**Historical Summary of Survey Station Relocations**

The southern Gulf snow crab annual survey has a 34-year history, from initial exploratory forays in 1987 and 1988 up to the present. Over this period, the survey has undergone multiple expansions of its survey area, as well as changes in spatial sampling design. Details on the sampling protocol and development of this survey can be found in Moriyasu et al. 2008.

The spatial sampling design is based on randomly selected sampling stations within a regular grid overlaying the survey area. From 1988 to 2011, rectangular 10’x10’ grids were used and subsequently replaced square of square grids in 2012 onwards. Large subsets of sampling stations were fixed (i.e. resampled) from year to year, though new sampling stations were continually added through survey expansions, relocation of sampling stations from difficult to more favourable trawling locations, and in response to changes in spatial sampling design in 1991, 2006, and in 2012 and 2013.

**Figure 1** shows a generated historical summary of the complete set of sampling stations used in the snow crab surveys from 1988 to 2020. Stations lying within a 1.5 km distance of each other were labelled as belonging to the same sampling station.

Macintosh HD:Users:crustacean:Desktop:Stock-Assessment-2020:results:figures:Survey Station History.pdf

**Figure 1**: Historical cumulative summary of sampling stations added during the annual southern Gulf of Saint Lawrence snow crab survey. Shaded lines indicate that a station was successfully sampled for a particular year. The y-axis shows the order of appearance of sampling stations, with older sampling stations found near the bottom and the most recent stations near the top. Annotations show major changes in survey sampling design.

From an initial set of stations in 1988, this figure shows that stations were added or redistributed over most years of the survey. In particular, new stations were rapidly added in the early part of the survey, which had its greatest areal expansion from 1988 to 1993. Only a partial survey was conducted in 1996 due to lack of funding.

The period from 1994 to 2005 saw progressively smaller proportions of stations being re-located, in part due to improvements in geo-location technologies and a general tendency to relocate stations from difficult trawling areas to areas within its sampling grid more suitable to trawling.

After a major survey sampling redesign in 2006, which saw a redistribution of stations in order to have a more uniform spatial distribution over the survey area, the set of sampling stations remained constant from 2006 to 2011, indicating that the survey crews heavily favoured resampling after a failed tow attempt, rather than relocating at an alternate sampling station.

