An update on the population structure, residency, and movements of North Atlantic right whales in the Gulf of St. Lawrence

Crowe L.M.[1]; Brown M.[2,3]; Corkeron P.J.[3]; Duley P.[4]; Hamilton P.K.[3]; Ogilvie A.[1]; Ratelle S.[5]; Vanderlaan A.S.M.[6]; Cole T.V.N.[4]

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Survey effort in the Gulf of St. Lawrence (GSL) during 2015, 2017, 2018, and 2019 has provided insight into North Atlantic right whale *(Eubalaena glacialis*) use and movement in the area. Here we present findings from all photographic captures in 2017, as well as individual captures from dedicated mark-recapture aerial surveys in the 2015, 2018 and 2019 summer seasons. Within these data, 176 individuals visited the GSL and 95% of the animals sighted in 2019 (*n* = 128, calves excluded) were seen in the prior two seasons. Between 2017 and 2019, individuals were sighted on 1 to 14 different survey days within each year. In 2017, a total of 133 unique right whales were sighted from 14 organizations on 23 different platforms in the GSL in all months between June and December, and the maximum time between an initial and final sighting was 163 days. Dedicated aerial surveys designed to maximize capture of individuals were flown from 23 June to 29 July 2017 and sighted 83% of the total individuals for the year. While most resightings of individuals in 2017 occurred in the southern GSL, three individuals were sighted only off of Anticosti Island, and four were seen in both locations indicating movement across a shipping zone. Animals sighted between the northern and southern GSL in 2017 included two reproductive females who brought calves to the GSL in 2019. Results indicate that the mark-recapture flight methods effectively captured most individuals in this region, animals are exhibiting a high rate of inter-annual return, there is capture heterogeneity of individuals, and whales are moving around this region, including within and across management areas.

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1. Population structure
    a. # of individuals captured
    b. Demography
    c. Inter-annual return
2. Capture rates
3. “Residency”
4. Abundance Estimates
5. Movement

Mark-recapture aerial surveys (MRAS)

NARWC 2017 data

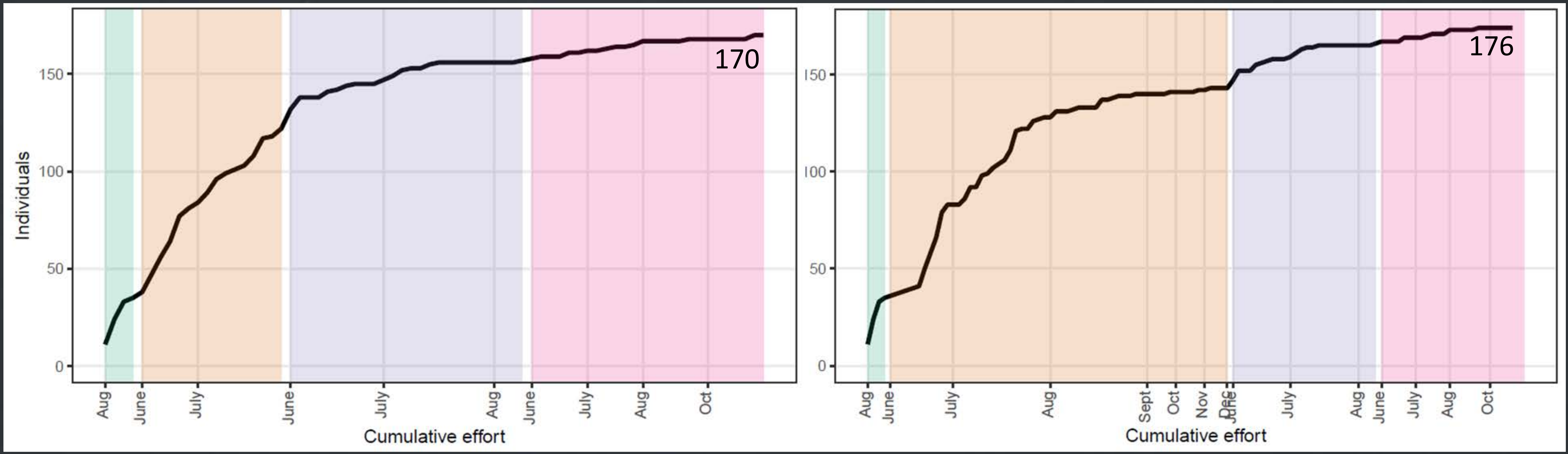
NARWC 2017 data

GOALS:

1. Provide better insight into right whale use of the GSL
2. Evaluate effectiveness of M/R survey methods

1. Population structure | a. # of individuals captured overall

Mark-recapture aerial surveys   Mark-recapture aerial surveys + NARWC 2017 data



Year	Survey Days	First	Last
2015	4	07 August	20 August
2017	16	22 June	29 July
2018	26	04 June	12 August
2019	26	04 June	29 October

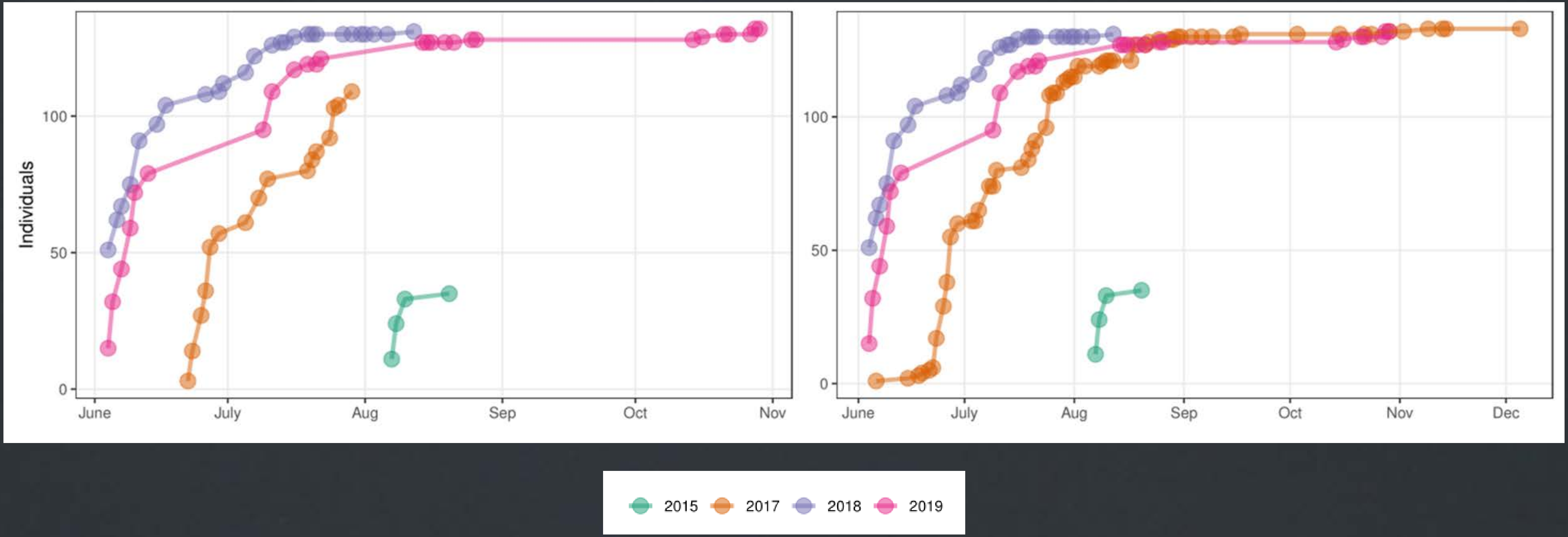
2017	60	06 June	05 December

Includes sightings from 14 organizations / sources on 23 different platforms

1. Population structure | a. # of individuals captured by year

Mark-recapture aerial surveys (MRAS)

