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BRANCH: FISHERIES MANAGEMENT

Estimation of the effective proportion of sardine biomass contributing to putative western stock recruitment by including the proportion of eggs transported to the West Coast nursery area from South Coast spawning areas

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Introduction

The OMP currently in use for calculating TACs for the sardine fishery (OMP-14) is based on a single sardine stock assessment model, despite strong arguments that the sardine population consists of at least a West Coast and a South Coast Stock. In accepting OMP-14, the Small Pelagic Scientific Working Group agreed, at that time, that in the absence of a defensible 2-sardine stock operating model which would allow for the appropriate testing of an OMP with area-based quotas, some form of spatial management should be implemented. The reason for implementing an interim form of spatial management was, in part, based on work conducted by Miller *et al.* (1996) which suggested that eggs spawned on the Central and Eastern Agulhas Bank were less likely to be successfully transported to the West Coast nursery areas and hence did not make a meaningful contribution to western sardine stock recruitment – which has up until recently contributed almost all of the total sardine recruitment.

Further arguments in favour of managing sardine catches in proportion to the relative (i.e. % of total) biomass distributions west and east of Cape Agulhas included information on the productivity of the western stock relative to the southern stock (de Moor and Butterworth, 2015), the fact that recruitment had remained low since the shift of the bulk of the sardine population to the South Coast in the late 1990s and early 2000s and the need to consider ecosystem impacts of a depleted forage fish biomass on the West Coast.

The agreed rule for apportioning the TAC between the stocks was that catches on the West Coast and South Coast should be in proportion to the average proportion of the biomass measured by the November hydro-acoustic survey to the west and east of Cape Agulhas respectively over the most recent two years. A tolerance of 10% on either side of this average was included to give the pelagic industry time to adjust to catching a larger proportion of the TAC on the South Coast in years when the biomass on the South Coast was high relative to the biomass on the West Coast.

In formulating this rule, the underlying principle was that overall sardine recruitment was dependent on spawning products from the area to the west of Cape Agulhas reaching the West

Coast nursery area. Hence it was considered there was a need to ensure a sufficiently large spawner biomass in this western area without regard for the smaller proportion of eggs spawned on the South Coast that could also potentially be successfully transported to the west coast nursery area. Including the proportion of eggs spawned on the South Coast that are successfully transported to the West Coast would result in a larger "effective proportion" of the spawner biomass in the area to the west of Cape Agulhas and potentially allow for a slightly higher catch to be taken in the west without further compromising future recruitment.

Methods

Data from the study conducted by Miller *et al*. (2006) and sardine distribution data collected during November pelagic surveys are used to derive a biomass-weighted proportion of South Coast eggs that contribute to West Coast recruitment. Table 1 lists the number of eggs released in each of 9 spawning areas and the number of eggs successfully transported to or retained in either the West Coast or South Coast nursery areas (See annexure A for spawning area naming convention and location of spawning and nursery areas).

Because the survey estimates of biomass are not split according to the same spawning areas as were used by Miller *et al*. (2006), the number of eggs released and successfully transported or retained were summed to obtain an aggregated proportion of successfully transported eggs for the larger areas to the west and east of Cape Agulhas (Table 2). However, because the proportion of successfully transported eggs from the Central and Eastern Agulhas Bank spawning areas varied greatly (areas F and G compared to H and I) and because these two spawning areas coincide with the existing November survey boundary between stratum D and E off Mossel Bay and Port Alfred, a biomass-weighted annual proportion of successfully transported eggs from the South Coast ($q_{y,s}$) to the West Coast nursery was calculated instead as:

$$q_{y,s} = \left(\frac{B_{y,D}}{B_{y,D} + B_{y,E}} \times q_D\right) + \left(\frac{B_{y,E}}{B_{y,D} + B_{y,E}} \times q_E\right)$$

Where $B_{y,D}$ and $B_{y,E}$ are the annual hydro-acoustic estimates of biomass obtained in stratum D and E respectively and $q_D = 0.148$ and $q_E = 0.027$ are the proportions of eggs transported to the west coast nursery area from the spawning areas between Cape Agulhas and Mossel Bay (F&G) and Mossel Bay and Cape St Francis (H&I) respectively.

