

# Simulation of the combined effects of artisanal and recreational fisheries on a Mediterranean MPA ecosystem using a trophic model

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## Supplement 1. Additional data

Supplement 1A. Input data and references by biotic group for the Bonifacio Straits Natural Reserve (BSNR) model. *B*: biomass; *P/B*: production per unit of biomass; *Q/B*: consumption rate per unit of biomass; *EE*: ecotrophic efficiency; *Z*: total mortality; *F*: fishing mortality rate; *M*: non-predation natural mortality rate

Group	<i>B</i>	<i>P/B</i>	<i>Q/B</i>	<i>EE</i>	Diets
1 <i>Tursiops truncatus</i>	Life Linda 2000 to 2001 data from visual survey units of individuals has been transformed to t km <sup>-2</sup> with the mean body weight per species	Data from Coll et al. (2006) corrected to consider differences of temperature with the equation of Opitz (Opitz 1996)			Blanco et al. (2001)
2 <i>Sphyraena sphyraena</i>	Unpublished BSNR data \ estimates from fishing data	$Z = F + M$ ; $M =$ empirical equation from Pauly (1980)	Empirical relationship from Pauly et al. (1990)		See Supplement 1C
3 <i>Scyliorhinus canicula</i>	Unpublished BSNR data \ estimates from fishing data	$Z = F + M$ ; $M =$ empirical equation from Pauly (1980)	Empirical relationship from Pauly et al. (1990)		See Supplement 1C

4	Piscivorous fish	Unpublished BSNR data \ estimates from fishing data and visual census	$Z = F + M$ ; $M =$ empirical equation from Pauly (1980)	Empirical relationship from Pauly et al. (1990)	See Supplement 1C
5	Small pelagic feeders	Unpublished BSNR data \ estimates from fishing data	$Z = F + M$ ; $M =$ empirical equation from Pauly (1980)	Empirical relationship from Pauly et al. (1990)	See Supplement 1C
6	<i>Epinephelus marginatus</i>	Unpublished BSNR data \ visual census data	$Z = F + M$ ; $M =$ empirical equation from Pauly (1980)	Empirical relationship from Pauly et al. (1990)	Renones et al. (2002)
7	Opportunist piscivorous fish	Unpublished BSNR data \ estimates from fishing data and visual census	$Z = F + M$ ; $M =$ empirical equation from Pauly (1980)	Empirical relationship from Pauly et al. (1990)	See Supplement 1C
8	Cephalopods	Unpublished BSNR data \ estimates from fishing data	Data from Opitz (1996) corrected to consider differences of temperature between areas with the Opitz equation		Ambrose & Nelson (1983)
9	Birds	Unpublished data from visual survey units of individuals has been transformed to $t \text{ km}^{-2}$ with the mean body weight per species	Data from Pinnegar & Polunin (2004) corrected to consider differences of temperature between areas with the Opitz equation		Hickling (1983)
10	Benthic invertebrate feeders	Unpublished BSNR data \ estimates from fishing data and visual census	$Z = F + M$ ; $M =$ empirical equation from Pauly (1980)	Empirical relationship from Pauly et al. (1990)	See Supplement 1C
11	Zooplanktivorous fish	Data from the Pinnegar & Polunin (2004) model \ unpublished fishing data	$Z = F + M$ ; $M =$ empirical equation from Pauly (1980)	Empirical relationship from Pauly et al. (1990)	See Supplement 1C
12	Mollusc feeders	Unpublished BSNR data \ estimates from fishing data and visual census	$Z = F + M$ ; $M =$ empirical equation from Pauly (1980)	Empirical relationship from Pauly et al. (1990)	See Supplement 1C

