Summary of available data for modelling African Penguin *Spheniscus demersus* Populations

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INTRODUCTION

This document serves as a compilation of all data currently available as inputs to the African penguin spatial model (Plagányi and Butterworth 2007) being developed. 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. Note that this is a working group document only and hence should be extended and improved in future, particularly as regards critical evaluation of different data sources.

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 being split in an updated 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. An Algoa Bay component can also be linked to the model if required.

A summary of all the breeding colonies of penguins in 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 area i) model (which includes Dassen, Robben, Dyer Island and Boulders) and preliminary model for area iii) (St Croix).

The model time step is one year and hence average trends are modelled. Penguins in each sub-area are modelled starting from 1987.

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 data are generally considered more precise as a population measure (based on c. 24 counts per year) than the breeding pairs count (one count per year aimed to hit the peak of the breeding season) (L. Underhill, pers. commn). 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). To obtain an aggregated index for Dassen and Robben Islands, the numbers of moulters at each locality were added together (Table 1). As no moult count data were available for Dassen Island for the period 1989-1994, these values were assumed equal to the 1994 value (i.e. it is assumed the population stayed approximately constant over this period as is suggested by the breeding pairs count data) so that a combined index could be obtained.

Separate moult count series are given in Table 1 for Robben and Dassen Islands given that these colonies may be modelled separately. Table 1 also summarises available estimates of the numbers of breeding females at Algoa Bay (Nelson Mandela Bay) for years as shown.

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).

New data that have been included in the model and provide valuable insights into the age structure, are those provided by Les Underhill regarding adult and juvenile (birds undergoing first moult) penguin moult counts at Dassen, Robben and Dyer Islands. These data as well as a combined Dassen/Robben series are given in Table 2. A combined index of the juvenile proportion for Robben and Dassen was derived by summing adult and juvenile numbers for all years for which data are available for both islands, and using just the Robben Island data for the remaining years.

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.

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 have also recently become 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.

A derived Dassen Island series (for purposes of experimenting within the model before a functional relationship has been determined) has been computed by assuming the trends are similar at Robben and Dassen, but scales the Robben data for missing years at Dassen by multiplying by the average ratio of the Dassen to Robben values (Table 3, Fig. 6)). Values for

2000 are considered unreliable because of the 2000 oil spill and hence these data have been omitted.

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.

Survival estimates

Table 4 summarises estimates of adult and first-year survival for African penguins available in the literature. These confirm the notion that juvenile survival is typically less than adult survival. As previously discussed, it is often practice in marine population modelling to estimate *S* by fitting to an index/indices of abundance for the species because of problems in quantifying biases in direct estimates of survival rates and of the sensitivity of population trends to the choice of an adult survival parameter *S*. Model simulations are conducted both with S fixed at values in the literature as well as by estimating *S* (as well as juvenile survival and recent decreases in *S*).

La Cock and Hänel (1987) computed survival rates based on ringing of 512 fledglings, 27 juveniles and rebanding of 86 adult penguins at Dyer Island in October/November 1978. They recaptured banded penguins during subsequent visits over the period 1982-1985 and computed survival from the formula:

$$\phi = \left(\frac{n_x}{n_1}\right)^{1/x}$$

where ϕ = survival coefficient;
n_1 = number banded in first year; and
n_x = number retrapped *x* years later.

They noted that their juvenile annual survival rate estimate of 69% was a minimum and was lower than rates for five of six penguin species examined by Croxall (1981).

Based on his study of penguins at St Croix Island over the period 1976-1982, Randall (1983) found post fledgling survival varied between years from 4% to 35%, with average second year survival being 90.5%. The post fledgling survival rate estimates are likely biased downwards because he notes that fledged chicks were often not seen back on the Island until their second or third years. Moreover he notes that the 1976 and 1977 seasons were characterised by exceptionally high post-fledgling mortalities. Adult annual survival based on resightings of known breeding age adults over a six-year period ranged from 87.8% to 95.7%, with an average of 91.1%. Furthermore, he notes that by the end of 1982 there were still large numbers of known age birds (158) aged 14 years or more, giving some idea of life expectancy i.e. it must be more than 14 years.

Whittington (2002) used the program MARK to evaluate annual survival rates using data on re-sightings of flipper-banded birds from seventeen penguin colonies. His results suggest mean annual adult survival of 0.81 for birds banded at Robben and Dassen Islands, and ranged between 0.1 and 0.8 (average = 0.35) for first year birds.

Altwegg (2006) computed penguin survival estimates for Dassen 1995 to 2004. These were all penguins that were oiled in 1994, rehabilitated and released again. It wasn't known how old they were when they were banded, nor whether the oiling had an effect on their long-term survival. His results indicated mean survival between 1995 and 2002 was 0.852 (se=0.018). The year-to-year variability measured by the standard deviation was sigma=0.054. This last estimate is corrected for sampling variance, and so is an estimate of the process variance only. If the years 2003 and 2004 are included, mean survival drops to 0.780 (se=0.054) and sigma=0.168.

Literature:
Ricklefs (2000), using data from 34 studies comprising 32 bird species, demonstrated a strong correlation between annual fecundity (number of fledglings per year) and annual adult mortality. Using Ricklefs (2000) relationship and computing adult survival as $S = e^{-M}$, yields corresponding theoretical average and maximum survival estimates of 0.88 and 0.92 yr for African penguins. Moreover, Ricklefs (2000) found that mortality from fledging to maturity is a function of annual adult mortality, roughly suggesting from his relationship that pre-reproductive survival rates in this case are of the order 0.74 to 0.82/yr. First-year survival rates can naturally be expected to be less than this.

