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Exploring MSY strategies for elasmobranch fishes in an ecosystem perspective

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Abstract. An ecotrophic model of the neritic ecosystem of southern Brazil was developed and some strategies for elasmobranch fishes exploitation were analyzed using Ecopath with Ecosim. Fisheries policy optimization analysis showed that the elasmobranchs are badly affected by almost all fishing fleets, thus management and conservation actions must take this fact into account. The dynamic simulations showed that applying Maximum Sustainable Yield fishing strategies to several species (multi-species MSY) would cause the decrease in abundance of top predators, including some elasmobranchs groups, although the simulated changes were not as dramatic as we expected. The model analysis also revealed that the available data on biomass and on exploitation need to be reviewed and new studies must be conducted in order to assess the state of these elasmobranch populations in the area.

Keywords: Ecopath, Ecosim, Elasmobranchs fisheries, Southern Brazil continental shelf.

Resumo. Explorando estratégias de RMS para peixes elasmobrânquios desde uma perspectiva ecossistêmica. Foi construído um modelo do ecossistema da plataforma continental do Sul do Brasil e avaliadas algumas estratégias para a explotação de peixes elasmobrânquios, usando o pacote Ecopath com Ecosim. As analises de otimização de explotação mostraram que os elasmobrânquios são fortemente afetados por quase todas as frotas pesqueiras atuantes na região, pelo que qualquer ação de manejo e conservação deverá levar em conta este fator. As simulações dinâmicas mostraram que a aplicação de estratégias de Rendimento Máximo Sustentável para várias espécies simultaneamente (RMS multiespecífico) poderia causar uma redução na abundância dos predadores de topo, incluindo os grupos de elasmobrânquios. De qualquer forma, as mudanças observadas nestas simulações não foram tão dramáticas como esperado. A análise do modelo revelou também que as informações sobre biomassa e nível de explotação precisam ser revistas e novos estudos deveriam ser realizados para avaliar o estado das populações destes elasmobrânquios na área.

Palavras-chave: Ecopath, Ecosim, Pescarias de elasmobrânquios, Plataforma continental do Sul do Brasil.

Introduction

The impact of fishing on chondrichthyan populations around the world is currently the focus of considerable international concern (Musick 2004). Most chondrichthyan species are of low productivity if compared with teleost fishes, a consequence of their different life-history strategies. In contrast to bony fishes, that have a greater capacity for density-dependent change because of their (generally) high fecundity–high mortality strategy, Chondrichthyes would take several decades to recover once overfished (Stevens *et al.* 2000, Musick & Bonfil 2004, Musick *op. cit.*) if ever recover.

In the last decades, elasmobranchs populations (namely sharks, rays and skates) have already declined as a result of overfishing (Vooren 1997, Stevens *et al*. 2000, Baum *et al*. 2003, Cortés 2004).

As an example, in the NW Atlantic (including the North Sea and Irish Sea) there are already two locally extinct species of skate (Rajiformes, Rajidae) (Brander 1981, Casey & Myers 1998) and at least seven critically endangered (Dulvy & Reynolds 2002). Sawfishes (Pristiformes, Pristidae) may be one of the most threatened groups, although quantitative catch data are mostly lacking (Stevens *et al*. 2000). As an example of shark species, it can be mentioned the case of *Centrophorus* spp. (Squaliformes, Centrophoridae) which catch rates have declined from 126 to 0.4 kg/h in Australia (Graham *et al*. 1997). And these are just a few examples. The poor record of sustainability of target shark fisheries is cited as evidence of their vulnerability, but this is also magnified by the fact that few countries have any form of management for these resources (Stevens *et al*. 2000).

For the SW Atlantic Ocean, specifically the Southern Brazilian area (latitudes 20° to 35° S, approximately), there are at least nine species threatened of extinction and six other are overexploited because of the fishing pressure –both direct and indirect– they have suffered for many years (Vooren 1997, Vooren & Klippel 2005). Commercially important species as the tope-shark *Galeorhinus galeus* (Linnaeus, 1758), the Patagonian smooth-hound *Mustelus schmitti* Springer, 1939, and the angel-sharks *Squatina guggenheim* Marini, 1936 and *Squatina occulta* Vooren & Silva, 1991 are among the worse affected. Large pelagic sharks like *Prionace glauca* (Linnaeus, 1758), *Sphyrna lewini* (Griffith & Smith, 1834), *Sphyrna tiburo* (Linnaeus, 1758), *Sphyrna zygaena* (Linnaeus, 1758), *Lamna nasus* (Bonnaterre, 1788) and *Carcharias taurus* Rafinesque, 1810 are already considered as overexploited (Brasil 2004).

Study area

The continental shelf of southern Brazil, from Santa Marta Grande Cape (28°40' S, 48°50'W) to Chuí (33°40' S, 53°20' W) (area c.a. 100,000 km^2, Fig. 1), is relatively wide compared with the rest of the Brazilian shelf (up to 180 km). It is considered one of the most productive marine areas of this country, after the upwelling regions of the Southeastern Bight (Castello 1997, Haimovici *et al*. 1997, Odebrecht & Castello 2001). This area is under the influence of the subtropical convergence formed by the southward flowing Brazil Current (tropical water, T>20 °C and S>36,00 ppt) and the northward flowing Malvinas current (sub-antarctic water, T: 4 – 15 °C, S: 33,70 – 34,15 ppt) forming, at the sub-tropical convergence, a water mass known as South Atlantic Central Water (SACW) (Garcia 1997, Piola *et al*. 2000). The region receives the continental water runoff from Patos Lagoon and the De La Plata River (Garcia 1997, Odebrecht & Castello 2001) that contributes to the enrichment of the shelf waters, increasing the productivity.

