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North Atlantic right whale abundance, demography and residency in the southern Gulf of St. Lawrence derived from directed aerial surveys

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

During summer 2015, 2017 and 2018, we used aerial photo-identification to obtain estimates of stock size, abundance and residency time of North Atlantic right whales (*Eubalaena glacialis*) in the southern Gulf of St. Lawrence (GSL). Flights were made on four days in 2015, 15 days in 2017 and 26 days in 2018. Preliminary matching to the North Atlantic Right Whale Catalog identified a total of 153 individuals, of which 144 were matched to cataloged individuals and of the nine that were not, four were calves from the previous year. The proportions of sex and age classes we saw in the GSL did not differ substantially from the North Atlantic population as a whole. Based on recognized individuals of known sex, adult males comprised 48.6–55.9% of the individuals seen each year, adult females 23.5–28.2%, juvenile males 8.4–12.4%, and juvenile females 4.6–9.5%. Mark-recapture techniques applied to the photographic capture of individuals in the study area during 2017 and 2018 resulted in abundance estimates of 111 and 132 whales, respectively, with few individuals undetected and apparent extended residency of individuals.

INTRODUCTION

North Atlantic right whales (*Eubalaena glacialis*) were extirpated from the eastern Atlantic Ocean by centuries of whaling (National Marine Fisheries Service 2005), but a remnant population continues to occur along the east coast of Canada and the United States. A recent estimate of approximately 458 whales in 2015 (Pace et al. 2017) places this species among the most endangered whale species in the world. The population has grown slowly since monitoring began in the early 1980s (Pace et al. 2017). However, changes in the right whales' occupancy of coastal regions since 2010 (Davis et al. 2018) have been accompanied by an increase in mortality and a decrease in calf production (Corkeron et al. 2018). The net result is that the population is now in decline (Pace et al. 2017). Between 1970 and 2009, 80% (70 of 87) of examined right whale carcasses found the proximate cause of death to be anthropogenic, either from entanglement in fixed fishing gear or collision with vessels (van der Hoop et al. 2013). Identifying where and when right whales overlap with these threats is therefore critical to the species' conservation.

In the spring of 2013, few right whales were seen by the National Oceanic and Atmospheric Administration (NOAA) aerial surveys for right whales in the Gulf of Maine's Great South Channel, a significant change for a habitat that used to see a large proportion of the right whale population each year (Khan et al. 2014). This prompted the NOAA right whale aerial survey program to check other potential habitats, including the Scotian Shelf and Gulf of St. Lawrence (GSL) (Cole & Henry 2015, Cole et al. 2016). Following the discovery of a large number of right whales in offshore waters of the GSL in 2015, the NOAA survey team returned to the region in 2017 and 2018 to further assess this component of the population.

In this paper we present the results of the NOAA photo-identification efforts during three summers and examine right whale stock size, residency, capture heterogeneity, and abundance in the southern GSL.

MATERIALS AND METHODS

DATA COLLECTION

Our primary study area in the southern GSL was within 47°00' N and 49°00' N between 062°00' W and 065°00' W. Our surveys were flown at 185 km/h and 305 m altitude in a de Havilland DHC-6 Twin Otter equipped with an auxiliary fuel tank to provide 5–6 h endurance. Surveys were typically flown with two primary observers stationed at large bubble windows on either side of the plane, a data recorder, and an auxiliary observer at a small window towards the rear of the cabin. Environmental conditions including sea state, cloud cover, visibility, and overall quality of sighting conditions for visually detecting large whales were recorded while on effort during both systematic surveys, and transits to and from offshore study areas. Surveys were flown in areas and during periods of good visibility (at least >3.7 km) and low winds (preferably <5 m/s). We looked for and recorded only large whale sightings, i.e., anything larger than a North Atlantic minke whale (*Balaenoptera acutorostrata*). When a whale was sighted, we measured its declination from the plane using vertically spaced hatch marks on the bubble windows as it passed perpendicular to our flight path. If the sighting was of a right whale, we broke from the trackline and flew over it to obtain overhead images of the whale's callosity pattern for individual identification. If more right whales were seen in the area, we would continue to circle until we had obtained images of all the individuals we could find, and then resumed our flight path and survey coverage.

PHOTOGRAPHIC IDENTIFICATION

Right whales have irregular cornified skin eruptions on their heads called callosities. The patterns of these callosities are unique to each individual and stable through time (Kraus et al. 1986). Colonization of the callosities by light colored cyamids—a commensal amphipod—highlight the whales' callosity patterns and make them visible from an airplane. The images we collected of right whale callosity patterns were compared to the North Atlantic Right Whale Catalog, a repository of images of every individual right whale photographed by a consortium of survey teams and organizations working throughout the right whales' range since 1980. The Catalog also contains the sighting histories and, in many cases, the sex, age and genealogy of individuals. Right whales are considered adults at primiparity or once they are 9 years old.