Many of the survival rate estimates provided in the literature are based on large-scale banding of penguins. However, some studies have shown that flipper-bands may have negative long-term effects on penguins (e.g. Jackson and Wilson 2002). For example, Gauthier-Clerc *et al.* (2004) report that for king penguins *Aptenodytes patagonicus* the survival rate of unbanded electronically tagged chicks after 2-3 years is approximately twice as large as that reported in the literature for banded chicks. They also found that banded birds arrived later at breeding colonies, and showed lower breeding probability and chick production. It is not known to what extent flipper banding of African penguins may have biased available survival estimates.

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.* 2005b). Based on re-sightings of flipper-banded chicks over the period 1989 to 1999, Whittington *et al.* (2005b) 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.* 2005c). 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.* 2005b, 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 0.5 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. Initial model versions have focused on using estimates of anchovy recruit biomass. Janet Coetzee and Carryn Cunningham kindly provided data on the abundance of anchovy and sardine spawners and recruits. Data from Coetzee were in the form of May recruit survey biomass for the various strata. Inshore and offshore estimates were summed for each stratum and combined biomass series computed by summing over different combinations of strata corresponding to the areas modelled. In each case the biomass estimates for a series were divided by the maximum observed value for that series, yielding relative abundance series. Some examples are given in Tables 5-6 and Figs. 7-8, with no final decision as yet as to which series are the most appropriate to use.

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, recent data on fledgling success (Fig. 6) suggest that this is not necessarily the case. Given the difference in these two fledging success data series, together with the fact that Robben Island is a relatively “new” colony (i.e. the average age of birds is likely to be less than at Dassen), it is perhaps surprising that the proportion of juvenile to total moulters at these two islands is remarkably similar (Table 2 and figure below). Note that the proportion of juveniles at Dyer Island is substantially less, possibly indicative of emigration of young birds away from the island. 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, the current model will be altered to model these two colonies separately.

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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. Data shown in italics are interpolated or computed as described in the text.

	Number of female moulters				Number of breeding pairs						
	Robben and Dassen	Robben	Dassen	Dyer	Robben and Dassen	Robben	Dassen	Dyer	Boulders	Western Cape	Algoa
1987					5064	476	4588		7	23504	
1988						849			34	23077	
1989	*7909*	1729			9257	829	8428		38	22236	
1990	*7876*	1696				1278		8349	54	20395	
1991	*8545*	2365			10891	1879	9012	6115	131	18971	
1992	*8638*	2458			9590	2027	7563	7579	158	19015	
1993	*9449*	3269			9375	2176	7199	2374	241	13109	22747
1994	*10181*	4001			12188	2799	9389	4649	359	19245	
1995	10154	3974	6180		12071	2279	9792	4260	366	18219	
1996	9392	3282	6111		12599	3097	9502	3279	416	17716	
1997	9280	2804	6477		11987	3336	8651	2745	726	17060	
1998	12496	4348	8148		14385	3467	10918	1963	555	18386	
1999	15418	4699	10719		19554	4399	15155	2363	906	24278	18490
2000	18419	5882	12537	2289	21303	5705	15598	2220	949	26238	20331
2001	19729	6681	13048		28132	6723	21409	2088	1054	33633	22695
2002	21029	8219	12809	2108	30135	7252	22883	2145	1083	35274	
2003	18624	7368	11255		26752	6433	20319	1929	1033	31389	10193
2004	17508	8712	8796	3088	33425	8524	24901	2216	1196	38610	13865
2005	15584	6435	9149		29839	7152	22687	2053	1227	34840	8050
2006	9557	3884	5672	1674	16980	3697	13283	2057	1075	21319	11467
2007		3314		1472							5418

Table 2. Summary of adult and juvenile (birds undergoing first moult) penguin moult counts (from L. Underhill). The numbers represent males and females combined. The proportion of juveniles is computed as the number of juveniles divided by the sum of the adult and juvenile numbers. A combined index for this proportion for Robben and Dassen Islands combined has been derived by summing adult and juvenile numbers for all years for which data are available for both islands, and using just the Robben Island data for the remaining years (shown in italics).

	Robben		Robben	Dassen		Dassen	Combined	Dyer		
	Ad	Juv	Prop. Juvs/total	Ad	Juv	Prop. Juvs/total	Prop. Juvs/total	Ad	Juv	Prop. Juvs/total
1989	3459	842	0.196				*0.196*			
1990	3392	866	0.203				*0.203*			
1991	4730	911	0.161				*0.161*			
1992	4915	1598	0.245				*0.245*			
1993	6538	1597	0.196				*0.196*			
1994	8002	1585	0.165				*0.165*			
1995	7948	1373	0.147	12360	1578	0.113	0.127			
1996	6563	1403	0.176	12222	1767	0.126	0.144			
1997	5608	2138	0.276	12953	4823	0.271	0.273			
1998	8696	2351	0.213	16296	3418	0.173	0.188			
1999	9397	2834	0.232	21438	8380	0.281	0.267			
2000	11765	2803	0.192	25074	8462	0.252	0.234	4579	269	0.055
2001	13362	2565	0.161	26095	6683	0.204	0.190			
2002	16439	3921	0.193	25619	8380	0.246	0.226	4216	405	0.088
2003	14737	3330	0.184	22511	5409	0.194	0.190			
2004	17424	3440	0.165	17592	3864	0.180	0.173	6177	239	0.037
2005	12871	2617	0.169	18298	5134	0.219	0.199			
2006	7768	2653	0.255	11345	2184	0.161	0.202	3348	161	0.046
2007	6629	2023	0.234				*0.234*	2944	180	0.057