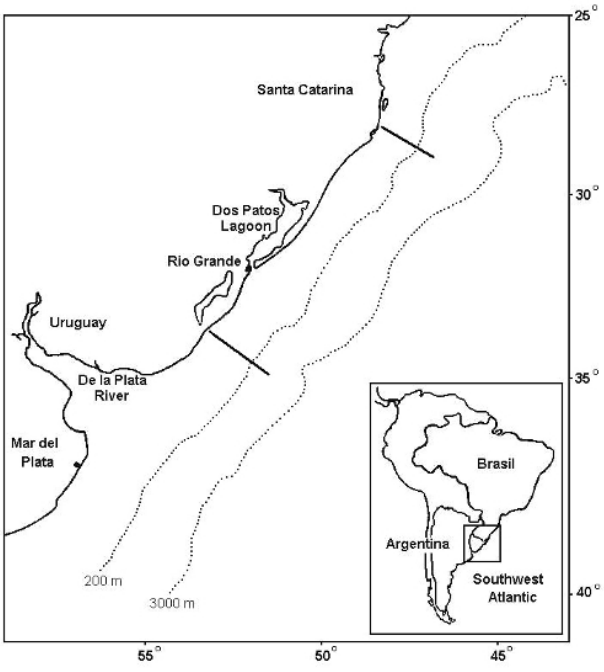

Figure 1 – Study area: the continental shelf of Southern Brazil (c.a. 100,000 km^2).

The dominant fisheries in this region are bottom and pair trawling, both for several Sciaenidae fishes like the whitemouth croaker *Micropogonias furnieri* (Desmarest, 1823), the weakfish *Cynoscion guatucupa* (Cuvier, 1830), the king-weakfish *Macrodon ancylodon* (Bloch and Schneider, 1801) and the Argentinean croaker *Umbrina canosai* Berg, 1895, flatfishes of the genus *Paralichthys* and coastal shrimps *Artemesia longinaris* (Bate, 1888) (Penaeidae) and *Pleoticus muelleri* (Bate, 1888) (Solenoceridae) (Haimovici *et al.* 1997, IBAMA 2002). In these fisheries, some elasmobranchs are important (landed) as by-catch: *Galeorhinus galeus*, *Mustelus schmitti* and *Squatina* spp., as well as several shelf skates and rays of the genus *Symterygia*, *Atlantoraja* and *Myliobatis* (Vooren 1997, Vooren & Klippel 2005). There is also a gillnet fishery for blue-fish *Pomatomus saltatrix* (Linnaeus, 1766) (Pomatomidae) and whitemouth croaker (Reis 1992, Haimovici *et al*. 1997) and a bottom long-line for wreckfish *Polyprion americanus* (Bloch e Schneider, 1801) (Polyprionidae) and other large fishes such as *Pseudopercis* spp (Pinguipedidae) and *Lopholatilus villarii* Miranda Ribeiro, 1915 (Malacanthidae) (Haimovici & Velasco 2001). During spring and summer months an important pole and live-bait fishery for skipjack *Katsuwonus pelamis* (Linnaeus, 1758) has been developed on the outer shelf waters. Along the upper slope area and the adjacent oceanic region, a long-line fishery for tunas and pelagic sharks has been developed (Castello 1997).

Modeling ecosystem and fisheries

In recent years, the neritic ecosystem of this region has been analyzed under a multispecific, ecotrophic modeling perspective (Vasconcellos & Gasalla 2001, Velasco 2004, Velasco & Castello 2005). Ecotrophic modeling is becoming a reliable tool to describe and analyze aquatic ecosystems as a whole, including fisheries in a holistic approach, and more recently, to test some “what-if” fisheries and productivity oscillations scenarios (Pauly & Christensen 1993, 2002, Walters *et al.* 1997, Pauly *et al.* 2000, Christensen & Mclean 2004, Daan *et al.* 2005, Velasco & Castello 2005, Araújo *et al*. 2006).

The *Ecopath with Ecosim* (EwE) is the most widely used package to construct such ecotrophic models. It works with the main groups in the ecosystem, here considered as species or groups of ecologically similar species, the trophic linkages among them (predation), and the fishing mortality. The basic inputs for each group are biomass data (*B*), the production/biomass ratio (*P/B*) (assumed equivalent to the instantaneous rate of total mortality *Z* in most cases) and the consumption/biomass ratio (*Q/B*), fisheries landings and diet for each group (Pauly & Christensen 1993, Pauly *et al.* 2000, Christensen & Walters 2004). The ecotrophic efficiency (*EE*) (a measure of how much of a group’s production is used within the ecosystem), can be entered when one of the other parameters (*B*, *P/B* or *Q/B*) is missing. However, due to the difficulty of estimating *EE* in the field, it is rather left to be estimated as an output by the program and considered as a diagnostic variable of the model (Christensen & Walters *op. cit.*, Christensen *et al.* 2005). With this information, three basic input data matrices are built and used to describe the energy flux in the ecosystem: 1) a matrix containing data on *B*, *P/B*, *Q/B*, and *EE*, 2) a matrix with fisheries landings per group and fleet and/or gear type, and 3) a diet matrix containing the proportion of each prey in each predator’s average diet (DC_{ji}).

Ecopath then solves a set of linear equations like the one below (one per modeled species or group) calculating the missing parameter and giving us a representation of the biomass composition and fluxes of the ecosystem, under dynamic equilibrium conditions:

$$B_i * (P/B)_i * EE_i - \sum_{j=1}^{n} B_j * (Q/B)_j * DC_{ji} - Y_i - E_i - BA_i = 0$$

were Y_i is the annual fisheries yield of species *i*; E_i is the net migration rate, BA_i is the biomass accumulation and the other parameters are the ones described above (for more details see Christensen & Walters *op. cit.*, Christensen *et al*. *op cit.*, and other articles in the present Volume).

Ecosim is the time dynamic version of Ecopath. It can be used to simulate the ecosystem effects of fishing mortality changes and environmental forcing over time. The process is based on the set of linear equations used in Ecopath, isolating the biomass accumulation term, and setting up a set of differential equations of the form:

$$dB_i / dt = g_i \cdot \sum_j Q_{ji} - \sum_j Q_{ij} + I_i - (M_i + F_i + e_i) \cdot B_i$$

where dB_i/dt represents the growth rate of group (*i*) during the time interval *dt* in terms of its biomass B_i, g_i is the net growth efficiency (production/consumption ratio), M_i the non-predation natural mortality rate, F_i is fishing mortality rate, e_i is emigration rate, I_i is immigration rate, (and $e_i \cdot B_i - I_i$ is the net migration rate). The two summations estimate consumption rates, the first expressing the total consumption by group (*i*), and the second the predation by all predators on the same group (*i*).

