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Maritimes Region

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Science Advisory Report 2021/054

REVIEW OF METHODS FOR DEVELOPING CATCH LIMITS FOR GREENLAND COCKLE (*SERRIPES GROENLANDICUS*) AND NORTHERN PROPELLER CLAM (*CYRTODARIA SILIQUA*) IN THE BANQUEREAU AND GRAND BANK OFFSHORE CLAM FISHERIES

Northern Propeller Clam (Cyrtodaria siliqua; left) and Greenland Cockle (Serripes groenlandicus; right). Photo credit: DFO Science, Maritimes Region.

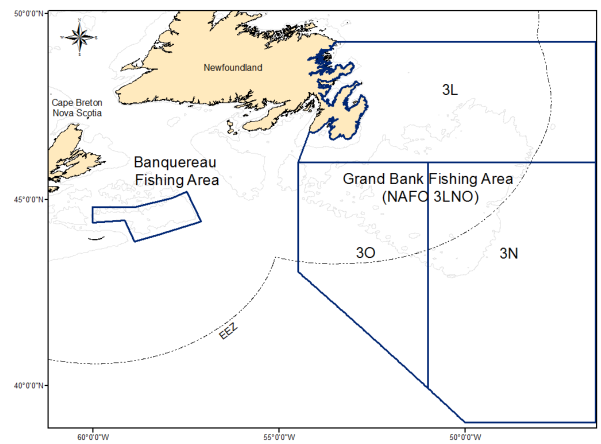

Figure 1. Banquereau and Grand Bank offshore clam fishing areas (solid lines) from licence conditions

Context:

The offshore clam fishery for Arctic Surfclam (Mactromeris polynyma) on Banquereau and Grand Bank is managed with individual Total Allowable Catches (TACs) for each Bank. The co-occurring fishery for Ocean Quahog (Arctica islandica) is managed with an 800 tonne (t) TAC on Banquereau, and a catch limit on Grand Bank that limits landings to 10% of Surfclam catch, to a maximum of 500 t. In the offshore clam fishery there is unlimited retention of non-quota molluscs (DFO 2020a). Martitimes Region Resource Management requested biological information, landings and catch per unit effort information, biomass estimates from available methods, and advice on potential catch limits for two non-quota molluscs: Greenland Cockle (Serripes groenlandicus) and Northern Propeller Clam (Cyrtodaria siliqua) on Banquereau and Grand banks. The advice will be used to support decisions about harvest levels in the offshore clam fishery.

This Science Advisory Report is from the March 10–11, 2021, Regional Advisory Meeting on the Review of Methods for Developing Catch Limits for Greenland Cockle (Serripes groenlandicus) and Northern Propellerclam (Cyrtodaria siliqua) in the Banquereau and Grand Bank Offshore Clam Fisheries. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- The Arctic Surfclam fishery began on Banquereau in 1986 and on Grand Bank in 1989. The directed Surfclam fishery allows for the retention of Greenland Cockle and Northern Propeller Clam.
- Greenland Cockle have been landed in the Banquereau fishery since 1999 and from Grand Bank since 1994. Northern Propeller Clam have been landed in the Banquereau fishery since 1996 and from Grand Bank since 1994. The amount and frequency of landings have varied over the time series for both species.
- A complete time series of actual catch (discards plus landings) is unavailable for Greenland Cockle and Northern Propeller Clam. Changes in landings over time is a function of economics and fishery behaviour as much as species densities or biomass.
- Landings-based approaches do not account for discards and should be used with caution until more discard information can be collected.
- Approaches based on biomass estimates, from survey or from landings per unit effort, are sensitive to the catchability coefficient, the area used to calculate the biomass, and the removal rate applied to the biomass.
- Length-based indicators provide information on size distribution of the stock and are a simple means for monitoring.

BACKGROUND

Biology and Life History

Greenland Cockle (*Serripes groenlandicus*), and Northern Propeller Clam (*Cyrtodaria siliqua)* are both sedentary species that use broadcast spawning to reproduce. As sedentary animals, they are limited in reproductive opportunities. Broadcast spawners rely on certain densities of conspecifics to ensure reproductive success. If areas are exploited and locally depleted, these species may be limited in their abilities to sustain the population. Greenland Cockle grow rapidly in the first nine years until they reach 80–90 mm in shell length, after which their growth rate decreases (Kilada et al. 2007a). Greenland Cockle are hermaphroditic, and a study on Greenland Cockle from Banquereau and Grand Bank found the size- and age-at-50% sexual maturity to be 27.92 mm and 2.83 years for male tissues and 37.22 mm and 3.69 years for female tissues (Kilada et al. 2007a). Northern Propeller Clam grow rapidly in the first 20 years (approximately 3 mm per year) then the growth rate decreases to approximately 0.5 mm per year for clams over 60 years (Kilada et al. 2009). Propeller Clam have separate male and female individuals. A study on Propeller Clam from Banquereau found the size- and age-at-50% sexual maturity to be 28.6 mm and 4.7 years (Kilada et al. 2009). Table A1 contains a summary of the life-history traits of the clam species retained in this fishery.

Commercial Fishery

The Arctic Surfclam fishery began on Banquereau in 1986 and on Grand Bank in 1989. The directed Surfclam fishery allows for the retention of Greenland Cockle and Northern Propeller Clam. Some amounts of Greenland Cockle have been landed in the Banquereau fishery since 1999 and from Grand Bank since 1994. Some amounts of Northern Propeller Clam have been landed in the Banquereau fishery since 1996 and from Grand Bank since 1994. The amount and frequency of landings have varied over the time series for both species. Although these two species have been landed for over two decades, the vessel capacity, and fishing and processing methods of the fishery have been changing. Markets for these species are still being developed, and past fishing activity is not anticipated to reflect future fishing efforts.

Fishery Data and Conversion Factors

Commercial data used in this document are stored in the DFO Science Offshore Clam Data Archival (CLAM) database. In 2020, DFO Science conducted a detailed data review after some discrepancies were noted by Industry. Once the causes of the discrepancies were identified, the correct landings data to the end of 2010 were loaded into the CLAM database (DFO 2020b).

Greenland Cockle and Northern Propeller Clam are landed as species-specific products (i.e., siphon and foot) and as components in mixed-species products. The species-specific products are converted to a round weight for monitoring. Conversion factors for these species are currently based on a generic clam and quahog shucked conversion factor from a Statistical Coordinating Committee for the Atlantic Coast report (STACAC 1984; Table 1). Data collection in support of revised conversion factors is currently ongoing. Preliminary results indicate the conversion factor is lower for Northern Propeller Clam and higher for Greenland Cockle relative to the value that is currently used. A change in conversion factors would impact the commercial landing and discard values used in this report; however, the relative patterns would not change.

Table 1. Species product types landed in the offshore clam fishery and the conversion factors applied to the product types.

Species	Product Type	Conversion Factor
Northern Propeller Clam	Blanched siphon	5.5
Greenland Cockle	Blanched foot (tongue)	5.5
Greenland Cockle	Raw foot (tongue)	5.5

The mixed species product that may contain siphon or foot is called C-grade. C-grade sampling data were examined to determine the amount of Northern Propeller Clam and Greenland Cockle within the C-grade product. A 3 kg sample is taken from the C-grade processing line prior to freezing to identify, sort, and weigh the component parts (C. Boyd, *Pers. Comm.*). The data consisted of 107 samples over 6 years on Banquereau, and 47 samples over 5 years on Grand Bank. An analysis of C-grade sampling data indicate Northern Propeller Clam was present in 36% and 67% of Banquereau and Grand Bank samples, respectively. When present, it accounted for very small proportions of the C-grade product landings: 0.0013 on Banquereau and 0.0003 on Grand Bank. For these reasons, the Northern Propeller Clam component of C-grade was not included in the analyses in this document. Greenland Cockle was present in most (97–98%) of the samples on both Banks. It also accounted for a larger proportion of the C-grade product: 0.12 on Banquereau and 0.088 on Grand Bank. The Greenland Cockle component of C-grade is included in the analyses in this document. The conversion factor used for C-grade product is the conversion factor multiplied by the component factor (e.g., 5.5 x 0.12; Table 2).

Table 2. The C-grade component factors used for Greenland Cockle on both Banks

Bank	Cockle C-grade Component Factor	Cockle foot Conversion Factor	Cockle C-grade Conversion x Component
Banquereau	0.12	5.5	0.66
Grand Bank	0.088	5.5	0.48

At-Sea-Observer Program Data

At-sea observers have been used in the offshore clam fishery since the late 1980s. Observer coverage has varied over time. Current requirements for the fishery are one observed trip per year per bank, which is approximately 10% coverage. Observer data can provide information on discards; however, observer protocols have changed for the fisheries on both banks and the data are fishery dependent, so there is no observer coverage in years with no fishery. The discarded species weight per unit effort (km^2) from the observed trips within a year was multiplied by the effort in that year to create an annual discard estimate. There is currently no other data source of discards to validate this information against, and it is anticipated that the discard rates change throughout the year as fishing efforts shift on a bank.

Data Limitations

Discard information for both species is limited to fishing trips with at-sea observers; therefore, a complete time-series of actual catch (discards plus landings) is unavailable for Greenland Cockle and Northern Propeller Clam. Given the co-occurrence of these species, when a species has no landings listed for a specific year, it should be assumed that the species was encountered and discarded. Changes in landings over time is a function of economics and fishery behaviour as much as species densities or biomass. Fishing efficiency has increased through vessel capacity and the use of technology to locate, sort, and process each species. Landings Per Unit Effort (LPUE) for the co-occurring species in this fishery is lower than it would be if these species were targeted.

