Online Resources

A Survey summaries

A.1 Country transects

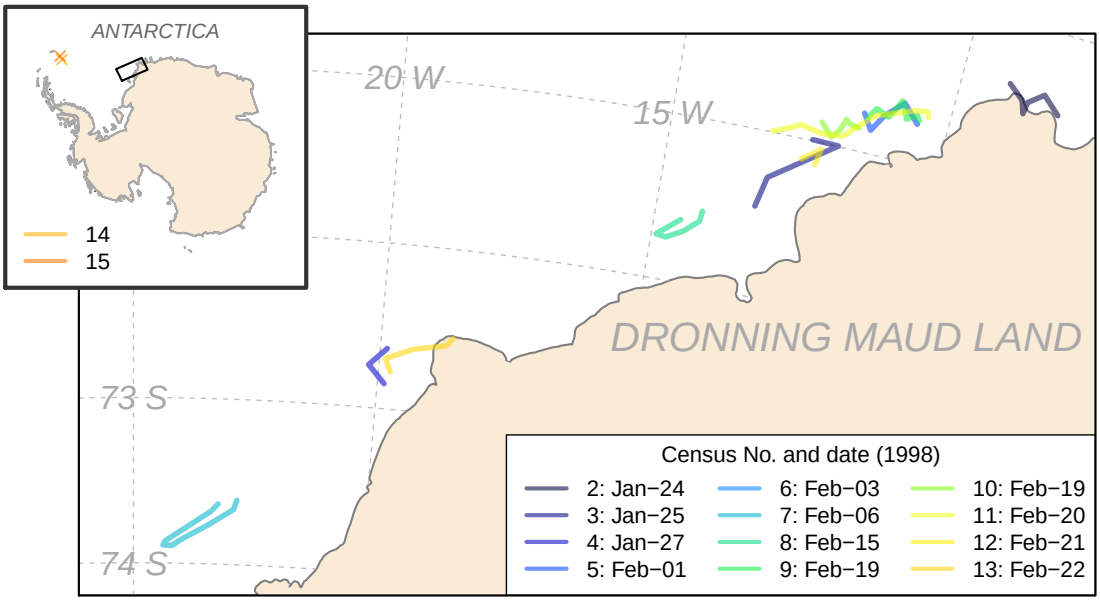

Fig. A1 South African survey: Map of survey flights.

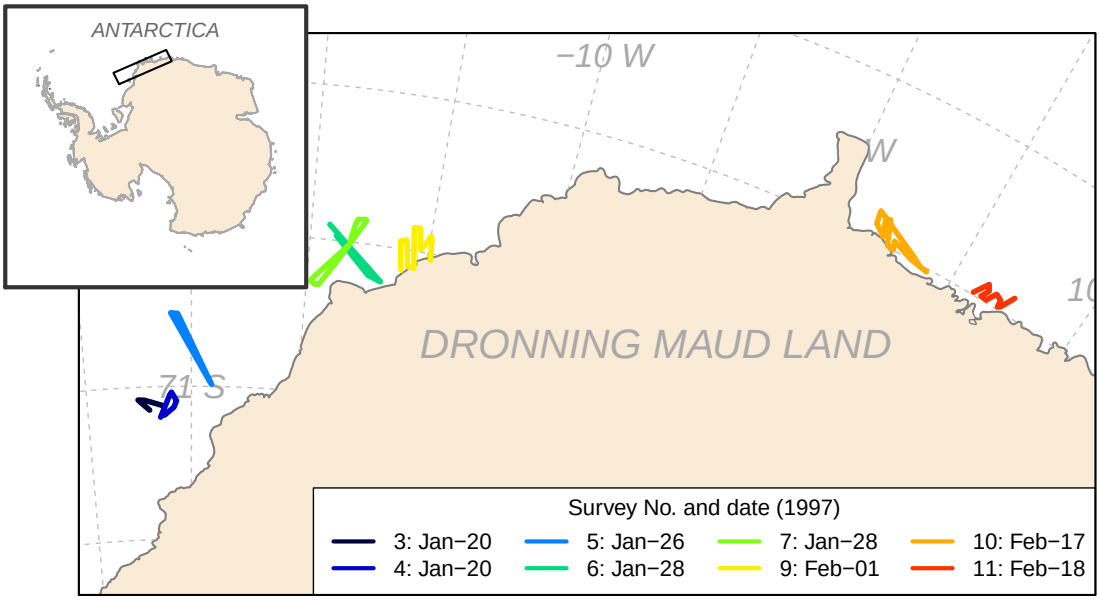

Fig. A2 Norwegian survey: Map of survey flights.

