Supplementary Materials

Keen et al. (2022) Ship-strike forecast & mitigation for whales of the Gitga'at First Nation

8/15/2022

Marine traffic

Table 2: Table S2. AIS traffic in 2019, restricted to prime fin whale habitat in Squally Channel, including Lewis Passage and north Campania Sound (W 129.4519 - 129.26239, N 53.069 - 53.3218)

				Speed (kn)			Length (m)				Bea	
Vessel type	**IDs**	**Transits**	**Transits/day**	**mean**	**sd**	**max**	**mean**	**sd**	**min**	**max**	**mean**	**sd**
Cargo > 180m	4	4	0.01	12.4	1.6	14.6	187	8	180	200	31	1
Fishing < 60m	30	75	0.21	8.2	4.3	32.2	17	6	10	37	6	2
Other < 40m	6	20	0.05	8.8	4.9	31.5	26	8	7	40	6	2
Other > 100m	5	9	0.02	10.4	2.0	13.5	157	19	134	178	18	8
Other > 40m	13	59	0.16	9.5	2.4	15.0	55	14	42	98	13	3
Passenger > 180m	5	19	0.05	18.1	2.5	22.0	270	39	197	301	33	1
Pleasurecraft < 40m	70	142	0.39	7.4	3.6	34.4	15	5	7	28	5	1
Sailing	17	35	0.10	5.6	1.4	9.0	15	5	8	32	4	2
Towing < 50m	14	40	0.11	9.2	1.4	11.8	34	4	26	41	10	2
Tug < 50m	17	74	0.20	7.1	1.9	11.2	23	9	12	41	8	2

Table 1: Table S1. Summary of 2019 marine traffic within the lower Kitimat Fjord System, as reported by archival AIS data. Column "VIDs" indicates number of unique Vessel ID codes observed for each vessel type.

			Speed (kn)			Length (m)				Bea	
Type	**VIDs**	**Transits**	**mean**	**sd**	**max**	**mean**	**sd**	**min**	**max**	**mean**	**sd**
Cargo ship	54	157	12.7	1.7	17.1	159	53	26	200	26	8
Cargo ship:DG,HS,MP(X)	1	2	11.9	0.7	13.7	67	0	67	67	13	0
Diving op.	1	4	7.8	0.7	10.0	10	0	10	10	4	0
Dredging or underwater op.	3	36	9.7	2.4	15.0	63	34	35	119	14	6
Fishing	308	829	8.4	3.2	32.2	20	9	6	100	6	2
HSC	3	8	13.0	8.1	28.6	25	13	7	35	7	3
Law enforcement	3	3	9.7	1.5	12.6	42	16	26	68	8	3
Local ship	2	10	12.4	6.5	26.5	13	4	10	18	4	0
Military op.	1	4	9.1	2.4	15.0	33	0	33	33	8	0
Other	22	78	8.6	2.4	24.9	37	22	6	76	9	5
Passenger ship	58	803	15.1	5.7	35.6	108	75	11	301	18	10
Passenger ship:DG,HS,MP(Y)	1	2	11.1	0.4	11.8	64	0	64	64	12	0
Pilot	2	6	19.9	3.1	25.8	19	1	17	20	4	1
Pleasure Craft	275	1213	8.2	3.7	37.5	20	16	7	154	6	3
Port tender	1	2	7.4	1.1	8.8	26	0	26	26	8	0
Sailing	117	426	6.0	1.3	12.6	14	4	8	35	4	1
Search/rescue	14	193	10.3	4.0	39.2	52	15	7	83	11	3
Tanker	2	7	12.1	0.8	13.9	141	5	134	145	24	0
Towing	36	356	7.0	1.7	21.7	27	21	6	162	8	3
Towing(200/25)	42	382	8.8	1.6	13.7	32	6	12	41	10	2
Tug	62	873	7.4	1.8	13.9	27	28	11	178	8	3

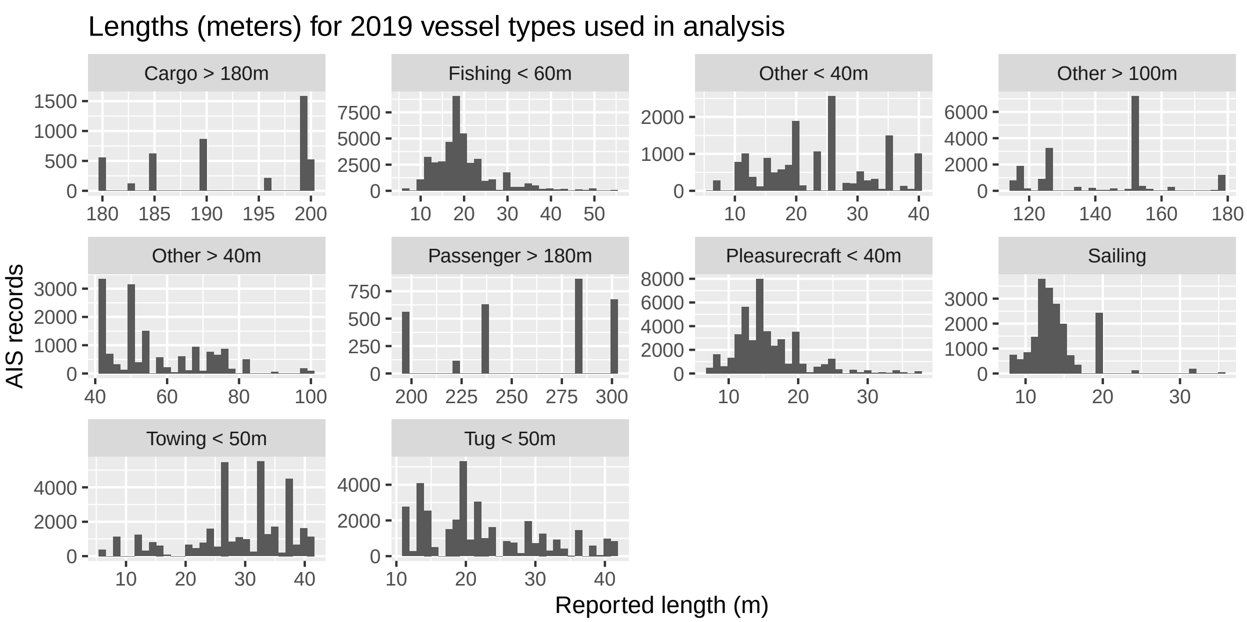


Figure 1: Figure S1. Length distributions of the ten vessel classes used to summarize marine traffic in 2019.

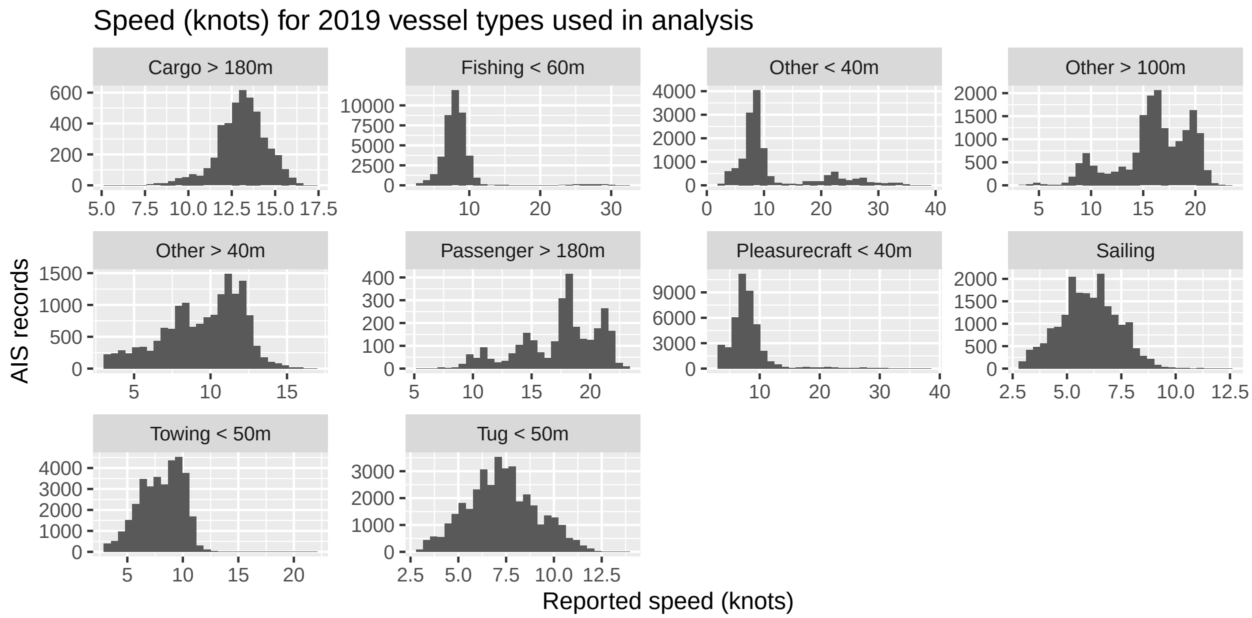


Figure 2: Figure S2. Speed distributions, in knots, of the ten vessel classes used to summarize marine traffic in 2019.

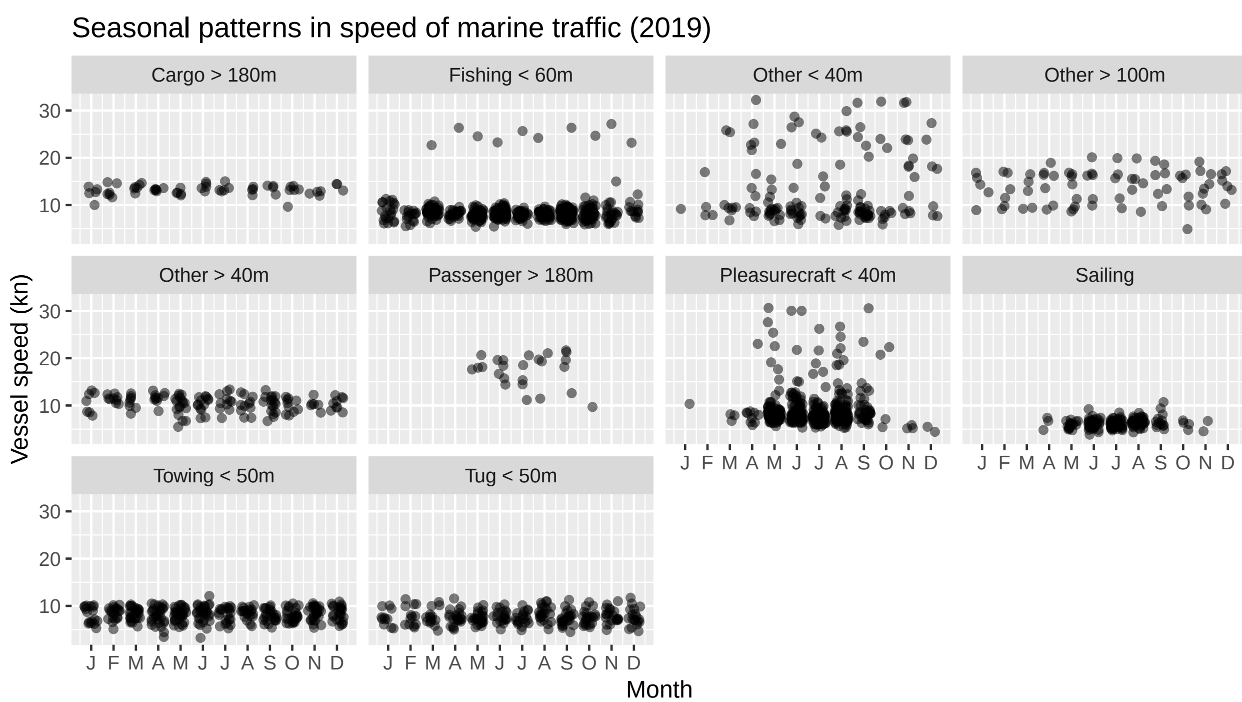


Figure 3: Figure S3. Seasonal patterns in the speed (knots) of marine traffic, grouped iinto the 10 vessel classes used in this study.

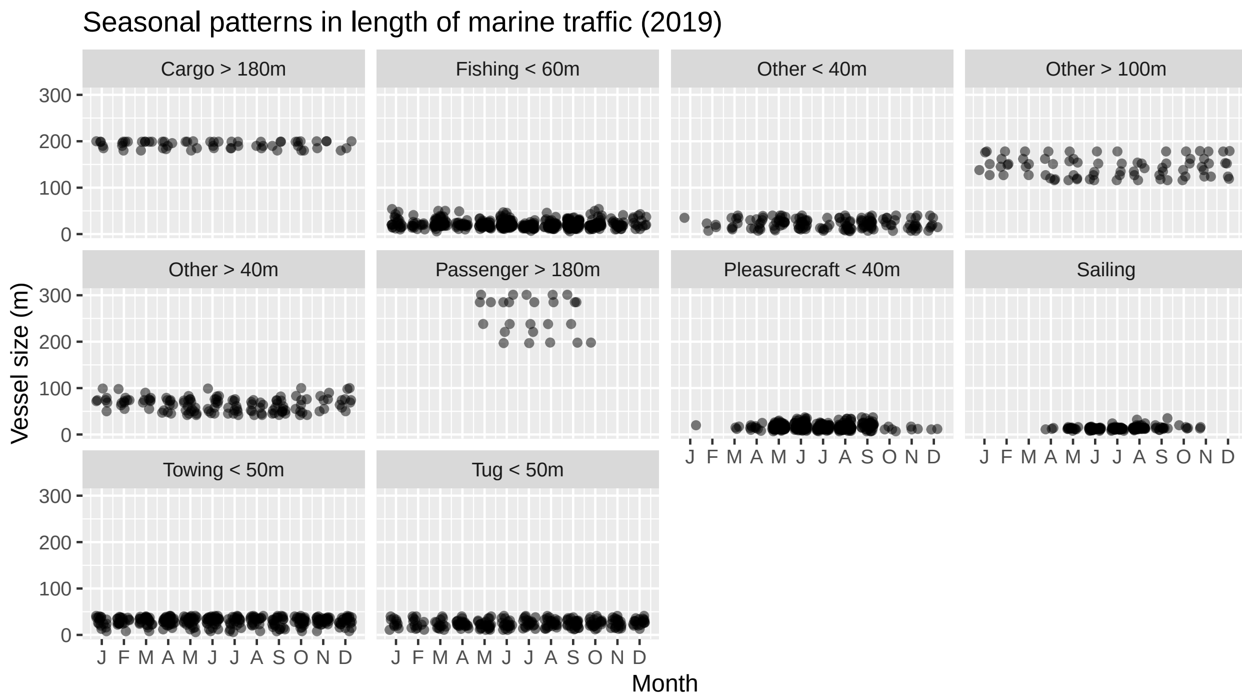
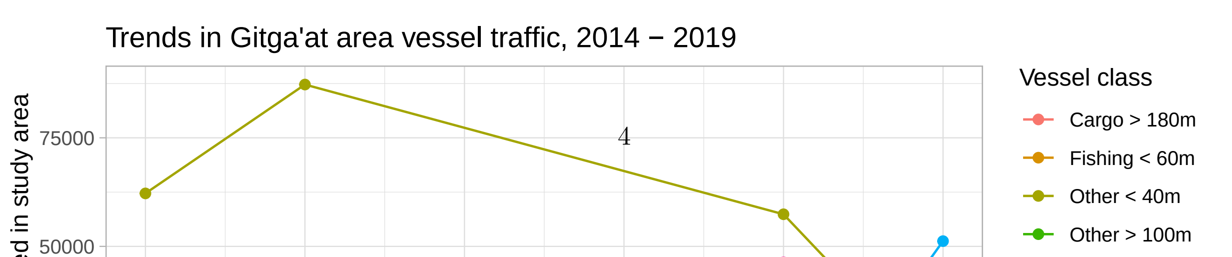


Figure 4: Figure S4.Seasonal patterns in the length (meters) of marine traffic, grouped iinto the 10 vessel classes used in this study.

Table 3: Table S3. Trends (historical and predicted) in AIS traffic, 2014 - 2030. Kilometers transited in 2014 - 2019 are observations, while the 2030 numbers are predicted based on linear models. The "scale factor" is the multiplier used, based on those models, to estimate 2030 transits based on 2019 data. "Prop. change" is the proportional rate of annual change in total transits (e.g., the "2019" proportion column shows the rate of change as a proportion of 2019 transits). The p-value refers to the linear model for each vessel class.

	Kilometers transited						Prop. change		
Vessel class	**2014**	**2015**	**2018**	**2019**	**2030**	**Scale factor**	**2019**	**2030**	**p-value**
Cargo > 180m	0	0	0	9444	16943	1.79	0.15	0.08	0.30
Fishing < 60m	17165	16377	31949	45784	86437	1.89	0.12	0.06	0.05
Other < 40m	62201	87269	57399	18723	0	0.00	-0.48	-0.24	0.24
Other > 100m	25213	19011	27281	26166	33552	1.28	0.03	0.03	0.44
Other > 40m	27391	9943	23408	29184	37725	1.29	0.05	0.04	0.60
Passenger > 180m	6212	5489	10403	6168	11554	1.87	0.07	0.04	0.55
Pleasurecraft < 40m	0	0	56	51215	91952	1.80	0.15	0.08	0.30
Sailing	357	1553	12538	20934	50795	2.43	0.19	0.08	0.02
Towing < 50m	35311	15299	39409	42838	67175	1.57	0.08	0.05	0.38
Tug < 50m	30971	44685	46344	43301	61901	1.43	0.05	0.03	0.33



Joint Venture Partner	Capacity (m^3)	DWT	Gross Tonnage	Length (m)	Breadth (m)	Draught (m)
SHELL	170,000	86,000	109,000	290	45	12.0m
	215,000	107,000	136,000	315	50	12.0m
KOGAS	165,000	82,000	104,000	286	43	11.9m
MITSUBISHI	150,000	85,000	100,000	288	44	11.5m
CNPC	130,000	71,000	85,000	286	41	11.8m

Methods details

Line-transect surveys

Table 4: Table S5. Effort and sighting details from line-trasect surveys within the Kitimat Fjord Surveys, 2013 - 2015. For each species, "total" counts include all detections while on systematic effort, while "valid" counts include detections with valid detection-distance estimates.