ANALYSIS

Natural Mortality

Natural mortality, M, has not previously been estimated for either species. Using empirical relationships between von Bertalanffy growth coefficients (Table A1) and natural mortality, an estimate can be made using the equation:

$$M = 1.5k$$

where *k* is the growth coefficient (Jensen 1997). The resulting values are summarized in Table 3. When this method is compared to values of M currently used for other species in this fishery, this method results in higher values of M. For Grand Bank Arctic Surfclam, this method is within the range of M values estimated for that stock (0.06–0.1; Roddick et al. 2011). However, the results of this method are not within previous ranges for Banquereau Surfclam (0.06–0.082; Roddick et al. 2012), or Ocean Quahog (Kilada et al. 2007b; Table 3). There are numerous ways to estimate M; however, this method results in more conservative values of M than other methods and does not require additional data collection. Growth coefficient estimates are available for most species of interest on each bank.

Table 3. Estimates of natural mortality for these retained species in the offshore clam fishery. '–' indicates no data available.

Species	Bank	Natural Mortality Estimates: This paper	Other sources
Northern Propeller Clam	Banquereau	0.11	–
Greenland Cockle	Banquereau	0.32	–
Greenland Cockle	Grand Bank	0.26	–
Arctic Surfclam	Banquereau	0.12	0.08

Species	Bank	Natural Mortality Estimates This paper	Natural Mortality Estimates Other sources
Arctic Surfclam	Grand Bank	0.09	0.08
Ocean Quahog	Sable Bank	0.08	0.03

Banquereau

Commercial Fishery

Since 1999, Greenland Cockle landings have been reported annually and have ranged from 3.8 to 451.7 t, with an average of 131.9 t and a median of 116.2 t (Figure 2). As a percentage of annual Surfclam catch, Cockle landings have ranged from 0.02 to 2.4%, with an average of 0.7% and a median of 0.5%. The LPUE ranged from 0.02 to 3.0 g/m^2 (Figure 2), with an average of 0.8 g/m^2 and a median of 0.5 g/m^2. Discards of Greenland Cockle were observed in 13 years since 1993. The annual estimate of discards ranged from 0.01 to 479.0 t, with an average of 121.1 t and a median of 18.9 t.

Since 1996, Northern Propeller Clam landings on Banquereau have ranged from 147.8 to 8,746.8 t, with an average of 2,008.5 t and a median of 1,395.4 t (Figure 2). Since 1996, there have been 3 years with no Northern Propeller Clam landings. As a percentage of annual Surfclam catch, Propeller Clam landings have ranged from 0.8 to 42.3%, with an average of 10.4% and a median of 8.5%. Since 1996, the LPUE has ranged from 0.8 to 61.2 g/m^2 (Figure 2), with an average of 12.4 g/m^2 and a median of 9.4 g/m^2. Discards of Northern Propeller Clam were observed in 20 years since 1986. The annual estimate of discards ranged from 1.8 to 5,243.0 t, with an average of 1,094.5 t and a median of 485.6 t.

There is no minimum legal size for the non-quota molluscs in the offshore clam fishery, although juvenile clams are not typically retained due to gear selectivity. Greenland Cockle length-frequency samples were collected on Banquereau for two years by industry (2004 and 2005) and by at-sea observers (2018 and 2019). The mean size of Greenland Cockle in the length-frequency data is 66 to 72 mm. For Northern Propeller Clam, there are three years of length-frequency sampling by industry (2004–2006). The mean size of Northern Propeller Clam in the length-frequency data is 74 to 81 mm.

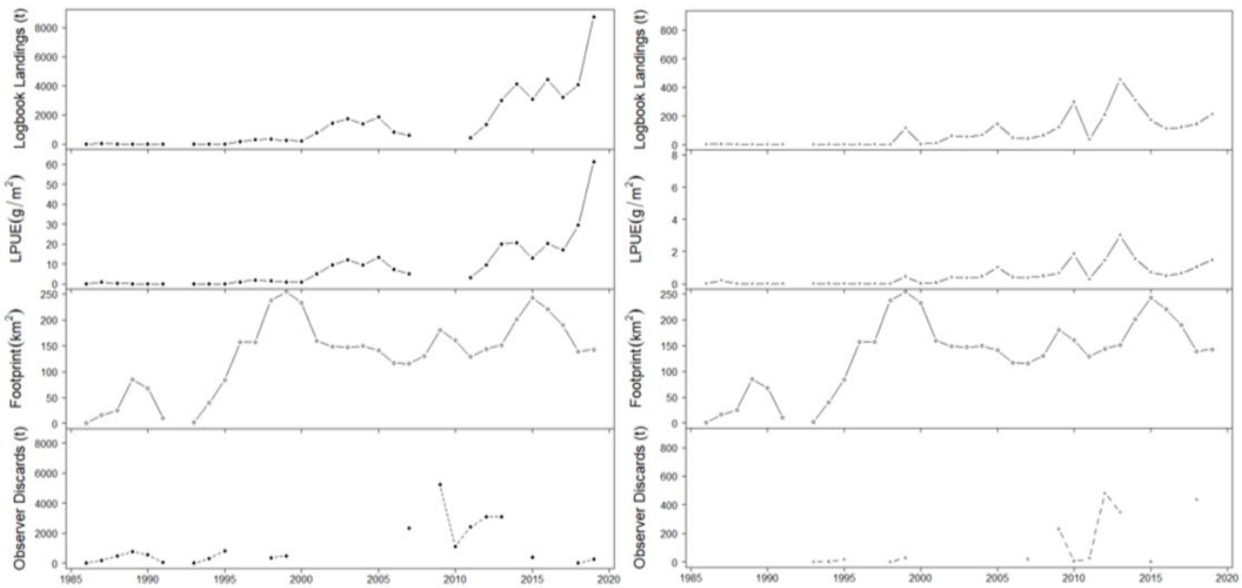

Figure 2. Banquereau logbook landings (tonnes), landings per unit effort (g/m²), offshore clam fishery footprint (km²), and estimated annual discards from the at-sea-observer program (tonnes) for Northern Propeller Clam (black circles, left column) and Greenland Cockle (grey triangles, right column) in the offshore clam fisheries.

The Framework for Arctic Surfclam defines the Banquereau stock based on the fished area of the Bank as determined by Vessel Monitoring System (VMS) data from 2004–2016 (Hubley and Heaslip 2018, Hubley et al. 2020). This fished area is then divided into five spatial assessment areas. A summary of catch within the Banquereau fished area stock definition, by assessment area, for Greenland Cockle and Northern Propeller Clam is shown in Table 4.

Table 4. Average landings (tonnes) of Greenland Cockle and Northern Propeller Clam by assessment area on Banquereau since 2004.

Species	Year Range	Area 1	Area 2	Area 3	Area 4	Area 5
Greenland Cockle	2004–2019	47.4	57.0	7.5	25.9	20.3
Northern Propeller Clam	2004–2007, 2011–2019	587.5	819.7	382.0	426.7	365.4

Biomass was estimated from LPUE using the methods in Hubley and Heaslip (2018). For catchability, a conservative estimate of 1 was used (that is, all Cockle and Propeller Clam are caught). The LPUE was used to estimate biomass for each of the five assessment areas used for Arctic Surfclam. Since the Arctic Surfclam fishery on Banquereau is not managed by assessment areas, the biomass of Greenland Cockle and Northern Propeller Clam from each assessment area was summed to produce a combined annual trend (Figure 3). The 2019 biomass estimate from this method was 2,289 t for Greenland Cockle and 113,995 t for Northern Propeller Clam.

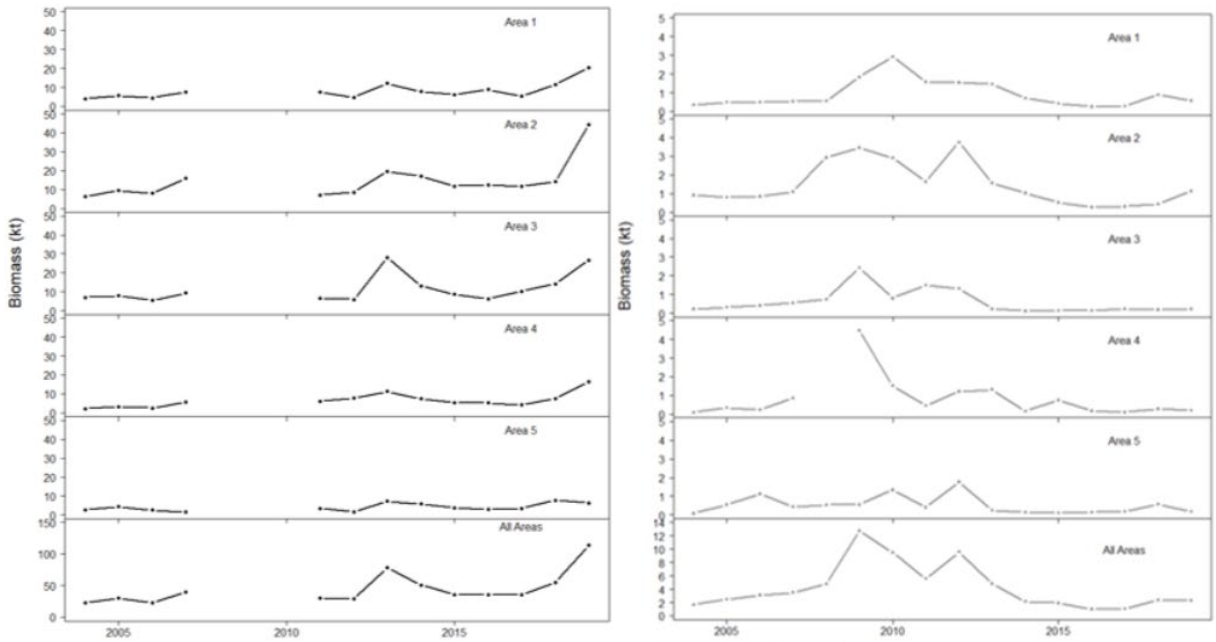

Figure 3. Biomass estimates (kilotonnes) based on landings per unit effort of Northern Propeller Clam (black circles, left column) and Greenland Cockle (gray triangles, right column) on Banquereau since 2004 for the five assessment areas (panels 1-5) and all areas combined (bottom panel).