In the present contribution, we aim to analyze some possible strategies for the exploitation of several elasmobranch species, since some of them are already overfished and/or highly impacted as by-catch. In addition several species are already endangered, as above mentioned and most of the times they are set aside in the management plans.

Material & Methods

An Ecopath model previously constructed (Velasco 2004) to represent the above described area for the late 1990' was modified and improved in order to assess the effect of some exploitation measures using Ecosim scenarios. For the present work, two groups that were originally divided into different live stages (*multi-stanza*: juveniles – adults), each one with their own ecological and biological parameters (Velasco 2004), were combined since multi-species maximum sustainable yield simulations (see below) with the original model structure led to the exclusion of the multi-stanza groups (Araújo unpublished data). In addition to these modifications, catches of some groups were raised to reflect the exploitation ratios reported in Vooren & Klippel (2005) and mainly in Cergole *et al.* (2005). The estimates published in these reports were obtained with a variety of single-species methods and suggested that the fishing mortality rates of several groups included originally in the model of the continental shelf of southern Brazil were underestimated. The model used here included 31 living groups, from primary producers (phytoplankton) to top predators (teleost fishes, elasmobranchs and marine mammals), plus a group of discards and the detritus group (Table I). Biological data were obtained and/or adapted from numerous sources (see Velasco 2004 and Velasco & Castello 2005), but mainly from Seeliger *et al.* (1997), Martins (2000), Palomares & Pauly (1998), Guénette *et al.* (2001) and the FishBase (www.fishbase.org, Froese & Pauly 2003); landings were extracted from IBAMA (2002); discards were estimated using Haimovici *et al.* (1997) and Haimovici (1998).

The optimum policy search module of Ecosim in the EwE version 5.1 (Christensen & Walters 2004, Christensen *et al.* 2005) was used to search for fishing fleets configurations (represented in terms of relative effort) that maximize elasmobranchs biomasses. To do so, the policy search tool was used to optimize the ecosystem structure function that maximizes an index of ecosystem maturity (*sensu* Odum 1969 *apud* Christensen *et al. op. cit.*) calculated as the longevity-weighted summed biomass over ecosystem groupings. The ecosystem structure function uses the inverse of the *P/B* ratio of each functional group, which is an index of longevity, as a weighting factor for the group biomasses (Christensen *et al. op. cit.*). The other objective functions of the module (*i.e.*, economic, social, and mandate rebuilding) were given zero weights. The maximum fishing mortality allowed for each group in the optimization was set as 5 times the base estimates (*i.e.*, the mortality of the base balanced Ecopath model). The vulnerability parameter was left as default (mixed top-down and bottom-up predation effects).

The optimum policy search module uses a non-linear optimization procedure known as the Fletcher method to iteratively improve an objective function by running through a series of relative fishing effort rates. As any complex non-linear procedure, it can "get stuck" at local optima, therefore, twenty years trials were run over 30 times with random starting values of fishing effort (Christensen & Walters 2004, Araújo *et al.* 2006).

In addition to the harvest policy optimization conducted by varying fishing effort, we used another Ecosim facility to evaluate the elasmobranchs fisheries in the ecosystem context. The "Equilibrium" routine in Ecosim was used to carry out a series of long term (100+ yr) simulations to estimate single species maximum sustainable yield (MSY) and fishing mortality reference points at MSY (F_{MSY}) and to evaluate ecosystem-scale performance if these reference points were simultaneously implemented. Therefore, according to Christensen *et al.* (2005), three types of results are produced by the analysis:

"(1) An estimate of MSY and F_{MSY} for each harvested group, obtained by running the Ecosim model to equilibrium for a range of F values while holding biomasses of all other groups constant. This essentially means treating the ecosystem that 'surrounds' each group as constant, then examining predicted compensatory responses by the group (…) caused by the foraging arena functional response and related foraging time adjustment parameters.

(2) An estimate of the MSY that would be realized for each group if the single-species F_{MSY} policy from (1) were applied simultaneously to all groups in the model.

(3) An estimate of the change in MSY from step (2), *i.e.* in MSY evaluated while considering species interactions, due to reducing the F for each group by 10% from the single-species F_{MSY} value."

Results

The groups and parameters values for the model are shown in Table I and II, while the diet matrix is presented in Table III. The fishing fleets along with the landings and discards are shown in

Tables IV and V, respectively. There were four elasmobranch compartments in the model: the tope-shark *Galeorhinus galeus*, the narrownose smooth-hound *Mustelus schmitti*, a group of nektophagous elasmobranchs (pelagic sharks and angel sharks, mainly) and another of benthophagous elasmobranchs (skates, rays and some small demersal sharks).

Table I – List of the 33 groups included in the ecotrophic model of Southern Brazil continental shelf with a summarized description of each group.