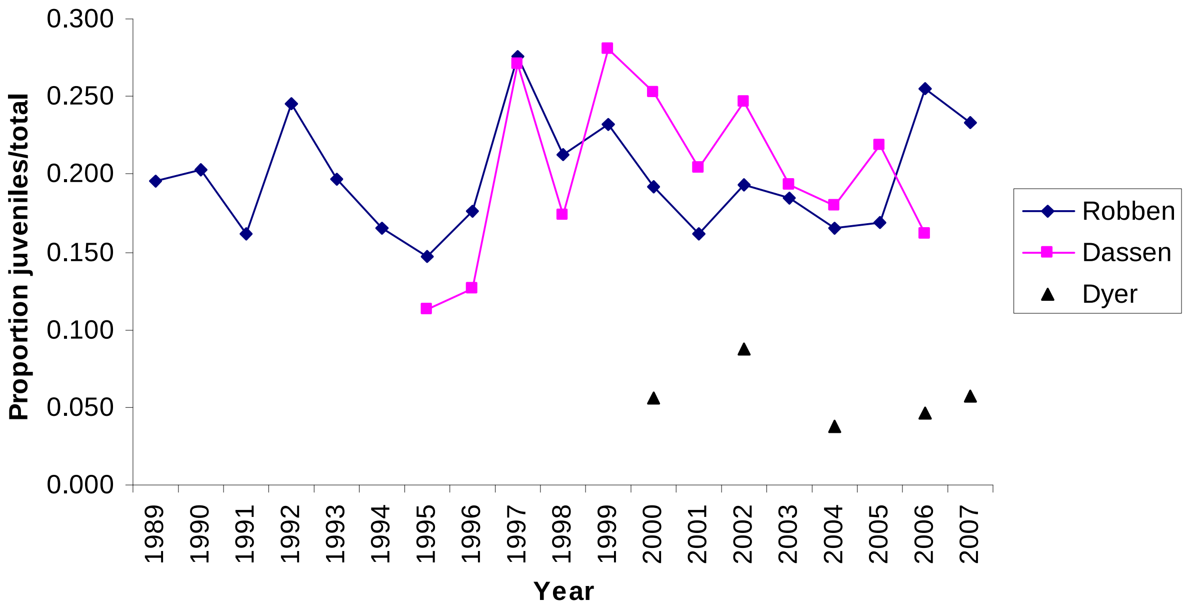

Table 3. Breeding success data from R. Crawford for Robben Island representing the average numbers of chicks fledged per pair (i.e. per female) per year. The breeding success data from A. Wolfaardt for Dassen Island represent the average numbers of chicks fledged per pair (i.e. per female) per breeding attempt, and thus are expected to be lower than estimates per year. The third last column shows a derived Dassen Island series (for purposes of experimenting within the model before a functional relationship has been determined) that assumes the trends are similar at Robben and Dassen, but scales the Robben data for missing years at Dassen by multiplying by the average ratio of the Dassen to Robben values. Values for 2000 are considered unreliable because of the 2000 oil spill and hence these data have been omitted. 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)		Wolfaardt BR(DAS)
	Chicks/pr/year	Chicks/pr	Chicks/pr		Chicks/pr/year
	Robben	Dassen	Dassen extrapolated series		1.27*Dassen extrapolated series
1989	0.42		0.590		0.75
1990	0.32		0.454		0.58
1991	0.59		0.841		1.07
1992	0.59		0.839		1.07
1993	0.54		0.761		0.97
1994	0.45		0.634		0.80
1995	0.38	0.650	0.650	1.70	0.82
1996	0.65	0.805	0.805	1.23	1.02
1997	0.97	0.929	0.929	0.96	1.18
1998	0.75	1.057	1.057	1.41	1.34
1999	0.60	1.083	1.083	1.81	1.38
2000					
2001	0.84		1.195	Ave=	1.52
2002	0.90		1.281	1.42	1.63
2003	0.57		0.812		1.03
2004	0.72		1.016		1.29
2005	0.90		1.279		1.62
2006	0.58		0.824		1.05
Max	0.97	1.08	1.28		1.63
Average	0.63	0.90	0.89		1.12
Median	0.59	0.93	0.84		1.07

Table 4. Summary of adult and juvenile survival rates estimated for African penguins.

Adult survival rate

Value	Locality	Period	Source
0.91	St Croix Island	1976-1982	Randall 1983
0.69	Dyer Island	1979-1985	La Cock and Hänel 1987
0.82 model estimate	Robben Island	1993-1994	Crawford *et al*. 1999
0.80	Dassen Island	1990-1999	Whittington 2002
0.82	Robben Island	1990-1999	Whittington 2002
0.852 (SE = 0.018)	Western Cape	1994-2002	Altwegg 2006
0.69	Robben Island	Apr 2005 – Apr 2006	L. Underhill pers commn

Juvenile survival rate

Value	Locality	Period	Source
0.32 ?	St Croix Island	1976-1982	Randall 1983
0.69 minimum	Dyer Island	1979-1985	La Cock and Hänel 1987
0.31	Robben Island	1987-1999	Whittington 2002
0.38	Dassen Island	1987-1999	Whittington 2002

Table 5. Summary of anchovy and sardine biomass abundance estimates (inshore and offshore data combined) from surveys (from J. Coetzee, MCM) summed over strata as shown (see Fig. 2 for summary of strata) for a) spatial area (i) and b) spatial area (iii). Note that the data are sparse for spatial area (iii) so that it is not straightforward to derive a series for this region.

a)