Given the proportion of eggs successfully transported and retained from the West Coast (q_w) and South Coast ($q_{y,s}$) to the West Coast nursery area, the proportion of the effective biomass west of Cape Agulhas (de Moor and Butterworth 2016, Equation 1) is:

$$Effective\ p_w = \frac{q_w p_{y,w} + q_{y,s}(1 - p_{y,w})}{q_w}$$

Where $p_{y,w} = \frac{B_{y,w}}{B_{y,w}+By_{,s}}$, $p_{y,s} = \frac{B_{y,s}}{B_{y,w}+B_{y,s}}$ and $B_{y,w}$ and $B_{y,s}$ are estimates of total biomass for the area to the west and east of Cape Agulhas respectively. These calculations are undertaken using both model (de Moor and Butterworth 2016b) and survey (Coetzee et al. 2015) estimated biomass.

Results

The aggregated proportion of eggs transported or retained on the West Coast from West Coast spawning (Miller *et al*., 2006 areas A to E) is 0.285 (Table 2) and that from South Coast spawning (areas F-I) is 0.102. Weighting the proportion of eggs transported from the south coast strata by their survey estimated biomass results in an average proportion (1984-2015) of 0.083 (Figure 1, Tables 3 and 4). The proportion of effective biomass west of Cape Agulhas increases substantially in years when the biomass on the South Coast is large and is on average 1.34 times higher than the model estimated proportion of the biomass (Table 3). Using the model estimated biomass, the effective biomass proportion west of Cape Agulhas in 2014 and 2015 is 0.74 and 0.35 respectively, with an average proportion over these two years of 0.54 (Table 3). This is 39% higher than the modelled proportion of biomass west of Cape Agulhas over the past two years (0.391). Using the survey estimated biomass, the effective biomass proportion west of Cape Agulhas in 2014 and 2015 is 0.661 and 0.395, respectively, with an average proportion over these two years of 0.53 (Table 4). This is 49% higher than the survey estimated proportion west of Cape Agulhas during the same two years (0.356). If the existing spatial management rule were applied using the effective average proportion rather than the survey proportion of 0.356, the proportion would be 49% (survey based) or 39% (model based) higher at 0.528 or 0.495, respectively. Using these effective proportions west of Cape Agulhas, the targeted catch west of Cape Agulhas would increase from 23 114t to 32 100 - 34 282 t and not exceeding 34 440 - 40 775 t (+10 % tolerance; Table 5).

The current spatial management rule is based on survey estimated biomass proportions as these are immediately available following completion of the survey. It should be noted though that the effective proportion of biomass west has varied greatly over the recent past depending on whether this estimate is derived from the survey or model estimated proportion of biomass west and east of Cape Agulhas (Figure 2).

Conclusion

OMP-14 was adopted conditional on the implementation of an interim spatial management rule based on survey estimated proportions west of Cape Agulhas in the previous 2 years. Given the calculated potential contribution of eggs from the South Coast to West Coast recruitment, the extent to which future recruitment depends on the biomass located in the area to the west of Cape Agulhas would have been overstated and hence the possibility of adjusting the spatial management targets for 2016 and beyond to take account of the contribution of South Coast spawning exists. Nevertheless, the biomass of sardine in the area to the west of Cape Agulhas is presently at its lowest level in the past 8 years and increased exploitation of this biomass will likely have implications for future spatial management targets and growth of the sardine population.

These should be weighed up against the potential loss of not catching the 2016 sardine TAC at a time when the TAC is at its lowest level since 1995.

References

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Table 1. The numbers of eggs and proportion transported/retained (in each of the nurseries) and lost within each of the spawning areas (from Miller *et al*., 2006).