The demographic data from the Catalog was used to compile the proportions of sex and age class of whales present in the GSL. We compared these proportions to those of the entire North Atlantic population, as recorded in the Catalog at the end of 2017 (Hamilton, pers. comm).

We defined the stock size for the southern GSL as the total number of unique individuals identified from images collected over the three summers of aerial survey effort. A discovery curve was created to assess our progress in capturing all of the individuals in the study area.

MARK-RECAPTURE ANALYSES

Mark-recapture photographic data collected in 2017 and 2018 allowed for the analysis of residency, capture heterogeneity, and abundance. We defined residency in the GSL as the number of days between an individual's first and last photographic capture within each survey year. Individuals captured on only one survey in a year were excluded. To assess heterogeneity of capture, the time between subsequent sightings of an individual within years was calculated and rounded to the nearest day for all individuals seen on more than one survey day. If an individual was sighted more than once on a survey day, the first sighting was retained. Additionally, the number of survey days an individual was captured was compiled within each year.

We defined abundance as the number of whales present in the study area at any given time during our surveys. To calculate right whale abundance, the study periods were divided into sampling blocks according to natural breaks in the survey timeline. This resulted in the following three blocks in 2017: June 23–29, July 5–10, and July 19–29. There were five time blocks for 2018: June 4–17, June 26–July 7, July 11–21, July 27–August 3, and August 6–12. Using an open Jolly-Seber model in the mra R package (Amstrup et al. 2005), for both years, we compared multiple mark-recapture models, run using maximum likelihood. These were:

1) a base model (constant probabilities of capture, survival, and probabilities of entering the study population);

2) a model with the probability of capture varying with time;

3) a model varying probability of survival over time;

4) one varying probability of entry over time, and varying probabilities of both capture and survival; and

5) one varying both probabilities of capture and entry.

RESULTS

SURVEY EFFORT

In 2015, we made four flights on four days in August totaling 11 h effort in the southern GSL study area (Figure 1). These surveys were directed to the western side of the southern GSL following the advice of experts. This area has oceanographic and bathymetric features potentially attractive to right whales, and a history of opportunistic right whale sightings in nearby coastal zones (Brown and Taggart pers. comm.). In 2017, we made 21 flights over 15 days between June 22 and July 29 totaling 75 h survey effort directed to right whale aggregations and searches for right whale carcasses in the southern GSL. During this period, we also surveyed other parts of the GSL and the Scotian Shelf to check potential right whale habitats identified by copepod energy density plots (Johnson and Plourde pers. comm.). In 2018, all our flights were directed to right whale aggregations in the southern GSL. We completed 27 flights over 26 days between June 4 and August 12 totaling 115 h effort in the study area.

STOCK SIZE AND DEMOGRAPHICS

A total of 153 individual right whales were identified from our aerial photographs taken over the three summers. Preliminary matching to the Catalog identified 144 cataloged individuals and nine additional individuals, four of which have been identified as prior years' calves that have not yet been added to the Catalog. We photographed 34 individuals in 2015, 105 in 2017, and 131 in 2018 (Table 1). Twenty individuals sighted in 2015 were sighted again in 2017, 22 from 2015 were sighted again in 2018, 94 individuals sighted in 2017 were sighted again in 2018, and 19 individuals were sighted in all three survey years. Our overall discovery rate of new individuals was high in 2015, 2017, and the beginning of 2018, but leveled off on July 19, 2018 (Figure 2a). One additional new animal was sighted on the last survey (August 12, 2018). Overall, new males were captured on the most surveys with this rate falling off on July 19, 2018, before one additional male was sighted on the last survey. The additional capture of new animals of unknown sex leveled off around the same time, on July 16, 2018. No new known females were discovered after July 05, 2018 (Figure 2b). While there was no observed influx of new, known females to this study area after July 05, males and females were sighted on every survey. Adult males comprised 48.6–55.9% of the individuals seen each year, adult females 23.5–28.2%, juvenile males 8.4–12.4%, and juvenile females 4.6–9.5% (Table 1). The proportions of sex and age class we saw in the GSL did not differ substantially from that of the North Atlantic population as a whole. Detailed sighting information is presented in the supplementary material (S2 and S3).

RESIDENCY, CAPTURE HETEROGENEITY AND ABUNDANCE

The residency times in both 2017 and 2018 ranged from one day to the duration of the survey time frames. The distribution of residency times was skewed toward the longer periods (Figure 3). In 2018, 74% of individuals were seen beyond the 36-day maximum observed in the 2017 season. The number of days between subsequent captures of individuals averaged eight calendar days in 2017 and 10 calendar days in 2018. In both 2017 and 2018, one individual was captured on only the initial and final surveys (Figure 4a). In 2017, 68% of individuals were photographed on more than one survey day, while in 2018, 96% of individuals were captured on more than one survey day (Figure 4b).