13	Benthic invertebrate feeders 2	Unpublished BSNR data \ estimates from fishing data and visual census	$Z = F + M$ ; $M =$ empirical equation from Pauly (1980)	Empirical relationship from Pauly et al. (1990)		See Supplement 1C
14	Shrimp		Data from Coll et al. (2006), corrected to consider differences of temperature between areas with the Opitz equation (Opitz 1996)		Fixed to current values	Opitz 1996
15	Macroplanktivorous fish	Unpublished BSNR data \ estimates from fishing data and visual census	$Z = F + M$ ; $M =$ empirical equation from Pauly (1980)	Empirical relationship from Pauly et al. (1990)		See Supplement 1C
16	Decapods	Data from Sala (1997)	Data from Opitz (1996) corrected to consider differences in temperature between areas with the Opitz equation (Opitz 1996)	Data from Arias-Gonzales (1994) corrected to consider differences in temperature between areas with the Opitz equation (Opitz 1996)		Pinnegar & Polunin (2004)
17	Lobster & spiny lobster	Unpublished BSNR data \ estimates from fishing and sampling data	Data from Marin (1987) and Opitz (1996) corrected to consider differences in temperature between areas with the Opitz equation (Opitz 1996)			Opitz (1996)
18	Gastropods		Data from Opitz (1996) corrected to consider differences of temperature between areas with the Opitz equation (Opitz 1996)		Fixed to current values	Opitz (1996), Pearson & Gage (1984)
19	Zooplankton		Data from Pinnegar & Polunin (2004) corrected to consider differences of temperature between areas with the Opitz equation (Opitz 1996)		Fixed to current values	Kleppel (1993), Kleppel et al. (1996)
20	Polychaetes	Data from Sala (1997)	Data from Pinnegar & Polunin (2004) corrected to consider differences of temperature between areas with the Opitz equation (Opitz 1996)			Opitz (1996), Fauchald & Jumars (1979)

21	Suspension feeders		Data from Opitz (1996) corrected to consider differences in temperature between areas with the Opitz equation (Opitz 1996)	Fixed to current values	Chintiroglou & Koukouras (1992), Arias-Gonzales (1994), Coma et al. (1995), Ribes et al. (1999)
22	Echinoderms	Data from the Pinnegar & Polunin (2004) model	Data from Opitz (1996) and Pauly et al. (1993) corrected to consider differences in temperature between areas with the Opitz equation (Opitz 1996)		Arias-Gonzales (1994), Frantzis et al. (1988), Pearson & Gage (1984), Verlaque & Nedelec (1983)
23	Protozoan plankton		Data from Pinnegar & Polunin (2004) corrected to consider differences of temperature between areas with the Opitz equation (Opitz 1996)	Data from Sanchez & Olaso (2004) corrected to consider differences of temperature between areas with the Opitz equation (Opitz 1996)	Fixed to current values Olivieri et al. (1993)
24	<i>Sarpa salpa</i>	Unpublished BSNR data \ estimates from fishing data	$Z = F + M$ ; $M =$ empirical equation from Pauly (1980)	Empirical relationship from Pauly et al. (1990)	Havelange et al. (1997)
25	Other crustaceans	Data from the Pinnegar & Polunin (2004) model	Data from Pinnegar & Polunin (2004) corrected to consider differences of temperature between areas with the Opitz equation (Opitz 1996)		Arias-Gonzales (1994), Caine (1977), Vannier et al. (1998), Viejo & Arrontes (1996)
26	Amphipods		Data from Vetter (1996) and Schwinghamer et al. (1986) and corrected using the Opitz equation (Opitz 1996)	Data from Opitz (1996) corrected to consider differences in temperature between areas with the Opitz equation (Opitz 1996)	Fixed to current values Greze (1968)
27	Bivalves		Data from Opitz (1996) corrected to consider differences in temperature between areas with the Opitz equation (Opitz 1996)	Fixed to current values	Opitz (1996)

28	Macroplankton		Data from Pinnegar & Polunin (2004) modified to consider area's temperature (Opitz 1996)	Fixed to current values	Dauby (1980), Hobson & Chess (1976), Kinsey & Hopkins (1994), Purcell (1981), Sullivan et al. (1994)
29	Phytoplankton		Data from Pinnegar & Polunin (2004) and modified to consider area's temperature (Opitz 1996)	Fixed to current values	
30	Macro-algae		Data from Opitz (1996) corrected to consider differences in temperature between areas with the Opitz equation (Opitz 1996)	Fixed to current values	
31	<i>Posidonia oceanica</i>	Data from Gobert (2002) modified to include the meadow surface	Data from Opitz (1996) corrected to consider differences in temperature between areas with the Opitz equation (Opitz 1996)		
32	Detritus	Data from the Pinnegar & Polunin (2004) model			