Spawning Area	Eggs released	Eggs (n) transported to/retained in WC nursery	Eggs (P) transported to/retained in WC nursery[1]	Eggs (n) transported to/retained in SC nursery	Eggs (P) transported to/retained in SC nursery[2]	Eggs (n) lost to the system	Eggs (P) lost to the system
A	1441729	351092	0.244	0	0.000	1090637	0.756
B	1861286	467263	0.251	1	0.000	1394022	0.749
C	259595	98341	0.379	4	0.000	161250	0.621
D	273508	108913	0.398	4	0.000	164591	0.602
E	590546	235708	0.399	22500	0.038	332338	0.563
F	1528492	221989	0.145	729649	0.477	576854	0.377
G	1079128	163430	0.151	258506	0.240	657192	0.609
H	426108	11384	0.027	271713	0.638	143011	0.336
I	1170968	31044	0.027	669836	0.572	470088	0.401

Table 2. The aggregated numbers of eggs and proportion transported/retained (in each of the nurseries) and lost within each of the major spawning areas.

Spawning Area	Eggs released	Eggs (n) transported to/retained in WC nursery	Eggs (P) transported to/retained in WC nursery	Eggs (n) transported to/retained in SC nursery	Eggs (P) transported to/retained in SC nursery	Eggs (n) lost to the system	Eggs (P) lost to the system
A-E	4426664	1261317	0.285	22509	0.005	3142838	0.710
F-I	4204696	427847	0.102	1929704	0.459	1847145	0.439

[1] These are the percentages plotted as white bars in Figure 4 of Miller et al 2006 (see annexure A)
[2] These are the percentages plotted as black bars in Figure 4 of Miller et al 2006 (see annexure A)

Table 3. Effective proportion of *model* (de Moor and Butterworth 2016b) *predicted total biomass* (Effective *Pw*) in the area to the west of Cape Agulhas after including the weighted (by biomass) proportion of eggs being transported to or retained on the West Coast from South Coast spawning.

Year	B_w	B_E	B_{W+E}	*Pw*	*Qw*	*Ps*	*qs*	Effective *Pw*	*Effective Pw/Pw*
1984	42 676	1 569	44 245	0.965	0.285	0.035	0.147	0.983	1.02
1985	82 480	92 800	175 280	0.471	0.285	0.529	0.137	0.725	1.54
1986	239 019	88 838	327 858	0.729	0.285	0.271	0.029	0.756	1.04
1987	357 227	87 513	444 740	0.803	0.285	0.197	0.097	0.870	1.08
1988	357 264	52 112	409 376	0.873	0.285	0.127	0.131	0.931	1.07
1989	554 874	88 497	643 371	0.862	0.285	0.138	0.066	0.894	1.04
1990	542 901	92 838	635 739	0.854	0.285	0.146	0.128	0.919	1.08
1991	352 156	109 524	461 681	0.763	0.285	0.237	0.148	0.886	1.16
1992	367 319	173 285	540 605	0.679	0.285	0.321	0.039	0.723	1.06
1993	653 686	170 863	824 548	0.793	0.285	0.207	0.116	0.877	1.11
1994	641 695	230 338	872 033	0.736	0.285	0.264	0.031	0.764	1.04
1995	682 506	155 304	837 810	0.815	0.285	0.185	0.039	0.840	1.03
1996	655 231	256 205	911 436	0.719	0.285	0.281	0.047	0.766	1.06
1997	1 188 484	286 118	1 474 602	0.806	0.285	0.194	0.147	0.906	1.12
1998	770 750	357 247	1 127 997	0.683	0.285	0.317	0.070	0.761	1.11
1999	594 278	785 858	1 380 136	0.431	0.285	0.569	0.077	0.584	1.36
2000	623 400	768 552	1 391 952	0.448	0.285	0.552	0.038	0.521	1.16
2001	851 945	1 921 351	2 773 296	0.307	0.285	0.693	0.097	0.543	1.77
2002	1 002 332	3 118 677	4 121 008	0.243	0.285	0.757	0.070	0.429	1.76
2003	1 088 850	2 676 540	3 765 391	0.289	0.285	0.711	0.064	0.449	1.55
2004	286 595	1 936 150	2 222 745	0.129	0.285	0.871	0.049	0.277	2.15
2005	161 200	964 729	1 125 929	0.143	0.285	0.857	0.104	0.455	3.18
2006	168 083	392 792	560 874	0.300	0.285	0.700	0.074	0.481	1.61
2007	66 841	286 364	353 205	0.189	0.285	0.811	0.040	0.303	1.60
2008	173 345	181 452	354 797	0.489	0.285	0.511	0.045	0.569	1.17
2009	381 038	237 334	618 372	0.616	0.285	0.384	0.145	0.812	1.32
2010	813 840	146 065	959 906	0.848	0.285	0.152	0.062	0.881	1.04
2011	610 845	373 384	984 229	0.621	0.285	0.379	0.073	0.717	1.16
2012	533 120	121 482	654 603	0.814	0.285	0.186	0.079	0.866	1.06
2013	224 056	292 008	516 065	0.434	0.285	0.566	0.098	0.628	1.45
2014	366 455	283 735	650 190	0.564	0.285	0.436	0.112	0.736	1.31
2015	140 134	504 422	644 556	0.217	0.285	0.783	0.049	0.351	1.61
Model based Ave 1984-2015							0.083		1.34
Model based Ave 2014-2015				0.391				0.543	1.39