	Effort		Fin whales		Humpback whales	
Year	segments	km	total	valid	total	valid
2013	143	712.5204	8	6	68	38
2014	168	800.5337	18	17	134	130
2015	402	2083.1364	19	19	253	251

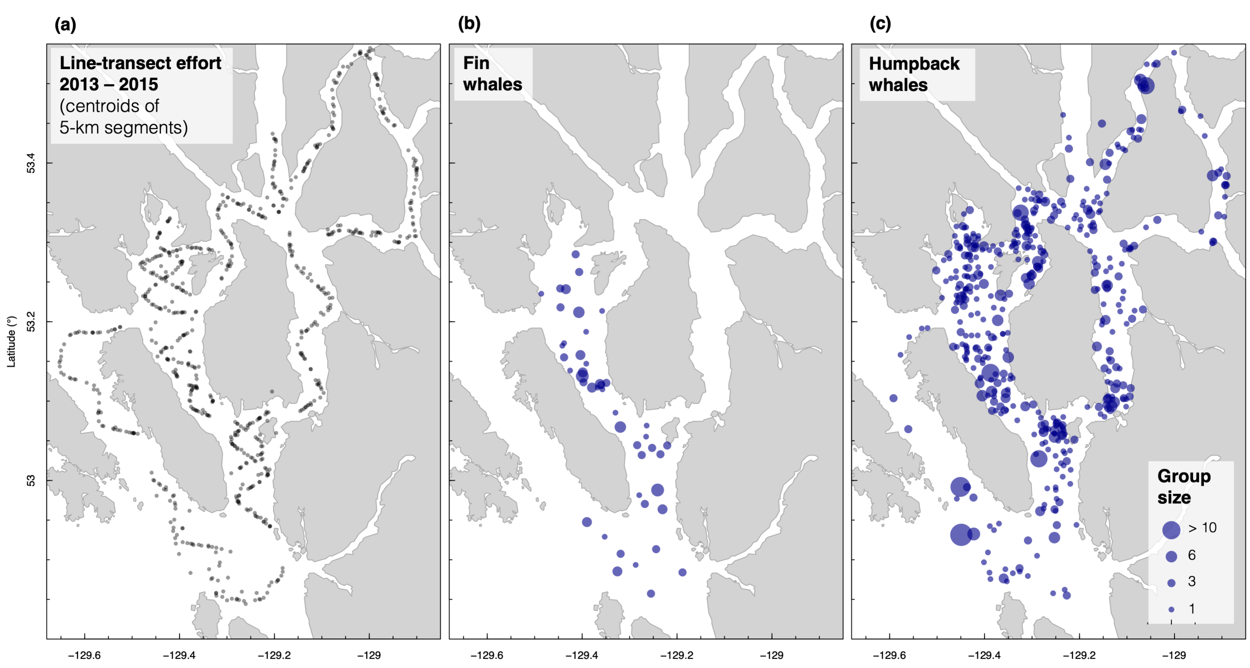


Table 5: Table S6. Best-fitting models of the detection functions for fin whales and humpback whales, based upon 2013-2015 line-transect surveys. Abbreviation "bft" refers to Beaufort Sea State.

	Species	Model	Key function	Formula	C-vM p-value	$\hat{P_a}$	se($\hat{P
1	Fin whale	1	Half-normal	~1	0.8405095	0.5500191	0.0
3		2	Half-normal	~1 + factor(year)	0.7815848	0.5231299	0.0
2		3	Half-normal	~1 + bft	0.8250065	0.5465154	0.0
31	Humpback whale	1	Half-normal	~1 + factor(year)	0.9652267	0.5204825	0.0
21		2	Half-normal	~1 + bft	0.9637787	0.5296131	0.0
11		3	Half-normal	~1	0.9430440	0.5364511	0.0

Figure S6. (a) Design-based line-transect survey effort throughout the central Gitga'at waters of the Kitimat Fjord System (each dot is the center of a 5-km segment of systematic effort), yielding detections of (b) fin whales and (c) humpback whales. Detection dot size reflects group size

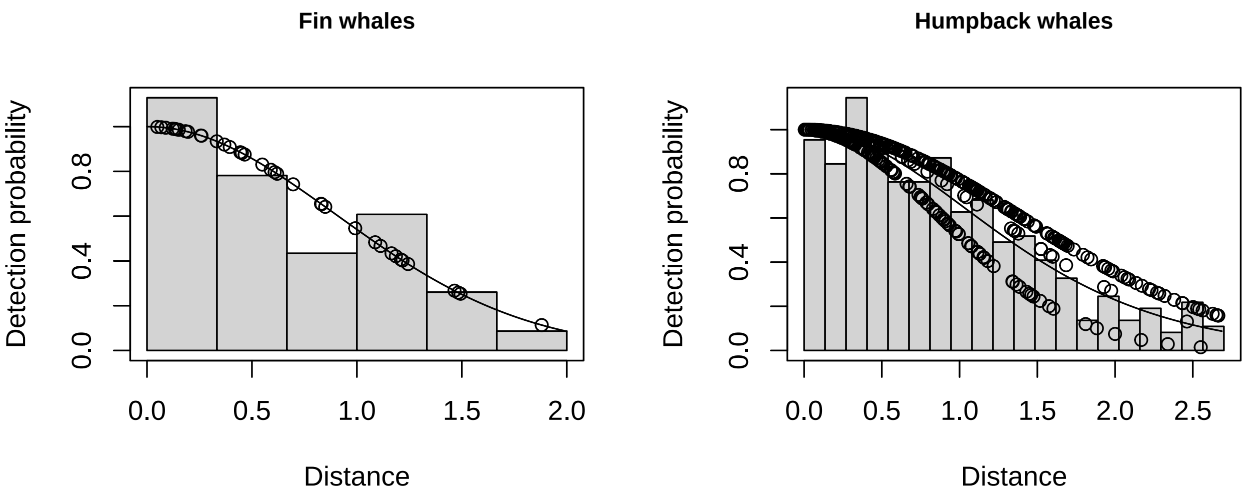


Figure 6: Figure S7. Best-fitting detection function models superimposed upon histograms of detection distances for each species.

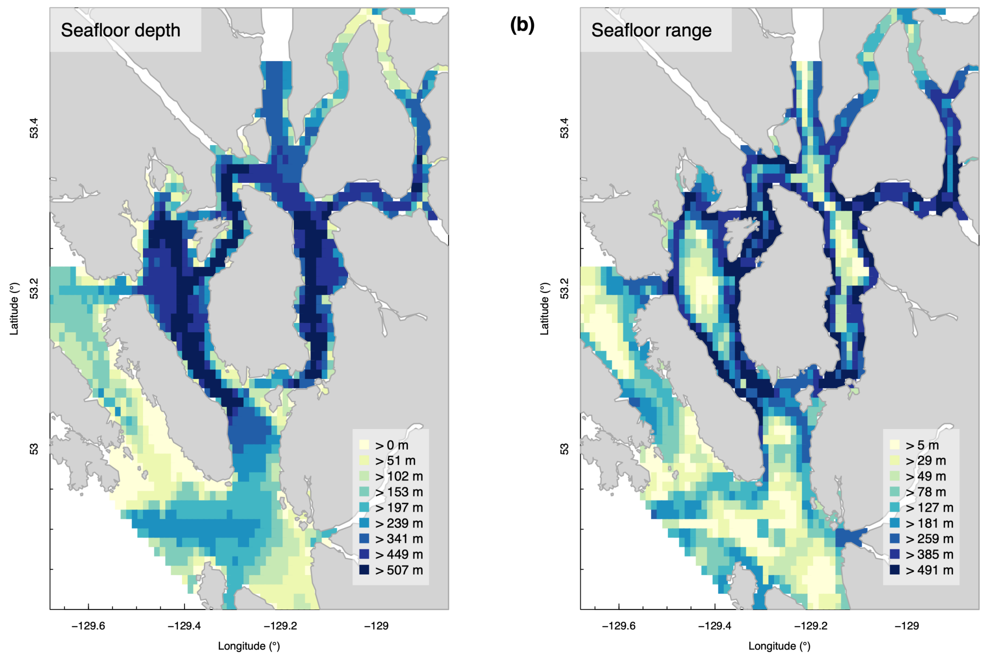


Figure S8. Bathymetric characteristics of the study area, as summarized for the square-kilometer grid used in density surface modeling.

Humpback whale UAS analysis

Supplemental details to data collection & analysis:

Briefly, a licensed pilot (author ÉOM, research permit DFO XR83 2019) launched the UAS (DJI Mavic 2 Pro, www.dji.com) opportunistically from either FIRS or a 6m research vessel. When deciding whether or not to launch a UAS flight, a conscientious effort was made not to give preference to certain behavioral states or demographic groups. The UAS was equipped with a Hasselblad camera, 1-Hz LiDAR (Light Detection And Ranging), and GPS data-logger. Throughout a whale's surfacing sequence in between dives, the UAS was hovered above the whale at a target elevation of 30m. Stills were extracted from the video footage, their timestamps were matched to the LiDAR elevation data, and camera tilt was used to correct the altimeter reading. Images were evaluated using a three-tier quality score based upon water visibility, image sharpness and whale body position. Top-tier photographs required the entire length of the individual whale to be visible: from rostrum tip to fluke notch, without a visibly arched back. Middle-tier photographs required rostrum tip and fluke notch to be, at minimum, just visible without body arching, but image sharpness and/or water visibility were reduced. Bottom-tier photographs included all video stills where either the whale's rostrum and/or fluke notch were not visible, preventing an estimate of length. Bottom-tier images were discarded, and only whales with at least one top-scored image were kept. Whale dimensions were measured using 'Whalength' (Dawson et al. 2017) in MATLAB (MathWorks Inc.). Measures from multiple images of the same whale were averaged to estimate length and fluke width, in meters. To confirm that middle-tier photographs were not biasing our results, we compared means derived solely from top-tier measurements to those from middle-tier measurements (Table S7).

Fin whale dive tag analysis

Supplemental details for data collection & processing:

Table 6: Table S7. Humpback whale morphometrics (n=13 individuals) measured by UAS in Gitga'at waters in 2019.

	Measurements			Body length (m)				Fluke width (m)			
Whale ID	**Total**	**Score 1**	**Score 2**	**Mean**	**SD**	**Score 1**	**Score 2**	**Mean**	**SD**	**Score 1**	**Score 2**
20190611 1A	5	3	2	11.19	0.27	11.09	11.34	3.52	0.11	3.49	3.60
20190829 1A	1	1	0	11.08		11.08		3.58		3.58	
20190829 1B	4	1	3	10.92	0.33	11.10	10.86	3.76	0.15	3.92	3.69
20190905 1A	10	4	6	11.17	0.62	11.08	11.22	3.93	0.22	3.89	3.96
20190905 1B	2	1	1	11.39	0.20	11.25	11.53	4.21	0.08	4.27	4.15
20190905 2A	4	2	2	14.45	0.29	14.68	14.22	4.38	0.11	4.44	4.33
20190905 2B	3	2	1	13.26	0.28	13.42	12.94	4.21	0.10	4.17	4.28
20190907 1A	3	1	2	11.67	0.22	11.90	11.55	3.98	0.03	3.96	3.99
20190908 1A	1	1	0	10.97		10.97		3.53		3.53	
20190909 1A	3	2	1	13.34	0.11	13.34	13.32	4.44	0.12	4.51	4.30
20190909 1B	5	2	3	10.41	0.35	10.77	10.17	3.59	0.10	3.67	3.53
20190910 1A	1	0	1	12.36			12.36	4.01			4.01
20190911 1A	8	3	5	10.94	0.48	10.93	10.95	3.54	0.10	3.54	3.54
20190911 1B	1	0	1	11.08			11.08	3.96			3.96
20191004 1A	9	7	2	13.64	0.21	13.68	13.49	4.13	0.06	4.13	4.09

Table 7: Table S8. Summary of UAS flights used to estimate humpback whale swimming speed. Multiple follows of the same group were averaged together before calculating speed.

			Duration (sec)		Distance (km)		
Date	**File**	**Follows**	**Mean**	**Total**	**Mean**	**Total**	**Speed (m/s)**
2019-06-06	20190606_DJI_0079	1	31.00	31	0.03	0.03	0.836
2019-08-28	20190828_DJI_0552_Group1	1	43.00	43	0.00	0.00	0.039
2019-08-29	20190829_DJI_0556_Group1	3	50.67	152	0.03	0.08	0.501
2019-09-03	20190903_DJI_0564_Group1	1	68.00	68	0.07	0.07	1.017
2019-09-05	20190905_DJI_0575_Group1	1	71.00	71	0.01	0.01	0.210
2019-09-05	20190905_DJI_0578_Group1	2	84.50	169	0.04	0.07	0.430
2019-09-05	20190905_DJI_0582_Group2	1	42.00	42	0.03	0.03	0.768
2019-09-05	20190905_DJI_0585_Group2	2	50.50	101	0.02	0.04	0.353
2019-09-07	20190907_DJI_0591_Group3	2	48.00	96	0.03	0.06	0.675
2019-09-07	20190907_DJI_0593_Group3	2	98.00	196	0.07	0.15	0.754
2019-09-08	20190908_DJI_0597_Group1and2	1	41.00	41	0.02	0.02	0.580
2019-09-08	20190908_DJI_0600_Group3	1	64.00	64	0.03	0.03	0.525
2019-09-11	20190911_DJI_0620_Group2	2	46.50	93	0.04	0.08	0.812
2019-10-04	20191004_DJI_0624_Group1	1	78.00	78	0.05	0.05	0.663

Tags were deployed from 30-ft and 70-ft vessels in Squally Channel and the near vicinity (Caamaño Sound and southern Hecate Strait) using pneumatic rifles. The tags were programmed to sample whale depth once per second and store the depth reading every 75 s, then transmit these data in the form of batched messages via the Argos satellite system. Daily messages were limited to 500 in 2013 and 450 in 2014, effectively duty-cycling the depth sampling regime (Figure S9). A ground-based receiving station (Mote; Wildlife Computers) was installed near Squally Channel in 2014, improving the number of dive sensor messages that could be received from nearby-transmitting tags. Gaps of > 75 s in the depth sensor data were removed, and the sun altitude for each timestamp was calculated using the package 'oce' (Kelly & Richards 2022) based upon an approximate location for the geographic center of tag deployments (52.8 N, 129.8 W). Timestamps were then classified as nighttime or daytime according to a sun angle of -12 degrees (nautical dusk/dawn).

One tag (ID 7 in Table S9) yielded only 4 hours of valid depth sensor data during an 11-hour deployment, and was thus discarded, leaving six valid deployments. After this, the total depth samples across all tags was 9,793. Mean depth sample size per deployment was 1,631 (SD = 1,274). Daytime sample sizes (mean=1,164, SD=781) were higher than nighttime (mean=468, SD=518), due to the high-latitude summertime sampling. While 71% of depth records occurred during daytime, nighttime depths were sampled in all six deployments (Fig S10).

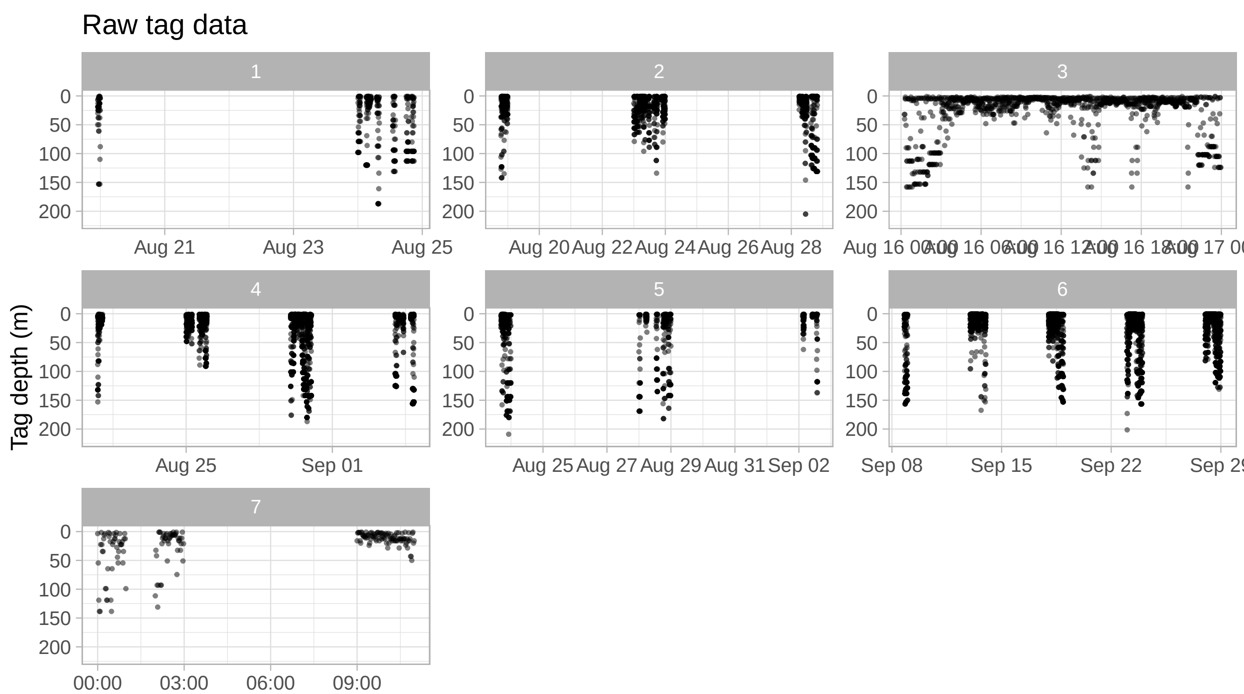


Figure 7: Figure S9. Raw time- and depth-distributions of depth sensor readings for each of the 7 SPLASH-10 tag deployments.

Collision & mortality analysis

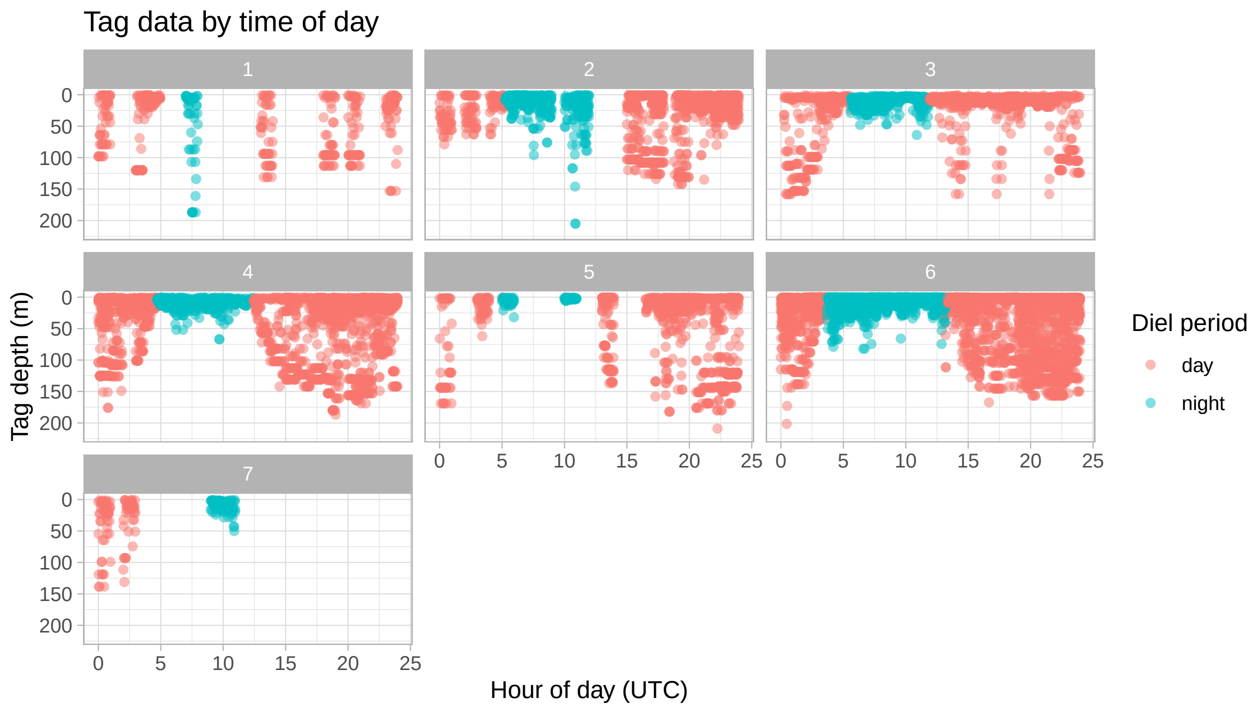


Figure 8: Figure S10. Time distribution (hour of day, color-coded by daytime/nighttime) of depth samples from SPLASH10 tags, displayed for each deployment separately.