MRAS + NARWC 2017 data



MRAS in 2015: just starting to figure out where the right whales were *
MRAS in 2017: field season ended before discovery curve leveled off, effort was spread out spatially in the GSL, and the aircraft was often used for carcass relocation (many two flight days)

1. Population structure | b. Demography

Mark-recapture aerial surveys

AgeClass	F	M	X
2015: 35 individuals			
A	8 (23%)	18 (51%)	0
J	1 (3%)	3 (9%)	0
C	3 (9%)	1 (3%)	1 (3%)
2017: 109			
A	28 (26%)	55 (50%)	0
J	12 (11%)	10 (9%)	2 (2%)
U	0	0	2 (2%)
2018: 131			
A	36 (27%)	66 (50%)	2 (2%)
J	8 (6%)	13 (10%)	3 (2%)
U	0	0	3 (2%)
2019: 132			
A	36 (27%)	68 (52%)	3 (2%)
J	7 (5%)	10 (8%)	1 (1%)
U	0	0	3 (2%)
C	0	0	4 (3%)
***Catalog 2018: 462**			
A	145 (31%)	227 (49%)	17 (4%)
J	29 (6%)	35 (8%)	4 (< 1%)
U	2 (< 1%)	0	3 (< 1%)

- Similar proportions of sex and age classes between years and between datasets

- Inclusion of all available sightings in 2017 brings the total # of observed individuals to similar levels observed in years with longer MRAS effort.

Mark-recapture aerial surveys + NARWC 2017 data

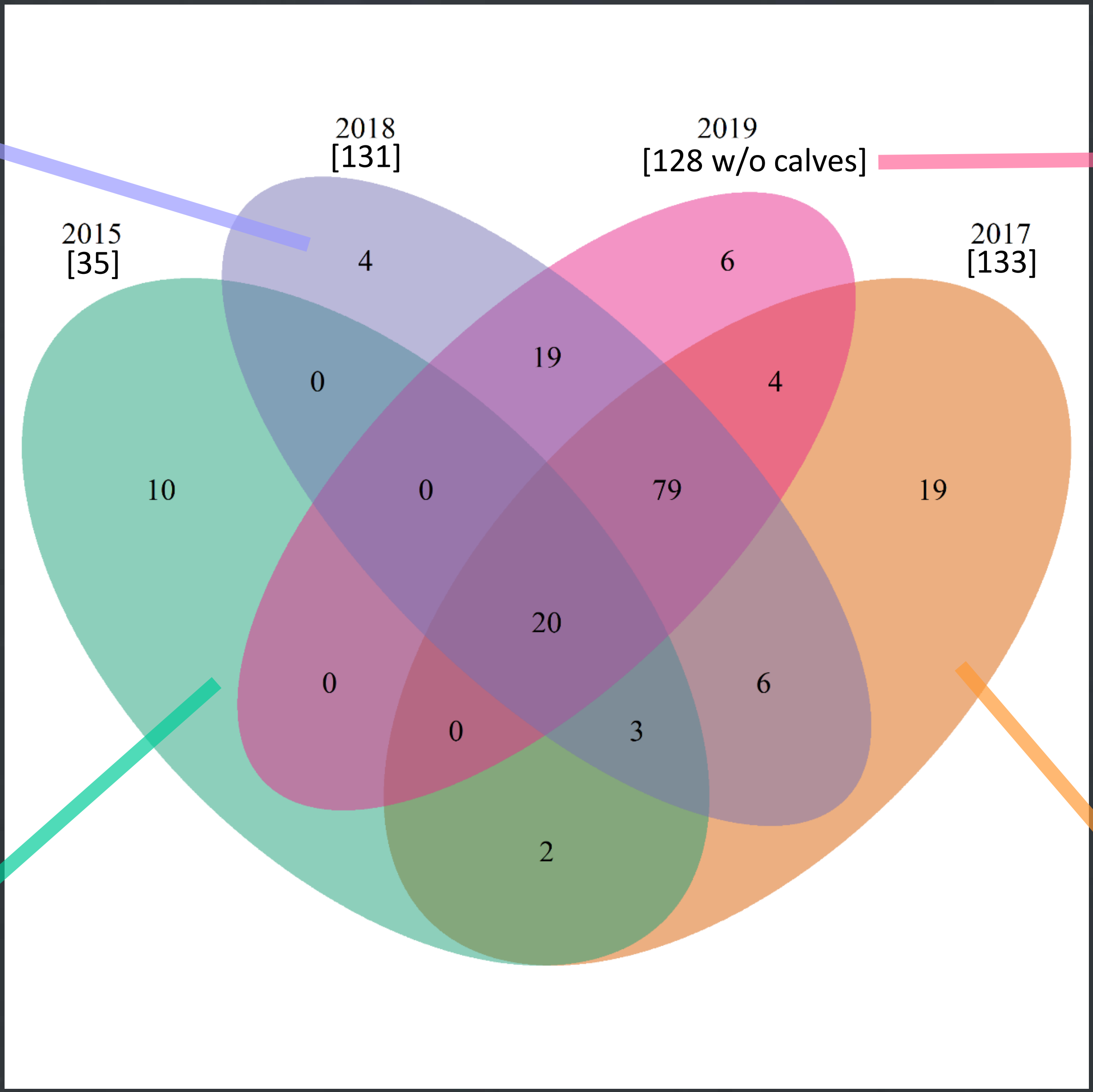
2017 MRAS (109) + NARWC only (24): 133			
A	34 (26%)	68 (51%)	0
J	14 (11%)	13 (10%)	2 (2%)
U	0	0	2 (2%)