Group	Description	#
Other_Odontoceti	Continental shelf dolphins and porpoises	1
Pinipeds	Sea-lions	2
P_blainvillei	Estuarine/coastal dolphin - *Pontoporia blainvillei*	3
Other_cephalopods	Several oceanic squids	4
I_argentinus	Argentinean squid - *Illex argentinus*	5
L_sanpaulensis	Coastal squid - *Loligo sanpaulensis*	6
Octopuses	*Octopus spp. and Eledone spp.*	7
Elasmo_nektophagous	Other nektophagous elasmobranchs (sharks, angel-sharks, rays, etc.)	8
Elasmo_benthophagous	Other benthophagous elasmobranchs (skates, rays, sharks, etc.)	9
M_schmitti	Patagonian smooth-hound - *Mustelus schmitti*	10
G_galeus	School-shark - *Galeorhinus galeus*	11
Other_ichthyophagous teleosts	Other ichthyophagous teleosts (gulf-hake, red-porgi, Atlantic wreckfish, etc.)	12
Other plankt-benthoph. teleosts	Other planktophagous and benthophagous teleosts (congers, weak-fish, etc.)	13
P_patagonicus	White flat-fish - *Paralichthys patagonicus*	14
M_hubbsi	Argentinean hake - *Merluccius hubbsi*	15
T_lepturus	Sabre-fish - *Trichiurus lepturus*	16
U_canosai	Argentinean croaker - *Umbrina canosai*	17
M_ancylodon	King weakfish - *Macrodon ancylodon*	18
C_guatucupa	Stripped weakfish - *Cynoscion guatucupa*	19
M_furnieri	Whitemouth croaker - *Micropogonias furnieri*	20
Tunas_2	Big-eye tuna *Thunnus obesus* and Sword-fish *Xiphias gladius*	21
Tunas_1	Several tunas *Thunnus* spp., dolphinfish *Coryphaena* spp. and relatives	22
P_saltatrix	Blue-fish - *Pomatomus saltatrix*	23
K_pelamis	Skipjack-tuna - *Katsuwonus pelamis*	24
M_stehmanni	Lantern-fish - *Maurolicus stehmanni*	25
T_lathami	Horse mackerel - *Trachurus lathami*	26
E_anchoita	Anchovy - *Engraulis anchoita*	27
Benthos_Macro_crust	Coastal shrimps (*Pleoticus muelleri* and *Artemesia longinaris*)	28
Benthos	Benthic infauna and epifauna	29
Zooplankton	Several species of planktonic feeders	30
Phytoplankton	Several species of primary producers	31
Discards	Fishes discarded by the fishing fleets	(32)
Detritus	All organic material in decomposition and remineralization	(33)

Table II – Parameters for the model's groups.

Group name	B in area (t/km²)	P/B (/year)	Q/B	EE
Other_Odontoceti	0.05	0.02	12	
Pinipeds	0	0.06	24	
P_blainvillei	0	0.06	12	
Other_cephalopods		1.5	8	0.97
I_argentinus		1.5	3	0.97
L_sanpaulensis		1.5	3.23	0.97
Octopuses		1.64	6	0.95
Elasmo_nektophagous	0.22	0.3	4.3	
Elasmo_benthophagous	0.4	0.3	3.6	
M_schmitti		0.3	4.03	0.95
G_galeus	0.04	0.3	2.73	
Other_ichthyophagous teleosts		0.8	3.5	0.98
Other plankt-benthoph. teleosts		0.88	4	0.98
P_patagonicus	0.01	0.8	5.2	
M_hubbsi		0.8	3.11	0.9
T_lepturus		0.41	3.41	0.97
U_canosai	0.37	0.8	5.52	
M_ancylodon		1.74	5.82	0.95
C_guatucupa	3.08	0.95	6.62	
M_furnieri	2.6	0.68	4.46	
Tunas_2	0.01	0.6	6.75	
Tunas_1	0.01	1.78	8.82	
P_saltatrix	0.11	0.77	4.98	
K_pelamis	0.71	1.95	32.57	
M_stehmanni	0.78	1.2	20	
T_lathami	0.9	1.06	5.1	
E_anchoita	11.81	1.47	9.39	
Benthos_Macro_crust	5	4	19.13	
Benthos	9	4	23	
Zooplankton	9	64.9	200	
Phytoplankton	16.7	120		
Discards	0.06			
Detritus	1			

Table III – Diet matrix (two pages).

	Prey \ Predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Other_Odontoceti	0.000														
2	Pinipeds	0.000														
3	P_blainvillei	0.000														
4	Other_cephalopods	0.097		0.001	0.108	0.416	0.006		0.068			0.001	0.013	0.001	0.006	0.020
5	I_argentinus	0.009	0.002			0.052							0.004	0.005		0.089
6	L_sanpaulensis	0.031	0.011	0.761		0.048	0.059		0.013	0.007	0.010	0.021	0.024	0.020	0.051	0.009
7	Octopuses	0.027		0.001				0.041	0.002	0.021	0.028	0.021	0.001	0.021		
8	Elasmo_nektophagous	0.002							0.010	0.006		0.021	0.001	0.000		
9	Elasmo_benthophagous								0.020			0.035	0.001	0.001	0.010	
10	M_schmitti	0.002							0.006							
11	G_galeus								0.000							
12	Other_ichthyophagous teleosts	0.066	0.004	0.001		0.001		0.000	0.013	0.005		0.200	0.000	0.000		
13	Other plankt-benthoph. Teleosts	0.066	0.100	0.101	0.105		0.093	0.010	0.204	0.203	0.107	0.196	0.149		0.208	0.250
14	P_patagonicus								0.001	0.001						
15	M_hubbsi	0.005	0.061			0.059			0.036	0.039		0.205	0.014		0.026	0.050
16	T_lepturus	0.017	0.001	0.038									0.015	0.003	0.002	0.007
17	U_canosai	0.012							0.013	0.003		0.012	0.024	0.006	0.131	
18	M_ancylodon	0.025		0.007			0.051		0.010	0.010		0.002	0.033	0.013		
19	C_guatucupa	0.050	0.283	0.025			0.040		0.022	0.005		0.012	0.043	0.006	0.358	0.024
20	M_furnieri	0.121	0.071	0.005			0.051		0.031	0.007		0.002	0.039	0.012	0.001	
21	Tunas_2	0.000							0.001							
22	Tunas _1	0.000							0.001							
23	P_saltatrix								0.007				0.008	0.003		
24	K_pelamis	0.005							0.008				0.000			
25	M_stehmanni				0.040	0.059			0.002			0.020	0.094	0.008		
26	T_lathami	0.017	0.005		0.001				0.040	0.003	0.005	0.062	0.039	0.008	0.013	0.041
27	E_anchoita	0.027	0.379		0.150	0.107	0.020		0.106	0.081	0.011	0.053	0.110	0.020	0.002	0.199
28	Benthos_Macro_crust	0.023	0.026	0.060			0.180	0.223	0.030	0.430	0.758	0.021	0.029	0.202	0.042	
29	Benthos					0.043		0.668	0.021	0.177	0.081		0.010	0.403	0.150	0.061
30	Zooplankton				0.348	0.129	0.500	0.000	0.016	0.002			0.082	0.212		0.020
31	Phytoplankton													0.010		
32	Discards		0.000					0.002	0.001	0.001			0.001	0.000		
33	Detritus							0.056								
34	Import	0.399	0.058		0.248	0.086			0.318			0.116	0.266	0.047		0.231
35	Sum	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table III. (cont.)