Table 8: Table S9. Summary of SPLASH10 depth data used in fin whale depth distribution analysis.

Deployment ID		Deployment period			Depth sample s	
This study	**Nichol et al. (2018)**	**Start**	**Stop**	**Hours**	**Hours valid**	**Total**
1	132219-132219	2013-08-19 23:00:00	2013-08-24 20:58:45	117.97917	8.00000	384
2	132220-132220	2013-08-18 18:47:30	2013-08-28 19:57:30	241.16667	26.18750	1257
3	137684-137684	2014-08-16 00:15:00	2014-08-16 23:57:30	23.70833	23.72917	1139
4	137685-137685	2014-08-20 18:22:30	2014-09-04 21:58:45	363.60417	45.62500	2190
5	137686-137686	2014-08-23 16:30:00	2014-09-02 13:57:30	237.45833	18.47917	887
6	142546-142546	2014-09-08 19:00:00	2014-09-28 23:58:45	484.97917	82.00000	3936
7	142547-142547	2014-09-14 00:00:00	2014-09-14 10:58:45	10.97917	4.00000	192

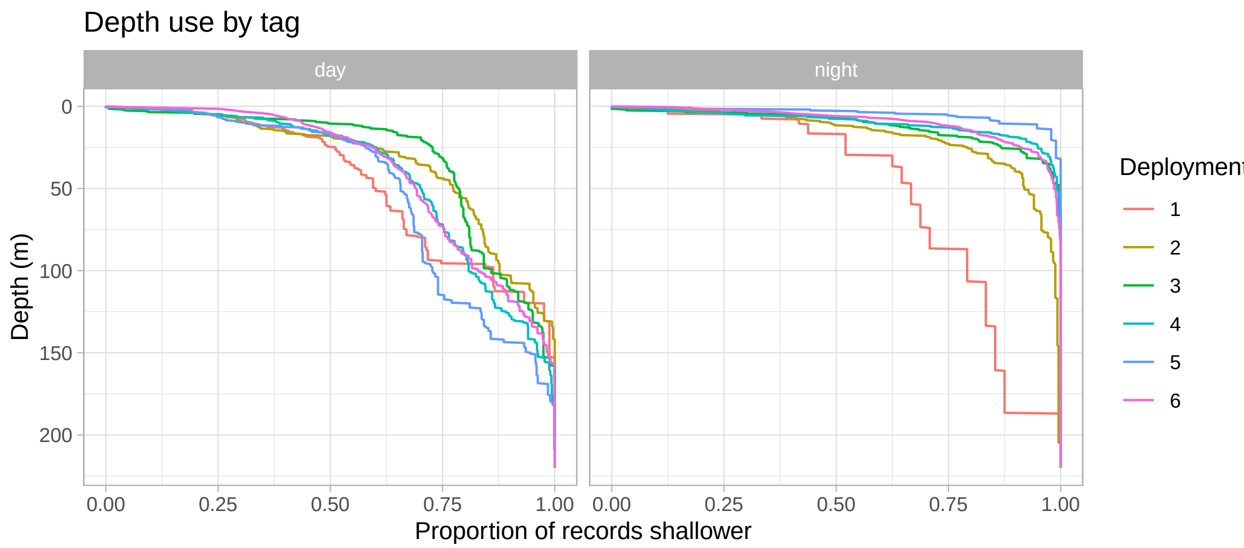


Figure 9: Figure S11. Daytime (left) and nighttime (right) depth distribution curves, representing the proportion of time spent above a given depth, for six SPLASH-10 deployments on fin whales (colored lines).

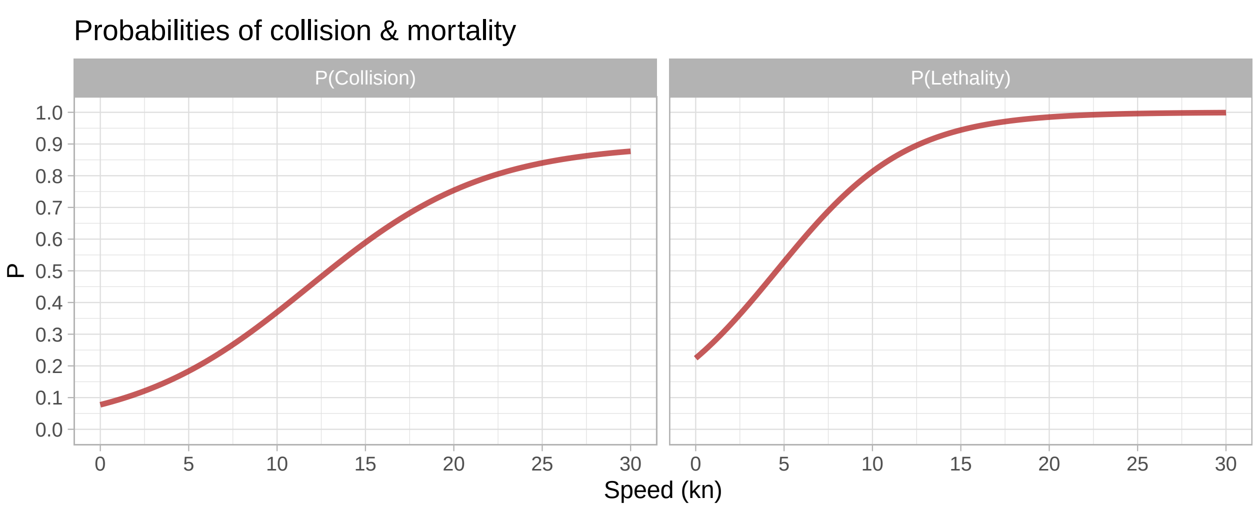


Figure 10: Figure S12. Probabilities of collision (left) and mortality (right) as a function of ship speed (>180m length), adapted from Gende et al. (2011) and Kelley et al. (2020), respectively.

Potential Biological Removal

Fin whales – Canadian Pacific stock (Wright et al. 2022):

```r
pbr(N = 2893, CV = 0.15) %>% cbind
```

```
##         .
## PBR     15.31982
## Nmin    765.9909
## Rmax    0.08
## Fr      0.5
## Nmedian 2828.472
```

Fin whales – North Coast Sector (Wright et al. 2022):

```r
pbr(N = 161, CV = 0.50)  %>% cbind
```

```
##         .
## PBR     1.292768
## Nmin    64.63838
## Rmax    0.08
## Fr      0.5
## Nmedian 160.0511
```

Fin whales – coastal (Queen Charlotte, Hecate Strait) (Nichol et al 2017):

```r
pbr(N = 405, CV = 0.6)  %>% cbind
```

```
##         .
## PBR     2.796341
## Nmin    139.817
## Rmax    0.08
## Fr      0.5
## Nmedian 409.2232
```

Humpback whales – Canadian Pacific stock (Wright et al. 2022):

```r
pbr(N = 7030, CV = 0.1)  %>% cbind
```

```
##         .
## PBR     36.19652
## Nmin    1809.826
## Rmax    0.08
## Fr      0.5
## Nmedian 7130.255
```

Humpback whales – North Coast sector (Wright et al. 2022):

```r
pbr(N = 1816, CV = 0.13)  %>% cbind
```

```
##         .
## PBR     10.17047
## Nmin    508.5237
## Rmax    0.08
## Fr      0.5
## Nmedian 1796.92
```

Results details

Vessel traffic

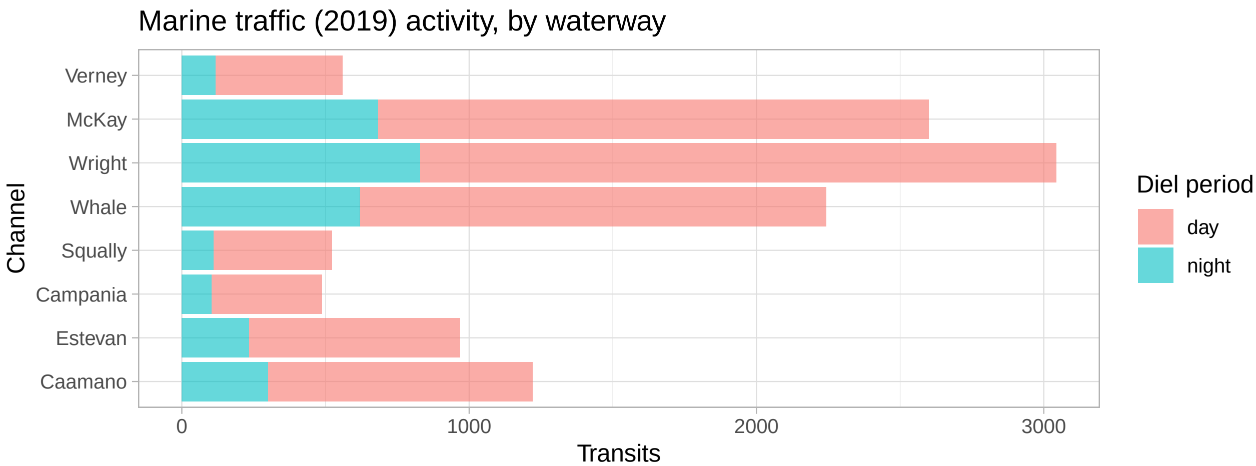


Figure 11: Figure S13. Distribution of 2019 marine traffic parsed by waterway and time of day.

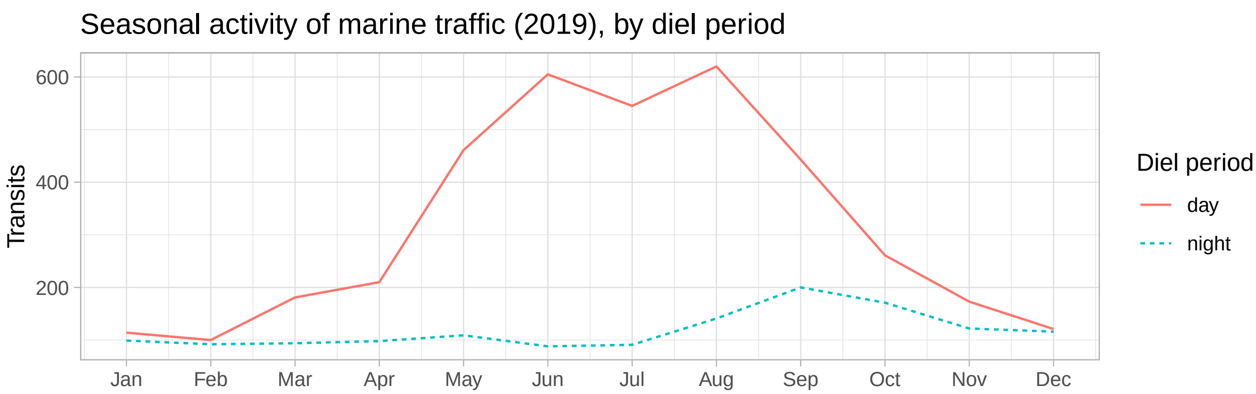


Figure 12: Figure S14. Monthly distribution of 2019 marine traffic, parsed by time of day.

Species distribution models

Table 9: Table S10. Best-fitting density surface models for fin whales and humpback whales for mid-June – early-September.

Species	Formula	Trunc. dist.	Family	Link function	Delta AIC	Deviance expla
Fin whale	(Lat x Lon) + seafloor depth + seafloor range	2.0 km	Tweedie	log	104	54%

Humpback whale	(Lat x Lon x DOY) + seafloor depth + seafloor range + year	2.7 km	Tweedie	log		14	51%

Figure S16. Smooth terms from species distribution models.

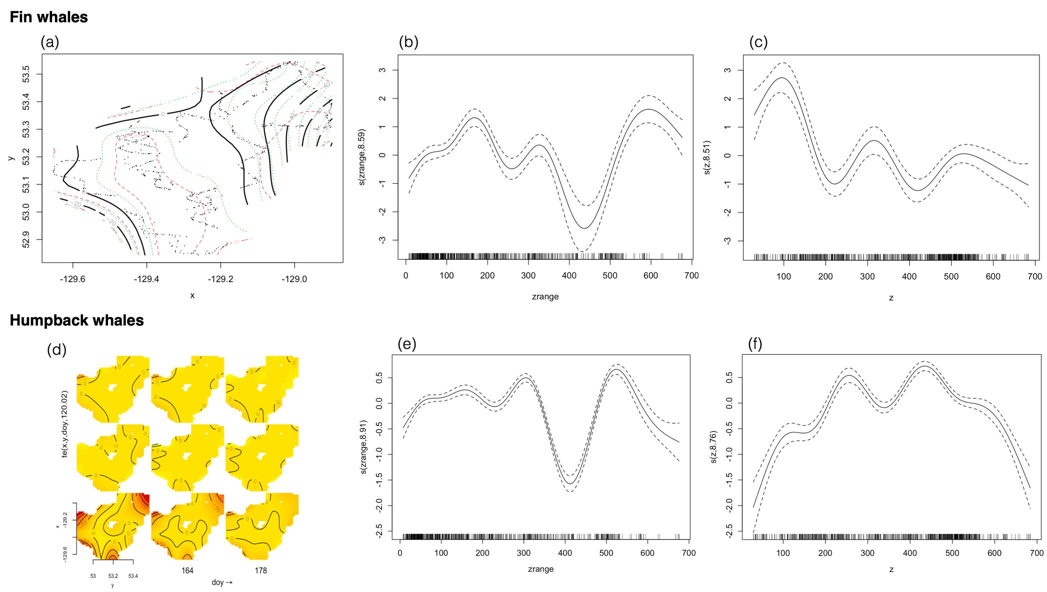


Table 10: Table S11. Fin whale density (bootstrapped 95% confidence interval) by waterway (whales per square km), , as estimated from the best-fitting density surface model.

Waterway	**Season**
Caamano	0.022 (0-0.126)
Campania	0.024 (0-0.148)
Estevan	0 (0-0)
McKay	0 (0-0)
Squally	0.031 (0-0.169)
Verney	0 (0-0)
Whale	0 (0-0)
Wright	0 (0-0)
Study area	0.014 (0-0.118)

Table 11: Table S12. Humpback whale density (bootstrapped 95% confidence interval) by waterway (whales per square km), , as estimated from the best-fitting density surface model.

Waterway	**Season**	**June**	**July**	**August**	**September**
Caamano	0.059 (0.012-0.153)	0.119 (0.006-0.74)	0.057 (0.006-0.113)	0.046 (0.005-0.094)	0.049 (0.013-0.139)
Campania	0.07 (0.012-0.139)	0.056 (0.001-0.131)	0.063 (0.01-0.158)	0.071 (0.007-0.186)	0.097 (0.015-0.249)
Estevan	0.037 (0.004-0.071)	0.119 (0.006-0.153)	0.021 (0.001-0.024)	0.046 (0.006-0.121)	0.047 (0.008-0.107)

McKay	0.049 (0.003-0.112)	0.007 (0.001-0.036)	0.02 (0.001-0.04)	0.068 (0-0.134)	0.102 (0.017-0.313)
Squally	0.11 (0.025-0.251)	0.132 (0.021-0.429)	0.041 (0.002-0.099)	0.161 (0.037-0.448)	0.102 (0.01-0.2)
Verney	0.072 (0.006-0.282)	0.006 (0-0.035)	0.029 (0.001-0.108)	0.085 (0.006-0.231)	0.154 (0.004-0.786)
Whale	0.113 (0.023-0.298)	0.03 (0.003-0.111)	0.015 (0.002-0.048)	0.196 (0.026-0.502)	0.165 (0.034-0.512)
Wright	0.117 (0.007-0.308)	0.033 (0-0.139)	0.081 (0.01-0.204)	0.164 (0.034-0.566)	0.154 (0-0.425)
Study area	0.079 (0.01-0.223)	0.083 (0.001-0.417)	0.046 (0.002-0.125)	0.1 (0.007-0.359)	0.095 (0.01-0.32)

Seasonality

Table 12: Table S13. Summary of GAM of seasonal fin whale abundance. This model was used to scale the June-September density estimate.

Family	**Formula**	**edf**	**P-value of coefficient**	**Deviance explained**
Negative binomial	count ~ s(doy, k=5) + offset(log(minutes))	2.803	7e-04	26%

Close-encounter rates

Table 13: Table S14. Close encounter rate estimates for each species and vessel class used in this study. Here summertime and wintertime distributions are pooled.