Details of the Jolly-Seber model results are presented as part of the supplementary material (S3–S7). The best-fit Jolly-Seber model, from its AIC value (S3), was one with time-varying probability of capture. The estimate of survival was high for this model (0.853), and probability of

entry into the study population was low (0.205 and moderately uncertain; SE 0.0728). Probability of capture varied substantially over the three time blocks (S4). The model estimated about six whales (n = 5.71, SE = 5.360) entered the population undetected, and the estimated abundance for 2017 was 111 (sighted n = 105 + estimated undetected n = 6).

The best-fit Jolly-Seber models, from their AIC values (S5), were the base model and the model with time-varying probability of entering the study population. Estimates of survival and probability of detection were high for both models (0.977 and 0.713 for the base model, 0.973, and 0.732 for the time-varying entry model). Probabilities of entry into the study population were low and uncertainties of the estimates were high (S6). Both models estimated about one whale entered the population undetected (base model n = 1.38, SE 1.605; time-varying entry n = 1.132, SE = 1.420; S7), and the estimated of abundance for 2018 was 132 whales (sighted n = 131 + estimated undetected n = 1).

DISCUSSION

Our whale-directed aerial surveys photographically captured 153 individual right whales in the GSL over the course of three summers. This represents slightly over a third of the North Atlantic population. The discovery curve of individuals leveled off about midway through the 2018 survey period. The intensive photographic effort in 2018 captured 131 of the 132 individuals estimated to be present in the survey area. Although the area was limited, we currently are not aware of individuals sighted in other parts of the GSL that were not captured in our survey area. This, coupled with the high rate of return of individuals from previous years, indicates that only a component of the North Atlantic population is currently using the GSL.

The demographics of the identified right whales in the GSL did not differ substantially from the North Atlantic population as a whole. The proportions of males to females and adults to juveniles seen in the GSL was similar to the Catalog's compendium of right whales still alive at the end of 2017. It is therefore unlikely that the GSL serves a particular role for a specific sex or age class, such as a nursery or mating ground.

The residency of individuals, which we defined as the number of days between an individual's first and last photographic capture within each year, was skewed toward the duration of the sampling time frames in 2017 and 2018. However, gaps in the capture of individuals extended to the duration of the sampling periods. In both 2017 and 2018, one individual was captured only on our first and last survey of the year, gaps of 36 d and 62 d, respectively. It seems likely that individuals with longer gaps in sightings moved out of our sampling area, but the distance or nature of their displacement cannot be inferred from sightings data. Anecdotally, one individual was photographed 50 km from where it had been captured the previous day. A few individuals seen in the southern GSL were also sighted by researchers in the northern GSL during the 2017 and 2018 study periods (Ramp, pers. comm.). Vanderlaan (2010) found that right whales may enter, leave and then re-enter important right whale habitats including the Bay of Fundy, Roseway Basin, Cape Cod Bay, Great South Channel, and the Gulf of Maine.

Our abundance estimates for 2017 and 2018 were 111 and 132, respectively. The Jolly-Seber model selection differed for the two years. In 2017, the selected model was one with time-varying probability of capture, whereas for 2018 the selected models included one with constant probabilities of capture, survival and entering the study population, and a model with time-varying probability of entry into the study population. In 2017, our aerial survey effort covered more area in the southern GSL than in 2018, and was divided between flights directed to right whale aggregations and searches for right whale carcasses. The apparent distribution of the right whale aggregations was also more widespread in 2017, and a group we came across 70 km east of the primary aggregation areas that year was composed of individuals that did not

appear among our captures to the west. In 2018, we spent a similar number of hours on effort but over a longer time frame, and our coverage was almost exclusively over established aggregation areas with only brief forays to check the areas where we had groups in 2017.

There was heterogeneity in capture rates between individuals, potentially biasing our abundance estimates. In 2017, individuals were most commonly captured only once, but most individuals were captured multiple days. One individual was photographed on 10 different days. In 2018, the capture frequency of individuals had a normal distribution with individuals most commonly captured on six days and a maximum of 14 different days.

CONCLUDING REMARKS

This study does not represent the entire scope of right whale presence in the southern GSL, but the findings here suggest movement in and out of this region throughout the summer, capture heterogeneity of individuals, and a high rate of return between seasons.

ACKNOWLEDGEMENTS

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REFERENCES CITED

Amstrup, S.C., McDonald, T.L., and Manly, B.F.J. 2005. Handbook of Capture-Recapture Analysis. Princeton University Press.

Cole, T.V.N., Henry, A.G. 2015. Scotian Shelf Right Whale Aerial Survey Project July 18-30, 2014. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 15-09; 8 p. doi: 10.7289/V5MK69VR

Cole, T.V.N., Duley, P., Foster, M., Henry, A., Morin, D.D. 2016. 2015 Right Whale aerial surveys of the Scotian Shelf and Gulf of St. Lawrence. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 16-02; 9 p.

