**Swept Area during the Passive Trawling Phase:**

Any additional swept area incurred by the trawl during the passive trawling phase is presently unaccounted for when standardizing catches. However, calculation of this component of the swept area is more complex than that of the active trawling phase, as the forward movement of the trawl is due to combination of two forces: the forward movement of the vessel plus that of the winch pulling the trawl towards the vessel.

If we assume the vessel has more or less the same bearing during the passive phase, we can calculate vessel’s contribution to the trawl movement using , where is the vessel’s average speed and is the duration of the passive phase. The when the winch speed is known, the distance that the winch drags the trawl across the sea floor is given by:

where is the water depth, is the warp cable length during regular trawling (i.e. ). The average winch speed for each tow was calculated by dividing the total warp length by the time it took for the doors to breach the surface of the water. The total swept area of the passive phase for each tow is given by , where is the average trawl wing spread. The lift off angle between the trawl cables and the sea bottom are given by . For a 3:1 warp ratio, during regular trawling up to the beginning of the passive phase. As the trawl approaches the vessel, will increase up to some value until the trawl finally lifts off the bottom.

Vessel

Door at stop

position

Door at liftoff

position

Depth

Warp length stop

Door movement

Warp length liftoff

**Figure X** : Trigonometric model of the distance travelled by the trawl due to winch action alone (movement due to vessel movement is ignored).

**Table X**: Description of input parameters used to calculate statistics of the passive trawling phase for each survey tow.

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Description** | **Source** |
|  | Passive phase duration | Analysis of Star Oddi tilt probe data. |
|  | Vessel speed | Vessel GPS. |
|  | Warp length | Counting off 25 fathom cable markers by captain. |
|  | Winch speed | Haul time divided by warp length. |
|  | Water depth | Water depth according to ship sonar. |
|  | Trawl width | eSonar wing spread observations. |

Vessel and trawl characteristics during the passive trawling phase during the 2019 survey were compared to those of 2017 and 2018. The data and methods used were identical between years. Table X shows a summary of the input parameters used to characterize and derive other passive phase statistics, as well as their respective data sources.

**Results**

Summary statistics for the passive phase swept area calculation are shown in Table X.

Most of the measured values scale with water depth and so deep-water tows along the Laurentian Channel consequently have much higher values than most other tows in the Gulf, but these represent only about X % of trawl stations and generally have low densities of snow crab.

This aspect of the data implies some of the data are left-skewed, leading to a contrast between median and mean values, through both are presented.

Statistics show that overall vessel speeds during the passive phase were comparable between years, at around 0.8 meters per second. The median passive phase duration went from 50 and 43 seconds in 2017 and 2018, to 89 seconds in 2019. The increase in durations led to corresponding increases in the distance covered by the vessel during the passive phase, to a median of 158.5 meters in 2019, from median values of 102.6 in 2017 and 89.9 meters.

The calculated winch speeds were comparable during the 2017 and 2018 with median values of 1.26 meters per second, whereas the 2019 median dropped to 0.90 meters per second. Liftoff angles increased slightly to a median of 34.0o in 2019, from 27.9 o in 2017 and 28o in 2018. Higher liftoff angles in 2019 imply that the trawl was brought closer to the vessel before lifting off the bottom. Thus, we see a corresponding increase in the distance travelled by the trawl due to winch action to a median value of 87.6 meters in 2019, up from 65.9 meters in 2017 and 56.9 meters in 2018. Trawl wing spread values decreased slightly to a median of 6.5 meters in 2019, from 6.9 meters in 2017 and 7.0 meters in 2018.

The resulting swept area estimates for the passive trawling phase increased to 992 m2 in 2019, from 688 m2 (44% increase) in 2017 and 605 in 2018 (64% increase).

