eaters were calculated using Hoenig's (1983) equation for estimating mortality in marine mammals (Eq. 6)

Because there is no fishing mortality, the *P/B* ratio for the group is the average natural mortality (Table 6) and is the same for both study areas. Maximum age estimates are obtained from Trites and Pauly (1998), except for the common dolphin and white sided dolphin, which were obtained from NOAA (2022b), and white beaked dolphin, which was obtained from Galatius and Kinze (2016).

Table 6 Production to biomass ratios for whale fish eater for both 2J3K and 3LNO 2018-2020 models.

	Max age	*Z*
Common dolphin	35	0.115
Fin whale	98	0.047
Harbour porpoise	13	0.273
Humpback whale	75	0.059
Minke whale	47	0.088
White beaked dolphin	36	0.112
White sided dolphin	27	0.144
P/B for group (average)		**0.120**

Consumption: Biomass

An average *Q/B* ratio was calculated for the whale fish eater group for each study area, with the associated residency times in mind. Humpback whales were estimated to consume 3% of their body mass per day (Lockyer 1981). Other species daily consumption rates were obtained from Tam and Bundy (2019) with minke whale added to the group. The calculated average *Q/B* estimate used for the 3LNO and 2J3K model was **6.0 $\mathbf{yr^{-1}}$,** assuming the percent body weight consumed remained constant for humpback whales.

Diet

Diet proportions for the whale fish eaters were adapted from estimates in Tam and Bundy (2019). The composite diet was calculated by scaling each diet component proportional to the biomass of each of the predators in the group. For example, humpback whales had the highest biomass contribution to the group average (~0.4 t/km^2 out of 0.8 t/km^2 total) meaning each prey item composing their diet matrix was scaled by ~0.5, and each scaled prey item was averaged for a final proportion of the composite diet (Table 7 and 8).

Table 7 Composite diet of fish eating whales for the 2J3K 2018-2020 model.

	Common dolphin	Fin Whale	Harbour porpoise	Humpback whale	Minke whale	White beaked dolphin	White sided dolphin	Composite diet (average)
Cod ≤ 35 cm	0	0	0.1	0	0	0	0	**0**
Arctic cod	0.1	0	0.1	0	0	0.1	0.1	**0.0134**
Large Benthivorous fish	0.1	0	0	0	0	0.09	0.1	**0.0127**
Med Benthivorous fish	0.15	0	0	0	0	0.2	0.2	**0.0212**
Small Benthivorous fish	0.2	0	0	0	0	0.2	0.2	**0.0260**
Capelin	0	0.5	0.5	0.5	0.5	0	0	**0.4350**
Sandlance	0.05	0.25	0.2	0.25	0	0.11	0	**0.1451**
Other Plank Fish	0.1	0.083	0.2	0.167	0.25	0.05	0.05	**0.1724**
Squid	0.3	0.083	0.0	0.0	0.1	0.2	0.25	**0.0788**
Macrozooplankton	0	0.083	0.0	0.083	0.1	0	0	**0.0774**
L. mesozooplankton	0	0	0	0	0.05	0	0	**0.0161**
Suspension feeding inverts	0	0	0	0	0	0.05	0.1	**0.0018**

Table 8 Composite diet of fish eating whales for the 3LNO 2018-2020 model.

	Common dolphin	Fin Whale	Harbour porpoise	Humpback whale	Minke whale	White beaked dolphin	White sided dolphin	Composite diet (average)
Cod ≤ 35 cm	0	0	0.1	0	0	0	0	**0.0001**
Arctic cod	0.1	0	0.1	0	0	0.1	0.1	**0.0160**
Large benth fish	0.1	0	0	0	0	0.09	0.1	**0.0151**
Med benth fish	0	0	0	0	0	0.05	0.05	**0.0021**
Small benth fish	0.2	0	0	0	0	0.2	0.2	**0.0311**
Capelin	0.074	0.3	0.25	0.25	0.25	0.05	0.05	**0.2295**
Sandlance	0	0	0.15	0.25	0	0	0	**0.1237**
Other Plank Fish	0.126	0.3	0.2	0.25	0.2	0.11	0.1	**0.2282**
Squid	0.1	0.234	0.2	0.167	0.3	0.15	0.05	**0.1945**
Macrozooplankton	0.3	0.083	0	0	0.1	0.2	0.25	**0.0747**
L. mesozooplankton	0	0.083	0	0.083	0.1	0	0	**0.0730**
Suspension feeding inverts	0	0	0	0	0.05	0	0	**0.0095**

2.1.2 Whale zooplankton eater

Whale zooplankton eaters are defined as baleen whales whose primary prey are zooplankton and other planktonic species. The sei whale (*Balaenoptera borealis*) and the blue whale (*Balaenoptera musculus*) are the representative species for this functional group.

The 2J3K region is relatively poor habitat for blue whales and sightings of blue whales or detections of blue whale calls in the area are rare (Moors-Murphy et al. 2019). There are consistent sightings of blue whales off the southwest coast of Newfoundland in the spring, adjacent to 3LNO. It is estimated that the Northwest Atlantic population of blue whales is under 250 individuals, based on an assessment by the Committee on the Status of Endangered Wildlife in Canada (‘COSEWIC’; COSEWIC 2012).

Although rare, sei whales have been detected in 2J3K and 3LNO. According to sightings and acoustic recordings data, the Atlantic sei whale population is roughly estimated to be a few hundred individuals (COSEWIC 2019).

Biomass

Biomass estimates for planktivorous whales were calculated by multiplying the estimated abundance by mean body weight, then adjusted by multiplying the percentage of days out of 365 they are present in the study area. The biomass of each species was averaged to create a mean biomass per km^2 for each study area (Table 9 and 10).

Residency times for sei whales were set at 180 days for both models. Blue whale residency times were set lower for both models, 125 days for 3LNO and 90 days for 2J3K based on seasonal observation data (Moors-Murphy et al. 2019). Population estimates for sei and blue whales were based on COSWEIC assessments for both whales (COSEWIC 2019, COSEWIC 2012).

Table 9 Whale zooplankton eater biomass calculations for the 2J3K 2018-2020 model.

Species	Number of individuals	Mean body weight (t)	Biomass (t/km^2)	~Days spent in 2J3K	Biomass adjustment for time spent in 2J3K (t/km^2)
Blue whale	250	76.7	0.0807	90	0.0199
Sei whale	500	14.3	0.0301	180	0.0148
Total Average Biomass					**0.0136**

Table 10 Whale zooplankton eater biomass calculations for the 3LNO 2018-2020 model.

Species	Number of individuals	Mean body weight (t)	Biomass (t/km^2)	~Days spent in 3LNO	Biomass adjustment for time spent in 3LNO (t/km^2)
Blue whale	250	76.7	0.0745	125	0.0255
Sei whale	500	14.3	0.0278	180	0.0137
Total Average Biomass					**0.0164**

Production: Biomass

P/B ratios for whale zooplankton eaters were calculated using Hoenig's (1983) equation for estimating mortality in marine mammals (Eq. 6). Because there is no fishing mortality for whales, the *P/B* ratio for the group is the average natural mortality (Table 11) and is the same for both study areas. Maximum age estimates are obtained from Trites and Pauly (1998).

Table 11 Production to biomass ratios for whale zooplankton eater for both 2J3K and 3LNO 2018-2020 models.

	Age	Z
Blue whale	100	0.045
Sei whale	69	0.064
P/B for group (average)		**0.055 yr^{-1}**

Consumption: Biomass

Daily consumption estimates for blue and sei whales in both models were obtained from Lien (1985). The calculated average *Q/B* estimate used for the 3LNO and 2J3K model was **3.47 $\mathbf{yr^{-1}}$.**

Diet

Diet proportions for the whale zooplankton eaters were adapted from estimates in Tam and Bundy (2019). The composite diet used to represent the group was calculated by scaling each diet component by the predator groups proportional biomass for the group, then averaging each item across predator groups (Table 12 and 13).

Table 12 Composite diet of zooplankton eating whales for the 2J3K 2018-2020 model. Adapted from Tam and Bundy (2019).

Prey / Predator	Blue whale	Sei whale	Composite diet (average)
Capelin	0	0.083	**0.035**
Sandlance	0	0.083	**0.035**
Macrozooplankton	1.000	0.083	**0.609**
Large Mesozooplankton	0	0.750	**0.320**
Biomass of predator group	0.0199	0.0148	

Table 13 Composite diet of zooplankton eating whales for the 3LNO 2018-2020 model. Adapted from Tam and Bundy (2019).

Prey / Predator	Blue whale	Sei whale	Composite diet (average)
Capelin	0	0.083	**0.029**
Sandlance	0	0.083	**0.029**
Macrozooplankton	1.000	0.083	**0.680**
Large mesozooplankton	0	0.750	**0.262**
Biomass of predator group	0.0255	0.0137	

2.1.3 Whale squid eater

Whale squid eaters are defined as toothed whales whose primary prey are squid and other cephalopod species. The northern bottlenose whale (*Hyperdon ampullatus*), the long-finned pilot whale (*Globicephala melas*), and the sperm whale (*Physeter macrocephalus*) are the representative species for this functional group.

There are two northern bottlenose whale populations in the Northwest Atlantic. A Scotian Shelf population, which extends into NAFO divisions 3NO, and a Baffin Bay–Davis Straight–Labrador Sea population, which extends into NAFO divisions 2J3K and 3L. The two populations are considered genetically distinct from one another, but the boundary lines between the two populations are still unclear (COSEWIC 2011). Data is sparse on sperm whale (*Physeter macrocephalus*) populations around Newfoundland and Labrador, but they have been observed in both 2J3K and 3LNO (DFO 2022b).

Biomass

Biomass estimates for squid eating whales were calculated by multiplying the estimated abundance by mean body weight, then adjusted by multiplying the percentage of days out of 365 they are present in the study area. The biomass of each species was averaged to create a mean biomass per km^2 for each study area (Table 14 and 15). A residency time of 180 days was assumed for all species in both study areas. Population estimates for pilot whales and sperm whales were reused from Bundy et al (2000) due to lack of updated population information on these species in Newfoundland and Labrador waters.

Population estimates for northern bottlenose whales was obtained from the COSEWIC assessment report for the two subpopulations (COSEWIC 2011). The Scotian Shelf population of northern bottlenose whales (which includes part of 3LNO) was estimated to have 164 individuals, whereas the Baffin Bay-Davis Strait-Labrador Sea population, which spans 2J3K, does not currently have an estimated population size. For the purposes of my models, it was assumed the Baffin Bay-Davis Strait-Labrador Sea population has a similar number of individuals as the Scotian Shelf population, and was assigned 150 individuals.

Individual body masses of sperm and pilot whales were obtained from Bundy et al. (2000) who averaged estimates across several literature sources. Female sperm whales tend to not migrate as far north as males (Reeves and Whitehead 1997), so the body weight used for sperm whales only includes male whales. Individual body mass for northern bottlenose whale was obtained from Kenney et al. (1997).

Table 14 Whale squid eater biomass calculations for the 2J3K 2018-2020 model.

Species	Number of individuals	Mean body weight (t)	Biomass (t/km^2)	~Days spent in 2J3K	Biomass adjustment for time spent in 2J3K (t/km^2)
Northern Bottlenose Whale	150	4.7	0.0030	180	0.0015
Pilot Whale	9000	1.4	0.0530	180	0.0262
Sperm Whale	1000	45	0.1894	180	0.0934
Total Average Biomass					**0.1210**

Table 15 Whale squid eater biomass calculations for the 3LNO 2018-2020 model.

Species	Number of individuals	Mean body weight (t)	Biomass (t/km^2)	~Days spent in 3LNO	Biomass adjustment for time spent in 3LNO (t/km^2)
Northern Bottlenose Whale	164	4.7	0.0030	180	0.0015
Pilot Whale	9000	1.4	0.0490	180	0.0241
Sperm Whale	1000	45	0.1748	180	0.0862
Total Average Biomass					**0.1118**

Production: Biomass

P/B ratios for whale squid eaters were calculated using Hoenig's (1983) equation for estimating mortality in marine mammals (Eq. 6).

Because there is no fishing mortality for whales, the *P/B* ratio for the group is the average natural mortality (Table 16) and is the same for both study areas. Maximum age estimates are obtained from Trites and Pauly (1998) for sperm and pilot whales, and from COSEWIC (2011) for northern bottlenose whales. Pilot whales had maximum age estimates for male and female whales, so an average was taken.

Table 16 Production to biomass ratios for whale squid eater for both 2J3K and 3LNO 2018-2020 models.

	Age	Z
Northern Bottlenose Whale	37	0.110
Pilot Whale	41.5	0.099
Sperm Whale	69	0.064
P/B for group (average)		**0.091 yr^{-1}**

Consumption: Biomass

Daily consumption estimates were obtained from Spitz et al. (2018), for sperm and pilot whales and from Hooker et al. (2002) for northern bottlenose whales. The calculated average *Q/B* estimate used for the 3LNO and 2J3K model was **6.0 yr^{-1}.**

Diet

Diet proportions for the whale squid eaters were adapted from estimates in Tam and Bundy (2019). The composite diet used to represent the group was calculated by scaling each diet component by the predator groups proportional biomass for the group, then averaging each item across predator groups (Table 17 and 18). Diet proportions for northern bottlenose whale were adapted from Hooker et al. (2001), and Lick and Piatkowski (1998).

Table 17 Composite diet of squid eating whales for the 2J3K 2018-2020 model. Adapted from Tam and Bundy (2019).

	Northern bottlenose whale	Pilot whale	Sperm whale	Composite diet (average)
American plaice > 35 cm	0	0.002	0.008	**0.007**
American plaice ≤ 35 cm	0	0.002	0.008	**0.007**
Thorny skate	0	0.013	0.041	**0.034**
Other large benthivorous fish	0.04	0.055	0.05	**0.051**
Other medium benthivorous fish	0.03	0.055	0.05	**0.051**
Capelin	0.03	0.013	0.043	**0.036**
Other planktivorous fish	0.05	0.01	0.05	**0.041**
Squid	0.85	0.85	0.75	**0.773**
Biomass of predator group	0.0015	0.0262	0.0934	

Table 18 Composite diet of squid eating whales for the 3LNO 2018-2020 model. Adapted from Tam and Bundy (2019).

	Northern bottlenose whale	Pilot whale	Sperm whale	Composite diet (average)
American plaice > 35 cm	0	0.002	0.005	**0.004**
American plaice ≤ 35 cm	0	0.002	0.005	**0.004**
Thorny skate	0	0.01	0.039	**0.032**
Other large benthivorous fish	0.04	0.012	0.04	**0.034**
Yellowtail flounder	0	0.05	0.07	**0.065**
Other medium benthivorous fish	0.03	0.052	0.02	**0.027**
Capelin	0.03	0.012	0.021	**0.019**
Other plank fish	0.05	0.01	0.05	**0.041**
Squid	0.85	0.85	0.75	**0.773**
Biomass of predator group	0.0015	0.0241	0.0862	

2.1.4 Whale mammal eater

Whale mammal eaters are defined as whales whose primary prey are other mammals such as seals or other cetaceans. Killer whales (*Orcinus orca*) are the only species for this functional group. Killer whales have been sighted from southern Newfoundland to the North Labrador Sea, although relatively little is known about the exact population size.

Biomass

Biomass estimates for mammal-eating whales were calculated by multiplying the estimated abundance by mean body weight, then adjusted by multiplying the percentage of days out of 365 they are present in the study area (Table 19). Residency time for killer whales was estimated to be 180 days.

Sightings of killer whales are infrequent off the coast of Newfoundland and Labrador. Lawson et al. (2007) estimated a population of approximately 63 individuals, but an estimate from Lawson and Stevens (2014) states a minimum abundance of 67 confirmed individuals. The mean body weight of killer whales was averaged between male and female estimates from Trites and Pauly (1998).

Table 19 Whale mammal eater biomass calculations for both the 2J3K and 3LNO 2018-2020 models.

Model	Number of individuals	Mean body weight (t)	Biomass (t/km^2)	~Days spent in area	Biomass adjustment for time spent in area (t/km^2)	Total
2J3K	67	2.28	0.0006	180	0.000306	**3.06×10^{-4}**
3LNO	67	2.28	0.00057	180	0.000282	**2.82×10^{-4}**

Production: Biomass

The *P/B* ratio for killer whales was calculated using Hoenig's (1983) equation (Eq. 6) for estimating marine mammal mortality, based off a maximum age of 50 years (Trites and Pauly 1998). The *P/B* ratio for killer whales was calculated to be **0.084 $\mathbf{yr^{-1}}$**.

Consumption: Biomass

Based on a daily consumption of 0.068 t (Trites and Pauly 1998), the *Q/B* of killer whales in 2J3K and 3LNO was **8.1 $\mathbf{yr^{-1}}$** for both models.

Diet

Diet composition was adapted from the 2013-2015 model (Tam and Bundy 2019).

Table 20 Diet composition for Whale mammal eaters for 2J3K and 3LNO.

Killer whale	2J3K	3LNO
Whale fish eater	0.1	0.1
Whale zooplankton eater	0.15	0.15
Harp seals	0.4	0.4
Hooded seals	0.1	0.1
Seabird piscivore	0.05	0.05
Greenland Halibut	0.05	0.05
Other piscivorous fish	0.05	0.05
Capelin	0.05	0.05
Squid	0.05	0.05

2.2 Seal groups

Seals are an abundant predator in the Canadian Arctic and Atlantic. There are six species of seal found off the coast of the Arctic and Atlantic, although just four of them occur with regularity in both study areas (harp seals, hooded seals, harbour seals, and grey seals). All but harbour seals are harvested either commercially by licensed sealers or for subsistence by coastal community residents that live north of 53°N latitude (DFO 2011).

2.2.1 Seal Harp

Harp seals (*Pagophilus groenlandicus)* are the most abundant seal in Atlantic Canada. The Northwest Atlantic population is comprised of two herds, one of which seasonally migrates to whelp on the pack ice that forms in southern Labrador, known as the “Front”.

Biomass

There has not been an update in harp seal biomass estimations since the 2013-2015 model (Tam and Bundy 2019), which assumed mean weight of an individual harp seal is 80 kg or 0.08 t, which resulted in a biomass estimate of 0.326 t/km^2 for 2J3KLNO. Based on the DFO (2020) stock status report, it is estimated that the harp seal population has increased since 2013-2015 by approximately 25%.

A big challenge of these models was determining the splitting and scaling of biomass between 2J3K and 3LNO. Neither Bundy et al (2000) or Tam and Bundy (2019) used a residency time for the harp seal biomass, but did note that the herds will migrate from north to south every year to whelp, mate, and moult on the pack ice that forms around Newfoundland and Labrador. According to a satellite tagging study by Stenson and Sjare (1997), harp seals tend to migrate between the northern Labrador Shelf / Davis Straight and the southern Labrador Shelf / Grand Banks, spending about half of the year in each area. It was noted the timing and uniformity of these migrations varied among individuals every year, but generally seals will spend approximately 212 days south of the 2J boundary (Stenson et al. 1997).

There are three age groups of harp seals that undergo various stages of feeding, fasting, and rapid energy use while in the study area: mature female seals, mature male seals, and immature seals. Mature seals haul onto pack ice close to shore to whelp (Give birth, lactate /feed young, then mate again) while immature seals will generally remain in the water, both inshore and offshore (Sergeant 1991).

Chabot and Stenson (2002) examined the growth patterns of male harp seals to infer changes in feeding behaviours leading up to and following the mating period. They found that male harp seals will feed during their migration to and from the mating sites but will cease feeding about a month prior to mating when they rely on fat stores gained while feeding further north. Male harp seals will also fast after mating in the time leading up to moult, where they will shed their skin and hair before returning to the Arctic to feed, and can lose up to 15% of their body mass (Hammill et al. 2010).

Based on the variable energy requirements and residency times of the seals in the area and considering the balancing requirements for the models, the biomass estimate of 0.326 t/km^2 used by Tam and Bundy was increased to **0.38 t/km^2** for both areas.

Production: Biomass

The *P/B* ratio for harp seals was calculated using Hoenig's (1983) equation (Eq. 6) for estimating marine mammal mortality, based off a max age of 26 years (Trites and Pauly 1998). The *P/B* ratio for harp seals was calculated to be **0.149 yr^{-1}** for both 2J3K and 3LNO.

Consumption: Biomass

The mean annual consumption for harp seals is from the Tam and Bundy (2019) estimate, which used information from consumption models produced by Buren and Stenson. The *Q/B* ratio for harp seal was estimated to be **17.642 yr^{-1}** for both 2J3K and 3LNO for 2018-2020.

Diet

Diet information was adapted from the 2013-2015 model in Tam and Bundy (2019) (Table 21). Slight modifications were made to the 2J3K diet to account for species that aren't commonly found that far north. Atlantic cod was given more emphasis to account for no silver hake/pollock in 2J3K, as it is also a large piscivorous fish and is a primary diet component of harp seals in the area (Foley 2018). Squid was also added to the diet based on findings from Foley (2018).

Table 21 Diet composition for Harp seals for 2J3K and 3LNO, adapted from Tam and Bundy (2019).

Harp seals	2J3K	3LNO
Cod > 35 cm	0.12	0.033
Cod < 35 cm	0	0.001
Greenland halibut	0.01	0.01
Silver hake/ Pollock	0.0	0.007
Redfish	0.015	0.015
Arctic cod	0.143	0.075
American plaice > 35 cm	0.032	0.032
American plaice ≤ 35 cm	0.048	0.048
Thorny skate	0	0.003
Other medium benthivorous fish	0.005	0.005
Small benthivorous fish	0.02	0.01
Herring	0.2	0.2
Sandlance	0.1	0.201
Capelin	0.148	0.174
Other planktivorous fish	0	0.057
Squid	0	0.004
Shrimp	0.006	0.001
Predatory invertebrates	0.001	0.001
Deposit feeding invertebrates	0.037	0.037
Macrozooplankton	0.055	0.036

Catch

Catch of harp seals in Canadian waters averaged to 46,500 individuals per year for the 2018-2020 time period (DFO 2019). Unfortunately, the DFO status report does not indicate the distribution of these catches across sealing areas.

If we assume an average weight of 0.08 t per seal and an approximate 50/50 split of catch between 2J3K and 3LNO, that results in a catch of **0.008 t/yr/km^2** for 2J3K and **0.007 t/yr/km^2** for 3LNO.

2.2.2 Seal Hooded

Hooded seals (*Cystophora cristata*) are larger than harp seals but occur less frequently in the study area. Similar to the harp seals, hooded seals also whelp on pack ice that forms in southern Labrador in the early fall, before returning to the drifting pack ice farther north in April.

Biomass

There has not been an update in hooded seal biomass estimations since the 2013-2015 model (Tam and Bundy 2019), which had a biomass estimate of 0.038 t/km^2 for 2J3KLNO. Similar to harp seals, hooded seals will migrate into the study area to breed for about half of the year and spend the other half in southeastern Greenland to moult (Anderson et al. 2013).

To accurately assign biomass estimates for 2J3K and 3LNO, the seasonal and regional distribution of hooded seals was examined. Stenson and Kavanagh (1994) performed annual at sea surveys throughout the Grand Banks and the Newfoundland and Labrador Shelf reported that Hooded seals were rarely observed south of the 3K/3L boundary from 1993-1995. Similarly, Anderson et al. (2013) found that adult hooded seals tend to remain in southern Labrador, but juvenile seals ventured into 3LNO more frequently. Based on these tagging studies, a residency time of 180 for both areas is used, with 80% of biomass in 2J3K and 20% in 3LNO (Table 22).

Table 22 Biomass estimates for hooded seals for the 2018-2020 time period in 2J3K and 3LNO.

Model	Biomass (t)	Biomass (t/km^2)	~Days spent in area	Biomass adjustment for time spent in area (t/km^2)
2J3K	15,176.72	0.064	180	**0.0315**
3LNO	3794.18	0.015	180	**0.0073**

Production: Biomass

The *P/B* ratio for hooded seals was calculated using Hoenig's (1983) equation (Eq. 6) for estimating marine mammal mortality, based off a max age of 35 years (Kovacs 2002). The *P/B* ratio for hooded seals was calculated to be **0.115 yr^{-1}** for both 2J3K and 3LNO.

Consumption: Biomass

The mean annual consumption for hooded seals is the Tam and Bundy (2019) estimate, which used information from consumption model produced by Buren and Stenson. The *Q/B* ratio for hooded seal was estimated to be **18.33 yr^{-1}** for both 2J3K and 3LNO for 2018-2020.

Diet

Diet information for hooded seals was adapted from the 2013-2015 model in Tam and Bundy (2019). The 2J3K diet was modified slightly to remove yellowtail flounder from the diet, as 2J3K is outside of yellowtail flounder's range. More emphasis was given to witch flounder and the '*other medium benthivorous fish'* functional group as they are of a similar size and trophic level to yellowtail flounder, and common in the hooded seal diet (Foley 2018). Similarly, the diet was slightly modified in 3LNO to reduce Greenland halibut consumption, more emphasis put on other pleuronectiform fish and sandlance (Table 23).

Table 23 Diet composition for Hooded seals for 2J3K and 3LNO.

Hooded seals	2J3K	3LNO
Cod > 35 cm	0.08	0.09
Greenland halibut	0.316	0.162
Other piscivorous fish	0.016	0.08
Redfish	0.043	0.043
American plaice > 35 cm	0.01	0.05
American plaice ≤ 35 cm	0.021	0.021
Yellowtail flounder	0	0.3
Witch flounder	0.15	0.02
Other medium benthivorous fish	0.147	0.012
Small benthivorous fish	0.047	0.047
Sandlance	0.035	0.04

Capelin	0.009	0.009
Squid	0.126	0.126

Catch

Hooded seal catch in the Northwest Atlantic has been recorded since the 1940s, however catch has declined since the early 2000's (DFO 2006b). There was no recorded commercial catch of hooded seals for the 2018-2020 time period in either study area.

2.2.3 Seal other

The 'Seal other' functional group includes Harbour seals (*Phoca vitulina*) and Grey seals (*Halichoerus grypus*). Grey seal populations are centralized around the coasts of Nova Scotia / Sable Island and the Gulf of St. Lawrence where they pup, but they are still known to occur in Southern Newfoundland. Harbour seals are more widely distributed along the Atlantic coast, occurring along most shorelines in the northern hemisphere reaching from Florida to Baffin Island and northwestern Greenland.

Biomass

There has not been an update in other seal biomass estimates since the 2013-2015 model (Tam and Bundy 2019), which had a biomass estimate of 0.015t/km^2 for 2J3KLNO. Unlike harp or hooded seals, harbour seals tend not to migrate from their place of birth and can be found in both study areas year round (Lien 1985). Grey seals are also not considered to be migratory, but tend to travel longer distances than harbour seals post-breeding (Lien 1985). The biomass estimate of 7425 t from Tam and Bundy (2019) was split 50/50 between 2J3K and 3LNO for these models.

Table 24 Biomass estimates for other seals for the 2018-2020 time period in 2J3K and 3LNO.

Model	Biomass (t)	Biomass (t/km^2)
2J3K	3712.5	**0.016**
3LNO	3712.5	**0.014**

Production: Biomass

The *P/B* ratio for other seals was calculated using Hoenig's (1983) equation (Eq. 6) for estimating marine mammal mortality, based off an average max age of 29.5 years (Trites and Pauly 1998). The *P/B* ratio for other seals was calculated to be **0.134 yr^{-1}** for both 2J3K and 3LNO.

Consumption: Biomass

The mean annual consumption for other seals is based on the Tam and Bundy (2019) estimate, which used information from consumption model produced by Buren and Stenson. The *Q/B* ratio for other seals was estimated to be **13.00 yr^{-1}** for both 2J3K and 3LNO for 2018-2020.

Diet

Diet matrices were based on the 2013-2015 model diet (Tam and Bundy 2019). The 2J3K diet was modified slightly to remove yellowtail flounder, silver hake/pollock, and haddock from the diet, as 2J3K is beyond the usually range for these species. More emphasis given to *other medium benthivorous fish* and *other piscivorous fish* functional groups as they are of a similar size and trophic level to the other fish, and common in seal diets (Foley 2018).

Table 25 Diet composition for other seals for 2J3K and 3LNO

Seals other	2J3K	3LNO
Cod > 35 cm	0.063	0.051
Cod ≤ 35 cm	0.007	0.01
Greenland halibut	0.06	0.06
Silver hake/ pollock	0	0.022
Other piscivorous fish	0.03	0.04
Redfish	0.081	0.081
Arctic cod	0.021	0.021
American plaice > 35 cm	0.02	0.01
American plaice ≤ 35 cm	0.025	0.02
Thorny skate	0.027	0.027
Haddock	0	0.02
Yellowtail flounder	0	0.05
Witch flounder	0.008	0.02
Other large benthivorous fish	0.05	0
Other medium benthivorous fish	0.1	0.06
Small benthivorous fish	0.045	0.045
Herring	0.145	0.145
Sandlance	0.09	0.09
Capelin	0.199	0.199
Other planktivorous fish	0.02	0.02
Squid	0.007	0.007
Macrozooplankton	0.002	0.002

Catch

There was no commercial catch of seals in the ‘other’ category for the 2018-2020 time period in either study area.

2.3 Seabird groups

The abundance of seabirds within the study area varies widely throughout the year. As seasonal migrations take place, large numbers of birds move in and out of the study area to breed or feed along coastal and offshore waters. The biomass of species who do not remain in the study area year-round is scaled using a residency time by multiplying biomass by the proportion of days in a year spent in the study area. The species included in the model are separated into three groups determined by primary diet composition. Seabird data were provided form yearly seabird surveys that were conducted by Canadian Wildlife Services for the Seabirds at Sea program (ECCC 2023).

2.3.1 Seabird piscivore

The seabird piscivore functional group includes all seabirds who spend some or all of their time in the study area and eat primarily fish (Table 26).

Table 26 List of piscivore seabirds found in both study areas.