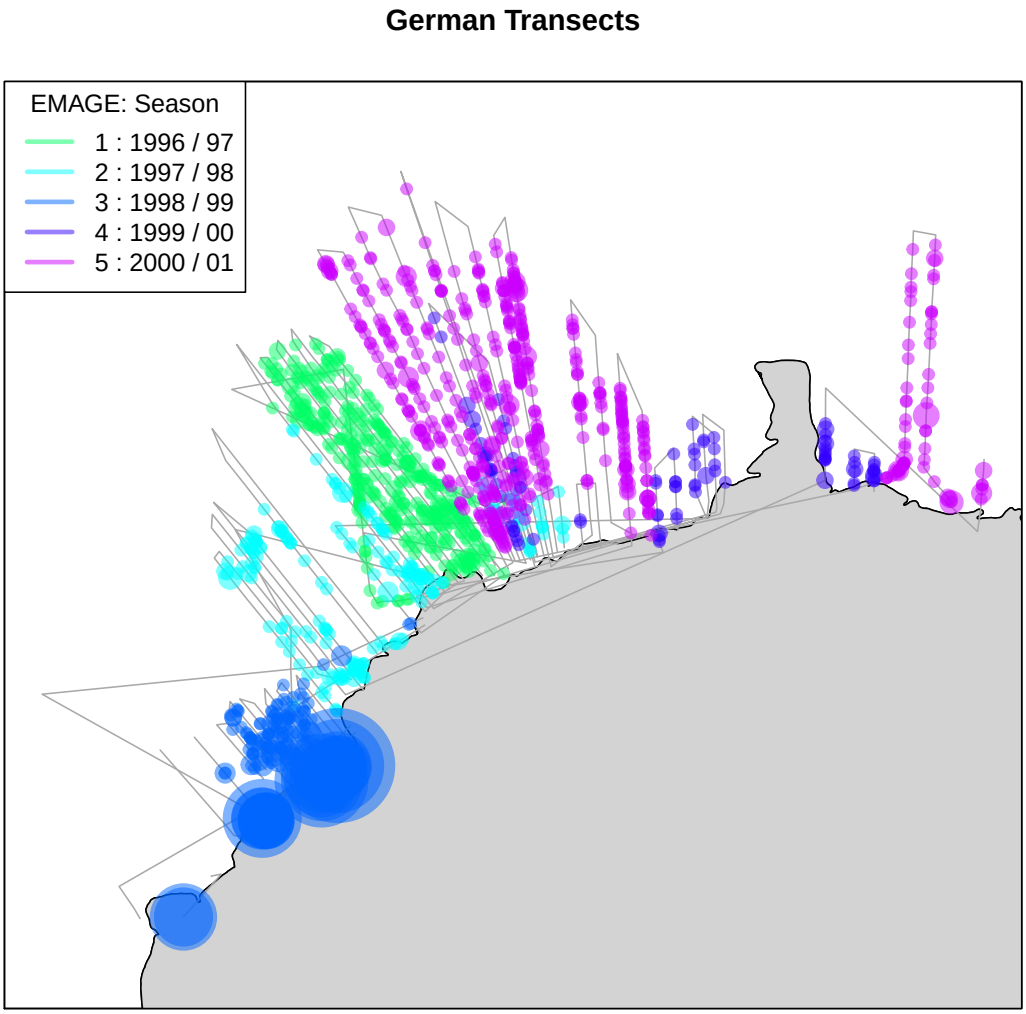

Fig. A3 German survey: Map of survey flights across years. Size of circles is proportional to number of seals sighted.

A.2 Survey maps by species

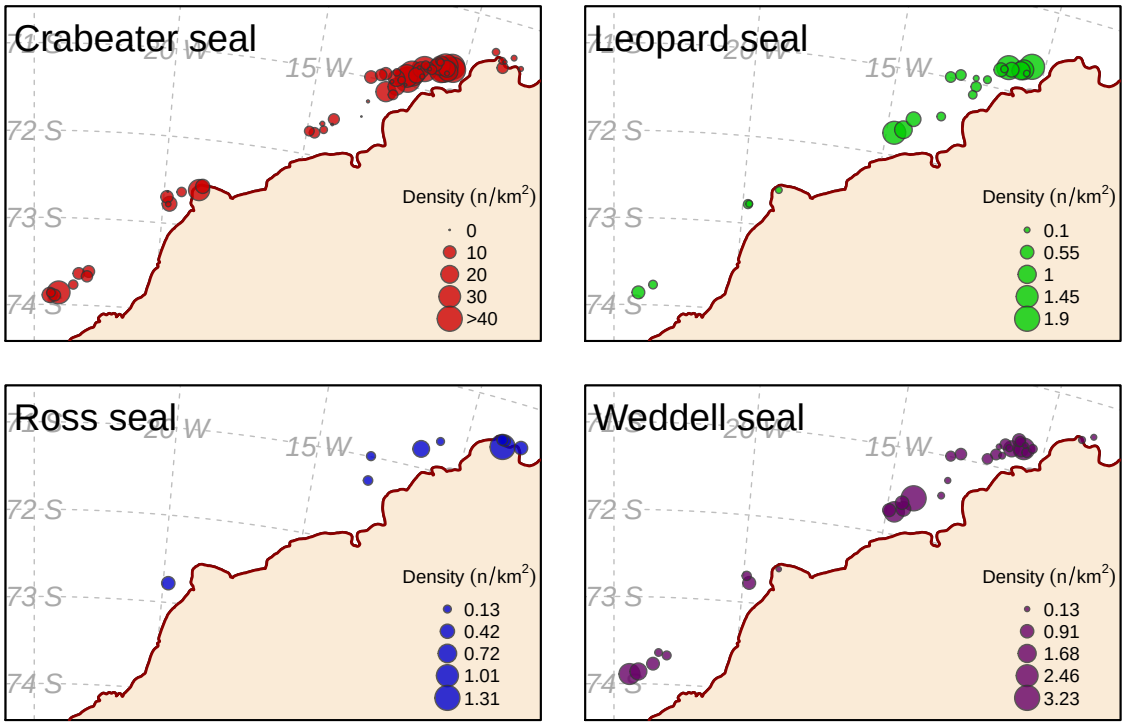

Fig. A4 South African survey: Map of seal sighting locations by species. The densities are computed with respect to the reported variable-area blocks.