**Table** : Tow summary statistics of the passive trawling phase from the 2017, 2018 and 2019 surveys.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | **Percentiles** | | | | |  |
| **year** | **variable** | **units** | **2.5%** | **25%** | **50%** | **75%** | **97.5%** | **average** |
| 2017 | vessel speed | m/s | 0.24 | 0.61 | 0.82 | 0.99 | 1.44 | 0.81 |
| 2018 | vessel speed | m/s | 0.32 | 0.66 | 0.81 | 1.00 | 1.32 | 0.82 |
| 2019 | vessel speed | m/s | 0.46 | 0.65 | 0.81 | 1.03 | 1.45 | 0.86 |
| 2017 | duration | s | 9 | 25 | 50 | 82 | 439 | 82.1 |
| 2018 | duration | s | 8 | 24 | 43 | 75 | 441 | 74.6 |
| 2019 | duration | s | 15 | 58.75 | 89 | 117 | 544 | 116.2 |
| 2017 | vessel distance | m | 25.5 | 60.0 | 102.6 | 154.7 | 715.2 | 149.2 |
| 2018 | vessel distance | m | 22.2 | 57.1 | 89.9 | 137.7 | 749.7 | 135.6 |
| 2019 | vessel distance | m | 39.4 | 113.5 | 158.5 | 202.8 | 965.4 | 203.1 |
| 2017 | winch speed | m/s | 1.01 | 1.21 | 1.26 | 1.30 | 1.39 | 1.25 |
| 2018 | winch speed | m/s | 1.03 | 1.22 | 1.26 | 1.30 | 1.36 | 1.25 |
| 2019 | winch speed | m/s | 0.71 | 0.84 | 0.90 | 0.97 | 1.31 | 0.92 |
| 2017 | liftoff angle | degrees | 19.1 | 24.9 | 27.9 | 32.2 | 56.1 | 29.3 |
| 2018 | liftoff angle | degrees | 19.7 | 24.7 | 28.0 | 31.5 | 47.6 | 29.2 |
| 2019 | liftoff angle | degrees | 20.5 | 26.7 | 34.0 | 42.6 | 64.2 | 35.5 |
| 2017 | winch distance | m | 13.0 | 35.8 | 65.9 | 105.4 | 511.1 | 100.3 |
| 2018 | winch distance | m | 11.9 | 33.5 | 56.9 | 89.3 | 515.3 | 89.9 |
| 2019 | winch distance | m | 20.9 | 58.4 | 87.6 | 113.8 | 482.6 | 112.1 |
| 2017 | wing spread | m | 4.5 | 6.3 | 6.9 | 7.5 | 9.4 | 6.9 |
| 2018 | wing spread | m | 4.2 | 6.4 | 7.0 | 7.5 | 9.5 | 6.9 |
| 2019 | wing spread | m | 3.3 | 5.5 | 6.5 | 7.2 | 8.9 | 6.3 |
| 2017 | swept area | m2 | 160 | 425 | 688 | 1118 | 4932 | 1014 |
| 2018 | swept area | m2 | 135 | 394 | 605 | 945 | 4781 | 938 |
| 2019 | swept area | m2 | 227 | 613 | 992 | 1392 | 6067 | 1270 |

**Discussion**

The new survey vessel, the Avalon Voyager II is a heftier, more powerful vessel than the previous survey vessel, the Jean Mathieu. In particular, the winch aboard the Avalon was somewhat over-powered with respect to the survey trawl, leading to gear entanglements early on in the survey, which in turn forced the captain to use a slower speed setting for the remainder of the survey.

Unfortunately, this lower speed setting was markedly slower than those of the Jean Mathieu in previous years. This led to large increases in the bottom time during the passive trawling phase, a phase which is currently unaccounted for in survey catch standardizations. Based on auxiliary survey data, it was possible to approximate the swept area for individual tows during the passive phase which, as expected, showed large increases in 2019 relative to 2017 and 2018. This was in large part due to the survey vessel travelling further during the prolonged time periods. A secondary factor was the winch having to drag the trawl closer to the survey vessel due to its slower haul speed.

Median passive swept area estimates represent 24.8%, 22.3% and 32.2% of regular swept areas estimated for the active trawling phases, out of 2278 m2, 2709 m2 and 2739 m2, for 2017, 2018 and 2019, respectively. This component of the swept area is currently unaccounted for in catch standardizations and would lead to correspondingly large decreases in abundance and biomass if they were included in their estimates, relative to the current method.