*

*Hamilton et al. 2019 NARWC Oral Presentation

1. Population structure | c. Inter-annual Return

1 confirmed dead



95% seen before

Includes 6 that died in June

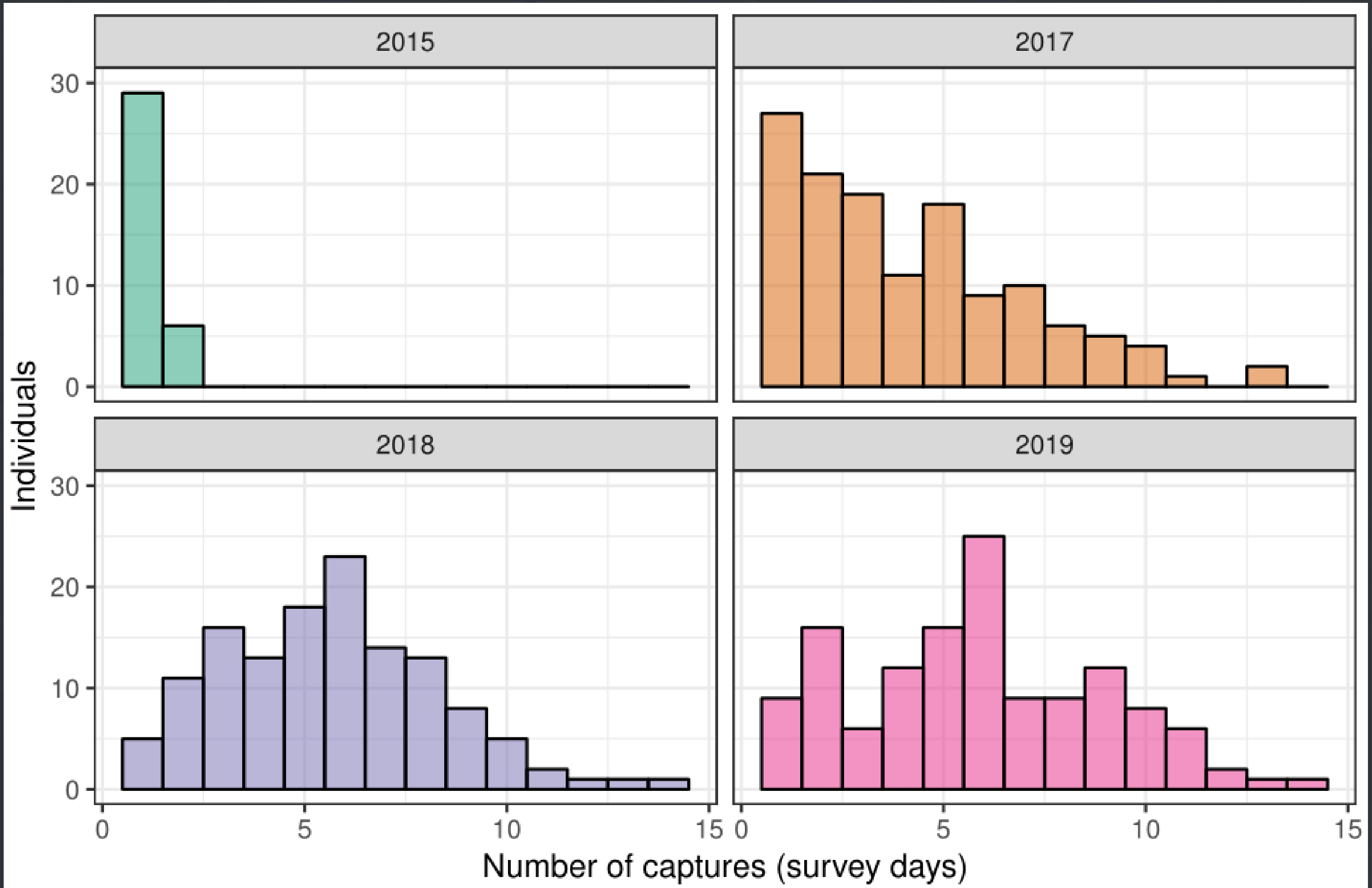
- Not all known dead in 2019 captured by us

15 of the 44 not seen in 2019 are confirmed dead

1 confirmed dead
1 in calf year only

11 confirmed dead

2. Capture rates



Survey days captured:

1 – 14

Average:

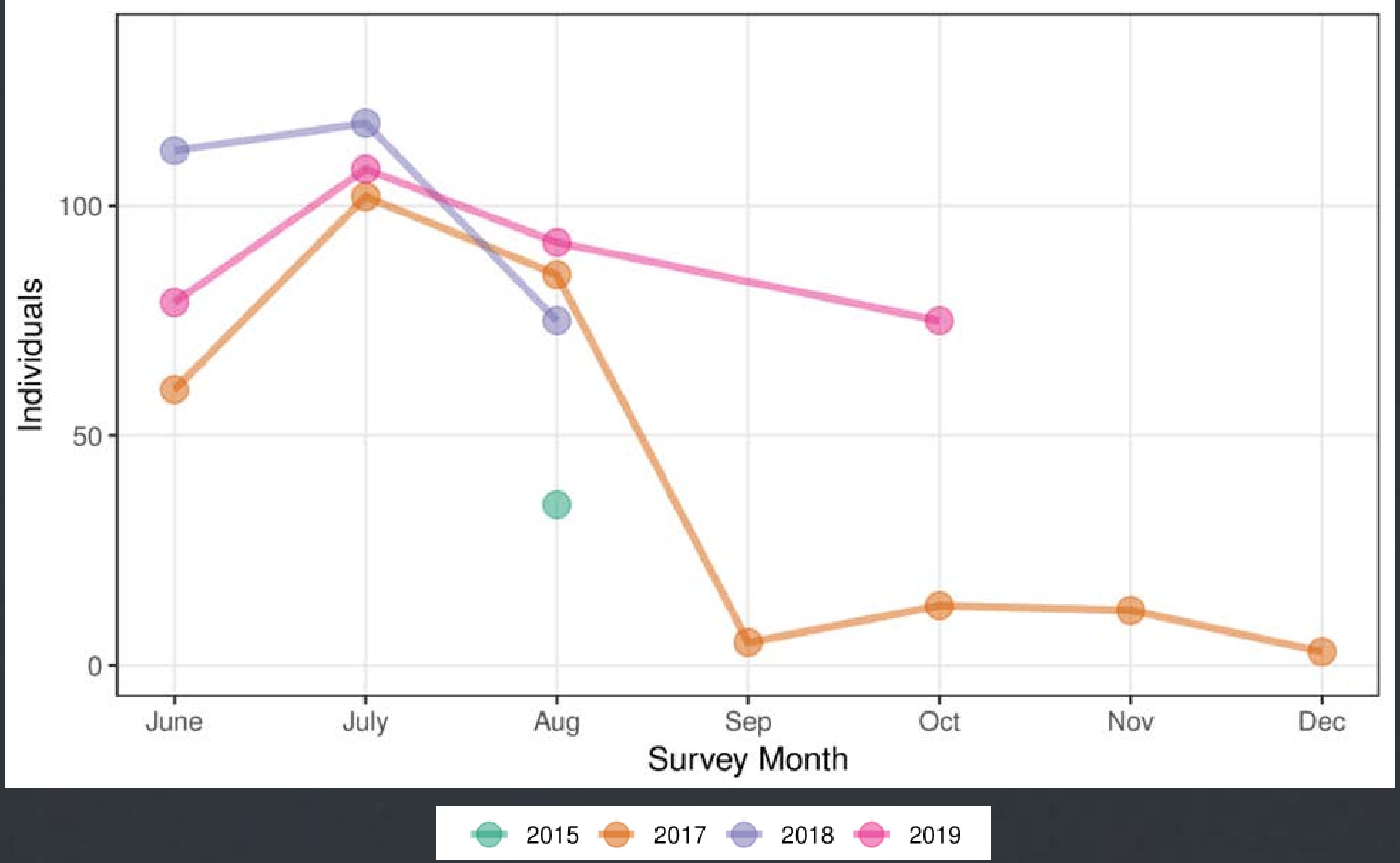
2017 = 4.2 (SD = 2.8)

2018 = 5.7 (SD = 2.7)

2019 = 5.9 (SD = 3.0)

Year	Max Captures	EGNO	AgeClass	Sex
2017	13	3942	J	F
2017	13	3442	A	M
2018	14	3317	A	F
2019	14	4617	J	F

3. “Residency”



Time between initial and final sighting (NARWC 2017):

2 – 163 days

Average = 53.3 days (SD = 41.8)