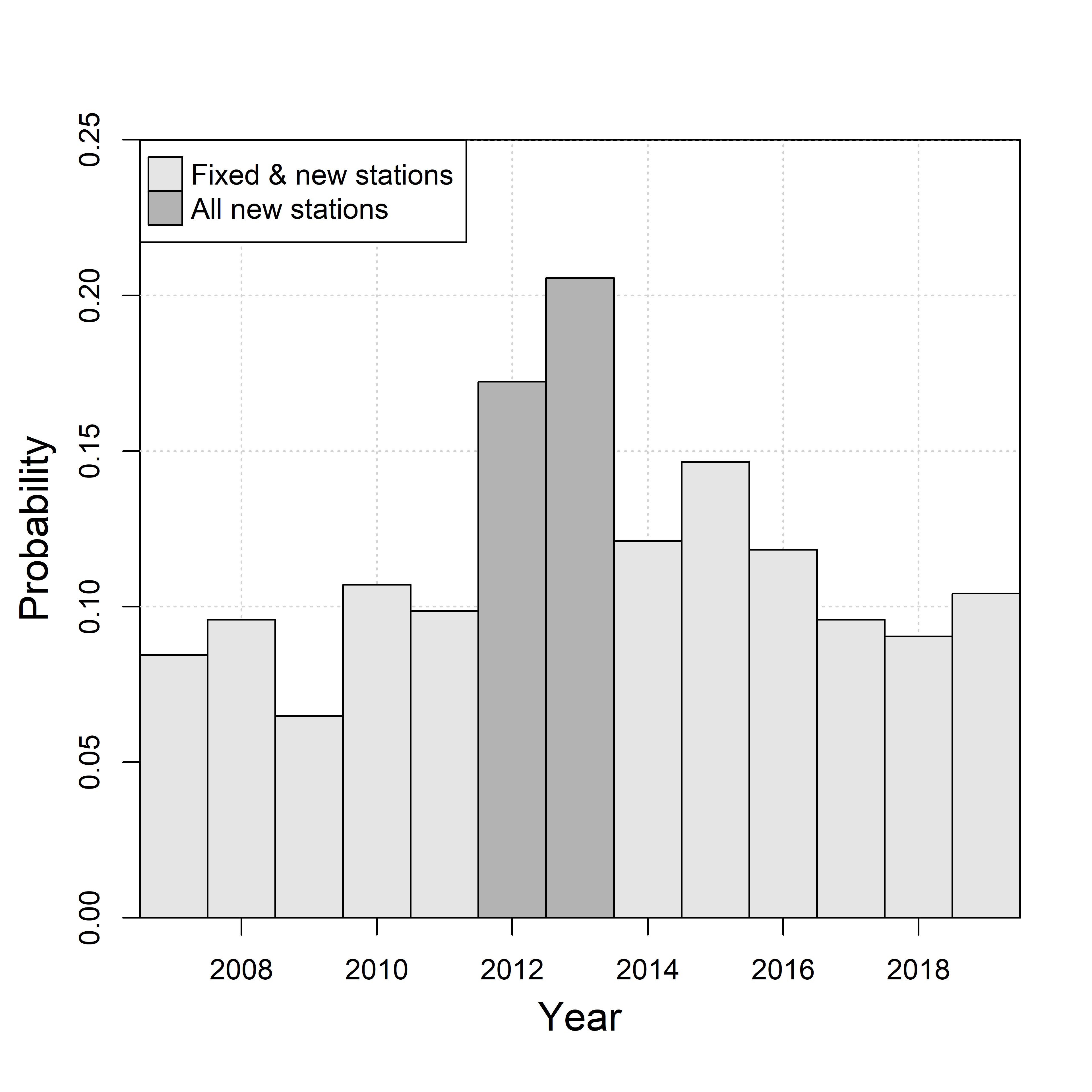
Following a spatial sampling design was changed in 2012 a completely new set of survey stations were generated. The process was repeated in 2013.

From 2013 onward, the survey crew favoured alternate sampling stations, rather than repeating tows after a failed attempt at towing.