In particular, the commercial snow crab biomasses were calculated at 52271 tonnes in 2017, down 20.5%, 65136 tonnes in 2018, down 19.3% and 57681 tonnes, down 27% in 2019. Thus, when we account for the passive swept area, there is a relative decrease of 11.4% between the corrected commercial biomasses from 2018 to 2019. This decrease was only 2.1% for the uncorrected estimates.

**Historical perspective:**

Past survey protocols intended to limit the scale of trawling after the stop time by recommending that the survey vessel slow down to a negligible speed, then back up slowly during hauling. The execution of this step must be undertaken with special care to avoiding gear entanglement with itself and the survey vessel’s propeller. GPS vessel tracks from the 2012 survey, performed by the CFV Marco Michel, showed that this practice was commonly in use.

With the introduction of the Jean Mathieu in 2013, it appears that this practice was somewhat, though not completely, relaxed. There is also some indirect evidence that the winch was slower on board the Jean Mathieu versus the Marco Michel, as its passive phase duration were slightly longer. GPS vessel tracks in 2017, 2018 and 2019, showed that the survey vessel almost consistently held its bearing, i.e. continuing along the tow path, during the passive phase. This shows that the behaviour of the behaviour of the survey captain changed sometime between 2013 and 2017.

Since the intended purpose of manoeuvering backwards was to minimize the swept area of the passive phase, the failure to adhere to this aspect of the protocol probably led to introduction of significant negative bias in swept area estimates. These lead in turn to corresponding overestimations in abundance and biomass indices for the affected years.

**Uncertainties:**

The passive swept area estimates rely on a number of simplifying assumptions, the violation of which would lead to biases in its estimation.

The trigonometric model outlined above relies on the warp cables being a straight line to the survey vessel when in reality they will sag under their own weight. This implies that the trawl is generally closer to the survey vessel than we consider here, making the distance travelled due to winching, and thus its contribution to the swept area, smaller by comparison. Shrinking this component of the passive swept area would make the passive swept area relatively larger in 2019 than in 2018. Also, estimates of lift off times, though calculated using the same method for all years considered, may be somewhat overestimated. The lifting off of the footrope is a more protracted process, unlike the touch down. In particular, the contact of the footrope in locations other than its center, which is monitored by the tilt probe, is unknown during the lifting of the trawl doors, which may be lifting the trawl wings.

Other factors might be affecting the catchability of crab encountering the trawl. For example, it is known that the trawling speed is generally faster during the passive trawling phase than in the active trawling phase. In addition, the configuration of the trawl may be less than optimal during this phase, leading to possibly lower catchability. In particular, asymmetry between the warp cables would lead to a lower effective wing spread, and thus to lower effective swept areas.

**Assumptions and deviations:**

* Using trigonometry, it can then be shown that for a warp to water depth ratio of 3:1, and . Now we consider that the trawl doors will lift off from the bottom when the warp cables reach some characteristic angle . The particular value of will depend on the weight/bottom friction of the trawl, the winch, vessel, and current speeds, among other factors. Let correspond to horizontal distance at the new angle with respect to the vessel. We refer to this point as the *liftoff position*.
* Under this simple model, we can show that , thus that the forward distance travelled by the trawl due to winching alone is given by . As an example, supposing that the liftoff angle is yields .
* Note that this corresponds to a not inconsiderable distance, given that depths in snow crab habitat range from 40 to 150+ meters, though in the real world values will be less than this, given that will be less than the theoretical value.