Davis, G.E., Baumgartner, M. F., Bonnell, J. M., Bell, J., Berchok, C., Bort Thornton, J., Brault, S., Buchanan, G., Charif, R. A., Cholewiak, D., Clark, C. W., Corkeron, P., Delarue, J., Dudzinski, K., Hatch, L., Hildebrand, J., Hodge, L., Klinck, H., Kraus, S., Martin, B., Mellinger, D., Moors-Murphy, H., Nieukirk, S., Nowacek, D., Parks, S., Read, A., Rice, A., Risch, D., Širović, A., Soldevilla, M., Stafford, K., Stanistreet, J., Summers, E., Todd, S., Warde, A., and Van Parijs, S. 2017. Long-term passive acoustic recordings track the changing distribution of North Atlantic right whales (*Eubalaena glacialis*) from 2004 to 2014. Scientific Reports volume 7, Article number: 13460.

Kraus, S.D., Moore, K.E., Price, C.A., Crone, M.J., Watkins, W.A., Winn, H.E., and Prescott, J.H. 1986. The use of photographs to identify individual North Atlantic right whales (*Eubalaena glacialis*). In: Brownell RL, Best PB, Prescott JH (eds) Right whales: past and present status. IWC, Cambridge, p 145−151.

Khan, C., Duley, P., Henry, A., Gatzke, J., and Cole, T.V.N. 2014. North Atlantic Right Whale Sighting Survey (NARWSS) and Right Whale Sighting Advisory System (RWSAS) 2013 Results Summary. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 14-11; 10 p. doi: 10.7289/V5PN93MK.

National Marine Fisheries Service. 2005. Recovery Plan for the North Atlantic Right Whale (*Eubalaena glacialis*). National Marine Fisheries Service, Silver Spring, MD. 137 p.

van der Hoop, J.M., Moore, M.J., Barco, S.G., Cole, T.V.N, Daoust, P., Henry, A.G., McAlpine, D.F., McLellan, W.A., Wimmer, T., and Solow, A.R. 2013. Assessment of Management to Mitigate Anthropogenic Effects on Large Whales. Conservation Biology, 27: 121-133. doi:10.1111/j.1523-1739.2012.01934.

Vanderlaan, A.S.M., 2010. Estimating Risk to the North Atlantic right whale (*Eubalaena glacialis*) From Ocean-going Vessels and Fishing Gear. PhD Thesis, Dalhousie University, Halifax, NS Canada (176p.).

Table 1. Demographic composition of right whales photographed in the southern Gulf of St. Lawrence. from NOAA aerial surveys 2015, 2017 and 2018 as well as the proportions of each age and sex class in the North Atlantic Right Whale Catalog as of the end of 2017 (Hamilton, pers. comm.). Right whales are considered adults at primiparity or once they are 9 years old.

Age/Sex	2015 Count	2015 %	2017 Count	2017 %	2018 Count	2018 %	Catalog %
Adult Male	19	55.9	51	48.6	65	49.6	47.3
Adult Female	8	23.5	26	24.8	37	28.2	28.8
Juvenile Male	3	8.8	13	12.4	11	8.4	8.4
Juvenile Female	3	8.8	10	9.5	6	4.6	8.8
Unknown Age & Sex	1	2.9	2	1.9	5	3.8	1.5
Adult Unknown Sex	0	0	0	0	4	3.1	3.7
Juvenile Unknown Sex	0	0	2	1.9	2	1.5	0.6
Unknown Aged Female	0	0	1	1	1	0.8	0.9
Total	34		105		131		