Common name	Latin name
Arctic Tern	*Sterna paradisaea*
Atlantic Puffin	*Fratercula arctica*
Audubon's Shearwater	*Puffinus lherminieri*
Black-headed Gull	*Chroicocephalus ridibundus*
Black-legged Kittiwake	*Rissa tridactyla*
Black Guillemot	*Cepphus grylle*
Black Tern	*Chlidonias niger*
Bonaparte's Gull	*Chroicocephalus philadelphia*
Caspian Tern	*Hydroprogne caspia*
Common Murre	*Uria aalge*
Common Tern	*Sterna hirundo*
Cory's Shearwater	*Calonectris borealis*
Double-crested Cormorant	*Phalacrocorax auritus*
Glaucous Gull	*Larus hyperboreus*
Great Black-backed Gull	*Larus marinus*
Great Cormorant	*Phalacrocorax carbo*
Greater Shearwater	*Ardenna gravis*
Great Skua	*Stercorarius skua*
Herring Gull	*Larus argentatus*
Iceland Gull	*Larus glaucoides*
Iceland Gull	*Larus glaucoides*
Laughing Gull	*Leucophaeus atricilla*
Leach's Storm-Petrel	*Oceanodroma leucorhoa*
Least Tern	*Sternula antillarum*
Lesser Black-backed Gull	*Larus fuscus*
Long-tailed Jaeger	*Stercorarius longicaudus*
Manx Shearwater	*Puffinus puffinus*
Murre or Razorbill	*Alca torda*
Northern Fulmar	*Fulmarus glacialis*
Northern Gannet	*Morus bassanus*
Parasitic Jaeger	*Stercorarius parasiticus*
Pigeon Guillemot	*Cepphus columba*
Pomarine Jaeger	*Stercorarius pomarinus*
Razorbill	*Alca torda*
Red-footed Booby	*Sula sula*
Ring-billed Gull	*Larus delawarensis*
Ross's Gull	*Rhodostethia rosea*

Sabine's Gull	*Xema sabini*
Sooty Shearwater	*Ardenna grisea*
South Polar Skua	*Stercorarius maccormicki*
Thick-billed Murre	*Uria lomvia*
Townsend's Shearwater	*Puffinus auricularis*
White-faced Storm-Petrel	*Pelagodroma marina*
White-tailed Tropicbird	*Phaethon lepturus*
Wilson's Storm Petrel	*Oceanites oceanicus*
Yelkouan Shearwater	*Puffinus yelkouan*

Biomass, Production: Biomass and Consumption: Biomass

Biomass estimates for piscivorous seabirds was taken from Tam and Bundy (2019) 2013-2015 model which estimated **0.007 t/km^2** in both areas. Production to biomass of piscivorous seabirds was assumed to be **0.25 yr^{-1}** (Bundy et al. 2000). As in Tam and Bundy (2019), the *Q/B* for piscivorous seabirds was based off Barret et al. (2006) study of seabird consumption in 2GHJ3KLNO, which resulted in a *Q/B* of **119.41 yr^{-1}**.

Diet

Diet for piscivorous seabirds was adapted from the 2013-2015 model in Tam and Bundy (2019).

Table 27 Diet of seabird piscivore group for 2J3K and 3LNO, adapted from Tam and Bundy (2019).

Seabird piscivore	2J3K	3LNO
Atlantic cod ≤ 35cm	0.01	0
Other piscivorous fish	0.002	0.01
Arctic cod	0.015	0.02
Other plank-piscivorous fish	0.003	0
Small benthivorous fish	0.064	0.064
Herring	0.08	0
Sandlance	0.08	0.07
Capelin	0.346	0.55

2.3.2 Seabird planktivore

The seabird planktivore functional group is represented by a single species, dovekie or little auk (*Alle alle*). Dovkies are small planktivorous birds in the Auk family that are found across the North Atlantic and can be found year-round residing in large colonies along marine cliffsides in the Northeast Atlantic. Migrants reside in 2J3K and 3LNO in the winter.

Biomass, Production: Biomass and Consumption: Biomass

Biomass estimates for dovkie was taken from Tam and Bundy (2019) 2013-2015 model which estimated **0.00561 t/km^2.** The *P/B* ratio for dovekies was obtained from Tam and Bundy (2019), who estimated **0.15 yr^{-1}**, based on Gabrielsen et al. (1991) estimates of dovekie production. The *Q/B* ratio for dovekies was based on an estimate from Vermeer (1984) who estimated a consumption rate of 17.7% of adult body weight, resulting in a *Q/B* of **64 yr^{-1}.**

Diet

Diet for planktivorous seabirds was adapted from the 2013-2015 model in Tam and Bundy (2019).

Table 28 Seabird planktivore diet for 2J3K and 3LNO, adapted from Tam and Bundy (2019).

Seabird planktivore	2J3K	3LNO
Suspension feeding invertebrates	0.01	0.01
Macrozooplankton	0.212	0.212
Large mesozooplankton	0.444	0.444
Small mesozooplankton	0.333	0.333

2.3.3 Seabird benthivore

The seabird benthivore group is primarily comprised of ducks, geese and loons, with common eiders (*Somateria mollissima*) being the most abundant species. Most species are present in both study areas year-round.

Table 29 Seabird benthivore species that are present in both study areas for the 2018-2020 models.

Species	Latin name
American Black Duck	*Anas rubripes*
American Green-winged Teal	*Anas carolinensis*
Black Scoter	*Melanitta americana*
Canada Goose	*Branta canadensis*
Common Eider	*Somateria mollissima*
Common Loon	*Gavia immer*
Common Merganser	*Mergus merganser*
Harlequin Duck	*Histrionicus histrionicus*
Long-tailed duck	*Clangula hyemalis*
Red-breasted Merganser	*Mergus serrator*
Red-necked Grebe	*Podiceps grisegena*
Red-necked Phalarope	*Phalaropus lobatus*
Red-throated Loon	*Gavia stellata*
Red Phalarope	*Phalaropus fulicarius*
Surf Scoter	*Melanitta perspicillata*
White-winged Scoter	*Melanitta fusca*

Biomass, Production: Biomass and Consumption: Biomass

Biomass estimates for benthivorous seabirds was taken from the Tam and Bundy (2019) 2013-2015 model which estimated **0.00168 t/km^2.** The *P/B* ratio for benthivorous seabirds was obtained from Tam and Bundy (2019), who estimated **0.13 yr^{-1}**, based on an estimate by Mawhinney et al. (1991). The *Q/B* ratio for benthivorous seabirds was based on an estimate from Guillemette et al. (1996), resulting in a *Q/B* of **45.3 yr^{-1}.**

Diet

Diet for benthivorous seabirds was adapted from the 2013-2015 model in Tam and Bundy (2019).

Table 30 Seabird benthivore diets for 2J3K and 3LNO.

Seabird benthivore	2J3K	3LNO
Small benthivorous fish	0.1	0.1
Predatory invertebrates	0.2	0.2
Suspension feeding invertebrates	0.25	0.25
Macrozooplankton	0.25	0.25
Large mesozooplankton	0.2	0.2

2.4 Fish groups

Over 22 species of fish have had a commercial or recreational fishery regulated by DFO within 2J3K and/or 3LNO. Due to the economic and ecological interest of these species, many of them have their own functional group in this model, while other fish are aggregated into groups based on their size and known feeding habits. Most biomass estimates are derived from the DFO multi-species research vessel (RV) survey, which is a stratified trawl survey that occurs every spring and fall across NAFO divisions 2J3KLNO and others. For species that are not well sampled by RV surveys, other methods such as acoustic surveys may be used to supplement biomass estimates. Commercial catch data for all groups was obtained from the NAFO STATLANT 21A database.

2.4.1 Greenland Shark

Greenland sharks *(Somniosus microcephalus)* are long-lived, cold-water sharks that live in the Arctic and North Atlantic Ocean, although they have been found as far south as the Gulf of Mexico (Benfield, Thompson and Caruso 2008). They are found at different depths seasonally, ranging from near surface to 730 m.

Greenland sharks belong to the Somniosidae family, also known as 'sleeper sharks' due to their slow swim speed and low metabolism, and reach an average size of 3.5-5 m. Despite their sluggish behaviour, Greenland sharks primarily consume fast moving prey such as seals and fish, with some research suggesting they are capable of active predation as opposed to scavenging, but this behaviour has never been observed (Nielson et al. 2019). There is no commercial or recreational fishery for Greenland sharks in either study area, but they are the commonly caught as bycatch in Greenland halibut and redfish trawl fisheries (Hendrickson et al. 2018).

Biomass

There were no Greenland sharks caught in the RV survey for the 2018-2020 time period. We know they occur in both study areas from previous years RV survey data and NAFO bycatch reports (Simpson et al. 2021). Although they are theorized to have a higher fecundity than previously thought (Nielsen et al. 2020), their slow growth, late maturity, and long gestation periods lead us to assume that the overall biomass of sharks in the study areas has not changed since the 2013-2015 model.

Tam and Bundy (2019) estimated a biomass of 0.0088t/km^2 for 2J3KLNO, which equates to 4356t when multiplied by their study area of 495,000km^2. Assuming an average of 0.3t per individual (MacNeil et al. 2012) leads to an estimate of 14,520 individuals in the study area. There is little evidence to suggest that Greenland sharks are more abundant in one study area over the other. Other than a preference for colder temperatures, habitat preferences for Greenland sharks are not fully understood (Stokesbury et al. 2005). Biomass for the 2018-2020 models was split evenly between the two study areas, resulting in a biomass of **0.0088t/km^2** for both models (Table 31).

Table 31 Biomass estimates for 2J3K and 3LNO Greenland shark for the 2018-2020 time period.

Model	Biomass (t)	Biomass (t/km^2)
2J3K	2091	0.0088
3LNO	2265	0.0088

Production: Biomass

The *P/B* ratio was calculated using Hoenig's equation for estimating fish mortality (Eq. 5). A maximum age of 392 year was used (Nielsen et al. 2016) resulting in a natural mortality of **0.01 yr^{-1}.**

Consumption: Biomass

The *Q/B* for both models was based on a Tam and Bundy (2019) estimate of **0.125 yr^{-1}**, based on diet studies in the north Atlantic.

Diet

The base diet was adapted from the 2013-2015 model (Tam and Bundy 2019). The 2J3K diet was modified to remove silver hake / pollock, and haddock from the diet, and more emphasis was given to *other piscivorous fish* and *other large benthivorous fish* respectively.

While balancing the model slight adjustments were made to the diet composition. The largest change reduced Greenland halibut consumption from 0.18 to 0.05-0.08 which was more in line with findings of Nielson et al. (2019) who reconstructed the diet from 78 sharks off the coast of Greenland.

Table 32 Diet composition for Greenland shark in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Greenland shark	2J3K	3LNO
Seal harp	0.18	0.18
Seal hooded	0.22	0.22
Seal other	0.059	0.059
Cod > 35 cm	0.1	0.1
Cod ≤ 35 cm	0.02	0.02
Greenland halibut	0.084	0.05
Silver hake/ pollock	0	0.02
Other piscivorous fish	0.026	0.031
Redfish	0.004	0.004
Other plank-piscivorous fish	0.02	0.02
American plaice > 35 cm	0.013	0.013
American plaice ≤ 35 cm	0.01	0.01
Thorny skate	0.001	0.01
Haddock	0	0.022
Other large benthivorous fish	0.102	0.08
Other medium benthivorous fish	0.054	0.054
Small benthivorous fish	0.05	0.05
Squid	0.017	0.017
Suspension feeding invertebrates	0.04	0.04

Catch

There is no commercial fishery for Greenland shark in the study area, however the species is caught as bycatch in other commercial fisheries, such as Greenland halibut and redfish trawls (Hendrickson et al. 2018). Accurate estimates of fishing mortality are difficult to obtain, as occurrences of bycatch are not always recorded, but Simpson et al (2021) found that bycatch occurrences are highest in deep waters along shelf edges outside of Canada’s EEZ, which would be outside of both study areas. Therefore, catch is being treated as effectively 0.

2.4.2 Atlantic Cod > 35 cm and Atlantic Cod ≤ 35 cm

Atlantic cod (*Gadus morhua*) is a species of gadid fish that holds a high amount of cultural, historic, and economic importance in Atlantic Canada, particularly in Newfoundland and Labrador (Pope 2004). Records of Atlantic cod exploitation by Europeans date back to the 1500s and continue to present day (Pringle 1997). Before the groundfish collapse in the early 1990s, cod was the highest value fishery in Atlantic Canada (DFO 2016), and there has been special interest in monitoring its recovery since.

There are two Atlantic cod stocks within the study area, the 2J3KL or "Northern cod" stock and the 3NO stock. For both 2018-2020 models, Atlantic cod are a multi-stanza group separated by size/age. The smaller group (≤ 35 cm, roughly corresponding to age 0-3) and larger groups (>35 cm, roughly corresponding to age 3+) represent the approximate size at which their diet transitions to piscivory and when they become commercial size. Unfortunately this size split does not capture the size at 50% maturity, which was found to be 41-42 cm for males and 50-51 cm for females (Shelton et al. 1996).

Biomass, Production: Biomass and Consumption: Biomass

In multistanza groups the secondary stanzas biomass is estimated from the leading groups based on a population growth rate-corrected survivorship term (Christensen and Walters 2004). Estimates of Atlantic cod ≤ 35 cm (ages 0-3) will be estimated by Ecopath based on the biomass of the Atlantic cod > 35 cm (Table 33).

Biomass data for Atlantic cod > 35 cm in 2J3K was obtained from the 2021 stock assessment estimate for Northern cod (2J3KL). The estimates were separated by each region (i.e., a separate estimate for 2J, 3K and 3L) so 3L was excluded from the estimate.

Biomass for Atlantic cod > 35 cm in 3LNO was obtained from the Rideout (2021) RV survey biomass estimates. The 3L biomass excluded from the 2J3K model was then added to this estimate.

Tam and Bundy (2019) used mortality estimates from the Northern Cod Assessment Model (NCAM) presented at the DFO stock assessment for Northern Cod, so I am using the same method. From the DFO stock assessment for Northern Cod (DFO 2022c), the average natural mortality (M) for 2018-2020 was **0.4** with fishing mortality average being **0.02** for a total Z of **0.42 yr^{-1}.**

The *Q/B* used was taken from Tam and Bundy (2019) who used a weighted average on consumption values based on the Scotian Shelf Ecopath model by Araujo and Bundy (2011), resulting in a value of **1.615 yr^{-1}** for both study areas. The K parameter and Weight at maturity/Weight infinity parameter (W_{mat}/W_{inf}) for Atlantic cod was obtained from Fishbase (Froese and Pauly 2023).

Table 33 Multistanza input parameters for Atlantic cod for 2J3K and 3LNO in the 2018-2020 time period. Values in blue are estimated by Ecopath.

Model	Group name	Age start (months)	Biomass (t/km^2)	Z	*Q/B*	$K_{(annual)}$	W_{mat}/W_{inf}	Landings
2J3K	Cod > 35 cm	36	2.18	0.42	1.615	0.114	0.047	0.01764
2J3K	Cod < 35 cm	0	0.2001	0.42	4.102			0.00323
3LNO	Cod > 35 cm	36	0.568	0.42	1.165	0.114	0.047	0.0181
3LNO	Cod < 35 cm	0	0.0521	0.42	2.959			0.00331

Diet

Adapted from the 2013-2015 model from Tam and Bundy (2019). The 2J3K diet was modified slightly to remove yellowtail flounder from the diet, and more emphasis was given to *other medium benthivorous fish*. Based on RV survey data, Cod in 3LNO consume much more sandlance than in 2J3K, where they consume more shrimp and amphipods. The diets for each were adjusted accordingly.

Table 34 Diet composition for Atlantic cod in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Atlantic cod	2J3K		3LNO	
	>35 cm	≤ 35 cm	>35 cm	≤ 35 cm
Cod ≤ 35 cm	0.008	0	0.002	0
Greenland halibut	0.02	0	0.014	0
Redfish	0.01	0	0.031	0
Arctic cod	0.01	0.002	0.005	0.002
American plaice > 35 cm	0.004	0	0	0
American plaice ≤ 35 cm	0.1	0.011	0.208	0.011
Thorny skate	0.002	0	0.002	0
Yellowtail flounder	0	0	0.075	0
Witch flounder	0.001	0	0	0
Other medium benthivorous fish	0.004	0.007	0.003	0.007
Small benthivorous fish	0.04	0.003	0.022	0.003
Herring	0.007	0	0	0
Sandlance	0.002	0.06	0.166	0.06
Capelin	0.224	0.081	0.224	0.081
Other planktivorous fish	0.001	0	0.001	0
Squid	0.001	0.01	0.001	0
Shrimp	0.155	0.058	0.03	0.058
Snow crab	0.007	0	0.009	0.01
Predatory invertebrates	0.15	0.05	0.08	0.05
Deposit feeding invertebrates	0.1	0	0.034	0
Suspension feeding invertebrates	0.027	0.001	0.018	0.001
Macrozooplankton	0.12	0.45	0.075	0.45
Large mesozooplankton	0.007	0.117	0	0.117
Small mesozooplankton	0	0.1	0	0.1
Microzooplankton	0	0.05	0	0.05

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. Catch was distributed between size classes using the catch curve data from DFO for 2J3K (DFO 2022) and NAFO for 3NO (Rideout et al 2021). For 3LNO, 15.5% of the catch was older than 3 years on average for 2018-2020, resulting in a catch of **0.018062 t/km^2/yr** for Cod >35 cm and **0.003313 t/km^2/yr** for Cod ≤ 35 cm. For 2J3K, 15.% of the catch was older than 3 years on average for 2018-2020 resulting in a catch of **0.01764 t/km^2/yr** for Cod >35 cm and **0.003236 t/km^2/yr** for Cod ≤ 35 cm.

2.4.3 Greenland Halibut

Greenland halibut *(Reinharditus hippoglossoides)* are a deep-water flatfish that have a circumpolar distribution with populations extending down into the Atlantic and Pacific ocean (CAFF 2017). Greenland halibut are usually found on soft substrates between 500-1000 m deep and reach a maximum size of approximately 1 m.

Biomass

Biomass information for Greenland Halibut (*Reinharditus hippoglossoides*) biomass were averaged for the 2018-2020 time period based on estimates from Regular et al. (2021) and Rideout et al. (2021) spring and fall RV surveys, and RV survey data. The general trend was that 2018-2020 relative average biomass in 2J3K was lower than it was compared to 2013-2015, and biomass in 3LNO was higher relative to 2013-2015, although overall 2J3K has more Greenland halibut biomass than 3LNO. As a point of reference, Tam and Bundy (2019) estimated a biomass of 0.69 t/km^2 for 2J3KLNO as a whole in 2013-2015. My biomass estimates are summarized in Table 35.

Table 35 Biomass estimates for Greenland Halibut in 2J3K and 3LNO for the 2018-2020 time period.

Model	Biomass (t)	Biomass (t/km^2)
2J3K	127,332.2	0.8
3LNO	19,911.8	0.15

Production: Biomass

Estimates of natural mortality for Greenland halibut were based on estimates from Tam and Bundy (2019), which accounted for size based mortality, and currently fishing mortality rates for a final estimate of **0.645 yr^{-1}** in both areas.

Consumption: Biomass

The *Q/B* used for both models are based on Tam and Bundy (2019) estimates of **2.4 yr^{-1}.**

Diet

Adapted from the 2013-2015 model in Tam and Bundy (2019). The 2J3K diet was modified slightly to remove yellowtail flounder from the diet, and more emphasis was given to *other medium benthivorous fish*. Based on RV survey stomach content data, Greenland halibut in 3LNO consume much more sandlance than in 2J3K, where they consume more Greenland halibut (cannibalism) and Arctic cod. The diets for each were adjusted accordingly.

Table 36 Diet composition for Greenland halibut in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Greenland halibut	2J3K	3LNO
Atlantic cod ≤ 35cm	0.018	0.011
Greenland halibut	0.109	0.026
Redfish	0.045	0.04
Arctic cod	0.08	0
American plaice > 35 cm	0.006	0.006
American plaice ≤ 35 cm	0.05	0.05
Other large benthivorous fish	0.046	0.002
Yellowtail flounder	0	0.046
Other medium benthivorous fish	0.01	0.005
Small benthivorous fish	0.033	0.033
Sandlance	0.001	0.163
Capelin	0.29	0.355
Other planktivorous fish	0.017	0.017
Squid	0.1	0.1
Shrimp	0.022	0.022
Snow crab	0	0.001
Predatory invertebrates	0.01	0
Deposit feeding invertebrates	0.05	0.01
Suspension feeding invertebrates	0.016	0.016
Macrozooplankton	0.097	0.097

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. Catch for Greenland halibut was **0.0074 t/km^2/yr** in 2J3K, and **0.0019 t/km^2/yr** in 3LNO**.**

2.4.4 Silver hake / Pollock

Silver hake *(Merluccius bilinearis)* and Pollock (*Pollachius virens*) are both large piscivorous fish that live in depths of approximately 50-400 m. Although both are caught commercially, there is not a large fishery for either species in the study areas. The 3Ps fishery for pollock is considered the species' northern limit, and therefore is not represented in the 2J3K model. Similarly, silver hake does not appear to exist in large numbers in 2J3K, and therefore the functional group is only present in the 3LNO model.

Biomass

There is no official stock assessment for pollock or silver hake in the Newfoundland region. Biomass estimates were calculated from stratified RV survey data, averaged by year and area using the Rstrap package. The original biomass estimate of 0.08 t/km^2 was increased to **0.128 t/km^2** during balancing, based on the energy needs of the system but with the general understanding that biomass had decreased since the 2013-2015 model.

Production: Biomass

Estimates of natural mortality for both silver hake and pollock were derived from Hoenig's (1983) equation for estimating fish mortality with an assumed max age of 12 years for silver hake and 25 years for pollock (Cohen et al. 1990). Fishing mortality was calculated by dividing catch data by biomass data for both species (Table 37).

Table 37 Natural mortality, fishing mortality, and the Production to Biomass ratio (*P/B*) for silver hake and pollock in 3LNO in 2018-2020.

Model	Natural mortality (M)	Fishing mortality (F) (Catch/ Biomass)	*P/B* (Z)
3LNO	0.34	0.05	**0.4**

Consumption: Biomass

The *Q/B* ratio for the group was taken from Tam and Bundy (2019) who estimated **4.1 yr^{-1}**, based off consumption and diet studies in the Northeastern USA.

Diet

Diet matrices taken unmodified from the 2013-2015 model in Tam and Bundy (2019) (Table 38).

Table 38 Diet composition for silver hake and pollock in 3LNO. Adapted from Tam and Bundy (2019).

Silver hake and pollock	3LNO
Redfish	0.068
Other large benthivorous fish	0.003
Sandlance	0.367
Capelin	0.333
Shrimp	0.024
Macrozooplankton	0.206

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. There was no reported catch of silver hake or pollock in the 2J3K, and a small amount of catch was reported in 3LNO amounting to **4.2 x 10^{-4} t/km^{2}/yr**.

2.4.5 Other piscivorous fish

Other piscivorous fish are defined as non-commercial fish species that have other fish as their primary prey and exist within the study area. The list of species included in this group can be found in table 39.

Table 39 List of *other piscivorous fish* adapted from Tam and Bundy (2019).

Common name	Order	Latin name
Gulper	Anguilliformes	*Saccopharynx ampullaceus*
Shortnose lancetfish	Aulopiformes	*Alepisaurus brevirostis*
Longnose lancetfish	Aulopiformes	*Alepisaurus ferox*
Daggertooth	Aulopiformes	*Anotopterus pharao*
Barricudinas	Aulopiformes	Paralepididae (Family)
Longnose greeneye	Aulopiformes	*Parasudis truculenta*
Blue shark	Carcharhiniformes	*Prionace glauca*
Polar cod	Gadiformes	*Arctogadus glacialis*
Greenland cod	Gadiformes	*Gadus ogac*
Offshore hake	Gadiformes	*Merluccius albidus*
Other hake	Gadiformes	*Merluccius* sp.
White hake	Gadiformes	*Urophycis tenuis*
Other gadiformes	Gadiformes	Numerous
Shortfin mako	Lamniformes	*Isurus oxyrinchus*
Mackerel sharks	Lamniformes	Lamnidae (Family)
Anglers	Lophiformes	Numerous
Atlantic halibut	Pleruonectiformes	*Hippoglossus hippoglossus*
Lamprey	Petromyzontiformes	*Petromyzon marinus*
Atlantic salmon	Salmoniformes	*Salmo salar*
Black scabbardfish	Scombriformes	*Aphanopus carbo*
Frostfish	Scombriformes	*Benthodesmus simonyi*
Portuguese dogfish	Squaliformes	*Centroscymnus coelolepis*
Black dogfish	Squaliformes	*Centroscyllium fabricii*
Spiny dogfish	Squaliformes	*Squalus acanthias*
Other dogfish sharks	Squaliformes	Numerous
Sloan's viperfish	Stomiiformes	*Chauliodus sloani*
Boa dragonfish	Stomiiformes	*Stomias boa ferox*
Other dragonfish	Stomiiformes	Stomiidae (Family)

Biomass

Biomass estimates for *other piscivorous fish* were calculated from stratified RV survey data , averaged by year and area using the Rstrap package (Table 40).

Table 40 Biomass estimates for 2J3K and 3LNO *other piscivorous fish* for the 2018-2020 time period.

Model	Biomass (t)	Biomass (t/km^2)
2J3K	8795.2	**0.037**
3LNO	31,507.5	**0.122**

Production: Biomass

Due to a lack of detailed production/consumption information on many of the species in this functional group, three species have been selected to represent the functional group: Atlantic Halibut (*Hippoglossus hippoglossus*), White hake (*Urophycis tenuis*), and Black dogfish (*Centroscyllium fabricii*). Estimates of natural mortality for these three representative species were derived from Hoenig's (1983) equation for estimating fish mortality (Eq. 5), with an assumed max age of 50 years for Atlantic halibut (Muus and Dahlström 1974), 65 years for Black dogfish (Qvist 2017), and 23 years for White hake (Beverton and Holt 1959). The three estimates were averaged to give a group M estimate of **0.109 yr^{-1}.** Fishing mortality was calculated as catch divided by total biomass (Table 41).

Table 41 Natural mortality, fishing mortality, and the Production to Biomass ratio (*P/B*) for *other piscivorous fish* in 3LNO in 2018-2020.

Model	Natural mortality (M)	Fishing mortality (F) (Catch/ Biomass)	*P/B* (Z)
2J3K	0.31	0.0017	**0.3117**
3LNO	0.31	0.066	**0.376**

Consumption: Biomass

The *Q/B* ratio for the *other piscivorous fish* group was based off consumption and diet studies for Atlantic halibut, black dogfish, and white hake (Table 42).

Table 42 Consumption and Consumption to Biomass ratio (*Q/B*) for *other piscivorous fish* in 3LNO and 2J3K in 2018-2020.

Species	Consumption (t)	Estimated 2J3K biomass (t)	Estimated 3LNO biomass (t)	Reference
Atlantic halibut	20,551.25	4759.05	11,902.5	Araujo and Bundy 2011
Black dogfish	6744.29	1435.58	535.15	Jakobsdottir 2001
White hake	3446	10.263	6178.9	Garrison and Link 2000
Total	30,741.54	6204.893	18,616.55	
Q/B		**4.954**	**1.651**	

Diet

Adapted from the 2013-2015 model in Tam and Bundy (2019). Diet for the entire group was taken from the composite diets of Atlantic halibut, Black dogfish, and white hake. Slight modifications were made to the 2J3K diet to remove yellowtail flounder, haddock, and silver hake/pollock from the diet, more emphasis was given to other fish in a similar trophic group (Table 43).

Table 43 Diet composition for *other piscivorous fish* in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Other piscivorous fish	2J3K	3LNO
Cod > 35 cm	0.02	0.02
Cod ≤ 35 cm	0.02	0.02
Greenland halibut	0.01	0.01
Silver hake/ pollock	0.01	0.01
Redfish	0.02	0.02
Arctic cod	0.01	0.01
Other plank-piscivorous fish	0.01	0.01
American plaice ≤ 35 cm	0.12	0.12
Thorny skate	0.01	0.01
Haddock	0.01	0.02
Other large benthivorous fish	0.01	0
Yellowtail flounder	0.01	0.01
Witch flounder	0.01	0.01
Other medium benthivorous fish	0.01	0.01
Small benthivorous fish	0.01	0.01
Herring	0.01	0.01
Sandlance	0.02	0.27
Capelin	0.5	0.25
Other planktivorous fish	0.05	0.05
Shrimp	0.05	0.05
Macrozooplankton	0.08	0.08

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. Catch for 2J3K only included Atlantic halibut, totalling **6.45×10^{-5} t/km^2/yr.**

Catch for 3LNO included Atlantic halibut, American angler, dogfishes, blue shark, shortfin mako shark, and white hake totalling at **0.0081 t/km^2/yr.**

2.4.6 Redfish

This functional group contains the Acadian redfish (*Sebastes fasciatus*) and the deepwater redfish (*Sebastes mentella*). There are three stocks of redfish within the study area, 2J3K, 3LN and 3O, although the 2+3K stock has been under fishing moratorium since 1997. Redfish are a long living and slow growing semi-pelagic fish found along underwater slopes and channels around 100-700 m depth. Redfish are ovoviviparous, with mating occurring in April – July each year. Individuals reach maturity at 8-10 years or at 25 cm in length. The population experiences episodic recruitment pulses, where decades may pass between strong cohorts joining the population, making management of the stock difficult (DFO 2023).

Biomass

Biomass estimates for 3LNO redfish were calculated from RV surveys, averaged by year and area obtained from the Rstrap data package, as well as NAFO assessments for 3LN and 3O redfish (Rogers et al. 2022; Wheeland et al. 2022). Biomass information for 2J3K redfish was based on survey biomass recorded in the DFO stock status report (DFO 2023). Redfish biomass in 2J3K was estimated as **1.2 t/km^2,** and **1.25 t/km^2** for 3LNO.

Production: Biomass

Originally, estimates of natural mortality for redfish were derived from Hoenig's (1983) equation for estimating fish mortality (Eq. 5) with an assumed max age of of 75 years for *S. mentella* (Campana et al 2000) and 37 years for *S. fasciatus* (Sullivan et al 2016). In the balancing natural M was set at **0.125** based on Bundy et al 2000. Fishing mortality was calculated as catch divided by total biomass (Table 44).

Table 44 Natural mortality, fishing mortality, and the Production to Biomass ratio (*P/B*) for redfish in 2J3K and 3LNO in 2018-2020.

Model	Natural mortality (M)	Fishing mortality (F) (Catch/ Biomass)	*P/B* (Z)
2J3K	0.125	0.000124	**0.125**
3LNO	0.125	0.08	**0.205**

Consumption: Biomass

The *Q/B* ratio for redfish for both models was based on the Bundy et al. (2000) estimate of **2.00 yr^{-1}**.

Diet

Diet matrix for redfish was adapted from the 2013-2015 model in Tam and Bundy (2019). Slight modifications were made to the 2J3K diet to remove yellowtail flounder, more emphasis was given to American plaice ≤ 35 cm. Based on RV survey data, redfish in 3LNO consume more sandlance and other shrimp than in 2J3K, where they consume more amphipods and myctophids to their 3LNO counterparts. The diets for each were adjusted accordingly (Table 45).