	Prey \ Predator	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	Other_Odontoceti															
2	Pinipeds															
3	P_blainvillei															
4	Other_cephalopods	0.001			0.001		0.263	0.070		0.000						
5	I_argentinus						0.010									
6	L_sanpaulensis	0.021	0.000	0.032	0.014	0.000		0.003	0.030	0.006						
7	Octopuses															
8	Elasmo_nektophagous															
9	Elasmo_benthophagous															
10	M_schmitti	0.001														
11	G_galeus															
12	Other_ichthyophagous teleosts			0.005		0.001			0.030	0.010						
13	Other plankt-benthoph. Teleosts	0.110	0.025	0.021			0.050	0.099	0.160	0.020						
14	P_patagonicus															
15	M_hubbsi	0.002				0.012										
16	T_lepturus	0.070						0.003	0.080							
17	U_canosai	0.005							0.014							
18	M_ancylodon	0.003	0.020	0.160	0.038				0.010							
19	C_guatucupa	0.051		0.000	0.018	0.028			0.050							
20	M_furnieri			0.001					0.009							
21	Tunas_2						0.010	0.028								
22	Tunas _1							0.004								
23	P_saltatrix															
24	K_pelamis							0.016		0.000						
25	M_stehmanni							0.020		0.008						
26	T_lathami	0.016	0.014		0.014	0.005		0.001								
27	E_anchoita	0.311		0.032	0.264	0.010		0.001	0.090	0.118						
28	Benthos_Macro_crust	0.015	0.078	0.450	0.254	0.354		0.072	0.080	0.001				0.002		
29	Benthos	0.004	0.862	0.071	0.043	0.527								0.096	0.043	
30	Zooplankton	0.390	0.001	0.228	0.354	0.001	0.010	0.203	0.010	0.233	1	1	0.900	0.140	0.053	
31	Phytoplankton												0.100		0.051	1
32	Discards															
33	Detritus					0.062								0.762	0.853	
34	Import						0.657	0.479	0.436	0.603						
35	Sum	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table IV – Reported official landings by group and fleet (t/km^2/year).

Group Name	Artisanal	Simple Trawl	Pair-Tr.	Double-Tr.	Purse-seine	Coastal and oceanic gillnets	Long-line	Live bait	Others	Mid-water Tr.	Total
Other_Odontoceti											0
Pinipeds											0
P_blainvillei											0
Other_cephalopods											0
I_argentinus											0
L_sanpaulensis		0.00000	0.00001	0.00022		0.00002					0
Octopuses			0.00000	0.00009		0.00001					0
Elasmo_nektophagous	0.00037	0.00016	0.00032	0.00054	0.00000	0.00174	0.00050		0.00005		0.004
Elasmo_benthophagous	0.00009	0.00033	0.00055	0.00054	0.00000	0.00029			0.00013		0.002
M_schmitti	0.00046	0.00014	0.00016	0.00025	0.00011	0.00202	0.00020		0.00015		0.003
G_galeus	0.00069	0.00021	0.00024	0.00037	0.00016	0.00302	0.00030		0.00022		0.005
Other_ichthyophagous teleosts	0.00031	0.00231	0.00186	0.00852	0.00030	0.00342	0.00024	0.00005	0.00866		0.026
Other plankt-benthoph. Teleosts	0.00314	0.00235	0.00397	0.00257	0.00372	0.00604	0.00002		0.00123		0.023
P_patagonicus	0.00014	0.00020	0.00042	0.00288		0.00031			0.00000		0.004
M_hubbsi	0.00001	0.00012	0.00004	0.00096		0.00023			0.00001		0.001
T_lepturus	0.00000		0.00004	0.00002		0.00010			0.00003		0
U_canosai	0.00469	0.01050	0.02890	0.00332		0.01330	0.01180		0.00459		0.077
M_ancylodon	0.00016	0.00016	0.00632	0.00092	0.00008	0.00081			0.00003		0.008
C_guatucupa	0.03490	0.07840	0.19800	0.01320	0.00003	0.12100	0.06060		0.01220		0.518
M_furnieri	0.09380	0.01120	0.05130	0.00859	0.00157	0.18800			0.01050		0.365
Tunas_2							0.00026				0
Tunas_1	0.00000					0.00000	0.00049	0.00561	0.00002		0.006
P_saltatrix	0.00081	0.00001	0.00002	0.00031	0.00676	0.00520			0.00028		0.013
K_pelamis	0.00000	0.00000						0.04880	0.00000		0.049
M_stehmanni											0
T_lathami											0
E_anchoita										1.00E-10	0
Benthos_Macro_crust	0.00123			0.01160							0.013
Benthos											0
Zooplankton											0
Phytoplankton											0
Sum	0.141	0.106	0.292	0.055	0.013	0.346	0.074	0.054	0.038	1.00E-10	1.119

Table V – Discards by group and fleet (t/km^2/year).