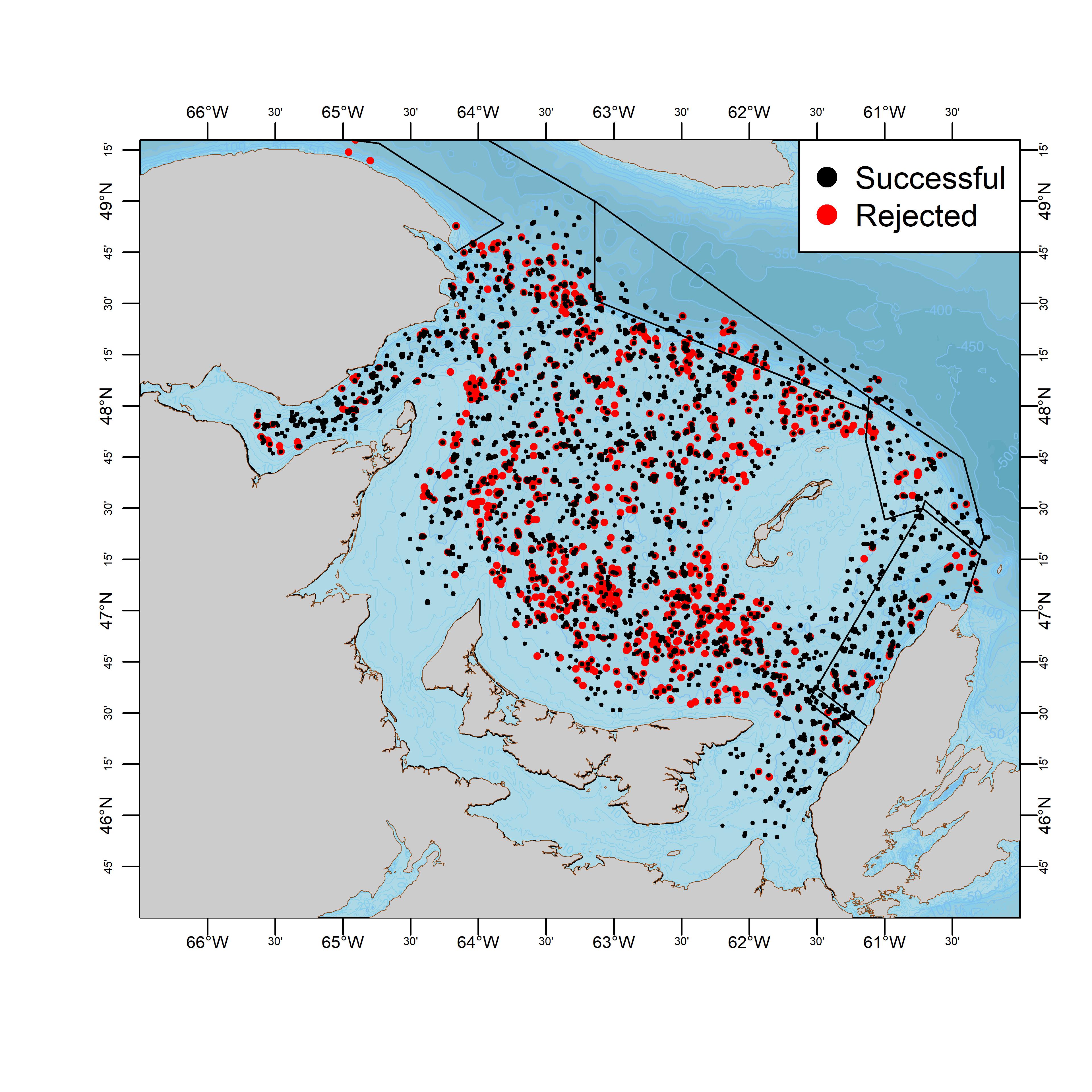
**Figure 2** shows the proportion of failed tows for each survey year. In 2012 and 2013, 17% and 20% of attempted tows failed on the first attempt. Given that the spatial sampling density over the survey area is fairly uniform, these proportions also represent the proportion of the current survey area which is trawlable on the first attempt.

However, these proportions were much higher than in previous years, which were around 8% to 10% in 2006 to 2011. Largely because of this, the trawl stations were held fixed from 2013 onward, with the proportion of failed tows again decreasing as alternate sampling stations replaced many stations from the original 2013 station set. Since 2013, about 200 sampling stations have been moved, which represent an important proportion of the survey’s 355 stations.