Table 45 Diet composition for redfish in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Redfish	2J3K	3LNO
American plaice ≤ 35 cm	0.008	0.007
Yellowtail flounder	0	0.002
Sandlance	0.001	0.051
Capelin	0.149	0.087
Other planktivorous fish	0.08	0.05
Squid	0.03	0.07
Shrimp	0.02	0.02
Macrozooplankton	0.709	0.709
Large mesozooplankton	0.003	0.003

Catch

Redfish was under fishing moratorium during the 2018-2020 time period in 2J3K in Canadian waters, but small amounts of catch were still reported. Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. Catch for redfish was **0.00013 t/km^2/y** in 2J3K, and **0.0726 t/km^2/y** in 3LNO.

2.4.7 Arctic cod

Arctic cod *(Boreogadus saida)*, also known as polar cod, are a small forage fish present throughout the Northwest Atlantic and Arctic. They are often found dispersed throughout the water column, with both demersal and pelagic aggregations observed. This spread makes population estimates difficult, as using only one type of sampling gear will often miss some aggregations and are often underestimated from RV survey sampling.

Biomass

Bundy et al (2000) and Tam and Bundy (2019) both used a scaling factor of 479.1 to acoustic estimates of biomass for Arctic cod, to account for assumed under representation of biomass estimates from RV survey estimates. The same scalar was used to the RV survey estimates for 2018-2020 (Table 46).

Table 46 Biomass estimates for 2J3K and 3LNO Arctic cod for the 2018-2020 time period.

Model	Biomass (t)	Biomass (t/km^2)
2J3K	1,080,684	4.55
3LNO	270,171	1.05

Production: Biomass

Estimates of natural mortality for Arctic cod were derived from Hoenig's (1983) equation for estimating fish mortality (Eq. 5) with an assumed max age of 7 years (Cohen et al. 1990). Fishing mortality was calculated as catch divided by total biomass (Table 47).

Table 47 Natural mortality, fishing mortality, and the Production to Biomass ratio (*P/B*) for Arctic cod in 2J3K and 3LNO in 2018-2020.

Model	Natural mortality (M)	Fishing mortality (F) (Catch/ Biomass)	*P/B* (Z)
2J3K	0.6	0	**0.6**
3LNO	0.6	0	**0.6**

Consumption: Biomass

Bundy et al (2000) assumed a ratio of 0.15 between production and consumption, resulting in a *Q/B* of **4 yr^{-1}.**

Diet

Diet matrix for Arctic cod was modified from the 2013-2015 model in Tam and Bundy (2019).

Capelin consumption was slightly decreased in favour of macrozooplankton in 2J3K (Table 48).

Table 48 Diet composition for Arctic cod in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Arctic cod	2J3K	3LNO
Other plank- piscivorous fish	0	0.001
Capelin	0.01	0.039
Suspension feeding invertebrates	0.089	0.089
Macrozooplankton	0.622	0.592
Large mesozooplankton	0.279	0.279

Catch

There was no commercial catch of Arctic cod for the 2018-2020 time period for either region.

2.4.8 Other plank-piscivorous fish

Other plank-piscivorous fish include other fish that primarily consume both fish and plankton.

The list of species included in this functional group can be found in Table 49.

Table 49 of *other plank-piscivorous fish* adapted from Tam and Bundy (2019).

Common name	Order	Latin name
Pelican eel	Anguilliformes	*Eurypharynx pelecanoides*
Waryfishes	Aulopiformes	Notosudidae (Family)
Longfin hake	Gadiformes	*Urophycis chesteri*
Beardfishes	Polymixiiformes	Polymixiidae (Family)
Seasnail	Scorpaeniformes	*Careproctus sp.*
Rockfishes	Scorpaeniformes	Scorpaenidae (Family)

Biomass

Biomass information for *other plank-piscivorous fish* was calculated from stratified RV survey data, averaged by year and area using the Rstrap package (Table 50).

Table 50 Biomass estimates for 2J3K and 3LNO *other plank-piscivorous fish* for the 2018-2020 time period.

Model	Biomass (t)	Biomass (t/km^2)
2J3K	6,652.8	0.028
3LNO	7,207.2	0.028

Production: Biomass

Tam and Bundy (2019) used longfin hake (*Urophycis chesteri*) and Seasnail sp. as representatives for the group, as they had the most biomass of species in the functional group. Estimates of natural mortality for the two representatives was hindered by lack of information on age dynamics for the species. Otolith aging of longfin hake was found to be difficult to accomplish (Wenner 1983), and little information exists on the life history of snailfish in the Northwest Atlantic. It was assumed a *P/B* ratio similar to redfish or Arctic cod would be appropriate for this group, so a *P/B* of **0.35 yr^{-1}** was used for both study areas (Tam and Bundy 2019).

Consumption: Biomass

Bundy et al (2000) assumed a ratio of 0.15 between production and consumption, resulting in a Q/B of **2.3 $\mathbf{yr^{-1}}$.**

Diet

Diet matrices were adapted from the 2013-2015 model from Tam and Bundy (2019) (Table 51).

Table 51 Diet composition for *other plank-piscivorous fish* in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Other plank-piscivorous fish	2J3K	3LNO
Small benthivorous fish	0.05	0.05
Herring	0.01	0.01
Sandlance	0.01	0.01
Capelin	0.01	0.01
Other planktivorous fish	0.01	0.01
Shrimp	0.05	0.05
Predatory invertebrates	0.05	0.05
Deposit feeding invertebrates	0.3	0.3
Suspension feeding invertebrates	0.1	0
Macrozooplankton	0.31	0.41
Large mesozooplankton	0.1	0.1

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. There was no commercial catch reported for 2J3K for the time period. There was some commercial catch of Longfin hake for 3LNO, resulting in a catch of **7.77E-06 $\mathbf{t/km^2/yr}$**.

2.4.9 American plaice >35 cm and American plaice ≤ 35 cm

American plaice *(Hippoglossoides platessoides*) are a benthic flatfish found primarily on continental shelves less than 300 m depth with a maximum size of approximately 60 cm. There are three commercial stocks of American plaice in Canadian waters, 2GHJ3K , 3LNO, and 3M, although all stocks have been under moratorium since 1994. There has been little evidence of population recovery since the initial collapse in the early 1990's.

For both 2018-2020 models, American plaice are a multi-stanza group separated by age/length. The smaller group (≤ 35 cm, roughly corresponding to age 0-7) and larger group (>35 cm, roughly corresponding to age 7+) represent the approximate size at maturity for 50% of the population and the size of first capture for the fishery.

Multi-stanza parameters

In multistanza groups, the secondary stanzas biomass is estimated from the leading groups, so estimates of American plaice ≤ 35 cm will be estimated by Ecopath based on the biomass of the American plaice > 35 cm.

Biomass data for the leading group of American plaice was calculated from stratified RV survey data, averaged by year and area using the Rstrap package, as well as the stock status reports provided by DFO (2020) (Table 52).

Estimates of natural mortality in 3LNO were obtained from Wheeland (2021), who examined a range of natural mortality assumptions in the Virtual Population Analysis model used in 3LNO American plaice stock assessment. The *P/B* ratio for American plaice greater than 35 cm was **0.5 yr^{-1}**. As in Tam and Bundy (2019), *P/B* for American plaice less then 35 cm was calculated by adding an M of 0.5 plus 0.0065 of fishing mortality results in a Z of **0.507 yr^{-1}**. A *P/B* ratio of **0.6**

yr^{-1} was used for American plaice greater than 35 cm in 2J3K, with negligible landings results in Z of **0.6 yr^{-1}**.

The *Q/B* ratio was based on the 1985-1987 and 2013-2015 models in Tam and Bundy (2019), which used a value of **2.0 yr^{-1}**.

The K parameter and Weight at maturity/Weight infinity parameter (W_{mat}/W_{inf}) for American plaice was obtained from Fishbase (Froese and Pauly 2023).

Table 52 Multi-stanza input parameters for 2J3K and 3LNO American plaice for the 2018-2020 time period. Values in blue are estimated by Ecopath.

Model	Group name	Age start (months)	Biomass (t/km^2)	*Z*	*Q/B*	$K_{(annual)}$	W_{mat}/ W_{inf}	Landings (t/km^2)
2J3K	American plaice > 35 cm	84	0.4	0.6	2.0	0.13	0.06	1.45E-5
2J3K	American plaice ≤ 35 cm	0	1.41	0.607	3.86			0
3LNO	American plaice > 35 cm	84	0.83	0.5	2.0	0.13	0.06	0.0043
3LNO	American plaice ≤ 35 cm	0	1.78	0.507	3.73			6.0E-5

Diet

Taken from the 2013-2015 model from Tam and Bundy (2019). The 2J3K diet was modified slightly to remove yellowtail flounder from the diet, and more emphasis was given to *other medium benthivorous fish.* Based on RV survey data, American plaice in 3LNO consume much more sandlance than in 2J3K, where they consume more amphipods and capelin. The diets for each were adjusted accordingly (Table 53).

Table 53 Diet composition for American plaice in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

	2J3K		3LNO	
	American plaice > 35 cm	American plaice ≤ 35 cm	American plaice > 35 cm	American plaice ≤ 35 cm
Redfish	0	0	0.004	0
Arctic cod	0.07	0	0.007	0
Yellowtail flounder	0	0	0	0.007
Other medium benthivorous fish	0.01	0	0.01	0
Small benthivorous fish	0.002	0.01	0.002	0.001
Sandlance	0.02	0.133	0.3	0.133
Capelin	0.1	0.01	0.1	0.204
Squid	0	0.002	0	0.012
Shrimp	0.07	0.01	0.009	0
Snow crab	0.008	0.006	0.008	0.005
Predatory invertebrates	0.094	0.117	0.099	0.074
Deposit feeding invertebrates	0.1	0.05	0.195	0.033
Suspension feeding invertebrates	0.226	0.3	0.241	0.176
Macrozooplankton	0.3	0.362	0.025	0.355

Catch

According to the 3LNO assessment of American plaice (Wheeland et al. 2021), bycatch of American plaice in 3LNO predominately came from the Yellowtail Flounder fishery for an average of 676.5 t per year in the 2018-2020 time period. In the same report, catch of American plaice under 35 cm amounted to **0.00006 t /km^2** based on catch at age and length data.

American plaice bycatch amounted to an average of 4.05 t in 2J3K (DFO 2021b). There was little catch in 2018-2020, such that catch of American plaice under 35 cm is effectively **0** t.

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. Catch for 2J3K American plaice amounted to **0.0000154 t/km^2/yr**, and 3LNO amounted to **0.00426 t/km^2/yr**.

2.4.10 Thorny skate

Thorny skate (*Amblyraja radiata*) is a large skate with a broad Atlantic distribution from western Greenland to South Carolina. They are found on hard and soft substrate from 18-1400 m depth but most commonly found below 110 m. Thorny skates are commonly caught as bycatch in other fisheries and usually discarded at sea (DFO 2017). This changed in 1995, when thorny skate became a species of interest after DFO established a skate fishery along the Grand Banks in response to the groundfish collapse in the early 1990s (DFO 2017). Since then, there has been a moderate thorny skate fishery in 3LNO and 3Ps, however bycatch still occurs from the Greenland halibut and shrimp fisheries in all areas (DFO 2017).

Biomass

Biomass estimates for 3LNO thorny skate were averaged for the 2018-2020 time period from Rideout et al (2021) spring and fall RV surveys (Table 54). No updated stock assessments exist for 2J3K thorny skate for the 2018-2020 time period. However according to a 2017 science update (DFO 2017), the 2J3K biomass dropped in 2015 from a recent high in 2013/2014. The short-term survey average of 18,260.869 t was used as an estimate for the 2018-2020 time period.

Table 54 Biomass estimates for 2J3K and 3LNO Thorny Skate for the 2018-2020 time period.

Model	Biomass (t)	Biomass (t/km^2)
2J3K	30,888	0.130
3LNO	182,489	0.709

Production: Biomass

Estimates of natural mortality for Thorny skate were derived from Hoenig’s (1983) equation for estimating fish mortality (Eq. 5) with an assumed max age of of 28 (McPhie and Campana

2009). Fishing mortality was calculated as catch (t) divided by total biomass (t) for both regions (Table 55).

Table 55 Production to Biomass ratio calculations for 2J3K and 3LNO Thorny Skate (*Amblyraja radiata*) for the 2018-2020 time period.

Model	Natural mortality (M)	Fishing mortality (F) (Catch/ Biomass)	*P/B* (Z)
2J3K	0.1487	0.000234	**0.1489**
3LNO	0.1487	0.04743	**0.1961**

Consumption: Biomass

Consumption rates for thorny skate were obtained from Link and Sosebee (2008) who created a time series of thorny skate consumption in the Northeastern United States, resulting in an estimated *Q/B* of **1.792 $\mathbf{yr^{-1}}$**.

Diet

Adapted from the 2013-2015 model from Tam and Bundy (2019). Based on RV survey data, thorny skate in 3LNO consume much more sandlance than in 2J3K, where they consume more shrimp and snow crab . The diets for each were adjusted accordingly (Table 56).

Table 56 Diet composition for thorny skate in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Thorny skate	2J3K	3LNO
Redfish	0.01	0.012
Other large benthivorous fish	0.04	0.016
Other medium benthivorous fish	0.02	0.02
Small benthivorous fish	0.054	0.028
Sandlance	0	0.355
Capelin	0.058	0.058
Squid	0.058	0.058
Shrimp	0.2	0.004
Snow crab	0.1	0.104
Predatory invertebrates	0.2	0.165
Deposit feeding invertebrates	0.06	0.02
Macrozooplankton	0.2	0.16

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. The STATLANT 21A database does not distinguish species of skates when reporting skate catch, however NAFO has noted during spring and fall surveys that 97-99% of skate catch in 3LNOPs is Thorny skate (Simpson and Miri 2020). Similarly, the last stock status update for thorny skate in 2J3K also assumed that 95% of skate catch in SA 2 and 3 was Thorny skate (DFO 2017).

Therefore, for the 2018-2020 models it will be assumed that the total catch of skates is 98% thorny skate in 3LNO and 95% thorny skate in 2J3K. With these proportions, the total catch for 2J3K amounted to **0.000018 t/km^2/yr**, and 3LNO amounted to **0.01121 t/km^2/yr.**

2.4.11 Haddock

Haddock (*Melanogrammus aeglefinus*) are a benthic gadid fish. The 3LNO stock has been under fishing moratorium since 1993, although they are still caught as bycatch in other fisheries (DFO 2018). Although present near western Greenland, they are not present at similar latitudes in northeastern Canada and therefore are excluded from the 2J3K model.

Biomass

Biomass estimates for haddock were obtained from the DFO stock assessment document (DFO 2018) in 3LNO, which resulted in an estimate of **0.0386 t/km^2.**

Production: Biomass

Estimates of natural mortality for haddock was derived from Hoenig's (1983) equation for estimating fish mortality (Eq. 5) with an assumed max age of of 20 years (Muus and Dahlström 1978). Fishing mortality was calculated as catch divided by total biomass (Table 57).

Table 57 Production to Biomass ratio calculations for 3LNO haddock (*Melanogrammus aeglefinus*) for the 2018-2020 time period.

Model	Natural mortality (M)	Fishing mortality (F) (Catch/ Biomass)	*P/B* (Z)
3LNO	0.2089	0.0048	0.2137

Consumption: Biomass

The *Q/B* ratio for Haddock was based off of values used in Araujo and Bundy (2011) Ecopath model for NAFO area 4X, which used **2.08 yr^{-1}.**

Diet

Taken unmodified from the 2013-2015 model from Tam and Bundy (2019) (Table 58)

Table 58 Diet composition for haddock in 3LNO. Adapted from Tam and Bundy (2019).

Haddock	3LNO
Small benthivorous fish	0.012
Herring	0.013
Sandlance	0.05
Capelin	0.092
Shrimp	0.056
Predatory invertebrates	0.232
Deposit feeding invertebrates	0.367
Suspension feeding invertebrates	0.142
Large mesozooplankton	0.036

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. Catch for Haddock was **0.0002 t/km^2/y** in 3LNO.

2.4.12 Other large benthivorous fish

Other large bethivorous fish are defined as fish who consume benthic prey such as crustaceans and other small invertebrates with a maximum mean size greater than 80 cm. The list of species in this functional group can be found in Table 59.

Table 59 List of *other large benthivorous fish* adapted from Tam and Bundy (2019)

Common name	Order	Latin name
Atlantic sturgeon	Acipenceriformes	*Acipenser oxythynchus*
Atlantic snipe eel	Anguilliformes	*Nemichthys scolopaceus*
Smoothheads	Alepocephaliformes	*Alepocephalidae (Family)*
Longnose chimaera	Chimaeriformes	*Harriotta raleighana*
Deepwater chimaera	Chimaeriformes	*Hydrolagus affinis*
Knifenose chimaera	Chimaeriformes	*Rhinochimaera atlantica*
Cusk cusk	Gadiformes	*Brosme brosme*
Roughhead grenadier	Gadiformes	*Macrourus berglax*
Krøyer’s deep sea angler	Lophiiformes	*Ceratius holboelli*
Sea devils	Lophiiformes	*Ceratiidae (Family)*
Monkfish	Lophiiformes	*Lophius americanus*
Atlantic hagfish	Myxiniformes	*Myxine glutinosa*
Spiny eels	Notacanthiformes	Notacanthidae (Family)
Longnose tapirfish	Notacanthiformes	*Polyacanthonotus challengeri*
Spinytail skate	Rajiformes	*Bathyraja spinicauda*
Abyssal skate	Rajiformes	*Raja bathyphila*
Arctic skate	Rajiformes	*Raja hyperborea*
Jensen's skate	Rajiformes	*Raja jenseni*
Barndoor skate	Rajiformes	*Raja laevis*
White skate	Rajiformes	*Raja lintea*
Winter skate	Rajiformes	*Raja ocellata*
Broadhead wolffish	Scorpaeniformes	*Anarhichas denticulatus*
Striped wolffish	Scorpaeniformes	*Anarhichas lupus*
Spotted wolffish	Scorpaeniformes	*Anarhichas minor*
Wrymouth	Scorpaeniformes	*Cryptacanthodes maculatus*
Ocean pout	Scorpaeniformes	*Macrozoarces americanus*

Biomass

Biomass information for *other large benthivorous fish* was calculated from stratified RV survey data, averaged by year and area using the Rstrap package (Table 60).

Table 60 Biomass estimates for 2J3K and 3LNO *other large benthivorous fish* for the 2018-2020 time period.

Model	Biomass (t)	Biomass (t/km^2)
2J3K	213,840	0.9
3LNO	102,960	0.4

Production: Biomass and Consumption: Biomass

Based on Bundy et al (2000), *P/B* for *other large benthivorous fish* for both models is **0.3 yr^{-1}**.

Bundy et al (2000) assumed a ratio of 0.15 between production and consumption, resulting in a *Q/B* of **1.33 yr^{-1}**.

Diet

Slight modifications were made to the 2J3K diet to remove yellowtail flounder from the diet, more emphasis given to *other medium benthivorous fish*. Diets were averaged from Atlantic Wolfish, Ocean Pout, and Monkfish (Table 61).

Table 61 Diet composition for *other large benthivorous fish* in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Other large benthivorous fish	2J3K	3LNO
Other piscivorous fish	0.001	0.001
Redfish	0.042	0.042
Thorny skate	0.001	0.001
Yellowtail flounder	0	0.012
Small benthivorous fish	0.045	0.033
Sandlance	0.016	0.016
Capelin	0.029	0.029
Other planktivorous fish	0.029	0.029
Shrimp	0.013	0.013
Snow crab	0.001	0.001
Predatory invertebrates	0.089	0.089
Deposit feeding invertebrates	0.44	0.44
Suspension feeding invertebrates	0.148	0.148
Macrozooplankton	0.026	0.026
Large mesozooplankton	0.109	0.109
Small mesozooplankton	0.011	0.011

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. Catch of *other large benthivorous fish* is represented by roughhead grenadier (*Macrourus berglax*) and cusk (*Brosme brosme*). Catch was **6.31×10^{-6} t/km^2/y** for 2J3K, and **0.0006 t/km^2/y** for 3LNO.

2.4.13 Yellowtail flounder

Yellowtail flounder (*Limanda ferruginea*) are a benthic flatfish with a range from the coast of North Carolina to southern Newfoundland. They are usually found in depths of 40-70 m and grow to a maximum size of 40 cm. The Grand Banks (3LNO) is considered the species' northernmost distribution; they are absent as a functional group from the 2J3K model.

Biomass

Estimates of abundance and biomass for yellowtail flounder were averaged for the 2018-2020 time period from Rideout et al (2021) spring and fall RV surveys, for a final estimate of **1.008 t/km^2.**

Production: Biomass

Mortality for yellowtail flounder was calculated from adding natural mortality and fishing mortality (Table 62). Natural mortality was calculated using Hoenigs equation (eq.5) for estimating fish mortality with the assumption of a maximum age of 12 years (Bowering and Brodie 1991).

Table 62 Production to Biomass ratio calculations for 3LNO yellowtail flounder (*Pleuronectes ferruginea*) for the 2018-2020 time period.

Model	Natural mortality (M)	Fishing mortality (F) (Catch/ Biomass)	*P/B* (Z)
3LNO	0.35	0.04119	**0.3912**

Consumption: Biomass

Based on mean calculations made in Bundy et al (2000), *Q/B* for yellowtail flounder in the 3LNO region is **3.6**.

Diet

Adjusted from the 2013-2015 model from Tam and Bundy (2019) with information from the RV survey diet studies, which shows sandlance as a top prey type, and not as much emphasis on *predatory invertebrates*.

Table 63 Diet composition for yellowtail flounder in 3LNO. Adapted from Tam and Bundy (2019).

Yellowtail flounder	3LNO
Sandlance	0.1
Predatory invertebrates	0.609
Deposit feeding invertebrates	0.15
Suspension feeding invertebrates	0.07
Macrozooplankton	0.064
Large mesozooplankton	0.007

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. Yellowtail flounder catch was **0.0174 t/km^2/yr** in 3LNO.

2.4.14 Witch flounder

Witch flounder *(Glyptocephalus cynoglossus*) are a deepwater flatfish with a range from the southern United States to Newfoundland, Canada. Witch flounder are usually found on soft substrates between 100-400 m depth and reach a maximum size of 78 cm. The 2J3KL stock has been under moratorium in Canadian waters since 1995, with most catch occurring as bycatch (DFO 2018).

Biomass

The latest stock assessment for the 2J3KL stock covers until 2017, with an annual estimated biomass of 17,200t for the entirety of 2J3KL (DFO 2018). Biomass estimates in just 3L were a mean 5450t (CI 2215t – 8750t), meaning for my models I am estimating approximately 11,750t for 2J3K. NAFO surveys in the 3NO region estimate an annual average biomass of 10,689t for the 2018-2020 time period. Adding the additional estimate of 3L biomass to the 3NO estimate, gives an estimate of 16,139t.

Table 64 Biomass estimates for 2J3K and 3LNO witch flounder for the 2018-2020 time period.

Model	Biomass (t)	Biomass (t/km^2)
2J3K	11,750	**0.06**
3LNO	16,139	**0.063**

Production: Biomass

Estimates of natural mortality for Witch flounder was derived from Hoenig's (1983) equation for estimating fish mortality (Eq. 5) with an assumed max age of of 25 (Robins and Ray 1986). Fishing mortality was calculated as catch divided by total biomass.

Table 65 Production to Biomass ratio calculations for 2J3K and 3LNO witch flounder (*Glyptocephalus cynoglossus*) for the 2018-2020 time period.

Model	Natural mortality (M)	Fishing mortality (F) (Catch/ Biomass)	*P/B* (Z)
2J3K	0.1668	0.00528	**0.17208**
3LNO	0.1668	0.02999	**0.1968**

Consumption: Biomass

The *Q/B* ratio for Witch flounder was taken from Bundy et al (2000), where they calculated **2.599 yr^{-1}** based on values found in literature.

Diet

Taken from the 2013-2015 model from Tam and Bundy (2019). More emphasis was added to *deposit feeding invertebrates* instead of *predatory invertebrates* because of the prevalence of polychaetes in their diet observed from the RV survey data.

Table 66 Diet composition for witch flounder in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Witch flounder	2J3K	3LNO
Small benthivorous fish	0.009	0.009
Shrimp	0	0
Snow crab	0.001	0.001
Predatory invertebrates	0.211	0.211
Deposit feeding invertebrates	0.5	0.5
Suspension feeding invertebrates	0.278	0.278
Large mesozooplankton	0.001	0.001

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. Catch for Witch Flounder was **0.00026 t/km^2/y** in 2J3K, and **0.002988 t/km^2/y** for 3LNO.

2.4.15 Other Medium benthivorous fish

Other medium bethivorous fish are defined as fish that consume benthic prey such as crustaceans and other small invertebrates with maximum mean size between 45 cm and 80 cm. The list of species included in this functional group can be found in Table 67.

Table 67 List of *other medium benthivorous fish* adapted from Tam and Bundy (2019).

Common name	Order	Latin name
Duckbill	Anguilliformes	*Nessorhamphus ingolfianus*
Shortnose snipe eel	Anguilliformes	*Serrivomer beani*
Snubnosed eel	Anguilliformes	*Simenchelys parasiticus*
Kaup’s arrowtooth eel	Anguilliformes	*Synaphobranchus kaupi*
Deepsea cat shark	Carchariniformes	*Apristurus profundorum*
Blue hake	Gadiformes	*Antimora rostrata*
Longnose grenadier	Gadiformes	*Coelorinchus caelorhincus*
Roundnose grenadier	Gadiformes	*Coryphaenoides rupestris*
Blue whiting	Gadiformes	*Micromesistius poutassou*
Moras	Gadiformes	Moridae (Family)
Mora	Gadiformes	*Halargyreus affinis*
Mora	Gadiformes	*Halargyreus johnsonii*
Red (Squirrel) hake	Gadiformes	*Urophycis chuss*
Halosaurus	Notacanthiformes	Halosauridae (Family)
Lipogenys	Notacanthiformes	*Lipogenys gillii*
Bigeyes	Perciformes	Priacanthidae (Family)
Winter flounder	Pleuronectiformes	*Pseudoplueronectes americanus*
Little skate	Rajiformes	*Raja erinacea*
Deepwater (Round) skate	Rajiformes	*Raja fyllae*
Soft skate	Rajiformes	*Raja mollis*
Smooth skate	Rajiformes	*Raja senta*
Common lumpfish	Scorpaeniformes	*Cyclopterus lumpus*
Fish doctor	Scorpaeniformes	*Gymnelis viridis*
Sea raven	Scorpaeniformes	*Hemitripterus americanus*
Snakeblenny	Scorpaeniformes	*Lumpenus lampretaeformis*
Snakeblennies	Scorpaeniformes	*Lumpenus sp.*
Esmark's eelpout	Scorpaeniformes	*Lycodes esmarki*
Arctic eelpout	Scorpaeniformes	*Lycodes reticulatus*
Vahl's eelpout	Scorpaeniformes	*Lycodes vahlii*
Longhorn sculpin	Scorpaeniformes	*Myoxocephalus octodecemspinosus*
Fourhorn sculpin	Scorpaeniformes	*Myoxocephalus quadricornis*
Shorthorn sculpin	Scorpaeniformes	*Myoxocephalus scorpius*
Ribbed (Horned) sculpin	Scorpaeniformes	*Myoxocephalus sp.*

Biomass

Biomass information for *other medium benthivorous fish* was calculated from stratified RV survey data, averaged by year and NAFO division using the Rstrap package (Table 68).

Table 68 Biomass estimates for 2J3K and 3LNO *other medium benthivorous fish* for the 2018-2020 time period.

Model	Biomass (t)	Biomass (t/km^2)
2J3K	91,476	0.385
3LNO	82,368	0.32

Production: Biomass and Consumption: Biomass

An estimate of **0.4 yr^{-1}** was used based on Bundy et al (2000) estimate for small demersal feeders. Bundy et al (2000) assumed a ratio of 0.15 between production and consumption, resulting in a *Q/B* of **2.0 yr^{-1}.**

Diet

Diet matrix modified from the 2013-2015 model in Tam and Bundy (2019) (Table 69).

Table 69 Diet composition for *other medium benthivorous fish* in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Other medium benthivorous fish	2J3K	3LNO
Redfish	0.005	0.005
Small benthivorous fish	0.079	0.079
Sandlance	0.03	0.03
Capelin	0.048	0.048
Other planktivorous fish	0.061	0.061
Shrimp	0.01	0.01
Predatory invertebrates	0.123	0.123
Deposit feeding invertebrates	0.185	0.185
Suspension feeding invertebrates	0.209	0.209
Macrozooplankton	0.235	0.235
Small mesozooplankton	0.015	0.015

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. There was no reported catch for any medium benthivorous fish species in 2J3K, and a small amount of catch reported in 3LNO consisting of red hake (*Urophycis chuss*) and roundnose grenadier (*Coryphaenoides rupestris*), for a total catch of **0.000158 t/km^2/y.**

2.4.16 Small benthivorous fish

Small bethivorous fish are defined as fish that consume benthic prey such as crustaceans and other small invertebrates with maximum mean size less than 45 cm. The list of species included in this functional group can be found in Table 70.

Table 70 List of *small benthivorous fish* adapted from Tam and Bundy (2019).

