

**Spatial management of the European hake *Merluccius
merluccius* fishery in the Catalan Mediterranean:
Simulation of management alternatives with the
InVEST model**

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Supplementary material

Table S1. – Main characteristics of the fishing grounds.

Nº	Average coordinates MEAN_X MEAN_Y		Fishing ground	Medium depth (m)	Substrate	Biozone
1	3747765.466	2060699.092	Malica	630	Mud	Bathyal
2	3758848.976	2124115.892	L Estartit	80	Sandy mud	Deep Circalittoral
3	3766404.211	2121918.538	Somera	141	Sandy mud	Deep Circalittoral
4	3774888.283	2117170.902	El Darrer	322	Mud	Deep Circalittoral
5	3750886.389	2065297.876	Sot Malica	434	Mud	Bathyal
6	3751240.214	2070771.865	Barana	318	Rock or other hard substrata	Bathyal
7	3746611.969	2090204.119	Planassa	111	Rock or other hard substrata	Deep Circalittoral
8	3746862.581	2078600.037	Fluviana	154	Sandy mud	Deep Circalittoral
9	3705140.896	2075733.035	Les Quaranta	80	Sandy mud	Deep Circalittoral
10	3705126.776	2081913.395	Malgrat-Garotes	64	Sandy mud	Upper Circalittoral
11	3715697.624	2070418.857	Turó-Paneca	335	Sandy mud	Deep Circalittoral
12	3709985.807	2073420.798	Capets	129	Sandy mud	Deep Circalittoral
13	3759875.802	2110452.369	CuldeRecElPas	182	Rock or other hard substrata	Bathyal
14	3715840.815	2062544.283	Paneca	555	Mud	Bathyal
15	3774149.401	2094936.291	GambaLlevant	410	Sandy mud	Deep Circalittoral
16	3773044.364	2112937.556	GambaStSebastià	518	Mud	Deep Circalittoral
17	3767283.137	2087065.943	Bravada dpt	247	Sandy mud	Deep Circalittoral
18	3760964.679	2090116.639	Bravada dbf	141	Mud	Deep Circalittoral
19	3773251.715	2082138.435	Abissínia	627	Mud	Bathyal
20	3770038.54	2083686.82	Putxet	370	Sandy mud	Deep Circalittoral
21	3760020.721	2102446.47	Vol de fora	131	Rock or other hard substrata	Deep Circalittoral
22	3755720.707	2105442.224	L'Avió	99	Rock or other hard substrata	Deep Circalittoral
23	3733147.569	2081327.156	Turó Gros	108	Rock or other hard substrata	Deep Circalittoral
24	3744849.393	2102257.061	Vol de terra	75	Sandy mud	Deep Circalittoral
25	3725028.47	2081917.482	Rocassa	254	Sandy mud	Deep Circalittoral
26	3729898.714	2079765.515	Can Ferrer	131	Sand	Upper Circalittoral
27	3737612.127	2069005.178	Través	432	Muddy sand	Bathyal
28	3730104.528	2073402.685	La Creu	394	Muddy sand	Bathyal

Table S2. – European hake growth parameters.

Von Bertalanffy growth equation	Size-weight relationship		
L_{inf}	110	a	0.0048
k	0.178	b	3.12
t_0	0		

Table S3. – Maturity and weight by age of the European hake population.

Age	Maturity	Wt (kg)	Wt (STECF, 2015)
0	0	0.000	0.022
1	0.15	0.039	0.12
2	0.82	0.261	0.4
3	0.98	0.715	0.991
4	1	1.369	1.62
5+	1	5.995	2.81

Table S4. – Fecundity by age of the European hake population.

Age	Fecundity (Mean)	Source
0	3555	MEDITS
1	18225	
2	77560	
3	169680	Commercial fishing
4	281438	
5	402275	

Table S5. – Fecundity coefficients of the European hake population.

Age	$N(t) = \text{Fecundity} * e^{(-0.1193 * 90)}$
0	0.077
1	0.396
2	1.685
3	3.686
4	6.115
5+	8.740

Table S6. – Natural mortality and survivorship by age of the European hake population.

Age	M (ProdBiom)	Sa ($Sa = e^{-Mar}$)
0	1.15	0.31663677
1	0.65	0.52204578
2	0.55	0.57694981
3	0.51	0.60049558
4	0.48	0.61878339
5+	0.47	0.62500227

Table S7. – Exploitation fraction by subregion based on fishing effort.