	Anchovy			**Sardine**			
		C_E: Doring Bay to Cape Agulhas	Strata D: Cape Columbine to Cape Point			C_E: Doring Bay to Cape Agulhas	Strata D: Cape Columbine to Cape Point
	A_E	C_E	D		A_E	C_E	D
1985	329195	251335	246033	1985	64864	27793	27744
1986	680938	343437	87050	1986	40825	40669	1490
1987	902910	462257	101289	1987	80008	65163	597
1988	629717	285755	115529	1988	17369	12388	1165
1989	200699	130824	79359	1989	113493	112142	56304
1990	197541	64663	12848	1990	54184	42448	6741
1991	583638	59172	14310	1991	50922	13512	12620
1992	509157	308914	207718	1992	139462	45738	44270
1993	532530	348037	290615	1993	169907	33832	21858
1994	159729	129047	31676	1994	123764	114793	1162
1995	432915	272194	88683	1995	300641	238025	7420
1996	80465	46498	8076	1996	108914	104383	9220
1997	437736	250489	44388	1997	267863	173065	77252
1998	452545	270880	62692	1998	132460	118493	539
1999	801347	549045	100027	1999	164472	150042	664
2000	2506925	1628173	515504	2000	277035	118692	33376
2001	1989761	847600	448321	2001	590918	381910	202825
2002	1400426	735762	78532	2002	504810	290430	35073
2003	1434396	726905	64834	2003	430193	377640	24851
2004	1054486	897374	80644	2004	39151	33836	3645
2005	301363	186011	1100	2005	9120	8824	62
2006	271751	186219	2690	2006	49727	33017	65

b)

	Sardine				Anchovy			
	F	G	H	I	F	G	H	I
1985		148.3488			50944.29	21732.13	4975.699	
1986	80368.83				9408.029			
1987								
1988								
1989								
1990								
1991								
1992								
1993								
1994	1646.15	47855.91	10702.79	104914.6	1790.212			6.381394
1995	281.3821	26.80978	9163.206	4517.718	129.7389		73059.05	4455.855
1996	57184.62				16424.09			
1997	9459.398				5392.18			
1998	2446.276	2307.592	5393.37		665.0279	13717.6	66.4411	
1999	71247.9	22963.05	162839.7	329.175	24743.21	52591.72	0	
2000	16718.24	118089.2	57086.27	41076.91	37122.66	21933.02	3114.82	194.6374
2001	2917.693	1.92365	6.29109		4822.636	4374.078	161.7545	0
2002	111520.7	6786.39	76352.26	16779.95	159675.8	222261.2	57848.62	14911.69
2003	171774.6	7233.1	27288.63	395788.2	503.3032	1265.9	0	0
2004	1267.926	0	75454.36	13524.52	17074.34	3819.319	24465.38	13576.45
2005	2730.649	60837.45	25870.29	1098.003	6685.588	2597.45	1867.757	0
2006	497.304	68133.37	3198.179	10227.04	4012.228	15697.98	3379.455	3029.161

Table 6a. Summary of anchovy and sardine biomass abundance estimates from surveys (from J. Coetzee, MCM) summed over strata as shown (see Fig. 2 for summary of strata) and after

dividing values by the maximum for each series so that the indices shown represent biomass as a proportion of the maximum observed value over the time series. The values have been plotted in Fig. 5.

	Anchovy			Sardine			Anchovy	
	A_E	C_E	D	A_E	C_E	D	G series	I series
1985	0.13	0.15	0.48	0.11	0.07	0.14	*0.13*	*0.13*
1986	0.27	0.21	0.17	0.07	0.11	0.01	*0.27*	*0.27*
1987	0.36	0.28	0.20	0.14	0.17	0.00	*0.36*	*0.36*
1988	0.25	0.18	0.22	0.03	0.03	0.01	*0.25*	*0.25*
1989	0.08	0.08	0.15	0.19	0.29	0.28	*0.08*	*0.08*
1990	0.08	0.04	0.02	0.09	0.11	0.03	*0.08*	*0.08*
1991	0.23	0.04	0.03	0.09	0.04	0.06	*0.23*	*0.23*
1992	0.20	0.19	0.40	0.24	0.12	0.22	*0.20*	*0.20*
1993	0.21	0.21	0.56	0.29	0.09	0.11	*0.21*	*0.21*
1994	0.06	0.08	0.06	0.21	0.30	0.01	*0.06*	0.06
1995	0.17	0.17	0.17	0.51	0.62	0.04	*0.17*	0.30
1996	0.03	0.03	0.02	0.18	0.27	0.05	*0.03*	0.15
1997	0.17	0.15	0.09	0.45	0.45	0.38	*0.17*	0.15
1998	0.18	0.17	0.12	0.22	0.31	0.00	0.06	0.15
1999	0.32	0.34	0.19	0.28	0.39	0.00	0.24	0.15
2000	1.00	1.00	1.00	0.47	0.31	0.16	0.10	0.01
2001	0.79	0.52	0.87	1.00	1.00	1.00	0.02	0.51
2002	0.56	0.45	0.15	0.85	0.76	0.17	1.00	1.00
2003	0.57	0.45	0.13	0.73	0.99	0.12	0.01	0.96
2004	0.42	0.55	0.16	0.07	0.09	0.02	0.02	0.91
2005	0.12	0.11	0.01	0.02	0.02	0.00	0.01	0.56
2006	0.11	0.11	0.01	0.08	0.09	0.00	0.07	0.20

Table 6b. Summary of ***combined*** anchovy and sardine biomass abundance estimates from surveys (from J. Coetzee, MCM) summed over strata as shown and after dividing values by the maximum for each series so that the indices shown represent biomass as a proportion of the maximum observed value (sardine + anchovy) over the time series.

