Multi-state open robust design applied to opportunistic data reveals dynamics of wide-ranging taxa: the sperm whale case

Rebecca M. Boys[1,2]†, Cláudia Oliveira[1,2], Sergi Pérez-Jorge[1,2], Rui Prieto[1,2], Lisa Steiner[3], Mónica A. Silva[1,2,4]

ESA Journal Ecosphere

Appendix S1

Two methods were used to locate whales during the full 28 year data collection period. Initially IFAW used a combination of a towed hydrophone and directional hydrophones to detect sperm whale clicks in the range of 5-7 miles (Whitehead and Gordon 1986). From 2001 onwards a lookout (vigia) network, (used during commercial whaling), was used to spot the whales from land using binoculars and then directed the vessels, such as whale watching, towards the animals. When animals were found they would be followed by whale watching vessels for up to 6 hours at a time, whilst the IFAW vessel would stay with a group for up to a few days (Steiner et al. 2012).

Table S1. Institutions providing photographs, photographic equipment used, and number of high quality (Q≥3) and distinctive (D≥3) photographs obtained over the 28 year period.

Name	**Type of institution**	**Camera/lens**	**Nº photographs**
DOP University of Azores	Research	Nikon F-90X, Nikon D70, D2H, D90, Nikon AF 70-300MM (f4-5.6) zoom lens	909
IFAW	Research	Canon T70 300mm f4 lens	190
Volunteers	Clients on whale watching	Unknown	9
Whale Watch Azores	Whale watching	Canon T70; 75- 300mm f4 lens; Canon D50; 100-400mm f4.5-5.6 auto focus lens; Canon D10, D30, 7DMII 100-40mm f4.5-5.6 auto focus lens	3707

Table S2. CloseTest results for the dataset from the period 2009-2015. Chi-square (χ^2) value, degrees of freedom (df) and significance (P) of the Stanley & Burnham Closure Test, and the tests for additions and deletions.

	Stanley & Burnham Closure Test			**Test for additions**			**Test for deletions**		
Year	**χ^2**	**df**	**P**	**χ^2**	**df**	**P**	**χ^2**	**df**	**P**
2009-2015	301.02	48	0.00	234.69	22	0.00	66.33	26	0.00
2009	9.49	1	0.00	Insufficient data			Insufficient data		
2010	9.79	1	0.00	Insufficient data			4.92	1	0.03
2011	0.38	1	0.54	Insufficient data			Insufficient data		
2012	0.36	1	0.55	Insufficient data			Insufficient data		
2013	0.00	1	0.95	Insufficient data			Insufficient data		
2014	3.98	1	0.05	Insufficient data			Insufficient data		
2015	0.13	1	0.72	Insufficient data			Insufficient data		

Table S3. Data used to fit POPAN models. Number of sperm whales captured and recaptured photographically per sampling year.

			Total recaptures in each year						
Year	**No. survey days**	**Total captured**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Total recaptured**
2009	32	91	13	4	0	2	4	1	24
2010	35	55		13	5	1	3	2	24
2011	41	83			5	3	1	3	12
2012	35	69				6	3	1	10
2013	34	48					0	3	3
2014	28	65						8	8
2015	37	66						-	-

Table S4. Data used to fit MSORD models. Number of sperm whales captured and recaptured photographically per secondary and primary occasions.

				2011		2012			2013			2014			2015			
Primary occasion	**Secondary occasion**	**No. survey days**	**Total captured**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Total recaptured**
2011	**02/07-23/07**	12	45	1	0	8	0	4	1	0	4	0	0	1	0	0	1	20
	24/07-15/08	16	43		1	3	5	2	0	0	3	0	0	0	0	0	0	14
	16/08-05/09	13	35			1	6	0	0	1	0	0	0	0	1	2	0	11
2012	**05/07-26/07**	16	45				0	1	3	2	2	3	0	0	0	0	2	13
	27/07-18/08	12	40					0	2	0	1	1	2	1	1	1	0	9
	19/08-07/09	10	27						0	0	1	0	2	0	0	0	0	3
2013	**01/07-22/07**	13	28							0	0	0	0	1	1	1	0	3
	23/07-15/08	12	32								0	1	0	2	0	0	1	4
	16/08-07/09	10	22									1	0	1	0	1	2	5
2014	**02/07-22/07**	13	46										0	0	4	2	2	8
	23/07-15/08	9	27											1	0	0	6	7