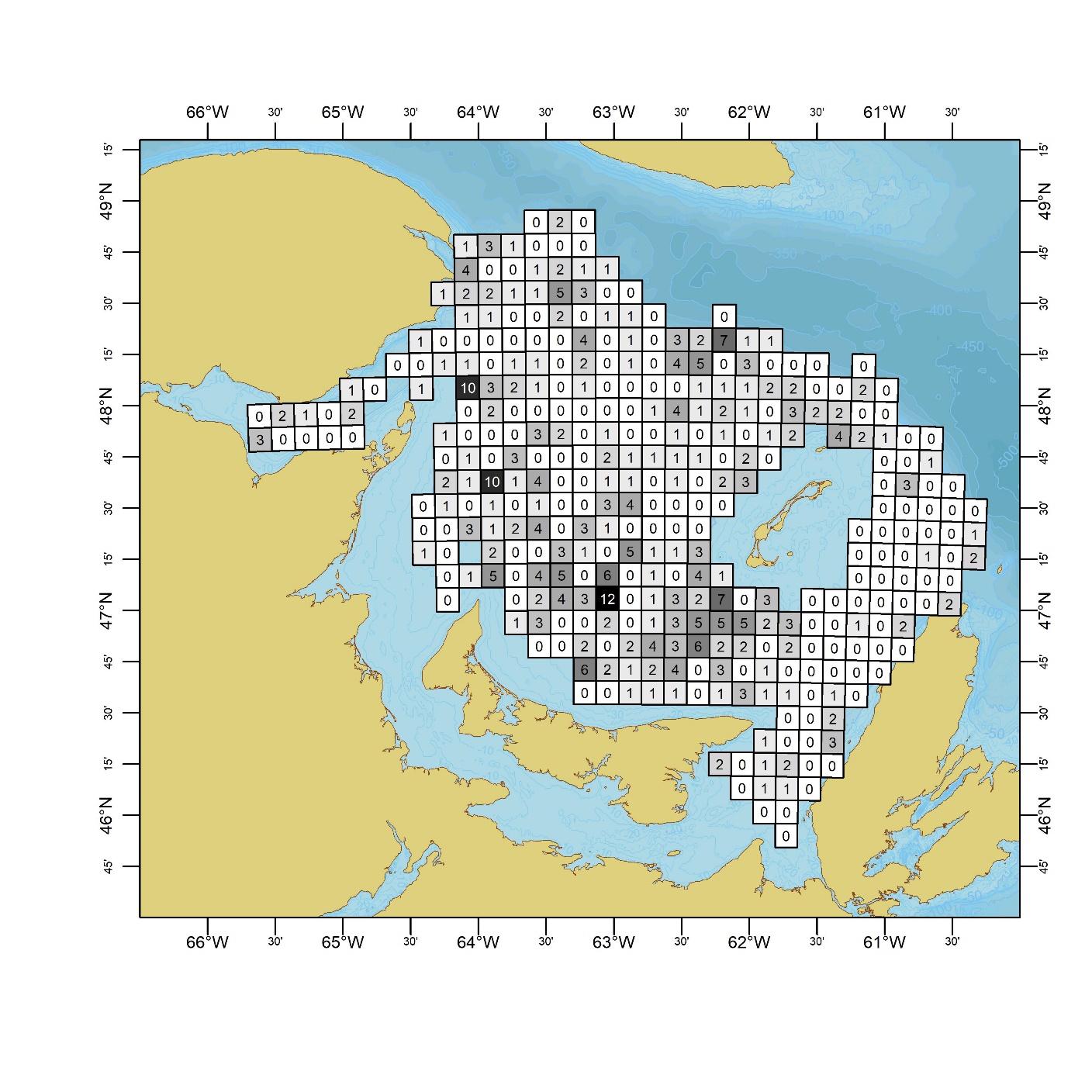
**Figure 3** shows where the relocations have occurred, indicating that problematic areas lie mostly between Prince Edward Island and the Magdalen Islands and along the Laurentian Channel.



**Figure 2**: Proportion of tows rejected on the first attempt during the 2007 to 2019 snow crab surveys.



**Figure 3**: Locations of successful (black) and rejected (red) tows in the 2000 to 2019 snow crab surveys.

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**Figure 4 :** Map of survey sampling grids and the total number of sampling station relocations which have occurred within them over survey years 2013-2019.

**Methodology:**

* Comparing different years

**Darrell Mullowney Comments (RAP, 2019)**

Major Concern of Increasing survey catchability (q) over the time series, particularly in recent years.