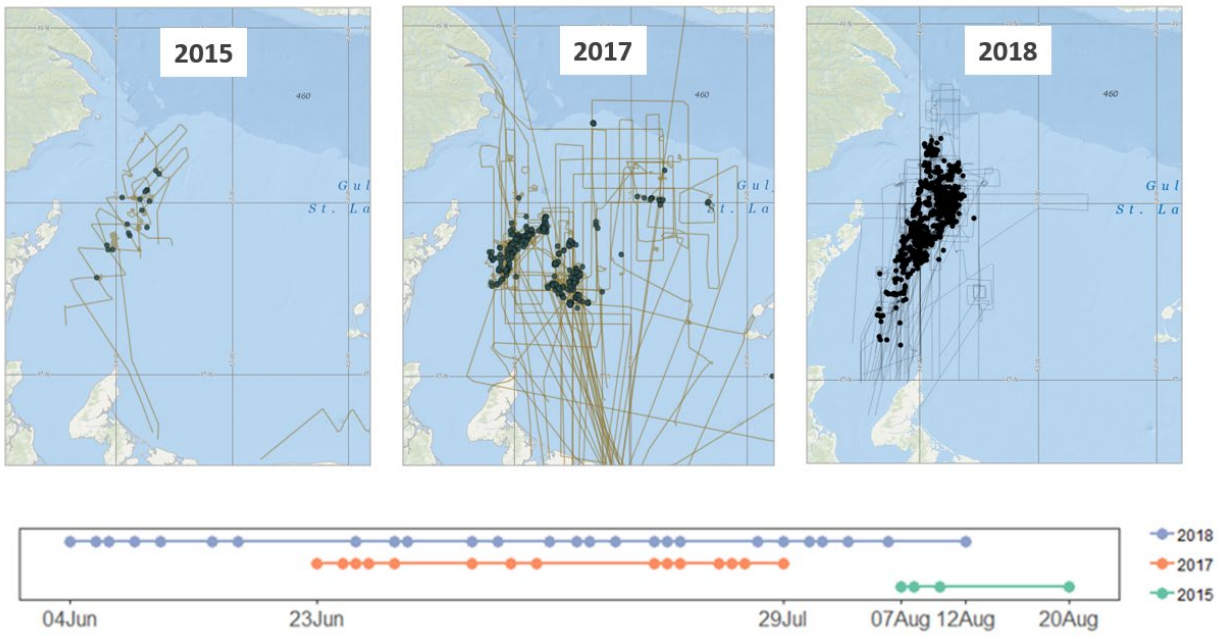


Figure 1. Distribution of NOAA aerial survey effort for 2015, 2017 and 2018 in space and time. Dots on the timeline are the dates of flights.

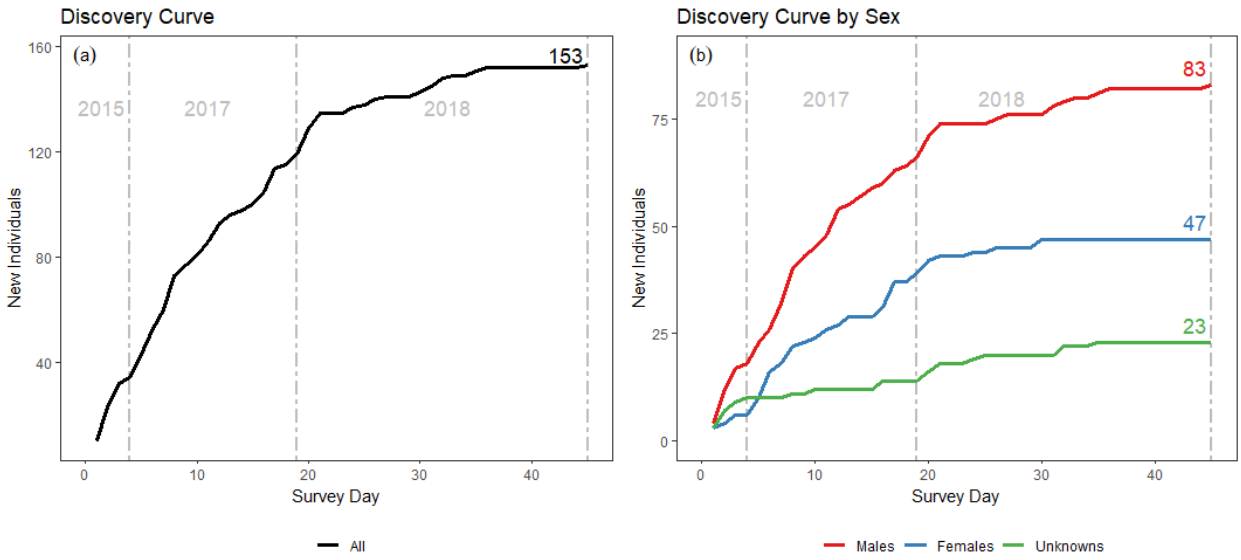


Figure 2. Discovery curves of individual right whales in the southern Gulf of St. Lawrence from NOAA aerial surveys 2015, 2017 and 2018 for (a) all whales and (b) by sex.