Group Name	Artisanal	Simple Trawl	Pair-T	Double-T	Purse-seine	Coastal and oceanic gillnets	Long-line	Live bait	Others	Mid-water Tr.	Total
Other_Odontoceti											0
Pinipeds											0
P_blainvillei						0.00016					0
Other_cephalopods											0
I_argentinus											0
L_sanpaulensis											0
Octopuses											0
Elasmo_nektophagous	0.00216	0.00280	0.00557	0.01250			0.00001				0.023
Elasmo_benthophagous	0.00081	0.00931	0.01560	0.02040							0.046
M_schmitti											0
G_galeus											0
Other_ichthyophagous teleosts	0.00003	0.00069	0.00056	0.00255		0.00103	0.00001				0.005
Other plankt-benthoph. Teleosts	0.00031	0.00071	0.00119	0.00077		0.00181	0.00000				0.005
P_patagonicus	0.00001	0.00006	0.00013	0.00086		0.00003					0.001
M_hubbsi	0.00000	0.00004	0.00001	0.00029							0
T_lepturus	0.00000			0.00001							0
U_canosai	0.00047	0.00314	0.00866	0.00100							0.013
M_ancylodon	0.00002	0.00005	0.00190	0.00028							0.002
C_guatucupa	0.00044	0.00297	0.00751	0.00050		0.00153					0.013
M_furnieri	0.00287	0.00103	0.00472	0.00079		0.00575					0.015
Tunas _2											0
Tunas _1											0
P_saltatrix	0.00008	0.00000	0.00001								0
K_pelamis											0
M_stehmanni											0
T_lathami											0
E_anchoita											0
Benthos_Macro_crust											0
Benthos											0
Zooplankton											0
Phytoplankton											0
Sum	0.00424	0.008838	0.024942	0.007476	0	0.01031	0.000013	0	0	0	0.055818

Estimated F_{MSY} values for the elasmobranchs groups were quite similar to the Ecopath base F estimates (Fig. 2). F_{MSY} and base F estimates were respectively 0.14 and 0.12 year^{-1} for the nektophagous elasmobranchs group, 0.13 and 0.12 year^{-1} for the benthophagous elasmobranchs group, 0.11 and 0.07 year^{-1} for *M. schmitti* and 0.14 and 0.13 year^{-1} for *G. galeus*. The ratios of "MSYs (ecosystem MSY)" predicted when all species are harvested at their F_{MSY} rates, to the "MSYs (single-species MSY)" predicted for each species when all other species are fished at Ecopath base rates, plotted against the species mean trophic level are presented in Figure 3. The trophic level of each species was calculated from Ecopath base diet compositions (Table III) as 1 (base, primary producers trophic level) added to the mean trophic level of the preys (Christensen *et al*. 2005).

High trophic level species had generally a poorer performance in the ecosystem MSY scenario than in the single-species MSY scenario, *i.e.*, had lower yields. Low trophic level groups, conversely, had a better performance in the ecosystem MSY scenario.

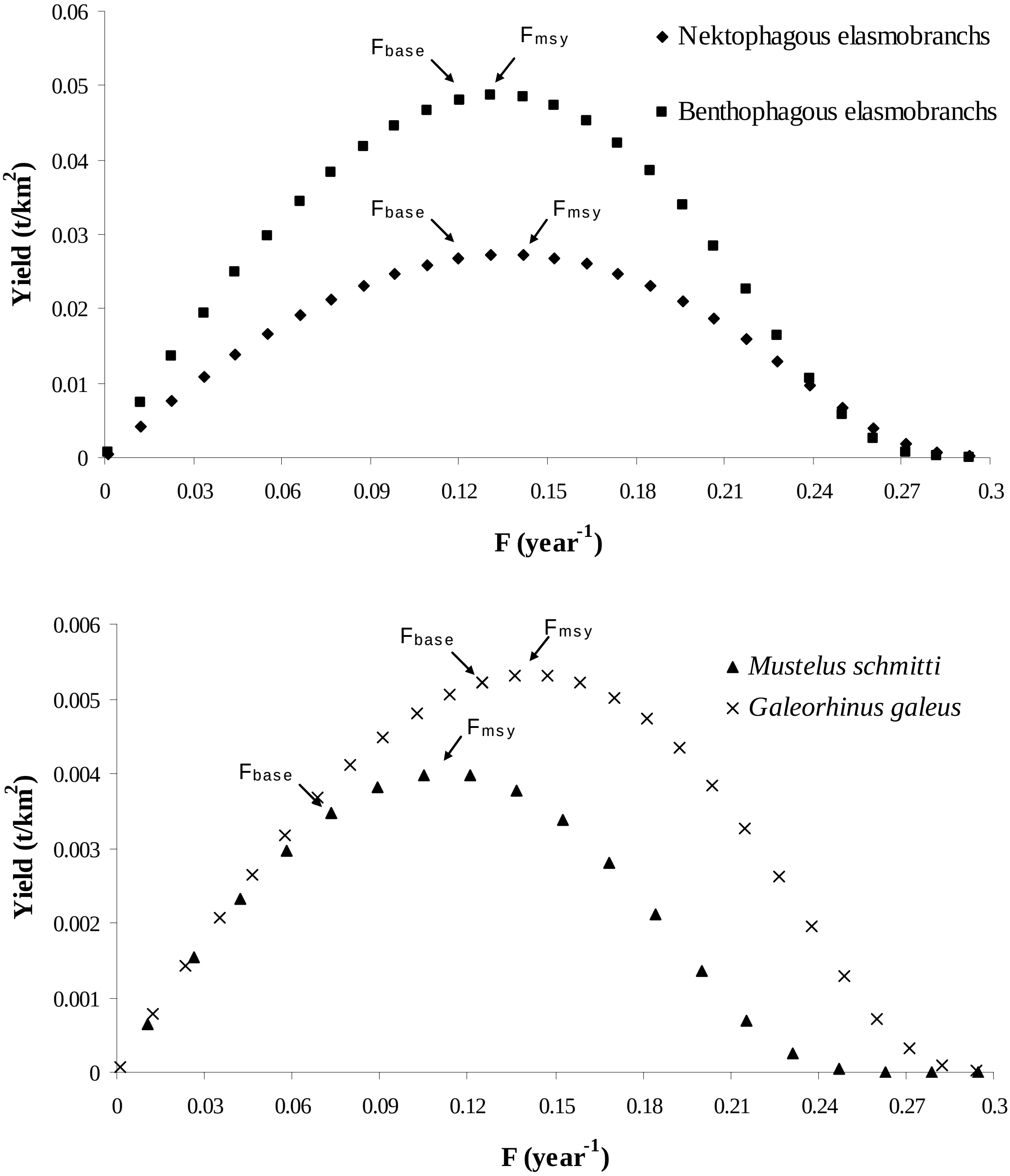

Figure 2 - Estimated base model fishing mortalities (F_{base}) and maximum sustainable fishing mortalities (F_{MSY}) values for the elasmobranchs groups included in the model for Southern Brazil.