	Fin whales					Humpback whales				
Vessel type	**Median**	**Mean**	**SD**	**LCI**	**UCI**	**Median**	**Mean**	**SD**	**LCI**	**UCI**
Cargo > 180m	0.06	0.061	0.024	0.02	0.11	0.05	0.048	0.022	0.01	0.10
Cedar LNG tanker in-heel	0.08	0.086	0.030	0.04	0.15	0.07	0.070	0.025	0.03	0.12
Cedar LNG tanker in-product	0.08	0.086	0.031	0.03	0.14	0.07	0.067	0.025	0.03	0.12
Cedar LNG tug in-heel	0.02	0.024	0.015	0.00	0.06	0.01	0.016	0.013	0.00	0.04
Cedar LNG tug in-product	0.02	0.023	0.016	0.00	0.06	0.02	0.017	0.012	0.00	0.04
Fishing < 60m	0.02	0.023	0.015	0.00	0.05	0.01	0.015	0.012	0.00	0.04
LNG Canada tanker in-heel	0.09	0.087	0.026	0.04	0.14	0.07	0.071	0.025	0.03	0.12
LNG Canada tanker in-product	0.08	0.085	0.027	0.04	0.14	0.07	0.071	0.025	0.02	0.12
LNG Canada tug in-heel	0.02	0.024	0.014	0.00	0.06	0.02	0.016	0.012	0.00	0.04
LNG Canada tug in-product	0.02	0.022	0.015	0.00	0.05	0.01	0.015	0.012	0.00	0.04
Other < 40m	0.02	0.021	0.014	0.00	0.05	0.01	0.016	0.013	0.00	0.05
Other > 100m	0.04	0.046	0.021	0.01	0.09	0.04	0.038	0.021	0.01	0.09
Other > 40m	0.03	0.033	0.017	0.01	0.07	0.03	0.026	0.016	0.00	0.06
Passenger > 180m	0.06	0.061	0.023	0.02	0.11	0.05	0.051	0.020	0.01	0.10
Pleasurecraft < 40m	0.02	0.019	0.014	0.00	0.05	0.01	0.015	0.012	0.00	0.04
Sailing	0.02	0.019	0.013	0.00	0.05	0.01	0.014	0.012	0.00	0.04
Towing < 50m	0.02	0.024	0.015	0.00	0.05	0.02	0.020	0.014	0.00	0.05
Tug < 50m	0.02	0.024	0.015	0.00	0.06	0.02	0.019	0.014	0.00	0.05

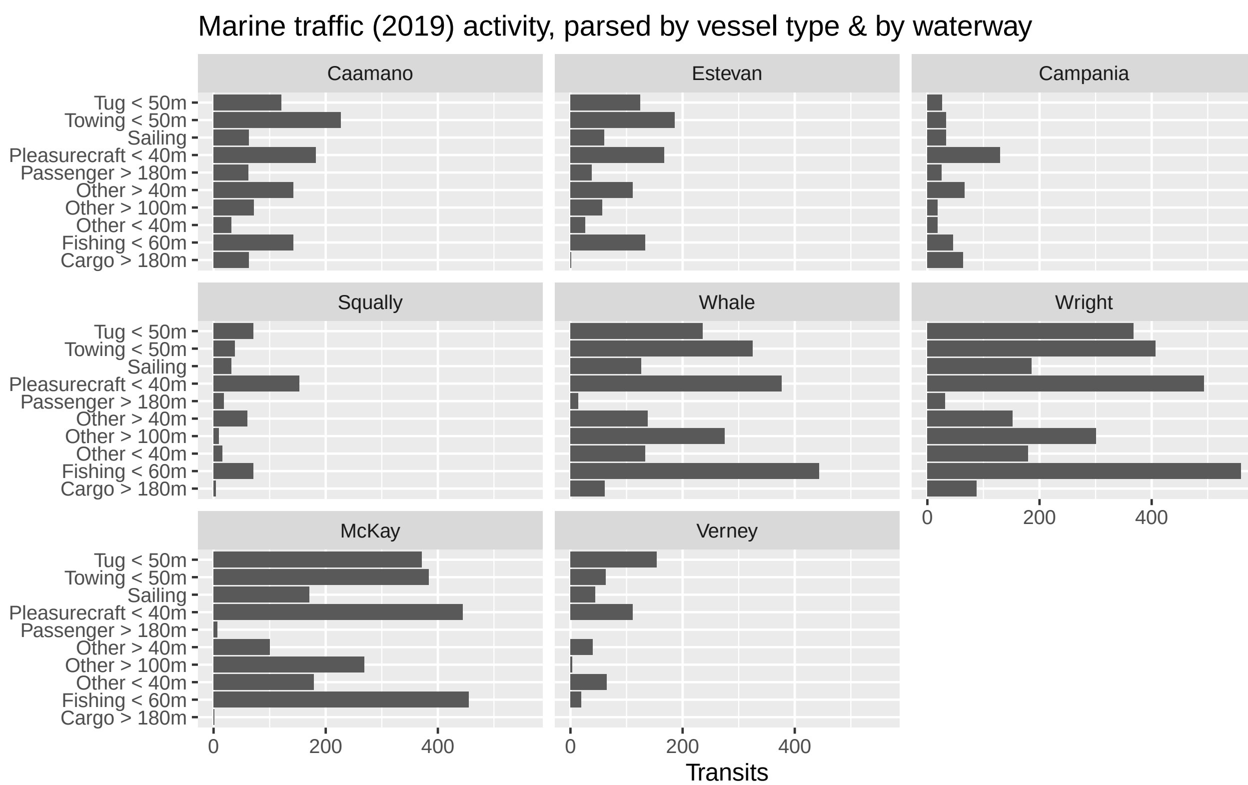


Figure 13: Figure S15. Transit counts for 10 vessel types in 2019, displayed for each waterway in the study area separately.

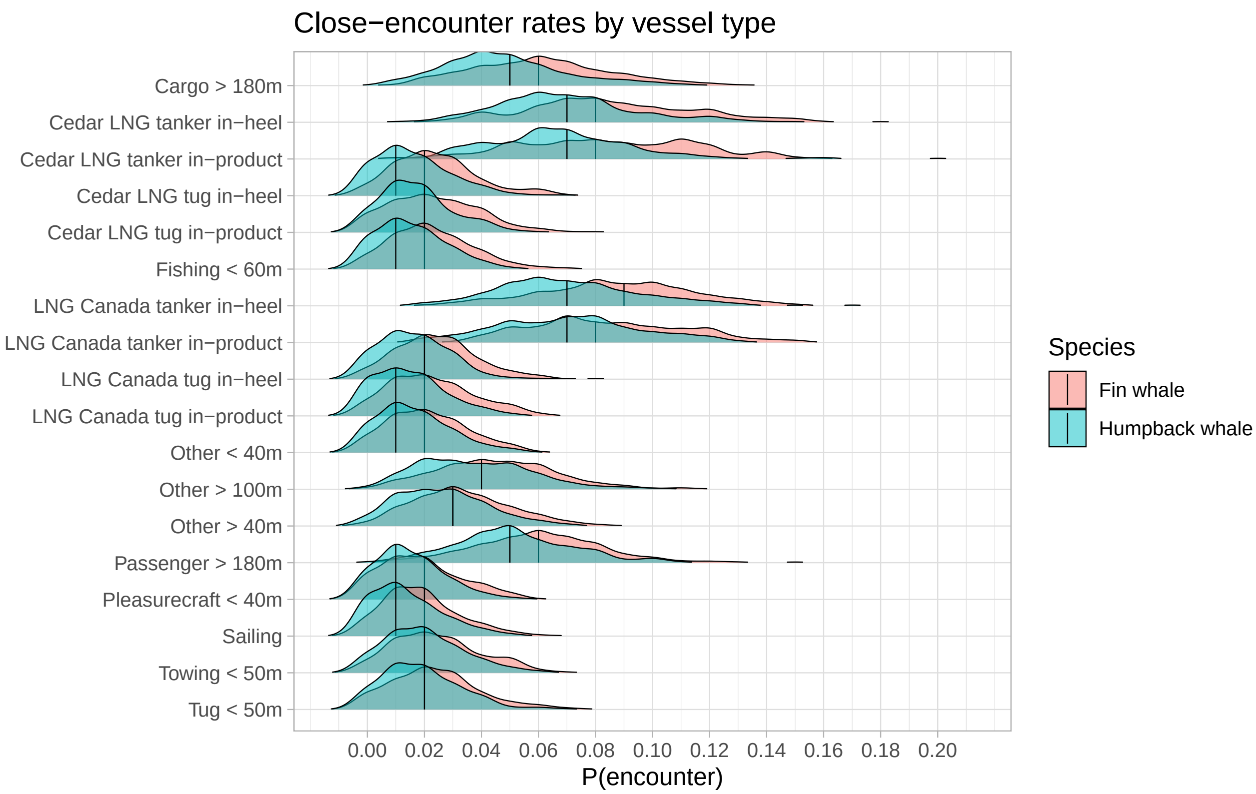


Figure 14: Figure S17. Distributions of close-encounter rate estimates for each vessel type (row) and each whale species (color), based upon iterative simulations. Vertical lines indicate the median of each distribution. Here summertime and wintertime distributions are pooled.

Depth distribution

Table 14: Table S15. Proportion of time fin whale spend above various depth cutoffs (1m, 2m, . . . , 30m), estimated for day and night separately based upon the mean and SD from six SPLASH-10 tag deployments.

	Daytime		Nighttime	
Depth (m)	**Mean**	**SD**	**Mean**	**SD**
1	8.7%	4.8%	8.3%	7.5%
2	14.4%	7.2%	18.1%	13.1%
5	26%	5.2%	41.1%	16.1%
10	37.1%	7.1%	59.2%	15.3%
15	47.5%	8%	72.1%	17%
20	55.4%	6.9%	82%	15.6%
25	60.9%	6.6%	85.3%	16%
30	63.3%	6.4%	89.5%	12.9%

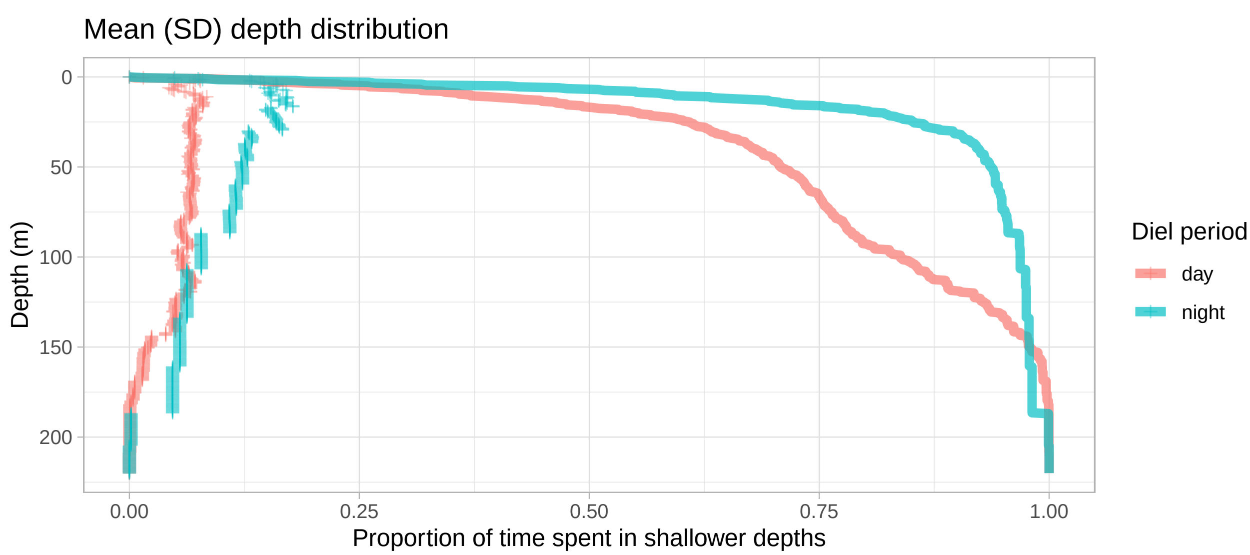


Figure 15: Figure S18. Daytime (pink) and nighttime (teal) depth distribution curves for fin whale in and near the Kitimat Fjord System, representing the average proportion of time spent above a given depth across all tag deployments (n=6 in 2013 and 2014). Points on the left side of the plot represent the SD at each depth.

Interaction rates

Table 15: Table S16. Predictions of whale-vessel interaction rates for all vessel types in each traffic scheme.

	Fin whales	Humpback

Traffic scheme	Event	Mean	Median	95% CI	80% Conf.	Mean	Median	95
AIS 2019	Cooccurrence	509.21	509.0	471 - 549	488	5958.69	5961.0	582
	Close encounter	13.59	13.5	8 - 19	10	119.59	120.0	10
	Strike-zone event	3.06	3.0	1 - 6	2	25.56	25.0	1
	(1.5x draft)	3.00	3.0	0 - 6	2	25.59	25.0	1
AIS 2030	Cooccurrence	855.99	856.0	802 - 912	827	9428.00	9428.0	922
	Close encounter	22.79	22.5	16 - 31	19	184.71	184.0	16
	Strike-zone event	4.89	5.0	2 - 9	3	39.13	39.0	2
	(1.5x draft)	5.03	5.0	2 - 9	3	38.87	38.5	3
LNG Canada	Cooccurrence	137.66	137.0	116 - 161	127	1710.28	1710.0	163
	Close encounter	7.20	7.0	3 - 12	5	70.41	70.0	5
	Strike-zone event	3.01	3.0	0 - 6	1	30.11	30.0	2
	(1.5x draft)	3.01	3.0	0 - 6	1	30.13	30.0	2
Cedar LNG	Cooccurrence	19.40	19.0	13 - 27	16	236.57	237.0	21
	Close encounter	1.06	1.0	0 - 3	0	9.75	10.0	5
	Strike-zone event	0.44	0.0	0 - 2	0	4.37	4.0	
	(1.5x draft)	0.45	0.0	0 - 2	0	4.33	4.0	
Total 2030	Cooccurrence	1013.05	1013.5	954 - 1074	981	11374.85	11373.0	1115
	Close encounter	31.05	31.0	23 - 40	26	264.87	265.0	23
	Strike-zone event	8.34	8.0	4 - 13	6	73.61	73.0	6
	(1.5x draft)	8.50	8.0	4 - 14	6	73.33	73.0	5

Shares of interaction risk by vessel

Table 16: Table S17. Share of interactions risk attributable to each vessel type, in 2019 and in 2030.

		Fin whales			
Year	**Vessel**	**Cooccurrence**	**Close encounter**	**Strike-zone event**	**Cooccurrence**
2019	Cargo > 180m	2	5	11	2
	Fishing < 60m	13	11	6	16
	Other < 40m	3	3	1	8
	Other > 100m	3	5	7	7
	Other > 40m	11	12	11	10
	Passenger > 180m	7	17	27	3

	Pleasurecraft < 40m	27	18	7	23
	Sailing	11	8	3	10
	Towing < 50m	14	12	16	9
	Tug < 50m	10	8	11	11
2030	Cargo > 180m	2	4	6	2
	Cedar LNG tanker in-heel	0	1	2	1
	Cedar LNG tanker in-product	0	1	2	1
	Cedar LNG tug in-heel	0	0	0	1
	Cedar LNG tug in-product	0	0	0	1
	Fishing < 60m	12	9	4	16
	LNG Canada tanker in-heel	3	9	17	4
	LNG Canada tanker in-product	3	9	15	4
	LNG Canada tug in-heel	3	3	2	4
	LNG Canada tug in-product	3	2	2	4
	Other < 40m	0	0	0	0
	Other > 100m	2	3	3	5
	Other > 40m	7	7	6	7
	Passenger > 180m	7	13	18	3
	Pleasurecraft < 40m	24	15	4	22
	Sailing	13	9	3	13
	Towing < 50m	11	9	9	8
	Tug < 50m	7	5	6	8

Shares of interaction risk by waterway

Table 17: Table S18. Share of interactions risk attributable to each waterway, in 2019 and in 2030.

		Fin whales			Humpback whales	
Year	**Channel**	**Cooccurrence**	**Close encounter**	**Strike-zone event**	**Cooccurrence**	**Close encounter**
2019	Caamano	61	60	63	14	14
	Estevan	0	0	0	5	5
	Campania	15	16	17	4	5
	Squally	24	23	20	8	7
	Whale	0	0	0	39	38
	Wright	0	0	0	12	12
	McKay	0	0	0	16	15
	Verney	0	0	0	4	3
2030	Caamano	51	44	37	12	11
	Estevan	0	0	0	6	7
	Campania	13	12	10	4	4
	Squally	35	43	52	11	13
	Whale	1	1	1	43	46
	Wright	0	0	0	9	8
	McKay	0	0	0	12	10

	Verney	0	0	0	3	2

Shares of interaction risk by month

Table 18: Table S19. Share of interactions risk attributable to each month, in 2019 and in 2030.

		Fin whales			Humpback whales		
Year	**Month**	**Cooccurrence**	**Close encounter**	**Strike-zone event**	**Cooccurrence**	**Close encounter**	**St**
2019	Jan	0	0	0	0	0	
	Feb	0	0	0	0	0	
	Mar	0	0	0	0	0	
	Apr	0	0	0	0	0	
	May	5	6	7	3	3	
	Jun	14	15	15	16	16	
	Jul	21	21	19	10	10	
	Aug	37	34	31	34	33	
	Sep	16	17	19	32	32	
	Oct	5	6	6	4	5	
	Nov	1	1	1	1	1	
	Dec	0	0	0	0	0	
2030	Jan	0	0	0	0	0	
	Feb	0	0	0	0	0	
	Mar	0	0	0	0	0	
	Apr	0	1	1	0	0	
	May	5	5	7	3	3	
	Jun	14	15	15	16	16	
	Jul	21	21	22	11	11	
	Aug	37	33	27	37	36	
	Sep	16	17	20	28	28	
	Oct	6	6	7	4	5	
	Nov	1	1	1	1	1	
	Dec	0	0	0	0	0	

Shares of interaction risk by diel period

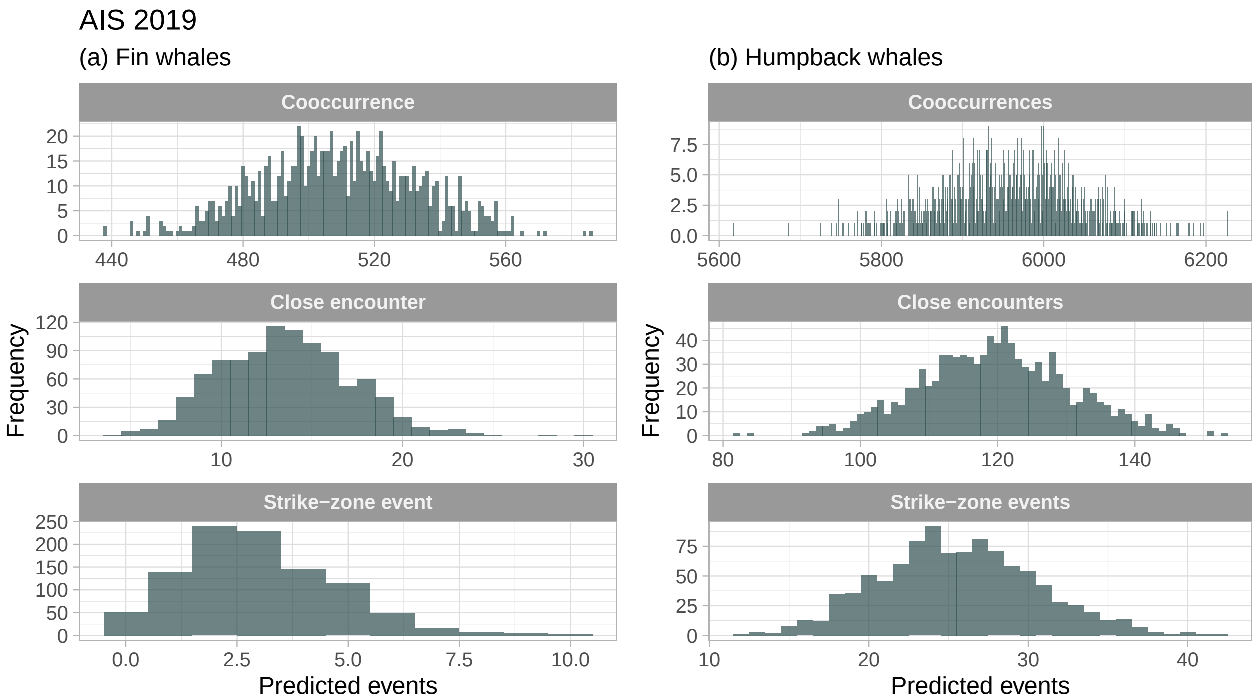


Figure 16: Figure S19. Distribution of whale-vessel interaction rate predictions for AIS traffic in 2019.