Survey

Greenland Cockle and Northern Propeller Clam were recorded in the 2010 Banquereau survey (Roddick et al. 2012). The distribution of these species across the Bank is shown in Figure 4. The most abundant species by weight were Arctic Surfclam, Northern Propeller Clam, sand dollars, and Greenland Cockle. The survey gear was lined with a 38 mm mesh to retain small clams, but there was no selectivity or dredge efficiency work completed for Cockle and Propeller Clam during the survey. The biomass of these two species was estimated from within the Banquereau stock definition by assessment area using inverse distance weighting interpolation (Table 5).

Table 5. Greenland Cockle and Northern Propeller Clam biomass estimates (tonnes) by assessment area from the 2010 survey on Banquereau using inverse distance weighting interpolation.

Species	Area 1	Area 2	Area 3	Area 4	Area 5	Total
Greenland Cockle	6,942	5,728	1,508	1,699	2,356	18,233
Northern Propeller Clam	18,281	21,045	37,381	11,553	7,707	95,967

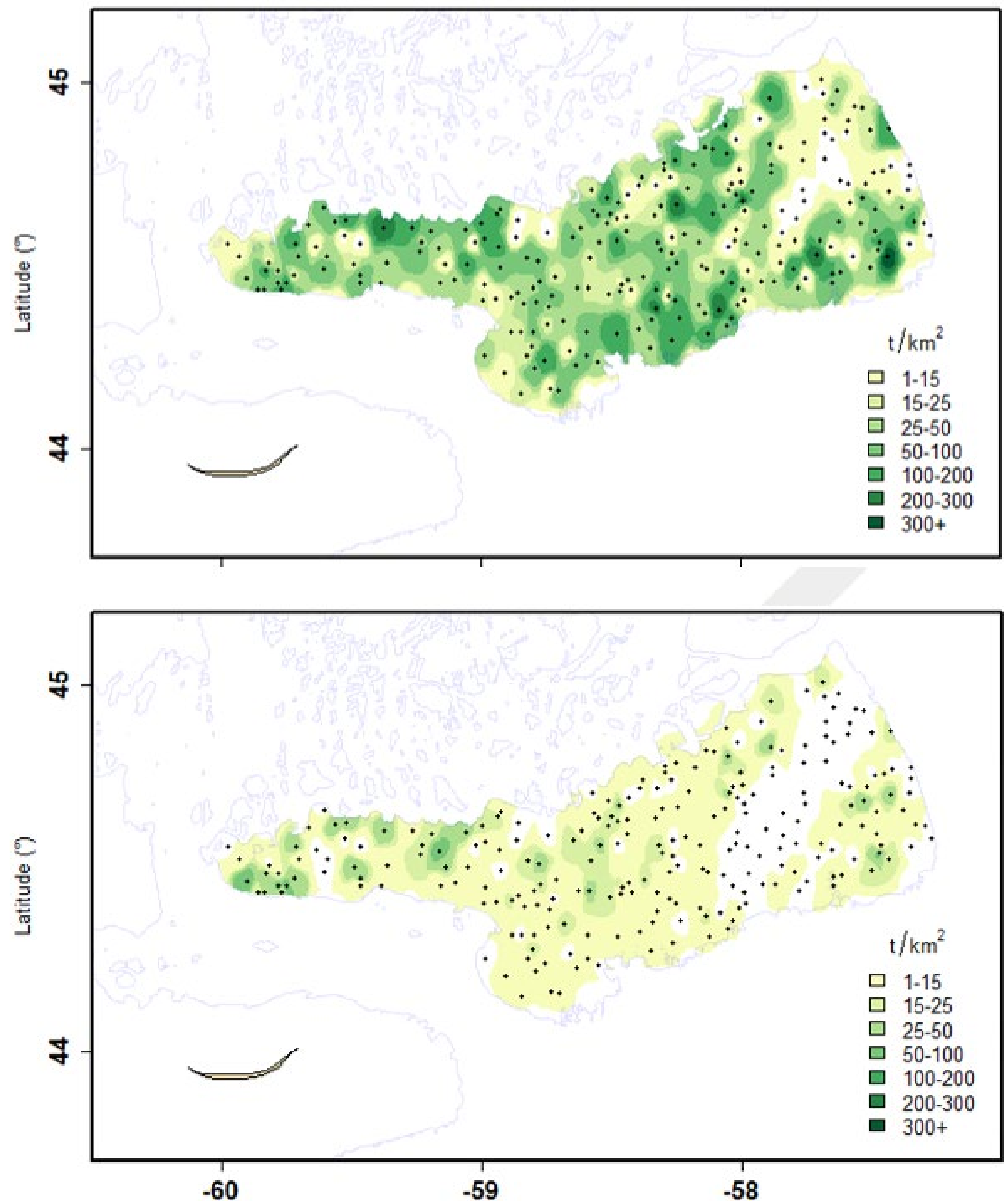

Figure 4. Contour plot of the estimated biomass density (t/km^2) of Northern Propeller Clam (top panel) and Greenland Cockle (bottom panel) from the 2010 Banquereau survey.

Grand Bank

Commercial Fishery

Landings of Greenland Cockle from Grand Bank have ranged from 0.4 to 3,674.3 t since 1994 (Figure 5). The average landings were 747.6 t, and the median was 393.7 t. Since 1994, there have been four years with no Cockle landings. As a percentage of annual Surfclam catch, Cockle landings have ranged from 0.004 to 721.8%, with an average of 63% and a median of 13%. In 2010, 2011, and 2013, the landings for Greenland Cockle were greater than the landings for Arctic Surfclam. Since 1994, the LPUE has ranged from 0.004 to 110.5 g/m^2

(Figure 5), with an average of 20.2 g/m² and a median of 8.9 g/m². Discards of Greenland Cockle have been observed in 11 years since 1989. The annual estimate of discards ranged from 0.16 to 259.3 t, with an average of 85.7 t and a median of 75.4 t.

Landings of Northern Propeller Clam from Grand Bank ranged from 3.7 to 2,143.0 t since 1995 (Figure 5). The average landings were 628.7 t, and the median was 397.7 t. Since 1995, there have been 13 years with no Propeller Clam landings. As a percentage of annual Surfclam catch, Propeller Clam ranged from 0.07 to 15.5%, with an average of 7.2% and a median of 7%. The LPUE of Propeller Clam ranged from 0.05 to 19.5 g/m² (Figure 5), with an average of 6.6 g/m² and a median of 6.7 g/m². Discards of Northern Propeller Clam were observed in 11 years since 1989. The annual estimate of discards ranged from 0.4 to 6,984.0 t, with an average of 1,550.9 t and a median of 303.7 t.

Length-frequency sampling of the commercial catch of Greenland Cockle was completed on Grand Bank by industry in 2000, 2004, and 2010, and by at-sea observers in 2018 and 2019. Mean size of Greenland Cockle in the length-frequency data available ranged from 73 to 98 mm. For Northern Propeller Clam, length-frequency samples were collected by industry in 2004 and 2005. The mean size of Northern Propeller Clam in the length-frequency data was 69 to 90 mm.

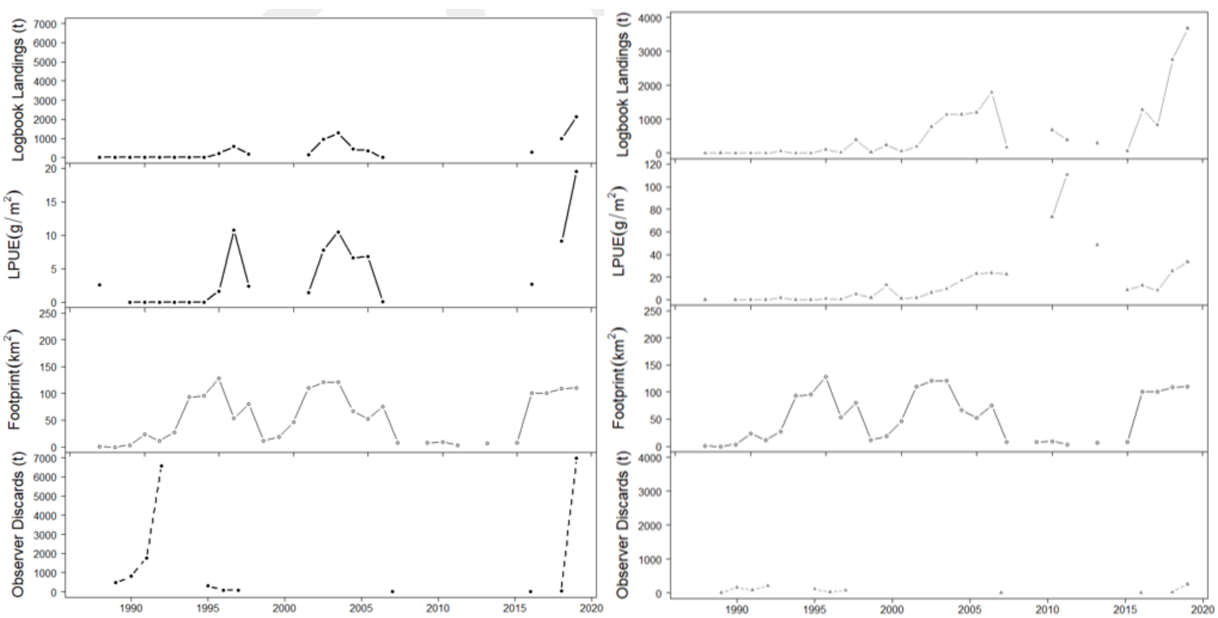

Figure 5. Grand Bank logbook landings (tonnes), landings per unit effort (g/m²), offshore clam fishery footprint (km²), and estimated annual discards from the at-sea-observer program (tonnes) for Northern Propeller Clam (black circles, left column) and Greenland Cockle (grey triangles, right column) in the offshore clam fisheries.