The analysis of cross-species MSY impacts, *i.e.* the estimates of the change in ecosystem MSY for a given elasmobranchs group due to reducing the *F* for each group at a time by 10% from the single-species F_{MSY} value, is presented in Figure 4. The effects of changes in other groups MSY on the elasmobranchs groups were not significant. The group that had the biggest effect on the elasmobranchs groups, except *Galeorhinus galeus*, was the benthos macro-crustaceans group, a group composed by shrimps. In the case of *G. galeus*, the benthophagous and ichthyophagous teleosts groups have more impact (negative and positive, respectively).

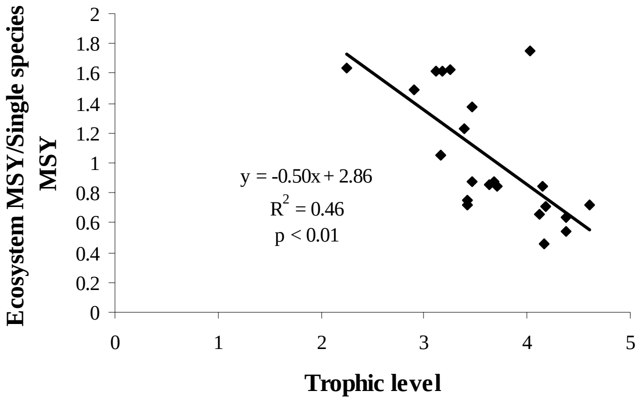

Figure 3 - The ratios of MSYs (ecosystem MSY), predicted when all species are harvested at their F_{MSY} rates, to the MSYs (single-species MSY), predicted for each species when all other species are fished at Ecopath base rates, as a function of the species mean trophic level (calculated from the diet matrix).

When the model was set to optimize the ecosystem structure, a huge decrease in fishing effort was predicted for eight out of 10 fleets (Fig. 5). The other two fleets, namely “live-bait” and “midwater trawl” (a dummy fleet set to simulate anchovy fisheries by Velasco 2004) had their effort increased. The application of this fleet effort configuration in a 20 years simulation led to an increase of 40, 24 and 59% of the initial biomass for nektophagous, benthophagous elasmobranchs and *Galeorhinus galeus* respectively, while *Mustelus schmitti* had its biomass reduced by 3%. This reduction in the abundance of *M. schmitti* seems to be related to relatively high predation pressure exerted on this group by the nektophagous elasmobranches. As the later had its biomass increased, the former was reduced. Among the other groups, the biggest change in biomass occurred for the Tunas_1 group (composed by large tunas and billfishes), a group that was “extinct” in the system under such simulated scenario.

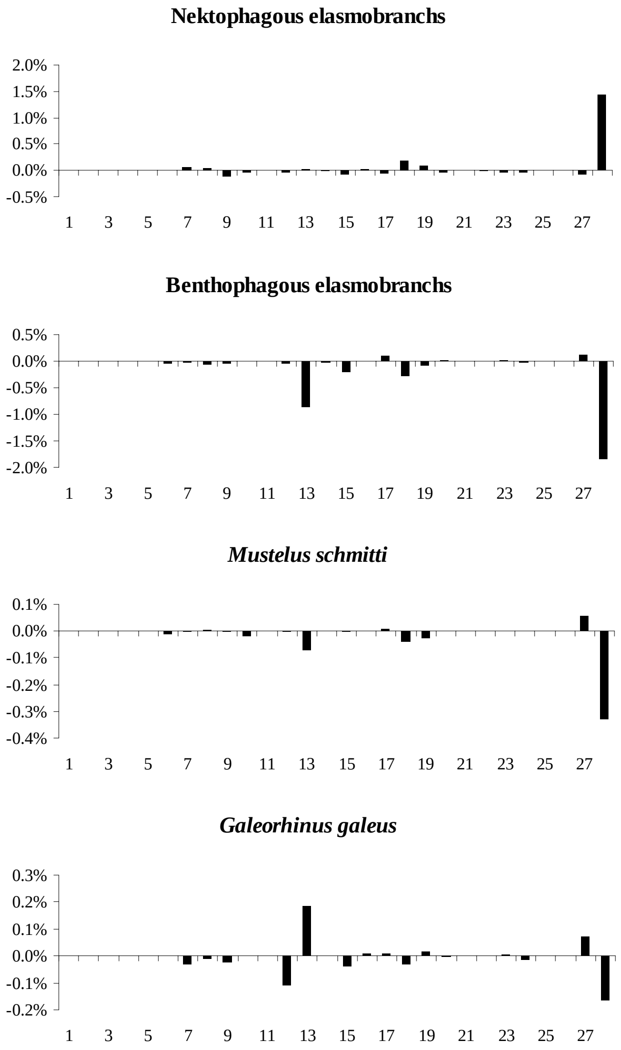

Figure 4 - Cross-species MSY impacts, showing the estimated changes in ecosystem MSY for a given species due to a reduction of 10% in F for each group at a time from the single-species F_{MSY} value (numbers on the x axis correspond to species as detailed in Table I)

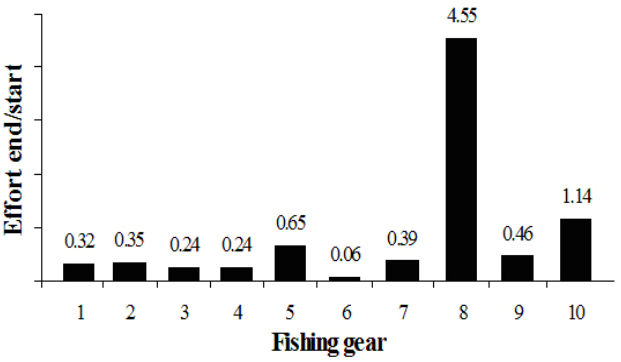

Figure 5 - Changes in fleet effort resulted from model optimization aimed at preserving ecosystem structure. Fleet numbers correspond to: 1) Artisanal, 2) Simple Trawl, 3) Pair-Trawl, 4) Double-Trawl, 5) Purse-seine, 6) Coastal and oceanic gillnets, 7) Long-line, 8) Live bait, 9) Others, 10) Mid-water trawl.