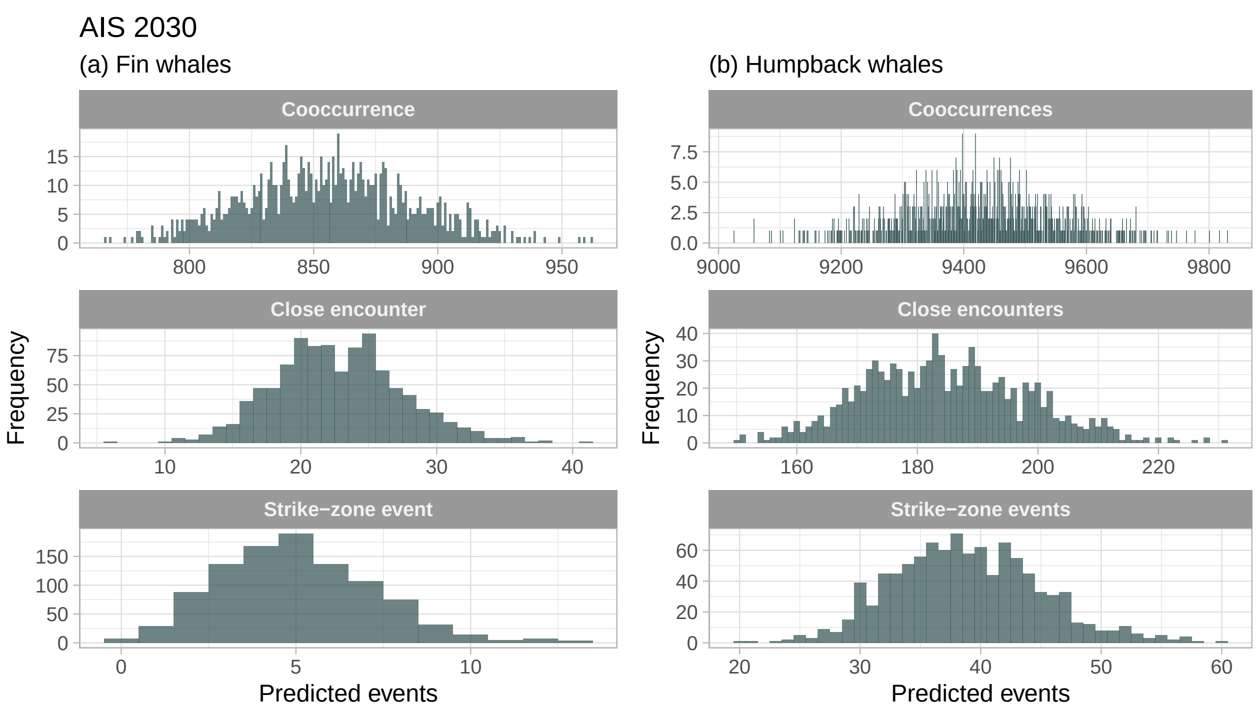


Figure 17: Figure S20. Distribution of whale-vessel interaction rate predictions for AIS traffic in 2030.

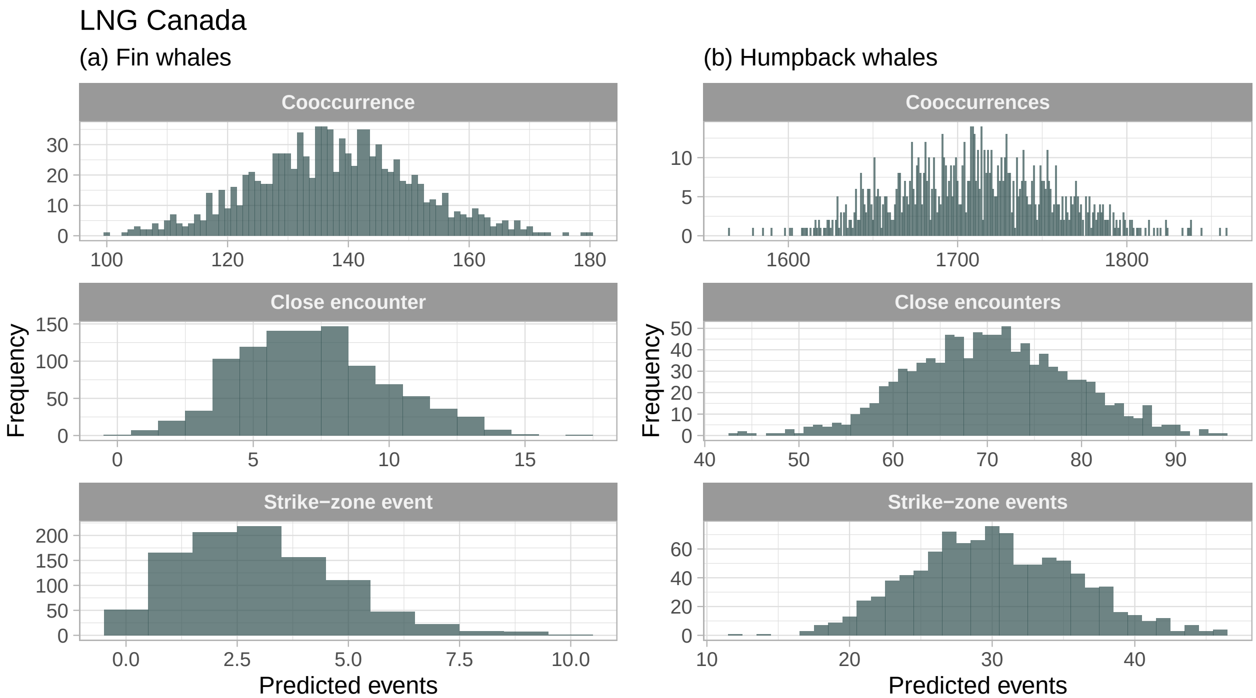


Figure 18: Figure S21. Distribution of whale-vessel interaction rate predictions for LNG Canada traffic in 2030.

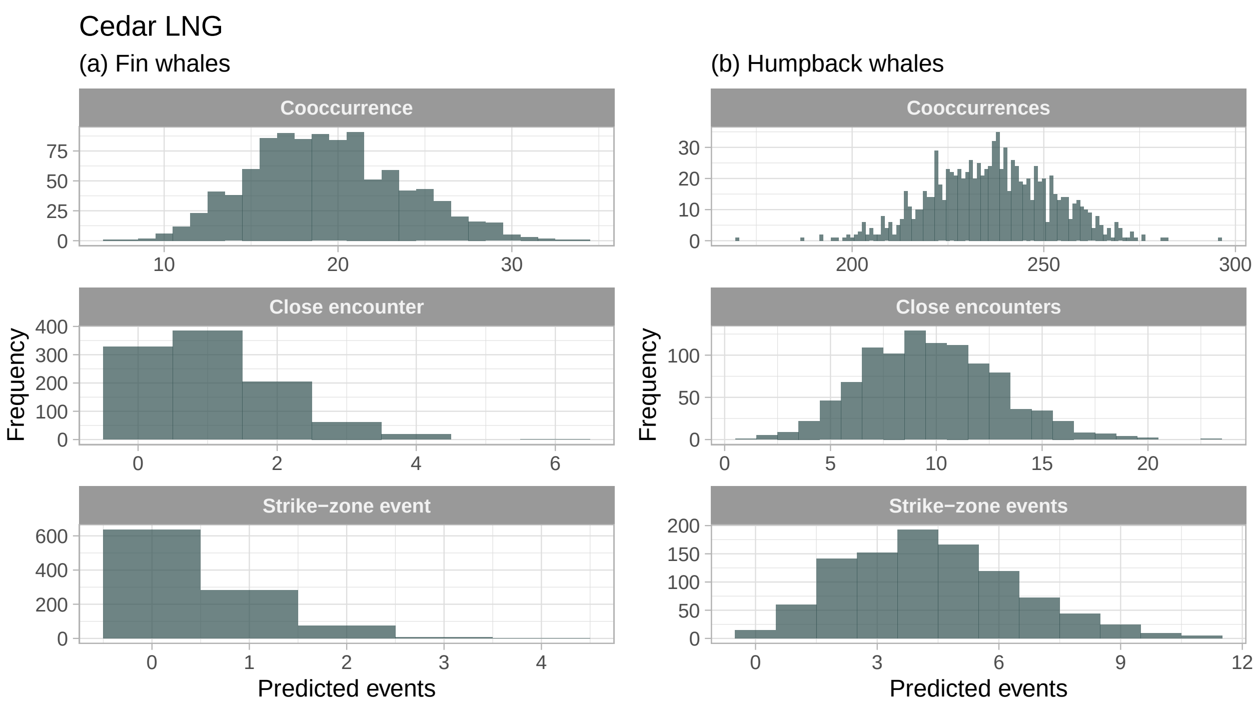


Figure 19: Figure S22. Distribution of whale-vessel interaction rate predictions for Cedar LNG traffic in 2030.

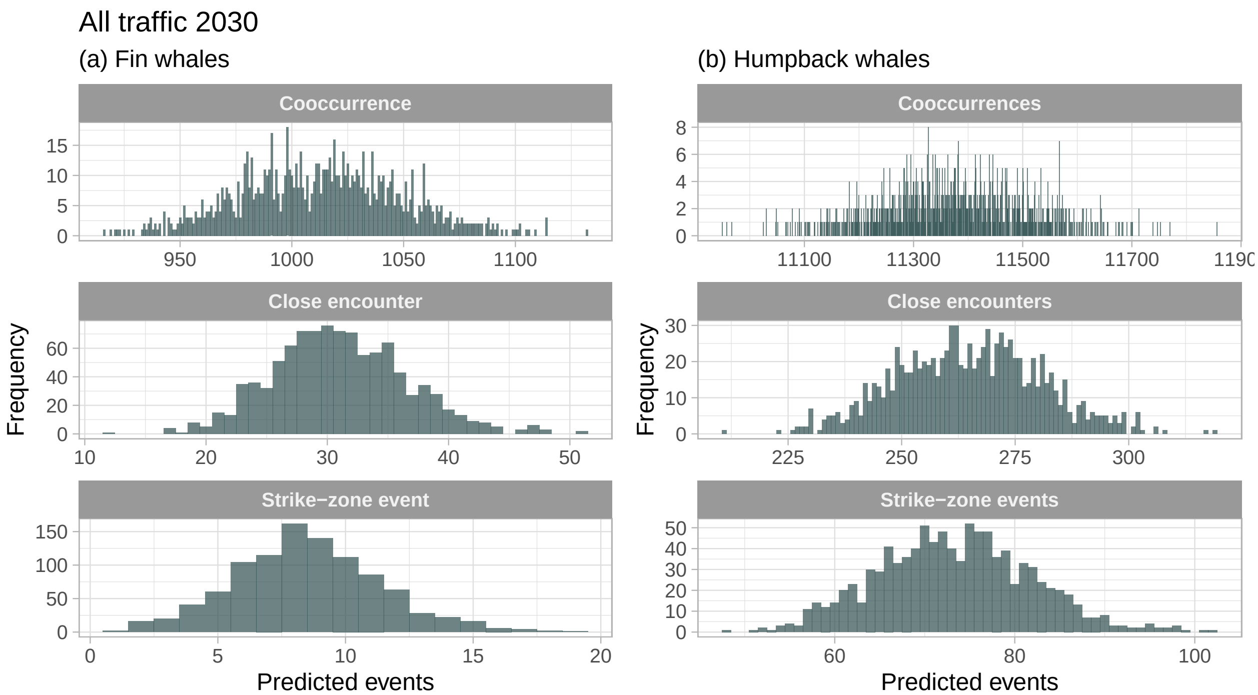


Figure 20: Figure S23. Distribution of whale-vessel interaction rate predictions for all traffic in 2030 (AIS and LNG combined).

Table 19: Table S20. Share of interaction risk attributable to each diel period, in 2019 and in 2030.

		Fin whales			Humpback whal	
Year	**Diel period**	**Cooccurrence**	**Close encounter**	**Strike-zone event**	**Cooccurrence**	**Close encounter**
2019	day	89	87	78	83	79
	night	11	13	22	17	21
2030	day	87	84	71	82	78
	night	13	16	29	18	22

Collisions & mortalities

Table 20: Table S21. Predicted rates of collision and mortality for large ships (> 180m) in each traffic scheme and for each whale species.

			Fin whales				Humpback whales		
Traffic scheme	**Event**	**Avoidance**	**Mean**	**Median**	**95% CI**	**80% Conf.**	**Mean**	**Median**	**95% CI**
AIS 2019	Collision	0.55	0.48	0	0 - 2	0	2.92	3	0 - 6
		~ Speed	0.7724	1	0 - 2	0	3.89	4	1 - 8
		None	1.13	1	0 - 3	0	6.44	6	2 - 11
	Mortality	0.55	0.47	0	0 - 2	0	2.73	3	0 - 6
		~ Speed	0.74	1	0 - 2	0	3.70	4	1 - 7

	None	5.10	5	2 - 9	3	42.94	43	33 - 54
Mortality	0.55	2.03	2	0 - 4	1	16.78	17	10 - 24
	~ Speed	2.44	2	0 - 5	1	18.02	18	12 - 25
	None	4.54	4	1 - 8	3	37.48	37	28 - 48

Table 21: Table S22. Share of large ship (>180m) collision and mortality risk attributable to each waterway, in 2019 and in 2030.

	Fin whales				Humpback whales			
	Collision		Mortality		Collision		Mortality	
Waterway	**2019**	**2030**	**2019**	**2030**	**2019**	**2030**	**2019**	**2030**
Caamano	59	29	61	30	17	9	17	10
Estevan	0	0	0	0	5	8	4	8
Campania	25	11	23	13	7	4	7	4
Squally	15	59	15	56	5	16	5	16
Whale	0	1	1	1	39	50	39	50
Wright	0	0	0	0	14	7	15	7
McKay	0	0	0	0	12	5	12	5
Verney	0	0	0	0	1	0	1	0

Table 22: Table S23. Share of large ship (>180m) collision and mortality risk attributable to each month, in 2019 and in 2030.

	Fin whales				Humpback whales			
	Collision		Mortality		Collision		Mortality	
Month	**2019**	**2030**	**2019**	**2030**	**2019**	**2030**	**2019**	**2030**
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	1	1	1	0	1	0	1
5	4	5	5	5	3	3	3	3
6	21	18	23	18	17	16	17	17
7	19	21	16	19	11	11	11	11
8	30	27	27	29	30	36	30	35
9	21	19	23	21	32	27	32	27

10	3	7	3	7	5	5	5	5
11	0	1	1	1	1	1	1	1
12	0	0	0	0	0	0	0	0

Table 23: Table S24. Share of large ship (>180m) collision and mortality risk attributable to each diel period, in 2019 and in 2030.

	Fin whales				Humpback whales			
	Collision		Mortality		Collision		Mortality	
Diel period	**2019**	**2030**	**2019**	**2030**	**2019**	**2030**	**2019**	**2030**
day	80	73	83	72	61	61	60	62
night	20	27	17	28	39	39	40	38

Chances of certain outcome severities

Table 24: Table S25. Chances of various large ship (>180m) impact severities for fin whales and humpback whales, due to present-day AIS-transmitting traffic (represented by 2019 traffic), projected AIS-transmitting traffic in 2030, projected LNG Canada traffic, projected Cedar LNG traffic, then all traffic in 2030 (previous categories combined).

		AIS 2019		AIS 2030		LNG Canada		Cedar LNG		All traffic	
Species	**Chances (%) of...**	**Coll.**	**Mort.**	**Coll.**	**Mort.**	**Coll.**	**Mort.**	**Coll.**	**Mort.**	**Coll.**	**M**
Fin whale	Zero	33.1	37.7	14.0	19.1	28.5	33.7	83.4	85.6	3.8	
	At least 1	66.9	62.3	86.0	80.9	71.5	66.3	16.6	14.4	96.2	9
	At least 2	32.9	26.6	55.0	45.8	34.8	27.1	1.3	0.9	83.7	7
	At least 3	11.1	7.5	27.1	20.9	13.8	9.3	0.0	0.0	65.2	5
	At least 4	3.4	1.6	11.7	8.5	4.8	2.1	0.0	0.0	41.9	3
	At least 5	0.6	0.2	5.2	2.6	0.9	0.4	0.0	0.0	24.2	1
Humpback whale	Zero	0.0	0.3	0.0	0.0	0.0	0.0	18.7	25.4	0.0	
	At least 1	100.0	99.7	100.0	100.0	100.0	100.0	81.3	74.6	100.0	1
	At least 2	99.8	99.4	100.0	100.0	100.0	100.0	49.4	38.3	100.0	1
	At least 3	99.1	97.9	100.0	100.0	100.0	99.8	24.3	18.1	100.0	1
	At least 4	97.8	96.1	100.0	99.8	99.9	99.6	9.7	6.2	100.0	1
	At least 5	95.6	89.8	99.9	99.4	99.5	98.6	3.0	1.3	100.0	1

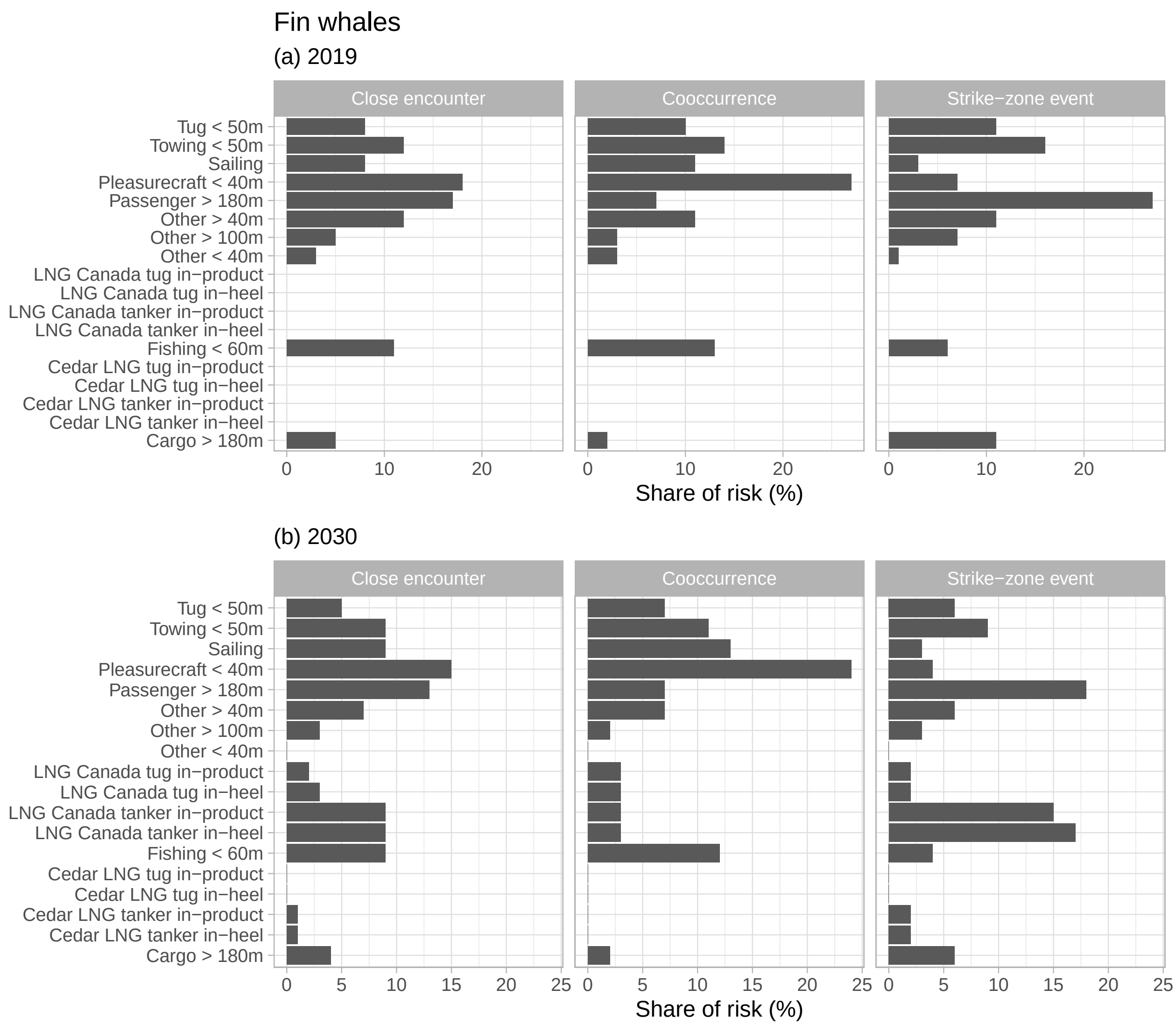


Figure 21: Figure S24. Share of interactions risk attributable to each vessel type, in 2019 and in 2030, for fin whales.