The current stock definition for Grand Bank is the entire bank, an area > 130,000 km². The fishery occurs on a very small proportion of the bank, and the average annual footprint of the fishery is approximately 100 km². A biomass estimate for the entire bank would over-estimate the biomass that would be encountered, and impacted, by regular fishing operations. A fishery footprint was estimated from the VMS data following the methods in Hubley and Heaslip (2018). The use of a low density level of 2 transmissions per km² over the time period 2004–2019 resulted in a footprint of 1,634 km², which is similar in an area to the sum of the fishery footprint from 1987–2019 (1,595 km²; Figure 6). Biomass was estimated from LPUE using the methods in Hubley and Heaslip (2018). As with the biomass estimate based on survey data, a conservative catchability coefficient of 1 was used. The 2019 biomass estimate from this method was 51,819 t for Greenland Cockle and 45,112 t for Northern Propeller Clam (Figure 7).

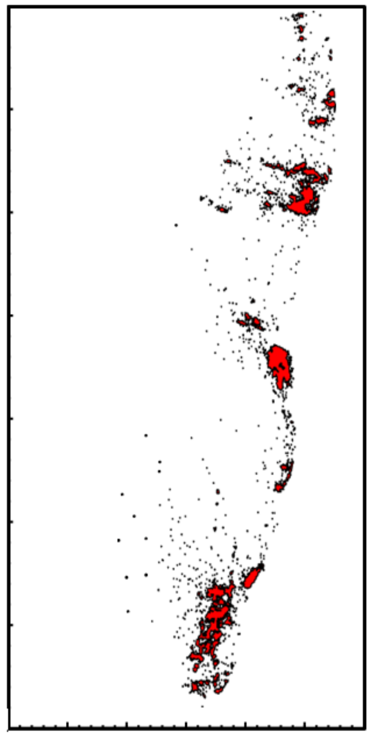

Figure 6. Vessel Monitoring System (VMS) density on Grand Bank. Areas shaded red shows the area where VMS intensity is greater than 2 pings/km^2 in the time period 2004–2019.

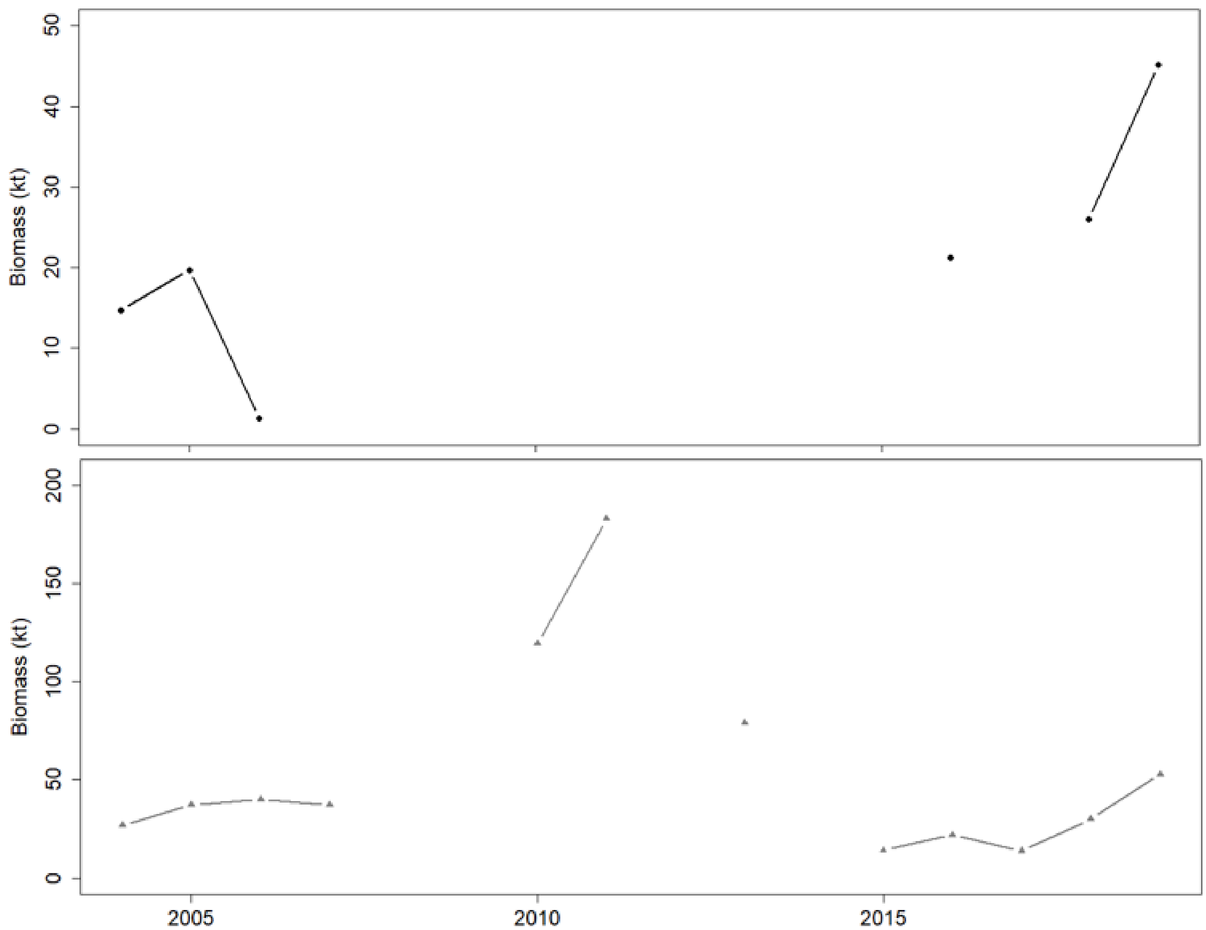

Figure 7. Biomass estimates (kilotonnes) based on landings per unit effort of Northern Propeller Clam (black circles, top panel) and Greenland Cockle (gray triangles, bottom panel) on Grand Bank since 2004.

Survey

Greenland Cockle and Northern Propeller Clam were recorded in the 2006, 2008, and 2009 Grand Bank survey (Roddick et al. 2011). The distribution of these species across the bank is shown in Figure 8. The survey gear was lined with a 38 mm mesh to retain small clams, but there was no selectivity or dredge-efficiency work completed for Cockle and Propeller Clam species during the survey. The most abundant species by weight were Arctic Surfclam, sand dollars, Northern Propeller Clam, and Greenland Cockle. The survey covered an area of 47,360 km^2. A biomass estimate from an area this large would significantly over-estimate the biomass that would be encountered, and impacted, by regular fishing operations; therefore, the fishery footprint was used to estimate biomass from the survey (Figure 6). The survey biomass within the fishery footprint was estimated using inverse distance-weighted interpolation. This provides an estimate of the biomass that is likely to be encountered during regular fishing operations for the directed species. The biomass estimate was 98,280 t for Greenland Cockle and 50,498 t for Northern Propeller Clam.

