SUPPLEMENTARY MATERIAL

Explanation of Virtual Population Analysis (VPA)

Virtual population analysis (VPA) is a technique employed to calculate fishing mortality rates and stock sizes (abundance) of a year-class (the fish hatched in a given year) at successive ages, given the known or assumed natural mortality rate and catch (in numbers) at each age and given the known or assumed fishing mortality rate at the oldest age (Anderson, 1978).

If the abundance (N) of a year-class is known at the beginning of two consecutive years, Ni and N;+I' the fraction surviving from year i to year i+1 is:

$$\frac{N_{i+1}}{N_i} = S_i \quad \text{(a)}$$

where S_i is the annual survival rate. It then follows that

$$S_i = 1 - A_i \quad \text{(b)}$$

where Ai is the annual mortality rate. In working with mortality rates it is most convenient to deal with instantaneous rates. Instantaneous total mortality is defined as:

$$Z_i = -log_e(1 - A_i) \quad \text{(c)}$$

or

$$1 - A_i = e^{-Z_i} = S_i \quad \text{(d)}$$

Therefore

$$N_{i+1} = N_i * e^{(-Z_i)} \quad \text{(e)}$$

There are two major causes of death or removal of fish from a stock: (1) fishing and (2) natural death or all causes except fishing (e.g. predation, disease, senility, etc.). These two

types of mortality are also expressed as instantaneous rates: (1) F or instantaneous fishing mortality and (2) M or instantaneous natural mortality. The sum of these is instantaneous total mortality:

$$F + M = Z \quad \text{(f)}$$

If N_i represents the abundance of a given year-class of fish at (f) the beginning of year i, then the total number of deaths (fishing + natural) during the year is the product of N_i and the annual mortality rate or 1 $N_i * A_i$;; substituting 1-e^{-Z_i} for A_i from equation (d) gives N_i (1-$e^{(-Z_i)}$). The number of deaths due only to fishing (catch or C_i) can be calculated by applying $\frac{F_i}{Z_i}$ (the ratio between fishing mortality and total mortality) to the above expression representing total deaths. This gives what is often known as the catch equation where

$$C_i = N_i \frac{F_i}{Z_i}(1\text{-}e^{(-Z_i)}) \quad \text{(g)}$$

The expression $\frac{F_i}{Z_i}(1\text{-}e^{(-Z_i)})$ is referred to as the rate of exploitation and represents the proportion (by number) of the fish in a year-class alive at the beginning of year i which are caught during year i. The abundance of a year-class at the beginning of year i+1 can be expressed as a proportion (r) of the catch during year i,

$$r_i = \frac{N_{i+1}}{C_i} \quad \text{(h)}$$

Based on equations (e) and (g), equation (h) can be written as

$$r_i = \frac{Z_i e^{-Z_i}}{F_i(1-e^{(-Z_i)})} \quad \text{(i)}$$

Therefore, if N_{i+1} and C_i are both known, F_i; can be solved by iteration which is time-consuming unless done by computer. In other words, by trial-and-error process the correct value for F_i is determined such that the expression $\frac{Z_i e^{-Z_i}}{F_i(1-e^{(-Z_i)})}$ is equal to the ratio $\frac{N_{i+1}}{C_i}$.

Virtual Population Analysis (VPA) principle and hypothesis

The biological parameters used are summarized in Table S1. The approximation method of Pope (1972) was applied to adjust the VPA. It assumes that catches were made instantaneously in the middle of the season. This allows to simplify the survival equation and makes possible to calculate the number of individuals directly from the data of natural mortality (M) and catches (C). This equation expresses the number of individuals at the beginning of the considered period of an age group from a cohort relative to the number of individuals of the previous age group:

$$N_{t+1} = N_t * e^{(-Z_t)*\Delta_t} \qquad (1)$$

With Z_t(total mortality) = M_t(natural mortality) +F_t (fishing mortality); $N_{(t+1)}$= number of individuals at time t_{+1}; $N_{(t)}$= number of individuals at time t; Δ_t= 0.25 (time interval)

Table S1: Parameters of the von Bertalanffy growth model for both sardinella species in Senegal waters. L_{inf}: the asymptotic length; K: the growth coefficient; t_0: is the hypothetical 'age' at zero length and M the natural fish mortality.

Parameters	*Sardinella aurita*	*Sardinella maderensis*
K per month	0.046	0.029
L_{inf} (cm)	37.4	33.4
t_0 (month)	-3.48	-5.52
M (month)	0.045	0.008
Sources	Fréon (1988)	Ba *et al*. (2016)

The catch equation (2) determines the catches made on a cohort taking into account the number of individuals of the cohort at the beginning of the season:

$$C_t = \frac{N_{(t)} * F_t\left[1 - e^{(-Z_t)}\right]}{Z_t} \qquad (2)$$

With C_t = instantaneous catches.

The fishing mortality (F_t) was used to initialize the calculations of the cohort analysis (Mesnil, 1988), carried out by back calculation and relies on the property of convergence highlighted by Jones (1961). A possible relative error in F_t fades to younger age groups of fish, however it is a function of cumulative fishing mortality and if fishing is not the major cause of mortality, convergence will not take place (Pope, 1972).

This calculation is carried out by iteration from an arbitrary value of F_t until the terminal fishing is equal to the mean of the last two ages of fishing mortality.