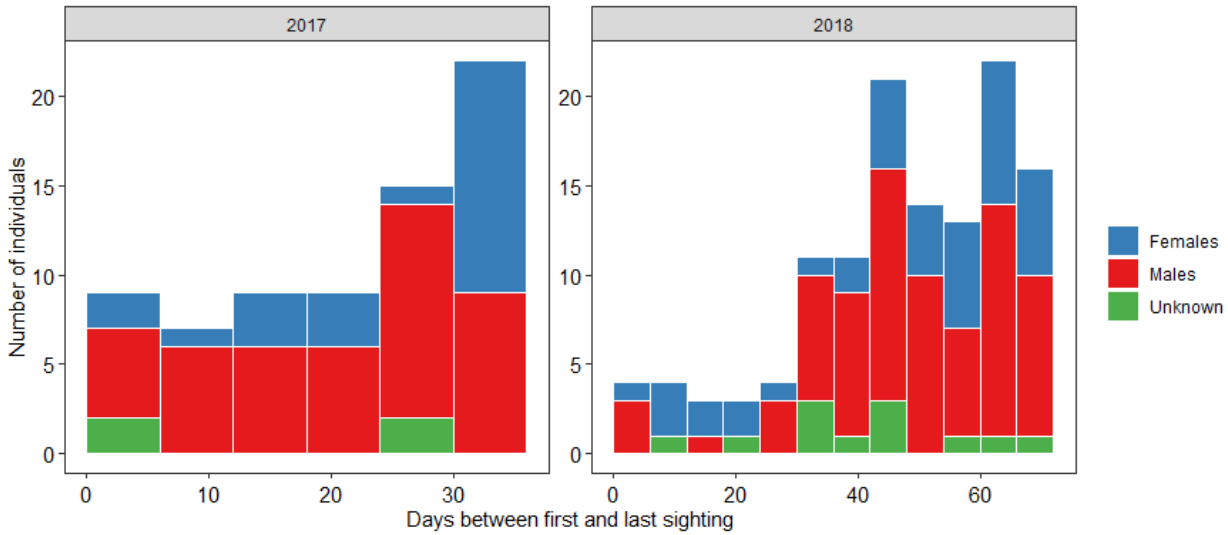


Figure 3. Distribution of residency times (the number of days between the first and last sighting) by sex split into 6-days bins for animals observed in the southern Gulf of St. Lawrence in 2017 and 2018. Maximum residency time in 2017 and 2018 was 36 and 69 days, respectively, which was the extent of the survey time frames.

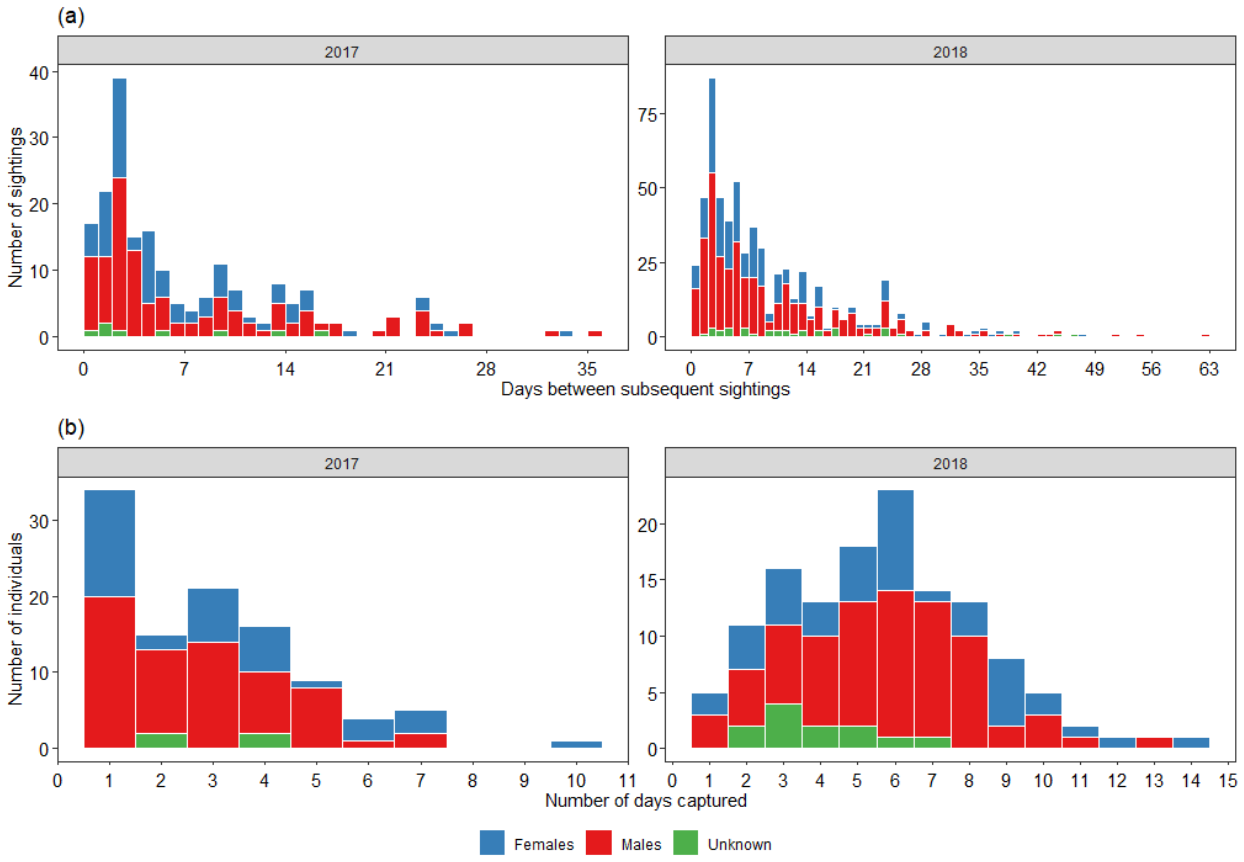


Figure 4. (a) Days between subsequent sightings and (b) number of days individual right whales were captured by sex in the southern Gulf of St. Lawrence from the NOAA aerial surveys in summer 2017 and 2018.