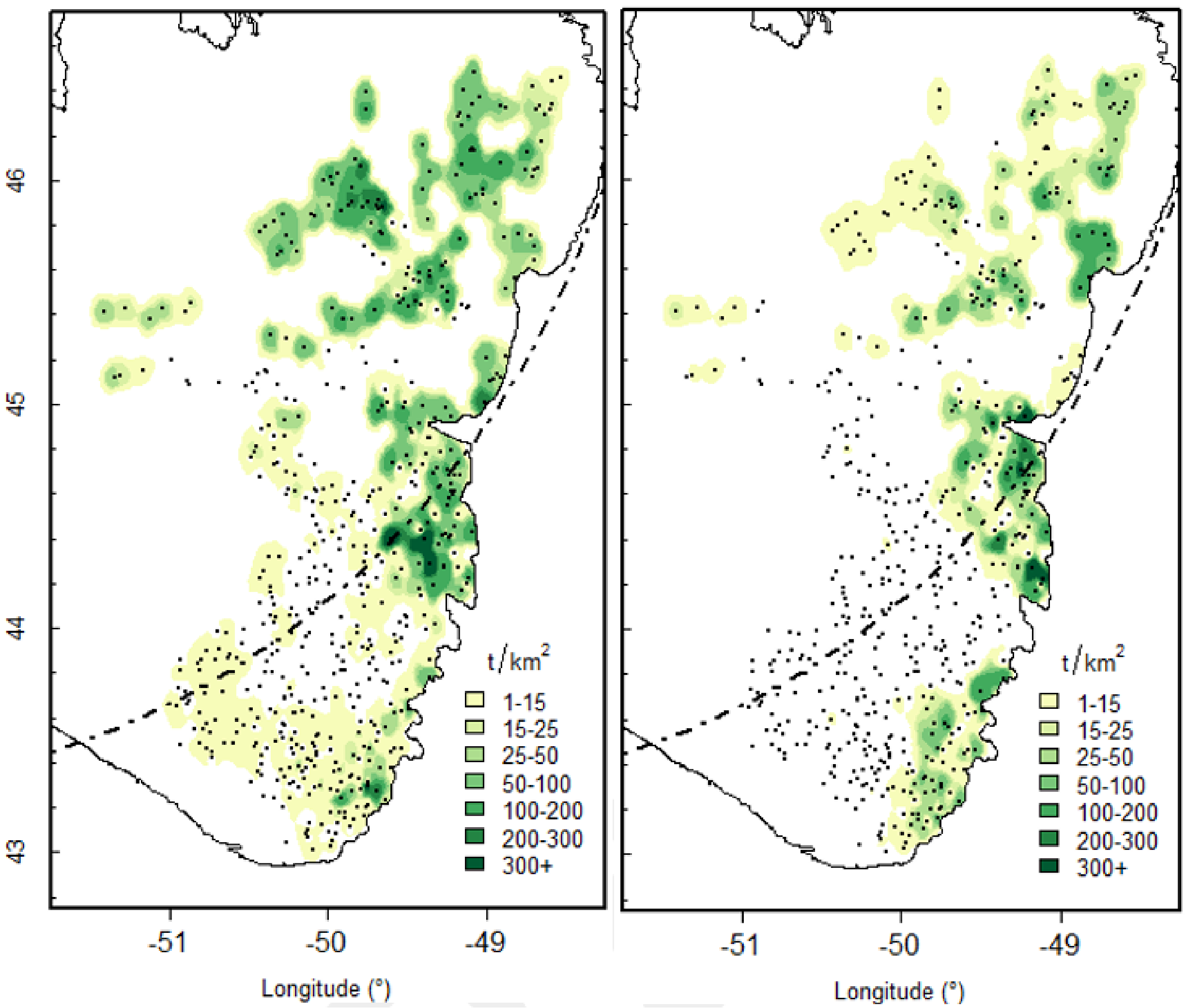

Figure 8. Contour plot of the estimated biomass density (t/km²) of Northern Propeller Clam (left panel) and Greenland Cockle (right panel) from the 2006, 2008, and 2009 surveys on Grand Bank.

Catch Limit Methods

Approach 1: Proportion of Directed Species Catch

On Grand Bank, the catch limit of Ocean Quahog is based on a proportion of Arctic Surfclam landings: 10% with a limit of 500 t. This approach assumes that the catch of co-occurring species will increase as the directed species quota increases. However, this approach is not considered precautionary, and the selection of catch percentage used to calculate the limit is subjective. Berkson et al. (2011) state that the choice of percentage should be guided by the precautionary principle to avoid overfishing but should also allow for data collection and potential fishery expansion and, therefore, ongoing monitoring is required. Where this method has been applied, percentages have ranged from 5–16% of the targeted species' catch limit (Berkson et al. 2011).

Banquereau

Since 1999, the median percent of Greenland Cockle in Surfclam landings on Banquereau is 0.5%. For Northern Propeller Clam, the median percent since 1996 is 9%. Based on the 2020 Total Allowable Catch (TAC) for Surfclam (20,943 t), this would result in a catch limit of 105 t for Greenland Cockle and 1,885 t for Northern Propeller Clam. These limits are lower than the reported landings for each species in the latter part of the time series. From 2010–2019, Cockle and Propeller Clam landings were 0.9 and 16% of Surfclam landings, respectively. Using catch percentages from this time frame would result in limits of 188 t for Greenland Cockle and 3,350 t for Northern Propeller Clam. If the 2019 values were used to account for recent changes in the fishery, the percentages (and limits) would be 42% (9,005 t) for Propeller Clam and 1% for Cockle (209 t).

Grand Bank

Since 1994, the median percent of Greenland Cockle in Surfclam landings on Grand Bank is 13%. For Northern Propeller Clam, the median since 1995 was 7%. Based on the 2020 TAC for Surfclam (14,756 t), this would result in a catch limit of 1,918 t for Greenland Cockle and 1,033 t for Northern Propeller Clam. These limits are lower than the reported landings for each species in the latter part of the time series. The fishing history on Grand Bank is less consistent over the past decade than on Banquereau, with Propeller Clam being landed in three of the last 10 years. From 2010–2019, there were 8 years of fishing, and Cockle landings were 23% of Surfclam landings. Using catch percentages from this time would result in a catch limit of 3,393 t for Greenland Cockle. If the 2019 values were used to reflect recent changes in the fishery, the percentages (and limits) would be 15% (2,213 t) for Propeller Clam and 26% (3,837 t) for Cockle.

Approach 2: Average Catch

Average catch is commonly used in data-limited fisheries. Generally, the average of the catch series is calculated and a modifier, which represents natural variability or incorporates risk, is applied (Berskon et al. 2011). When this approach is used, catch includes all removals, therefore, landings and discards. The applicability and performance of potential multipliers is uncertain and this method does not explicitly account for productivity. In situations where a stock has been lightly exploited, it does not allow for larger catch limits. This method is intended for short-term use, until additional data can be collected or an improved method can be developed (Berkson et al. 2011). More advanced methods of this approach that consider abundance, such as depletion-adjusted average catch, depletion-corrected average catch, or depletion-based-stock-reduction analysis have been developed. These methods are more robust but require estimates of unfished Biomass (B_0), Biomass at Maximum Sustainable Yield (B_{MSY}), and relative stock depletion over time.

Banquereau

Average landings (with and without at-sea-observer discard estimates) for the entire time series, and separately for the last decade, are presented in Table 6. From 1986 to 2019, 20 observer trips recorded Propeller Clam discards and 13 trips recorded Cockle discards. From 2010 to 2019, 7 at-sea-observer trips recorded Propeller Clam discards and 6 trips recorded Cockle discards. The inclusion of discards from observer trips increases average landings, and the last decade has higher averages reflecting the increase in landings over time.

Table 6. Summary of average landings (tonnes) for Greenland Cockle and Northern Propeller Clam on Banquereau, with and without observer discard estimates.

Species	1986–2019		2010–2019	
	Landings	Landings + Discards	Landings	Landings + Discards
Greenland Cockle	121	167	204	332
Northern Propeller Clam	1,834	1,882	3,601	4,265

Grand Bank

Average landings (with and without at-sea-observer discard estimates) for the entire time series, and separately for the last decade, are presented in Table 7. From 1987 to 2019, 11 observer trips recorded Propeller Clam and Cockle discards. From 2010 to 2019, 3 observer trips recorded Propeller Clam and Cockle discards. The inclusion of discards from observer trips increases the average landings, and the last decade has higher averages reflecting the increase in landings over time.

Table 7. Summary of average landings (tonnes) for Greenland Cockle and Northern Propeller Clam on Grand Bank, with and without observer discard estimates.

Species	1987–2019		2010–2019	
	Landings	Landings + Discards	Landings	Landings + Discards
Greenland Cockle	594	673	1,246	1,281
Northern Propeller Clam	540	1,296	1,133	3,476

Approach 3: Survey Biomass

This approach calculates a catch limit based on applying a removal reference to the survey biomass. It is sensitive to the spatial stock definitions, since the stock definition will change the biomass estimate and the resulting limit. The Arctic Surfclam fishery on Banquereau has two potential fishing mortality rate (F) values (Hubley and Heaslip 2018). The first is $0.5F_{MSY}$, which results in a rate of 0.045 since F_{MSY} is estimated to be near 0.09. This rate of F_{MSY} was most recently used for Arctic Surfclam on Banquereau. The second rate is 0.33M, which equals a rate of 0.026, where M is the Surfclam natural mortality rate of 0.08. The 0.33M is based on a maximum constant yield approach that sets removals at a low fraction of M (0.2–0.3), which is considered sustainable for fisheries with little to no monitoring. Since the Surfclam fishery has some monitoring, 0.33M was chosen. The rate of 0.33M was most recently used for Arctic Surfclam on Grand Bank. Using the M values estimated in this document (Table 1), different rates can be used for each species for 0.33M. The resulting rates (0.33 x M) are 0.036 for Propeller Clam on both Banks, 0.106 for Cockle on Banquereau, and 0.086 for Cockle on Grand Bank. The Surfclam 0.33M (denoted $0.33M_{surf}$) and Surfclam $0.5F_{MSY}$ (denoted $0.5F_{MSYsurf}$) are maintained for comparison.

Banquereau

On Banquereau, the status of Arctic Surfclam is assessed using assessment areas; however, the fishery is managed bank wide. This approach is applied to the total biomass within the stock definition used for the bank (Table 8).

Table 8. Catch limits (tonnes) based on 2010 Banquereau survey biomass estimates of Greenland Cockle and Northern Propeller Clam from fished area stock definition used in the Banquereau Arctic Surfclam assessment (See Table 3).

Removal rate	Greenland Cockle	Northern Propeller Clam
0.33M	1,834	3,421
$0.33M_{surf}$	468	2,463
$0.5F_{MSYsurf}$	802	4,222

Grand Bank

On Grand Bank, this approach is applied to the biomass estimate from within the VMS stock definitions (Figure 6; Table 9). The removal reference of 0.33M (M=0.08) has been used for Surfclam on Grand Bank in the past (DFO 2020a).

Table 9. Catch limits (tonnes) based on the 2006, 2008, 2009 Grand Bank survey-biomass estimates of Greenland Cockle and Northern Propeller Clam from within the VMS fishery footprint (see Figure 6).

Removal Rate	Greenland Cockle	Northern Propeller Clam
0.33M	8,080	1,800
$0.33M_{surf}$	2,522	1,296
$0.5F_{MSYsurf}$	4,325	2,222

Approach 4: LPUE Biomass

Although similar to the survey biomass approach, this approach uses biomass from LPUE. This approach assumes that a biomass estimate based on LPUE is informative of the stock; however, LPUE is influenced by fishery behavior, economics, vessel technology, and vessel capacity more so than population densities or biomass. Removal references are the same as described above in Approach 3.