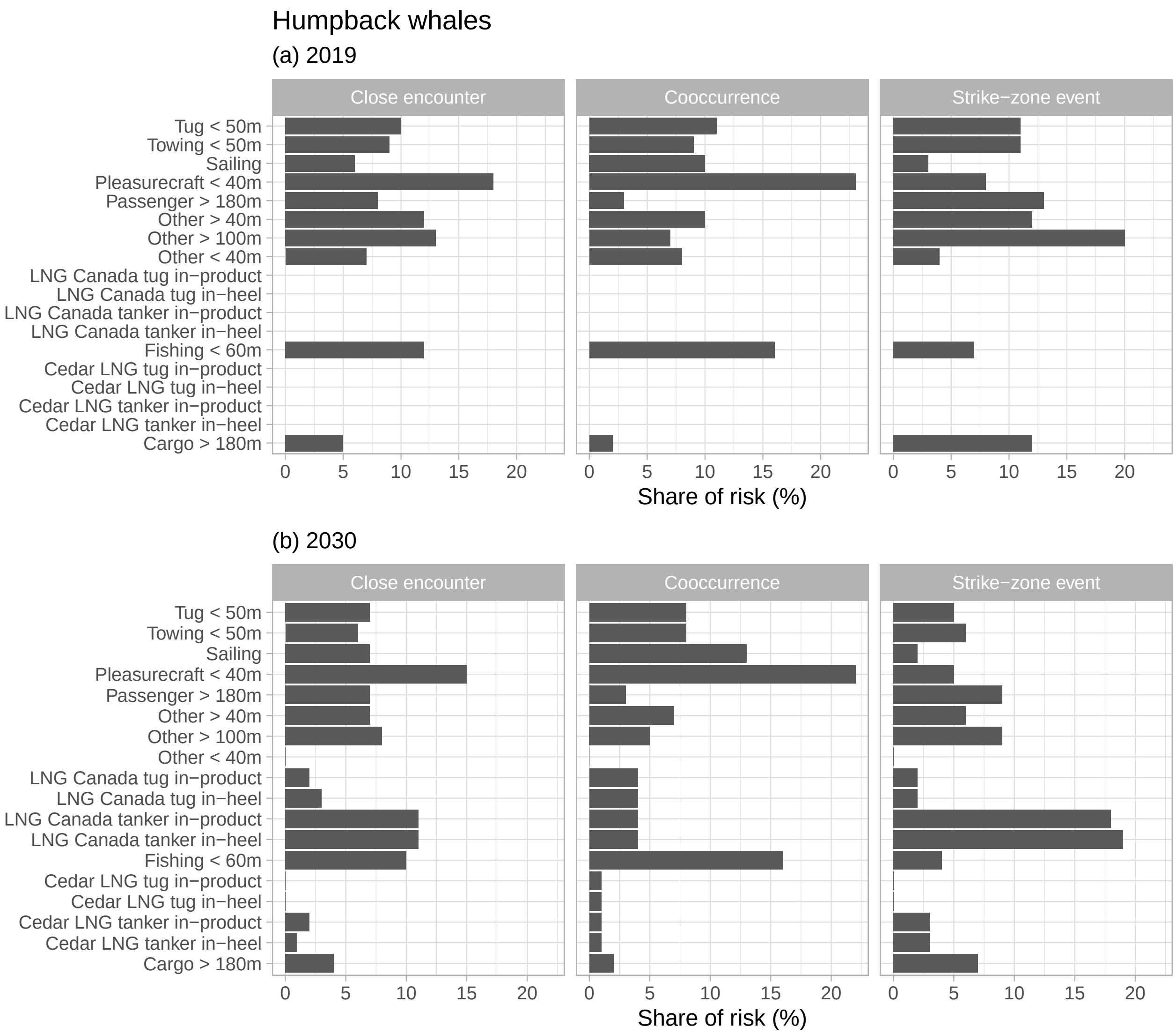


Figure 22: Figure S25. Share of interaction risk attributable to each vessel type, in 2019 and in 2030, for humpback whales.

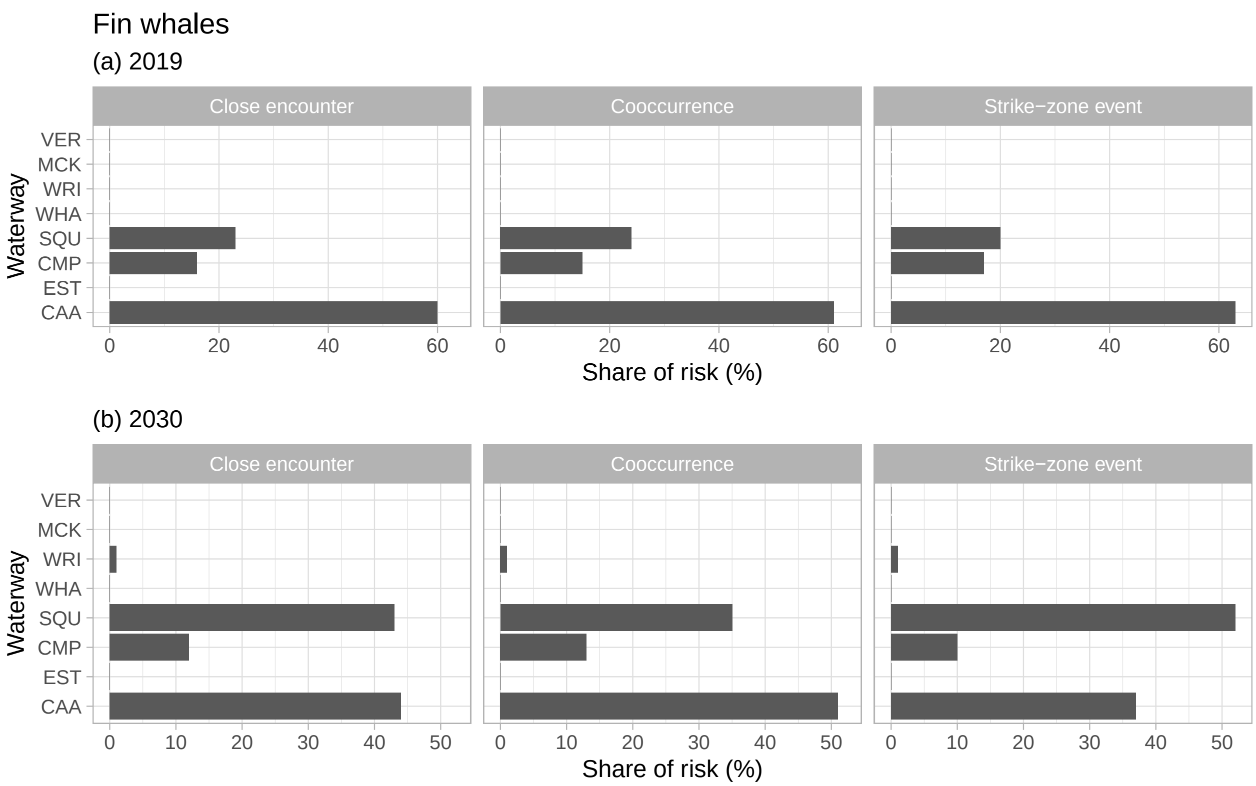


Figure 23: Figure S26. Share of interaction risk attributable to each waterway, in 2019 and in 2030, for fin whales.

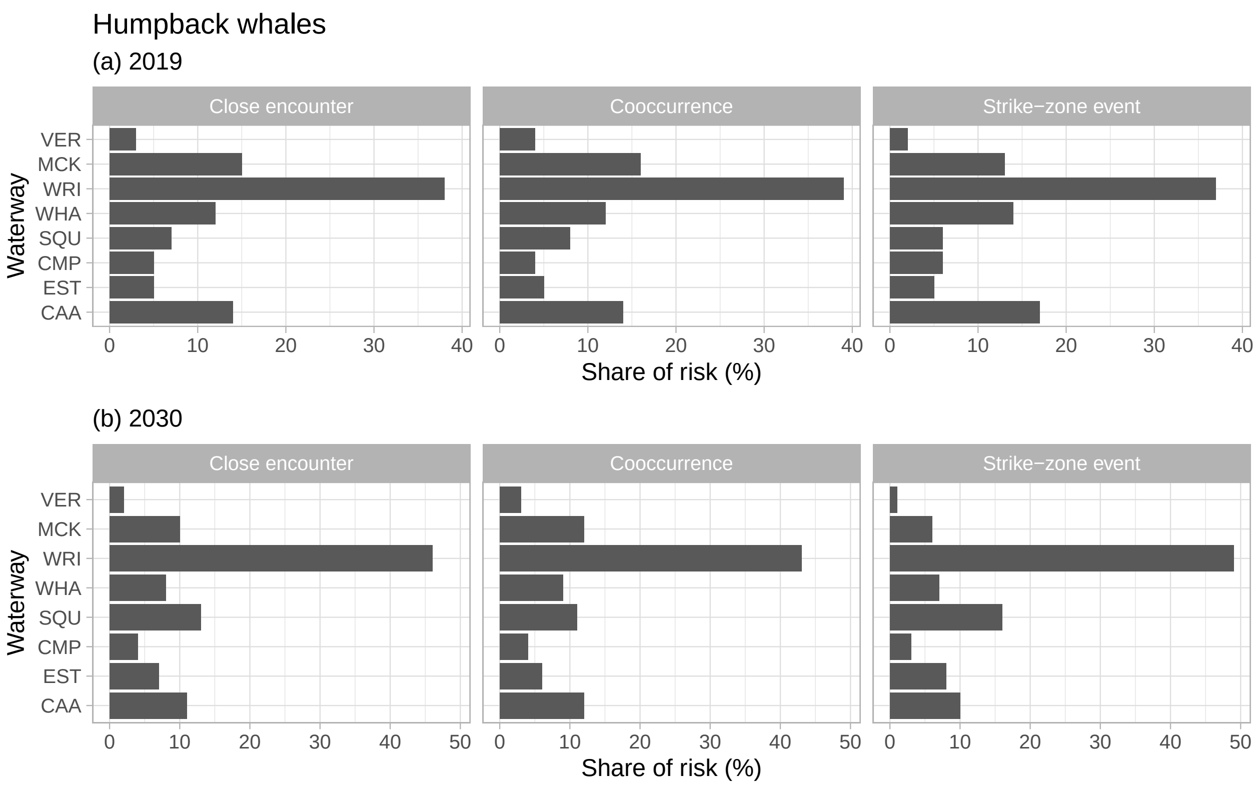


Figure 24: Figure S27. Share of interactions risk attributable to each waterway, in 2019 and in 2030, for humpback whales.

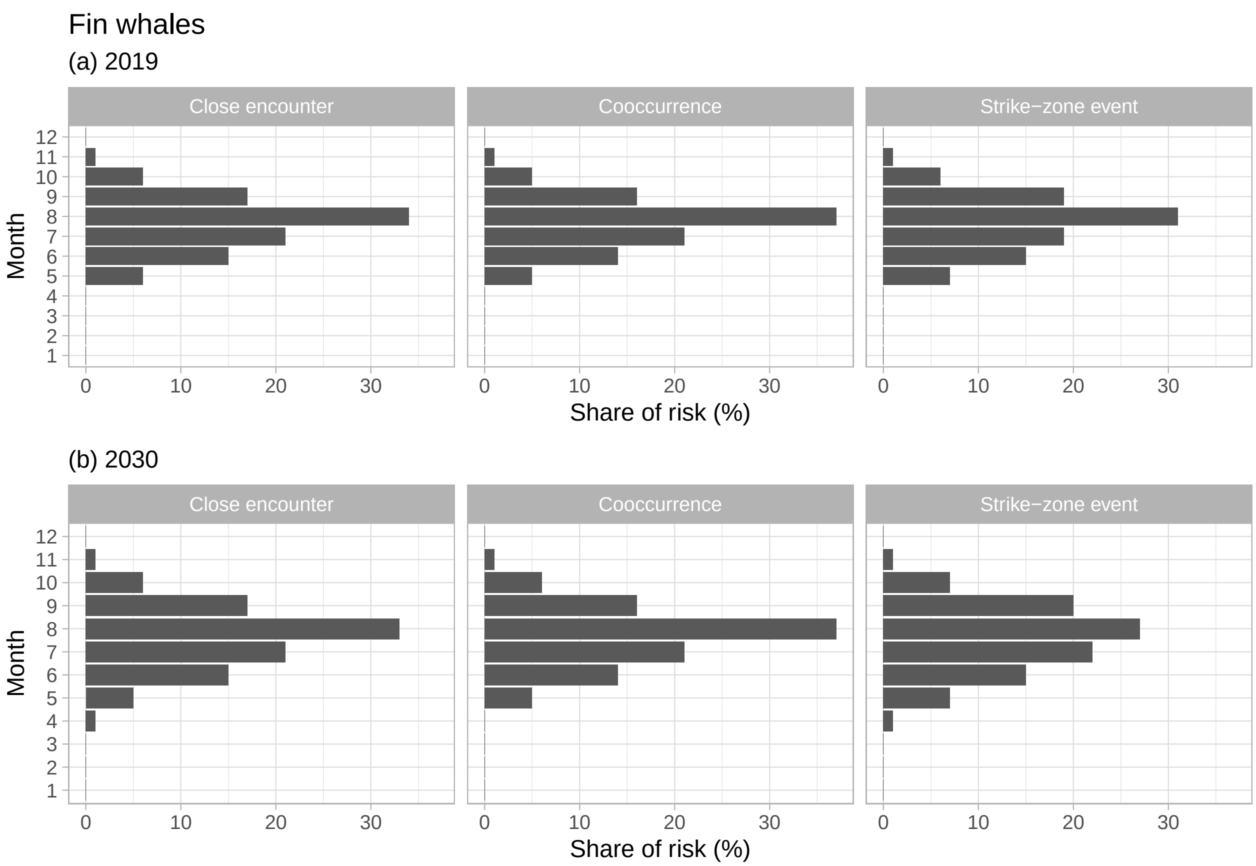


Figure 25: Figure S28. Share of interactions risk attributable to each month, in 2019 and in 2030, for fin whales.

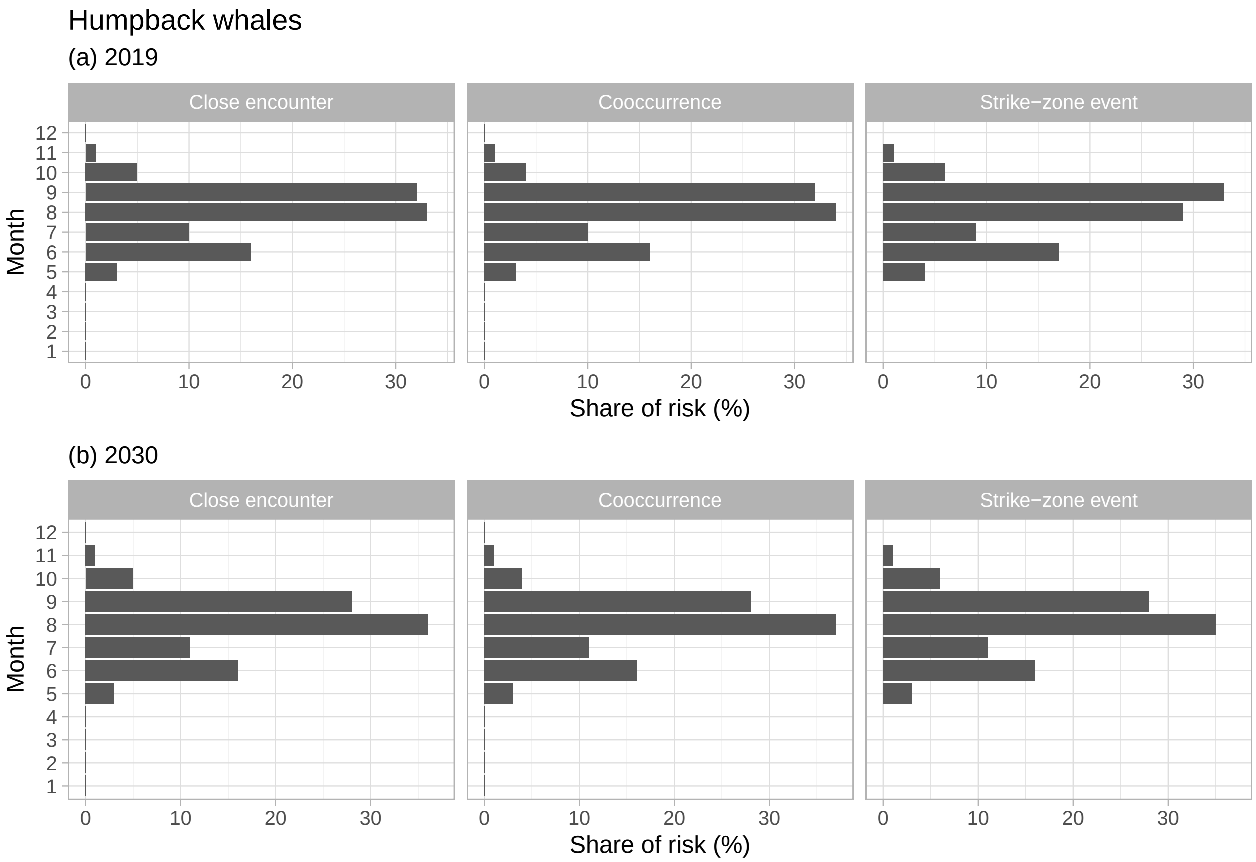


Figure 26: Figure S29. Share of interactions risk attributable to each month, in 2019 and in 2030, for humpback whales.