20 individuals >= 100 days

4. Abundance Estimates | MRAS 2017 vs. NARWC 2017

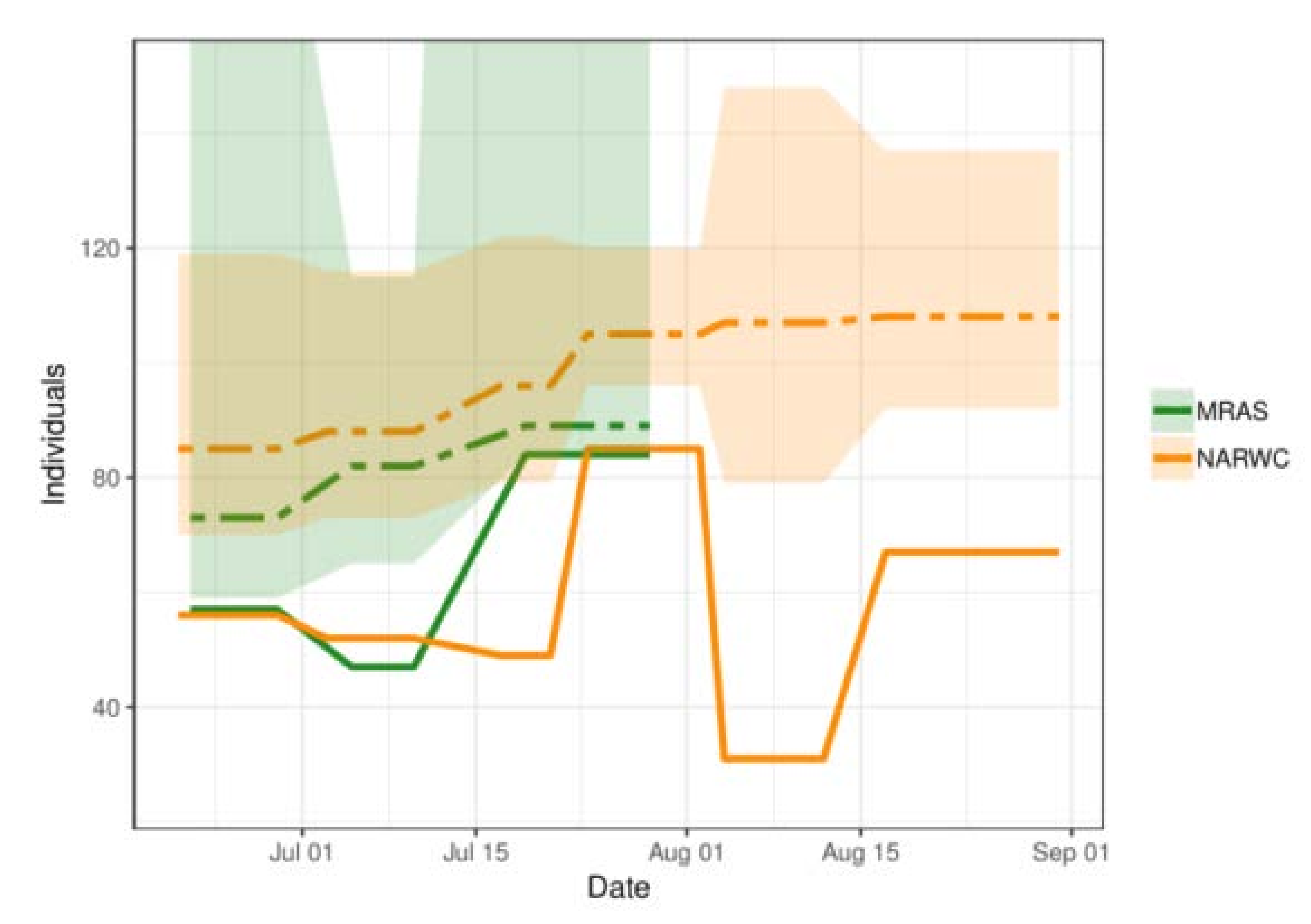
Jolly Seber

Model	Formula
Time-varying capture	$\phi(.)$ p(t) pent(.)

ϕ = survival probability, p = capture probability, pent = probability of entry, t = time

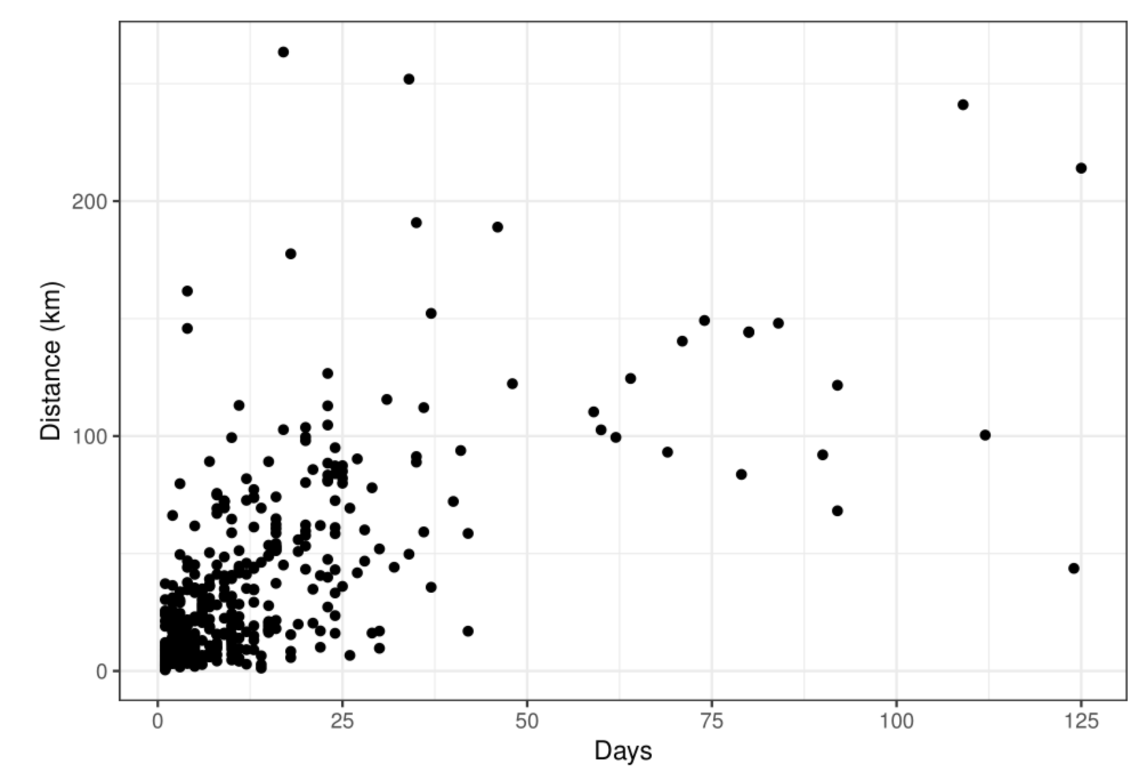
Only including sightings 21 June – 31 August when there was the most dedicated effort

Dotted = estimated
Solid = observed



- CI for MRAS estimates are off the chart (Block 1 = 197, Block 3 = 560)
- Adding more data decreases CI
- Abundance estimates between datasets are not too different