Supplement 1B. Final diet matrix of the Bonifacio Straits Natural Reserve (BSNR) model. BIF: benthic invertebrate feeders

Prey/predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1 <i>Tursiops truncatus</i>																												
2 <i>Sphyræna sphyraena</i>																												
3 <i>Scyliorhinus canicula</i>																												
4 Piscivorous fish	0.200	0.025		0.070		0.022		0.01																				
5 Small pelagic feeders	0.528		0.460	0.022	0.050		0.008																					
6 <i>Epinephelus marginatus</i>																												
7 Opportunist piscivorous fish		0.715		0.109	0.263	0.103	0.020		0.106																			
8 Cephalopods	0.032		0.090	0.099	0.010	0.213	0.125	0.030	0.005	0.010																		
9 Birds																												
10 BIF	0.034	0.101		0.090	0.108		0.027			0.000																		
11 Zooplanktivorous fish	0.202		0.090	0.114	0.220	0.011	0.042	0.001	0.366	0.001	0.009																	
12 Mollusc feeders		0.125		0.073			0.155		0.275	0.005																		
13 BIF2		0.034		0.011	0.257	0.101	0.090	0.150	0.246	0.017			0.000															
14 Shrimp				0.006	0.009	0.013	0.153	0.035		0.057		0.163		0.002	0.113													
15 Macrocarnivorous fish				0.020				0.022																				
16 Decapods				0.365		0.418	0.276	0.636		0.489		0.127	0.179		0.036	0.083		0.008										
17 Superior crustaceans	0.004		0.160	0.004		0.057	0.001			0.024																		
18 Gastropods						0.020	0.007	0.041		0.004		0.178	0.037	0.070	0.001	0.030	0.218	0.042		0.005		0.009						
19 Zooplankton					0.007								0.773	0.028	0.113	0.001	0.063		0.006	0.042		0.001		0.009	0.027		0.009	0.027
20 Polychaetes			0.005				0.012			0.109	0.084	0.034	0.406	0.050	0.001	0.012		0.125	0.089		0.001							
21 Suspensivores				0.005			0.003			0.001	0.009					0.010	0.375	0.090	0.027		0.073							
22 Echinoderms							0.013			0.098		0.008	0.012	0.016		0.001	0.032	0.001	0.001									
23 Protozoan plankton																0.050			0.394	0.050	0.063		0.247		0.009	0.050	0.100	0.010
24 <i>Sarpa salpa</i>						0.016																						
25 Other crustaceans			0.160	0.004		0.026	0.029	0.011		0.063	0.022	0.067	0.019	0.055		0.254		0.066		0.056		0.003						
26 Amphipods			0.040	0.001	0.009		0.007	0.049		0.114	0.074	0.067	0.214	0.087	0.150	0.262		0.006		0.048								
27 Bivalves							0.003	0.038					0.272		0.060	0.004	0.009											
28 Macroplankton					0.065		0.007				0.014			0.210	0.692	0.020				0.059	0.313	0.011		0.110				0.280
29 Phytoplankton										0.006									0.400	0.074	0.250			0.000	0.018		0.150	
30 Macro-algae				0.002							0.009	0.069	0.011	0.097	0.001	0.070	0.225	0.441	0.160		0.781	0.050			0.444	0.561		0.050
31 <i>Posidonia oceanica</i>													0.091									0.078		0.890				
32 Detritus														0.237		0.136	0.150	0.221	0.200	0.390	0.375	0.043	0.303		0.021	0.362	0.750	
33 Import																							0.400		0.499			0.660

Supplement 1C. Composition of fish groups and their associated references for diets. Asterisks show groups targeted by artisanal fishing, boat and shore fishing, or spearfishing