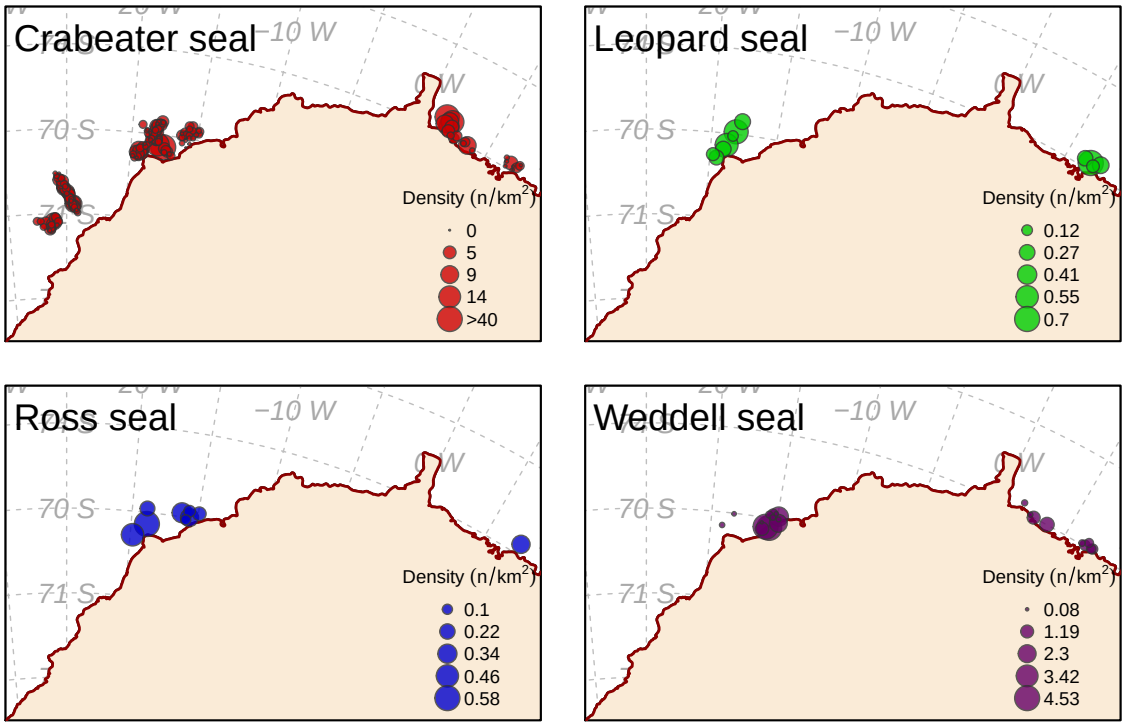

Fig. A5 Norwegian survey: Map of seal sighting locations by species. The densities are computed with respect to the reported variable-area blocks.

A.3 Count summaries

Table A1 Norwegian and South African surveys - Summary of seals counted by species.

A. Norwegian Survey (1997)							
Survey	Date	Distance (km)	Crabeaters	Leopards	Ross	Weddell	Unidentified
3	1997-01-20	105.02	112	-	-	-	-
4	1997-01-20	97.27	148	-	-	-	-
5	1997-01-26	250.41	275	-	-	-	-
6	1997-01-28	160.12	122	-	1	-	-
7	1997-01-28	264.34	333	7	2	2	16
9	1997-02-01	271.14	154	-	6	130	38
10	1997-02-17	241.67	188	-	-	9	6
11	1997-02-18	114.87	31	5	1	15	5
	Totals:	1505	1363	12	10	156	65

B. South African Survey (1998)							
Survey	Date	Distance (km)	Crabeaters	Leopards	Ross	Weddell	Unidentified
2	1998-01-24	106.50	66	-	6	2	24
3	1998-01-25	160.12	21	2	2	4	9
4	1998-01-27	69.18	1	-	-	-	7
5	1998-02-01	103.27	59	1	1	12	81
6	1998-02-03	23.43	15	2	3	-	14
7	1998-02-06	95.54	275	4	-	20	89
8	1998-02-15	94.62	112	15	-	44	54
9	1998-02-19	88.34	297	6	1	7	49
10	1998-02-19	60.43	142	-	-	1	20
11	1998-02-20	147.71	2515	8	1	10	57
12	1998-02-21	32.97	180	2	-	-	13
13	1998-02-22	97.81	474	2	-	10	50
	Totals:	1079.92	4157	42	14	110	467

Table A2 Table of counts per 0.25 km^2 block for the German surveys.

		Group size							
Survey	Year	0	1	2	3	4	5-10	10-101	> 100
1	1996-97	984	230	39	14	3	2		
2	1997-98	674	80	35	10	8	3		
3	1998-99	552	42	19	6	6	3	5	4
4	1999-00	284	51	18	4	2			
5	2000-01	883	238	81	27	10	12		

A.4 Bin distance tables

Norwegian survey

Table A3 Norwegian survey: Bin widths (m) estimated for flight transects. Bin 0 refers to observations made from the front of the helicopter exclusively.