	Anchovy + sardine		
	A_E	C_E	D
1985	394059	279128	273777
1986	721762	384106	88540
1987	982918	527420	101887
1988	647085	298144	116694
1989	314192	242967	135663
1990	251724	107111	19589
1991	634559	72684	26931
1992	648618	354652	251988
1993	702437	381869	312473
1994	283493	243840	32838
1995	733557	510219	96104
1996	189379	150881	17296
1997	705599	423554	121640
1998	585005	389373	63230
1999	965819	699086	100692
2000	**2783960**	**1746865**	548880
2001	2580679	1229510	**651146**
2002	1905236	1026191	113605
2003	1864590	1104544	89685
2004	1093637	931210	84289
2005	310483	194835	1162
2006	321478	219236	2755

	Anchovy + sardine		
	A_E	C_E	D
1985	0.142	0.160	0.420
1986	0.259	0.220	0.136
1987	0.353	0.302	0.156
1988	0.232	0.171	0.179
1989	0.113	0.139	0.208
1990	0.090	0.061	0.030
1991	0.228	0.042	0.041
1992	0.233	0.203	0.387
1993	0.252	0.219	0.480
1994	0.102	0.140	0.050
1995	0.263	0.292	0.148
1996	0.068	0.086	0.027
1997	0.253	0.242	0.187
1998	0.210	0.223	0.097
1999	0.347	0.400	0.155
2000	1.000	1.000	0.843
2001	0.927	0.704	1.000
2002	0.684	0.587	0.174
2003	0.670	0.632	0.138
2004	0.393	0.533	0.129
2005	0.112	0.112	0.002
2006	0.115	0.126	0.004

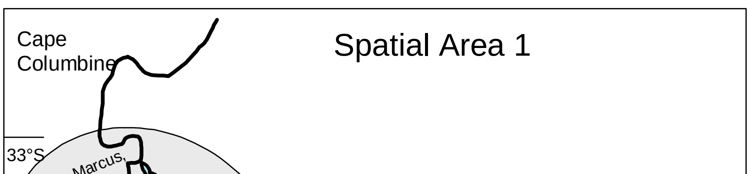

Fig. 1. Map showing location and possible grouping of penguin colonies in the "western" area (area i)). The colonies currently included in the model are shown in bold red text. The arrows represent movement of penguins from Dyer Island to Boulders, as well as movement to Robben and Dassen Islands as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

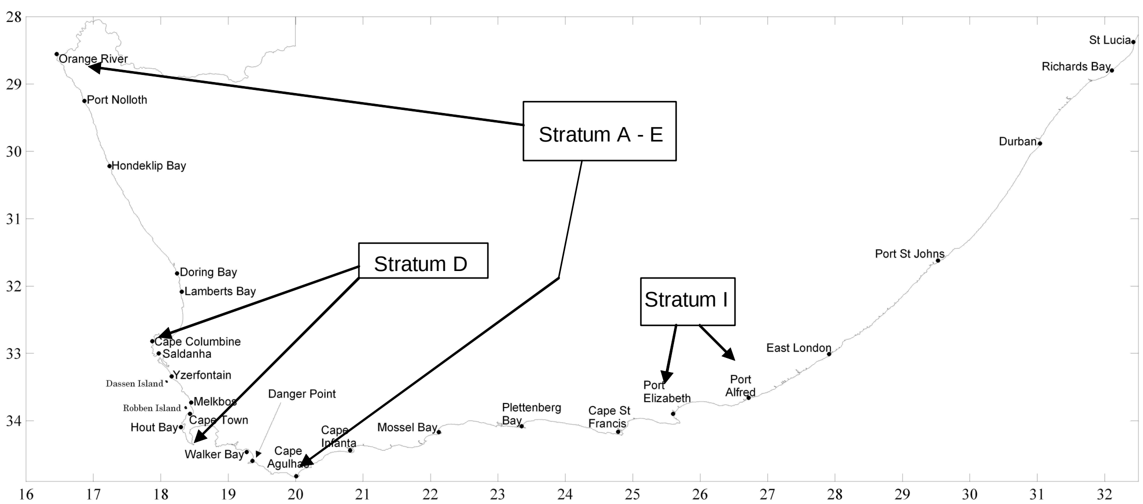

Fig. 2. Map showing extent of strata corresponding to pelagic fish biomass estimates used to link to penguin breeding success in the area i) model (which includes Dassen, Robben, Dyer Island and Boulders) and preliminary model for St Croix in area iii). Basic map provided by Janet Coetzee (MCM).