APPENDIX

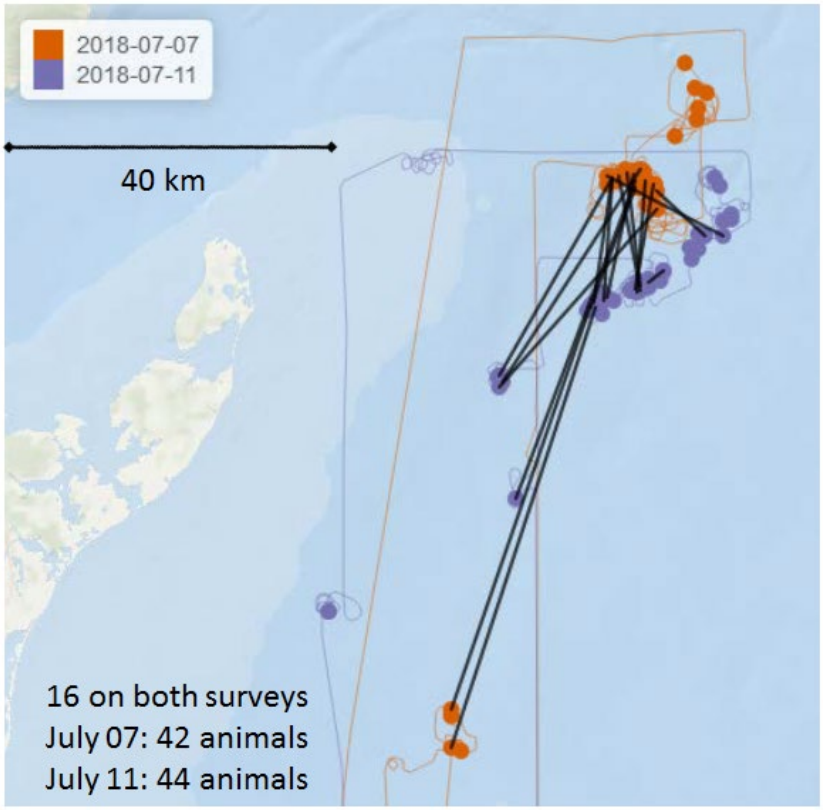
S1. North Atlantic right whale individual identifications from NOAA aerial surveys in the Gulf of St. Lawrence in 2015, 2017, and 2018.

		Observation Year					Observation Year					Observation Year		
Whale ID	**Sex**	**2015**	**2017**	**2018**	**Whale ID**	**Sex**	**2015**	**2017**	**2018**	**Whale ID**	**Sex**	**2015**	**2017**	**2018**
1017	M	x	x	x	1934	F	x	x	x	3157	F	x	-	x
1036	M	x	x	-	1971	M	-	x	-	3191	M	x	x	x
1042	M	-	x	x	2010	M	-	x	x	3193	M	-	x	x
1112	M	x	-	x	2040	F	-	x	x	3194	F	-	-	x
1142	F	-	-	x	2123	F	x	-	-	3229	M	x	-	-
1149	M	-	x	x	2140	M	-	x	-	3230	F	-	x	x
1209	F	-	-	x	2209	M	-	-	x	3232	F	-	x	x
1226	M	-	x	x	2223	F	-	x	x	3245	M	x	-	x
1245	F	-	x	x	2271	M	-	x	x	3296	M	x	-	-
1249	M	-	x	x	2303	M	-	-	x	3301	M	-	x	x
1271	M	-	x	x	2340	M	-	-	x	3310	M	-	-	x
1307	M	-	x	x	2427	M	-	x	-	3312	M	x	x	x
1317	M	x	x	x	2503	F	x	x	x	3317	F	-	x	x
1403	M	-	x	x	2510	M	x	x	x	3329	F	-	-	x
1419	M	x	x	x	2642	F	-	x	x	3333	M	-	x	x
1423	X	-	-	x	2681	M	-	x	x	3351	M	-	-	x
1427	M	-	x	-	2705	M	-	x	x	3380	M	-	x	x
1429	M	-	x	x	2743	M	-	x	x	3390	F	-	x	x
1506	M	-	-	x	2750	M	x	x	x	3420	F	-	x	x
1507	M	-	-	x	2753	F	-	x	x	3421	M	x	x	x
1514	M	-	x	x	2760	M	-	x	x	3440	F	x	-	-
1604	F	x	-	-	2791	F	-	x	x	3442	M	-	x	x
1616	M	x	x	x	2904	M	-	x	x	3450	F	-	x	x
1628	X	-	-	x	2910	M	-	x	x	3510	M	x	x	x
1703	F	-	-	x	2920	M	-	-	x	3515	F	-	x	x
1708	M	-	x	x	2930	M	-	x	x	3520	F	-	x	x

		Observation Year					Observation Year					Observation Year			
Whale ID	**Sex**	**2015**	**2017**	**2018**	**Whale ID**	**Sex**	**2015**	**2017**	**2018**	**Whale ID**	**Sex**	**2015**	**2017**	**2018**
1720	M	-	x	x	3101	F	-	x	x	3530	M	-	x	x
1801	M	-	-	x	3110	M	x	x	x	3546	F	-	x	x
1812	F	x	x	x	3115	F	-	x	x	3550	M	-	-	x
1817	F	-	-	x	3125	M	-	x	x	3560	F	-	x	x
1820	M	-	x	x	3140	M	x	-	-	3579	M	-	x	x

Continued.