Common name	Order	Latin name
Sherborn's cardinalfish	Acropomatiformes	*Howella sherboni*
Tubeshoulder	Alepocephaliformes	*Platytroctes apus*
Slickheads	Alepocephaliformes	*Xenodermichthys copei*
Goitre blacksmelt	Argentiniformes	*Bathylagus euryops*
Deepsea smelt	Argentiniformes	*Bathylagidae (Family)*
Greenland argentine	Argentiniformes	*Nansenia groenlandica*
Alfonsino	Beryciformes	*Beryx decadactylus*
Ridgeheads	Beryciformes	Melamphaidae (Family)
Four-bearded rockling	Gadiformes	*Enchelyopus cimbrius*
Three-bearded Rockling	Gadiformes	*Gaidropsarus vulgaris*
North Atlantic codling	Gadiformes	*Lepidion eques*
Common grenadier	Gadiformes	*Nezumia bairdi*
Roughnose grenadier	Gadiformes	*Trachyrhynchus murrayi*
Grenadiers	Gadifomes	Macrouridae (Family)
Warted sea devil	Lophiiformes	*Cryptosaras couesi*
Atlantic batfish	Lophiiformes	*Dibranchus atlanticus*
Smallmouth spiny eel	Notacanthiformes	*Polyacanthonotus rissoanus*
Greenland manefish	Scombriformes	*Caristius fasciatus*
Black swallower	Scombriformes	*Chiasmodon niger*
Butterfish	Scombriformes	Stromateidae (Family)
Hookear Sculpin	Scorpaeniformes	*Artediellus* sp.
Common alligatorfish	Scorpaeniformes	*Aspidophoroides monopterygius*
Arctic alligatorfish	Scorpaeniformes	*Aspidophoroides olriki*
Polar deepsea sculpin	Scorpaeniformes	*Cottunculus microps*
Pallid deepsea sculpin	Scorpaeniformes	*Cottunculus thompsoni*
Fourline Snakeblenny	Scorpaeniformes	*Eumesogrammus praecisus*

Lumpsuckers	Scorpaeniformes	*Eumicrotremus sp.*
Arctic Staghorn sculpin	Scorpaeniformes	*Gymnocanthus tricuspis*
Spatulate sculpin	Scorpaeniformes	*Icelus spatula*
Twohorn Sculpin	Scorpaeniformes	*Icelus sp.*
Atlantic alligatorfish	Scorpaeniformes	*Leptagonus decagonus*
Daubed shanny	Scorpaeniformes	*Leptoclinus maculatus*
Eelpouts	Scorpaeniformes	*Lycenchelys sp.*
Soft eelpout	Scorpaeniformes	*Melanostigma atlanticum*
Grubby	Scorpaeniformes	*Myoxocephalus aenaeus*
Arctic sculpin	Scorpaeniformes	*Myoxocephalus scorpioides*
Mailed Sculpins	Scorpaeniformes	*Triglops sp.*
Alligatorfish and Poachers	Scorpaeniformes	Agonidae (Family)
Sculpins	Scorpaeniformes	Cottidae (Family)
Seasnails	Scorpaeniformes	Liparidae (Family)
Gunnels	Scorpaeniformes	Pholidae (Family)
Anglemouths	Stomiiformes	*Cyclothone sp.*
Bristlemouths	Stomiiformes	*Gonostoma sp.*
Stoplight loosejaw	Stomiiformes	*Malacosteus niger*
Lightfishes	Stomiiformes	Gonostomatidae (Family)
Hatchetfishes	Stomiiformes	Sternoptychidae (Family)
Fangtooth	Trachichthyiformes	*Anoplogaster cornuta*
Spinyfin	Trachichthyiformes	*Diretmus argenteus*
Slimeheads	Trachichthyiformes	*Hoplostethus sp.*

Biomass

The Ecotrophic efficiency was set to **0.98** to allow Ecopath to estimate the biomass of *small benthivorous fish*, due to assumed underestimations in the RV survey. This resulted in a biomass estimation of **2.54 t/km^2** in 2J3K, and **1.65 t/km^2** in 3LNO.

Production: Biomass

Due to an inconsequential amount of catch in either study areas, the *P/B* ratio for *small benthivorous fish* was based on only natural mortality. Natural mortality for the group was calculated using Hoenig's (1983) equation for estimating fish mortality (Eq. 5) with a weighted average max age of 10, resulting in an M of **0.45 yr^{-1}.**

Consumption: Biomass

A *Q/B* ratio developed by Bundy et al (2000) of **2.0 yr^{-1}** was used for both models.

Diet

Diet matrix taken from the 2013-2015 model in Tam and Bundy (2019) (Table 71).

Table 71 Diet composition for *small benthivorous fish* in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Small benthivorous fish	2J3K	3LNO
Small benthivorous fish	0.003	0.001
Sandlance	0.005	0.05
Capelin	0.021	0.002
Other planktivorous fish	0.003	0.02
Shrimp	0.002	0.002
Predatory invertebrates	0.305	0.149
Deposit feeding invertebrates	0.326	0.5
Suspension feeding invertebrates	0.229	0.08
Macrozooplankton	0.01	0.1
Large mesozooplankton	0.048	0.048
Small mesozooplankton	0.048	0.048

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. There was no reported catch for any *small benthivorous fish* species in 2J3K, and a small amount of three-bearded rockling (*Gaidropsarus vulgaris*) catch reported for 3LNO of **$6.47x10^{-6}$ $t/km^2/y$.**

2.4.17 Herring

Atlantic herring (*Clupea harengus)* are small planktivorous pelagic fish that school in large numbers throughout the Atlantic. In Newfoundland, the herring fishery is divided into five stock complexes. The White Bay-Notre Dame Bay stock falls within 3K, the Bonavista Bay-Trinity Bay, Conception Bay-Southern Shore, and part of the St. Mary's Bay-Placentia Bay stock falls within 3L and 3O, with the Fortune Bay stock falling within 3Ps. Herring also exist in low abundances farther north in 2GHJ, however they are not closely monitored by DFO (DFO 2019).

Biomass

The Ecotrophic efficiency was set to **0.98** to allow Ecopath to estimate the biomass of herring, due to assumed underestimations in the RV survey. This resulted in a biomass estimation of **2.21 t/km^2** for 2J3K and **2.24 t/km^2** for 3LNO.

Production: Biomass and Consumption: Biomass

Similar to *other planktivorous fish*, an assumed instantaneous total mortality was **1.15 yr^{-1}.** The *Q/B* ratio for Atlantic herring was based off of an estimate from Bundy (2000) who used **3.15 yr^{-1}**. This value was used for both models.

Diet

Diet matrix modified from the 2013-2015 model in Tam and Bundy (2019) (Table 72).

Table 72 Diet composition for herring in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Herring	2J3K	3LNO
Other planktivorous fish	0.25	0.25
Predatory invertebrates	0.123	0.123
Deposit feeding invertebrates	0.1	0.1
Macrozooplankton	0.427	0.427
Large mesozooplankton	0.1	0.1

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. Catch for Atlantic Herring was **0.01 t/km^2/y** in 2J3K, and **0.0032 t/km^2/y** for 3LNO.

2.4.18 Sandlance

Sandlance (*Ammodytes dubius*) are a small semi-demersal forage fish that can be found on sandy substrate from western Greenland to North Carolina. While there is no commercial fishery for sandlance, they have been identified as an important forage species for Atlantic Cod and American plaice, especially on the Grand Banks (Morrison 2021).

Biomass

The Ecotrophic efficiency was set to **0.98** to allow Ecopath to estimate the biomass of sandlance, due to assumed underestimations in the RV survey. This resulted in a biomass estimation of **1.93 t/km^2** for 2J3K and **4.84 t/km^2** for 3LNO.

Production: Biomass and Consumption: Biomass

Estimates of natural mortality for sandlance was derived from Winters (1983), who estimated a *Z* for sandlance on the grand bank to be **1.15 yr^{-1}**. This estimate was used for both models. Bundy et al (2000) estimated a 0.15 gross growth ratio between production and consumption, resulting in a *Q/B* estimation of **7.66 yr^{-1}.**

Diet

Diet matrix taken from the 2013-2015 model in Tam and Bundy (2019) (Table 73).

Table 73 Diet composition for sandlance in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Sandlance	2J3K	3LNO
Capelin	0.002	0.002
Predatory invertebrates	0.178	0.178
Deposit feeding invertebrates	0.004	0.004
Suspension feeding invertebrates	0.002	0.002
Macrozooplankton	0.17	0.17
Large mesozooplankton	0.5	0.5
Small mesozooplankton	0.144	0.144

Catch

There was no reported commercial catch of sandlance for either area in 2018-2020.

2.4.19 Capelin

Capelin *(Mallotus villosus)* are considered the most important forage fish for the Newfoundland and Labrador ecosystem. They are a slender pelagic fish between 13-20 cm in length, with a circumpolar distribution. Most capelin are semelparous and have short life spans, rarely living longer than 5 years. Capelin are assessed as two stocks, one in 2J3KL and another in 3NO with the major difference being the 2J3KL stock migrates to inshore beaches to annually spawn whereas the 3NO stock spawns offshore (DFO 2022).

Biomass

Capelin and other small pelagic forage fish are often underrepresented from RV surveys, so often acoustic surveys will be used to provide estimates of biomass. However, the acoustic surveys only occur in divisions 3L and southern 3K. To give an accurate estimate of capelin for both study areas, Tam and Bundy (2019) used the acoustic survey estimates to prorate RV survey data in other divisions. Using a similar method, estimates for 2J3K and 3LNO were obtained (Table 74).

According to the 2022 stock assessment for Capelin (DFO 2022), there was a large spike in capelin biomass in 2015, which would be captured in the average of the 2013-2015 model in Tam and Bundy (2019). Therefore, I expected the estimate for both areas would be lower than their 2013-2015 estimate of 4.97 t/km^2.

Table 74 Biomass estimates for 2J3K and 3LNO capelin for the 2018-2020 time period.

Model	Biomass (t)	Biomass (t/km^2)
2J3K	700,920 t	3.05
3LNO	929,214 t	3.5

Production: Biomass and Consumption: Biomass

A *P/B* ratio of **1.2 yr^{-1}** was calculated by DFO (2022d). *P/B* estimates were based on Bundy et al. (2000), who assumed a daily consumption rate of 2% with a feeding period of 7 months, which resulted in a *Q/B* of **4.3 yr^{-1}**.

Diet

Adapted from the 2013-2015 model from Tam and Bundy (2019).

Table 75 Diet composition for capelin in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Capelin	2J3K	3LNO
Predatory invertebrates	0.005	0.005
Suspension feeding invertebrates	0.04	0.04
Macrozooplankton	0.2	0.2
Large mesozooplankton	0.53	0.53
Small mesozooplankton	0.2	0.2
Microzooplankton	0.025	0.025

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. Catch for capelin was **0.0113 t/km^2/y** for 2J3K and **0.0194 t/km^2/y** for 3LNO.

2.4.20 Other planktivorous fish

Other planktivorous fish are defined as fish who have plankton as a primary component of their diet. The list of species included in this functional group can be found in table 76.

Table 76 List of *other planktivorous fish* adapted from Tam and Bundy (2019)

Common name	Order	Latin name
Atlantic argentine	Argentiniformes	*Argentina silus*
Striated argentine	Argentiniformes	*Argentina striata*
Slickhead/ Smooth head	Argentiniformes	*Bathytroctes sp.*
Atlantic saury	Beloniformes	*Scomberesox saurus*
Whalefishes	Cetomimiformes	Rondeletiidae
Alewife	Clupeiformes	*Alosa pseudoharengus*
Fourspine stickleback	Gasterosteiformes	*Apeltes quadracus*
Threespine stickleback	Gasterosteiformes	*Gasterosteus aculateus*
Sticklebacks	Gasterosteiformes	Numerous
Basking shark	Lamniformes	*Cetorhinus maximus*
Lanternfishes	Myctophiformes	Myctophidae
Atlantic mackerel	Scombriformes	*Scomber scombrus*
Radiated shanny	Scorpaentiformes	*Ulvaria subbifurcata*

Biomass

The Ecotrophic efficiency was set to **0.95** to allow Ecopath to estimate the biomass of *other planktivorous fish*, due to assumed underestimations in the RV survey. This resulted in a biomass estimation of **3.06 t/km^2** for 2J3K and **3.245 t/km^2** for 3LNO.

Production: Biomass and Consumption: Biomass

Due to limited data on production or total mortality of *other planktivorous fish*, the value used in Tam and Bundy (2019) of **1.15 yr^{-1}** was used for both models as well. The value is based on the known values for herring, sandlance and capelin who are all also planktivorous fish. A *Q/B* of **4.19 yr^{-1}** from Tam and Bundy (2019) is used for both models.

Diet

Diet matrix for *other planktivorous fish* was adapted from the 2013-2015 model from Tam and Bundy (2019) (Table 77).

Table 77 Diet composition for *other planktivorous fish* in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Other planktivorous fish	2J3K	3LNO
Shrimp	0	0.01
Suspension feeding invertebrates	0.04	0.04
Large mesozooplankton	0.349	0.349
Small mesozooplankton	0.15	0.15
Microzooplankton	0.08	0.08
Large Phytoplankton	0.25	0.25
Small Phytoplankton	0.121	0.121

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. Catch for the *other planktivorous fish* group is represented by only Atlantic mackerel (*Scomber scombrus*). Catch was **0.01966 t/km^2/y** for 2J3K and **0.0001787 t/km^2/y** for 3LNO.

2.5 Invertebrate groups

Over 11 species of invertebrate have had a commercial or recreational fishery regulated by DFO within 2J3K and/or 3LNO. Due to the economic and ecological interest of these species, many of them have their own functional group in this model, while other invertebrates aggregated into groups based on their feeding habits (i.e., predatory, suspension feeding or deposit feeding). Most biomass estimates are derived from the DFO stock assessment documents, which often contain biomass estimates for commercially harvested species such as shrimp or snow crab. Non-commercially harvested invertebrates often do not have updated estimates of biomass, so information from previous models was used. Commercial catch data for all groups was obtained from the NAFO STATLANT 21A database.

2.5.1 Squid

The squid functional group predominantly includes Northern shortfin squid (*Illex illecebrosus*) but also other species of octopus and squid such as *Cirroctopus* sp., *Octopod* sp. and *Logio* sp.. The squid stock is managed by NAFO, and apart from a small inshore jig fishery in divisions 3+, there is no targeted squid fishery in Newfoundland.

Northern shortfin squid are highly migratory, with populations seasonally moving from southern Florida, where winter spawning occurs, to northern Newfoundland and Labrador. Larvae and young squid are advected via the Gulf Stream to the coast of Newfoundland in time to feed on the spring bloom. Seasonal abundance of squid in the study area seems to be related to local environmental conditions, with higher abundances of squid occurring in warmer years with less ice coverage (Dawe and Colbourne 1997).

Biomass

Biomass estimates were originally obtained from the R-strap estimates, which encompassed all squid and octopus observations recorded for 2018-2020 resulting in 0.0075 t/km^2 for 2J3K and 0.0114 t/km^2 for 3LNO. During model balancing, it was determined these estimates were too low and they were raised (See section 4.1.2 balancing the model) (Table 78).

Table 78 Biomass estimates for 2J3K and 3LNO squid for the 2018-2020 time period.

Model	Biomass (t)	Biomass (t/km^2)
2J3K	95,040	0.4
3LNO	154,440	0.6

Production: Biomass and Consumption: Biomass

P/B for squid was based off of the Araujo and Bundy (2011) Scotian Shelf model, which used an estimate of **3.4 yr^{-1}.** This value was used for both models. Similar to the *P/B* ratio, the *Q/B* ratio was also obtained from the Araujo and Bundy (2011) Scotian Shelf model, which estimated a *Q/B* of **13.2 yr^{-1}.** This value was used for both models.

Diet

Adapted from the 2013-2015 model from Tam and Bundy (2019) (Table 79).

Table 79 Diet composition for squid in 2J3K and 3LNO. Adapted from Tam and Bundy (2019).

Squid	2J3K	3LNO
Redfish	0.004	0.004
Arctic cod	0.004	0.004
Herring	0.02	0.02
Sandlance	0.004	0.004
Other planktivorous fish	0.004	0.004
Shrimp	0.001	0.001
Predatory invertebrates	0.075	0.075
Deposit feeding invertebrates	0.025	0.025
Suspension feeding invertebrates	0.025	0.025
Macrozooplankton	0.813	0.813
Large mesozooplankton	0.025	0.025

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. Catch for Northern shortfin squid was **0.00545 t/km^2/y** in 2J3K and **0.00526 t/km^2/y** in 3LNO.

2.5.2 Shrimp

The shrimp functional group includes all species in the *Pandalus* genus, dominated by *Pandalus borealis*, or Northern shrimp. Northern shrimp preferred habitat includes soft muddy substrate and a water temperature range of 1 °C to 6 °C, which correspond to depths of approximately 150-600 m throughout the Newfoundland and Labrador Shelf (DFO 2021c). Northern shrimp are protandrous hermaphrodites, with juveniles developing and maturing as males before changing sex to mature females around three years of age. This results in most of the fishable biomass of shrimp being female, but the exact proportion varies by year and location. The shrimp fishery is divided into seven shrimp fishing areas (SFAs) that extend from Devon Island (NAFO division 0) to southern Newfoundland (NAFO division 3L). The majority of shrimp biomass and catch occurs in SFAs 4-6 (NAFO divisions 2GHJ3K) (DFO 2021c).

Biomass

Biomass estimates for 2J3K were derived from the estimated exploitable biomass index from the DFO stock assessment for Northern shrimp (DFO 2021c), an average was taken for each area between the years of 2018-2019. The 95% confidence interval was noted for each year, to provide a range of values to work with while balancing the model.

Biomass estimate for 3LNO were derived from a combination of the Northern shrimp stock assessment and the NAFO assessment of offshore 3LNO shrimp based on Spanish trawl survey data (Román and Álvarez 2018). Both documents point to a significantly lower biomass of shrimp south of the 3K boundary, with most of the biomass occurring in 3L (Table 80).

Table 80 Biomass estimates for 2J3K and 3LNO shrimp for the 2018-2020 time period.

Model	Biomass (t)	Biomass (t/km^2)
2J3K	72,947.64	0.585
3LNO	171,653.5	0.12

Production: Biomass and Consumption: Biomass

A *P/B* ratio of **1.7 yr^{-1}** is estimated in the DFO stock assessment for shrimp (DFO 2021c), and is used in both models here. Assuming a 0.15 growth efficiency results in *Q/B* of **11.33 yr^{-1}**.

Diet

Diet matrices adapted from the 2013-2015 model in Tam and Bundy (2019) (Table 81).

Table 81 Northern shrimp diet for 2J3K and 3LNO in the 2018-2020 time period. Adapted from Tam and Bundy (2019)

Shrimp	2J3K	3LNO
Predatory invertebrates	0.06	0.06
Deposit feeding invertebrates	0.05	0.05
Suspension feeding invertebrates	0.012	0.012
Large mesozooplankton	0.05	0.05
Small mesozooplankton	0.05	0.05
Microzooplankton	0.078	0.078
Small Phytoplankton	0.4	0.4
Detritus	0.3	0.3

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. Catch for shrimp was **0.0466 $t/km^2/y$** in 2J3K, and **0 $t/km^2/y$** in 3LNO.

2.5.3 Snow crab

Snow crab *(Chionoectes opilio*) has become one of the most economically important fisheries in Newfoundland since the groundfish moratorium in the 1990s (DFO 2022a). Snow crab undergo several molts as they are maturing. While female crab reach sexual maturity when they experience their terminal moult, male crab may reach sexual maturity before their terminal moult into adulthood. Only mature male crab grow large enough to recruit into the fishery, and therefore represent 100% of the exploitable biomass (DFO 2022e). Snow crab undergo up and down slope migrations throughout their life cycle, with younger crab commonly found on deep, warm, soft substrate habitats and older crab in shallower, colder, hard substrate habitats (DFO 2022e). They can be found throughout both study areas, 2J3K and 3LNO.

Biomass

Biomass estimates were derived from the estimated exploitable biomass index from the snow crab stock assessment (DFO 2022e), an average was taken for each area between the years of 2018-2020. The 95% confidence interval was noted for each year, to provide a range of values to work with while balancing the model (Table 82).

Table 82 Biomass estimates for 2J3K and 3LNO snow crab for the 2018-2020 time period.

Model	Biomass (t)	Biomass (t/km^2)
2J3K	26,914.52	0.24
3LNO	59,275.04	0.43

Production: Biomass and Consumption: Biomass

Tam and Bundy (2019) based their *P/B* estimate off of a DFO stock assessment estimate of mortality at 0.46 yr^{-1}, based on the most recent stock assessment (DFO 2022) the total mortality index has increased since 2013-2015 so a *P/B* of **0.5 yr^{-1}** was used for both models. Assuming a 0.15 growth efficiency, results in a *Q/B* of **3.06 yr^{-1}** which was used in both models.

Diet

Taken from the 2013-2015 model from Tam and Bundy (2019) (Table 83).

Table 83 Snow crab diet for 2J3K and 3LNO in the 2018-2020 time period. Adapted from Tam and Bundy (2019)

Snow Crab	2J3K	3LNO
Small benthivorous fish	0.096	0.096
Shrimp	0.02	0.02
Predatory invertebrates	0.302	0.302
Deposit feeding invertebrates	0.302	0.302
Suspension feeding invertebrates	0.126	0.126
Macrozooplankton	0.01	0.01
Large mesozooplankton	0.024	0.024
Small mesozooplankton	0.01	0.01
Large Phytoplankton	0.01	0.01
Detritus	0.1	0.1

Catch

In the 2018-2020 time period, landings in Newfoundland reached a 25 year low in 2019 (26,400t) (DFO 2022) and fishing effort was also at historic lows in 2020.

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. Catch for snow crab was **0.0129 t/km^2/y** in 2J3K, and **0.0197 t/km^2/y** in 3LNO.

2.5.4 Predatory invertebrates, Deposit feeding invertebrates, and Suspension feeding invertebrates

The *predatory invertebrates* functional group includes lobster, other crab species, and other crustaceans.

The *deposit feeding invertebrates* functional group includes urchins, sand dollars, polychaetes, chaetognaths, and isopods.

The *suspension feeding invertebrates* functional group includes sponges, corals, bivalve molluscs, sea anemones, brittle / basket stars, and ascidians.

Biomass, production and consumption

Biomass estimates for all three invertebrate groups were based on estimates from Tam and Bundy (2019), who assessed the invertebrate structure based on the 2006 RV survey. Estimates were adjusted slightly during balancing (See section 4.1.2 balancing the model) (Table 84).

P/B ratios for *predatory invertebrates* were based on estimated made by Araujo and Bundy (2011) for the Scotian Shelf model. The *P/B* ratio for *deposit feeding invertebrates* and *suspension feeing invertebrates* was based on an average value used in Tam and Bundy (2019) from other Ecopath models in the area (Araujo and Bundy 2011, Bundy et al. 2000) (Table 84).

The *Q/B* ratios were based on the assumption that the *P/Q* ratio is 0.15 yr^{-1} (Christensen 1995) (Table 84).

Table 84 Biomass, *P/B* and *Q/B* estimates for invertebrate groups in the 2J3K and 3LNO model during the 2018-2019 time period.

Model	Group	Biomass (t/km2)	*P/B* (yr^{-1})	*Q/B* (yr^{-1})
2018-2020 (2J3K)	Predatory invertebrates	20	2.5	8.733
2018-2020 (2J3K)	Deposit feeding invertebrates	85	2.5	9.1
2018-2020 (2J3K)	Suspension feeding invertebrates	61	0.95	3.7
2018-2020 (3LNO)	Predatory invertebrates	20	2.5	8.733
2018-2020 (3LNO)	Deposit feeding invertebrates	85	2.5	10
2018-2020 (3LNO)	Suspension feeding invertebrates	61	1.4	3.7

Diet

Diet matrices adapted from the 2013-2015 model from Tam and Bundy (2019). Adjustments were made to reduce shrimp predation, with more emphasis on plankton groups (Table 85 and 86).

Table 85 Diet for invertebrate groups in 2J3K for the 2018-2020 time period.

	Predatory Inverts	Deposit feeding inverts	Suspension feeding inverts
Small benthivorous fish	0.001	0.000	0
Predatory invertebrates	0.195	0.000	0
Deposit feeding invertebrates	0.200	0.202	0
Suspension feeding invertebrates	0.120	0.030	0
Macrozooplankton	0.060	0.010	0
Large mesozooplankton	0.024	0.000	0
Small mesozooplankton	0.010	0.000	0
Microzooplankton	0.180	0.120	0
Large Phytoplankton	0.010	0.000	0
Detritus	0.200	0.638	1

Table 86 Diet for invertebrate groups in 3LNO for the 2018-2020 time period.

	Predatory Inverts	Deposit feeding inverts	Suspension feeding inverts
Small benthivorous fish	0.001	0.000	0
Predatory invertebrates	0.195	0.000	0
Deposit feeding invertebrates	0.200	0.202	0
Suspension feeding invertebrates	0.120	0.070	0
Macrozooplankton	0.060	0.010	0
Large mesozooplankton	0.024	0.000	0
Small mesozooplankton	0.010	0.000	0
Microzooplankton	0.180	0.100	0
Large Phytoplankton	0.010	0.000	0
Detritus	0.200	0.618	1

Catch

Catch data for 2018-2019 was obtained from the NAFO STATLANT 21A database for both study areas. *Predatory invertebrates* catch includes crustaceans such as lobster and rock crab, as well as predatory gastropods such as whelk. Catch for *predatory invertebrates* in 2J3K was **0.001761 t/km^2/y** and **0.00133 t/km^2/y** in 3LNO.

Deposit feeding invertebrates catch is only comprised of catch from a commercial sea urchin fishery in the 2J3KLPns NAFO area, where urchins are all harvested by hand. Catch for sea urchin in 2J3K was **0.0001 t/km^2/y** and **0.0004 t/km^2/y** in 3LNO.

Suspension feeing invertebrates catch include bivalves such as Icelandic scallop, ocean quahog, and surf clam which all have off-shore fisheries in the Newfoundland and Labrador region. Catch for *suspension feeding invertebrates* in 2J3K was **3.09 x 10^{-5} t/km^2/y** and **0.0642 t/km^2/y** in 3LNO.

2.6 Plankton groups

Zooplankton and phytoplankton play important roles in the ecosystem, providing a source of organic carbon and nutrients to higher trophic levels. In the Newfoundland and Labrador system, the copepod *Calanus finmarchicus* is one of the most abundant species, and considered one of the most important species due to its role as a nutritional prey item for the majority of plankton eating organisms in Newfoundland (Marshall and Orr 2013).

Zooplankton groups for the model are separated into size classes of macrozooplankton, large mesozooplankton, small mesozooplankton, and microzooplankton, and phytoplankton is separated into large and small celled phytoplankton. Plankton data and advice was provided by David Belanger (DFO).

2.6.1 Macrozooplankton, Large mesozooplankton, Small mesozooplankton, and Microzooplankton

Macrozooplankton consisted of gelatinous zooplankton, non-pandalus shrimp, Euphausiids and Amphipods.

Large mesozooplankton consisted primarily of large copepods (*Calanus finmarchicus, Calanus hyperboreus*, *Calanus glacialis*, calanoid nauplii and *Metridia* sp.).

Small mesozooplankton consisted of small copepod species (*Microcalanus* sp., *Oithona atlantica*, *Oithona similis*, *Centropages* sp., *Spinocalanus* sp., *Pseudocalanus* sp., *Triconia* sp., *Chiridius gracilis*, *Arctia* sp., *Paracalanus parvus*).

Microzooplankton are a group of heterotrophic and mixotrophic planktonic organisms. Important contributors to the group are phagotrophic protists such as flagellates, dinoflagellates, ciliates, acantharids, radiolarians, foraminiferans and metazoans such as copepod nauplii, rotiferans and meroplanktonic larvae.

Biomass, Production: Biomass , and Consumption: Biomass

All parameters used for the zooplankton groups are listed in Table 87, with *P/B,* and *Q/B* ratios based on estimates from Tam and Bundy (2019).

Macrozooplankton biomass was estimated by Ecopath at an EE of **0.98**.
For all other groups, zooplankton abundance data was provided by David Belanger from the continuous zooplankton monitoring program. The dry weight of the zooplankton was obtained from a literature review of the species listed above and their various life stages. Zooplankton abundance was multiplied by the dry weight and converted to a wet weight using a conversion factor from Raymont (1980). The resulting estimates were compared to the Tam and Bundy

(2019) 2013-2015 model and adjusted with the understanding that zooplankton biomass overall has increased since 2015 in both areas (DFO 2021a).

Table 87 Biomass, *P/B* and *Q/B* estimates for zooplankton groups in the 2J3K and 3LNO model during the 2018-2019 time period.

Model	Group	Biomass (t/km^2)	*P/B* (yr^{-1})	*Q/B* (yr^{-1})
2018-2020 (2J3K)	Macrozooplankton	17.88	3.43	19.5
2018-2020 (2J3K)	Large mesozooplankton	14.0	10.0	28.0
2018-2020 (2J3K)	Small mesozooplankton	5.5	33.0	105.4
2018-2020 (2J3K)	Microzooplankton	5.36	73.0	240
2018-2020 (3LNO)	Macrozooplankton	18.25	3.43	19.5
2018-2020 (3LNO)	Large mesozooplankton	15.4	10.0	28.0
2018-2020 (3LNO)	Small mesozooplankton	5.1	33.0	105.4
2018-2020 (3LNO)	Microzooplankton	5.6	72.00	240

Diet

Adapted from the 2013-2015 model from Tam and Bundy (2019) (Table 88 and 89).

Table 88 Zooplankton diet for 2J3K in the 2018-2020 time period.

	Macrozooplankton	Large mesozooplankton	Small mesozooplankton	Micro-zooplankton
Macrozooplankton	0	0.03	0	0
Large mesozooplankton	0.051	0.118	0.05	0
Small mesozooplankton	0.149	0.179	0.05	0
Microzooplankton	0.2	0.1	0.221	0
Large Phytoplankton	0.25	0.12	0.262	0.3
Small Phytoplankton	0.25	0.12	0.342	0.65
Detritus	0.1	0.333	0.075	0.05

Table 89 Zooplankton diet for 3LNO in the 2018-2020 time period.

	Macrozooplankton	Large mesozooplankton	Small mesozooplankton	Micro-zooplankton
Macrozooplankton	0	0.03	0	0
Large mesozooplankton	0.051	0.14	0.05	0
Small mesozooplankton	0.149	0.08	0.12	0
Microzooplankton	0.2	0.204	0.201	0
Large Phytoplankton	0.25	0.107	0.212	0.3
Small Phytoplankton	0.25	0.106	0.342	0.65
Detritus	0.1	0.333	0.075	0.05

2.6.2 Large phytoplankton and small phytoplankton

Phytoplankton were separated by size structure, with large phytoplankton referring to plankton between 20-200 μm and small phytoplankton referring to plankton between 0.2-20 μm.

Biomass and Production: Biomass

Biomass estimates for large and small phytoplankton were derived from data obtained from the PhytoFit R shiny application. Mean chlorophyll α concentrations from the surface layers of each study area were obtained from VIIRDS satellite images with 4km resolution (method Poly4) and separated by cell size, to give averages of large and small phytoplankton derived chlorophyll a for every week in 2018-2020. Chlorophyll α concentrations were converted to biomass estimates using a monthly chlorophyll: carbon conversion ratio from Hollibaugh and Booth (1981) (Table 90).

The *P/B* ratios for phytoplankton were the same as the 2013-2015 model in Tam and Bundy (2019), who received primary production estimates from a NL Shelf model (Table 90).