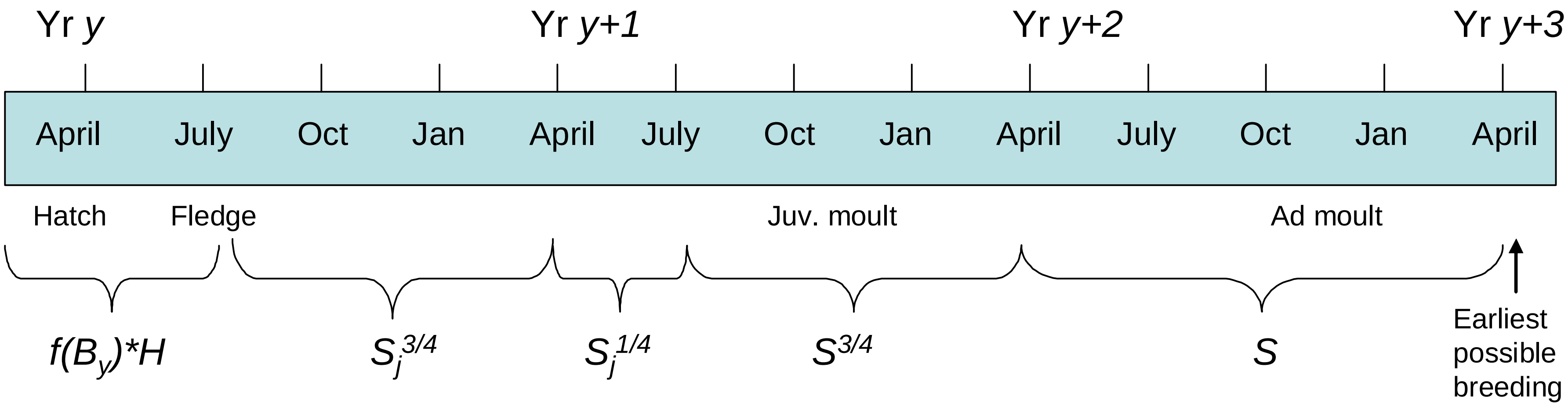

Fig. 3. Schematic summary of timeline detailing life history of an average penguin, to illustrate different survival factors applied in the modelling analyses.

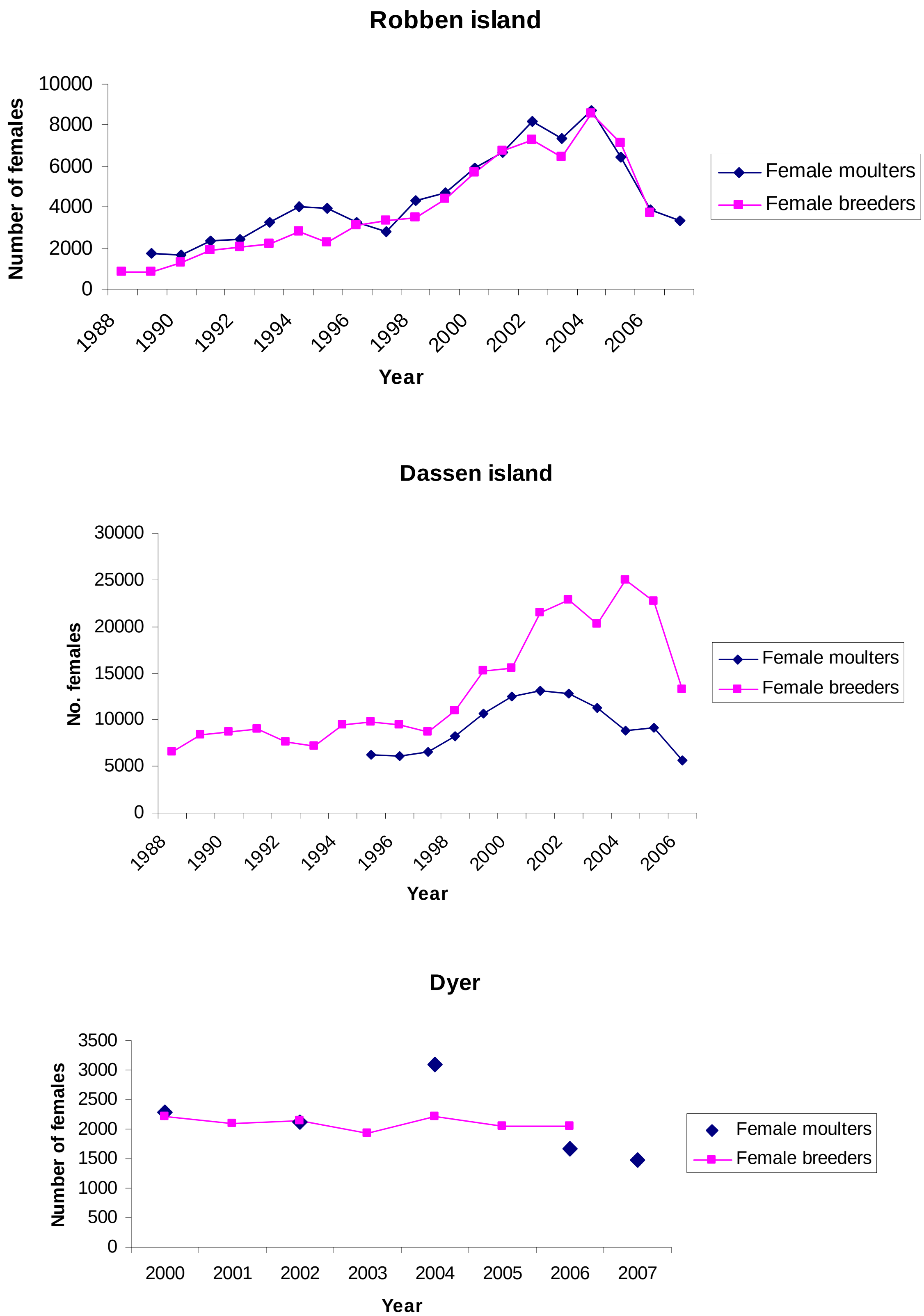

Fig. 4. Plot of numbers of female moulters (assuming a 50:50 sex ratio) and numbers of breeding pairs of penguins at Robben, Dassen and Dyer Island. The number of adult moulters includes all animals aged (approximately) two year and older whereas breeding females are aged approximately four years and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