	16/08-06/09	9	20												2	0	1	3
2015	**01/07-22/07**	13	38													3	0	3
	23/07-14/08	14	32														1	1
	16/08-05/09	12	44														-	-

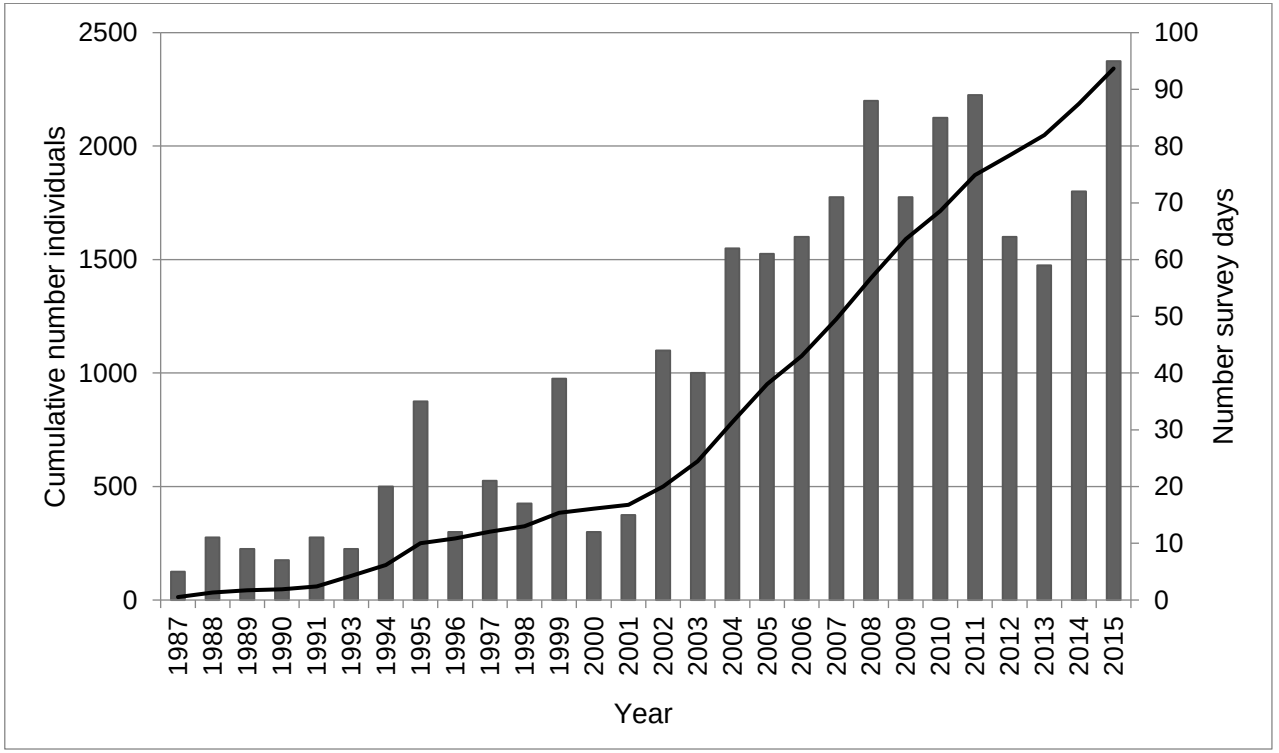

Fig S1. Cumulative number of new identifications (line) and number of survey days with photographs taken (bars) from 1987 to 2015.

On average, about 34% (SD=17.3) of the individuals captured each year had been sighted in previous years, meaning that most sightings were of new animals.

Individual sighting frequency varied from 1 to 30 (mean =13.2, SD=8.8), with 76% of individuals seen only once (Fig S2).