Table 90 Biomass and *P/B* ratio estimates for large and small phytoplankton.

Model	Group	Biomass (t/km2)	*P/B* (yr-1)
2018-2020 (2J3K)	Small Phytoplankton	11.785	106
2018-2020 (2J3K)	Large Phytoplankton	7.175	106
2018-2020 (3LNO)	Small Phytoplankton	15.8	106
2018-2020 (3LNO)	Large Phytoplankton	8.78	106

3. Results

3.1 <u>Model balancing</u>

3.1.1 Data sources

The quality of each data source was considered using the pedigree function during model balancing (Table 91 and 92). Biomass estimates were obtained from DFO or NAFO stock assessment documents, or from the research vessel (RV) random stratified sampling survey data when available, which were considered good data sources with relatively little uncertainty (Table 91 and 92). Many commercial species such as Atlantic cod, American plaice, Northern shrimp, and snow crab had stock assessments in both study areas. Forage fish such as capelin, herring, sandlance, and Arctic cod had less certain biomass estimates, as pelagic species are under sampled in RV surveys and robust acoustic surveys for pelagic species only covered portions of the study area. In the case of Atlantic herring, sandlance, and *other planktivorous fish*, biomass was estimated by Ecopath and was associated with a high level of uncertainty (Table 91 and 92). Cetacean biomass estimates were based on aerial surveys and opportunistic sightings, with many resident population species such as northern bottlenose whales not having formal estimates of population sizes. Harp seal biomass was obtained from DFO stock assessments but other seal data was based on estimates from the previous models.

Production to biomass ratios and consumption to biomass ratios are often empirical relationships, obtained from other studies or calculated based on equations found in the literature and have moderate uncertainty (Table 91 and 92).

The diet matrix from the 2013-2015 model was used as a baseline diet matrix for both models (Tam and Bundy 2019). As discussed for the 1985-1987 model, there was a high amount of uncertainty in the diet data for the 2J3KLNO study area, and compositions often did not account for seasonal or geographical variations in diet (Bundy et al. 2000). Most diets were based on fall

RV survey stomach content analyses or based on diet studies from the same species but in different locations, with greater uncertainty (Table 91 and 92).

Catch data were obtained from NAFO databases which did not include size distributions. To estimate catch by size class for multi-stanza groups, size distributions from catch-at-age stock assessment models were applied to catch data. This approach assumes that the size distribution of catch was the same as the size distribution of the stock and may introduce bias. There was a moderate amount of uncertainty for catch statistics due to an unknown amount illegal, unreported, and unregulated (IUU) catch (Table 91 and 92).

Table 91 Pedigree for parameters in the 2J3K 2018-2020 model. Higher numbers and darker shading indicate higher uncertainty.

Group name	*B*	*P/B*	*Q/B*	Diet	Catch
Whale fish eater	6	5	5	6	
Whale zooplankton eater	6	5	5	6	
Whale squid eater	6	5	5	6	
Whale mammal eater	6	5	5	6	
Seal harp	2	5	6	3	1
Seal hooded	3	5	6	3	
Seal other	3	5	6	3	
Seabird piscivore	5	5	6	6	
Seabird planktivore	5	5	6	6	
Seabird benthivore	5	5	6	5	
Greenland shark	6	5	2	6	
Atlantic cod greater than 35cm	1	1	6	1	3
Atlantic cod less than 35cm	1	1	6	1	1
Greenland halibut	1	1	1	1	3
Other piscivorous fish	1	5	6	6	3
Redfish	1	5	6	1	3
Arctic cod	1	5	6	6	
Other plank-piscivorous fish	1	5	6	3	
American plaice greater than 35cm	1	1	6	1	3
American plaice less than 35cm	1	1	6	1	
Thorny skate	1	5	6	3	3
Other large benthivorous fish	1	5	6	8	3
Witch flounder	3	5	6	6	3
Other medium benthivorous fish	1	5	6	8	
Small benthivorous fish	9	5	6	8	
Herring	9	5	6	6	3
Sandlance	9	5	6	3	
Capelin	3	5	6	3	3
Other planktivorous fish	9	5	6	8	3
Squid	8	6	6	6	3
Shrimp	1	1	6	5	3
Snow crab	1	1	6	3	3
Predatory invertebrates	5	6	6	6	3
Deposit feeding invertebrates	5	6	6	6	3
Suspension feeding invertebrates	5	6	6	6	3
Macrozooplankton	9	2	6	5	
Large mesozooplankton	6	2	6	6	
Small mesozooplankton	6	5	6	6	
Microzooplankton	6	2	6	5	
Large phytoplankton	5	1			
Small phytoplankton	5	1			

Table 92 Pedigree for parameters in the 3LNO 2018-2020 model. Higher numbers and darker shading indicate higher uncertainty.

Group name	*B*	*P/B*	*Q/B*	Diet	Catch
Whale fish eater	6	5	5	6	
Whale zooplankton eater	6	5	5	6	
Whale squid eater	6	5	5	6	
Whale mammal eater	6	5	5	6	
Seal harp	2	5	6	3	1
Seal hooded	3	5	6	3	
Seal other	3	5	6	3	
Seabird piscivore	5	5	6	6	
Seabird planktivore	5	5	6	6	
Seabird benthivore	5	5	6	5	
Greenland shark	6	5	2	6	
Atlantic cod greater than 35cm	1	1	6	1	3
Atlantic cod less than 35cm	1	1	6	1	1
Greenland halibut	1	1	1	1	3
Silver hake and pollock	1	5	2	1	3
Other piscivorous fish	1	5	6	6	3
Redfish	1	5	6	1	3
Arctic cod	5	5	6	6	
Other plank-piscivorous fish	1	5	6	3	3
American plaice greater than 35cm	1	1	6	1	3
American plaice less than 35cm	1	1	6	1	1
Thorny skate	1	5	6	3	3
Haddock	1	5	6	6	3
Other large benthivorous fish	1	5	6	8	3
Yellowtail flounder	1	5	6	3	3
Witch flounder	3	5	6	6	3
Other medium benthivorous fish	1	5	6	8	3
Small benthivorous fish	9	5	6	8	3
Herring	9	5	6	6	3
Sandlance	9	5	6	3	
Capelin	5	5	6	3	3
Other planktivorous fish	9	5	6	8	3
Squid	8	6	6	6	3
Shrimp	1	1	6	5	
Snow crab	1	1	6	3	3
Predatory invertebrates	6	6	6	6	3
Deposit feeding invertebrates	6	6	6	6	3
Suspension feeding invertebrates	6	6	6	6	3
Macrozooplankton	6	6	6	5	
Large mesozooplankton	6	2	6	6	
Small mesozooplankton	6	5	6	6	

Microzooplankton	6	2	6	5	
Large phytoplankton	5	1			
Small phytoplankton	5	1			

3.1.2 Pre-balanced vs balanced models

Initial parameter estimates (Appendices A and B) did not produce a balanced model and adjustments were made to achieve mass balance (Tables 93 and 94). The largest increases in 2J3K and 3LNO biomasses were made to squid, *other large benthivorous fish*, and *other medium benthivorous fish* (Figure 3 and 4). An increase in zooplankton biomass was necessary to balance the model in 3LNO, but not in 2J3K. The largest biomass decreases in both models were for *small benthivorous fish*. *Small benthivorous fish* biomass was estimated by Ecopath, which produced an unrealistically high estimate of 43 t/km^2 due to predation from other large groups, primarily *predatory invertebrates*. When predation levels were adjusted, the estimate fell by 1500% to a more reasonable estimate of 2.8 and 1.8 t/km^2 in 2J3K and 3LNO, respectively.

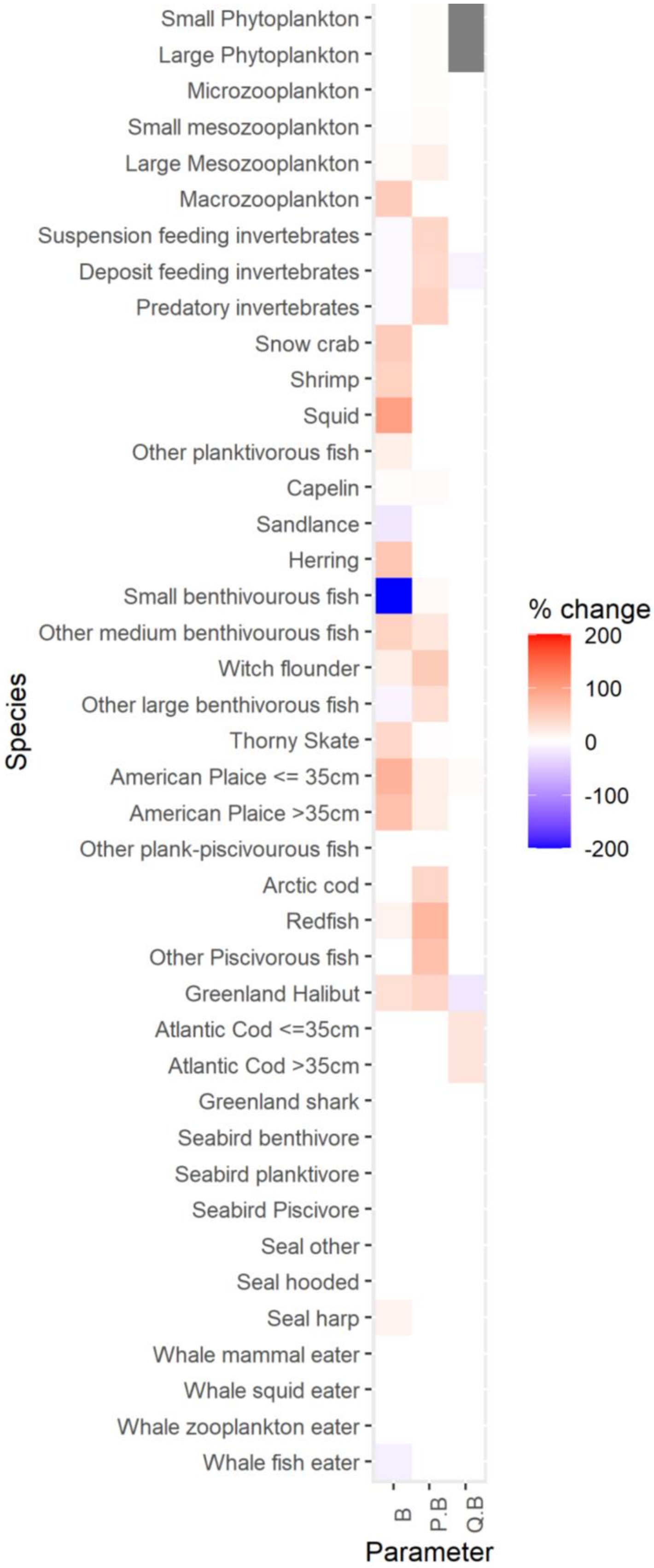

Figure 3 Percent change in parameters (Biomass, Production: Biomass, and Consumption: Biomass) between the 2J3K 2018-2020 unbalanced and balanced models. Note: The darkest blue squares include values that are under -200%.

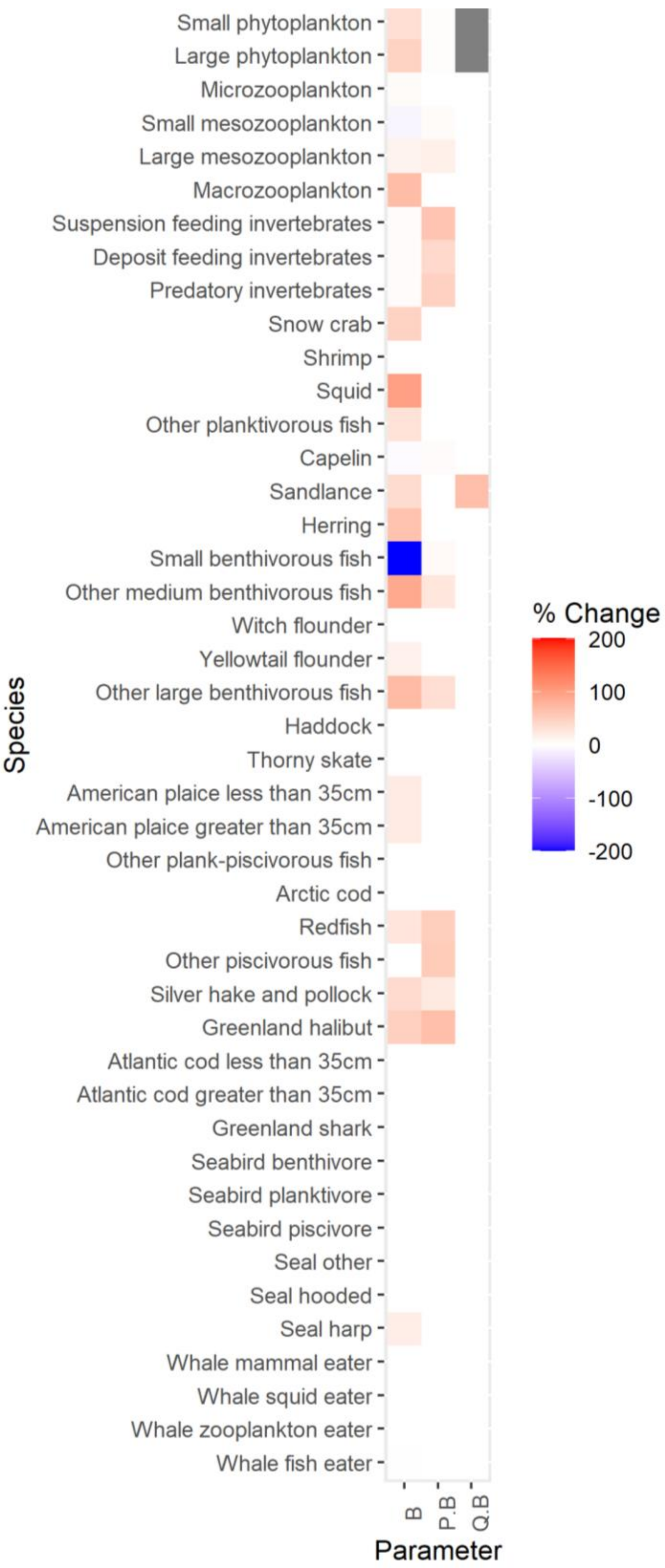

Figure 4 Percent change in parameters (Biomass, Production: Biomass, and Consumption: Biomass) between the 3LNO 2018-2020 unbalanced and balanced models. Note: The darkest blue squares include values that are under -200%.

Table 93 Balanced 2J3K model for 2018-2020 parameter estimates. Values in blue were estimated by Ecopath. Shaded rows indicate multi-stanza groups.

Functional group	Biomass (t/km^2)	*P/B*	*Q/B*	*EE*	Trophic level
Whale fish eater	0.700	0.12	6.00	0.00	4.30
Whale zooplankton eater	0.014	0.06	3.47	0.50	3.59
Whale squid eater	0.121	0.09	6.00	0.00	4.53
Whale mammal eater	0.000	0.08	8.10	0.00	5.25
Seal harp	0.380	0.15	17.64	0.59	4.49
Seal hooded	0.032	0.12	18.33	0.14	4.86
Seal other	0.016	0.13	13.00	0.03	4.69
Seabird piscivore	0.007	0.25	119.00	0.07	4.28
Seabird planktivore	0.006	0.15	64.61	0.00	3.48
Seabird benthivore	0.002	0.13	45.29	0.00	3.63
Greenland shark	0.009	0.01	0.13	0.00	5.18
Atlantic cod >35cm	2.180	0.40	1.62	0.97	4.05
Atlantic cod <=35cm	0.200	0.40	4.10	0.99	3.67
Greenland halibut	0.800	0.64	2.40	0.87	4.42
Other piscivorous fish	0.037	0.31	4.95	0.94	4.38
Redfish	1.200	0.33	2.00	0.89	3.71
Arctic cod	4.548	0.34	4.00	0.99	3.48
Other plank-piscivorous fish	0.028	0.35	2.30	0.79	3.56
American plaice >35cm	0.400	0.60	2.00	0.73	3.65
American plaice <= 35cm	1.411	0.60	3.86	0.99	3.59
Thorny skate	0.130	0.15	1.79	1.00	3.98
Other large benthivorous fish	0.985	0.30	1.33	0.83	3.63
Witch flounder	0.060	0.38	2.60	0.83	3.49
Other medium benthivorous fish	0.385	0.40	2.00	0.96	3.66
Small benthivorous fish	2.543	0.45	2.00	0.98	3.60
Herring	2.211	1.15	3.15	0.98	3.67
Sandlance	1.935	1.15	7.66	0.98	3.56
Capelin	3.400	1.15	4.30	0.93	3.48
Other planktivorous fish	3.061	1.15	4.19	0.98	2.89
Squid	0.400	3.40	13.20	1.00	3.56
Shrimp	0.585	1.70	11.33	0.99	2.44
Snow crab	0.242	0.50	3.06	0.95	3.56
Predatory invertebrates	20.000	2.70	8.73	0.78	3.16
Deposit feeding invertebrates	85.000	3.00	9.10	0.77	2.46
Suspension feeding invertebrates	61.000	1.50	3.70	0.56	2.00
Macrozooplankton	17.880	3.43	19.50	0.98	2.48

Large mesozooplankton	14.000	10.00	28.00	0.87	2.58
Small mesozooplankton	5.500	33.00	105.37	0.88	2.37
Microzooplankton	5.360	73.00	240.00	0.93	2.00
Large phytoplankton	7.175	107.00		0.88	1.00
Small phytoplankton	11.785	107.00		0.93	1.00
Detritus	1.000			0.91	1.00

Table 94 Balanced 3LNO model for 2018-2020 parameter estimates. Values in blue were estimated by Ecopath. Shaded rows indicate multi-stanza groups.

Functional group	Biomass (t/km^2)	*P/B*	*Q/B*	EE	Trophic level
Whale fish eater	0.730	0.12	6.00	0.00	4.35
Whale zooplankton eater	0.016	0.06	3.47	0.38	3.58
Whale squid eater	0.112	0.09	6.00	0.00	4.58
Whale mammal eater	0.000	0.08	8.10	0.00	5.29
Seal harp	0.380	0.15	17.64	0.53	4.50
Seal hooded	0.007	0.12	18.33	0.56	5.01
Seal other	0.014	0.13	13.00	0.03	4.78
Seabird piscivore	0.007	0.25	119.41	0.06	4.36
Seabird planktivore	0.006	0.15	64.60	0.00	3.52
Seabird benthivore	0.002	0.13	45.29	0.00	3.64
Greenland shark	0.009	0.01	0.13	0.00	5.27
Atlantic cod >35cm	0.568	0.40	1.17	0.48	4.45
Atlantic cod <=35cm	0.052	0.40	2.96	0.69	3.69
Greenland halibut	0.200	0.64	2.30	0.53	4.44
Silver hake / Pollock	0.128	0.40	4.10	0.65	4.32
Other piscivorous fish	0.122	0.38	1.65	0.99	4.48
Redfish	1.248	0.33	2.00	0.88	3.74
Arctic cod	1.050	0.60	4.00	0.95	3.52
Other plank-piscivorous fish	0.028	0.35	2.30	0.64	3.63
American plaice >35cm	0.830	0.50	2.00	0.62	3.91
American plaice <= 35cm	1.783	0.51	3.73	0.56	3.83
Thorny Skate	0.709	0.20	1.79	0.45	4.31
Haddock	0.039	0.21	2.08	0.96	3.75
Other large benthivorous fish	0.655	0.30	1.33	0.52	3.66
Yellowtail flounder	1.180	0.39	3.60	0.52	3.97
Witch flounder	0.063	0.20	2.60	0.92	3.50
Other medium benthivorous fish	0.320	0.40	2.00	0.74	3.67
Small benthivorous fish	1.618	0.45	2.00	0.99	3.62

Herring	1.893	1.15	3.15	0.98	3.69
Sandlance	4.529	1.15	7.66	0.98	3.58
Capelin	3.770	1.20	4.30	0.91	3.51
Other planktivorous fish	2.886	1.15	4.19	0.98	2.90
Squid	0.700	3.40	13.20	0.78	3.55
Shrimp	0.666	1.70	11.30	0.97	2.45
Snow crab	0.430	0.50	3.06	0.99	3.58
Predatory invertebrates	20.000	2.70	8.73	0.87	3.16
Deposit feeding invertebrates	85.000	3.00	10.00	0.83	2.48
Suspension feeding invertebrates	61.000	1.50	3.70	0.93	2.00
Macrozooplankton	21.018	3.20	19.50	0.98	2.50
Large mesozooplankton	22.857	8.20	28.00	0.99	2.59
Small mesozooplankton	7.816	31.00	105.40	0.92	2.45
Microzooplankton	7.470	72.00	240.00	0.94	2.00
Large phytoplankton	8.780	106.00		0.96	1.00
Small phytoplankton	15.800	106.00		0.97	1.00
Detritus	1.000			0.93	1.00

Estimated trophic levels for 2J3K and 3LNO followed the general trend of marine mammals, seabirds, and Greenland shark residing in the higher trophic levels, followed by fish and invertebrates (Figure 5 and 6). Atlantic cod >35 cm had a lower estimated trophic level in 2J3K compared to 3LNO, likely due to less fish consumption (Figure 7).

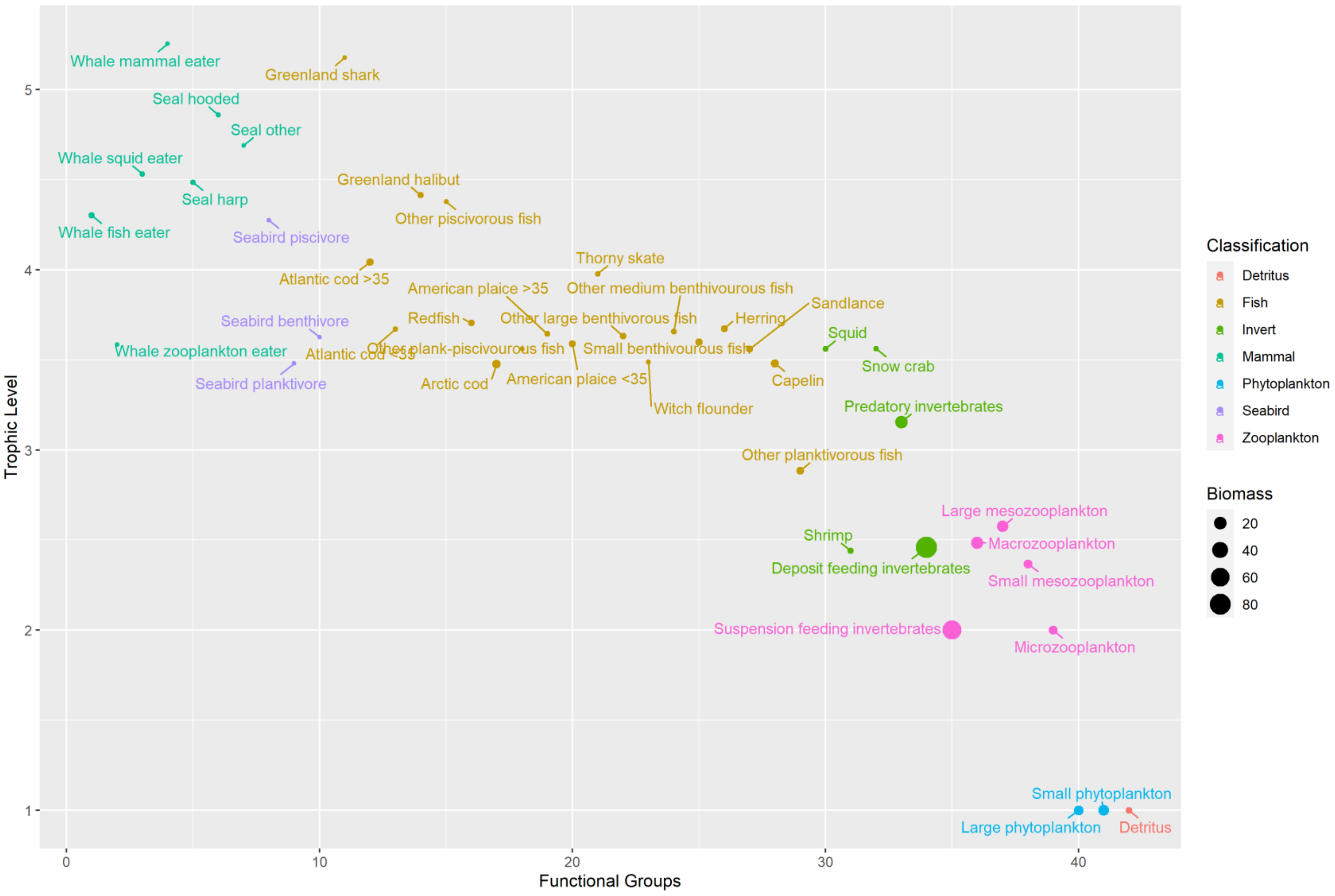

Figure 5 Estimated trophic levels of functional groups in the 2J3K 2018-2020 model. Biomass of functional group is indicated by circle size (t/km^2).

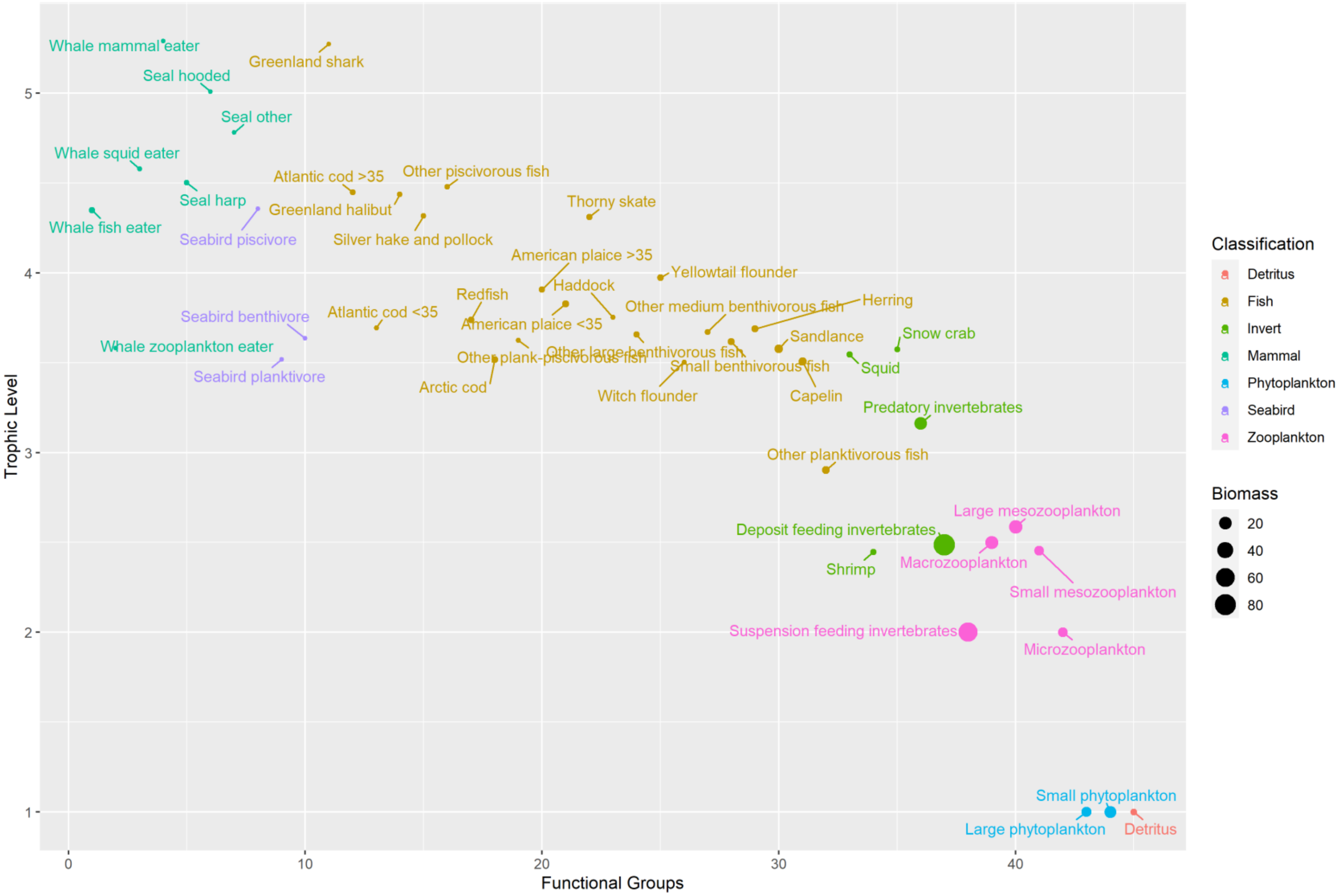

Figure 6 Estimated trophic levels of functional groups in the 3LNO 2018-2020 model. Biomass of functional group is indicated by circle size (t/km^2).

In both models, the largest changes in diet were made to witch flounder, decreasing their consumption of *predatory invertebrates* and increasing their consumption of *deposit feeding invertebrates*, based on RV diet data (Figure 7 and 8). Sandlance consumption by predators in 2J3K was decreased for many groups due to the lower abundance of sandlance in 2J3K, while sandlance increased in importance as a prey source in 3LNO. Sandlance as prey was exacerbated due to the decline of capelin biomass compared to the 2013-2015 model.

Due to their large biomass, the predatory / deposit / suspension feeding invertebrate diets were adjusted to decrease the amount of cannibalism and their predation on *small benthivorous fish*, as the high levels of predation were causing unrealistically high estimates of biomass in the group (Appendices C and D).

Figure 7 Percent change in 2J3K diet for the 2018-2020 model compared to the 2J3KLNO diet for the 2013-2015 model. Differences in diet are due to model balancing.