Table 4. Effective proportion of *acoustic survey estimated biomass* (Effective *Pw*) in the area to the west of Cape Agulhas after including the weighted (by biomass) proportion of eggs being transported to or retained on the West Coast from South Coast spawning.

Year	B_w	B_E	B_{W+E}	*Pw*	*qw*	*Ps*	*qs*	Effective *Pw*	*Effective Pw/Pw*
1984	48009	369	48378	0.992	0.285	0.008	0.147	0.996	1.00
1985	25457	19556	45013	0.566	0.285	0.434	0.137	0.775	1.37
1986	238230	61566	299797	0.795	0.285	0.205	0.029	0.815	1.03
1987	94165	17120	111285	0.846	0.285	0.154	0.097	0.899	1.06
1988	128043	6319	134362	0.953	0.285	0.047	0.131	0.975	1.02
1989	198328	58327	256655	0.773	0.285	0.227	0.066	0.826	1.07
1990	248855	41020	289876	0.858	0.285	0.142	0.128	0.922	1.07
1991	517180	80678	597858	0.865	0.285	0.135	0.148	0.935	1.08
1992	247756	246401	494157	0.501	0.285	0.499	0.039	0.570	1.14
1993	480822	79198	560019	0.859	0.285	0.141	0.116	0.916	1.07
1994	389730	128624	518354	0.752	0.285	0.248	0.031	0.779	1.04
1995	363542	480402	843944	0.431	0.285	0.569	0.039	0.509	1.18
1996	257763	271693	529456	0.487	0.285	0.513	0.047	0.572	1.18
1997	964835	259797	1224632	0.788	0.285	0.212	0.147	0.897	1.14
1998	1082547	524781	1607328	0.674	0.285	0.326	0.070	0.753	1.12
1999	708029	927381	1635410	0.433	0.285	0.567	0.077	0.586	1.35
2000	726230	1566150	2292380	0.317	0.285	0.683	0.038	0.407	1.29
2001	669617	1639983	2309600	0.290	0.285	0.710	0.097	0.531	1.83
2002	1184713	3021538	4206250	0.282	0.285	0.718	0.070	0.458	1.63
2003	1343118	2221053	3564171	0.377	0.285	0.623	0.064	0.517	1.37
2004	292522	2323193	2615715	0.112	0.285	0.888	0.049	0.263	2.35
2005	75604	973386	1048991	0.072	0.285	0.928	0.104	0.410	5.68
2006	177889	534667	712557	0.250	0.285	0.750	0.074	0.444	1.78
2007	53138	199061	252199	0.211	0.285	0.789	0.040	0.321	1.52
2008	211871	172209	384080	0.552	0.285	0.448	0.045	0.622	1.13
2009	262175	239400	501575	0.523	0.285	0.477	0.145	0.766	1.47
2010	309465	198927	508392	0.609	0.285	0.391	0.062	0.694	1.14
2011	182825	854235	1037060	0.176	0.285	0.824	0.073	0.386	2.19
2012	186109	158945	345054	0.539	0.285	0.461	0.079	0.666	1.24
2013	467613	144150	611763	0.764	0.285	0.236	0.098	0.845	1.11
2014	195786	248715	444500	0.440	0.285	0.560	0.112	0.661	1.50
2015	98467	264763	363230	0.271	0.285	0.729	0.049	0.395	1.46
Survey based Ave 1984-2015							0.083		1.46
Survey based Ave 2014-2015				0.356				0.528	1.49