	Front	Left	Right
Bin 0	162		
Bin 1		36	46
Bin 2		52	52
Bin 3		69	69
Bin 4		110	110
Bin 5		197	226
Bin 6		492	624
Bin 7		758	997

South African survey

Table A4 South African survey: Calculated distance of bin midpoints from the transect line and bin widths for the six observation bins at the two altitudes flown (61 and 91 m).

	Altitude: 61 m				Altitude: 91 m			
Bin	Distance (m)	Width (m)	N seals	Density (n/km^2)	Distance (m)	Width (m)	N seals	Density (n/km^2)
1	43	16	401	0.426	65	24	15	0.294
2	62	21	503	0.381	93	32	22	0.256
3	89	33	713	0.290	134	49	21	0.133
4	137	62	1008	0.149	205	93	32	0.108
5	257	178	1205	0.064	385	267	27	0.029
6	506	321	824	1.887	759	481	19	0.165

B Haul-out probabilities

B.1 Crabeater seals

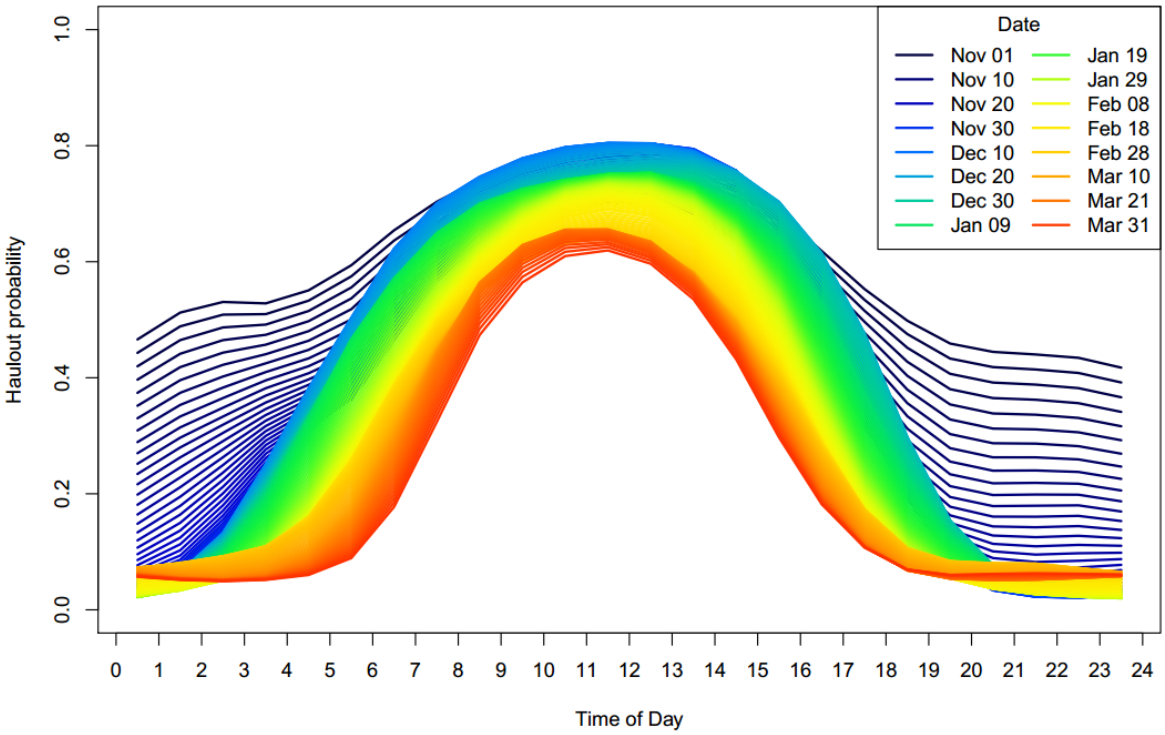

Fig. A6 Modeled crabeater haulout probabilities based on (Bengtson et al., 2011). The model is fitted for month of year (colors) and time of day.