* This concern extends beyond the 2019 extended tow length issue.
  + **Table :** Number of survey grids, out of a total of 355, having had a specified number of survey stations moved since 2013.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Year** | **0** | **1** | **2** | **3** | **4+** |
| 2013 | 288 | 57 | 9 | 1 | 0 |
| 2014 | 261 | 75 | 13 | 6 | 0 |
| 2015 | 237 | 79 | 25 | 12 | 2 |
| 2016 | 226 | 77 | 28 | 16 | 8 |
| 2017 | 217 | 76 | 26 | 25 | 11 |
| 2018 | 206 | 76 | 30 | 29 | 14 |
| 2019 | 195 | 78 | 28 | 28 | 26 |
| 2020 | 186 | 80 | 33 | 29 | 27 |

* + Table X shows a detailed breakdown of the number of survey grids, out of a total 355, which have had a specified number of sampling station relocations, between the 2013 and 2020 surveys.
  + In particular, 67 stations from the original set of 355 random stations in were already moved to alternates in 2013.
  + Progressively more and more grids contained relocated stations, though the number of original stations being moved has decreased to about 11 per annum in the past 4 years.
  + In 2020, only 186 from the original 2013 stations remained fixed, with 80 of the remaining stations moving once, 33 moving twice, 29 moving three times, and 27 moving four or more times.
  + Conclusion:
    - Almost half of survey stations have been moved at least once since 2013.
    - Recommendation: The survey sampling protocol should be modified in order to monitor the impact of these station relocations. The following change is recommended: Using the original 2013 set of random survey stations, a representative subset of the survey area should be chosen to remain fixed in subsequent surveys (say about half of stations), while the remaining stations may follow the current protocol.
* *There is now an extended period of a positive residual pattern between the survey and predicted R1 biomass, effectively since about 2012 and constituting near-half of the time series.* 
  + R1s are affected by by-catch mortality from fishing
  + R1s are subject to variations in natural mortality thought to be driven by high abundance of large commercial males (residuals)
  + Catchability is also an issue.
* A new survey design was instituted in 2012 with expanded boundaries and new site selection.
* Since 2013, there has been a practice to maintain successful sets from the previous survey and abandon unsuccessful sets in lieu of successfully occupied alternates.
* My guess is the successful alternates that become a fixed part of the survey design thereafter *would be systematically associated with softer substrates, upon which q would be higher (intro of trawl survey document says footrope digs into soft-sediment and increases q.*
* Survey Protocol section of Trawl Document says in 2018 31 stations (= near 10% of total survey) were re-assigned in 2019 survey design. Furthermore, the Characteristics of Tows in 2019 section says an additional 33 sites were completed on additional stations. This is a high rate of attrition, presumably toward softer sediments.
* Figure 7 in the trawling document suggests it’s mostly peripheral areas that are becoming abandoned. This pattern is even more exacerbated in previous assessment documents, such as in 2013-2015 survey years.
* The increasing attrition of shallow/hard bottom areas and increasing prominence of deeper/softer areas would lead to decreased presence of what would typically conform to small crab habitat and increased presence of what would typically conform to larger crab habitat and ultimately increase overall survey q, particularly for large crab (Mullowney review document on crab distribution and migration - Reviews Fish Biology & Fisheries).
* Potential issues of increasing survey q are also consistent with a pattern of increasing vessel horsepower on the survey vessels throughout the time series (ie. Benoit and Cadigan documents on the catchability of the RV vessels).
  + Benoit and Cadigan estimated a fairly large decrease in relative catchability between the Marco Michel (2012) and the Jean Mathieu (2013), although the Jean Mathieu had a more powerful engine, with 720hp versus 660hp.
  + CFVs Marco Michel and Avalon Voyager II have similar designs, with both having higher centers of gravity than the lower-lying Jean Mathieu.
* There is a flat or negligibly positive slope on the 34-44mm CW crab index since 2006. In contrast, larger crab stages R4-R1, which inform the stage-based model have more strongly increasing slopes. The document claims the model starts at 56-68mm CW because of decreasing trawl catchability at lower sizes, but this would not seem to explain the disconnect between the stages if there is a constant survey q at each stage over time.
  + Perform analysis using size-based categories, e.g. 95-110mmm versus instar VIII
* Trends in American Plaice capture in this survey appear consistent with an increasing survey q over the time series.
  + American Plaice abundance seemingly increased in abundance from 2006 to 2011. This survey period had a consistent set of stations and a single survey vessel and crew.
  + *Use the same scaling method to recalculate the American Plaice length-frequencies.*
  + The 2012 survey redesign saw a decrease in abundance with another comparable one in 2013, with a new set of survey stations and survey vessel. The period from 2013-2018 was relatively much lower compared to the high point in 2012. A moderate increase in abundance was observed over this period, though a small decrease in 2017 to 2018 was also observed.
  + 2019 saw a large significant increase of ~22% over 2018. The 2020 level was comparable to 2019.
  + However, length-frequencies show a recruitment pulse starting in 2018 through 2020 which affect the perceived relative abundance over these years.
* Priors used in the stage-based model come from a period of suspected lower survey q.
* Fig. 15 in the fishery document shows a loose positive correlation between biomass and CPUE over the time series (probably significant, not sure). Yet, CPUE in Area 12, the major crab area, has been flat for a decade and actually down in the past two years. This doesn’t appear to be associated with a trap saturation point, as other areas are/have shown higher CPUE.
* If I understand Fig. 11 and Fig 12. correctly, annual m for new-intermediate hard-shelled large adult males would be about 0.2-0.4 = Zm(0.2-0.5). This seems kinda high? I don’t see why a crab in its prime physical condition, virtually immune from predation, would have m this high? I could see if it was more relevant to older-shelled or smaller crab. All above points on increasing survey q would suggest exploitation rate is probably higher than suggested.