Group	Species	Artisanal fishing	Boat and shore fishing	Spear fishing	Source
Piscivorous	<i>Conger conger</i>	*		*	Cau & Manconi (1984)
	<i>Dentex dentex</i>	*	*	*	Morales-Nin & Moranta (1997)
	<i>Lophius piscatorius</i>	*			Macpherson (1981)
	<i>Muraena helena</i>	*		*	Cau & Manconi (1984)
	<i>Phycis phycis</i>	*		*	Papaconstantinou & Caragitsou (1989)
	<i>Synodus saurus</i>	*			Golani (1993)
Opportunist piscivorous fish	<i>Apogon imberbis</i>				Pinnegar & Polunin (2000)
	<i>Labrus viridis</i>	*		*	Bell & Harmelin-Vivien (1983)
	<i>Pagellus acarne</i>	*	*	*	Morato et al. (2001)
	<i>Pagrus pagrus</i>	*	*	*	Papaconstantinou & Caragitsou (1989)
	<i>Scomber</i> sp.	*		*	Cabral & Murta (2002)
	<i>Scorpaena porcus</i>	*		*	Arculeo et al. (1993)
	<i>Scorpaena scrofa</i>	*		*	Bell & Harmelin-Vivien (1983)
	<i>Serranus scriba</i>	*		*	Bell & Harmelin-Vivien (1983)
	<i>Uranoscopus scaber</i>	*			Sanz (1985)
Benthic invertebrate feeders	<i>Labrus merula</i>	*		*	Bell & Harmelin-Vivien (1983)
	<i>Pagellus erythrinus</i>	*	*	*	Rosecchi (1983)
	<i>Sciaena umbra</i>	*		*	Derbal & Kara (2007)
	<i>Scorpaena notata</i>	*		*	Bell & Harmelin-Vivien (1983)
	<i>Thalassoma pavo</i>				Bell & Harmelin-Vivien (1983)
Macroplanktivorous fish	<i>Serranus cabrilla</i>	*	*	*	Bell & Harmelin-Vivien (1983)
	<i>Spondyliosoma cantharus</i>	*	*		Bell & Harmelin-Vivien (1983)
	<i>Trachinus draco/araneus</i>	*			Morte et al. (1999)
	<i>Trisopterus minutus</i>	*			Le Loc'h (2004)

Small pelagic feeders	<i>Merluccius merluccius</i>	*		Le Loc'h (2004)
	<i>Sarda sarda</i>	*		* Campo et al. (2006)
	<i>Seriola dumerilii</i>	*	*	* Mazzola et al. (2000)
	<i>Trachurus mediterraneus</i>	*		Ben Salem (1988)
	<i>Zeus faber</i>	*		Bell & Harmelin-Vivien (1983)
Mollusc feeders	<i>Coris julis</i>		*	Bell & Harmelin-Vivien (1983)
	<i>Diplodus puntazzo</i>	*		* Sala & Ballesteros (1997)
	<i>Diplodus sargus</i>	*	*	Sala & Ballesteros (1997)
	<i>Diplodus vulgaris</i>	*	*	* Sala & Ballesteros (1997)
	<i>Symphodus</i> sp.	*		Bell & Harmelin-Vivien (1983)
	<i>Trigla lucerna</i>	*		Macpherson (1981)
Zooplanktivorous fish	<i>Atherina boyeri</i>			Pinnegar & Polunin (2000)
	<i>Boops boops</i>			Bell & Harmelin-Vivien (1983)
	<i>Chromis chromis</i>			Bell & Harmelin-Vivien (1983)
	<i>Engraulis encrasicolus</i>			Tudela & Palomera (1997)
	<i>Mugilidés</i>			Blaber (1976)
	<i>Oblada melanura</i>	*	*	Moreno & Castro (1995)
	<i>Spicara maena</i>	*		Khoury (1987)
Benthic invertebrate feeders 2	<i>Diplodus annularis</i>	*	*	Rossechi & Nouaze (1989)
	<i>Gobius</i> sp.			Dierter Zander & Berg (1984)
	<i>Lipophrys pavo</i>			Dierter Zander & Berg (1984)
	<i>Mullus surmuletus</i>	*		* Pinnegar & Polunin (2000)
	<i>Parablennius rouxi</i>			Pinnegar & Polunin (2000)
	<i>Solea</i> sp.	*		* Bell & Harmelin-Vivien (1983)
	<i>Symphodus tinca</i>	*		* Khoury (1987)
	<i>Tripterygion</i> sp.			Bell & Harmelin-Vivien (1983)
Single species groups	<i>Epinephelis marginatus</i>	*		Renones et al. (2002)
	<i>Sarpa salpa</i>			Havelange et al. (1997)
	<i>Sphyraena sphyraena</i>	*	*	* Barreiros et al. (2002)