B.2 Weddell seals

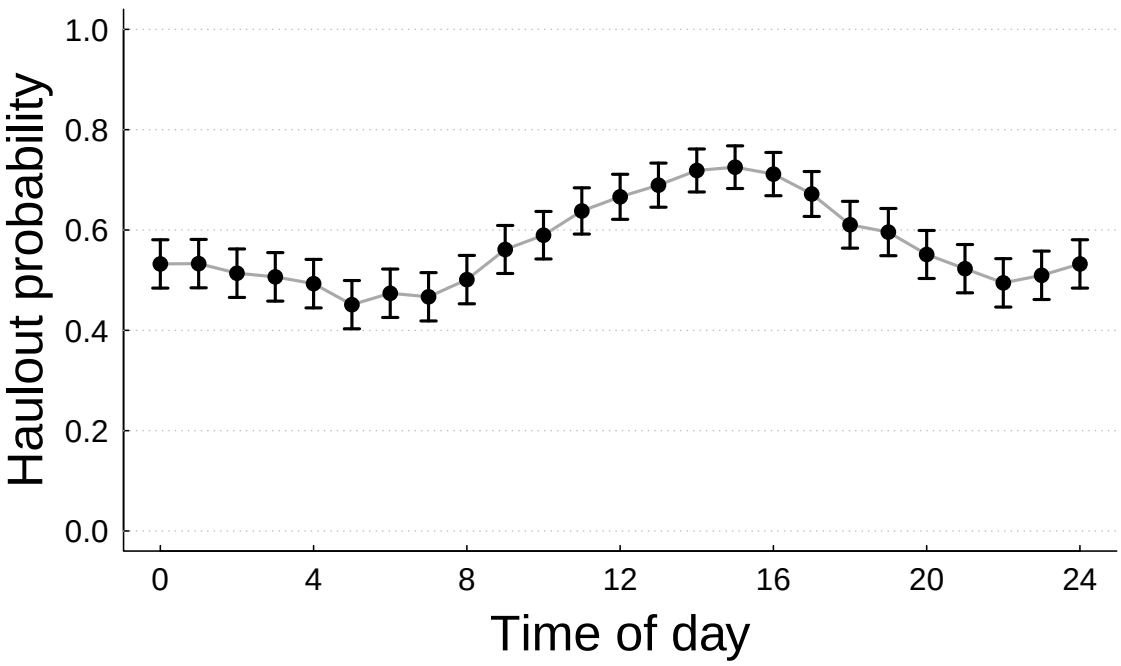

Fig. A7 Modeled Weddell seal haulout probabilities based on results of satellite tagged Weddell seals in January-March. The most parsimonious model includes only time of day.

C Predictions by date

C.1 German survey

Table A5 Abundance predictions for German seal surveys. The ice coverage represents the sum of the ice concentrations over the study area. Grouping refers to the subgrouping used in the model fitting stage.

Survey	Date	$\widehat{N}$ × 1000 ind.	(95 % C.I.)	Ice coverage (10^4 km^2)	Grouping
1	1996-12-25	1112	(758-1648)	38.75	High
	1996-12-26	1079	(726-1663)	37.19	High
	1996-12-27	1011	(680-1450)	35.11	High
	1996-12-28	985	(674-1393)	33.46	High
	1996-12-30	908	(608-1286)	29.17	High
2	1998-01-03	665	(393-1152)	14.51	Medium
	1998-01-04	666	(408-1112)	13.50	Medium
	1998-01-05	679	(392-1087)	12.66	Medium
	1998-01-15	280	(161-410)	4.50	Low
	1998-01-19	271	(163-403)	3.85	Low
	1998-01-20	268	(150-427)	3.53	Low
	1998-01-22	240	(137-365)	2.93	Low
	1998-01-23	227	(125-366)	2.81	Low
3	1999-01-27	294	(151-439)	4.63	Low
	1999-01-28	297	(161-448)	4.40	Low
	1999-01-29	292	(178-463)	4.19	Low
	1999-01-30	289	(161-429)	4.11	Low
	1999-02-01	286	(160-464)	3.97	Low
	1999-02-07	274	(142-430)	3.17	Low
	1999-02-09	260	(142-405)	2.92	Low
	1999-02-10	253	(158-407)	2.87	Low
	1999-02-11	259	(136-413)	2.91	Low
4	2000-01-08	660	(316-1282)	17.64	Medium
	2000-01-10	565	(323-983)	15.70	Medium
	2000-01-16	447	(244-768)	12.41	Medium
	2000-01-18	437	(236-765)	11.97	Medium
	2000-01-20	414	(234-705)	10.79	Medium
	2000-01-23	377	(222-630)	9.92	Medium
5	2000-12-21	1106	(839-1547)	36.62	High
	2000-12-22	1105	(834-1507)	35.67	High
	2000-12-24	1045	(777-1410)	34.55	High
	2000-12-26	990	(734-1380)	33.56	High
	2000-12-27	955	(691-1351)	32.83	High
	2001-01-05	675	(454-943)	25.27	High
	2001-01-09	715	(490-997)	23.69	High
	2001-01-11	675	(487-940)	22.66	High
	2001-01-12	666	(497-863)	22.43	High
	Low ice pooled:	260	(165-386)		
	Medium ice pooled:	435	(148-1004)		
	High ice pooled:	877	(449-1487)		
	Pooled total:	524	(662 - 792)		

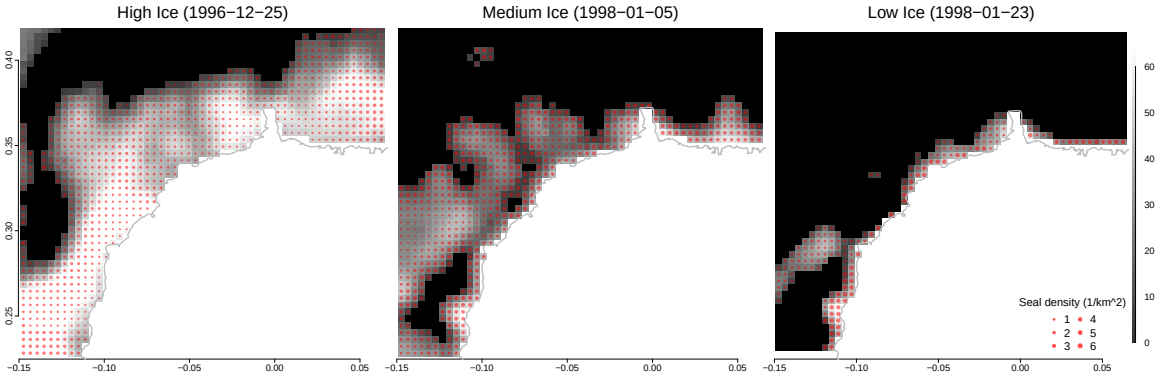

Fig. A8 Visualization of density predictions of seals (pale red dots) based on the German data on three representative days of high ice, medium ice and low ice, respectively. The high- and low-ice are the extreme days.