5. Movement | NARWC 2017 data

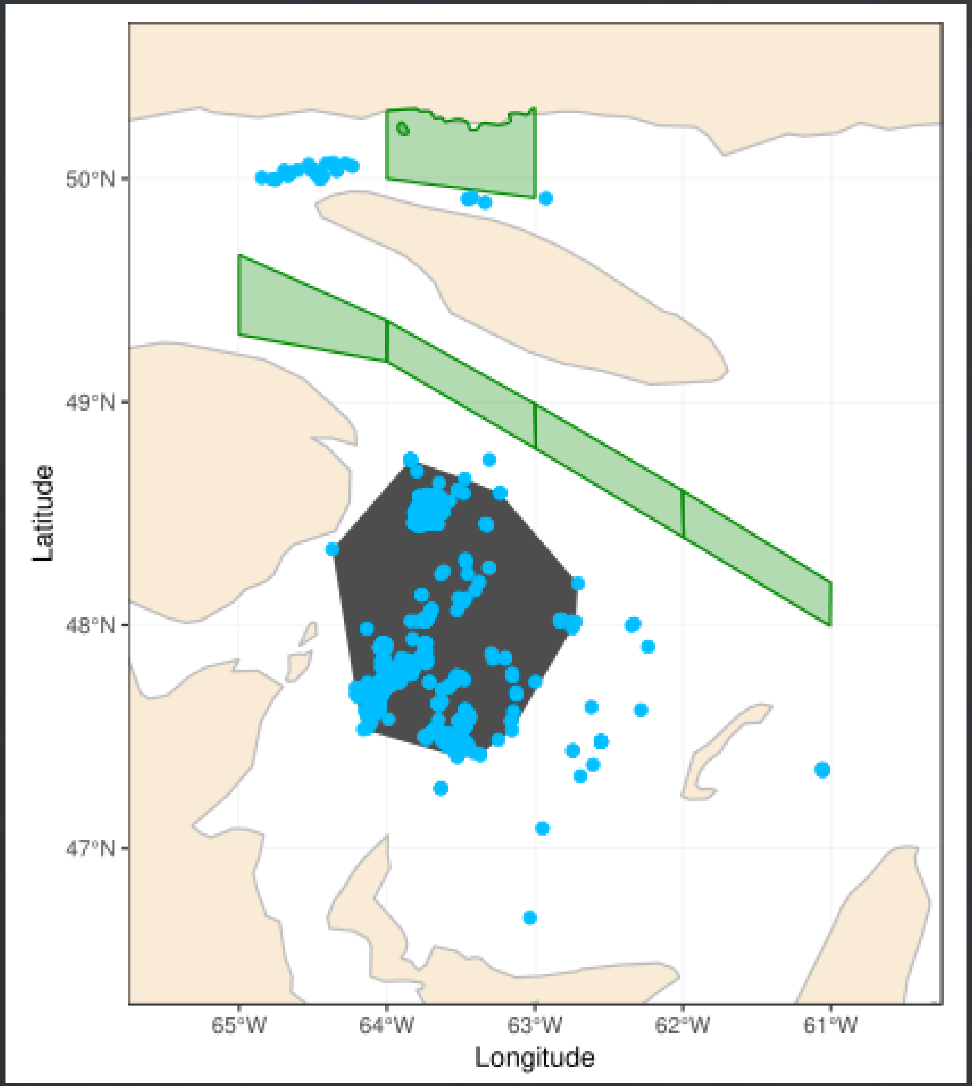


<u>Distance between sightings per day:</u>

0.1 – 40.4 km

Average = 4.6 km (SD = 5.2)