Subregion (Code)	Subregion (Name)	Average effort (Boats*days)	% Effort	Exploitation fraction (Ex)
1	Malica	61	2%	0.136
2	L'Estartit	89	3%	0.199
3	Somera	42	1%	0.094
4	El Darrer	49	2%	0.110
5	Sot Malica	302	10%	0.676
6	Barana	274	9%	0.613
7	Planassa	33	1%	0.074
8	Fluviana	30	1%	0.067
9	Les Quaranta	42	1%	0.094
10	Malgrat-Garotes	95	3%	0.213
11	Turó-Paneca	51	2%	0.114
12	Capets	69	2%	0.154
13	CuldeRecElPas	132	4%	0.295
14	Paneca	19	1%	0.043
15	GambaLlevant	46	2%	0.103
16	GambaStSebastià	447	15%	1.000
17	Bravada dpt	14	0%	0.031
18	Bravada dbf	29	1%	0.065
19	Abissínia	146	5%	0.327
20	Putxet	58	2%	0.130
21	Vol de fora	53	2%	0.119
22	L'Avió	119	4%	0.266
23	Turó Gros	60	2%	0.134
24	Vol de terra	260	9%	0.582
25	Rocassa	54	2%	0.121
26	Can Ferrer	80	3%	0.179
27	Través	224	8%	0.501
28	La Creu	94	3%	0.210

Table S8. – Fishing mortality and vulnerability by age class.

Age	F (STECF, 2015)	Vulnerability
0	0.119	0.0741433
1	1.227	0.76448598
2	1.605	1
3	1.34	0.83489097
4	0.283	0.17632399
5+	0.283	0.17632399

Table S9. – VIT inputs.

Age	Frequency (STECF 2015)	Maturity (Data Collection Framework 2003-2012)	Natural mortality (ProdBiom)
0	6589000	0	1.15
1	10610000	0.15	0.65
2	1997000	0.82	0.55
3	124000	0.98	0.51
4	9000	1	0.48
5+	3000	1	0.47
Parameters of Von Bertalanffy growth equation and Parameters of the length-weight relationship		(García-Rodríguez and Esteban 2002 in STECF, 2015)	
F terminal		0.5	
Total catch (2015) in weight (g)		73,725,000	

Table S10. – InVEST migration tables.

Migration matrix _age 2					
Sink / Source	2	7	22	23	24
1	0	0	0	0	0
2	0.9828	0	0	0	0
3	0.0172	0	0.0507	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0.8542	0	0	0.0008
8	0	0.007	0	0	0.0076
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0.0351	0	0	0.0351
14	0	0	0	0	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	0	0.0104	0	0	0.011
19	0	0	0	0	0
20	0	0	0	0	0
21	0	0.0301	0	0	0.0303
22	0	0	0.9493	0	0.0392
23	0	0	0	0.6663	0.0578
24	0	0	0	0	0.7556
25	0	0	0	0	0
26	0	0.0632	0	0.3337	0.0627
27	0	0	0	0	0
28	0	0	0	0	0

Migration matrix _age 3									
Sink / Source	2	7	8	10	18	21	22	23	24
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.05	0.00	0.00	0.00	0.00	0.06	0.06	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00
7	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.01
8	0.00	0.02	0.92	0.00	0.01	0.00	0.00	0.00	0.02
9	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.49	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00
13	0.00	0.03	0.00	0.00	0.03	0.02	0.00	0.00	0.03
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.03
18	0.00	0.02	0.00	0.00	0.94	0.00	0.00	0.00	0.02
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.03	0.00	0.00	0.00	0.92	0.00	0.00	0.03
22	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.00	0.04
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.05
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68
25	0.00	0.05	0.06	0.13	0.00	0.00	0.00	0.12	0.05
26	0.00	0.05	0.00	0.13	0.00	0.00	0.00	0.12	0.05
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table S10 (Cont.). – InVEST migration tables.

Migration matrix	_age 4												
Sink / Source	2	3	6	7	8	10	13	17	18	21	22	23	24
1	0.00	0.00	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.05	0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.03	0.00	0.00
4	0.07	0.07	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.07	0.07	0.00	0.00
5	0.00	0.00	0.02	0.02	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
6	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.09	0.11	0.00
12	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.04	0.00	0.00	0.04	0.00	0.00	0.90	0.00	0.05	0.04	0.01	0.00	0.05
14	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.12	0.00
15	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.04	0.04	0.02	0.00	0.00	0.00
16	0.05	0.02	0.00	0.00	0.00	0.00	0.03	0.05	0.05	0.05	0.04	0.00	0.00
17	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.90	0.01	0.00	0.00	0.00	0.02
18	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.01
19	0.00	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
20	0.00	0.00	0.02	0.02	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00	0.04
22	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.00	0.04
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.05
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.69
25	0.00	0.00	0.00	0.05	0.05	0.13	0.00	0.00	0.00	0.00	0.00	0.11	0.05
26	0.00	0.00	0.00	0.05	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.11	0.05
27	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00
28	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00