C.2 Norwegian and South African surveys

Crabeater seals

Table A6 Crabeater seal abundance estimates, with bootstrapped 95% confidence intervals, based on Norway and South Africa surveys.

Date	$\widehat{N}$ ($\times$ 1000)	95 % C.I.	Ice coverage (10^4 km^2)
Norway			
1997-01-20	597	(355-790)	17.08
1997-01-26	749	(370-1097)	13.60
1997-01-28	805	(405-1000)	12.29
1997-02-01	653	(329-938)	10.98
1997-02-17	540	(268-761)	10.20
1997-02-18	535	(259-740)	9.70
Pooled subtotal:	602	(328-980)	
South Africa			
1998-01-24	350	(103-1143)	2.77
1998-01-25	349	(90-1104)	2.73
1998-01-27	446	(110-1614)	2.39
1998-02-01	378	(72-1084)	1.65
1998-02-03	417	(111-1286)	1.68
1998-02-06	425	(102-1021)	1.49
1998-02-15	412	(84-1686)	1.32
1998-02-19	683	(156-2268)	1.19
1998-02-20	417	(107-1449)	1.15
1998-02-21	408	(85-1569)	1.12
1998-02-22	411	(71-1421)	1.12
Pooled subtotal:	451	(26-1486)	

Weddell and leopard seals

Table A7 Abundance estimates of Weddell and leopard seals by each date of survey with bootstrapped 95% confidence intervals.

	Weddell seals		Leopard seals	
Norway	$\widehat{N}(\times 1000)$	95% C.I.	$\widehat{N}(\times 1000)$	95% C.I.
1997-01-20	80.40	(59.7 - 128.9)	9.70	(1.7 - 39.8)
1997-01-26	84.30	(66.2 - 110.1)	10.40	(3.2 - 65.9)
1997-01-28	76.90	(63 - 112.5)	8.50	(2.2 - 44.3)
1997-02-01	63.40	(51.5 - 103.9)	10.40	(2.4 - 35.9)
1997-02-17	83.20	(67.7 - 107.5)	19.40	(5.5 - 43.7)
1997-02-18	83.50	(69.2 - 106.2)	22.10	(7.3 - 54.2)
South Africa				
1998-01-24	95.30	(65.5 - 118.7)	22.20	(12.9 - 35.3)
1998-01-25	94.80	(68.7 - 116)	21.30	(11.1 - 33.2)
1998-01-27	76.90	(48.6 - 100.3)	24.00	(12.5 - 39.9)
1998-02-01	35.90	(20.7 - 53.5)	14.10	(7.4 - 21.8)
1998-02-03	33.60	(19.3 - 48.9)	15.60	(7.2 - 23.3)
1998-02-06	31.70	(20.4 - 43.7)	14.80	(8.1 - 23.3)
1998-02-15	33.30	(22.3 - 43.8)	15.60	(8.6 - 25.4)
1998-02-19	40.50	(29.3 - 50.7)	16.80	(9.7 - 26.4)
1998-02-20	34.50	(23.9 - 43.4)	14.30	(8 - 22.9)
1998-02-21	26.60	(17.1 - 35.9)	14.80	(8.1 - 24.2)
1998-02-22	29.00	(17.6 - 39.7)	14.80	(7.9 - 22.3)
Pooled estimate:	57.1	(41.2 - 92.8)	14.0	(5.75-33.3)

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D Model tables

D.1 German survey

Low ice models

Table A8 BIC table of several low ice main effect models.

Factors	K	df	loglik	ΔAIC	ΔBIC	PDE	$\widehat{\theta}$
OnShelf	2	1293	-938.51	-12.44	-7.28	0.03	0.05
OnShelf + DIce	3	1292	-935.29	-16.89	-6.56	0.05	0.06
OnShelf + IC	3	1292	-936.67	-14.13	-3.80	0.04	0.06
OnShelf + MID	3	1292	-937.77	-11.93	-1.60	0.04	0.06
DIce	2	1293	-941.42	-6.63	-1.47	0.02	0.05
1	1	1294	-945.73	0.00	0.00	0.00	0.05
IC	2	1293	-945.03	0.59	5.75	0.00	0.05
MID	2	1293	-945.35	1.24	6.41	0.00	0.05

Medium ice models

Table A9 BIC table of several medium ice main effect models. The ΔBIC and ΔAIC values are relative to the ice extent (MID) main effect model. Note that while the BIC values are very close, there is a considerable improvement in AIC.