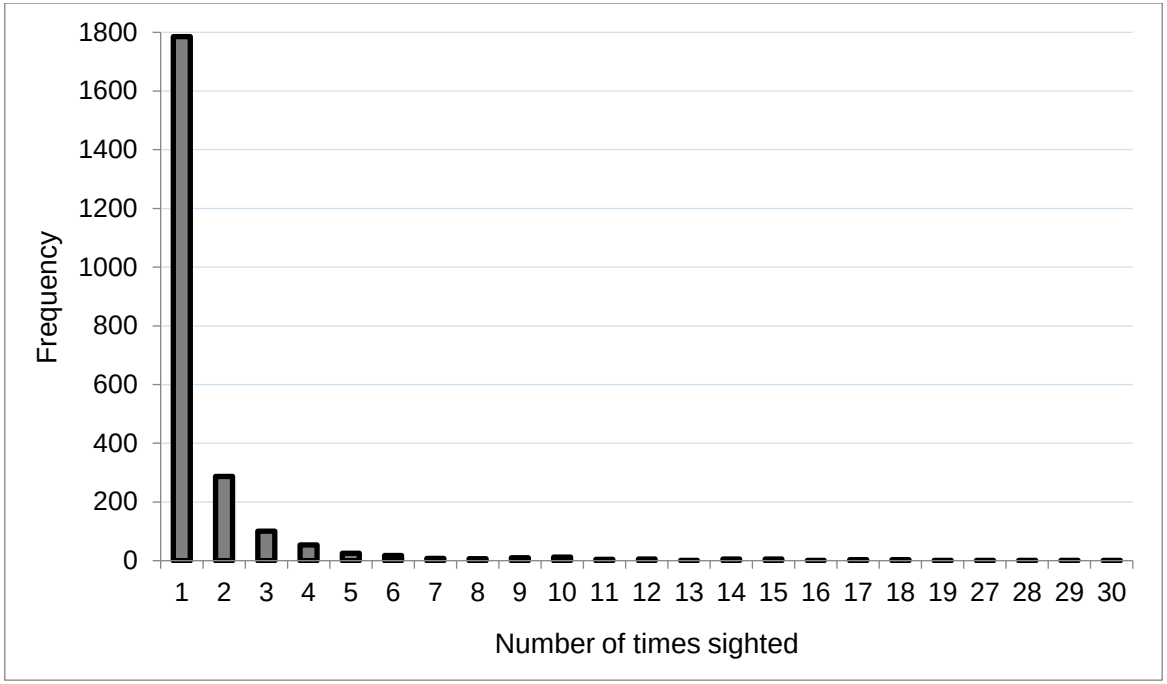

Fig S2. Sighting frequency of distinctive individual sperm whales from 1987-2015.

The maximum interval between individual resightings was 7123 days (>20 years) (Fig S3) but only 17% (n=282) of individuals were seen in 4 or more years. Nearly 60% of all resightings were within the same year, the majority of these were within the same month (Fig S3 inset).

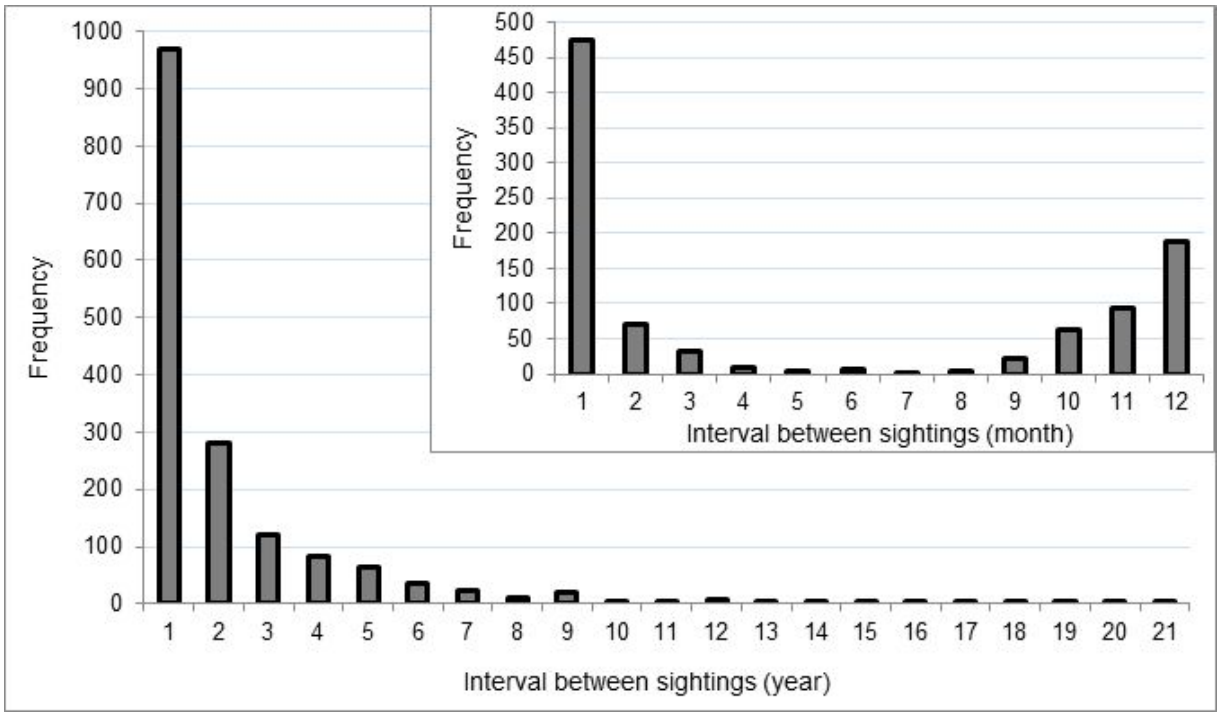

Fig S3. Interval between distinctive individual resightings between years, over the period 1987-2015 including all months of the year. Inset: Interval between individual resightings per month within a year.

Table S5. Parameter estimates from the best fitting POPAN model for sperm whale abundance and survival. Model-derived and total (corrected for the proportion of marked individuals, θ) estimates of annual and super-population abundance, and estimates of survival of sperm whales, with respective standard errors (SE), 95% log-normal confidence intervals (95% CI) and coefficients of variations (CV).

		Model-derived				**Total (corrected for θ)**			
Parameter	**Year**	**Estimate**	**SE**	**95%CI**	**CV**	**Estimate**	**SE**	**95%CI**	**CV**
Annual abundance	**2009**	529.1	108.84	355.0 - 788.6	0.21	726.8	156.60	478.7 – 1103.4	0.22
	2010	250.4	47.78	172.8 – 381.5	0.19	350.6	73.27	233.7 – 525.8	0.21
	2011	315.8	50.69	231.0 – 431.7	0.16	403.3	68.80	289.3 – 562.1	0.17
	2012	377.7	58.36	279.5 – 510.4	0.15	558.4	98.00	396.9 – 785.6	0.18
	2013	436.4	71.02	317.9 – 599.1	0.16	681.9	133.28	466.6 – 996.7	0.20
	2014	492.1	88.09	347.4 – 697.0	0.18	658.7	127.12	452.8 – 958.2	0.19
	2015	544.9	108.81	369.8 – 802.8	0.20	718.2	151.85	476.7 – 1082.1	0.21
Super-population abundance		1062.4	103.92	877.4 – 1286.3	0.10	1467.8	149.46	1202.8 – 1791.0	0.10
Apparent survival		0.95	0.067	0.560 – 0.996	0.007				

Table S6. Parameter estimates from the best fitting MSORD model. Model-derived and total (corrected for the proportion of marked individuals, θ) estimates of annual abundance, survival, temporary emigration, probability of entry and probability of remaining of sperm whales, with respective standard errors (SE), 95% log-normal confidence intervals (95% CI) and coefficients of variation (CV).

		Model-derived				**Total (corrected for θ)**			
Parameter	**Year**	**Estimate**	**SE**	**95%CI**	**CV**	**Estimate**	**SE**	**95%CI**	**CV**
Annual abundance	**2011**	270.46	49.69	173.1 – 367.9	0.18	345.40	66.53	237.6 – 502.1	0.19
	2012	248.11	45.59	158.8 – 337.5	0.18	366.76	73.98	248.0 – 542.5	0.20
	2013	183.28	33.68	117.3 – 249.3	0.18	286.38	61.07	189.4 – 433.0	0.21
	2014	205.64	37.78	131.6 – 279.7	0.18	275.24	54.33	187.6 – 403.8	0.20
	2015	245.87	45.18	157.3 – 334.4	0.18	324.10	63.66	221.3 – 474.6	0.20
Apparent survival		0.93	0.11	0.74 - 1	0.12				
Transition (Temporary emigration)	**2012-2013**	0.41	0.15						
	2013-2014	0.66	0.17						
	2014-2015	0.22	0.20						

Probability of entry within primary occasions	**Secondary occasion 1-2**	0.40	0.028						
	Secondary occasion 2-3	0.32	0.027						
Persistence/ remaining probability		0.053	0.025						
Capture probability within primary occasions	**Secondary occasion 1**	0.44	0.10						