Table 5. Calculated spatial management targets based on estimates of Effective biomass proportion west using either the survey-based or model-based proportion of observed biomass west of Cape Agulhas compared to the existing agreed target.

		Target	+10%
Existing agreement	$(Pw_{2014}+Pw_{2015})/2$	0.356	0.456
	Final TAC_{2016}	64 928	
	Catch $target_{(west)}$	23114	29607
Survey based effective biomass	$(Eff\ Pw_{2014}+Eff\ Pw_{2015})/2$	0.528	0.628
	Final TAC_{2016}	64 928	
	Catch $target_{(west)}$	34282	40775
Model based effective biomass	$(Eff\ Pw_{2014}+Eff\ Pw_{2015})/2$	0.543	
	$(Pw_{2014}+Pw_{2015})/2$	0.391	
	Eff Pw/Pw	1.39	1.49
	Catch $target_{(west)}$	32100	34440

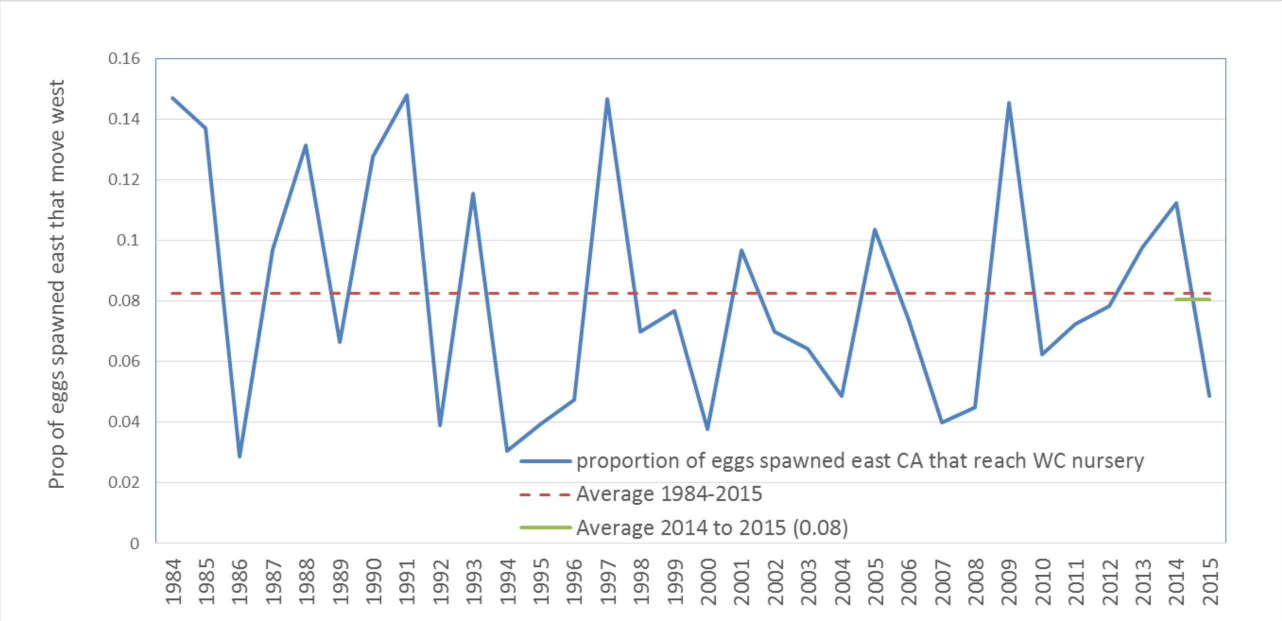