Factors	K	df	loglik	ΔAIC	ΔBIC	PDE	$\widehat{\theta}$
MID*$\sqrt{\text{IC}}$ + DIce	5	509	-352.66	-13.29	-0.56	0.06	0.55
MID + $\sqrt{\text{IC}}$	3	511	-359.06	-4.49	-0.25	0.02	0.48
MID * $\sqrt{\text{IC}}$	4	510	-356.03	-8.53	-0.05	0.04	0.51
MID	2	512	-362.30	0.00	0.00	0.00	0.45
MID + OnShelf	3	511	-359.50	-3.60	0.64	0.02	0.48
MID*$\sqrt{\text{IC}}$) + $\sqrt{\text{DIce}}$	5	509	-353.87	-10.87	1.86	0.05	0.53
MID + $\sqrt{\text{IC}}$ + DIce	4	510	-357.16	-6.29	2.20	0.03	0.51
MID*$\sqrt{\text{IC}}$*DIce	8	506	-346.38	-19.85	5.60	0.10	0.60
MID + DIce	3	511	-362.28	1.95	6.19	0.00	0.45

High ice models

Table A10 BIC table of several models for the high ice subset. Note that the selected (top) model has a much lower BIC than the next best model.

Factors	K	df	loglik	ΔAIC	ΔBIC	PDE	$\widehat{\theta}$
MID*($\sqrt{\text{DIce}}$ + DIce) + dMID * (IC + $\sqrt{\text{IC}}$)	11	2360	-1919.41	-93.12	-41.18	0.07	0.78
MID + $\sqrt{\text{DIce}}$ + DIce + dMID*(IC * $\sqrt{\text{IC}}$)	11	2360	-1922.48	-86.98	-35.04	0.06	0.77
MID*($\sqrt{\text{DIce}}$ + DIce) + (dMID + $\sqrt{\text{DIce}}$ + DIce) * (IC + $\sqrt{\text{IC}}$)	15	2356	-1913.60	-96.74	-21.72	0.07	0.80
MID + dMID * (IC + $\sqrt{\text{IC}}$)	7	2364	-1947.19	-45.57	-16.72	0.04	0.69
MID*($\sqrt{\text{DIce}}$ + DIce)	6	2365	-1954.45	-33.06	-9.97	0.03	0.67
MID*($\sqrt{\text{DIce}}$ + DIce) + dMID + IC + $\sqrt{\text{IC}}$	9	2362	-1942.80	-50.36	-9.96	0.04	0.70
(MID + $\sqrt{\text{DIce}}$ + DIce + dMID)*(IC * $\sqrt{\text{IC}}$)	20	2351	-1904.69	-104.57	-0.69	0.08	0.82
MID	2	2369	-1974.98	0.00	0.00	0.00	0.61
MID*$\sqrt{\text{DIce}}$	4	2367	-1974.53	3.11	14.65	0.00	0.61

D.2 Norwegian survey

Crabeater seals

Table A11 ΔAIC/BIC table of several models for Norway crabeater data.

Factors	K	df	loglik	ΔAIC	ΔBIC	R^2
OnShelf * (MID+dMID)	6	156	-219.58	-51.76	-36.32	0.32
OnShelf * (MID+dMID+IC+$\sqrt{\text{IC}}$)	10	152	-210.07	-62.77	-34.99	0.39
OnShelf * (sqrt(DIce)+DIce+MID+dMID)	10	152	-210.82	-61.27	-33.48	0.39
OnShelf * ($\sqrt{\text{DIce}}$+DIce+MID+dMID + IC+$\sqrt{\text{IC}}$)	14	148	-201.58	-71.75	-31.61	0.45
OnShelf * (MID+dMID+($\sqrt{\text{DIce}}$+DIce) * (IC+$\sqrt{\text{IC}}$))	22	140	-183.60	-91.72	-26.88	0.56
OnShelf * ((sqrt(DIce)+DIce) * (MID+dMID))	18	144	-194.47	-77.97	-25.48	0.50
OnShelf * (($\sqrt{\text{DIce}}$+DIce) * (MID+dMID)+IC+$\sqrt{\text{IC}}$)	22	140	-185.45	-88.02	-23.18	0.55
OnShelf * (($\sqrt{\text{DIce}}$+DIce + MID + dMID) * (IC+$\sqrt{\text{IC}}$))	30	132	-168.98	-104.94	-15.40	0.63
OnShelf * ($\sqrt{\text{DIce}}$+DIce +(MID+dMID) *(IC+$\sqrt{\text{IC}}$))	22	140	-189.82	-79.27	-14.43	0.53
OnShelf	2	160	-242.38	-14.15	-11.06	0.09
1	1	161	-250.46	0.00	0.00	0.00

Weddell seals

Table A12 ΔAIC/BIC table of several models for Norway Weddell seal data.

Factors	K	df	loglik	ΔAIC	ΔBIC	R^2
(DIce + sqrt(DIce))*MID	6	5909	-441.06	0.00	0.00	0.48
(DIce + sqrt(DIce))+dMID	4	5911	-470.61	55.09	41.72	0.44
(DIce + sqrt(DIce))*dMID	6	5909	-470.03	57.94	57.94	0.44
(DIce + sqrt(DIce))+MID	4	5911	-477.69	69.25	55.88	0.43
(IC+MID)*OnShelf	6	5909	-672.45	462.77	462.77	0.20
MID * OnShelf	4	5911	-674.54	462.95	449.58	0.20
MID + OnShelf	3	5912	-676.99	465.85	445.79	0.20
IC*OnShelf	4	5911	-678.98	471.84	458.47	0.20
OnShelf	2	5913	-681.03	471.93	445.19	0.19
(IC + sqrt(IC))*dMID	6	5909	-783.57	685.01	685.01	0.07
MID	2	5913	-800.51	710.89	684.15	0.05
DIce	2	5913	-832.74	775.35	748.61	0.01
1	1	5914	-843.58	795.03	761.60	0.00
IC	2	5913	-843.55	796.97	770.23	0.00

Leopard seals

Table A13 ΔAIC/BIC table of several models for the Norway leopard seal data.