Snow crab trends:

* The survey from 2006 to 2011 used the same sampling design, fixed stations and the same survey vessel and crew. As such, inter-annual comparisons over this period are less prone to some sampling biases which were identified, such as vessel effects and moving stations to more trawlable areas, which were present from 2012 to 2020.
* Annual trends for three snow crab categories were examined, immature females, mature females, immature males and commercial males.
  + Add commercial crab to analysis.
  + Over the period of 2006 to 2011, snow crab densities increased for all categories.
  + In 2012, densities remained comparable to 2011, except for mature females which increased by more than 20%.
  + In 2013, densities for all categories decreased by significant amounts: ~45% for immature females, ~25% for mature females, ~20% for immature males, and X% for commercial males.
  + During the period from 2013 to 2018, immature females saw a large increase of ~45% in 2016. Mature females saw gradual increases of 5-10%, immature males saw moderate increases in 2014 and 2015, and a large increase of ~35% 2018.
  + With the vessel change in 2019, densities saw large increases of almost 50% for immature females, almost 40% for mature females, 35% for immature males and X% for commercial males.
  + Survey year 2020 saw moderate increases of ~10% for mature females and immature males.

**Table 1** : Summary of survey stations having a fixed or new location relative to the those of the previous survey year. For the time period prior to 2012, new tows were labelled as such if the distance from its center point was more than 1.5 km of the previous year’s station. Also shown if the total number of rejected tows.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **Stations** | | |  | **Survey** |  |  |
| **Year** | **Vessel** | **Fixed** | **New** | **Total** | **Rejects** | **Survey area (km2)** | **Grid size** | **Comment** |
| 1989 | Emy Serge | 63 | 92 | 155 | 16 |  | 10'x10' |  |
| 1990 | Emy Serge | 40 | 172 | 212 | 43 |  | 10'x10' |  |
| 1991 | Emy Serge | 56 | 159 | 215 | 19 |  | 10'x10' | New survey stations |
| 1992 | Emy Serge | 59 | 174 | 233 | 9 |  | 10'x10' |  |
| 1993 | Emy Serge | 122 | 86 | 208 | 11 |  | 10'x10' |  |
| 1994 | Emy Serge | 128 | 131 | 259 | 23 |  | 10'x10' |  |
| 1995 | Emy Serge | 152 | 109 | 261 | 38 |  | 10'x10' |  |
| 1996 | Emy Serge | 41 | 31 | 72 | 3 |  | 10'x10' | Partial survey |
| 1997 | Emy Serge | 127 | 132 | 259 | 18 |  | 10'x10' |  |
| 1998 | Emy Serge | 125 | 136 | 261 | 16 |  | 10'x10' |  |