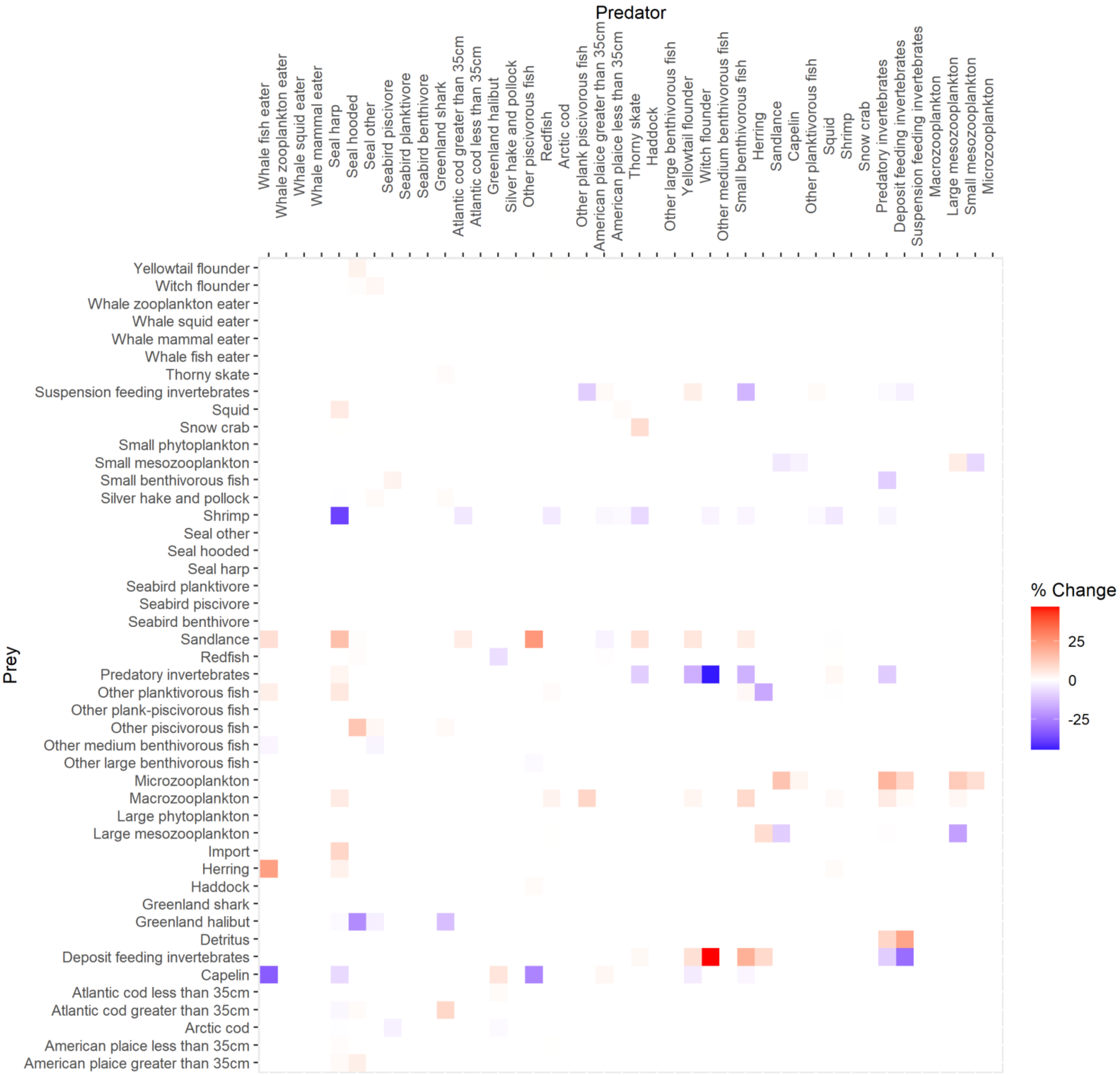

Figure 8 Percent change in 3LNO diet for the 2018-2020 model compared to the 2J3KLNO diet for the 2013-2015 model. Differences in diet are due to model balancing.

3.2 Model comparisons

3.2.1 Catch

When comparing commercial fishery catches across the three time periods in both regions, there was a large drop in annual catch magnitude (Figure 9C) and a change in species proportion (Figure 9A). In both 2J3K and 3LNO, between the 1985-1987 and 2013-2015 time periods, piscivorous fish (predominately cod) catches declined and invertebrate (predominately Northern shrimp and snow crab) catches increased (Figure 9A). In 2J3K, catch declined by approximately the same amount between each time period by ~0.2 t/km^2 at each (Figure 9C). In 3LNO, the initial decline between 1985-1987 and 2013-2015 was larger (approximately -0.4 t/km^2) than the decline between 2013-2015 and 2018-2020 (approximately -0.07 t/km^2). This trend in overall catch decline was reflected in declining fishing morality rates for all three time periods (Figure 10 and 11). In 2018-2020, no functional group experienced a higher fishing mortality rate than natural mortality (Figure 10), as opposed to 1985-1987 cod and 2013-2015 snow crab which had higher fishing mortality than natural mortality (Figure 11).

Comparing catch between 2J3K and 3LNO in 2018-2020, there was a greater diversity and magnitude of species caught in 3LNO compared to 2J3K (Figure 9B and 9D). Catches of *large benthivorous fish* (predominately thorny skate), *medium benthivorous fish* (predominantly yellowtail flounder), and plank-piscivorous fish (predominantly redfish) were almost non-existent in 2J3K (Figure 9B). Catch composition in 3LNO had less invertebrate and planktivorous fish catch (predominately capelin and herring) but more plank-piscivorous fish catch (predominately redfish) than 2J3K (Figure 9B).

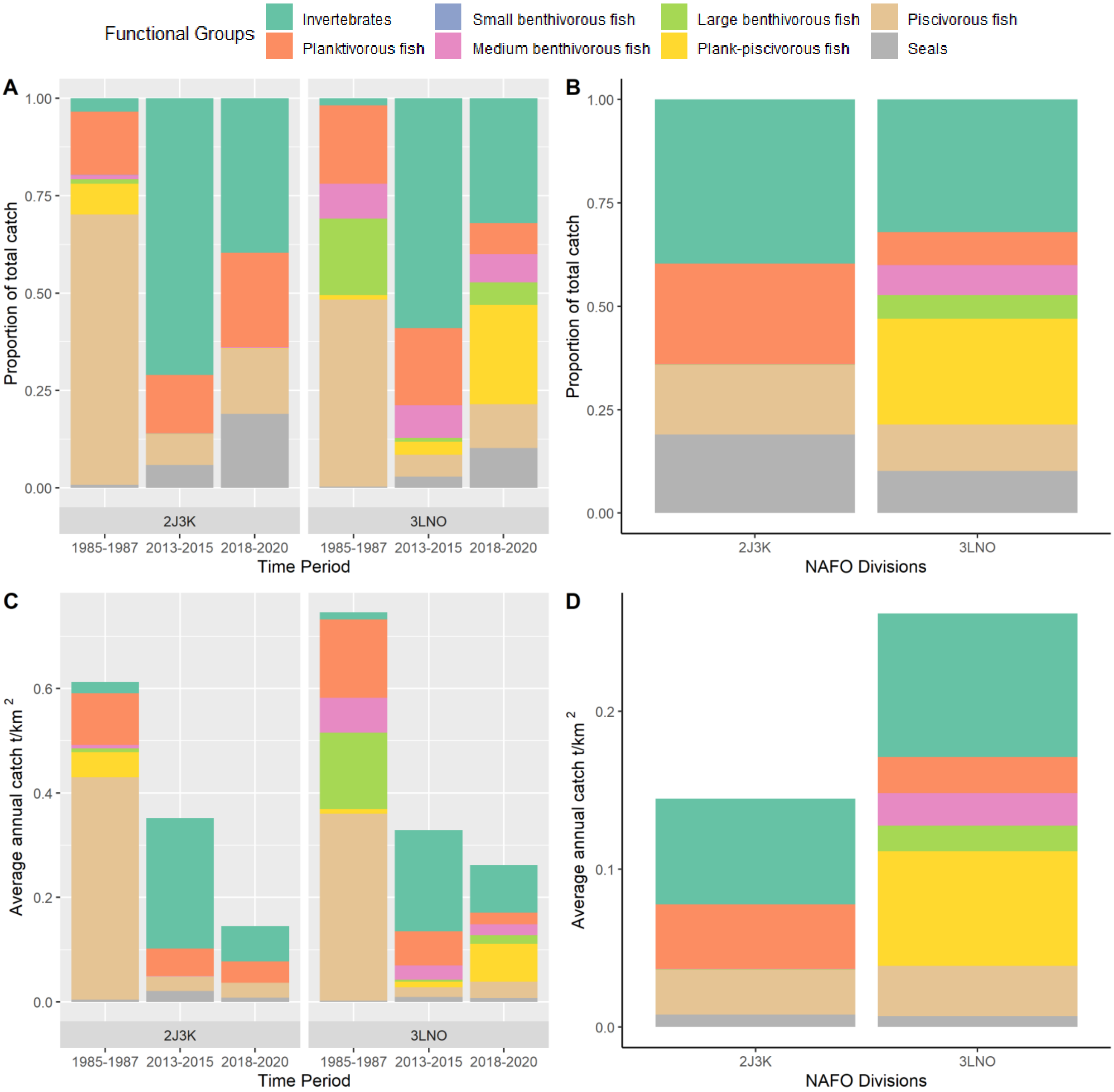

Figure 9 A) Proportion of total catch in 2J3K and 3LNO across three time periods. B) Proportion of total catch in 2J3K and 3LNO in 2018-2020. C) Magnitude of total catch in 2J3K and 3LNO across three time periods D) Magnitude of total catch in 2J3K and 3LNO in 2018-2020.

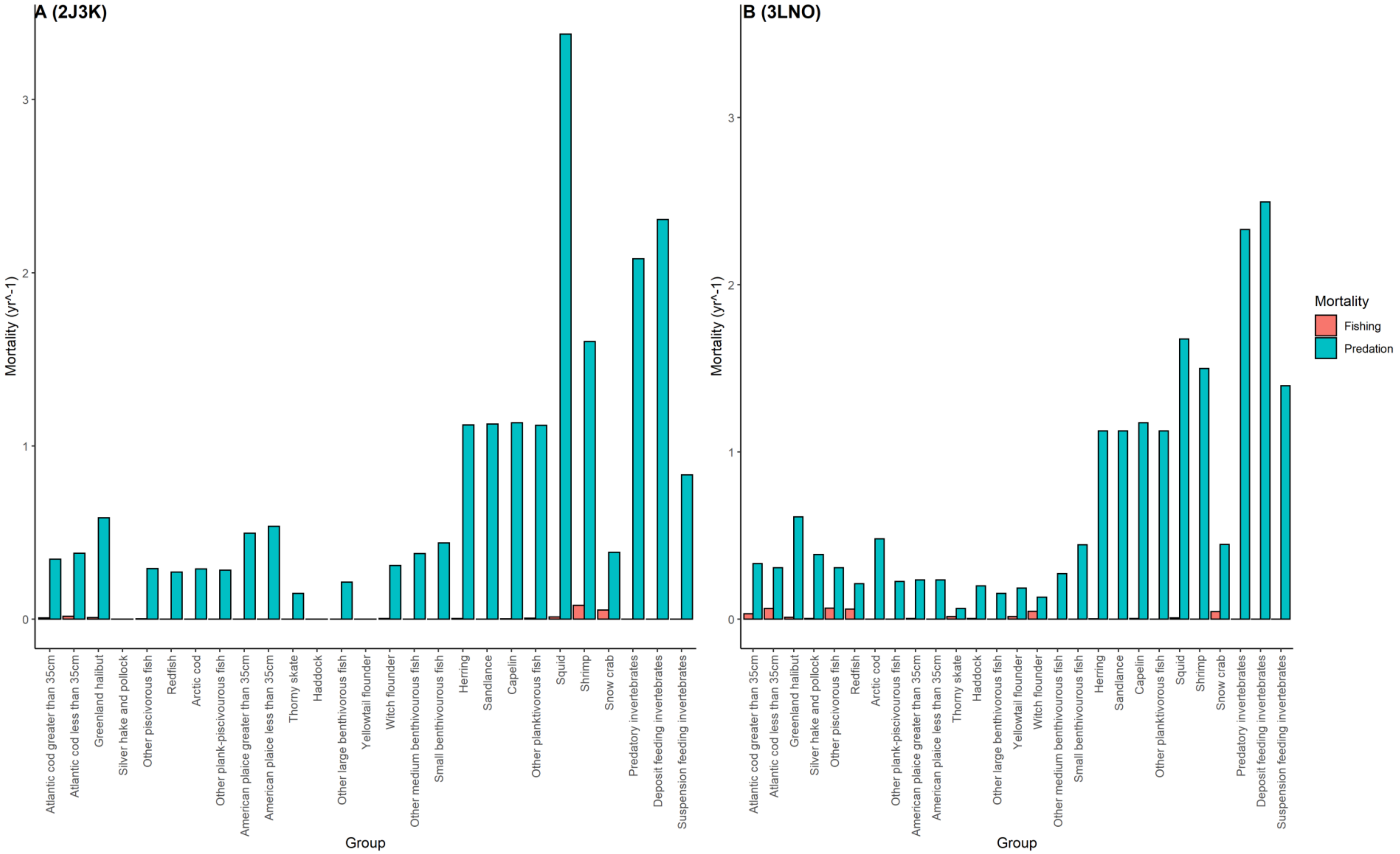

Figure 10 Fishing mortality vs predation mortality for commercial species in A) 2J3K and B) 3LNO in 2018-2020.

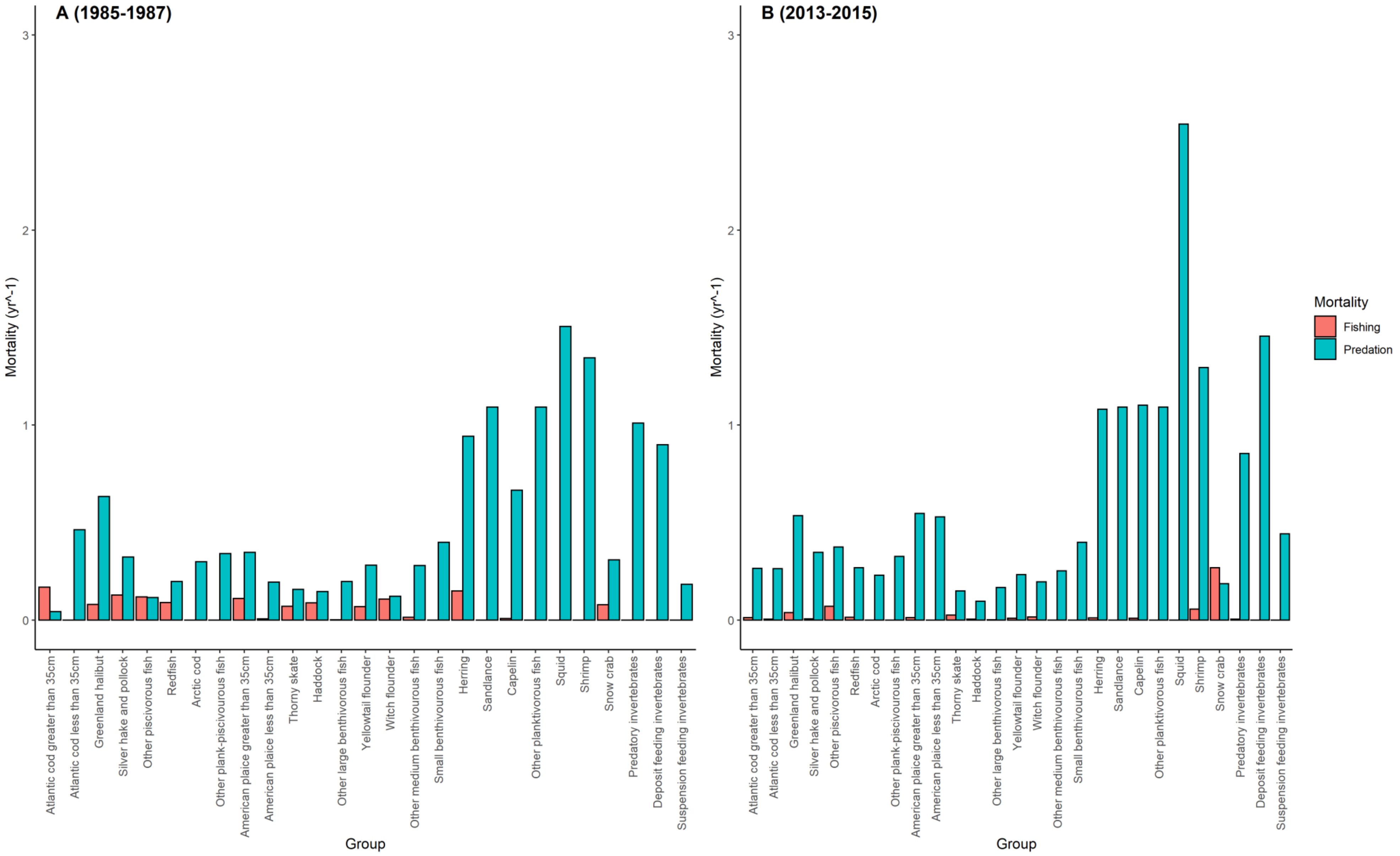

Figure 11 Comparison of fishing mortality vs predation mortality for commercial species in A) 1985-1987 and B) 2013-2015 2J3KLNO.

3.2.2 Biomass

Trends in functional groups were examined across the three time periods and two study areas (Figure 12). Biomass estimates could not be easily split between 2J3K and 3LNO for the 1985-1987 and 2013-2015 time periods, so while biomass proportions and magnitudes are all in t/km^2, the estimates for all time periods are for the entirety of 2J3KLNO in Figure 12A and 12C.

Total system biomass declined between 1985-1987 and 2013-2015 (2J3KLNO), then increased in 2018-2020 (Figure 12C), driven by increased secondary productivity (Figure 12A). The 2013-2015 time period had higher invertebrate biomass than all other time periods (predominately shrimp, Tables 95-98), similarly the 1985-1987 time period had the highest piscivorous and planktivorous fish biomasses (predominately cod and capelin, Tables 95-98).

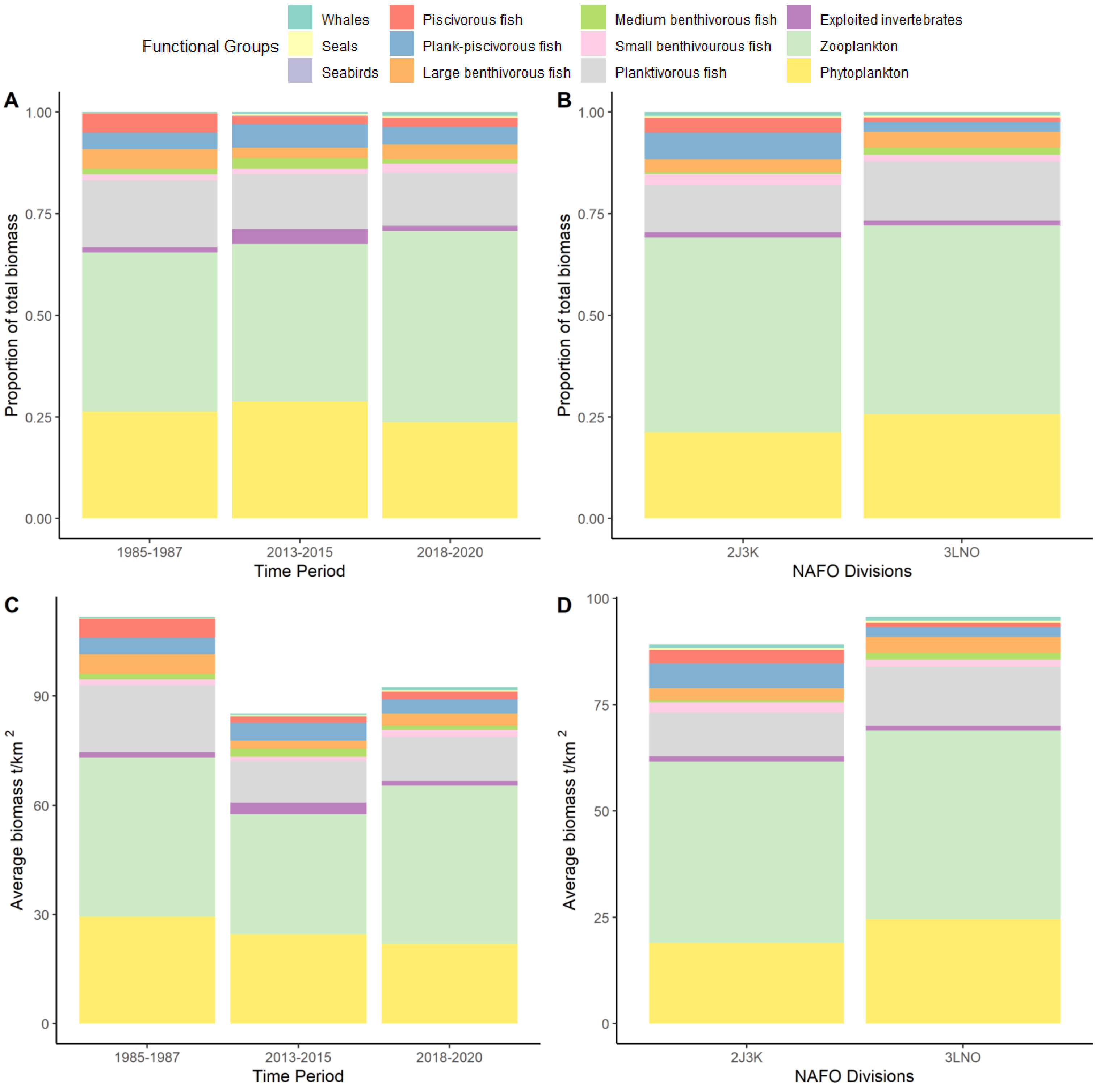

Figure 12 A) Proportion of total biomass in 2J3KLNO across the three time periods. B) Proportion of total biomass in 2J3K and 3LNO in 2018-2020. C) Magnitude of total biomass in 2J3KLNO across the three time periods D) Magnitude of total biomass in 2J3K and 3LNO in 2018-2020. Note: Biomasses exclude *predatory invertebrates*, *deposit feeding invertebrates*, and *suspension feeding invertebrates*.

Table 95 2J3K Functional group composition by species biomass (%).

Year	Group name	Species	Percentage
2J3K 2018-2020	Whales	Whale fish eater	83.84%
2J3K 2018-2020		Whale zooplankton eater	1.63%
2J3K 2018-2020		Whale squid eater	14.49%
2J3K 2018-2020		Whale mammal eater	0.04%
2J3K 2018-2020	Seals	Seal harp	88.89%
2J3K 2018-2020		Seal hooded	7.37%
2J3K 2018-2020		Seal other	3.74%
2J3K 2018-2020	Seabirds	Seabird piscivore	49.02%
2J3K 2018-2020		Seabird planktivore	39.22%
2J3K 2018-2020		Seabird benthivore	11.76%
2J3K 2018-2020	Piscivorous fish	Greenland shark	0.27%
2J3K 2018-2020		Atlantic cod greater than 35cm	67.58%
2J3K 2018-2020		Atlantic cod less than 35cm	6.20%
2J3K 2018-2020		Greenland halibut	24.80%
2J3K 2018-2020		Other piscivorous fish	1.15%
2J3K 2018-2020	Plank-piscivorous fish	Redfish	20.78%
2J3K 2018-2020		Arctic cod	78.74%
2J3K 2018-2020		Other plank-piscivorous fish	0.48%
2J3K 2018-2020	Large benthivorous fish	American plaice greater than 35cm	13.67%
2J3K 2018-2020		American plaice less than 35cm	48.22%
2J3K 2018-2020		Thorny skate	4.44%
2J3K 2018-2020		Other large benthivorous fish	33.67%
2J3K 2018-2020	Medium benthivorous fish	Witch flounder	13.04%
2J3K 2018-2020		Other medium benthivorous fish	86.96%
2J3K 2018-2020	Small benthivorous fish	Small benthivorous fish	100%
2J3K 2018-2020	Planktivorous fish	Herring	20.84%
2J3K 2018-2020		Sandlance	18.24%
2J3K 2018-2020		Capelin	32.06%
2J3K 2018-2020		Other planktivorous fish	28.86%
2J3K 2018-2020	Exploited invertebrates	Squid	32.60%
2J3K 2018-2020		Shrimp	47.68%
2J3K 2018-2020		Snow crab	19.72%
2J3K 2018-2020	Invertebrates	Predatory invertebrates	12.05%
2J3K 2018-2020		Deposit feeding invertebrates	51.20%
2J3K 2018-2020		Suspension feeding invertebrates	36.75%
2J3K 2018-2020	Zooplankton	Macrozooplankton	41.83%
2J3K 2018-2020		Large mesozooplankton	32.76%
2J3K 2018-2020		Small mesozooplankton	12.87%
2J3K 2018-2020		Microzooplankton	12.54%
2J3K 2018-2020	Phytoplankton	Large phytoplankton	37.84%
2J3K 2018-2020		Small phytoplankton	62.16%

Table 96 3LNO Functional group composition by species biomass (%).

Year	Group name	Species	Percentage
3LNO 2018-2020	Whales	Whale fish eater	85.03%
3LNO 2018-2020		Whale zooplankton eater	1.91%
3LNO 2018-2020		Whale squid eater	13.02%
3LNO 2018-2020		Whale mammal eater	0.03%
3LNO 2018-2020	Seals	Seal harp	94.69%
3LNO 2018-2020		Seal hooded	1.82%
3LNO 2018-2020		Seal other	3.49%
3LNO 2018-2020	Seabirds	Seabird piscivore	49.30%
3LNO 2018-2020		Seabird planktivore	39%
3LNO 2018-2020		Seabird benthivore	11.70%
3LNO 2018-2020	Piscivorous fish	Greenland shark	0.86%
3LNO 2018-2020		Atlantic cod greater than 35cm	55.20%
3LNO 2018-2020		Atlantic cod less than 35cm	5.07%
3LNO 2018-2020		Greenland halibut	14.58%
3LNO 2018-2020		Silver hake and pollock	12.44%
3LNO 2018-2020		Other piscivorous fish	11.86%
3LNO 2018-2020	Plank-piscivorous fish	Redfish	53.67%
3LNO 2018-2020		Arctic cod	45.14%
3LNO 2018-2020		Other plank-piscivorous fish	1.19%
3LNO 2018-2020	Large benthivorous fish	American plaice > 35cm	20.67%
3LNO 2018-2020		American plaice < 35cm	44.41%
3LNO 2018-2020		Thorny skate	17.65%
3LNO 2018-2020		Haddock	0.96%
3LNO 2018-2020		Other large benthivorous fish	16.31%
3LNO 2018-2020	Medium benthivorous fish	Yellowtail flounder	71.40%
3LNO 2018-2020		Witch flounder	3.79%
3LNO 2018-2020		Other medium benthivorous fish	24.81%
3LNO 2018-2020	Small benthivorous fish	Small benthivorous fish	100%
3LNO 2018-2020	Planktivorous fish	Herring	15.86%
3LNO 2018-2020		Sandlance	34.37%
3LNO 2018-2020		Capelin	26.75%
3LNO 2018-2020		Other planktivorous fish	23.03%
3LNO 2018-2020	Exploited invertebrates	Squid	52.17%
3LNO 2018-2020		Shrimp	10.43%
3LNO 2018-2020		Snow crab	37.39%
3LNO 2018-2020	Invertebrates	Predatory invertebrates	12.05%
3LNO 2018-2020		Deposit feeding invertebrates	51.20%
3LNO 2018-2020		Suspension feeding invertebrates	36.75%
3LNO 2018-2020	Zooplankton	Macrozooplankton	35.45%
3LNO 2018-2020		Large mesozooplankton	38.90%
3LNO 2018-2020		Small mesozooplankton	13.12%
3LNO 2018-2020		Microzooplankton	12.53%
3LNO 2018-2020	Phytoplankton	Large phytoplankton	35.72%
3LNO 2018-2020		Small phytoplankton	64.28%

Table 97 2013-2015 2J3KLNO Functional group composition by species biomass (%).

Year	Group name	Species	Percentage
2J3KLNO 2013-2015	Whales	Whale fish eater	66.38%
2J3KLNO 2013-2015		Whale zooplankton eater	7.01%
2J3KLNO 2013-2015		Whale squid eater	16.53%
2J3KLNO 2013-2015		Whale mammal eater	0.05%
2J3KLNO 2013-2015		Whales Minke	10.02%
2J3KLNO 2013-2015	Seals	Seal harp	85.79%
2J3KLNO 2013-2015		Seal hooded	10.19%
2J3KLNO 2013-2015		Seal other	4.02%
2J3KLNO 2013-2015	Seabirds	Seabird piscivore	49.30%
2J3KLNO 2013-2015		Seabird planktivore	39%
2J3KLNO 2013-2015		Seabird benthivore	11.70%
2J3KLNO 2013-2015	Piscivorous fish	Greenland shark	0.50%
2J3KLNO 2013-2015		Atlantic cod greater than 35cm	43.17%
2J3KLNO 2013-2015		Atlantic cod less than 35cm	2.16%
2J3KLNO 2013-2015		Greenland halibut	39.20%
2J3KLNO 2013-2015		Silver hake and pollock	9.23%
2J3KLNO 2013-2015		Other piscivorous fish	5.74%
2J3KLNO 2013-2015	Plank-piscivorous fish	Redfish	43.59%
2J3KLNO 2013-2015		Arctic cod	55.85%
2J3KLNO 2013-2015		Other plank-piscivorous fish	0.57%
2J3KLNO 2013-2015	Large benthivorous fish	American plaice > 35cm	10.78%
2J3KLNO 2013-2015		American plaice < 35cm	60.91%
2J3KLNO 2013-2015		Thorny skate	13.76%
2J3KLNO 2013-2015		Haddock	3.25%
2J3KLNO 2013-2015		Other large benthivorous fish	11.29%
2J3KLNO 2013-2015	Medium benthivorous fish	Yellowtail flounder	75.68%
2J3KLNO 2013-2015		Witch flounder	2.96%
2J3KLNO 2013-2015		Other medium benthivorous fish	21.36%
2J3KLNO 2013-2015	Small benthivorous fish	Small benthivorous fish	100%
2J3KLNO 2013-2015	Planktivorous fish	Herring	7.51%
2J3KLNO 2013-2015		Sandlance	31.18%
2J3KLNO 2013-2015		Capelin	43.01%
2J3KLNO 2013-2015		Other planktivorous fish	18.30%
2J3KLNO 2013-2015	Exploited invertebrates	Squid	11.64%
2J3KLNO 2013-2015		Shrimp	77.83%
2J3KLNO 2013-2015		Snow crab	10.53%
2J3KLNO 2013-2015	Invertebrates	Predatory invertebrates	12.05%
2J3KLNO 2013-2015		Deposit feeding invertebrates	51.20%
2J3KLNO 2013-2015		Suspension feeding invertebrates	36.75%
2J3KLNO 2013-2015	Zooplankton	Macrozooplankton	25.08%
2J3KLNO 2013-2015		Large mesozooplankton	41.96%
2J3KLNO 2013-2015		Small mesozooplankton	16.74%

2J3KLNO 2013-2015		Microzooplankton	16.22%
2J3KLNO 2013-2015	Phytoplankton	Large phytoplankton	46.67%
2J3KLNO 2013-2015		Small phytoplankton	53.33%

Table 98 1985-1987 2J3KLNO Functional group composition by species biomass (%).