Factors	K	df	loglik	ΔAIC	ΔBIC	PDE
OnShelf * IC	4	5911	-73.35	-20.08	-0.03	0.15
(IC + MID)*OnShelf	6	5909	-72.85	-17.08	16.35	0.16
IC	2	5913	-77.77	-15.25	-8.57	0.10
OnShelf + IC	3	5912	-77.76	-13.25	0.12	0.10
MID	2	5913	-85.29	-0.20	6.49	0.01
1	1	5914	-86.39	0.00	0.00	-0.00
OnShelf * MID	4	5911	-83.43	0.07	20.13	0.03
DIce	2	5913	-85.46	0.14	6.83	0.01
OnShelf + MID	3	5912	-84.96	1.14	14.51	0.02
OnShelf	2	5913	-86.36	1.94	8.63	0.00

D.3 South African survey

Crabeater seals

Table A14 ΔAIC/BIC table of several models for the log-transformed South African crabeater density data.

Factors	K	df	loglik	ΔAIC	ΔBIC	R^2
OnShelf * MID	4	158	-233.23	-28.45	-19.19	0.19
OnShelf + MID	3	159	-233.97	-28.97	-22.79	0.18
OnShelf	2	160	-242.38	-14.15	-11.06	0.09
OnShelf + DIce	3	159	-239.94	-17.03	-10.85	0.12
OnShelf + IC	3	159	-241.88	-13.15	-6.97	0.10
OnShelf * IC	4	158	-239.66	-15.59	-6.32	0.12
OnShelf * DIce	4	158	-239.89	-15.14	-5.87	0.12
1	1	161	-250.46	0.00	0.00	0.00
MID	2	160	-250.24	1.56	4.65	0.00
IC	2	160	-250.24	1.57	4.66	0.00
DIce	2	160	-250.45	1.98	5.06	0.00

Weddell seals

Table A15 ΔAIC/BIC table of several binomial model fits for the South African Weddell seal data.

Factors	K	df	loglik	AIC	BIC	PDE
DIce + sqrt(DIce)*MID + OnShelf	6	1988	-508.49	-125.69	-97.70	0.12
(DIce + sqrt(DIce)) * MID + OnShelf	7	1987	-505.99	-128.69	-95.10	0.12
DIce * MID + OnShelf	5	1989	-514.22	-116.23	-93.84	0.11
(DIce + sqrt(DIce)) * MID * OnShelf	12	1982	-495.28	-140.11	-78.53	0.14
(DIce + sqrt(DIce)) * MID	6	1988	-522.15	-98.37	-70.38	0.09
DIce * MID	4	1990	-530.27	-86.13	-69.34	0.08
(DIce + sqrt(DIce)) + MID + OnShelf	5	1989	-536.16	-72.35	-49.95	0.07
OnShelf	2	1992	-549.02	-52.63	-47.04	0.05
(IC) + MID + OnShelf	4	1990	-542.52	-61.63	-44.83	0.06
(IC + sqrt(IC)) * MID + OnShelf	7	1987	-532.69	-75.29	-41.71	0.08
DIce + MID + OnShelf	4	1990	-544.78	-57.11	-40.32	0.06
(IC + sqrt(IC)) + MID + OnShelf	5	1989	-541.14	-62.39	-40.00	0.06
(IC) * MID + OnShelf	5	1989	-542.50	-59.66	-37.27	0.06
DIce + sqrt(DIce)	3	1991	-563.50	-21.68	-10.48	0.02
IC + sqrt(IC)	3	1991	-566.19	-16.28	-5.09	0.02
1	1	1993	-576.34	0.00	0.00	-0.00
MID	2	1992	-573.49	-3.69	1.91	0.00
sqrt(DIce)	2	1992	-575.28	-0.12	5.48	0.00
(IC) * MID	4	1990	-567.75	-11.16	5.63	0.01
DIce	2	1992	-576.21	1.75	7.35	0.00
(IC + sqrt(IC)) * MID	6	1988	-564.04	-14.60	13.39	0.02

Leopard seals

Table A16 ΔAIC/BIC table of several binomial models for the South African leopard seal data.

Factors	K	df	loglik	AIC	BIC	PDE
MID + OnShelf	3	1991	-191.93	-19.51	-8.31	0.06
MID * OnShelf	4	1990	-191.91	-17.55	-0.76	0.06
(IC+MID)*OnShelf	6	1988	-190.93	-15.51	12.48	0.06
MID	2	1992	-195.76	-13.86	-8.26	0.04
IC*OnShelf	4	1990	-194.61	-12.14	4.65	0.04
IC	2	1992	-198.32	-8.74	-3.14	0.03
OnShelf	2	1992	-199.37	-6.63	-1.03	0.02
DIce	2	1992	-201.39	-2.59	3.01	0.01
1	1	1993	-203.68	0.00	0.00	0.00

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