**Deviations from the model:**

* The warp cable will sag under its own weight, thus lowering and by some unknown amount.
* Warp length to water depth ratios deviate from the target 3:1 since the warp cable lengths are rounded to the nearest 25 fathoms. Also the maximum length of cable available if 550-575 fathoms, which is limiting in deep water tows.
* If the vessel deviates from its forward trajectory during the passive phase, the movement of the trawl will also be reduced.
* The liftoff of the footrope from the bottom occurs over a much wider time interval than the touchdown. It is unclear to what extent the length of the footrope makes contact with the sea bottom, or at which point the trawl doors lift from the bottom. In other words, the trawl catchability may be much reduced at an earlier time than that estimated from the liftoff.
* The trawl winch speed is unknown and was known to be used at different speeds at the beginning of the survey, as well as the last two days of the comparative survey.

**Time dependence:**

* Let be the winch speed and be the elapsed time from when the stop signal was given. The warp length becomes a function of time .
* Let be the time required for the trawl doors to move from their stop position to the liftoff position. The corresponding warp length at this position is given by . Combining this with the previous equation, we get:
* We note that for a given tow, and are generally known. This may lead to estimates for winch speed and liftoff angle .
* If winch speed is known, then the liftoff angle is given by:
* Even if there is cable sagging, this will not change the duration of the hauling period, though the passive distance component due to winching will decrease. The intuition here is that just prior to liftoff the tension in the cables, plus the sharper angle , leads to cables which are more linear (i.e. little sag), and thus the duration required to get to that point is roughly invariant to cable sagging.

**Vessel movement during the passive phase:**

* Let the survey vessel move forward by an amount , where the subscript refers to the passive phase. We can express this distance measure as the product of the average vessel speed over the duration of the passive phase times its duration . In this sense, the distance is proportional to water depth and inversely proportional to winch speed, given the above equation for .
* The value is also generally known, though it may be complicated by deviations from linearity by the survey vessel.

**Swept area considerations:**

* Let be the swept area during the active phase (i.e. the one presently used to standardize catches), be the swept area represented by the forward due to winch action over the distance , and let be the swept area brought about by the forward movement of the vessel during the passive phase.
* The total swept area is given by:

where and are mean trawl widths during the winching and passive trawling phases, respectively. However, given that these phases occur simultaneously, we may assume that .

Thus the total swept area during passive trawling phase is:

This unaccounted-for component of the swept area is seen to be proportional to the average trawl width and water depth .

**Swept Area Issues Associated with the 2019 vessel change:**

* Liftoff times were estimated using a formal statistical analysis of tilt-probe data.
* The same method was applied to data from 2017, 2018 and 2019 survey tows.
* This analysis showed a 2-fold increase in the duration of the passive trawling phase, from a median 50.5 and 43 seconds in 2017 and 2018, to 89 seconds in 2019 (Table X).
* The distance travelled by the survey vessel during this period accordingly increased from a median of 33 meters in 2018 to 68 meters in 2019.
* The trawl wing spread also showed a decrease from a median of 7.0 meters in 2018 to 6.4 meters in 2019.

Given that the depth characteristics of the survey have not changed, then such a large increase is due to a change in the liftoff angle or more probably to a slower winch.

As was noted by the new survey vessel crew, which found that the high-speed setting of the winch led to gear entanglements. The captain thus used the medium speed setting, which was observed to be slower than the working winch speed of the old survey vessel.

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**Figure X :** Theoretical duration of passive phase for a 60-meter depth tow as a function of liftoff angles and three different winch speeds.



**Figure X :** Theoretical swept area incurred over the passive trawling phase, for a 60-meter depth tow, with a mean wing spread of 6.8 and average vessel speed of 0.81 m/s, expressed as a function of liftoff angle.

* Even for conservative values of the liftoff angle , the passive phase swept area estimates potentially represent substantial proportions of that of the active phase, whose average generally centers about 2700m2-2800m2.

Assuming there is a two-fold increase in tow duration, what is the expected increase in real swept area going from 2018 to 2019? If we assume that the characteristic liftoff angle does not change, then



Which is plotted in the above figure using wing spread and vessel speeds from 2018 and 2019 as input values and a common liftoff angle for both years.

This shows that the percentage change in total swept area is rather small relative to the perceived change observed in 2019 versus 2018.

However, the difference may also be due to a change in characteristic liftoff angle. If the angle increased by 15 degrees in 2019, this plot becomes:





