Data inputs for the African Penguin *Spheniscus demersus* Model to be coupled to the pelagic OMP

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INTRODUCTION

This document serves as an updated compilation of all data currently available as inputs to the African penguin spatial model which is to be coupled to the pelagic OMP. The data are presented here together with some comments as to how they are to be used in the model and notes on their derivation and potential reliability.

The model presented thus far is spatial in that different populations of penguins are represented, and different levels of movement between these populations are modelled. The main focus of the model is on Dassen and Robben Islands, which were originally combined for reasons of simplicity and because of their close proximity to each other, suggesting that the effects of external factors such as food availability would be highly correlated between the two. However, data that have recently become available indicate differences between these two colonies which suggest that it may no longer be appropriate to pool the two; hence they are split in the model. The third population is Dyer Island because it has the next largest numbers of penguins, recent declines in the population there are of concern and it is considered an important breeding site for penguins given the eastward shift of sardines. The fourth population is Boulders. Although relatively small, this colony was considered important to include because of its position, its role as the focus of several other studies and because penguins are known to have moved from Dyer Island to Boulders, Robben and Dassen, and hence it is useful to quantify to what extent movement of birds away from Dyer Island could account for observed declines at Dyer and increases at these other colonies.

A summary of all the breeding colonies of penguins in so-called area i) is provided in Fig. 1 which also shows the relative abundance of breeding pairs in the different sub-areas, computed from data in Underhill *et al.* (2006). The regional penguin population is dominated (in terms of numbers) by two large colonies, namely Robben Island and Dassen Island; thus the model here has focused on these two colonies, with the next most important colony being Dyer Island.

Fig. 2 maps the extent of strata corresponding to pelagic fish biomass estimates used to link to penguin breeding success in the model. Initially relationships were investigated with the west of Cape Agulhas pelagic spawner biomass and the west of Cape Infanta recruit abundances rather than the total South African pelagic fish abundance. More recently, this has been refined further still to use the Cape Columbine to Cape Point spawner biomass component only since this more accurately depicts the biomass available to penguins in the west coast model area. The west of Cape Infanta recruit estimates are retained because the anchovy and sardine recruits move down the West Coast.

The model time step is one year and hence average trends are modelled. Penguins in each sub-area are modelled starting from 1986.

DATA

Available Data - Penguins

A summary of the timeline assumed for an "average" penguin is given in Fig. 3.

A number of time series, both published and unpublished, are available and have been used both to compare with model trends and for use in estimating parameters by fitting to these data. The two main forms of data are counts of the numbers of moulting birds at the various colonies and counts of breeding pairs (Table 1). The data are from Underhill *et al.* (2006), and various published studies as well as recent updates provided by Les Underhill and Rob Crawford.

The moult count measures the size of the adult-plumaged population whereas the nest count measures the number of breeding pairs (L. Underhill, pers. commn). There are two slightly different series available describing the number of birds moulting at Robben Island, and the series used here are the set considered the more accurate of the two because they account for missing information (see Underhill and Crawford 1999).

It has been highlighted (Rob Crawford, pers. commn) that the counts are of birds moulting around the coastline but that at Dassen Island, where many birds construct burrows, birds also moult in burrows and are not counted. Furthermore the counts at Dassen Island do not cover the interior where penguins may be found in appreciable numbers. Therefore, the count at Dassen Island is not of all birds moulting, just an index. Anton Wolfaardt and Les Underhill (pers. commn) have similarly confirmed that the Dassen Island moult counts should be treated as an index of abundance, and not as an estimate of the absolute number of penguins. Given that the moulting process takes two weeks, the sum of counts made at two week intervals provides an estimate of the total population moulting at the locality, following adjustments for the fact that the counts are not made at exactly this frequency. Crawford (pers commn) notes that moulters will be undercounted at Robben Island to a lesser extent than at Dassen Island.

As the model represents numbers of female penguins, an even sex ratio was assumed and the numbers of moulters halved to derive an index of the number of female moulters (Table 1). Separate moult count series are given in Table 1 for Robben and Dassen Islands.

It has been noted that the Dyer moult count data are unreliable for some years due to cholera outbreaks at the peak moult period (Underhill, pers commn). The following data from Dyer have thus been excluded from the analysis:

- 2001 (counts were not made in September and October 2000)
- 2003 (counts were not made in October and November 2002)
- 2005 (an important count is missing for the first half of October 2004, so the interpolation is not really satisfactory).

Data to provide insights into the age structure are provided by Les Underhill in the form of adult and juvenile (birds undergoing first moult) penguin moult counts at Dassen, Robben and Dyer Islands (Table 2).

It has been noted that, when considering Robben, Dassen and Dyer Islands, the number of female moulters per year is approximately the same or less, rather than substantially more, than the number of breeding females (Fig. 4). This indicates that only a proportion of the population is counted during the moult counts because, for example, counts do not cover the island interiors where penguins may be found in appreciable numbers. It is assumed in the modelling exercise that the proportion of counted to uncounted birds remains approximately constant from

year to year and that the moult counts provide a reliable index of population trends even though only a proportion of the population is counted.

Using data on the numbers of breeding pairs (from Underhill *et al.* 2006), the observed trends in the Western Cape as a whole are compared in Fig. 5 with the trend obtained when summing the numbers of breeding pairs included in a model encompassing Dassen Island, Robben Island, Boulders and Dyer Island. This suggests that the model accounts for over 90% of all penguins in area (i) of the spatial model being developed for testing the pelagic OMP, and that the overall trend is the same as that for the Western Cape as a whole. The projected model will focus on Dassen and Robben Islands only which together currently account for 65% of all penguins in area (i), though the proportion has been 80-85% during the last 10 years.

Chick fledging success data

Data on the number of chicks fledged per pair per year were available for Robben Island based on values in Crawford *et al*. (2006) (Table 3), but with some recent updates and changes. Over the period 1989-2005 at Robben Island, penguin pairs fledged an average of 0.63 chicks annually, with a maximum of 0.97 in 1997 (Crawford *et al*. 1999, 2006 with changes to 2005 data and update for 2006 provided by Crawford pers commn.). There are no data for the year 2000, which corresponds to the year in which about 1900 birds died and breeding was disrupted following oiling in the *Treasure* spill (Crawford *et al*. 2000). Crawford *et al.* (2006) suggest that the increased mortality caused by the oil spill was ameliorated to a large extent by the high abundance of pelagic fish prey at the time.

Data are also available for Dassen Island from A. Wolfaardt (Table 3). The Robben series is longer than the Dassen series, and the Dassen values are higher (average = 0.9; maximum = 1.08), possibly mainly because the Robben breeders are new, less experienced birds (Crawford pers. commn) (Fig. 6). One difficulty with these data is that the Dassen data are for one breeding attempt, not for one year, hence the fledgling success estimates per year should actually be slightly higher (A. Wolfaardt, pers. commn).

Crawford (pers. commn) notes as follows: “Averaging Anton's values for those re-breeding within 2.5 months (25% of successful; 36% of failed at incubation; 21% of failed at brood) gives 27% of birds having a second clutch, which as Anton points out is the same as observed in an earlier study at Robben Island (27% p. 143, Crawford et al. 1999). Therefore to get an estimate of chicks fledged per pair per year, I would multiply Anton's chicks produced per breeding attempt by 1.27.” He notes further that differences between islands in breeding success may be due to island factors and not food effects, given for example that the cat population at Robben peaked in 1998. Moreover, Dassen Island is likely a more favourable breeding habitat than Robben Island.

Proportion that breed at various ages

African Penguins are known to breed for the first time when 4-5 years old (Randall 1983, Crawford *et al.* 1999, Whittington 2002). Based on data specifying the age at which known-age African penguins were first observed breeding at Robben Island, Crawford *et al.* (1999) assumed that the following proportions of birds of different ages were breeders:
Age 1 : 0.0; Age 2: 0.10; Age 3: 0.33; Age 4: 0.80 and Age 5+: 1.0. The base-case model assumes penguins breed for the first time when 4 years (i.e. 100% at age 4 and 0% for younger ages). Alternative sensitivities will also be investigated.

Immigration and Emigration

Adult African penguins very rarely breed at any other than the colony at which they first established breeding (Randall *et al*. 1987, Whittington 2002). However, first-time breeders are known to emigrate from natal colonies, likely in response to changing food availability (Whittington *et al.* 2005a). Based on re-sightings of flipper-banded chicks over the period 1989 to 1999, Whittington *et al.* (2005a) deduced that the predominant direction of movement of some young penguins was away from the south coast of the Western Cape (in the vicinity of Dyer Island), towards the western side of the Western Cape, centred on Robben and Dassen Islands.

Birds move regularly between Robben and Dassen Islands (Whittington *et al.* 2005b). Robben Island was recolonised by penguins in 1983 (Crawford *et al.* 2006). The mainland colonies of Boulders and Stony Point are considered to have been established through emigration of young penguins (Whittington 2002).

Based on resightings to October 1999 of birds banded as chicks, there were indications of little movement to the W Cape from the E Cape, with only one bird (out of a total of five observed moving) moving to the W Cape (Whittington *et al.* 2005c, Table 2). Approximately 71% of 14% of birds (10%) from Namibia moved to the W Cape. Crawford (pers. commn) notes that about 8000 pairs bred in Namibia in 1990 and about 6000 in 1999.

Whittington's study was conducted prior to very large increases in the anchovy and sardine abundance off the South African west coast, and hence if the penguins move around in response to local food availability, the movement patterns over the more recent period may have changed.

Major oil spills

The Apollo Sea oil spill in 1994 and Treasure oil spill in 2000 resulted in the death of approximately 5000 and 2000 breeding adults, mostly from Robben and Dassen Islands (Underhill *et al.* 1999, 2006, Crawford *et al.* 2000). As this is an important additional source of mortality, in the model it is assumed that an additional 2500 and 1000 breeding females from Dassen/Robben died in these years, with the number assumed dead from each age class computed on the assumption of proportionality to the abundance of that age class.

It is also assumed that a proportion (set at 0.2 in the current model version) of fledged chicks died at Robben and Dassen in these years.

Available Data – Pelagic fish

The diet of African penguins is dominated by anchovy and sardine (Hockey *et al*. 2005), and the breeding success of penguins is thought to be correlated with the abundance of these two pelagic fish species. Janet Coetzee and Carryn de Moor kindly provided data on the abundance of anchovy and sardine spawners and recruits. For recruits, the total "De Moor" assessment model recruit estimates for the whole region west of Cape Infanta were used. This is the recruit survey area used in the assessment of the sardine and anchovy resources.

November spawning biomass survey results were provided by C. de Moor. Inshore and offshore estimates were summed to obtain sardine and anchovy biomass series corresponding to the area between Cape Point and Cape Columbine (stratum B). The proportions of the total anchovy and sardine biomasses observed in stratum B were computed for each year. The assessment model biomass estimates for anchovy and sardine from C. de Moor were multiplied by the proportions

observed in stratum B. The results were summed to obtain a combined biomass series for stratum B. Dividing by the maximum value yielded the relative abundances used as the input series to the penguin model. These indices are given in Tables 4 and 5 and are shown in Fig. 7. Fig. 8 and 9 show graphically the proportions per year of the total anchovy and sardine biomasses that were observed in stratum B.

DISCUSSION

Previously arguments have been made by the task group that Dassen and Robben Island should show the same response to changing environmental conditions, and hence these two colonies were lumped in the initial model version. However, data on fledgling success (Fig. 6) suggest that this is not necessarily the case. A further problem with lumping Robben and Dassen Islands is that the ratio of the numbers breeding to the numbers moulting at these two islands is very different, particularly for recent years (see Fig. 4). For these reasons, these two colonies are modelled separately.

ACKNOWLEDGEMENTS

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LITERATURE CITED

Crawford, R.J.M, Barham, P.J., Underhill, L.G., Shannon, L.J., Coetzee, J.C., Dyer, B.M., Leshoro, T.M., and Upfold, L. 2006. The Influence of Food Availability on Breeding Success of African Penguins *Spheniscus demersus* at Robben Island. *Biological Conservation* 132: 119–125.

Crawford, R.J.M., Davis, S.A., Harding, R.T., Jackson, L.F., Leshoro, T.M., Meÿer, M.A., Randall, R.M., Underhill, L.G., Upfold, L., van Dalsen, A.P., van der Merwe, E., Whittington, P.A., Williams, A.J., Wolfaardt, A.C., 2000. Initial impact of the *Treasure* oil spill on seabirds off western South Africa. *South African Journal of Marine Science* 22, 157-176.

Crawford, R.J.M., Shannon, L.J., Whittington, P.A., 1999. Population dynamics of the African penguin *Spheniscus demersus* at Robben Island, South Africa. *Marine Ornithology* 27, 139-147.

Randall, R.M. 1983. Biology of the Jackass penguin *Spheniscus demersus* at St Croix Island, South Africa. PhD thesis, University of Cape Town. 262 pp.

Randall, R.M., Randall, B.M., Cooper, J., la Cock, G.D. and G.J.B. Ross. 1987. Jackass *penguin Spheniscus demersus movements, inter-island visits, and settlement.* J. Fld. Orn. 58(4): 445-455.

Underhill, L. G., and Crawford, R. J. M. 1999. Season of moult of African penguins at Robben Island, South Africa, and its variation, 1988–1998. *South African Journal of Marine Science,* 21: 437–441.

Underhill LG, Bartlett PA, Baumann L, Crawford RJM, Dyer BM, Gildenhuys A, Nel DC, Oatley TB, Thornton M, Upfold L, Williams AJ, Whittington PA, Wolfaardt AC (1999) Mortality and survival of African penguins *Spheniscus demersus* involved in the *Apollo Sea* oil spill: an evaluation of rehabilitation efforts. *Ibis* **141**: 29–37.

Underhill, L. G., Crawford, R. J. M., Wolfaardt, A. C., Whittington, P. A., Dyer, B. M., Leshoro, T. M., Ruthenberg, M., Upfold, L., and Visagie, J. 2006. Regionally coherent trends in colonies of African penguins *Spheniscus demersus* in the Western Cape, South Africa, 1987–2005. African Journal of Marine Science 28: 697-704.

Whittington, P.A., 2002. Survival and movements of African penguins, especially after oiling. Unpublished PhD Thesis, University of Cape Town. 286 pp.

Whittington, P. A., Randall, R. M., Crawford, R. J. M., Wolfaardt, A. C., Klages, N. T. W., Randall, B. M., Bartlett, P. A., Chesselet, Y. J., and Jones, R. 2005a. Patterns of immigration to and emigration from breeding colonies by African penguins. *African Journal of Marine Science.* 27: 205–213.

Whittington, P. A., Randall, R. M., Randall, B. M., Wolfaardt, A. C., Crawford, R. J. M., Klages, N. T. W., Bartlett, P. A., Chesselet, Y. J., and Jones, R. 2005b. Patterns of movement of the African penguin in South Africa and Namibia. *African Journal of Marine Science.* 27: 215–229.

Table 1. Summary of data input to model. Data kindly provided by R. Crawford and L. Underhill. Counts of the numbers of moulting birds have been halved to represent the number of female moulters per year, so as to make them comparable with the numbers of breeding pairs, which also comprises a count of the numbers of breeding females per year. Note 2007/2008 moulter data in italics still need to have the interpolation algorithm applied.

	Female moulters			Breeding pairs				
	Robben	Dassen	Dyer	Robben	Dassen	Dyer	Boulders	Western Cape
1987				476	4588		7	23504
1988				849			34	23077
1989	1729			829	8428		38	22236
1990	1696			1278		8349	54	20395
1991	2365			1879	9012	6115	131	18971
1992	2458			2027	7563	7579	158	19015
1993	3269			2176	7299	2374	241	13109
1994	4001			2799	9389	4649	359	19245
1995	3974	6180		2279	9792	4260	366	18219
1996	3282	6111		3097	9502	3279	416	17716
1997	2804	6477		3336	8740	2745	726	17060
1998	4348	8148		3467	10918	1963	555	18386
1999	4699	10719		3808	15155	2363	906	24278
2000	5882	12537	2289	5407	17042	2220	949	26238
2001	6681	13048		6247	21410	2088	1054	33633
2002	8219	12809	2108	7099	22681	2145	1083	35274
2003	7368	11255		5968	20196	1929	1033	31389
2004	8712	8796	3088	7798	24901	2216	1196	38610
2005	6435	9149		7152	22687	2053	1227	34840
2006	3884	5672	1674	3697	13283	2057	1075	21319
2007	*3379*	*4334*	1472	5935	11785	1513	824	21962
2008	*3303*	*1150*		2234	5719	1605	913	12126

Table 2. Summary of the observed proportions of juveniles (birds undergoing first moult), computed as the number of juveniles divided by the total number of moulters.

	Proportion juveniles : total moulters		
	Robben	Dassen	Dyer
1989	0.196		
1990	0.203		
1991	0.161		
1992	0.245		
1993	0.196		
1994	0.165		
1995	0.147	0.113	
1996	0.176	0.126	
1997	0.276	0.271	
1998	0.213	0.173	
1999	0.232	0.281	
2000	0.192	0.252	0.055
2001	0.161	0.204	
2002	0.193	0.246	0.088
2003	0.184	0.194	
2004	0.165	0.18	0.037
2005	0.169	0.219	
2006	0.255	0.161	0.046
2007	0.24	0.174	0.057

Table 3. Breeding success data from R. Crawford for Robben Island representing the average numbers of chicks fledged per pair (i.e. per female) per year. The breeding success data from A. Wolfaardt for Dassen Island represent the average numbers of chicks fledged per pair (i.e. per female) per breeding attempt, and thus are expected to be lower than estimates per year. The last column shows the Dassen series multiplied by 1.27 to convert them (making them comparable to the Robben Island data) from indices of mean chicks fledged per breeding attempt to mean chicks fledged per year.

	Crawford BR(Rob)	Wolfaardt BR(DAS)	Wolfaardt BR(DAS)
	Chicks/pr/year	Chicks/pr	Chicks/pr/year
	Robben	Dassen	1.27*Dassen
1989	0.42		
1990	0.32		
1991	0.59		
1992	0.59		
1993	0.54		
1994	0.45		
1995	0.38	0.650	0.82
1996	0.65	0.805	1.02
1997	0.97	0.929	1.18
1998	0.75	1.057	1.34
1999	0.60	1.083	1.38
2000			
2001	0.84		
2002	0.90		
2003	0.57		
2004	0.72		
2005	0.90		
2006	0.58		

Table 4. Summary of anchovy and sardine biomass estimates from the pelagic model used as inputs to the penguin model. The inshore and offshore November survey biomass data were combined and provided by J. Coetzee (MCM). The proportion observed in stratum B each year was calculated by summing over the relevant strata and dividing by the total abundance (see Fig. 2 for summary of strata). The proportions were used to calculate the predicted biomass in stratum B from the pelagic assessment model (provided by C. De Moor). The final columns show the relative anchovy and sardine model-predicted biomass estimates after dividing values by the maximum for each series so that the indices shown represent a proportion of the maximum observed value over the time series.

	Proportion in stratum B		Biomass in stratum B in '000t			Proportion of maximum		
Year	Anchovy	Sardine	Anchovy	Sardine	combined	Anchovy	Sardine	combined
1985	0.36376	0.17277	331.43	26.78	358.21	0.40878	0.05661	0.38379
1986	0.51883	0.76160	810.77	122.58	933.35	1.00000	0.25917	1.00000
1987	0.22037	0.54615	309.31	150.34	459.65	0.38150	0.31786	0.49247
1988	0.13533	0.02088	140.48	4.76	145.24	0.17326	0.01006	0.15561
1989	0.10938	0.09300	61.17	28.59	89.75	0.07544	0.06044	0.09616
1990	0.00198	0.02099	1.06	8.51	9.57	0.00130	0.01800	0.01025
1991	0.15049	0.08842	212.63	34.56	247.20	0.26226	0.07308	0.26485
1992	0.04091	0.00422	47.16	2.04	49.20	0.05817	0.00430	0.05271
1993	0.00017	0.16714	0.13	103.59	103.71	0.00016	0.21902	0.11112
1994	0.09767	0.22393	43.53	160.02	203.55	0.05369	0.33833	0.21808
1995	0	0	0	0	0	0	0	0
1996	0.04978	0.03850	20.52	46.67	67.19	0.02530	0.09868	0.07199
1997	0.01572	0.15150	12.23	305.10	317.33	0.01508	0.64507	0.33999
1998	0	0.21349	0	434.52	434.52	0.00000	0.91871	0.46555
1999	0.06730	0.07219	94.70	148.65	243.36	0.11680	0.31430	0.26073
2000	0.01580	0.25130	49.40	472.97	522.37	0.06092	1.00000	0.55967
2001	0.13746	0.08994	520.48	270.67	791.15	0.64196	0.57227	0.84765
2002	0.00800	0.00274	26.40	10.37	36.77	0.03257	0.02192	0.03940
2003	0.00327	0.00237	8.27	12.96	21.23	0.01021	0.02740	0.02275
2004	0.00201	0.00001	3.83	0.02	3.85	0.00472	0.00004	0.00413
2005	0.00000	0.00001	0.00	0.03	0.03	0.00000	0.00006	0.00003
2006	0.00165	0.08572	2.48	120.03	122.51	0.00306	0.25378	0.13126

Table 5. Summary of anchovy and sardine **recruit** estimates from the pelagic model used as inputs to the penguin model. The final columns show the relative anchovy and sardine model-predicted recruit estimates after dividing values by the maximum for each series so that the indices shown represent a proportion of the maximum observed value over the time series.

	Recruits in billions			Proportion of maximum		
Year	Anchovy	Sardine	combined	Anchovy	Sardine	combined
1985	85.70	6.05	91.75	0.163	0.032	0.12798
1986	204.08	3.85	207.93	0.389	0.020	0.29002
1987	124.41	8.88	133.29	0.237	0.046	0.18592
1988	105.73	2.58	108.31	0.201	0.013	0.15107
1989	27.81	9.44	37.25	0.053	0.049	0.05196
1990	53.45	11.84	65.29	0.102	0.062	0.09107
1991	232.84	7.79	240.63	0.443	0.041	0.33563
1992	120.04	14.83	134.87	0.229	0.077	0.18812
1993	71.22	27.99	99.21	0.136	0.146	0.13837
1994	35.29	8.96	44.25	0.067	0.047	0.06172
1995	72.26	44.87	117.13	0.138	0.234	0.16338
1996	24.83	13.33	38.16	0.047	0.070	0.05322
1997	93.30	78.44	171.74	0.178	0.409	0.23955
1998	98.52	36.71	135.23	0.188	0.191	0.18862
1999	180.35	43.07	223.42	0.343	0.225	0.31163
2000	514.52	62.47	576.98	0.980	0.326	0.80478
2001	525.18	191.76	716.94	1.000	1.000	1.00000
2002	247.52	144.25	391.77	0.471	0.752	0.54645
2003	218.65	89.49	308.14	0.416	0.467	0.42980
2004	130.44	12.31	142.76	0.248	0.064	0.19912
2005	175.84	8.75	184.59	0.335	0.046	0.25746
2006	103.30	33.15	136.45	0.197	0.173	0.19032

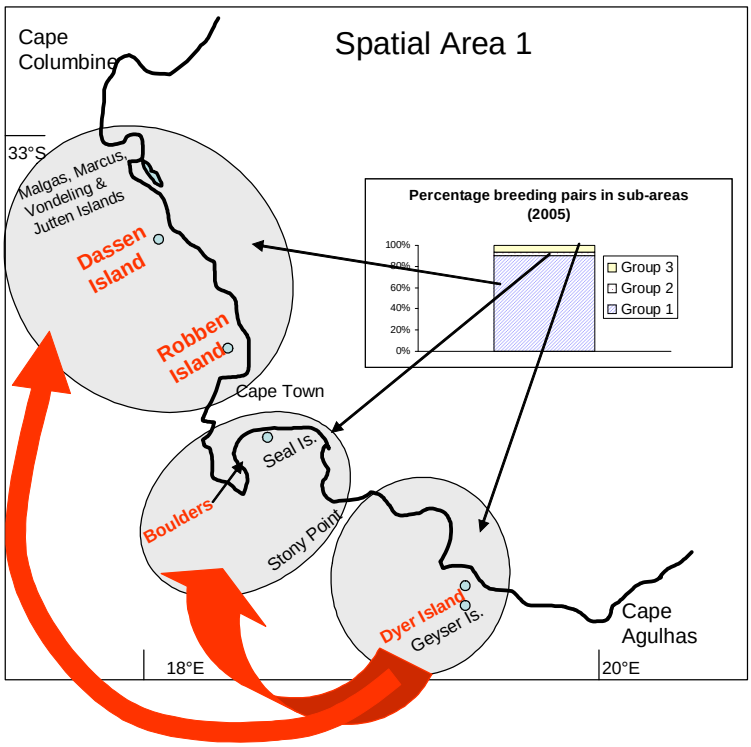

Fig. 1. Map showing location of penguin colonies in the "western" area. The colonies included in the model are shown in bold red text. The arrows represent movement of penguins from Dyer Island to Boulders, as well as movement to Robben and Dassen Islands as is included in the model.

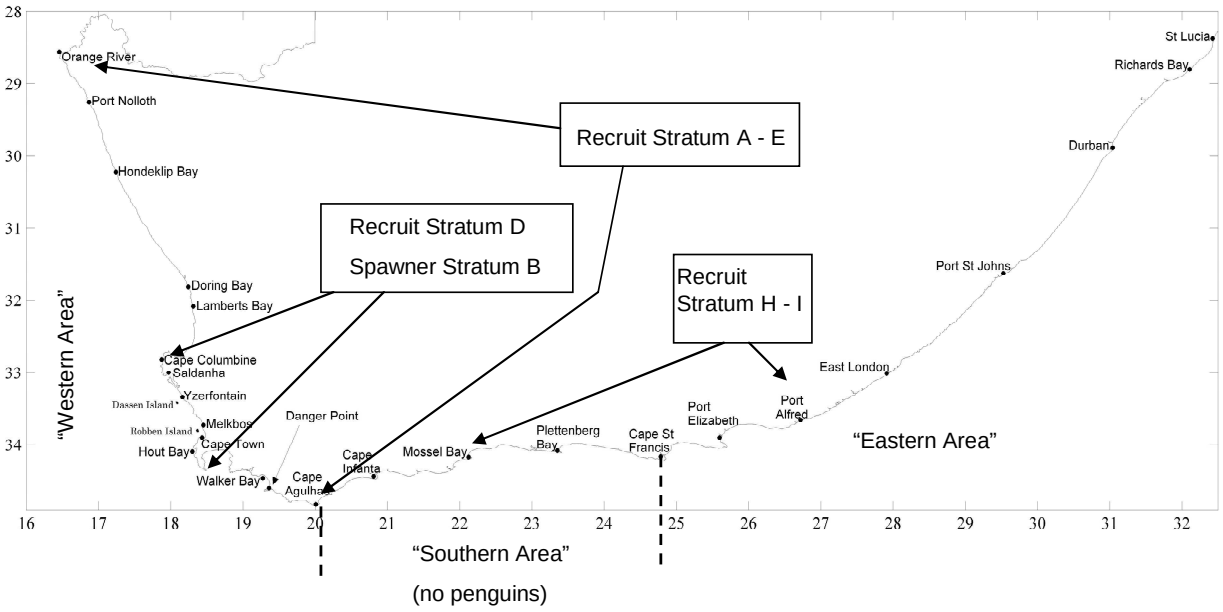

Fig. 2. Map showing extent of strata corresponding to pelagic fish biomass estimates used to link to penguin breeding success in the model (which includes Dassen, Robben, Dyer Island and Boulders – the "Western Area"). The region labelled as Spawner Stratum B corresponds to the spawner biomass survey designation, with penguin performance linked to spawner biomass from this local region. Basic map provided by Janet Coetzee (MCM).

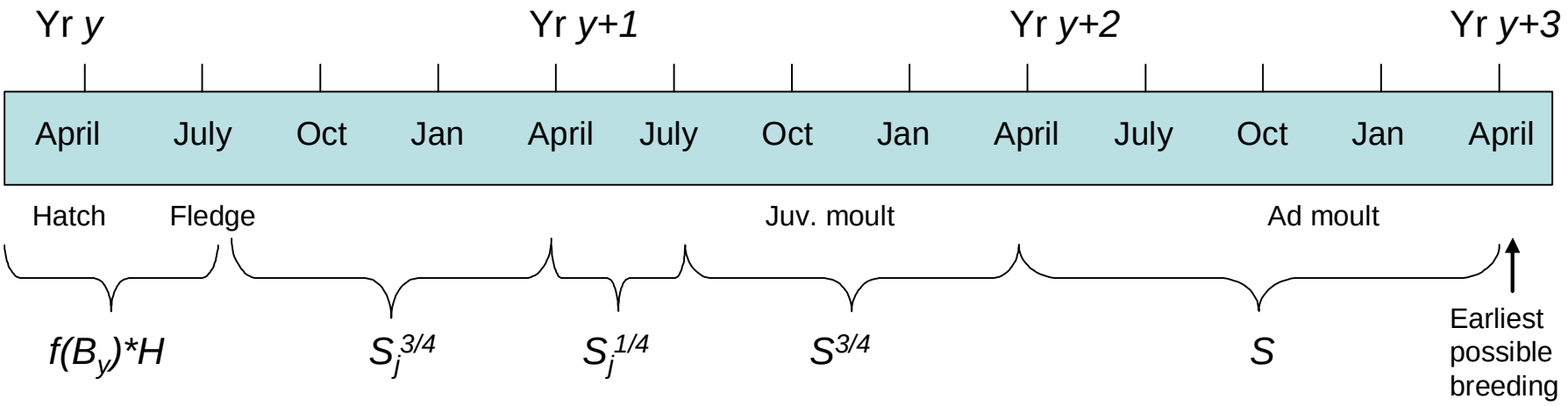

Fig. 3. Schematic summary of timeline detailing life history of an average penguin, to illustrate different survival factors applied in the modelling analyses.

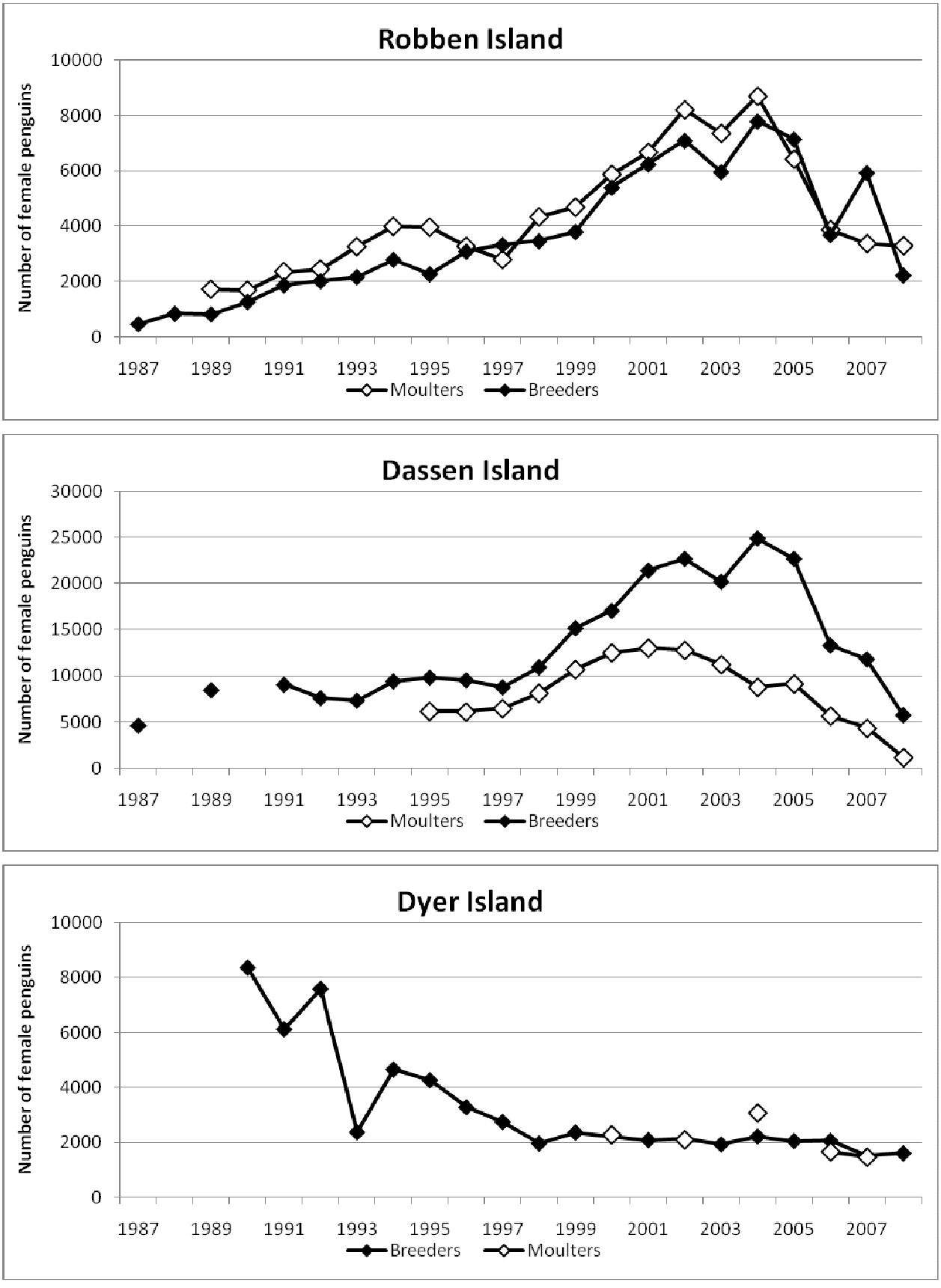

Fig. 4. Numbers of female moulters (assuming a 50:50 sex ratio) and breeding pairs of penguins at Robben, Dassen and Dyer Island. The number of adult moulters includes birds aged (approximately) two years and older whereas breeding females are aged approximately four years and older. The latter index would thus be smaller than the former if both reflected complete censuses.

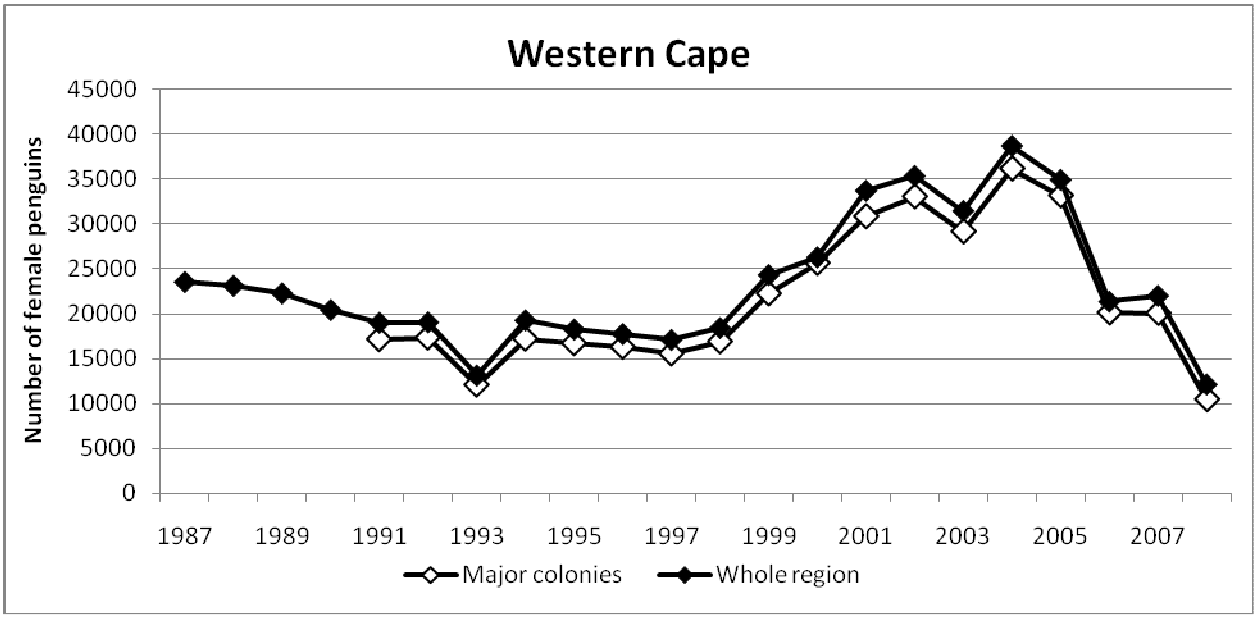

Fig. 5. Comparison of numbers of breeding pairs (from Underhill *et al.* 2006) and observed trends in the Western Cape as a whole and the numbers of breeding pairs included in a model encompassing Dassen Island, Robben Island, Boulders and Dyer Island.

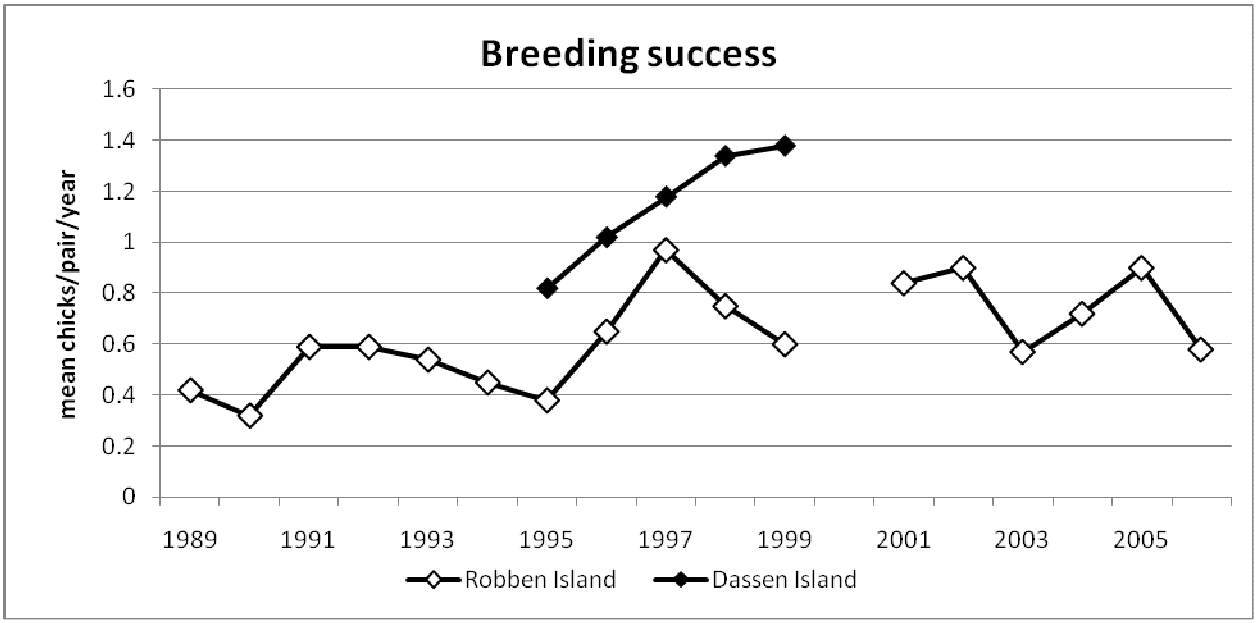

Fig. 6. Plots of chick fledging success data representing the average numbers of chicks fledged per pair (i.e. per female) per year for Robben Island (from R. Crawford) and for Dassen Island (derived by scaling data from A. Wolfaardt to account for multiple breeding attempts in the same year).

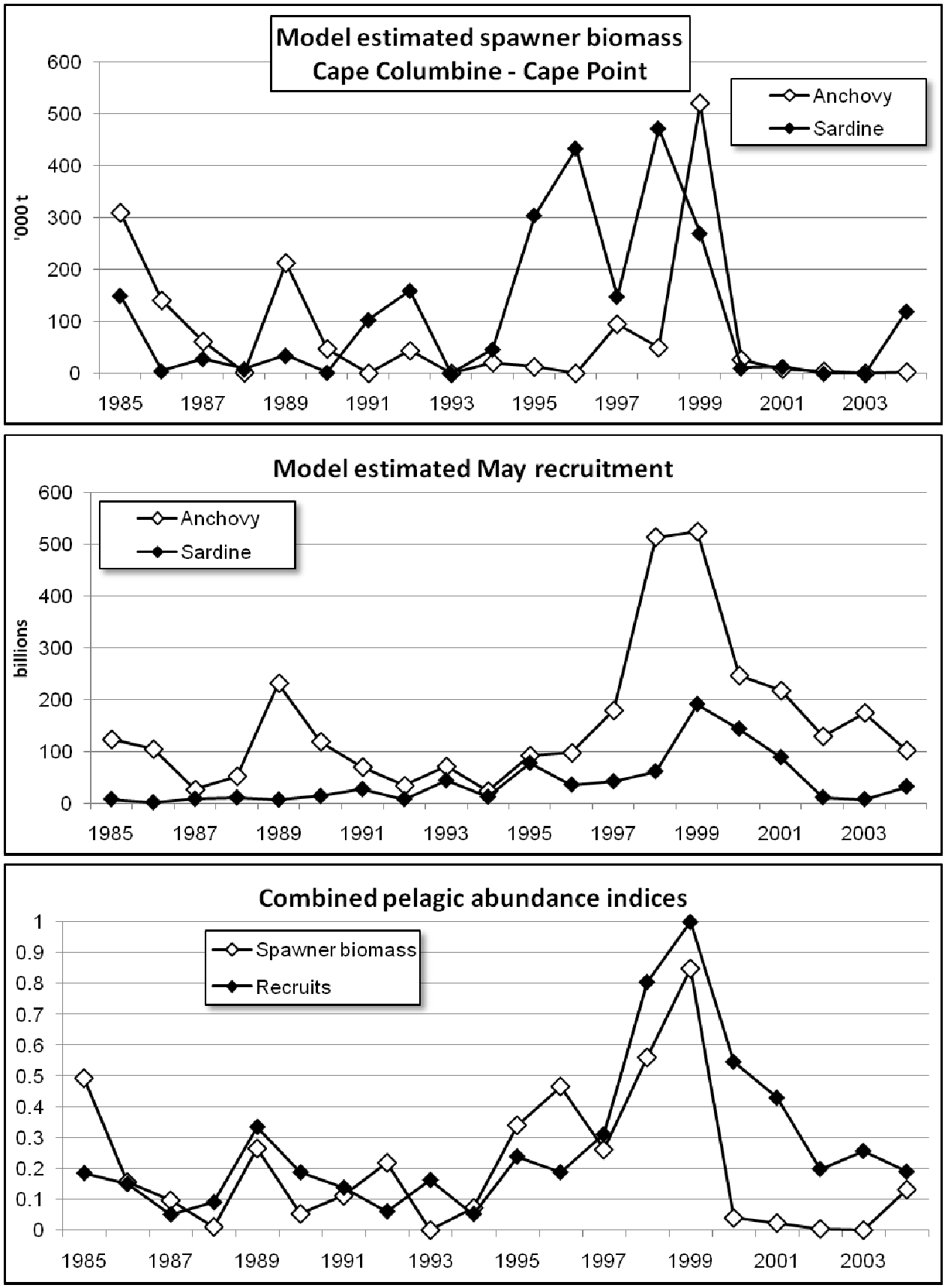

Fig. 7. Predicted anchovy and sardine biomass (top) and recruit (middle) abundances (from C. De Moor). The predicted biomass proportions west of Cape Agulhas are plotted, calculated using the historic proportions (from J. Coetzee). The relative abundances of the combined series are plotted on the bottom graph.

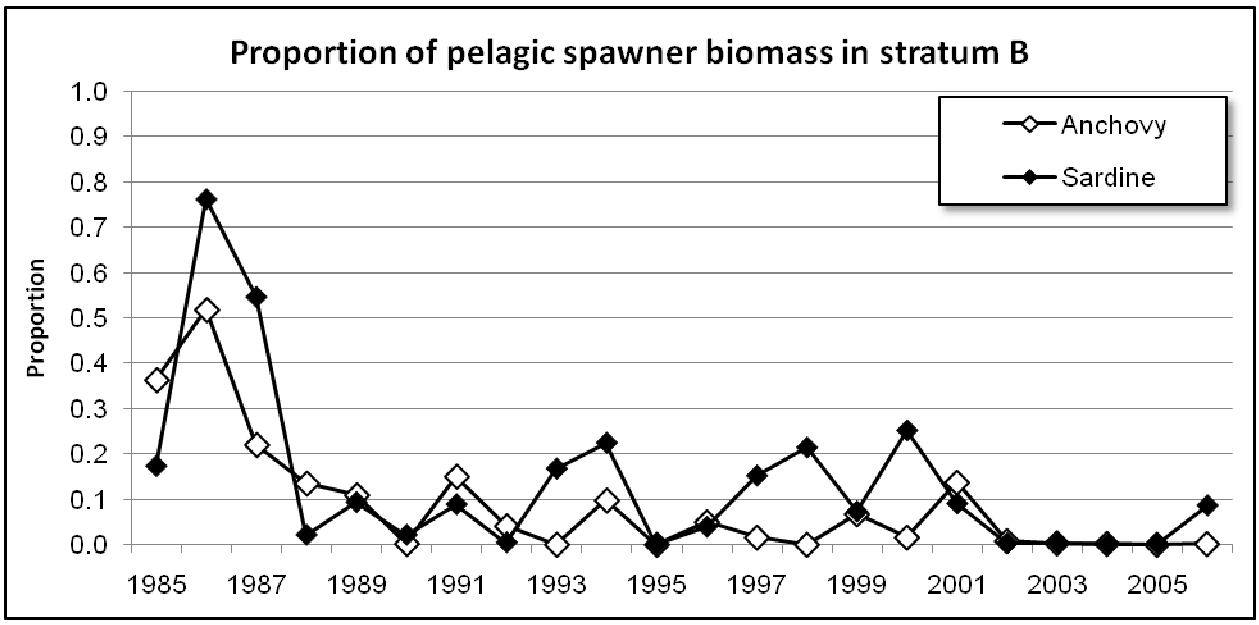

Fig. 8. Plot showing the historic proportions of anchovy and sardine November spawning biomass in the area between Cape Columbine and Cape Point (stratum B).

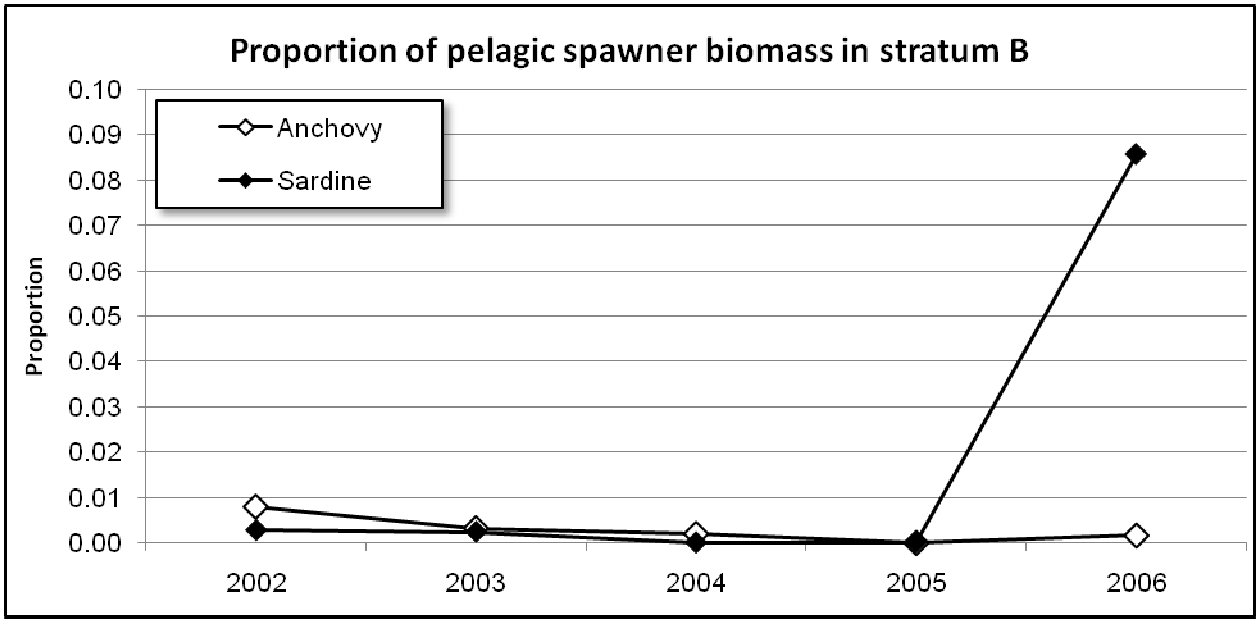

Fig. 9. Plot showing the extremely low historic proportions of anchovy and sardine November spawning biomass (stratum B) in recent years (2002-2006).