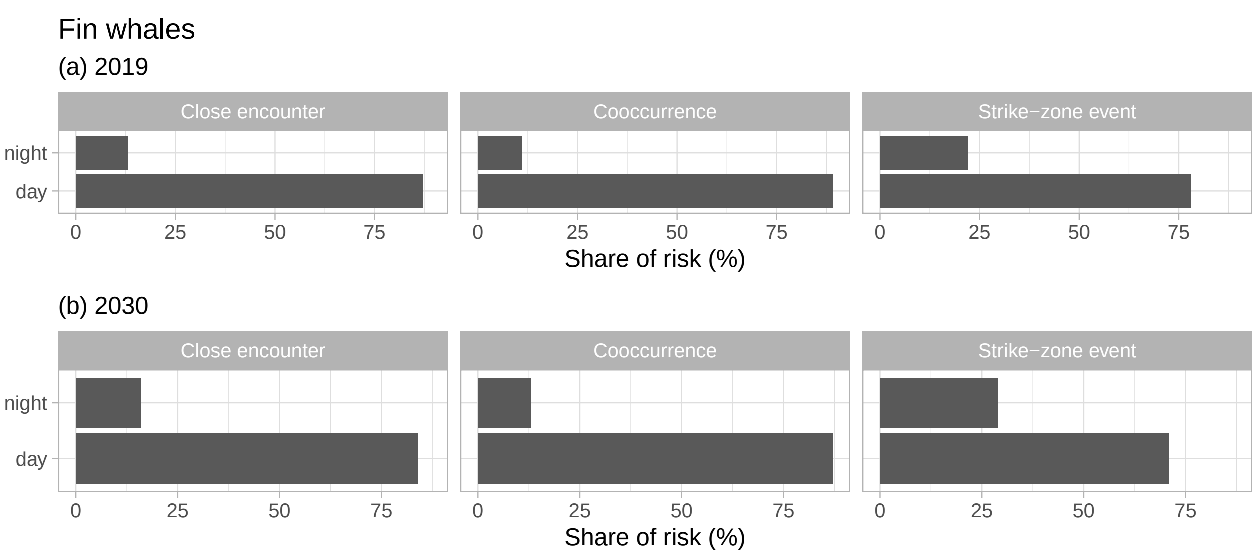


Figure 27: Figure S30. Share of interactions risk attributable to each diel period, in 2019 and in 2030, for fin whales.

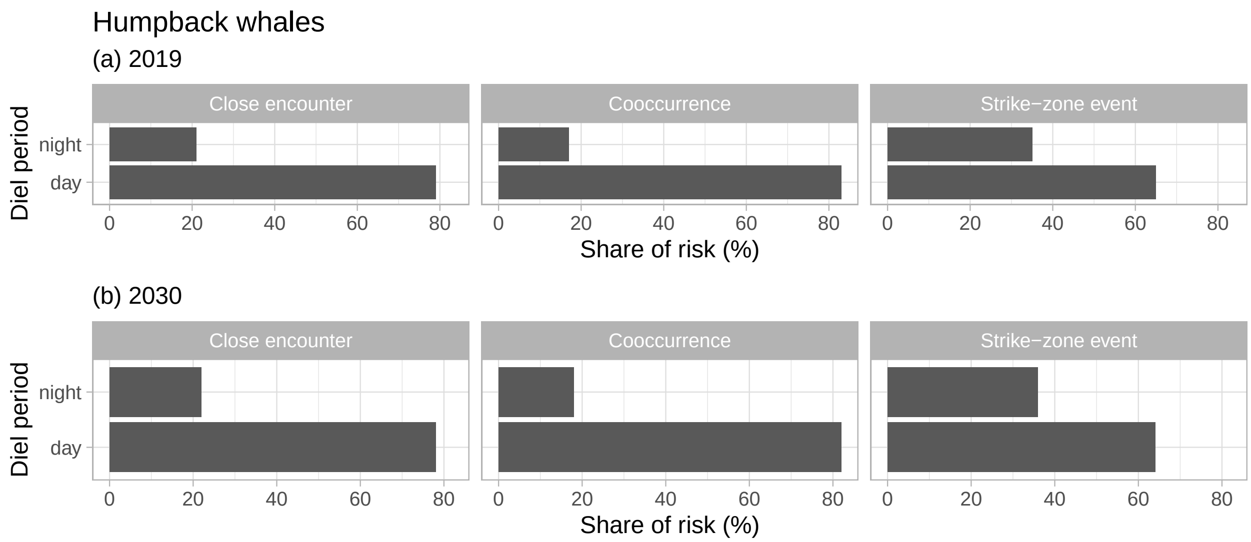


Figure 28: Figure S31. Share of interactions risk attributable to each diel period, in 2019 and in 2030, for humpback whales.

Table 25: Table S26. Chances of large ship (>180m) impact severities for fin whales and humpback whales, similar to above, now described as the chances of experiencing *no more than* the stated number of events.

		AIS 2019		AIS 2030		Cedar LNG		LNG Canada		All traffic
Species	**Chances (%) of...**	**Coll.**	**Mort.**	**Coll.**	**Mort.**	**Coll.**	**Mort.**	**Coll.**	**Mort.**	**Coll.**
Fin whale	Zero	33.1	37.7	14.0	19.1	83.4	85.6	28.5	33.7	3.8
	Max of 1	67.1	73.4	45.0	54.2	98.7	99.1	65.2	72.9	16.3
	Max of 2	88.9	92.5	72.9	79.1	100.0	100.0	86.2	90.7	34.8
	Max of 3	96.6	98.4	88.3	91.5	100.0	100.0	95.2	97.9	58.1
	Max of 4	99.4	99.8	94.8	97.4	100.0	100.0	99.1	99.6	75.8
	Max of 5	99.7	99.8	98.3	99.3	100.0	100.0	99.6	99.8	87.6
Humpback whale	Zero	0.0	0.3	0.0	0.0	18.7	25.4	0.0	0.0	0.0
	Max of 1	0.2	0.6	0.0	0.0	50.6	61.7	0.0	0.0	0.0
	Max of 2	0.9	2.1	0.0	0.0	75.7	81.9	0.0	0.2	0.0
	Max of 3	2.2	3.9	0.0	0.2	90.3	93.8	0.1	0.4	0.0
	Max of 4	4.4	10.2	0.1	0.6	97.0	98.7	0.5	1.4	0.0
	Max of 5	9.9	20.7	0.5	1.7	99.2	99.8	1.2	4.3	0.0

Validation

Fin whales

```
## Melting outcomes & prepping the posterior ...
```

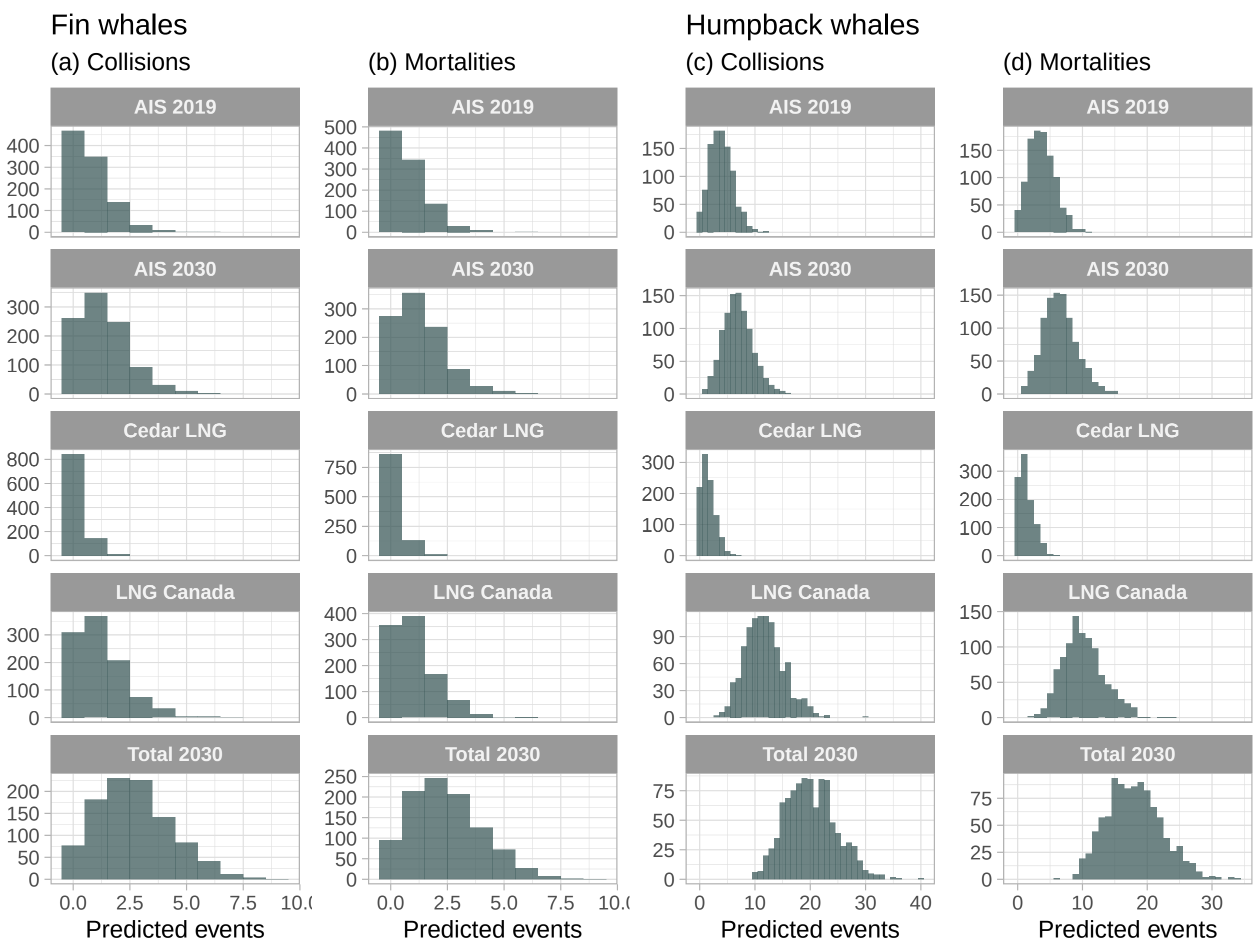


Figure 29: Figure S32. Posterior distributions of collision and mortality estimates for fin whales (a - b) and humpback whales (c-d), for each traffic scheme we analyzed.

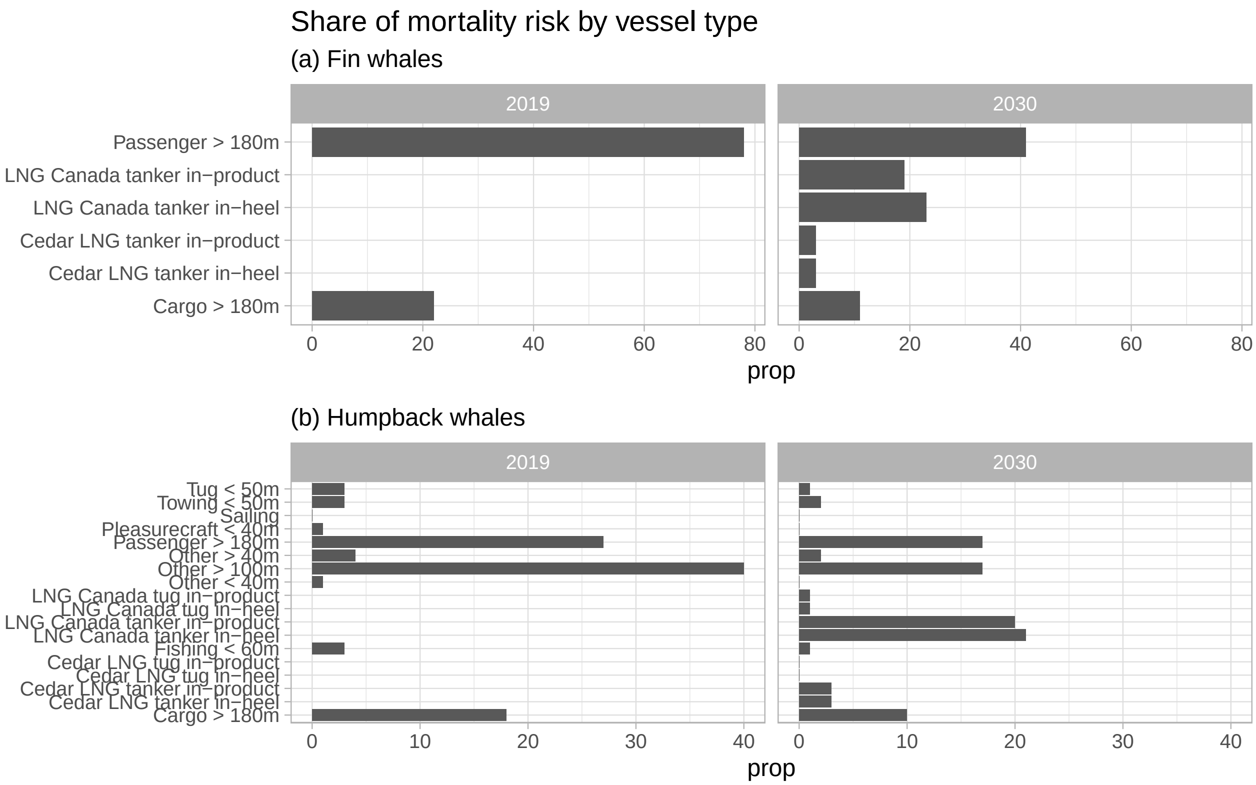


Figure 30: Figure S33. Share of collision and mortality risk attributable to each vessel type, in 2019 and in 2030.

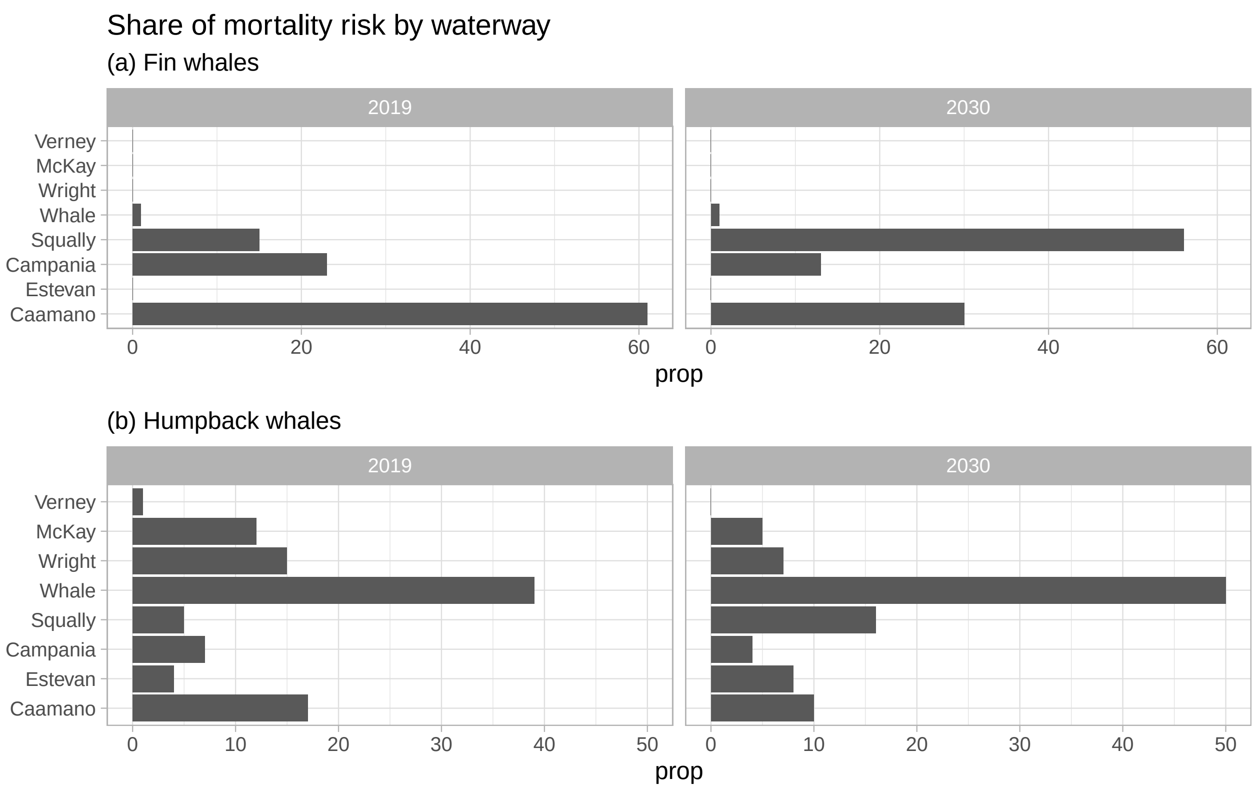


Figure 31: Figure S34. Share of collision and mortality risk attributable to each waterway, in 2019 and in 2030.