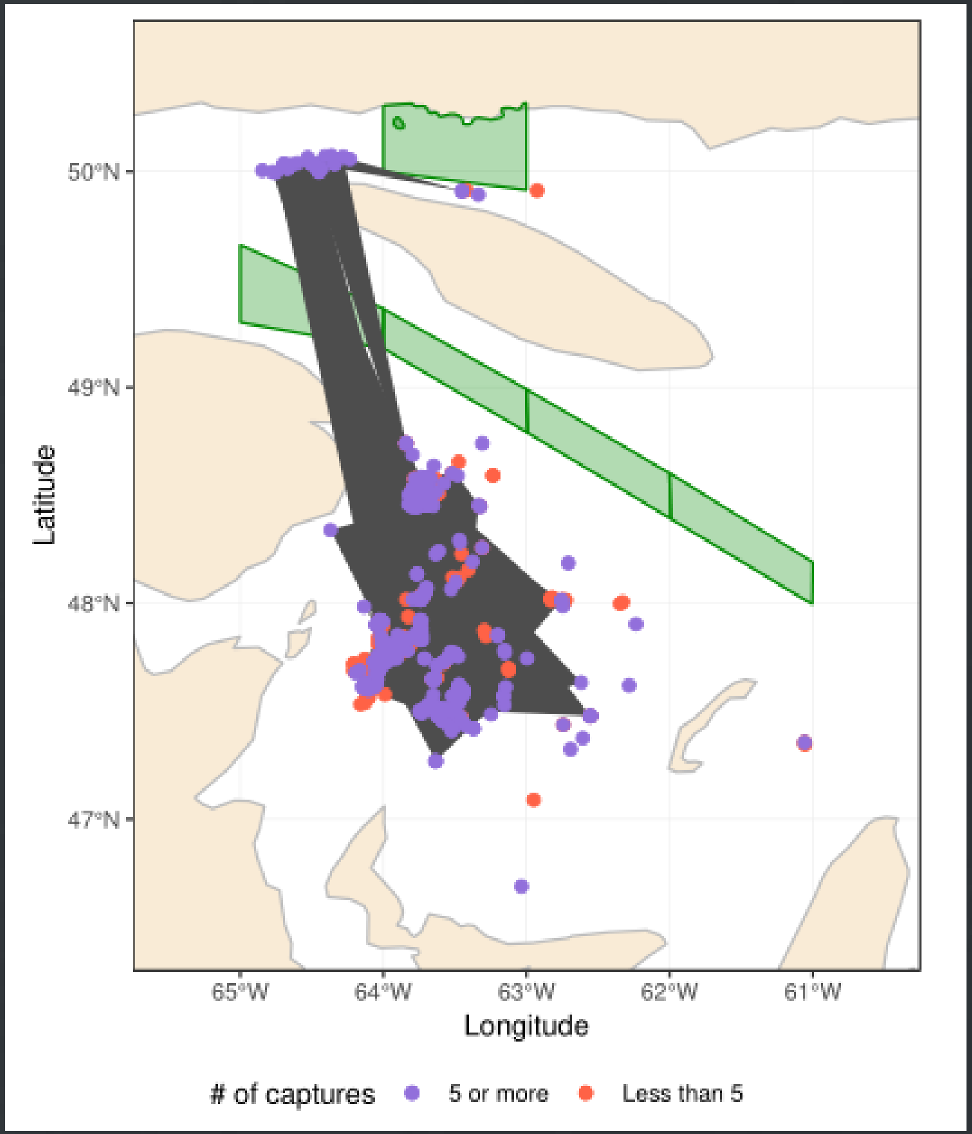
5. Movement | NARWC 2017 data



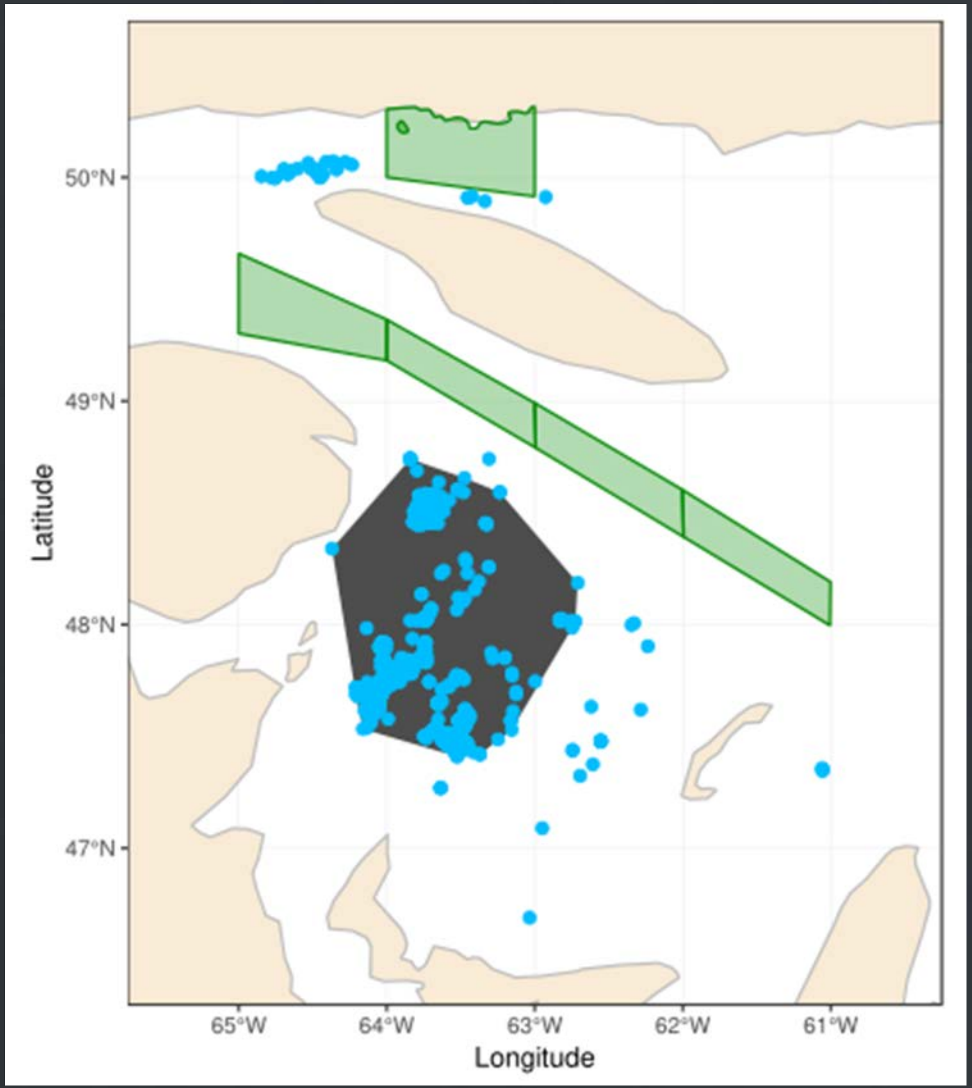
90% Minimum Convex Polygon Analysis

All sightings regardless of ID

Considering ID of animals sighted on 5+ days



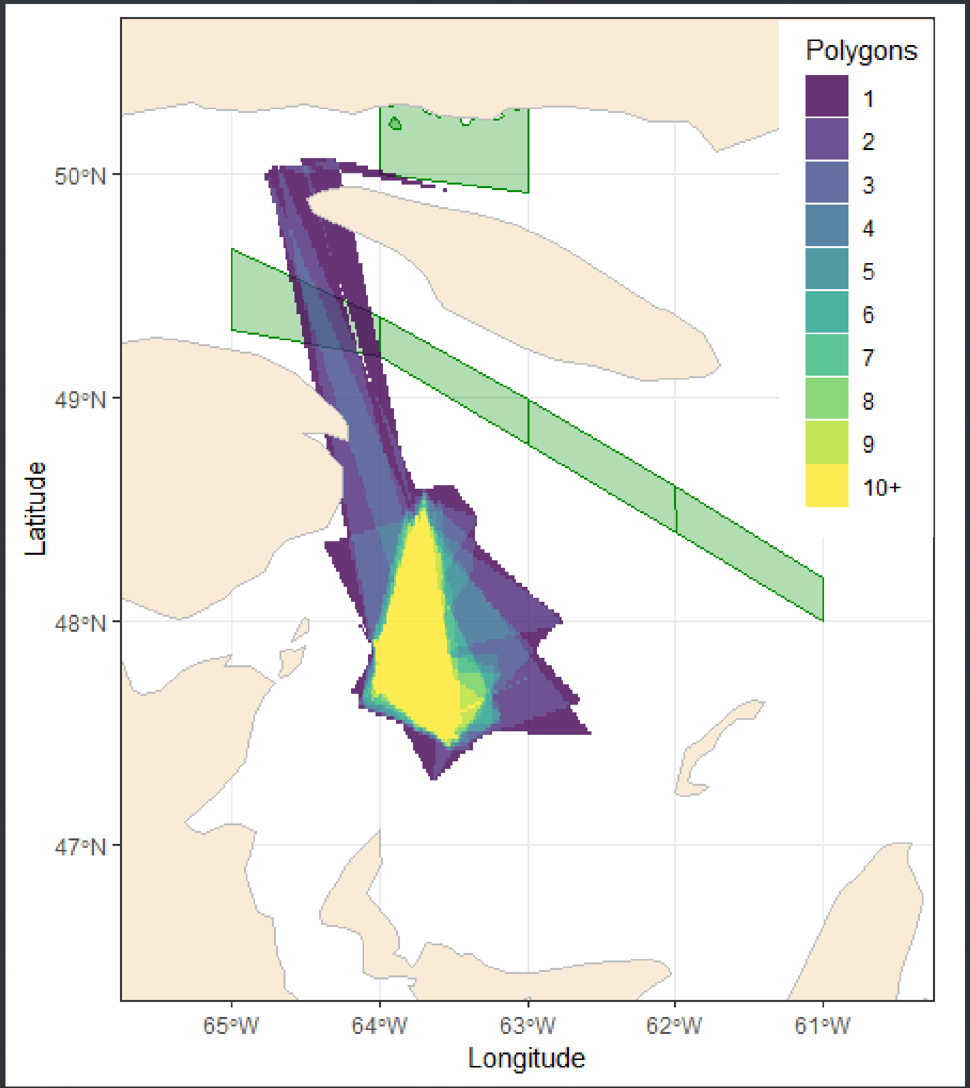
5. Movement | NARWC 2017 data



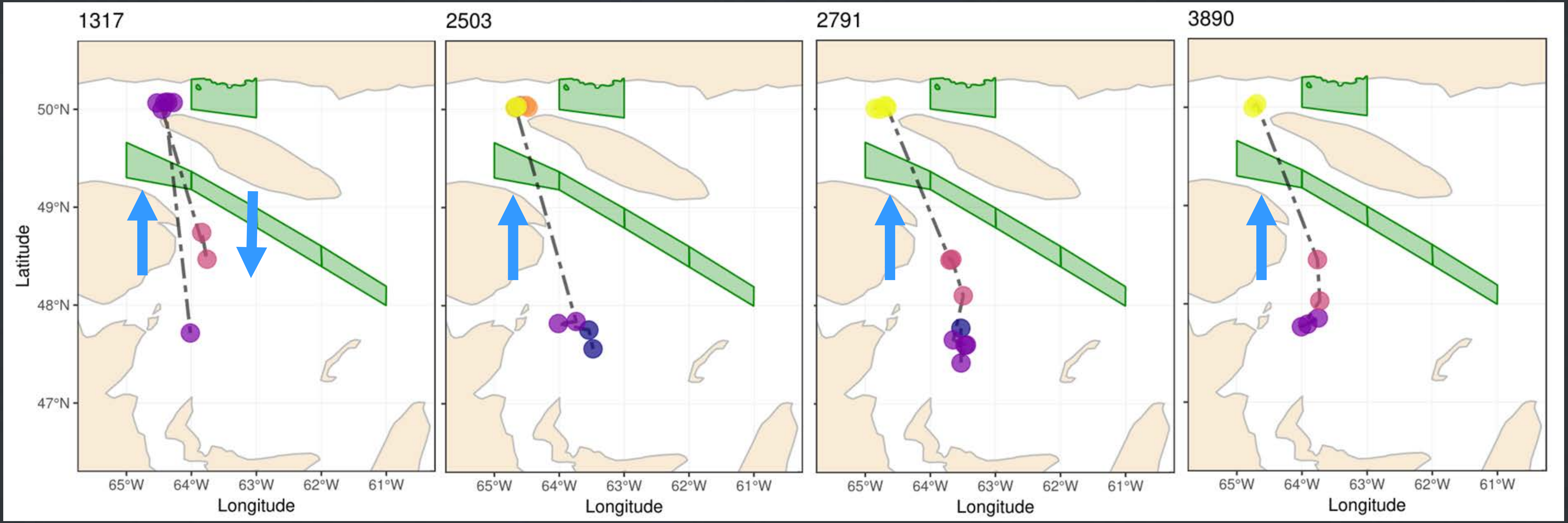
90% Minimum Convex Polygon Analysis

All sightings regardless of ID

Considering ID of animals sighted on 5+ days



5. Movement | NARWC 2017 data



EGNO	Sex	AgeClass
1317	M	A
2503	F	A
2791	F	A
3890	F	A

Seen only off Anticosti

	Demography			Month				
EGNO	Sex	Age	AgeClass	7	8	9	10	11
1281	F	36	A	-	-	1	1	-
3810	M	9	A	1	1	3	1	1
4042	M	8	J	2	4	1	-	-

GOALS: 1. Provide better insight into right whale use of the GSL

2. Evaluate effectiveness of M/R survey methods

1. Population structure:
   a. Approx. <u>ONE THIRD</u> of North Atlantic right whales go to the GSL
   b. Demography similar to entire population
   c. High rate of inter-annual return
2. Capture Rate: Varies between individuals
3. "Residency": 1.8 – 5.5+ months within June– Dec
4. 2017 Abundance estimates: estimates from M/R effort similar to overall NARWC data estimates
4. Movement: Staying close, going far, and across shipping zones

M/R methods allow us to look at these details and we seem to be capturing most of the individuals -- we look forward to the 2018 NARWC data.

<u>Acknowledgements</u>: The NARWC and the North Atlantic Right Whale Catalog/NEAq, particularly these contributors: the Canadian Coast Guard, DFO Conservation & Protection, Daisy Holmes and Biorex, Jack Lawson and the DFO North Atlantic Fisheries Centre, Marine Animal Response Society, Martin Noël, Mingan Island Cetacean Study, Parks Canada, Phillippe Poirier, Steve Cloutier, Transport Canada, and the University of PEI. The movement data between the southern Gulf and Anticosti would not have been possible without data from Christian Ramp and the Mingan Island Cetacean Society. Additionally, we thank observers/matchers Allison Henry, Marjorie Foster, Jen Jakush, Hannah Mark, and Delphine Durette Morin.

Supplementary materials for the 2019 North Atlantic Right Whale Consortium Oral Presentation:

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Slide 2

GSL = Gulf of St. Lawrence
M/R = mark-recapture

Mark-recapture aerial surveys (MRAS):
2015 = Collaboration between the National Oceanic and Atmopheric Administration (NOAA), Canadian Whale Institute, Dalhousie University, and the Department of Fisheries and Oceans Canada (DFO)
2016 = funding precluded MRAS surveys in the GSL
2017 − 2019 = Collaboration between NOAA and DFO

North Atlantic Right Whale Consortium (NARWC) data:
2017 = all photo sightings of individual right whales in the NARWC Database (includes MRAS data). We looked at comprehensive data from 2017 because there was more dedicated effort than in years prior, and these data were available (2018 should be available soon).

Slide 3

A total of 170 individuals were photographed from the MRAS, and 6 additional individuals were sighted when including all NARWC data from 2017.