Discussion

The reliability of a model structure, *i.e.*, its capacity to represent a real world system, is totally dependent on the way the researchers build it. This, in turn, obviously influences the output obtained in any simulation performed using such a model.

The elasmobranchs groups, as represented in this model, did not show the supposed degraded state which has been suggested by the decreasing yields they presented in the past decades, since MSY values estimated with Ecosim were quite similar to the initial (input) estimates. Even though, the data incorporated represent, at the present moment, the best available data for these species. Since Vooren (1997) and several authors in Vooren & Klippel (2005) alert about the overexploitation state of several coastal and neritic sharks, skates and rays, it is likely that the landings statistics, and perhaps specially the discards, are highly underestimated and/or underreported. There are indications that unreported landings, mainly associated with finning, may be one important cause of underestimation of shark landings in southern Brazil (Castello, pers. obs.).

In this sense, the base *Fs* in the Ecopath model were already underestimated, producing unexpected and unrealistic output results. Biomass determination studies are highly recommended and needed for this area, especially regarding the elasmobranchs.

It has been shown that in Ecosim, any model's behavior is dominated by the *vulnerability* parameter's settings rather than model structure accounting details (Walters & Martell 2004), and by far this is the aspect that has the strongest effect on model resilience and seems to dwarf the effects of model complexity observed in studies such as that of Pinnegar *et al*. (2005). Information about how abundant a species is relative to its virginal abundance might provide guidance on whether the vulnerability parameter should be high or low (Plagányi & Butterworth 2004, Araújo *et al.* 2006). Where a predator’s abundance is far below its carrying capacity, high vulnerabilities of its prey mean that the predator is capable of inflicting higher mortality, increasing its consumption and thus recovering more quickly.

However, it is advised to estimate the vulnerabilities by fitting the model estimates (*e.g.* biomasses) to observed time series data (Walters *et al*. 2000, Plagányi & Butterworth 2004, Walters & Martel 2004, Christensen *et al*. 2005). Hence, one of the biggest obstacles for the dynamic modeling the continental shelf of southern Brazil ecosystem is the present lack of information on abundance trends of species groups to allow the estimation of the vulnerability parameters that play such a critical role in Ecosim dynamics.

It is clear, nevertheless, that the elasmobranchs groups included in the present model are affected negatively by almost all fishing fleets that operate in the study area, since they showed a clear recovery in the “optimizing ecosystem structure” scenario by reducing overall fishing mortality. So any management strategy must include some effort reduction of these various fleets, an action that has already been advised for the management of other groups (Reis 1992, Vooren 1997, Haimovici 1998, Velasco 2004, Velasco & Castello 2005). Elasmobranchs’ low resilience to fishing is a consequence of their biological features. It should be noted, however, that at the present time, the model is in a preliminary version and a revision of biomass and catches estimates should be performed if the model were to be used for the planning of fishery management strategies.

As widely recognized, ecosystem and multispecies models have the advantage of accounting for trophic interaction and then are able to predict or at least provide warnings against otherwise unknown undesirable or even counterintuitive responses to fishery management actions (Hollowed *et al*. 2000, Fulton & Smith 2004, Walters *et al*. 2005, Velasco & Castello 2005). Walters *et al*. (*op. cit*.) showed that widespread application of single-species maximum sustainable yield (MSY) fishing rates would cause severe degradation of ecosystem structure with loss of top predators. Similarly, Collie & DeLong (1999) and Gislason (1999) have observed that maximizing total yield in multispecies models leads to the elimination of large predators. The results herein presented also lead to the same conclusion, *i.e.* that applying MSY fishing strategies to several species would cause the decrease in abundance of top predators, although the simulated changes were not as dramatic as the reported in some of the above cited studies. In other words, the biomasses of the higher trophic level organisms in this model were higher when applying single-species MSY than in the Multispecies MSY, in Ecosim. The relative resilience of some groups could be partially related to the underestimation of fishing mortalities as discussed above.

The results of the ecosystem structure policy optimizations showed a specialization of the fishing fleet, with some fleet types being almost excluded. This is a common output of Ecosim fishing policy optimization that has been reported in several studies (*e.g.* Pitcher & Cochrane 2002, Christensen &

Walters 2004). The fleets that are kept operating under unprofitable conditions may reduce or eliminate predators and competitors of long-lived species when the optimization routine is used. It is obvious that such fishing fleet structure is not feasible to be employed in a real situation. It has been used here just to identify those fishing fleets that should reduce their operations to allow the recuperation of long-lived species, especially elasmobranchs. A compromise solution, *i.e.*, a solution taking into account economic, social and environmental aspects, should be pursued. Christensen & Walters (2004) performed a detailed analysis of trade-offs of two objectives combined, *i.e.*, profits *vs*. ecosystem, profits *vs*. landed value and ecosystems *vs*. landed value. They found that optimizing landed value is incompatible with profit and ecosystem optimization while optimizing for economic profit is consistent with ecosystem considerations. Particularly, when analyzing the trade-offs between profits and ecosystem functions, they found in the parameter space a region where a clear improvement in profits was achieved, while at the same time the objective function for ecosystem structure was improved by a similar amount and the value of the landings was kept at the baseline level. This kind of results are encouraging and suggest that it is worthwhile to work on the improvement of trophic models to represent the southern Brazil continental shelf system and then allowing the planning of fisheries strategies under an ecosystem perspective.

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