Year	Group name	Species	Percentage
2J3KLNO 1985-1987	Whales	Whale fish eater	56.76%
2J3KLNO 1985-1987		Whale zooplankton eater	11.25%
2J3KLNO 1985-1987		Whale squid eater	23.08%
2J3KLNO 1985-1987		Whale mammal eater	0.08%
2J3KLNO 1985-1987		Whales Minke	8.84%
2J3KLNO 1985-1987	Seals	Seal harp	72.77%
2J3KLNO 1985-1987		Seal hooded	19.97%
2J3KLNO 1985-1987		Seal other	7.26%
2J3KLNO 1985-1987	Seabirds	Seabird piscivore	80.69%
2J3KLNO 1985-1987		Seabird planktivore	17.59%
2J3KLNO 1985-1987		Seabird benthivore	1.72%
2J3KLNO 1985-1987	Piscivorous fish	Greenland shark	0.23%
2J3KLNO 1985-1987		Atlantic cod > 35cm	68.78%
2J3KLNO 1985-1987		Atlantic cod < 35cm	18.43%
2J3KLNO 1985-1987		Greenland halibut	8.39%
2J3KLNO 1985-1987		Silver hake and pollock	0.33%
2J3KLNO 1985-1987		Other piscivorous fish	3.85%
2J3KLNO 1985-1987	Plank-piscivorous fish	Redfish	39.40%
2J3KLNO 1985-1987		Arctic cod	59.74%
2J3KLNO 1985-1987		Other plank-piscivorous fish	0.85%
2J3KLNO 1985-1987	Large benthivorous fish	American plaice > 35cm	18.41%
2J3KLNO 1985-1987		American plaice < 35cm	61.96%
2J3KLNO 1985-1987		Thorny skate	10.04%
2J3KLNO 1985-1987		Haddock	1.70%
2J3KLNO 1985-1987		Other large benthivorous fish	7.89%
2J3KLNO 1985-1987	Medium benthivorous fish	Yellowtail flounder	38.96%
2J3KLNO 1985-1987		Witch flounder	15.21%
2J3KLNO 1985-1987		Other medium benthivorous fish	45.83%
2J3KLNO 1985-1987	Small benthivorous fish	Small benthivorous fish	100%
2J3KLNO 1985-1987	Planktivorous fish	Herring	0.68%
2J3KLNO 1985-1987		Sandlance	17.65%
2J3KLNO 1985-1987		Capelin	74.93%
2J3KLNO 1985-1987		Other planktivorous fish	6.74%
2J3KLNO 1985-1987	Exploited invertebrates	Squid	25.70%
2J3KLNO 1985-1987		Shrimp	61.64%
2J3KLNO 1985-1987		Snow crab	12.67%
2J3KLNO 1985-1987	Invertebrates	Predatory invertebrates	6.86%
2J3KLNO 1985-1987		Deposit feeding invertebrates	38.51%
2J3KLNO 1985-1987		Suspension feeding invertebrates	54.63%

2J3KLNO 1985-1987	Zooplankton	Macrozooplankton	25.52%
2J3KLNO 1985-1987		Large mesozooplankton	46.84%
2J3KLNO 1985-1987		Small mesozooplankton	14.85%
2J3KLNO 1985-1987		Microzooplankton	12.79%
2J3KLNO 1985-1987	Phytoplankton	Large phytoplankton	43.49%
2J3KLNO 1985-1987		Small phytoplankton	56.51%

Finfish biomass was the highest in 1985-1987, followed by 2J3K (2018-2020), 3LNO (2018-2020), and 2013-2015 which has the lowest (Figure 13). The fish community composition was different for 2J3K and 3LNO, but with similar overall fish biomass (Figure 13).

The largest amount of plank-piscivorous fish biomass was in 2J3K, with four times as much biomass of Arctic cod compared to 3LNO, where redfish dominated the *plank-piscivorous fish* group. There were higher *small benthivorous fish* and piscivorous fish biomasses in 2J3K (2018-2020) compared to all other time periods but less fish biomass in every other functional group. The increase in piscivorous fish biomass in 2018 2J3K is mostly driven by Atlantic cod abundance, which decreased in 3LNO compared to 2013-2015.

75% of planktivorous fish biomass in the 1985-1987 time period was comprised of capelin, which declined to 40% of the group in 2013-2015, and 30% in 2018-2020 (Table 97-100). This decline was due to the collapse of capelin in the early 1990s, and the further decline from 2013-2015 represents the small spike in capelin biomass that was encompassed by the 2013-2015 model. Sandlance, herring, and *other planktivorous fish* biomass remained relatively stable, leading to similar levels across 2013-2015 and 2018-2020 (Figure 13).

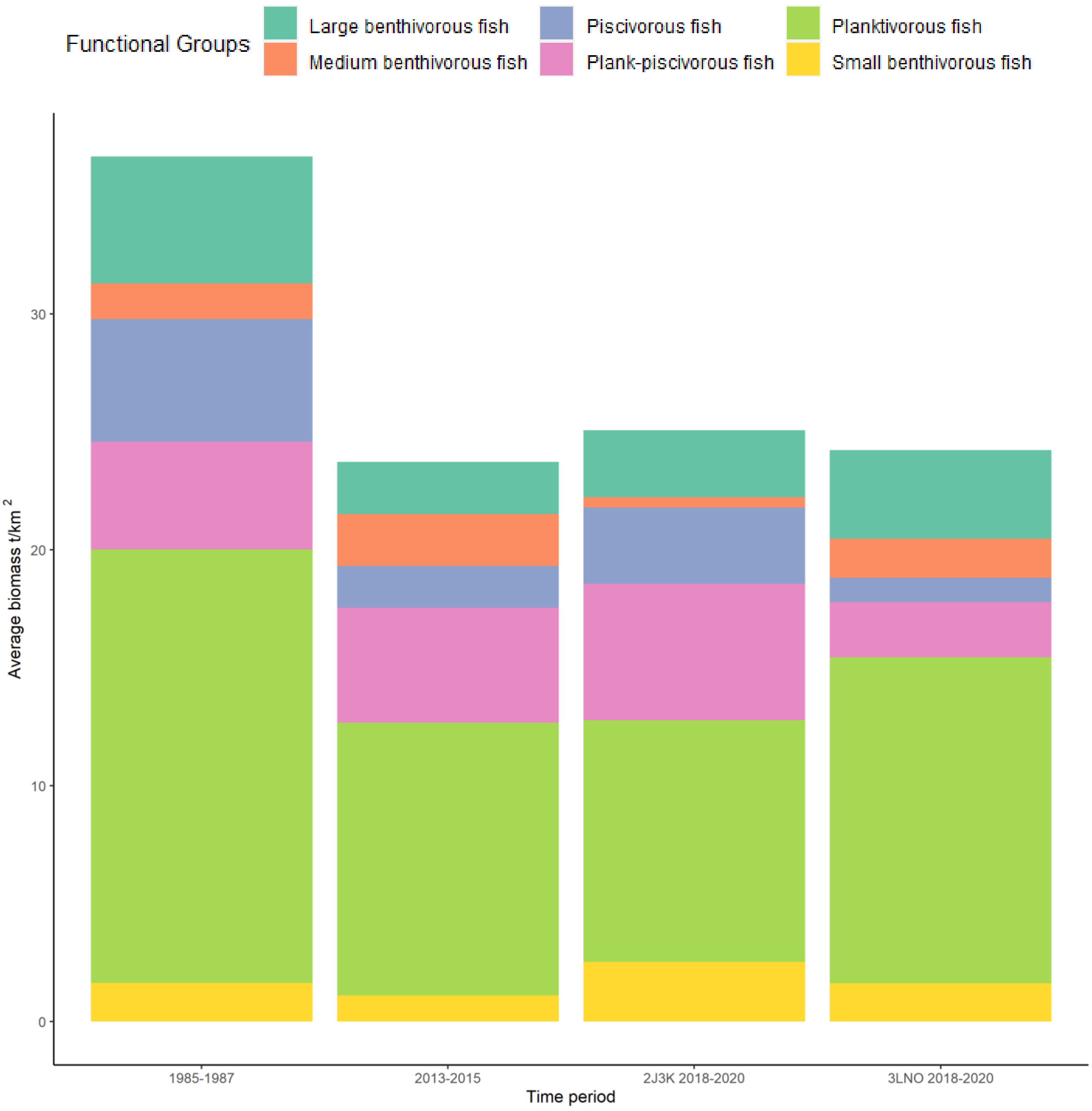

Figure 13 Finfish biomass (t/km²) by functional group between all models and time periods.

2013-2015 had noticeably higher invertebrate biomass than any other time period or study area, predominately driven by shrimp which declined rapidly between 2013-2015 and 2018-2020 (Figure 14). Shrimp biomass in 2J3K 2018-2020 was less than in 1985-1987 but snow crab increased moderately. Snow crab and squid biomasses in 3LNO were the highest in the time series, with shrimp biomass the lowest in the time series (Figure 14).

The proportion of biomass for every time period compared to the proportion of catch indicates that catch was not necessarily reflective of total consumer biomass (Figure 15). There was a large disparity between proportion of *exploitable invertebrate* catch in total system catch compared to proportion of biomass in total system biomass in the 2013-2015 and 2018-2020 models, indicating a large increase in fishing pressure in these time periods compared to 1985-1987. There was also an increase in the disparity between seal biomass and catch between 2013-2015 and 2018-2020, but this may be due to the fact hooded seal and other seal biomass estimates were not updated since the 2013-2015 model, but catch estimates were. Piscivorous fish tend to be fished in more equal proportions, except in 3LNO 2018-2020 where catch was higher than the proportion of biomass (Figure 15).

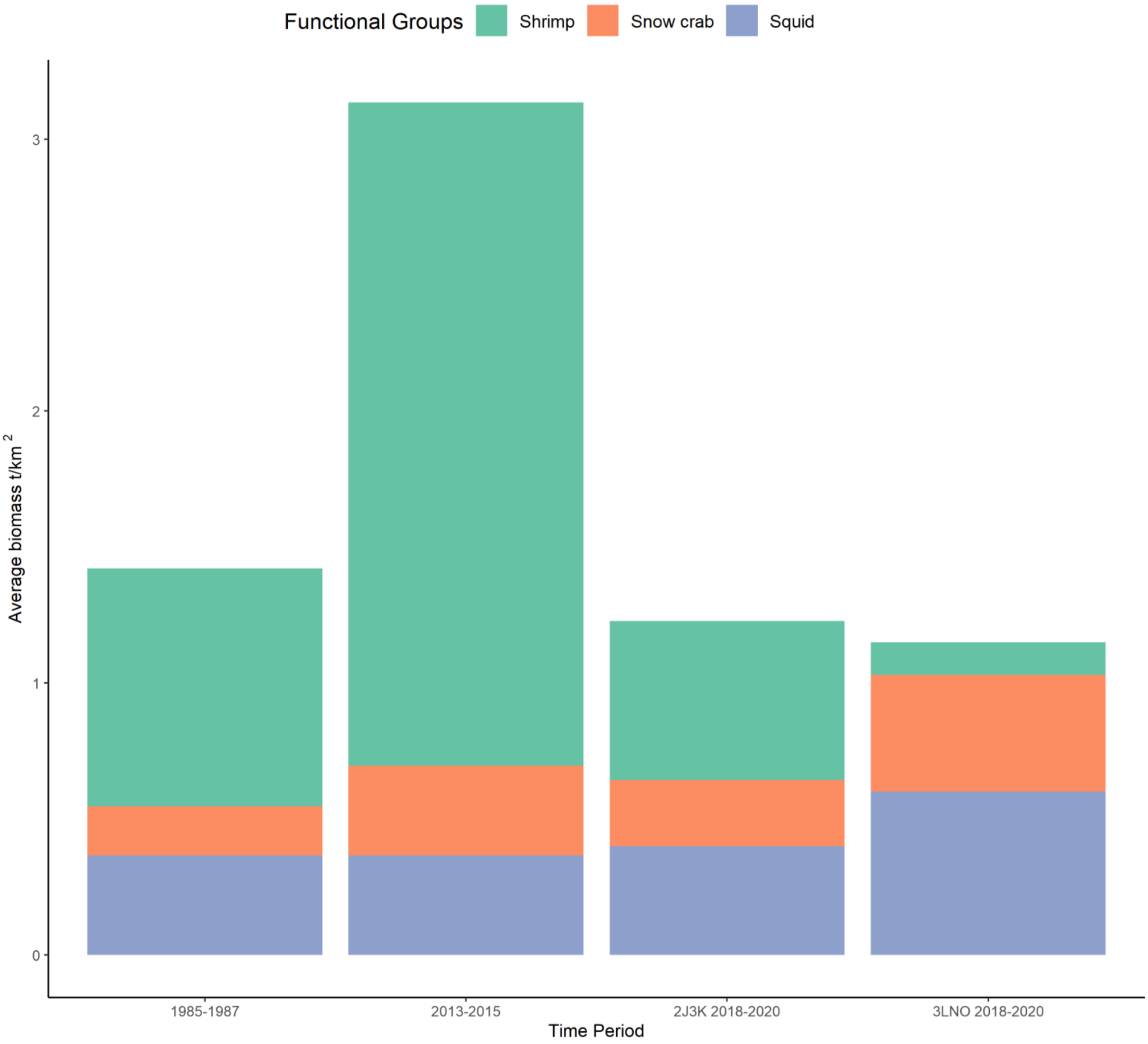

Figure 14 Magnitude of invertebrate biomass (t/km²) for all models and time periods.

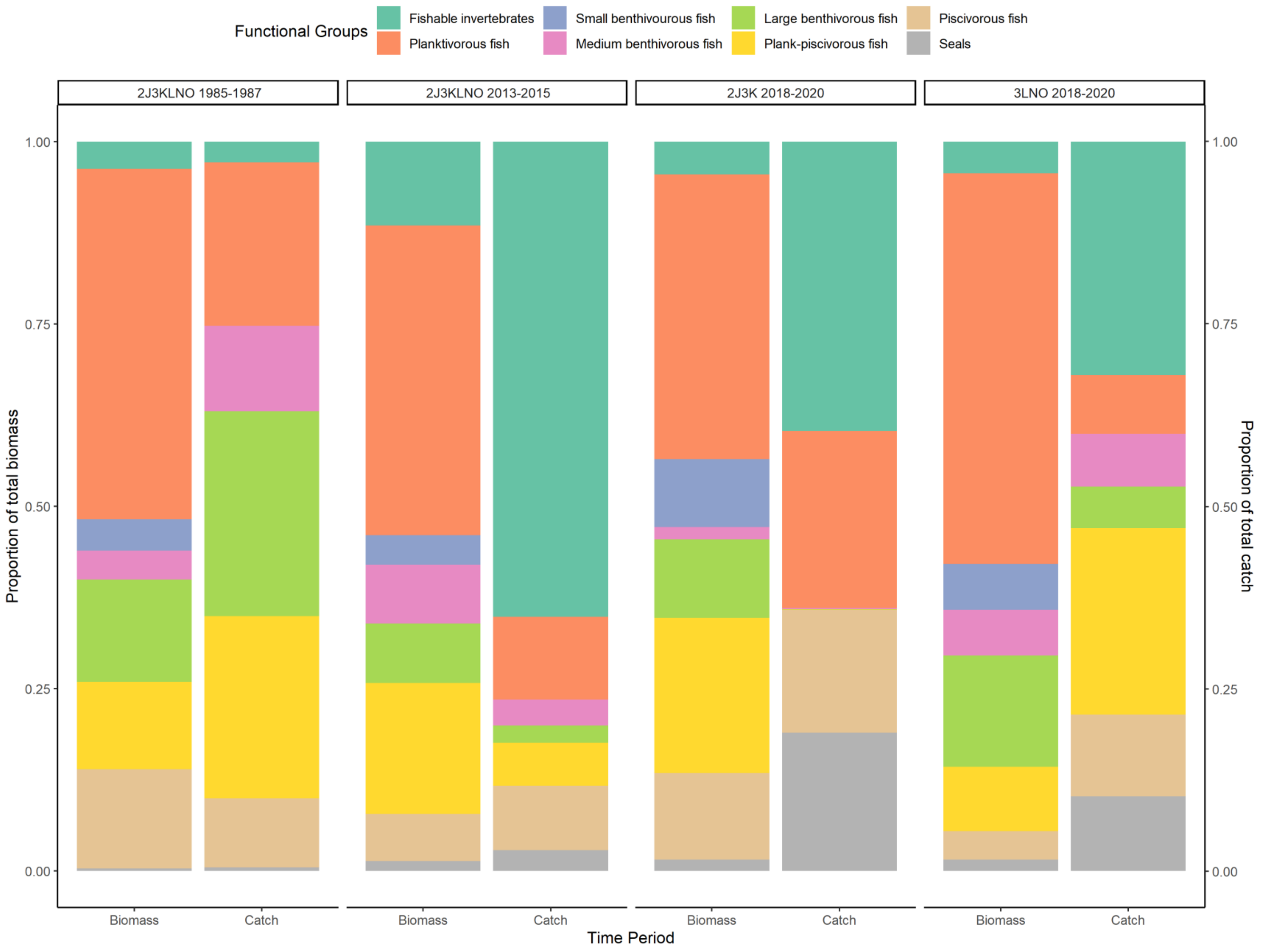

Figure 15 Proportion of biomass and catch by weight at each time period and study area across models. Note: catch data for 2J3KLNO have been aggregated for 2J3KLNO for 1985-1987 and 2013-2015

Overall system plankton biomass declined from 1985-1987 to 2013-2015 and increased in both 2J3K and 3LNO for 2018-2020 (Figure 16). This change was largely due to an increase in macrozooplankton and large mesozooplankton, which is comprised of non-pandalus shrimp, gelatinous zooplankton, and most importantly, large copepod species such as *Calanus finmarchicus*. Small mesozooplankton and microzooplankton biomass remained constant across the time periods (Figure 16). Large and small phytoplankton biomasses generally decreased through time, with the exception of 3LNO in 2018-2020 with increased small phytoplankton biomass but not large phytoplankton biomass (Figure 16).

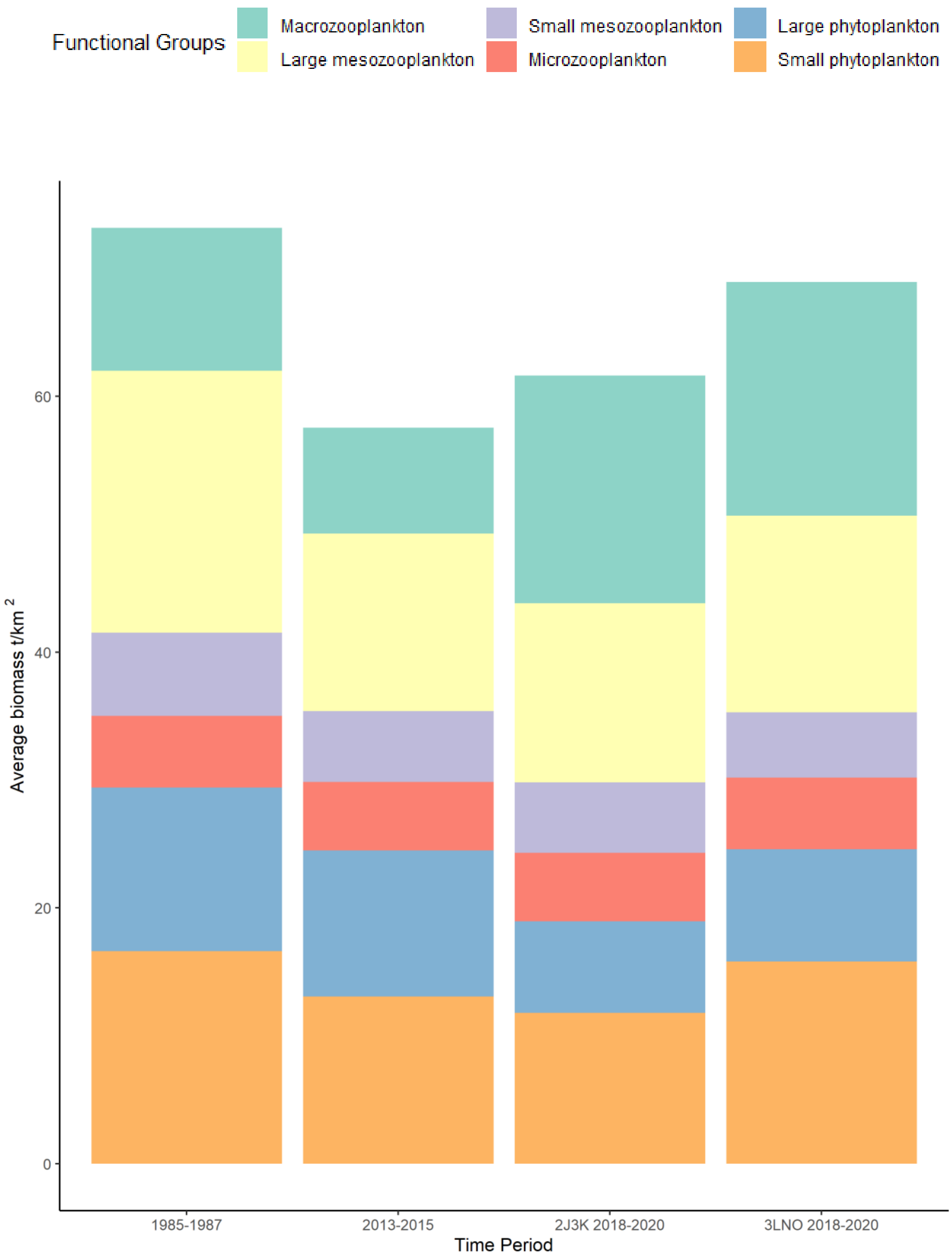

Figure 16 Magnitude of plankton biomass (t/km^2) between all models and time periods.

4. Discussion

4.1 Summary

4.1.1 Spatial Comparisons

When examining the results in the context of my first study objective, how ecosystem structure and function differs between the Newfoundland and Labrador Shelf and the Grand Banks, the models showed a difference in community structure and fishing patterns between 2J3K and 3LNO. Regarding fish communities, both areas had similar amounts of overall finfish biomass, but the group and species composition was different. 2J3K had less planktivorous fish, large benthivorous fish, and medium benthivorous fish than 3LNO, but had more small benthivorous fish, plank-piscivorous fish, and piscivorous fish. Species that were in high abundance in 2J3K but not 3LNO included Arctic cod and Atlantic cod. Alternatively, sandlance and American plaice were more both abundant in 3LNO than 2J3K. Overall invertebrate biomass was similar between the two regions, although species composition differed. 2J3K had more shrimp biomass whereas 3LNO had more squid and crab biomasses. Despite similar system biomasses, 3LNO had nearly double the amount of catch that 2J3K had, mostly driven by fisheries for yellowtail flounder and 3LN and 3O redfish that aren't present in 2J3K.

Environment and habitat preferences could explain the community differences between the two areas. For example, some fish such as American plaice prefer soft substrates that are found in 3LNO and some fish such as Arctic cod have better survivorship in the colder water found in 2J3K (Laurel et al. 2018). While estimates for geographically split 1985-1987 and 2013-2015 models don't exist, it could be interesting to investigate how each area responded to the groundfish collapse, and if there were any differences in resilience or magnitude of change due to species composition or biogeographical differences.

4.1.2 Temporal comparisons

Addressing my second study objective that examined how the structure and function of these two ecosystems have changed over time, the results showed drastic changes for some functional groups over the three time periods. The time gap between the first two models was over 25 years (1985-1987 and 2013-2015), while the latest models were developed only 5 years after the 2013-2015 model. Total system biomass was at similar levels in 2013-2015 compared to 2018-2020, but the composition of biomass was different, suggesting that the system is undergoing a period of rapid change. The reason behind this rapid change in structure is unclear. A drop in fishing pressure on invertebrates and fish and greater relative importance of predation on fish mortality was evident in 2018-2020 (Figure 10 and 11). This decrease in fishing pressure may be partially due to COVID 19 impacting 2020 fishing operations, but also there has been a steady decrease in fishing quotas and TAC for many commercial species in 2018-2020 such as Northern shrimp and snow crab (DFO 2021c; DFO 2022e).

Ecopath models have shown that a reduction in fishing pressure can produce large shifts in ecosystem structure (Christensen 1998; Taghavimotlagh et al. 2021), but environmental conditions can confound this relationship (Planque et al. 2010). Environment and climate change was not directly addressed by these models and could be contributing to changes in observed community structure. The Newfoundland and Labrador Climate Index (Cyr and Galbraith 2021) indicates that the 2013-2015 and 2018-2020 time periods are different in almost every component (e.g., SST, bottom temperature, cold intermediate layer area, etc.). Further research could examine the relationship between community structure and the climate regimes experienced over time on the Newfoundland Shelf and Grand Banks, to investigate if transitions in climate are correlated with transitions in community structure.

4.2 Ecopath and the Northwest Atlantic Ecosystem

4.2.1 Model Balancing

The balancing process is an important and necessary step in an Ecopath model, as the model framework relies on the concept of mass balance to produce a functioning model (Christensen 1995). Using the data pedigree as a guide, every parameter and data source must be scrutinized in high detail, to determine which numbers have the most, and least, justification to change. Each change should be made from a scientifically defensible position (Christensen et al. 2008), and a drawback of the balancing process is that finding harmony between 'scientifically plausible' and 'mass balanced' can be challenging. With each change, you can examine how it impacts the rest of the functional groups, and you begin to see which groups require the biggest changes.

For example, while balancing the 2018-2020 models squid had the largest EE of 60 in both unbalanced models (Appendix A and B). A large EE indicates that the energetic demand for squid was higher than what was available in the ecosystem. When re-assessing the biomass estimates for squid it was clear that seasonal abundance of squid in the area seems to vary depending on oceanographic conditions for that year (Dawe and Colbourne 1997). The initial estimates of squid from the RV surveys seemed low compared to estimates for the 2013-2015 model (0.0075 t/km2 and 0.0114 t/km2 compared to 0.365 t/km2; Tam and Bundy 2019) and there was reason to believe squid biomass should be higher than it was in 2015. There was a large spike in squid biomass in the fall RV survey in 2020 and a small spike in the 2018 spring survey that were 2-3 times the average biomass in their time series (Rideout et al. 2021). The squid biomass estimates in the 2013-2015 model were actually estimates from the 2006-2011 time period, which also had a spike in the spring survey biomass with a large standard deviation around the estimate. With the general understanding that squid are more abundant in 3LNO compared to 2J3K (based on RV survey observations), I felt comfortable increasing squid biomass for both models to produce EE values that were below 1, indicative of energetic balance.

Small benthivorous fish was one of five functional groups that had biomass estimated by Ecopath. This was accomplished by setting an EE to 0.95, implying a high percentage of biomass is consumed by higher trophic levels. Based on the energy requirements of predator groups that prey on *small benthivorous fish*, Ecopath originally estimated a biomass of 43 t/km^2 which was unrealistically high. This estimate was mostly driven by high predation mortality from the ‘predatory invertebrates’ group due to its relatively high biomass. To fix it, the proportion of *small benthivorous fish* in *predatory invertebrates* diet was adjusted from 0.1 to 0.001, with the remaining proportion allocated to *deposit feeding invertebrates* and *predatory invertebrates* (cannibalism). This adjustment brought the biomass of *small benthivorous fish* to a much more reasonable level. The change in *predatory invertebrates* diet composition is supported by findings in the American lobster stock assessment for Newfoundland (DFO 2021), which listed rock crab (*predatory invertebrates*), and echinoderms (*deposit feeding invertebrates*) as prominent diet items.

Harp seal diet required the greatest parameter adjustment during model balancing. The combined increase in seal biomass and reduction of capelin biomass observed during the 2018-2020 time period made balancing prey groups particularly challenging. To replace the absence of capelin in the diet of harp seals, more emphasis was given to species that had high availability in the area, such as squid, Arctic cod, and other benthivorous fish. All of these species have been observed in harp seal stomachs in various quantities in other diet studies (Foley 2018). Harp seal diet significantly differs between individuals foraging inshore vs offshore, with Arctic cod being an important prey item for inshore feeding, whereas capelin is an important prey item for feeding offshore Lawson et al. (1998).

Even with diet adjustments, the energy requirements of seals in the model were great. I had to assume that a small proportion of harp seal diet was being imported into the study area via fat reserves from foraging in the Arctic. Similar assumptions have been made for seals in Ecopath models before, for example Weigum (2019) assumed diet import from seals and penguins in Algoa Bay, South Africa, as those species only foraged in the study area for approximately half the year. Harp seals forage before entering the model study area, and their body condition can decrease by as much as 30% (in males) as fat reserves are burned during whelping/mating/moutling (Beck et al. 1993; Hammill et al. 2010). Harp seal biomass was already scaled to indicate seasonal presence in both areas, and it is known that the population has increased since the 2013-2015 model (DFO 2019), so further reducing biomass to indicate less foraging did not seem reflective of what was being observed in the ecosystem. To allow for mass balance, 10% of the harp seal diet proportion was assigned as import.

Overall, a lot of data poor functional groups had biomass estimates carried over from Tam and Bundy (2019) such as hooded seals, other seals and seabirds. This assumption may skew the 2018-2020 results into appearing more similar to the 2013-2015 model than they actually are, with some groups actually increasing or decreasing in that time frame. Results with higher uncertainty such as seals or forage fish that are estimated by Ecopath should be examined with scrutiny. While the current model is plausible from a mass-balance perspective, one should always be aware that it is unlikely to capture the true state of the ecosystem under these assumptions. However, many of the general group trends of increasing vs decreasing biomass are corroborated with other studies and expert opinion, and are therefore considered a reasonable estimate of the state of 2J3K and 3LNO.

4.2.2 Role of forage fish in the ecosystem

Trends of increasing large zooplankton and decreasing phytoplankton and small zooplankton could have strong impacts on the ecosystem. The Newfoundland and Labrador Shelf and The Grand Banks ecosystems are known to be influenced by bottom-up drivers such as primary and secondary production and forage fish abundance (Dawe et al. 2012). Top-down control is thought to occur more frequently following large scale perturbations to the ecosystem (Litzow and Ciannelli 2007). For example, the shrimp biomass boom following the groundfish collapse was thought to be partially due to a decrease in predation pressure from groundfish on shrimp (Boudreau et al. 2011). However, bottom-up environmental drivers appear to have more consistent influence on commercially harvested fish stocks on the Newfoundland Shelf and Grand Banks (Windle et al. 2012), which control primary and secondary productivity and feed key energy conduits such as forage fish.