Figure 1. The annual survey biomass-weighted proportion of eggs spawned east of Cape Agulhas that are transported to the West Coast nursery area (eggs lost to the system included; i.e., proportion of eggs successfully transported to the west and south coast do not sum to 1), $q_{y,s}$.

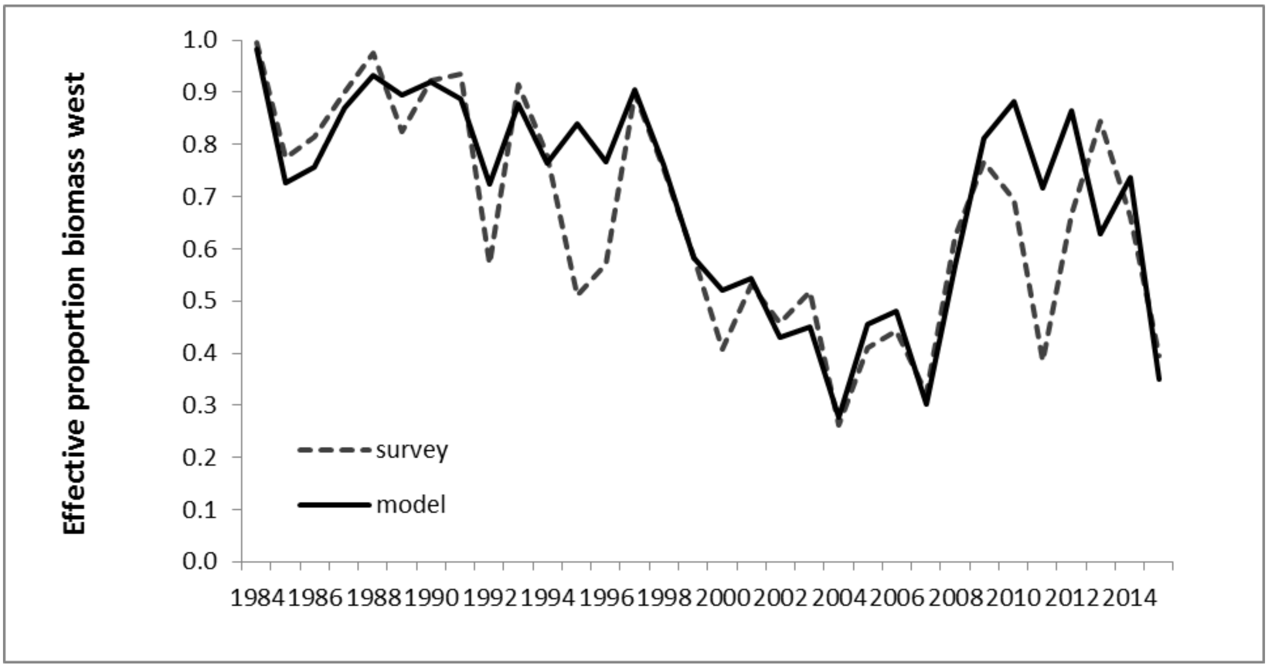

Figure 2. Effective proportion of biomass west estimated from either model or survey derived proportion of biomass west.

Annexure A

IBM simulation setup used by Miller *et al*. (2006). Eggs spawned within each of 9 sub regions, were either retained within a nursery area on the west coast or south coast, transported to a nursery area on the west coast or south coast, or lost to the system (did not make it to either nursery area).