| 1999 | Den C Martin | 151 | 126 | 277 | 26 |  | 10'x10' |  |
| 2000 | Den C Martin | 255 | 25 | 280 | 26 |  | 10'x10' |  |
| 2001 | Den C Martin | 268 | 24 | 292 | 26 |  | 10'x10' |  |
| 2002 | Den C Martin | 270 | 49 | 319 | 24 |  | 10'x10' |  |
| 2003 | Marco Michel | 306 | 11 | 317 | 44 |  | 10'x10' |  |
| 2004 | Marco Michel | 314 | 33 | 347 | 27 |  | 10'x10' |  |
| 2005 | Marco Michel | 283 | 72 | 355 | 51 |  | 10'x10' |  |
| 2006 | Marco Michel | 209 | 145 | 354 | 37 | 44302 | 10'x10' | Station redistribution |
| 2007 | Marco Michel | 351 | 4 | 355 | 47 | 44302 | 10'x10' |  |
| 2008 | Marco Michel | 347 | 8 | 355 | 50 | 44302 | 10'x10' |  |
| 2009 | Marco Michel | 354 | 1 | 355 | 38 | 44302 | 10'x10' |  |
| 2010 | Marco Michel | 354 | 0 | 354 | 47 | 44302 | 10'x10' |  |
| 2011 | Marco Michel | 352 | 1 | 353 | 46 | 44302 | 10'x10' |  |
| 2012 | Marco Michel | 8 | 313 | 321 | 80 | 57840 | 13.1 x 13.1km | Complete survey redesign |
| 2013 | Jean Mathieu | 13 | 339 | 352 | 92 | 57840 | 12.6x 12.6km | Complete survey redesign |
| 2014 | Jean Mathieu | 306 | 47 | 353 | 56 | 57840 | 12.6 x 12.6km |  |
| 2015 | Jean Mathieu | 298 | 55 | 353 | 71 | 57840 | 12.6 x 12.6km |  |
| 2016 | Jean Mathieu | 314 | 40 | 354 | 55 | 57840 | 12.6 x 12.6km |  |
| 2017 | Jean Mathieu | 319 | 34 | 353 | 50 | 57840 | 12.6 x 12.6km |  |
| 2018 | Jean Mathieu | 315 | 39 | 354 | 41 | 57840 | 12.6 x 12.6km |  |
| 2019 | Avalon Voyager II | 315 | 37 | 352 | 67 | 57842.8 | 12.6 x 12.6km |  |
| 2020 | Avalon Voyager II | 327 | 26 | 352 | 38 | 57842.8 | 12.6 x 12.6km |  |

**Catch comparisons:**

* For the purposes of annual comparisons, animal counts were analyzed using a Poisson count model with a random effect over survey grids.
* Annual densities over the sampled grids were obtained from the model, as well as density estimates for each sampled grid in a given survey year.
* The survey grid scheme which is currently used was used to spatially disaggregate data from 2006 to 2020.
* As the survey area from 2006-2011 was smaller than the current survey area, we expect that this portion of the series may not be comparable. With this in mind, we mostly expect that the densities over this period would be on a slightly higher scale than 2012-2020, as the later survey expansion was mostly into more marginal habitat for snow crab and most by-catch species.

**Bibliography:**

Moriyasu, M., Wade, E., Hébert, M. and Biron, M. 2008. Review of the survey and analytical protocols used for estimating abundance indices of southern Gulf of St. Lawrence snow crab from 1988 to 2006. DFO Can. Sci. Advis. Sec. Res. Doc. 2008/069.