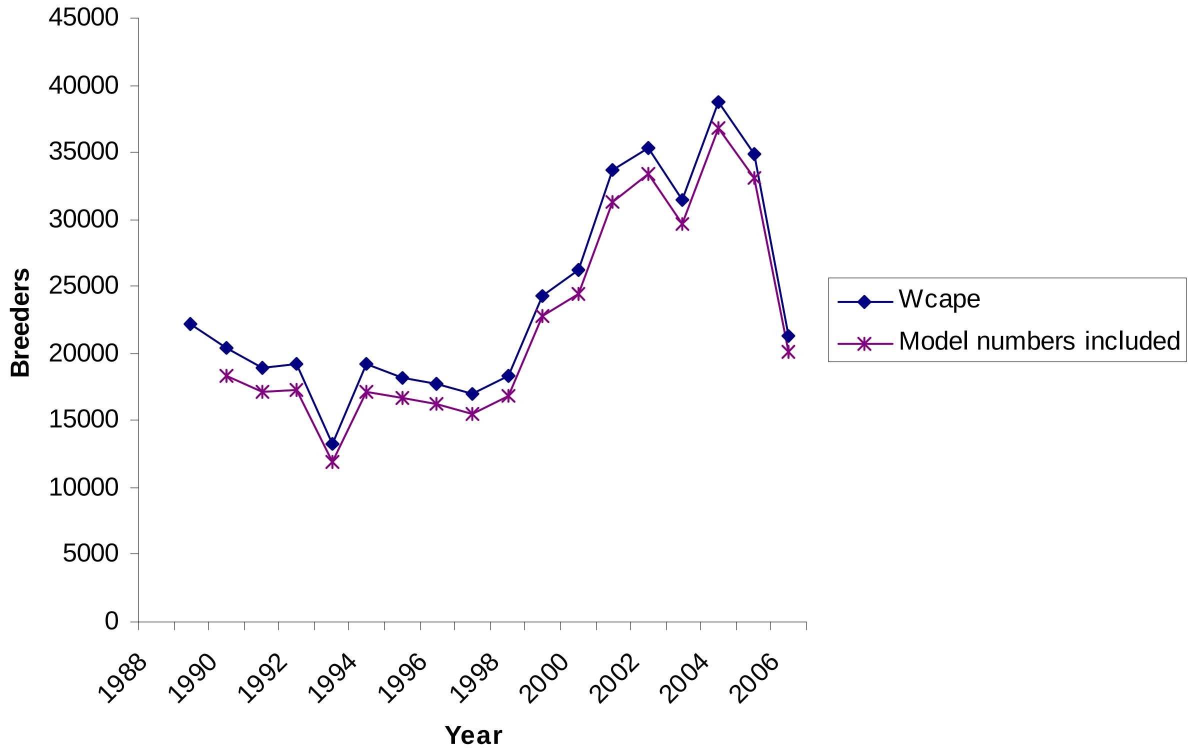

Fig. 5. Comparison of numbers of breeding pairs (from Underhill *et al.* 2006) and observed trends in the Western Cape as a whole and the numbers of breeding pairs included in a model encompassing Dassen Island, Robben Island, Boulders and Dyer Island.

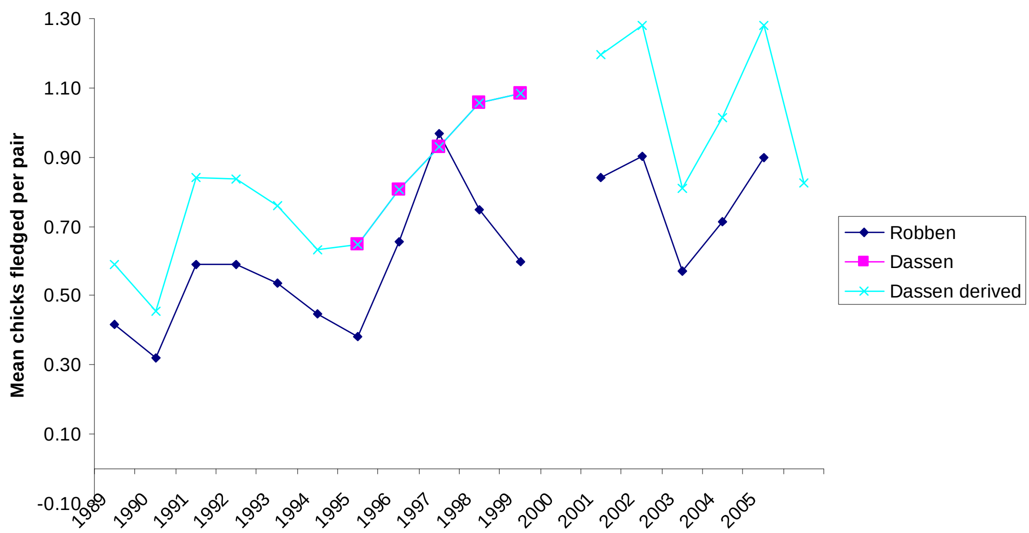

Fig. 6. Plots of chick fledging success data for Robben Island (from R. Crawford) representing the average numbers of chicks fledged per pair (i.e. per female) per year and for Dassen Island (from A. Wolfaardt) representing the average numbers of chicks fledged per pair (i.e. per female) per breeding attempt. The derived Dassen Island series assumes the trends are similar at Robben and Dassen, but scales the Robben data up for missing years at Dassen by multiplying by the average ratio of the Dassen to Robben values.