Banquereau

Using the species-specific 0.33M results in long-term average limits of 429 t and 1,584 t for Greenland Cockle and Northern Propeller Clam, respectively (Table 10 and Table 11).

Table 10. Examples of catch limits (tonnes) by year and the long-term (2004-2019) average for Greenland Cockle in the offshore clam fishery on Banquereau. These are based on biomass estimates from landings per unit effort in the fished area stock definition used in the Banquereau Arctic Surfclam assessment.

Removal Rate	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2004–2019 Average
0.33M	950	558	959	480	215	194	98	107	236	229	429
$0.33M_{surf}$	243	143	246	123	55	50	25	27	60	59	110
$0.5F_{MSYsurf}$	417	245	421	211	94	85	43	47	104	101	188

Table 11. Examples of catch limits (tonnes) by year and the long-term (2004-2019) average for Northern Propeller Clam in the offshore clam fishery on Banquereau. These are based on biomass estimates from landings per unit effort in the fished area stock definition used in the Banquereau Arctic Surfclam assessment. '–' indicates no data available.

Removal Rate	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2004–2019 Average
0.33M	–	1,089	1,020	2,782	1,810	1,271	1,262	1,244	1,947	4,064	1,584
$0.33M_{surf}$	–	784	734	2,002	1,303	915	909	896	1,402	2,926	1,140
$0.5F_{MSYsurf}$	–	1,344	1,259	3,433	2,234	1,569	1,558	1,536	2,403	5,016	1,955

Grand Bank

On Grand Bank, the LPUE biomass estimate was calculated using the VMS fishery footprint (Figure 6; Table 12 and Table 13). While this is more representative of the fishery, the fishery is often highly localized and that is not accounted for with assessment areas as on Banquereau.

Table 12. Examples of catch limits (tonnes) by year and the long-term (2004–2019) average for Greenland Cockle in the offshore clam fishery on Grand Bank. These are based on biomass estimates from landings per unit effort in the fished area stock definition used in this document for Grand Bank (Figure 6). '–' indicates no data available.

Removal Rate	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2004–2019 Average
0.33M	9,837	15,067	–	6,509	–	1,165	1,805	1,143	2,463	4,343	4,497
$0.33M_{surf}$	3,070	4,703	–	2,032	–	364	563	357	769	1,356	1,404
$0.5F_{MSYsurf}$	5,264	8,063	–	3,483	–	623	966	612	1,318	2,324	2,407

Table 13. Examples of catch limits (tonnes) by year and the long-term (2004–2019; 6 years of fishing) average for Northern Propeller Clam in the offshore clam fishery on Grand Bank. These are based on biomass estimates from landings per unit effort in the fished area stock definition used in this document for Grand Bank (Figure 6). '–' indicates no data available.

Removal Rate	2016	2017	2018	2019	2004–2019 Average
0.33M	756	–	928	1,608	822
$0.33M_{surf}$	545	–	668	1,158	547
$0.5F_{MSYsurf}$	934	–	1,146	1,985	939

Approach 5: LPUE Indicator

A Catch Per Unit Effort (CPUE) time series can be used as an indicator of status to inform management decisions concerning changes to catch limits, and harvest control rules could be used to interpret that indicator. This approach has been used in a data-poor crab fishery (Dichmont and Brown 2010). For that fishery, the indicator was based on a regression of CPUE against year for the most recent 6 years of data, with the percentage change in the fitted CPUEs between the first and last year being the indicator value. The indicator is monitored every year as a precaution, but changes to the catch limit are only made every second year. This CPUE indicator method also allows for a pooled indicator across areas, weighted by effort:

$$P = \frac{\sum_r DrEr}{\sum_r Er}$$

where *P* is the pooled index (%), *Dr* is the difference between the first and last years' fitted CPUE for each area (*r*), and *Er* is the total effort expended in each area. In this case, effort is the effort for the directed fishery. Since a CPUE time series is not available for Greenland Cockle and Northern Propeller Clam, the LPUE time series was used instead of CPUE. As with Approach 4, this approach assumes that LPUE is informative of the stock status and changes in the stock; however, LPUE is influenced by fishery behavior, economics, vessel technology, and vessel capacity more so than population densities or biomass.

Banquereau

The pooled indicator can be used on Banquereau for the assessment areas, and both species have reported landings in the last six years so the time span did not need to be modified (Figure 9). The pooled indicator was +28% for Greenland Cockle and +393% for Northern Propeller Clam. The breakdown of the values for the pooled indicators are in Table 14 and

Table 15. The product of effort and percent change (final column in Table 14 and Table 15) shows the influence each assessment area has on the pooled indicator. For Greenland Cockle, the greatest change in LPUE was seen in Area 5, but Area 1 was most influential as it had the most effort. For Northern Propeller Clam, the greatest change was seen in Area 2, but that was not the most influential area for the pooled indicator.

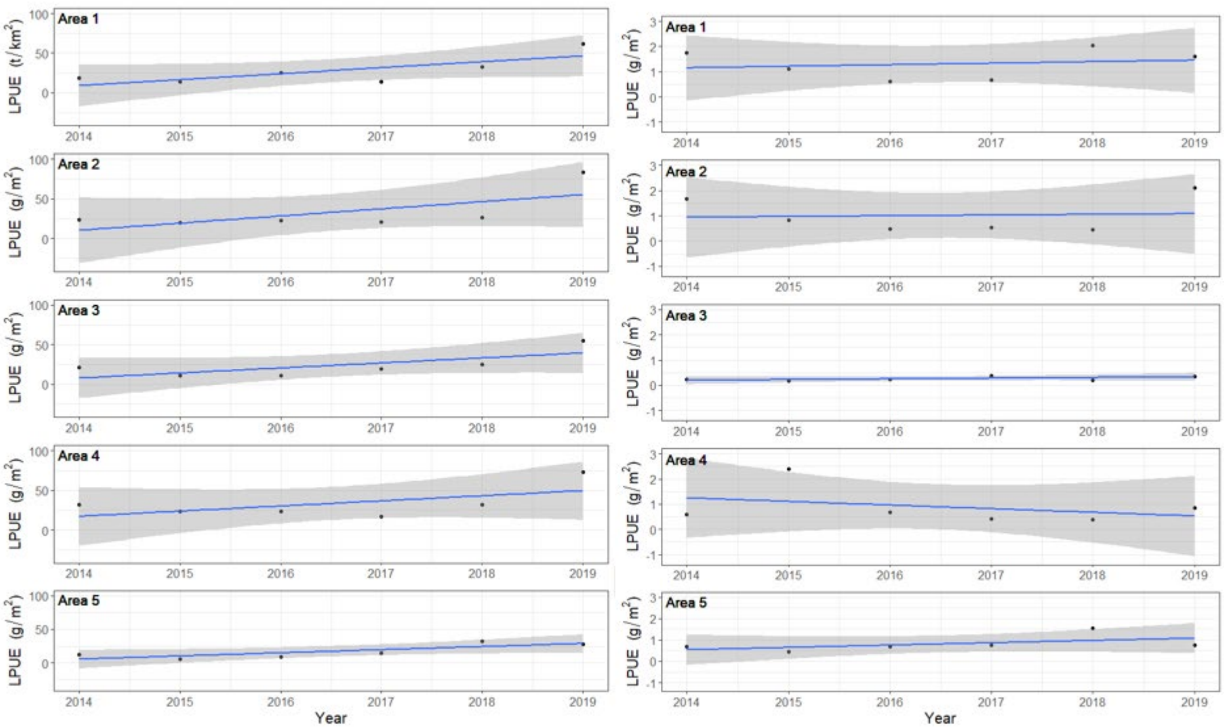

Figure 9. Regression of landings per unit effort (LPUE; g/m^2) by year for Northern Propeller Clam (left) and Greenland Cockle (right) for each assessment area on Banquereau. Note different Y axes. Grey shaded areas represent 95% confidence intervals.

Table 14. Greenland Cockle fitted landings per unit effort (LPUE; g/m^2) in the first (t_1; 2014) and last year (t_6; 2019) of the indicator time span, the percent change between those years, the effort in the final year (km^2), and the product of effort and percent change, for each assessment area used on Banquereau.

Area	Fitted LPUE t_1	Fitted LPUE t_6	% Change	Effort t_6	Effort x % Change
1	1.2	1.5	26.1	97.6	2,547.0
2	0.9	1.1	14.9	14.3	213.1
3	0.2	0.3	73.7	7.0	517.4
4	1.3	0.5	-59.2	10.2	-601.8
5	0.5	1.1	107.5	13.3	1,426.7

Table 15. Northern Propeller Clam fitted landings per unit effort (LPUE; g/m²) in the first (t_1; 2014) and last year (t_6; 2019) of the indicator time span, the percent change between those years, the effort in the final year (km²), and the product of effort and percent change, for each assessment area used on Banquereau.

Area	Fitted LPUE t_1	Fitted LPUE t_6	% Change	Effort t_6	Effort x % Change
1	9.2	46.3	403.3	97.6	39,358.3
2	10.3	55.4	437.9	14.3	6,265.8
3	7.8	39.4	405.1	7.0	2,835.9
4	17.2	49.5	187.8	10.2	1,908.0
5	5.5	28.8	423.6	13.3	5,634.4

Grand Bank

There are currently no assessment areas for Grand Bank, so all the data were used for the indicators. Greenland Cockle has an incomplete time series, as there was no fishing on Grand Bank in 2014. If 2013 is used as the start of the six-year span, the indicator is markedly different than if only five years are used (Figure 10, Table 16). If five years are used, the indicator is large and positive. If six years are used, the indicator is negative. This illustrates the sensitivity of this approach to time spans being used. This approach was not applied to Northern Propeller Clam since landings have only been reported for three years in the past decade.