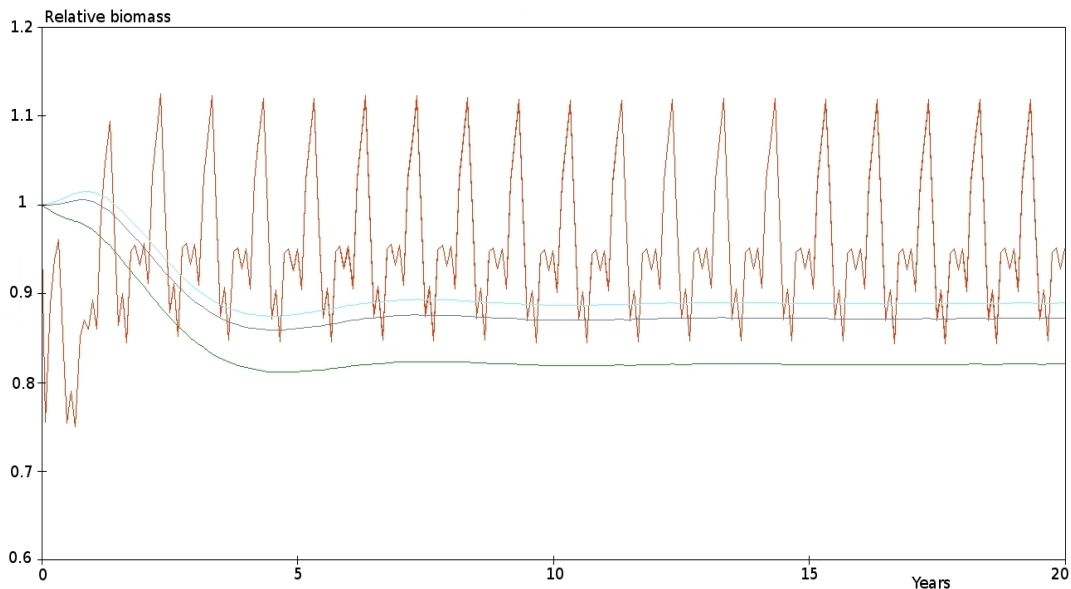


## Supplement 1D. Temperature assessment

An average temperature for the modelled area is primordial for assessing the consumption biomass ratio for fish (Eq. 6), and production per unit of biomass ( $P/B$ ) and consumption rate per unit of biomass ( $Q/B$ ) (for other groups). Values for other groups were taken from the worldwide literature and adapted to our system using the Opitz equation (Opitz 1996).

To estimate an annual average sea surface temperature (SST) of the Bonifacio Straits Natural Reserve (BSNR) we collected a grid (resolution of  $1^\circ$  of weekly SST values from the National Climatic Data Center (NCDC) National Operational Model Archive and Distribution System Meteorological Data Server (NOMADS) of the US National Oceanic and Atmospheric Administration (NOAA) Satellite and Information Service ([www.osdpd.noaa.gov/PSB/EPS/SST/al\\_climo\\_mon.html](http://www.osdpd.noaa.gov/PSB/EPS/SST/al_climo_mon.html)). Then, maps were interpolated at the  $0.1^\circ$  resolution needed for our analyses via ordinary kriging. Weekly SST values were averaged over the 2000 to 2001 period to provide 14 SST variables for each  $0.1^\circ$  grid cell. Twelve monthly means were used to calculate the mean annual SST then an average SST was extracted. The mean annual temperature for the BSNR was  $18.6^\circ\text{C}$  for the 2000 to 2001 period.

Supplement 1E. Ecosim output, with the variation of relative biomass for phytoplankton (red line), the variation of relative biomass for piscivorous fish in the absence of fishing effort ( $F = 0$ ) (light blue line), the variation of relative biomass for piscivorous fish and actual fishing effort ( $F = 1$ ) (dark blue line), and the variation of relative biomass for piscivorous fish and a 4-fold increase in fishing effort ( $F = 4$ ) (green line)



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