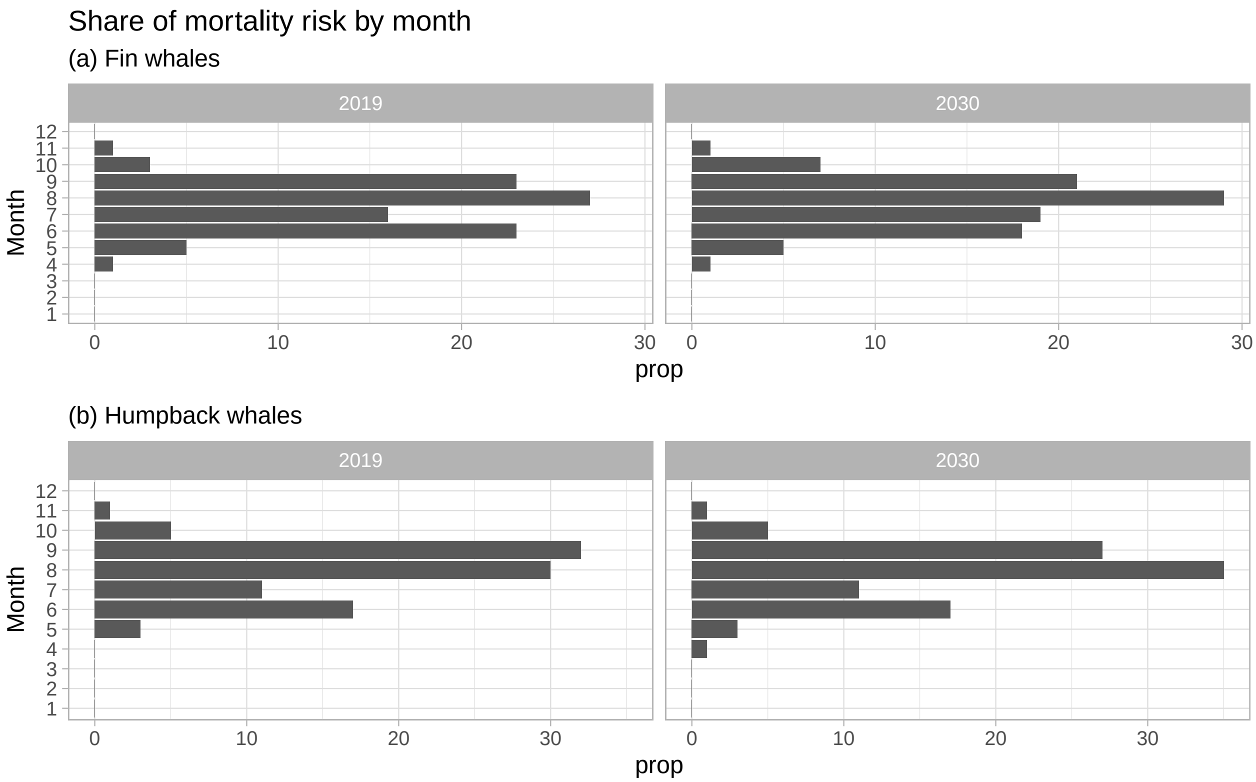


Figure 32: Figure S35. Share of collision and mortality risk attributable to each month, in 2019 and in 2030.

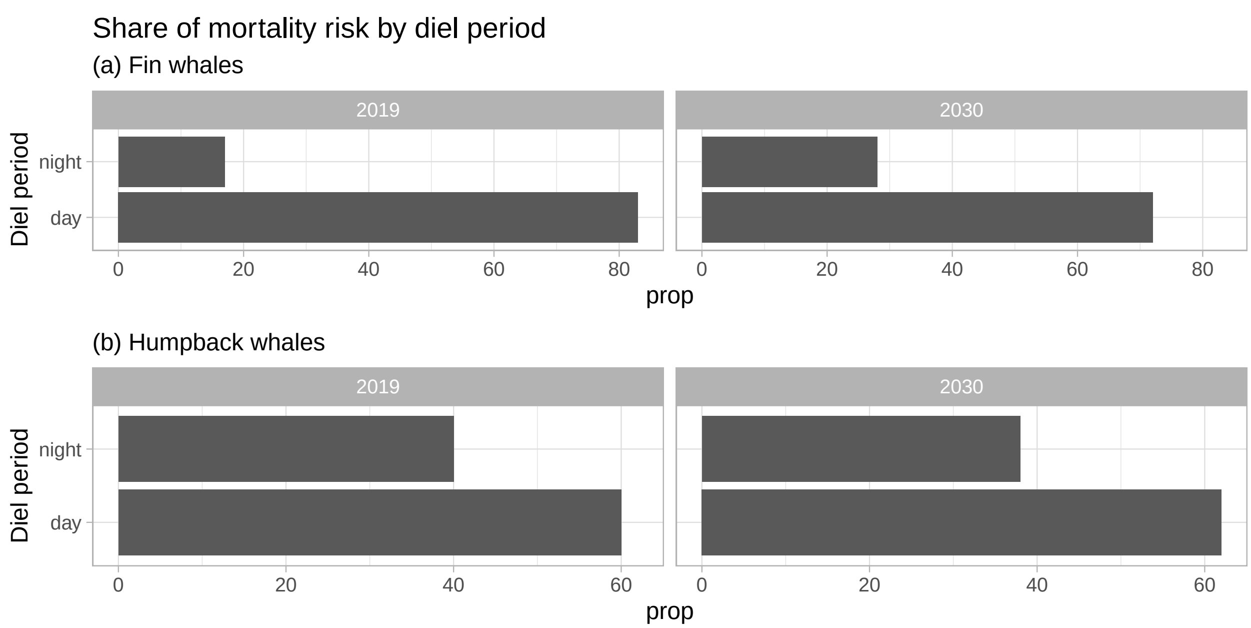


Figure 33: Figure S36. Share of collision and mortality risk attributable to each diel period, in 2019 and in 2030.

```
## Determining the probability of your observations ...
## Likelihood of your observation, assuming perfect detection = 0.003
## Finding the strike detection rate (SDR) that would make your observations plausible ...
## preparing L ~ SDR plot ...
## --- SDR needed for P(Observation) of 0.05 = 0.475
## --- SDR needed for P(Observation) of 0.10 = 0.375
## --- SDR needed for P(Observation) of 0.20 = 0.26
## --- SDR needed for P(Observation) of 0.55 = 0.1
```

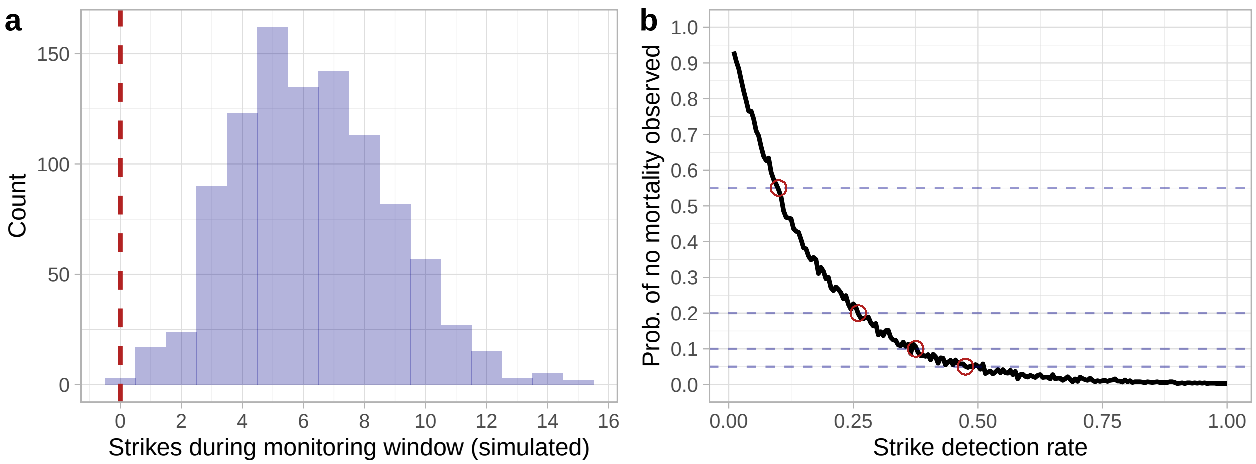


Figure 34: Figure S37. Results of ship-strike model validation for fin whales, in which the likelihood of not observing a strike in the last decade was estimated according to our model results. Left: Distribution of strike observations predicted with our models when assuming perfect detection (i.e., no strikes missed). The red dashed line indicates what we actually observed. Right: The probability of our observations under various scenarios of imperfect detection. Dashed lines indicate conventional alpha levels of significance.

Humpback whales

```
## Melting outcomes & prepping the posterior ...
## Determining the probability of your observations ...
## Likelihood of your observation, assuming perfect detection = 0
## Finding the strike detection rate (SDR) that would make your observations plausible ...
## preparing L ~ SDR plot ...
## --- SDR needed for P(Observation) of 0.05 = 0.155
## --- SDR needed for P(Observation) of 0.10 = 0.125
## --- SDR needed for P(Observation) of 0.20 = 0.085
## --- SDR needed for P(Observation) of 0.55 = 0.035
```

Mitigation measures

Scenarios 3 (rescheduling) & 4 (moratoria)

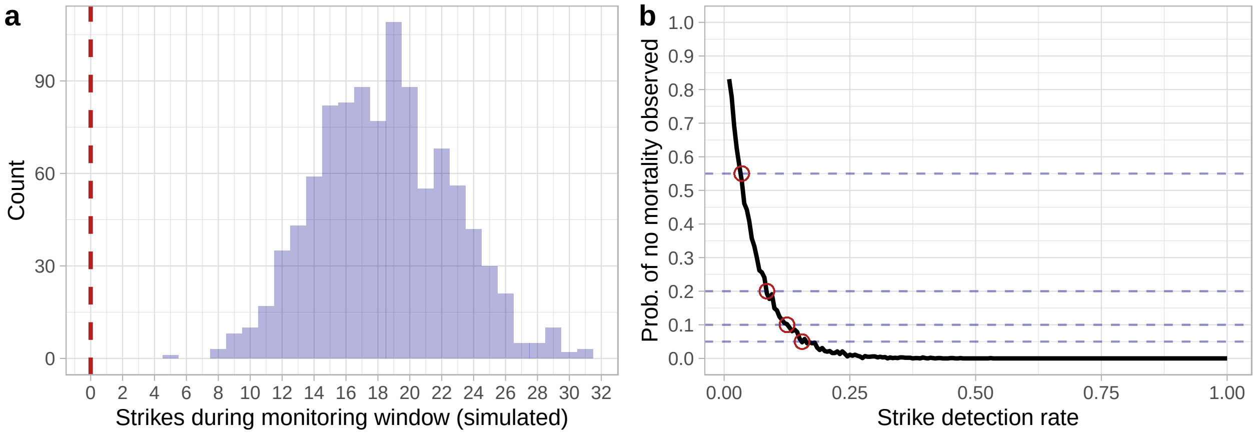


Figure 35: Fig S38. Results of ship-strike model validation for humpback whales, in which the likelihood of not observing a strike in the last decade was estimated according to our model results. Left: Distribution of strike observations predicted with our models when assuming perfect detection (i.e., no strikes missed). The red dashed line indicates what we actually observed. Right: The probability of our observations under various scenarios of imperfect detection. Dashed lines indicate conventional alpha levels of significance.

Discussion

Density estimate comparison throughout region

```
  # Fin whales (Gitga'at average)
  0.014 / 0.007 # eez (Wright)
## [1] 2
  0.014 / 0.002 # north coast (Wright)
## [1] 7
  0.014 / 0.003 # vancouver island (Nichol)
## [1] 4.666667

  # Fin whales (Squally Ch)
  0.031 / 0.007 # eez
## [1] 4.428571
  0.031 / 0.002 # north coast
## [1] 15.5
  0.031 / 0.003
## [1] 10.33333

  # Humpback whales (Gitga'at average)
  0.079 / 0.016 # eez (Wright)
## [1] 4.9375
  0.079 / 0.025 # north coast (Wright)
## [1] 3.16
  0.079 / 0.014 # vancouver island (Nichol)
## [1] 5.642857

  # Humpback whales (Wright Sound)
  0.0117 / 0.016 # eez
## [1] 0.73125
  0.0117 / 0.025 # north coast
```

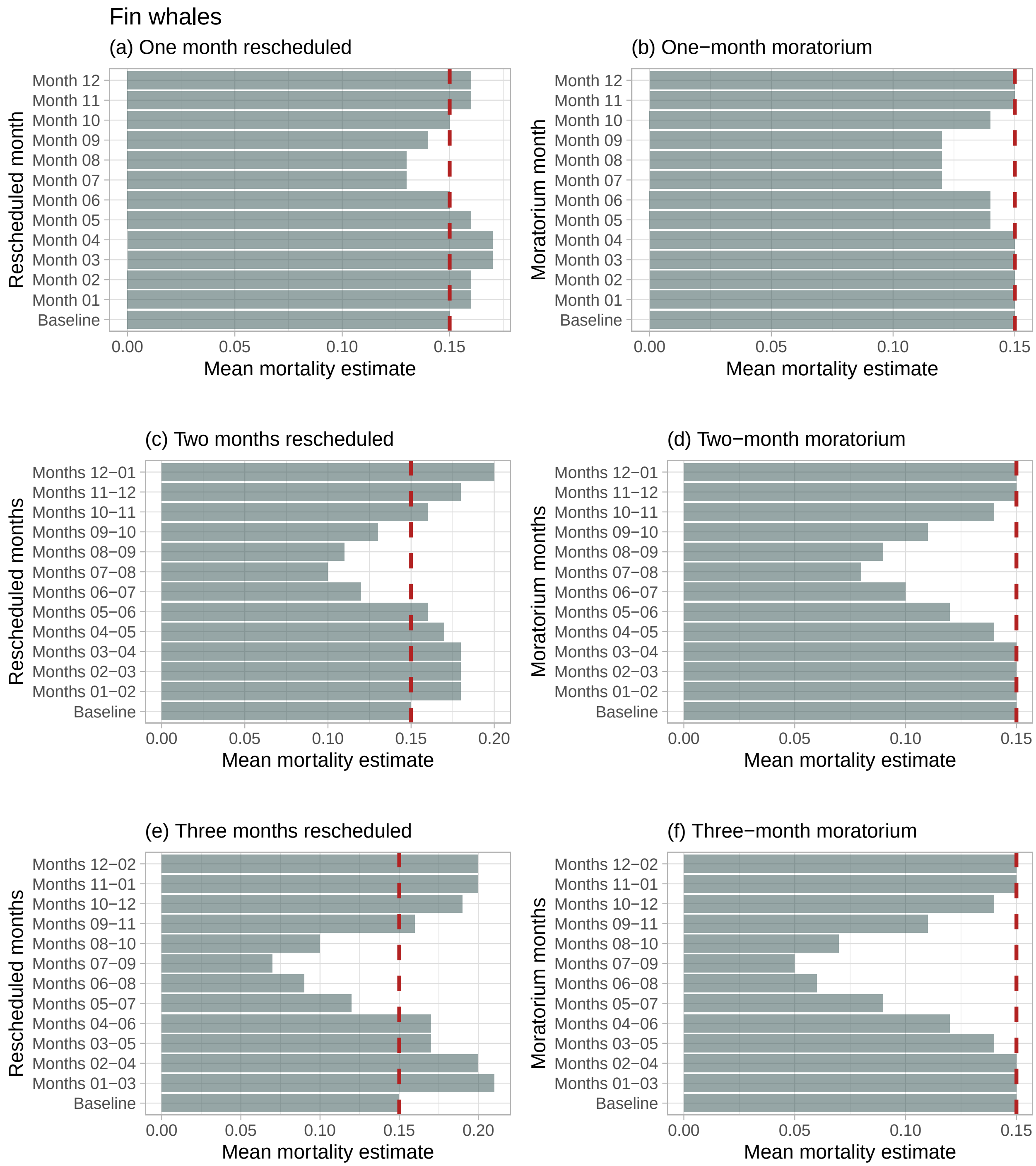


Figure 36: Figure S39. Efficacy of mitigation categories 3 (LNG rescheduling) and 4 (LNG moratoria) for fin whales, when those measures are applied to different months of the year for various durations (one - three months).

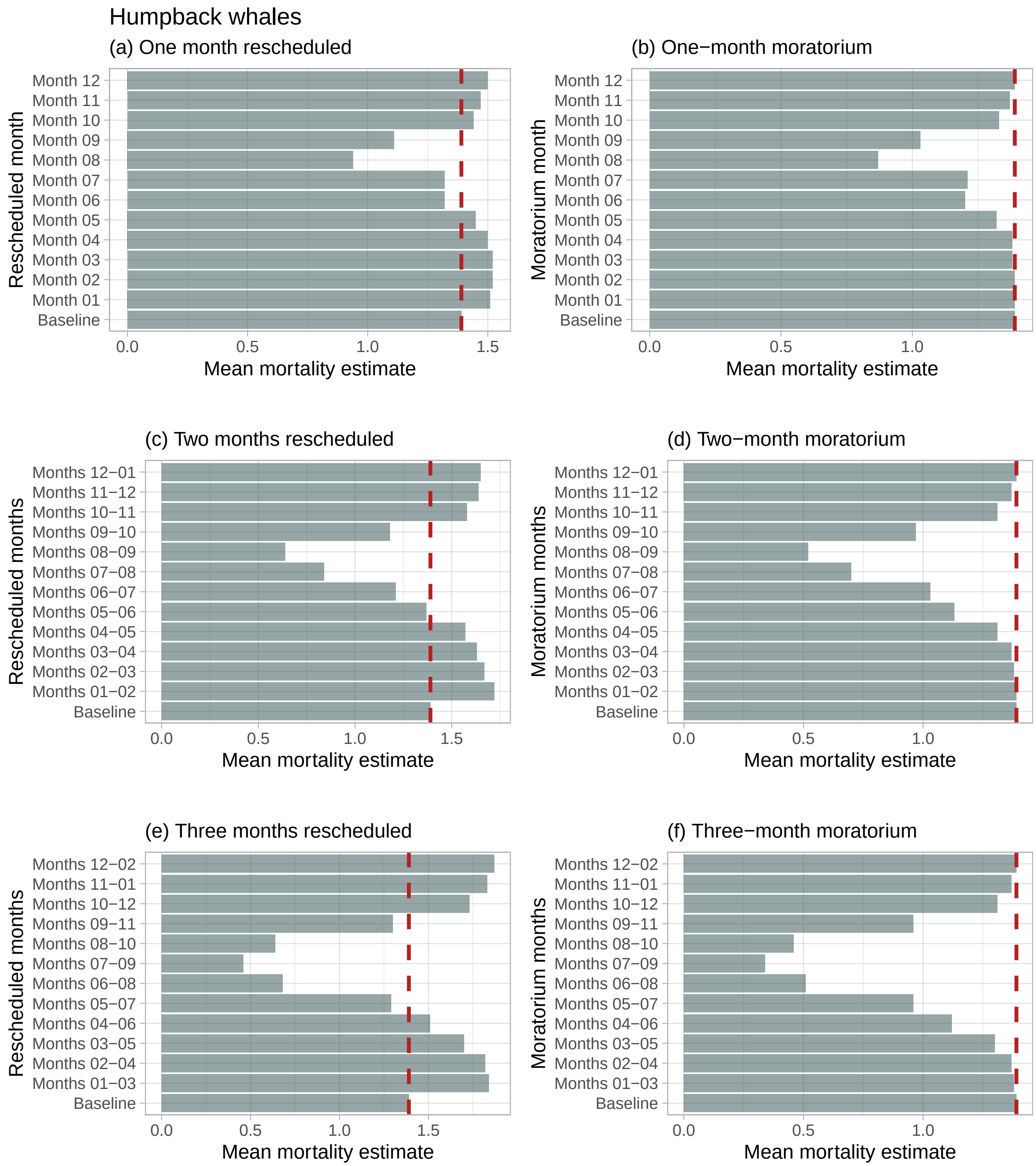


Figure 37: Figure S40. Efficacy of mitigation categories 3 (LNG rescheduling) and 4 (LNG moratoria) for humpback whales, when those measures are applied to different months of the year for various durations (one - three months).

```
## [1] 0.468
  0.0117 / 0.014
## [1] 0.8357143
```