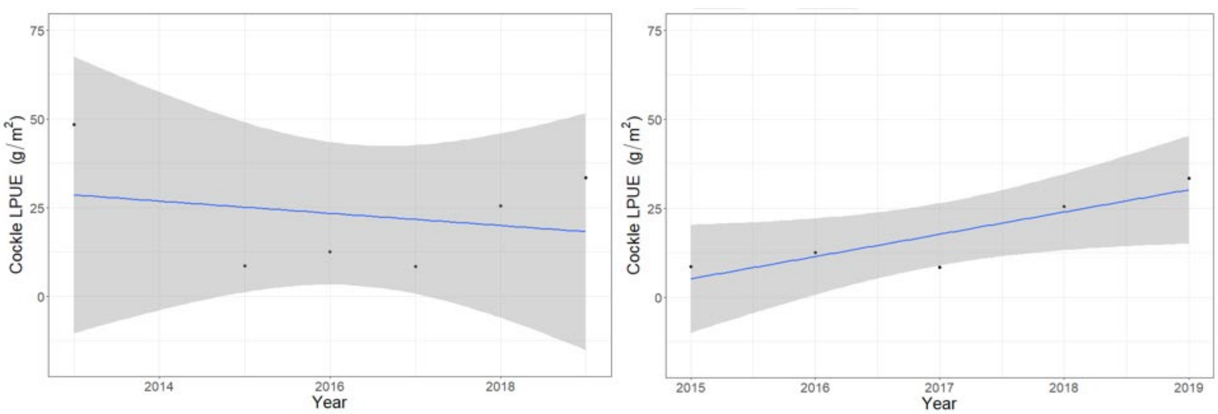

Figure 10. Regression landings per unit effort (LPUE; g/m²) by year for Greenland Cockle on Grand Bank, with six (left) and five years of data (right). Grey shaded areas represent 95% confidence intervals.

Table 16: Greenland Cockle fitted landings per unit effort (LPUE; g/m²) in the first (t_1) and last year (t_{final}) of the indicator time span and the percent change between those years, based on two different time spans.

No. Years (Range)	Fitted LPUE t_1	Fitted LPUE t_{final}	% Change
5 (2015–2019)	5.5	30.2	449%
6 (2013, 2015–2019)	28.5	18.2	-36.1%

Approach 6: Length-Based Indicators

A length-based secondary indicator is used for the Banquereau and Grand Bank Arctic Surfclam fisheries. The indicator is 1% of Surfclam in the commercial catch > 120 mm on Banquereau and > 105 mm on Grand Bank. These values represent the upper end of the size distribution of Surfclam on each bank. Another method of monitoring large individuals in the catch is $L_{max5\%}$, which examines the mean length of the largest 5% of individuals in the catch (Probst et al. 2013), although this approach is most informative with a time series of data to reflect changes over time. Regular monitoring of catch for the proportion above $L_{50\%}$ (size-at-50% sexual maturity) is another length-based metric that could be used to provide information on stock structure.

Using a length-based indicator requires regular collection of length data on these species. There are two sources of length data: sampling by industry and observer sampling. Sampling by industry is currently being done only for Surfclam. Industry sampling has the benefit of occurring year-round and samples are collected from all areas of the banks. Recent observer sampling has only collected length-frequency data for Greenland Cockle, and observer data are limited to the fished areas of the observed trip and not the entire bank.

Banquereau

Using the 2010 survey length frequency for Greenland Cockle, a potential size indicator of 87.5 mm shell length was selected (Figure 11). This represents the 93rd percentile and was chosen for illustrative purposes. This size could represent individuals as young as Age 9 but generally represent individuals aged 15 years or older, based on a growth curve published for this species on Banquereau (Kilada et al. 2007a). The industry samples and observer catch data were assessed against this size, and the percent of Cockle > 87.5 mm was above 1% in all years except 2005, which had a small sample size (Table 17).

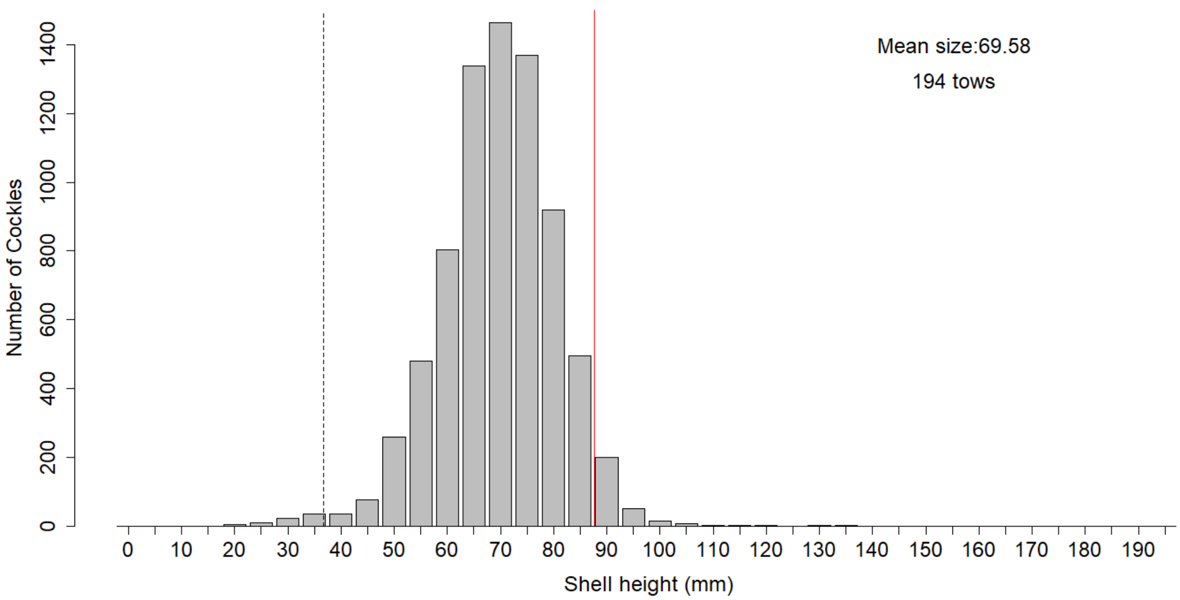

Figure 11. Greenland Cockle shell length frequency from the 2010 Banquereau Survey. The black dashed line is the size-at-50% sexual maturity, and the solid red line is 87.5 mm.

Table 17. Percent of Greenland Cockle > 87.5 mm and number of clams measured (n) in Industry and observer samples from Banquereau.

Year	% > 87.5 mm	n	Source
2000	9.3	108	Industry Samples
2005	0	46	Industry samples
2018	2.6	226	At-sea observer
2019	1.03	193	At-sea observer

The $L_{max5\%}$ approach was applied to both industry and at-sea-observer length-frequency data (Table 18). For Greenland Cockle, recent values are within the range seen in the fishery in 2004 and 2005.

Table 18. The mean length (mm) of the largest 5% of individuals in the catch in Industry length samples and observer length samples on Banquereau. '–' indicates no data available.

Species	Industry Samples			At-sea observer	
	2004	2005	2006	2018	2019
Greenland Cockle	97.4	83.5	–	88.5	87
Northern Propeller Clam	98.9	92	102	–	–

The length-at-50% sexual maturity is 27.9 mm for male tissue and 37.2 mm for female tissue in Greenland Cockle, and 28.6 mm for Northern Propeller Clam. Industry and observer length data were analyzed against these values. For Cockle, all of the clams in the industry samples were greater than the size-at-50% sexual maturity (37.2 mm) in both years. Of the clams in the at-sea-observer sampling, 99% in 2018 and 100% in 2019 were greater than the size-at-50% sexual maturity. For Northern Propeller Clam, in all three years clams in the industry samples were above the size-at-50% sexual maturity.

Grand Bank

Using the 2006–2009 survey length-frequency data for Greenland Cockle (Figure 12), a potential size indicator of 92.5 mm shell length was selected. This represents the 94th percentile and was chosen for illustrative purposes. This is larger than on Banquereau, but the mean size of Greenland Cockle in the available data is larger on Grand Bank. The Industry samples and observer catch data were assessed, and the percent of Cockle > 92.5 mm was above 1% in all years except 2018, which was 0.48% (Table 19). Large differences between years are seen in the Arctic Surfclam size indicator on Grand Bank and likely represent different size structures on different parts of the bank.