Observation Year					Observation Year				
Whale ID	**Sex**	**2015**	**2017**	**2018**	**Whale ID**	**Sex**	**2015**	**2017**	**2018**
3617	M	-	x	x	4129	M	x	x	x
3623	M	x	x	x	4140	M	-	x	x
3646	F	x	-	-	4180	X	-	x	x
3651	M	-	x	x	4190	F	-	x	x
3660	M	-	-	x	4310	F	-	-	x
3680	M	-	x	x	4340	F	-	x	x
3812	M	-	x	x	4423	M	-	x	x
3815	F	-	x	x	4440	M	-	-	x
3823	F	-	x	x	4445	M	-	x	-
3843	M	-	-	x	4446	M	-	-	x
3860	F	-	x	x	4457	M	-	x	x
3890	F	-	x	x	4504	F	x	-	-
3892	M	x	x	x	4510	F	-	x	x
3893	F	-	x	-	4523	M	x	x	x
3904	F	-	x	x	4530	X	x	-	-
3920	M	-	x	x	4545	F	-	x	x
3940	F	x	x	x	4546	F	x	-	-
3942	F	-	x	x	4615	M	-	x	x
3946	F	-	x	x	4617	F	-	-	x
3960	M	-	-	x	4620	F	-	x	-
3981	M	-	-	x	2016CalfOf1233	F	-	-	x
3989	M	-	x	x	2016CalfOf3101	X	-	-	x
3992	M	-	x	x	2016CalfOf3450	X	-	-	x
4005	M	-	x	-	G046	X	-	-	x
4023	M	-	x	x	G048	X	-	x	-
4040	X	-	x	x	G055	X	-	x	x
4042	M	-	-	x	G056	X	-	-	x
4057	M	x	-	-	M097	X	-	-	x
4092	F	-	x	x	2015CalfOf1701/M101	X	-	-	x
4094	F	-	x	-					
4123	M	-	x	x					



S2. Resightings of individual right whales on consecutive survey days four days apart. Black lines connect the same individual seen on both days. Orange dots are locations of individuals on 07 July (n=43), blue dots for individuals on 11 July (n=44). 16 individuals were seen on both days. Narrow orange and blue lines are the plane's flight path for each day.

S3. Comparisons of Jolly-Seber models run on the photo-identification data for 2017.

Model	Formula	AIC
Base	Phi(.), p(.), pent(.)	192.44
Time-varying capture	***Phi(.), p(time), pent(.)***	***181.36***
Time-varying survival	Phi(time), p(.), pent(.)	189.80
Time-varying probability of entry	Phi(.), p(.), pent(time)	189.26
Time-varying probability of capture and survival	Phi(time), p(time), pent(.)	183.10
Time-varying probability of capture and entry	Phi(.), p(time), pent(time)	182.91

S4. Estimates of probability of capture over the three time blocks, 2017.

Time period	Estimate	Standard Error
1	0.796	0.2140
2	0.594	0.0850
3	0.934	0.1225

S5. Comparisons of Jolly-Seber models run on the photo-identification data for 2018.

Model	Formula	AIC
Base	***Phi(.), p(.), pent(.)***	***598.47***
Time-varying capture	Phi(.), p(time), pent(.)	601.60
Time-varying survival	Phi(time), p(.), pent(.)	602.22
Time-varying probability of entry	***Phi(.), p(.), pent(time)***	***598.66***
Time-varying probability of capture and survival	Phi(time), p(time), pent(.)	606.63
Time-varying probability of capture and entry	Phi(.), p(time), pent(time)	604.06

S6. Estimates of probability of entry into the study population, for 2 models, 2018.

Model	Time period	Estimate	Standard Error
Base	N/A	0.0092	0.0102
Time-varying probability of entry	2	$5.378*10^{-5}$	0.0024
Time-varying probability of entry	3	$8.423*10^{-2}$	0.0353
Time-varying probability of entry	4	$6.462*10^{-7}$	0.0002
Time-varying probability of entry	5	$9.875*10^{-7}$	0.0004

S7. Estimates of the number of whales that were undetected in the study population, 2 models, 2018.

Model	Estimate	Standard Error
Base	1.38	1.605
Time-varying probability of entry	1.132	1.420