Within the MRAS, individual right whales were photographed on 16 different survey days in 2017. Layering in all photo sightings of right whales available in the NARWC database, individuals were photographed on 60 different survey days. These data were collected by 14 organizations/sources on 23 different platforms.

Slide 4

2015 MRAS effort in the GSL was conducted on four flights in August as surveys were just starting to figure out where the right whales were.

2017 MRAS effort was unlike effort conducted in later years as the field season was scheduled only during June and July (before the discovery curve leveled off), effort was spread out spatially in the GSL to continue to understand right whale distribution, and because of the mass mortalities, the aircraft was often used for carcass relocation.

2018 and 2019 MRAS had similar effort as far as length of survey seasons, they yielded about the same number of individuals, and the discovery curve leveled out about the same time of year.

Integrating all NARWC 2017 data resulted in a similar total of photographed individuals for that year similar to the totals captured in MRAS 2018 and 2019. Looking at the figure on the right, the discovery curve for each year levels out between the middle of July and the end of August, which could be dependent on effort.

The analysis of the NARWC 2018 data will give additional insight into whether a longer survey season allowed for the capture of effectively all individuals present.

Slide 5

The demographic breakdown of individuals captured during MRAS were very similar between years, and similar to the proportions in the catalog overall. This is also true when including the NARWC 2017 data.

Very similar totals among years when integrating all NARWC data in 2017. MRAS sighted 82% of the total (NARWC) animals sighted in 2017.

Slide 6

There is a high rate of inter-annual return for individuals sighted in the GSL. The numbers reported here for 2019 exclude the 2019 calves.

Highlights: 20 of the 35 animals sighted in 2015 were sighted again in 2017, 2018, AND 2019. 99 (20 + 79) animals were sighted in 2017, 2018, AND 2019.

Individuals only seen in one year and/or not seen in 2019 include some that are known dead, but many haven't been sighted in some time. Given the high rate of inter-annual return of 74 – 77% of individuals seen each year, this may indicate some undetected mortality.

Slide 7

Males and females were sighted on every flight. Sightings of carcasses are included here on their first sighting only.

Capture rates varying between individuals – some are seen a lot, and some were seen once. In 2017, capture rates were right skewed which could be due to the high number of mortalities, but this could also have been due to the shorter duration of the MRAS effort. The individuals captured the most in each year included both males and females as well as both juveniles and adults.

Slide 8

This figure shows the number of individuals captured by month.