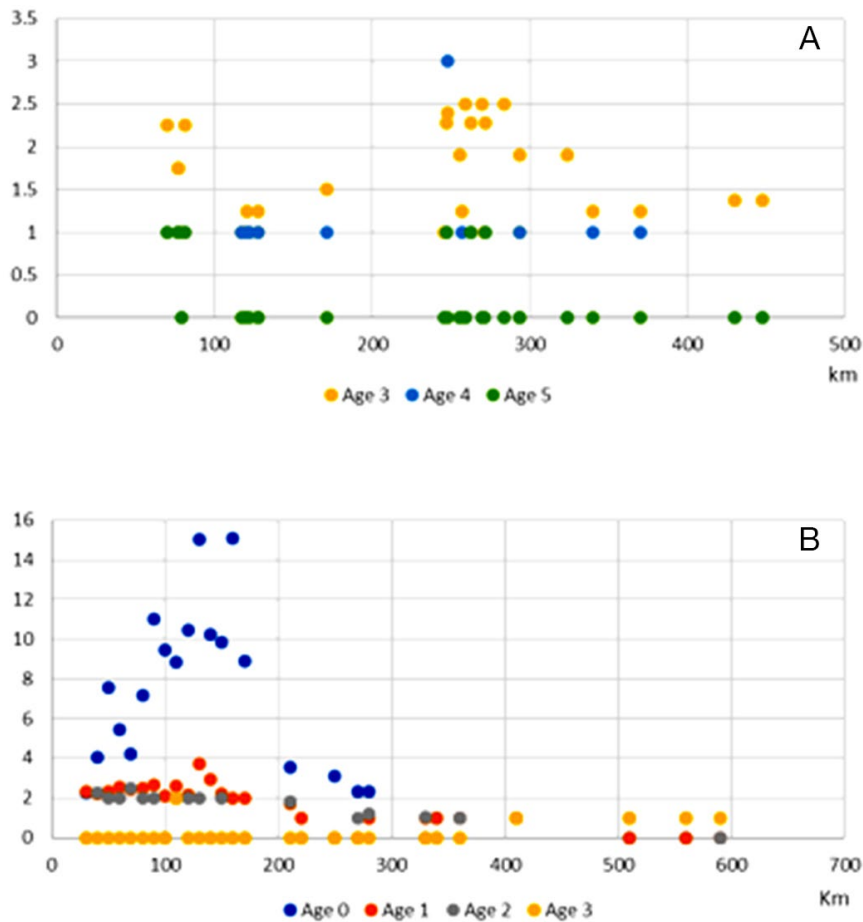


Fig. S1. – Spatial distribution of European hake by depth. A, abundance of ages 3, 4 and 5 by depth (commercial fishing data); B, abundance of hake by age (0-3) and depth (MEDITS 2012-2013).

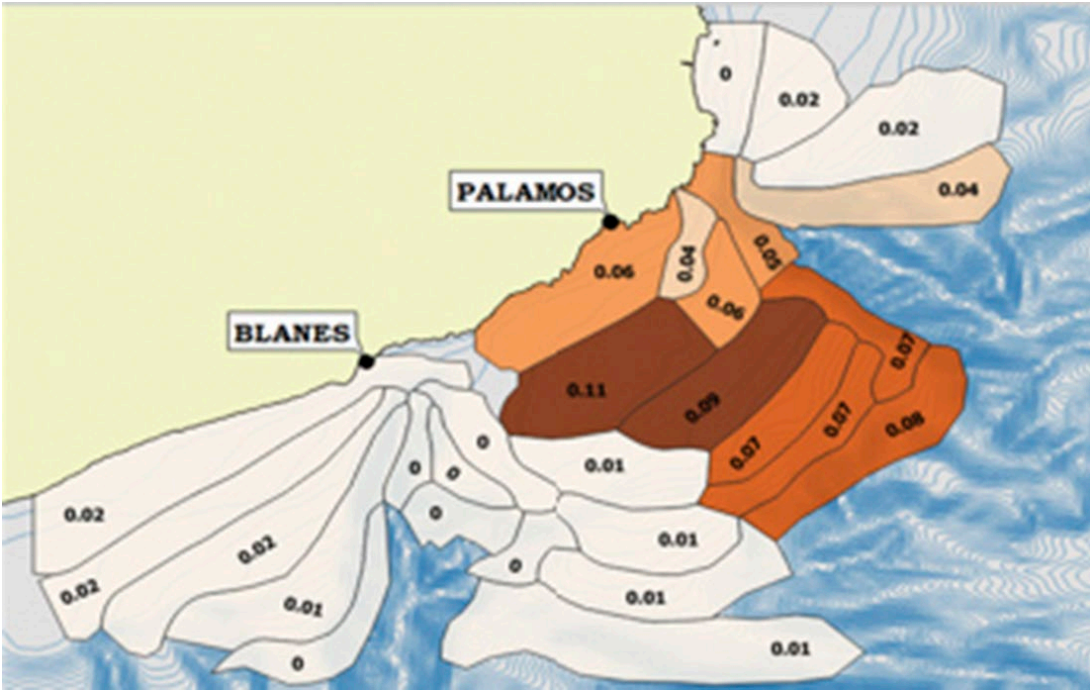


Fig. S2. – Larval dispersal by subregion or fishing ground according to the spatial distribution of age 0 individuals