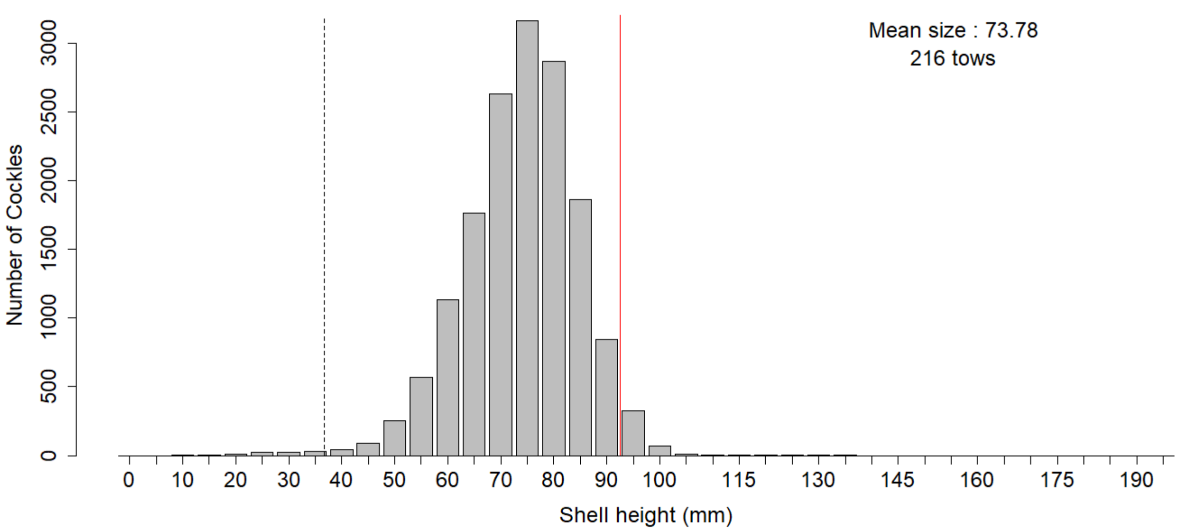

Figure 12. Greenland Cockle shell length frequency from the 2006–2009 Grand Bank Survey. The black dashed line is the size-at-50% sexual maturity, and the solid red line is 92.5 mm.

Table 19. Percent of Greenland Cockle > 92.5 mm and number of clams measured (n) in Industry and observer samples from Grand Bank.

Year	% > 92.5	n	Source
2000	47.8	201	Industry samples
2004	7.8	548	Industry samples
2010	54.4	241	Industry samples
2018	0.48	419	At-sea observer
2019	15.1	1191	At-sea observer

The $L_{max5\%}$ approach was applied to the available length-frequency data from both industry samples and recent observer data (Table 20). For Greenland Cockle, recent values are smaller than seen in the fishery in 2000, 2004, and 2010, but similar to Banquereau.

Table 20. The mean length (mm) of the largest 5% of individuals in the catch in Industry and at-sea-observer length samples on Grand Bank. '–' indicates no data available.

Species	Industry Samples				At sea observer	
	2000	2004	2005	2010	2018	2019
Greenland Cockle	103.4	101	–	154	87	87
Northern Propeller Clam	–	96	122	–	–	–

The length-at-50% sexual maturity is 27.9 mm for male tissue and 37.2 mm for female tissue in Greenland Cockle, and 28.6 mm for Northern Propeller Clam. For Cockle, all of the clams in the industry samples were greater than the size-at-50% sexual maturity (37.2 mm). Of the clams in the at-sea-observer sampling, 99% in 2018 and 98% in 2019 were greater than the size-at-50% sexual maturity. For Propeller Clam, all clams in the industry samples were above the size-at-50% sexual maturity.

Sources of Uncertainty

Changes in the Fishery

The offshore clam fishery is increasing in efficiency through vessel capacity and use of technology to find clams, but also for sorting and processing. Subsequently, the ability of the fishery to find and retain Northern Propeller Clam and Greenland Cockle is also increasing. In the past, these two species were not targeted and were sometimes actively avoided; however, as markets develop, it is anticipated that fishing efforts will encounter and retain more of these species. This analysis is reliant on historical data that are not expected to reflect future fishing patterns as the offshore fishery continues its development into a multi-species offshore clam fishery. A lot of analyses in this paper rely on past fishery information, but as these fisheries are still developing, past fishing activity is not a good predictor for future fishing activity.

Discards

The lack of data on discards, outside of observer coverage, is an impediment to determining the actual catch of these species, not just the landings. Current requirements for the fishery are one observed trip per year per bank, which is approximately 10% coverage by trip. The temporal and spatial distribution of observed trips increases uncertainty around discard estimates. It is unlikely that a single observed trip will encompass a large spatial area and be able to capture variability representative of the fishery. This document calculates discard rates based on observed effort, but the amount of effort observed varies throughout the time series.

Survey

Currently, the only source of fishery-independent information about these stocks are the DFO surveys conducted on Banquereau and Grand Bank. These surveys provide a historical snapshot and are not expected to occur in the future. Changes to biomass in the intervening years since the surveys is unknown. With the current available information, the survey biomass estimate is considered more relevant than the LPUE biomass estimate; however, if actual catch was known, a biomass estimate based on catch would be calculated from the most recent data that could be updated annually.

Length Frequency and Life History

Gaps remain in the life-history of Greenland Cockle and Northern Propeller Clam on Banquereau and Grand Bank. The life-history parameters of Northern Propeller Clam on Grand Bank are not known, and Banquereau values are applied to both banks in this analysis. Both Arctic Surfclam and Cockle show differences between the two banks in terms of growth rates and sexual maturity, and it is expected that these differences also occur for Propeller Clam. Additionally, the current size structure of Northern Propeller Clam on either bank is unknown due to the lack of recent length-frequency information.

Grand Bank

The assessment method for Arctic Surfclam on Banquereau considers spatial aspects of the stock, and some of those approaches were applied in this analysis. Currently, there is no method to assess Arctic Surfclam on Grand Bank. This analysis mitigates risk by using a stock definition rather than a bank-wide expansion for biomass estimates. The Grand Bank stock definition has not been peer reviewed for its relevance to the Surfclam fishery, and it is sensitive to the cutoff parameters used. Additionally, on Grand Bank, there are spatial fishing patterns that are not being accounted for in this analysis.

Future Research

The approaches presented in this document could be improved as additional data are collected or current data are re-examined; this may include for example, the use of a weighted regression for the LPUE indicator, or examining survey catch ratios for the species of interest to inform a percentage-of-catch approach.

Discard information from each trip, as opposed to one observed trip, would provide additional information on true catch. Discussions in support of a pilot study to collect discard information are ongoing between industry and DFO Science. Length-frequency data for Arctic Surfclam are already collected during regular fishing operations; however, shifting some sampling effort to Greenland Cockle and Northern Propeller Clam would increase length-frequency data for these species and allow for the ongoing monitoring of length-based indicators.

A directed study on the sexual maturity and growth of Northern Propeller Clam on Grand Bank would provide additional life-history information for this stock that is currently lacking.

The collection of fishery-independent biomass data is lacking for these species. These data could be collected through a multi-species survey, of the whole stock or with a targeted approach; however, surveys are logistically and financially challenging due to the sizes of the banks and the time required to survey them.

CONCLUSIONS

These stocks fall into a subset of data-limited fisheries that are data-rich but information-poor (Carruthers et al. 2014). There are a lot of data, but what those data can say about the stocks in question is limited. Care should be taken to remember the particulars of this fishery and the limitations in these data.

The two approaches based on landings, proportion of directed species catch, and average catch, are applied here using previous values to estimate future limits. The historical time series does not reflect the changes expected in the fishery moving forward, so using averages of proportion or landings for past time periods may not be relevant. Additionally, landings-based approaches do not account for discards and should be used with caution until more discard information can be collected.

Approaches based on biomass estimates, from survey or from LPUE, are sensitive to the catchability coefficient, the area used to calculate the biomass, and the removal rate applied to the biomass. In these cases, both VMS footprints are based on past fishing patterns, and, as discussed with landings-based approaches, the past fishery behaviour is not reflective of future fishing activity. The relevance of the survey data is uncertain given the time that has elapsed since the survey and the low likelihood that the information will be updated on an ongoing basis. The LPUE biomass is information that can be updated annually but currently does not represent actual catch and is not considered a proxy for biomass. A biomass estimate based on a time series of catch per unit effort, which incorporates discard data, would provide current biomass estimates unlike the biomass estimate from the survey, which only provides a snapshot.

Although length-based indictors would require a new stream of data collection, they provide information on size distribution of the stock and are easy to implement and monitor. The LPUE indicator could be useful if discard information is collected to allow for the indicator to be used as a CPUE indicator.

Efforts should be made to fill the existing data gaps to improve the available information. Regardless of the approaches, any catch limits used for Greenland Cockle and Northern Propeller Clam should be reviewed regularly and indicators should be monitored annually.

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SOURCES OF INFORMATION

This Science Advisory Report is from the March 10–11, 2021 Regional Advisory Meeting on the Review of Methods for Developing Catch Limits for Greenland Cockle (*Serripes groenlandicus*) and Northern Propellerclam (*Cyrtodaria siliqua*) in the Banquereau and Grand Bank Offshore Clam Fisheries. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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APPENDIX 1

Table A1. Life-history information for all species retained in the offshore clam fishery: age- and size-at-50% sexual maturity, von Bertalanfy growth parameters: growth coefficient (k), asymptotic average length (L_∞), age when average length is zero (t_0), and maximum size and age.

Species	Location	Age-at-50% Maturity (years)	Size-at-50% Maturity (mm)	k	L_∞ (mm)	t_0 (years)	Max. Age (years)	Max. Size (mm)	Source
Greenland Cockle	Grand Bank	2.83 (M) 3.69 (F)	27.92 (M) 37.22 (F)	0.171	96.3	0.328	39	93.3	Kilada et al. 2007a
Greenland Cockle	Banquereau	2.83 (M) 3.69 (F)	27.92 (M) 37.22 (F)	0.214	95.63	0.971	30	93.3	Kilada et al. 2007a
Northern Propeller Clam	Banquereau	4.7	28.6	0.07	92.9	0.18	105	106	Kilada 2009
Arctic Surfclam	Banquereau	8.3	45.2	0.083	119.56	0.098	98	159	Roddick et al. 2012
Arctic Surfclam	Grand Bank	5.3	39.9	0.063	112.4	-0.595	73	142	Roddick et al. 2011
Ocean Quahog	Sable Bank	8.2	30.96	0.05	90.48	-1.44	210	118.1	Kilada et al. 2007b, Roddick et al. 2007

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