The following equation is used to determine the abundance of the oldest age group:

$$N_t = \frac{C_{(t)} * Z_t}{F_t\left[1 - e^{(-Z_t)}\right]} \qquad (3)$$

The equation of Pope (1972) is applied to calculate the number of individuals per seasonal ages in an ascending way according to the following relation:

$$N_t = (N_{t+1} * e^{M_t}) + (C_{(t)} * e^{M_t * \frac{1}{2}}) \qquad (4)$$

The equation of fishing mortality is:

$$F_t = \ln\left(\frac{N_{(t)}}{N_{(t+1)}}\right) - Z_t \qquad (5)$$

Table S2: Number of sampled individuals per month from July 2014 to September 2015 for both sardinella species.

Species	July	Aug	Sept	Oct	Nov	Dec	Jan	Fev	Mar	Apr	May	Jun	July	Aug	Sept	Total
Sardinella aurita	256	2069	4133	3837	6455	6111	2775	1271	6325	6034	4663	4233	2052	762	319	51295
Sardinella maderensis	292	4285	3832	1506	2594	3305	2660	2278	4472	5072	4090	5567	5546	30	139	45668
Total	**548**	**6354**	**7965**	**5343**	**9049**	**9416**	**5435**	**3549**	**10797**	**11106**	**8753**	**9800**	**7598**	**792**	**458**	**96963**

Table S3: Number of individuals per size(Fork length in cm) per month from July 2014 to September 2015 (*Sardinella aurita*).

Size	July-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14	Jan-15	Fev-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug -15	Sept.-15
9				7			1								
10			19	18		2	4			1					
11			31	36	2	3	17	1							
12			25	91	13	22	27	1				7			
13			9	80	25	17	47	1							
14		5	3	40	33	5	45	16				8	2		
15		6	10	8	25	26	41	16				8	5		
16		8	8	15	34	40	59	12	2	2		27	24		
17		15	93	2	55	51	47	13	5	16		24	10		
18	4	48	376	17	118	31	69	8	28	46	11	17	11	1	
19	12	101	475	63	292	69	44	8	196	167	48	26	13		
20	31	215	1072	284	1095	423	65	11	632	519	200	99	72		1
21	25	220	742	447	1308	665	39	21	783	507	212	118	143	25	2
22	19	215	270	657	1136	1093	15	22	841	439	210	169	224	50	23
23	8	218	212	589	765	1038	3	12	523	201	174	240	322	115	30
24	6	230	169	347	367	656	25	4	163	133	295	456	552	347	93
25	4	129	66	89	136	240	32		12	87	158	289	347	192	129
26	4	52	54	77	128	180	51		15	44	73	66	47	31	31
27	14	57	35	54	205	161	88	3	15	65	210	101	33	1	7
28	17	41	33	73	271	204	186	14	20	108	345	227	53		2
29	27	53	56	92	242	205	278	86	110	99	345	338	49		
30	23	131	77	278	61	174	202	159	345	294	366	376	50		1
31	19	130	91	246	45	240	403	320	654	747	595	550	38		
32	24	103	119	156	46	256	505	293	753	950	669	579	37		
33	7	41	41	37	25	86	226	136	586	622	357	275	14		
34	3	29	27	32	18	39	146	85	354	584	256	172	4		
35	1	1	5	2	2	5	15	9	136	244	66	16	2		
36			1		1	1	4		39	71	22	6			
37					1				6	14	2	2			
38							1		1	3	1				

Table S4: Number of individuals per size (Fork length in cm) per month from July 2014 to September 2015 (*Sardinella maderensis*).

Size	July-14	Aug-14	Sept-14	Oct-14	Nov-14	Dec-14	Jan-15	Fev-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug -15	Sept.-15
10			4	48	3	7	7								
11			1	69	5	14	16	3		3					
12		4	5	7	10	56	32	19	3	8					
13		4	10	3	3	75	54	29		5			1		
14	3	43	10	1	29	82	71	54	15	13			4	1	
15		69	15		58	61	74	57	9	8		1	3		
16	2	90	13	6	32	118	60	45	24	7		2	4		
17		74	21	5	10	122	52	48	13	7	2	12	5		
18	1	91	37	6	27	100	34	40	17	11	7	99	33	1	
19	1	140	136	23	48	76	27	57	16	20	35	258	122		1
20	6	299	311	90	191	108	80	38	28	252	167	572	491	5	21
21	11	464	423	97	260	199	206	140	178	388	170	361	384	3	49
22	18	354	414	213	246	254	173	175	279	328	126	133	242	1	27
23	33	292	445	264	211	264	180	192	425	111	46	86	156	4	12
24	37	394	301	192	133	236	115	133	342	64	66	185	240	8	26
25	69	344	196	116	115	155	56	70	202	24	96	482	381	2	3
26	68	384	139	58	170	160	69	39	137	35	280	691	598	1	
27	24	341	162	77	282	292	193	105	202	170	467	721	675		
28	8	214	200	52	289	312	277	145	332	308	493	546	538	3	
29	5	189	209	69	233	294	378	269	501	566	548	501	487	1	
30	3	142	283	50	135	159	169	240	528	720	607	414	507		
31	1	132	241	34	59	111	174	221	406	858	594	330	483		
32	2	103	139	12	23	30	72	83	275	513	220	97	124		
33		59	48	6	16	7	44	49	164	225	74	27	26		
34		45	52	1	1	4	31	19	121	262	72	45	38		
35		6	9		1	3	7	4	51	101	11	2	2		
36		3					6	1	9	45	6	1	2		
37								1	1	7	2				
38										7					
39			4												