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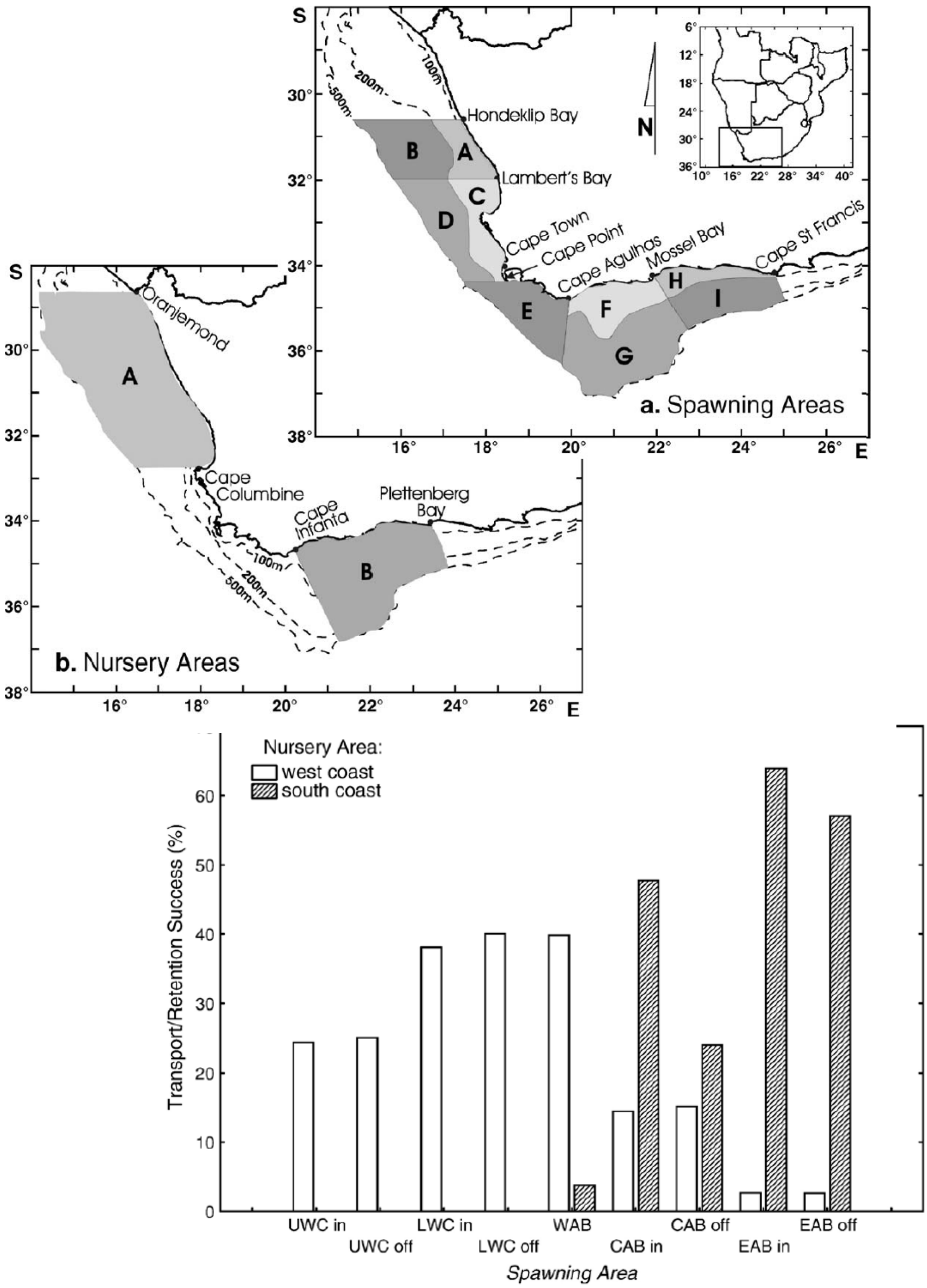

Fig. 4. Modelled transport/retention success to the west and south coast nursery grounds from the nine spawning areas.