Excluding 2015, when there was limited effort in the region, July yielded the most individuals in the GSL at one time in 2017, 2018, and 2019.

In 2017, many efforts to spot right whales were happening September – December, but MRAS as well as vessel based mark-recapture efforts designed to photograph individuals for ID did not continue after August. In 2019, the MRAS were able to occur in October and captured 75 individuals present within about a two week period. The difference in animals captured between October 2017 and October 2019 is likely due to effort and not due to changes in "residency".

"Residency" = time between initial and final sighting in the GSL. It is not necessarily true that animals stay in the GSL the entire time, but we don't currently have evidence of animals leaving the GSL and coming back within the year.

Looking only at NARWC 2017 data, average "residency" is 1.8 months. It is possible that some leave and come back OR they are there the whole time moving around a lot OR both. It doesn't take much movement (vertically or horizontally) to get out of our field of view in a survey day.

Slide 9

Abundance estimates were calculated to compare the 2017 MRAS data to the NARWC 2017 data overall to assess how well the MRAS data represents the best available data. Only captures occurring between 21 June and 31 August 2017 were included here because this was when the mark-recapture surveys were occurring. Eight models were tested and the model with time-varying capture fit each dataset best. The general trend of the estimated abundance between datasets was similar, but the confidence intervals decreased within the NARWC dataset. Overall, the MRAS captured most of the individuals within each period that were included in the NARWC data, so the abundance estimates were not that different comparatively. Only the first sighting of each individual carcass within each dataset was included here, and this caused some differences in the number of observed animals between datasets.

Table 1: MRAS 2017 Jolly Seber Model AIC

Model	Formula	AIC	ΔAIC
Time-varying capture	ϕ(.) p(t) pent(.)	193.77	0.00
Time-varying probability of capture and entry	ϕ(.) p(t) pent(t)	195.18	1.41
Time-varying probability of capture and survival	ϕ(t) p(t) pent(.)	195.60	1.83
Time-varying probability of capture, survival, and entry	ϕ(t) p(t) pent(t)	196.97	3.20
Time-varying probability of survival and entry	ϕ(t) p(.) pent(t)	201.65	7.88
Time-varying probability of entry	ϕ(.) p(.) pent(t)	203.68	9.91
Time-varying survival	ϕ(t) p(.) pent(.)	204.13	10.36
Base 2017	ϕ(.) p(.) pent(.)	207.74	13.97

Note:
ϕ = survival probability, p = capture probability, pent = probability of entry, t = time

Table 2: MRAS 2017 Jolly Seber Block Abundance Estimates

MRAS 2017							
Block	Dates	Observed	Estimated	Lower	Upper	p	SE
1	June 22 – 29	57	73	59	197	0.78	0.19
2	July 05 – 10	47	82	65	115	0.57	0.08
3	July 19 – 29	84	89	84	560	0.94	0.12

Table 3: NARWC 2017 Jolly Seber Model AIC

Model	Formula	AIC	ΔAIC
Time-varying capture	$\phi(.)$ p(t) pent(.)	616.28	0.00
Time-varying probability of capture and entry	$\phi(.)$ p(t) pent(t)	616.63	0.35
Time-varying probability of capture, survival, and entry	$\phi(t)$ p(t) pent(t)	618.02	1.74
Time-varying probability of capture and survival	$\phi(t)$ p(t) pent(.)	618.89	2.61
Time-varying probability of survival and entry	$\phi(t)$ p(.) pent(t)	647.43	31.15
Time-varying survival	$\phi(t)$ p(.) pent(.)	657.15	40.87
Time-varying probability of entry	$\phi(.)$ p(.) pent(t)	658.35	42.07
Base 2017	$\phi(.)$ p(.) pent(.)	667.67	51.39

Note:
ϕ = survival probability, p = capture probability, pent = probability of entry, t = time

Table 4: NARWC 2017 Jolly Seber Block Abundance Estimates

NARWC 2017							
Block	Dates	Observed	Estimated	Lower	Upper	p	SE
1	June 21 – 29	56	85	70	119	0.66	0.09
2	July 03 – 10	52	88	73	116	0.59	0.07
3	July 17 – 21	49	96	79	122	0.51	0.06
4	July 24 – Aug 02	85	105	96	120	0.81	0.05
5	Aug 04 – 12	31	107	79	148	0.29	0.05
6	Aug 17 – 31	67	108	92	137	0.62	0.06

Slide 10

From survey to survey, the same exact animals were not captured as there was turnover within our field of view. Distance between sightings per day can be minimal, or it can be a lot. The figure shows actual data of distance and time between successive sightings. PLEASE NOTE: These are the shortest distances between points, and animals are not exclusively tracking in straight lines.

Slide 11

Green polygons are 2019 dynamic shipping section scheme.

These figures only include photo-ID sightings for comparison, but it should be noted that there were many sightings of right whales in 2017 in the GSL where individuals were not photographed or at least not photographed well enough for photo-ID. The figure on the left is the 90% minimum convex polygon (MCP) analysis regardless of ID – this is the smallest polygon that encompasses 90% of points where animals were photographed. The figure on the right is the 90% MCP for each individual with 5 or more sightings (MCP analysis for individuals requires at least 5 sightings). When an animal's ID is considered, you get more information regarding their movement.

Slide 12

Green polygons are 2019 dynamic shipping section scheme.

The figure on the left is the 90% MCP analysis regardless of ID from the previous slide. The figure on the right is the density of the overlap of the 90% MCP for each individual with 5 or more sightings (MCP analysis for individuals requires at least 5 sightings). Most individual movement is captured within the Orpheline Trough region which is where most of the MRAS effort was focused, but there is a signal between the Orpheline Trough and Anticosti. This signal is not necessarily the route they are taking, but it is the most direct route. It is possible that they may go around the east side of Anticosti, but this would still require crossing shipping zones. The density of polygon overlap was analyzed within a one minute by one minute raster grid.

Slide 13

THESE ARE NOT REAL ANIMAL MOVEMENTS. THE DASHED LINES CONNECT A TIME SERIES OF SIGHTINGS. The blue arrows indicate the trajectory of the direction the animal was moving across the shipping zone.

Animals seen both in the Orpheline Trough and off Anticosti in 2017 were all adults including one male and three females. Both EGNO 2503 (Boomerang) and EGNO 2791 are reproductive females that brought their calves to the GSL in 2019. Animals moved across shipping lanes in both directions between July and October.

In 2017, three animals were only sighted off of Anticosti: EGNO 1281 (Punctuation) was seen in the southern GSL in 2019 alive and subsequently dead, EGNO 3810 has yet to be seen on a MRAS flight in the southern GSL, and EGNO 4042 was sighted in the southern GSL in 2018 and 2019. These animals could have also gone to the southern Gulf in 2017 undetected, or not.

Slide 14

The other two thirds could be aggregating somewhere else, perhaps somewhere that isn't prepared to manage for their presence. Additionally, the other two thirds could be dispersed throughout their range, making them more difficult to detect visually. Comprehensive M/R work in each month from ice out to ice in could give a better idea of right whale presence and individual residency throughout the entire season.

R Packages Used

adehabitatHR, data.table, dplyr, EasyMARK, ggplot2, ggpubr, kableExtra, knitr, lubridate, marked, pastecs, raster, R2ucare, Rcapture, RColorBrewer, rgdal, rlist, tidyr, scales, VennDiagram, viridis, and viridisLite

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