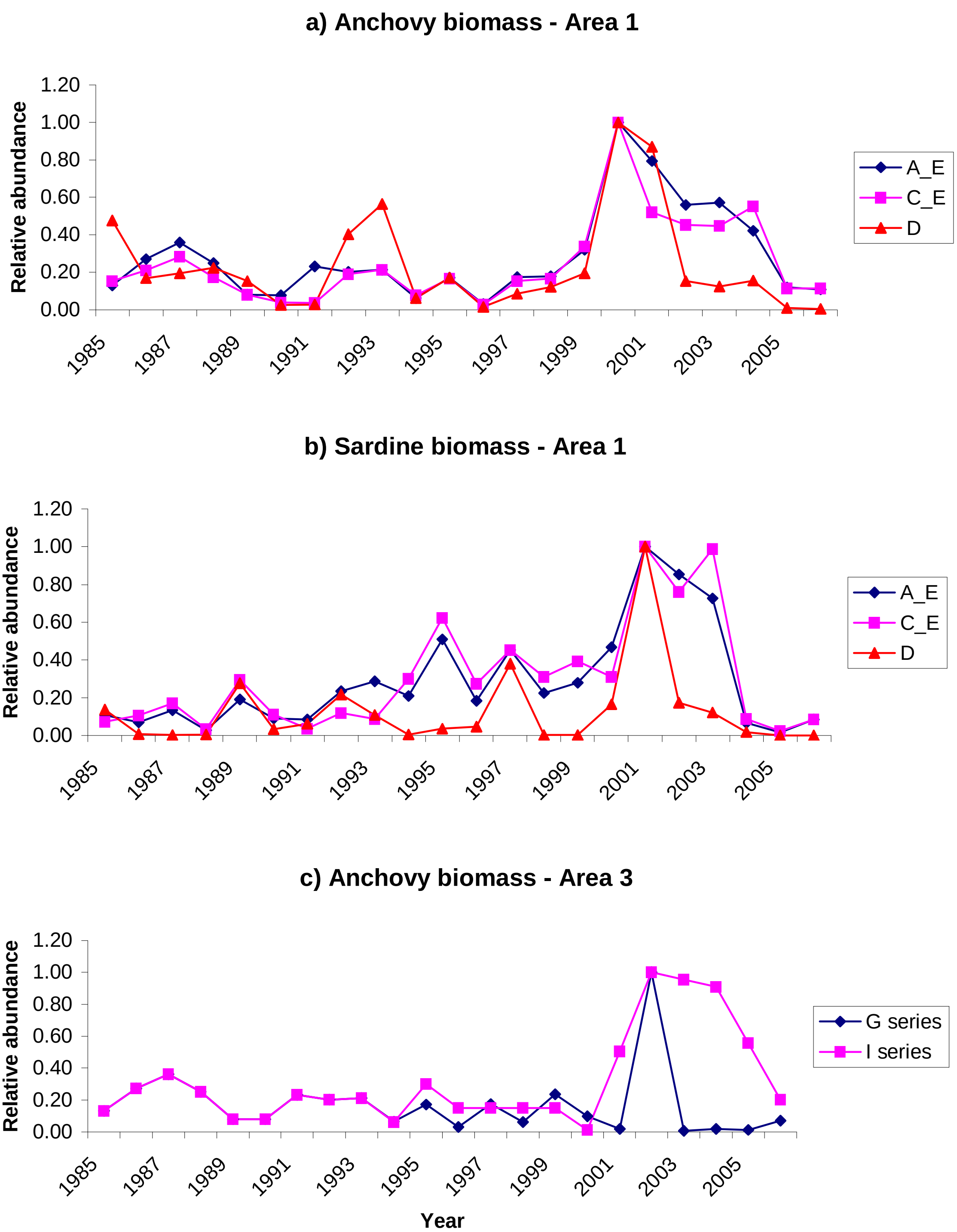

Fig. 7. Estimates from surveys (from J. Coetzee) of May anchovy and sardine recruit biomass in different strata. The data have been variously aggregated across different strata and are shown as a proportion of the maximum observed value for each series.

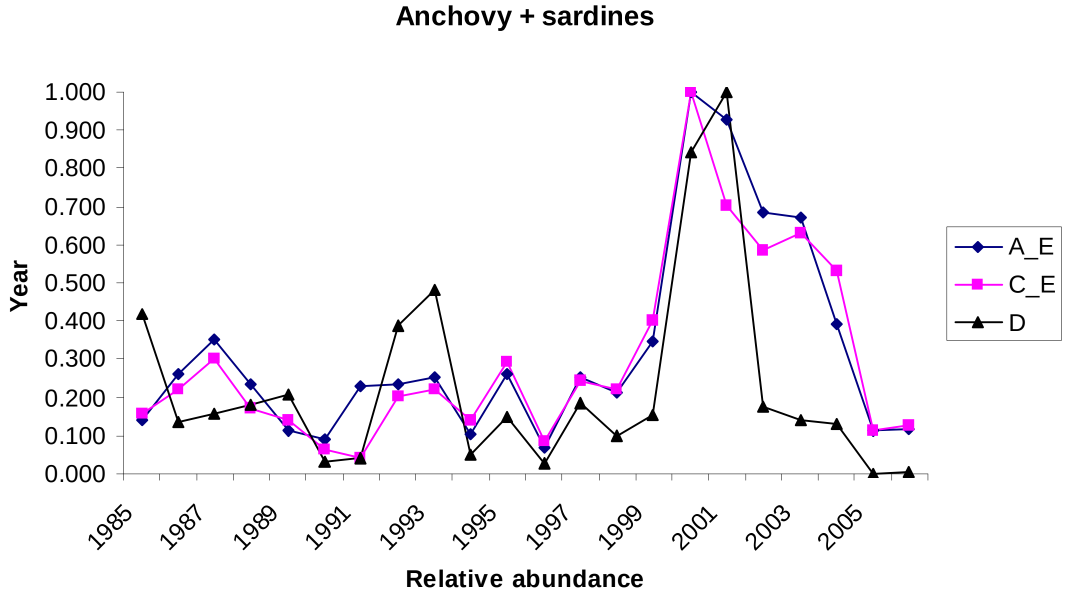

Fig. 8. Estimates from surveys (from J. Coetzee) of May anchovy and sardine ***combined*** recruit biomass in different strata. The data have been variously aggregated across different strata and are shown as a proportion of the maximum observed value for each series.