Forage fish play a crucial role in food webs and ecosystem dynamics globally, by providing a link between the highly productive plankton groups and larger predators in the ecosystem (Pikitch et al. 2014). In extreme cases, this important role can create what is known as a ‘wasp waist’ ecosystem, where the link between lower and higher trophic levels in a food web pinches in on one key species (Fauchald et al. 2011). Predator biomass is highly sensitive to the depletion of lower trophic level fish via fishing pressure, and forage species with a higher number of links to the food web have larger impacts (Smith et al. 2011). In order to reduce the negative effects on commercially important high-trophic-level fish stock, fishing pressure should remain low on low-trophic-level fish, and the impact of fishing down the food web should be considered when building management frameworks for high-trophic-level species.

In the study area, capelin is a forage fish with a large influence on higher trophic levels. For example, capelin and Atlantic cod recovery are highly linked on the Newfoundland and Labrador Shelf and The Grand Banks (Koen-Alonso et al. 2021). Atlantic cod recovery in the Barents Sea compared to the lack of recovery in Newfoundland and Labrador was due to carefully managed fishing pressure in combination with an increase in capelin biomass that produced similar increases in cod biomass Koen-Alonso et al. (2021). Another example of capelin influence on higher trophic levels is their impact on humpback whales. Seasonal humpback whale distributions are directly tied to capelin abundance and date of spawning (Johnson and Davoren 2021), with whales returning to the same foraging sites every year. A final example is the relationship between capelin abundance in 3L and harp seal fecundity rates, with high capelin abundances correlated with successful pregnancies in the same year (Stenson et al. 2020). Given the high capelin abundance in 2013-2015, and the maturation age of harp seals being 5-7 years (Sjare et al. 1996) it is likely that the increase in the harp seal population observed in 2019 is tied to this increase in capelin (DFO 2019).

Capelin abundance has decreased in both study areas since the 2015 peak (DFO 2022). Each area had another key forage fish that was abundant in biomass and was a prominent component in many predator diets in the models – Arctic cod in 2J3K and sandlance in 3LNO. Neither species has a DFO stock assessment and information on biomass estimates were limited due to their under-representation in trawl surveys. Squid was an important alternative prey species in the models, as its abundance and biomass spiked in the late 2010s. This diet shift in response to decreased capelin availability has been documented in numerous predator groups since capelin collapsed in the 1990’s, such as Greenland halibut shifting towards more shrimp predation (Dawe et al. 2012), gulls shifting towards a more generalist diet including other birds’ eggs (Gulka et al. 2017; Massaro et al. 2000) and Atlantic cod towards invertebrate prey (Berard and Davoren 2020). Interestingly, humpback whale diets still tend to be dominated by capelin despite their reduced availability, indicating a very narrow predatory niche for humpbacks (Johnson and Davoren 2021).

Despite a lower biomass, caplin have high connectivity in both models’ food webs and based on their strong influence on higher trophic levels, capelin is a key species in the structure of both ecosystems. There is an increase in capelins preferred prey of copepods and euphausiids in both 2J3K and 3LNO (Figure 16), and a small shift toward finfish abundance increasing in the late 2010’s/early 2020’s. However, this increase in abundance does not necessarily mean the ecosystem is in a favourable state for capelin population growth or recovery.

Capelin growth rates and body condition on the Grand Banks were significantly poorer compared to capelin found on the Eastern Scotian Shelf (Obradovich et al. 2013). This difference seems to be attributable to a lower consumption of euphausiid prey causing slower growth rates and lower individual body masses, which may hinder population growth (Obradovich et al. 2013). Euphausiids in all models were included in the macrozooplankton functional group, and often had Ecopath estimate the groups biomass by inputting an EE of 0.95 - 0.98. This means it was assumed that 95 - 98% of macrozooplankton biomass was being consumed by higher trophic levels in the system. Unfortunately, this also means that the proportion of euphausiids to non-euphausiids being consumed is unknown. However, the general trend appears to be a decline in euphausiid biomass in both regions (Edwards et al. 2021). In both diet matrices, macrozooplankton accounted for 20% of capelins diet in both areas. Although there was an increase in macrozooplankton and large mesozooplankton biomass in both study areas, there wasn’t a similar increase in capelin biomass. This could mean euphausiids are not contributing large amounts of biomass to the macrozooplankton group, and/or prey availability is not the only driver of capelin dynamics in the study area.

In both models, capelins’ largest source of mortality is predation (Figure 10) with minimal fishing pressure, which may imply some top-down controls on the population. The top predators of capelin in my models were piscivorous whales, seabirds, harp seals, Atlantic cod and American plaice, many of which experienced moderate biomass growth in 2018-2020 (Figure 12). Other drivers that are outside the scope of these models may also play a role as well, such as climate (Buren et al. 2014). Negative climate indices in spanning 2018-2021 hinder capelin recovery due to delayed spawning and shifts to early maturation in adults (Murphy et al. 2021). Overall, this indicates that there are several drivers of capelin population dynamics, and the increase in zooplankton biomass observed in the models does not seem to be linked to an increase in capelin biomass in the ecosystem.

4.2.3 Ecosystem-based fisheries management

There are other ecosystems around the world that share structural and functional similarities to the Newfoundland Shelf and the Grand Banks. Comparisons have been made between Newfoundland’s ecosystem and the Barents Sea ecosystem, particularly surrounding cod and capelin dynamics (Koen-Alonso et al. 2018; Dalpadado and Mowbray 2013). Both systems historically had Atlantic cod as a dominant predator in the ecosystem and as the main target of fishing activity, and both experienced collapses or declines in groundfish and forage fish in the past few decades (Johannesen et al. 2012). The cod population in the Barents Sea has recovered from its decline despite frequent collapses in the capelin populations (Johannesen et al. 2012).

The lack of a recovery in Newfoundland was attributed to differing responses to fishing pressure and changing environmental conditions, but it was clear that both systems would benefit greatly from the implementation of capelin-informed data (Koen-Alonso 2018). In the Barents Sea, potential value was found in a multi-model approach where complimentary ecosystem models explored different aspects of trophic interactions between cod, capelin, polar cod and copepods under varying amounts of fishing pressure (Nilsen et al. 2022). The use of multiple models of varying complexity provided a better picture of ecosystem and wood web structure under different fishing scenarios, which could be useful in helping fisheries managers understand how prey stocks such as capelin may inform predator stocks such as Atlantic cod (Nilsen et al. 2022).

The Gulf of Alaska (GOA) is another highly dynamic system that is also heavily influenced by bottom-up drivers such as climate change (Barbeaux et al. 2020). In 2014-2016, the GOA experienced a prolonged period of high SST which greatly reduced system productivity and increased metabolic demands on many key species (Suryan et al. 2021). The combined stressors on the ecosystem led to a rapid 70% decline in Pacific cod stocks over the next three years. Despite this large decline, management decisions and practices in response to this decline were considered well-implemented and an effective example of EBFM (Barbeaux et al. 2020). Their strategies included a ban on forage fish catch, focusing on system level groundfish yield, as opposed to single species, and open inclusion of various stakeholders in industry and science in the decision-making process. EBFM practices used in the response to the pacific cod collapse, while not perfect, shows high potential to promote resiliency in the way groundfish stocks are fished, mitigating socio-economic and biological loss if climate driven declines occur again in the future (Holsman et al. 2020).

Considering the comparisons to similar ecosystems with the results of the model comparisons in this paper, some key takeaways in the context of EBFM for the Newfoundland Shelf and Grand Banks include :

> (1) Forage fish commercial catch rates should remain low. Given their high importance and high impact on commercially target species, their biological contributions to the ecosystem far outweighs the economic value of their catch (Pikitch et al. 2014; Smith et al. 2011).
>
> (2) More research into predator diet variability, especially under scenarios of low forage fish, would be highly beneficial to the understanding of the ecosystem. The suggested diet matrices in the models are hypothesized and are supported from an energy-balance perspective, but validating these hypotheses could provide valuable insight to ecosystem structure under different biological regimes.

Some potential future uses of the Ecopath model could explore ecosystem scenarios under various plankton and predator states to see what it would take to create a forage fish recovery in the system, and if that would result in an overall system biomass recovery. These scenarios could also explore different diet structures to examine how predator consumption may shift if the ecosystem were to experience another large perturbation. Having a deeper understanding of the ecosystem factors that regulate the system will be critical to successfully managing any emerging recovering stocks in the coming years.

4.2.4 Conclusion

While describing the basic ecosystem structure is not tailored to directly answer management questions, the value of synthesizing data of these basic ecosystem structures and functions is a crucial first step. There were differences in ecosystem structure and function spatially, between

2J3K and 3LNO, and temporally, with shifts in biomass and predation from the 1980's to the late 2010's. Type and quantity of catch has overall declined since 1985-1987 and is lower in 2J3K compared to 3LNO. The fact that differences in ecosystem structure and function were observed between the short time span of 2013-2015 and 2018-2020 shows that the system is currently undergoing a period of rapid change. While a modest increase of ground fish may not be indicative of a full system recovery, increases in zooplankton biomass in combination with favourable environmental factors could set the stage for a further shift away from invertebrate dominance, and towards improving groundfish and forage fish stocks in the next decade.

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6. Appendices

Appendix A Initial unbalanced 2J3K model for 2018-2020, values in blue are estimated by Ecopath. Values that are bolded were changed in the balancing process.

Functional group	Biomass (t/km^2)	*P/B*	*Q/B*	*EE*	Trophic level
Whale fish eater	**0.7944**	0.120	6.0	0.00	4.47
Whale zooplankton eater	**0.0136**	**0.055**	3.47	0.67	3.66
Whale squid eater	0.1210	**0.091**	6.0	0.00	4.69
Whale mammal eater	**0.0003**	**0.084**	8.1	0.00	5.30
Seal harp	**0.3346**	**0.149**	17.64	0.53	4.34
Seal hooded	**0.0315**	**0.115**	18.33	0.16	5.27
Seal other	0.0160	**0.134**	13.00	0.03	4.98
Seabird piscivore	0.0070	0.250	**119.41**	0.10	4.47
Seabird planktivore	**0.0056**	0.150	**64.61**	0.00	3.60
Seabird benthivore	**0.0017**	0.130	**45.29**	0.00	3.91
Greenland shark	**0.0088**	0.010	**0.13**	0.00	5.45
Atlantic cod >35cm	2.1800	**0.402**	**1.17**	0.26	4.63
Atlantic cod <=35cm	**0.1998**	0.4	**2.96**	0.18	3.82
Greenland halibut	**0.5360**	**0.367**	**2.90**	1.76	4.60
Other piscivorous fish	0.0370	**0.111**	**4.95**	17.73	4.57
Redfish	**1.0520**	**0.084**	2.00	4.94	3.79
Arctic cod	**4.5483**	0.350	4.00	0.40	3.57
Other plank-piscivorous fish	**0.0277**	0.350	2.30	2.26	3.90
American plaice >35cm	**0.1427**	**0.5**	2.00	1.95	4.27
American plaice <= 35cm	**0.3013**	**0.5**	**3.71**	6.02	4.00
Thorny skate	**0.0768**	**0.149**	**1.79**	4.33	4.62
Other large benthivorous fish	0.9850	**0.200**	1.33	0.79	4.11
Witch flounder	**0.0495**	**0.172**	**2.60**	10.41	4.48
Other medium benthivorous fish	**0.2031**	**0.300**	2.00	11.09	3.99
Small benthivorous fish	**47.2786**	**0.421**	2.00	0.95	4.15
Herring	**0.9154**	1.150	**3.15**	0.95	3.91
Sandlance	**2.9539**	1.150	7.66	0.95	3.91
Capelin	**2.9500**	1.150	4.30	2.92	3.61
Other planktivorous fish	**3.2900**	1.150	4.19	0.95	2.96
Squid	**0.0075**	3.400	13.20	60.44	3.64
Shrimp	**0.3070**	1.700	11.33	16.37	2.55
Snow crab	**0.1130**	0.500	3.06	0.98	4.14
Predatory invertebrates	**20.8330**	**1.310**	**8.73**	3.26	4.14
Deposit feeding invertebrates	**88.5417**	**1.5**	**10.00**	3.98	3.20
Suspension feeding invertebrates	**63.5417**	**0.556**	3.70	3.89	2.00

Macrozooplankton	**8.7800**	**3.430**	19.50	0.95	2.51
Large mesozooplankton	**13.5000**	**8.4**	28.00	1.77	2.71
Small mesozooplankton	**5.5340**	**31.610**	**105.40**	0.97	2.51
Microzooplankton	5.3600	**72**	240.00	0.35	2.00
Large phytoplankton	7.1750	**103.3**		0.81	1.00
Small phytoplankton	**11.7800**	**103.3**		0.92	1.00
Detritus	1.0000			1.39	1.00

Appendix B Initial unbalanced 3LNO model for 2018-2020, values in blue are estimated by Ecopath, values that are bolded were changed in the balancing process.

Functional group	Biomass (t/km^2)	*P/B*	*Q/B*	EE	Trophic level
Whale fish eater	**0.7333**	0.120	6.0	0.00	4.47
Whale zooplankton eater	**0.0164**	**0.055**	3.468	0.51	3.64
Whale squid eater	**0.1118**	**0.091**	6.0	0.00	4.76
Whale mammal eater	**0.0003**	**0.084**	8.1	0.00	5.32
Seal harp	**0.3088**	**0.149**	17.642	0.57	4.34
Seal hooded	**0.0073**	**0.115**	18.330	0.66	5.47
Seal other	0.0140	**0.134**	13.000	0.03	5.03
Seabird piscivore	**0.0071**	0.250	119.410	0.09	4.47
Seabird planktivore	**0.0056**	0.150	64.600	0.00	3.60
Seabird benthivore	**0.0017**	0.130	**45.291**	0.00	3.91
Greenland shark	**0.0088**	0.010	**0.125**	0.00	5.51
Atlantic cod >35cm	0.5680	**0.402**	**1.165**	0.78	4.70
Atlantic cod <=35cm	**0.0521**	**0.402**	**2.959**	0.50	3.82
Greenland halibut	**0.0770**	**0.216**	**2.900**	7.99	4.64
Silver hake / pollock	**0.0800**	**0.310**	4.100	1.93	4.48
Other piscivorous fish	0.1220	**0.175**	**1.651**	1.06	4.63
Redfish	**0.9070**	**0.164**	2.000	1.80	3.79
Arctic cod	**1.0496**	0.600	4.000	0.92	3.57
Other plank-piscivorous fish	**0.0277**	0.350	2.300	0.64	3.90
American plaice >35cm	**0.6557**	0.500	2.000	0.46	4.27
American plaice <= 35cm	**1.4089**	**0.507**	**3.727**	0.55	4.00
Thorny skate	**0.7089**	**0.196**	**1.792**	0.68	4.62
Haddock	**0.0386**	**0.214**	2.080	0.71	4.29
Other large benthivorous fish	**0.1149**	**0.200**	1.330	8.56	4.12
Yellowtail flounder	**1.0079**	**0.391**	3.600	0.72	4.90
Witch flounder	**0.0627**	**0.197**	**2.599**	0.57	4.48
Other medium benthivorous fish	**0.0448**	**0.300**	2.000	23.90	3.99

Small benthivorous fish	**43.4176**	**0.421**	2.000	0.95	4.15
Herring	**0.8397**	1.150	3.148	0.95	3.91
Sandlance	**3.6632**	1.150	2.540	0.95	3.91
Capelin	**3.6100**	**1.150**	4.300	2.20	3.61
Other planktivorous fish	**3.0179**	1.150	4.190	0.95	2.96
Squid	**0.0114**	3.400	13.200	60.71	3.64
Shrimp	**0.3970**	1.700	11.300	11.58	2.55
Snow crab	**0.2303**	0.500	3.060	0.78	4.14
Predatory invertebrates	**19.2300**	**1.310**	**8.733**	3.31	4.14
Deposit feeding invertebrates	**81.7308**	**1.500**	10.000	3.98	3.20
Suspension feeding invertebrates	**58.6539**	**0.556**	3.700	3.88	2.00
Macrozooplankton	**5.9711**	**3.430**	19.500	0.95	2.51
Large mesozooplankton	**13.5040**	**8.400**	28.000	1.65	2.71
Small mesozooplankton	**5.5340**	**31.610**	**105.367**	0.92	2.51
Microzooplankton	**5.3600**	72.000	240.000	0.32	2.00
Large phytoplankton	**4.7511**	**103.300**		1.19	1.00
Small phytoplankton	**10.5087**	**103.300**		1.02	1.00
Detritus				2.65	1.00

Appendix C 2J3K diet matrix for 2018-2020

2J3K	Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Whale fish eater	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Whale zooplankton eater	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Whale squid eater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Whale mammal eater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Seal harp	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Seal hooded	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Seal other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Seabird piscivore	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Seabird planktivore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Seabird benthivore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Greenland shark	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	Atlantic cod greater than 35cm	0.00	0.00	0.00	0.00	0.10	0.25	0.06	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
13	Atlantic cod less than 35cm	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.02	0.01	0.00	0.02	0.02	0.00	0.00	0.00	0.00
14	Greenland halibut	0.00	0.00	0.00	0.05	0.00	0.22	0.06	0.00	0.00	0.00	0.08	0.02	0.00	0.11	0.01	0.00	0.00	0.00	0.00
15	Other piscivorous fish	0.00	0.00	0.00	0.05	0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Redfish	0.00	0.00	0.00	0.00	0.02	0.05	0.08	0.00	0.00	0.00	0.00	0.01	0.00	0.05	0.02	0.00	0.00	0.00	0.00
17	Arctic cod	0.05	0.00	0.00	0.00	0.14	0.18	0.02	0.02	0.00	0.00	0.00	0.01	0.00	0.08	0.01	0.00	0.00	0.00	0.07
18	Other plank-piscivorous fish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
19	American plaice greater than 35cm	0.00	0.00	0.01	0.00	0.02	0.01	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
20	American plaice less than 35cm	0.00	0.00	0.01	0.00	0.05	0.02	0.03	0.00	0.00	0.00	0.01	0.10	0.01	0.05	0.12	0.01	0.00	0.00	0.00
21	Thorny skate	0.00	0.00	0.01	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
22	Other large benthivorous fish	0.01	0.00	0.06	0.00	0.01	0.00	0.05	0.00	0.00	0.00	0.10	0.00	0.00	0.05	0.02	0.00	0.00	0.00	0.00
23	Witch flounder	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
24	Other medium benthivorous fish	0.00	0.00	0.05	0.00	0.00	0.01	0.10	0.00	0.00	0.00	0.05	0.00	0.01	0.01	0.02	0.00	0.00	0.00	0.01
25	Small benthivorous fish	0.05	0.00	0.00	0.00	0.02	0.05	0.05	0.06	0.00	0.10	0.05	0.04	0.00	0.03	0.01	0.00	0.00	0.05	0.00
26	Herring	0.23	0.00	0.00	0.00	0.19	0.00	0.15	0.08	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00
27	Sandlance	0.12	0.04	0.00	0.00	0.10	0.04	0.09	0.08	0.00	0.00	0.00	0.00	0.06	0.00	0.02	0.00	0.00	0.01	0.02
28	Capelin	0.10	0.04	0.04	0.05	0.07	0.03	0.20	0.35	0.00	0.00	0.00	0.20	0.08	0.29	0.50	0.15	0.01	0.01	0.10
29	Other planktivorous fish	0.23	0.00	0.06	0.00	0.00	0.00	0.02	0.40	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.08	0.00	0.01	0.00
30	Squid	0.08	0.00	0.77	0.05	0.00	0.13	0.01	0.00	0.00	0.00	0.02	0.03	0.01	0.10	0.00	0.03	0.00	0.00	0.00
31	Shrimp	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.06	0.02	0.05	0.02	0.00	0.05	0.07
32	Snow crab	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
33	Predatory invertebrates	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.20	0.00	0.15	0.05	0.01	0.00	0.00	0.00	0.05	0.09
34	Deposit feeding invertebrates	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.05	0.00	0.00	0.00	0.30	0.10
35	Suspension feeding invertebrates	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.25	0.04	0.03	0.00	0.02	0.00	0.00	0.09	0.10	0.23
36	Macrozooplankton	0.08	0.61	0.00	0.00	0.06	0.00	0.00	0.00	0.21	0.25	0.00	0.12	0.45	0.10	0.08	0.71	0.62	0.31	0.30
37	Large mesozooplankton	0.04	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.20	0.00	0.01	0.12	0.00	0.00	0.00	0.28	0.10	0.00
38	Small mesozooplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
39	Microzooplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
40	Large phytoplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
41	Small phytoplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
42	Detritus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43	Import	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix C continued

2J3K	Species	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
1	Whale fish eater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Whale zooplankton eater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Whale squid eater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Whale mammal eater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Seal harp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Seal hooded	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Seal other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Seabird piscivore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Seabird planktivore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Seabird benthivore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Greenland shark	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	Atlantic cod greater than 35cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Atlantic cod less than 35cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Greenland halibut	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Other piscivorous fish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Redfish	0.00	0.01	0.04	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	Arctic cod	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	Other plank-piscivorous fish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	American plaice greater than 35cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	American plaice less than 35cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	Thorny skate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	Other large benthivorous fish	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	Witch flounder	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Other medium benthivorous fish	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Small benthivorous fish	0.01	0.05	0.05	0.01	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Herring	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	Sandlance	0.13	0.00	0.02	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	Capelin	0.01	0.06	0.03	0.00	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	Other planktivorous fish	0.00	0.00	0.03	0.00	0.06	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	Squid	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	Shrimp	0.01	0.20	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	Snow crab	0.01	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
33	Predatory invertebrates	0.12	0.20	0.09	0.21	0.12	0.31	0.12	0.18	0.01	0.00	0.08	0.06	0.30	0.20	0.00	0.00	0.00	0.00	0.00	0.00
34	Deposit feeding invertebrates	0.05	0.06	0.44	0.50	0.19	0.33	0.10	0.00	0.00	0.00	0.03	0.05	0.30	0.20	0.20	0.00	0.00	0.00	0.00	0.00
35	Suspension feeding invertebrates	0.30	0.00	0.15	0.28	0.21	0.23	0.00	0.00	0.04	0.05	0.03	0.01	0.13	0.12	0.03	0.00	0.00	0.00	0.00	0.00
36	Macrozooplankton	0.36	0.20	0.03	0.00	0.24	0.01	0.43	0.17	0.20	0.00	0.81	0.00	0.01	0.06	0.01	0.00	0.00	0.03	0.00	0.00
37	Large mesozooplankton	0.00	0.00	0.11	0.00	0.00	0.05	0.10	0.40	0.53	0.35	0.03	0.05	0.02	0.02	0.00	0.00	0.05	0.12	0.05	0.00
38	Small mesozooplankton	0.00	0.00	0.01	0.00	0.02	0.05	0.00	0.10	0.20	0.15	0.00	0.05	0.01	0.01	0.00	0.00	0.15	0.18	0.05	0.00
39	Microzooplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.03	0.08	0.00	0.08	0.00	0.18	0.12	0.00	0.20	0.10	0.22	0.00
40	Large phytoplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.01	0.01	0.00	0.00	0.25	0.12	0.26	0.30
41	Small phytoplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.40	0.00	0.00	0.00	0.00	0.25	0.12	0.34	0.65
42	Detritus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.20	0.64	1.00	0.10	0.33	0.08	0.05
43	Import	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix D 3LNO diet matrix for 2018-2020.

3LNO	Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	Whale fish eater	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Whale zooplankton eater	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Whale squid eater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Whale mammal eater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Seal harp	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Seal hooded	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Seal other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Seabird piscivore	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Seabird planktivore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Seabird benthivore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Greenland shark	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	Atlantic cod > 35cm	0.00	0.00	0.00	0.00	0.01	0.09	0.05	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
13	Atlantic cod < 35cm	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00
14	Greenland halibut	0.00	0.00	0.00	0.05	0.00	0.08	0.06	0.00	0.00	0.00	0.05	0.01	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00
15	Silver hake and pollock	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
16	Other piscivorous fish	0.00	0.00	0.00	0.05	0.00	0.16	0.04	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	Redfish	0.00	0.00	0.00	0.00	0.02	0.05	0.08	0.00	0.00	0.00	0.00	0.03	0.00	0.04	0.07	0.02	0.00	0.00	0.00	0.00	0.00
18	Arctic cod	0.01	0.00	0.00	0.00	0.07	0.00	0.02	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00
19	Other plank-piscivorous fish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
20	American plaice > 35cm	0.00	0.00	0.00	0.00	0.03	0.05	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.12	0.00	0.00	0.00	0.00	0.00
21	American plaice < 35cm	0.00	0.00	0.00	0.00	0.05	0.02	0.02	0.00	0.00	0.00	0.01	0.21	0.01	0.05	0.00	0.00	0.01	0.00	0.00	0.00	0.00
22	Thorny skate	0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
23	Haddock	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
24	Other large benthivorous fish	0.01	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Yellowtail flounder	0.00	0.00	0.06	0.00	0.00	0.30	0.05	0.00	0.00	0.00	0.00	0.08	0.00	0.05	0.00	0.01	0.00	0.00	0.00	0.00	0.01
26	Witch flounder	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
27	Other M benthivorous fish	0.00	0.00	0.03	0.00	0.01	0.01	0.06	0.00	0.00	0.00	0.05	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00
28	Small benthivorous fish	0.03	0.00	0.00	0.00	0.01	0.05	0.05	0.06	0.00	0.10	0.05	0.02	0.00	0.03	0.00	0.01	0.00	0.00	0.05	0.00	0.00
29	Herring	0.23	0.00	0.00	0.00	0.20	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
30	Sandlance	0.22	0.03	0.00	0.00	0.20	0.04	0.09	0.07	0.00	0.00	0.00	0.17	0.06	0.16	0.37	0.27	0.05	0.00	0.01	0.30	0.13
31	Capelin	0.10	0.03	0.02	0.05	0.07	0.01	0.20	0.55	0.00	0.00	0.00	0.22	0.08	0.36	0.33	0.25	0.09	0.04	0.01	0.10	0.20
32	Other planktivorous fish	0.21	0.00	0.04	0.00	0.06	0.00	0.02	0.29	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.05	0.05	0.00	0.01	0.00	0.00
33	Squid	0.08	0.00	0.77	0.05	0.05	0.13	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.10	0.00	0.00	0.07	0.00	0.00	0.00	0.01
34	Shrimp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.02	0.02	0.05	0.02	0.00	0.05	0.01	0.00
35	Snow crab	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
36	Predatory invertebrates	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.20	0.00	0.08	0.05	0.00	0.00	0.00	0.00	0.00	0.05	0.10	0.07
37	Deposit feeding inverts	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.30	0.20	0.03
38	Suspension feeding inverts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.25	0.04	0.02	0.00	0.02	0.00	0.00	0.00	0.09	0.00	0.24	0.18
39	Macrozooplankton	0.08	0.68	0.00	0.00	0.05	0.00	0.00	0.00	0.21	0.25	0.00	0.08	0.45	0.10	0.21	0.08	0.71	0.59	0.41	0.03	0.36
40	Large mesozooplankton	0.02	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.20	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.28	0.10	0.00	0.00
41	Small mesozooplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
42	Microzooplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43	Large phytoplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

44	Small phytoplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45	Detritus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
46	Import	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix D continued

3LNO	Species	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
1	Whale fish eater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Whale zooplankton eater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Whale squid eater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Whale mammal eater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Seal harp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Seal hooded	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Seal other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Seabird piscivore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Seabird planktivore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Seabird benthivore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Greenland shark	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	Atlantic cod > 35cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Atlantic cod < 35cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Greenland halibut	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Silver hake and pollock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Other piscivorous fish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	Redfish	0.01	0.00	0.04	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	Arctic cod	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	Other plank-piscivorous fish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	American plaice > 35cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	American plaice < 35cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	Thorny skate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	Haddock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Other large benthivorous fish	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Yellowtail flounder	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Witch flounder	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	Other M benthivorous fish	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	Small benthivorous fish	0.03	0.01	0.03	0.00	0.01	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	Herring	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	Sandlance	0.36	0.05	0.02	0.10	0.00	0.03	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	Capelin	0.06	0.09	0.03	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	Other planktivorous fish	0.00	0.00	0.03	0.00	0.00	0.06	0.02	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
33	Squid	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	Shrimp	0.00	0.06	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
35	Snow crab	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36	Predatory invertebrates	0.17	0.23	0.09	0.61	0.21	0.12	0.15	0.12	0.18	0.01	0.00	0.08	0.06	0.30	0.20	0.00	0.00	0.00	0.00	0.00	0.00
37	Deposit feeding inverts	0.02	0.37	0.44	0.15	0.50	0.19	0.50	0.10	0.00	0.00	0.00	0.03	0.05	0.30	0.20	0.20	0.00	0.00	0.00	0.00	0.00
38	Suspension feeding inverts	0.00	0.14	0.15	0.07	0.28	0.21	0.08	0.00	0.00	0.04	0.05	0.03	0.01	0.13	0.12	0.07	0.00	0.00	0.00	0.00	0.00
39	Macrozooplankton	0.16	0.00	0.03	0.06	0.00	0.24	0.10	0.43	0.17	0.20	0.00	0.81	0.00	0.01	0.06	0.01	0.00	0.00	0.03	0.00	0.00
40	Large mesozooplankton	0.00	0.04	0.11	0.01	0.00	0.00	0.05	0.10	0.40	0.53	0.35	0.03	0.05	0.02	0.02	0.00	0.00	0.05	0.14	0.05	0.00

41	Small mesozooplankton	0.00	0.00	0.01	0.00	0.00	0.02	0.05	0.00	0.10	0.20	0.15	0.00	0.05	0.01	0.01	0.00	0.00	0.15	0.08	0.12	0.00
42	Microzooplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.03	0.08	0.00	0.08	0.00	0.18	0.10	0.00	0.20	0.20	0.20	0.00
43	Large phytoplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.01	0.01	0.00	0.00	0.25	0.11	0.21	0.30
44	Small phytoplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.40	0.00	0.00	0.00	0.00	0.25	0.11	0.34	0.65
45	Detritus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.10	0.20	0.62	1.00	0.10	0.33	0.08	0.05
46	Import	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00