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Assessing the sources of the fishing down marine food web process in the Argentinean-Uruguayan Common Fishing Zone

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SUMMARY: The temporal trend in the mean trophic level (*mTL*), fisheries-in-balance index (FIB), trophic categories landing (TrC) and landing profile (LP) of the exploited marine community (82 species) in the Argentinean-Uruguayan Common Fishing Zone (AUCFZ) were examined from 1989 to 2003. The total landings (Y_t) (rs=-0.561; P<0.05) and the Yt of carnivores and top predators has declined, while the Y_t of herbivores, detritivores and omnivores has increased. Consequently, the *mTL* significantly decreased (rs =-0.88; P<0.01) at a rate of 0.41 from 1991 (*mTL* =3.81) to 2003 (*mTL* =3.4), and the FIB index has declined in the last 6 years. The LP temporal pattern showed four periods with significant differences in their species composition and Primary Production Required, which shows a strong decline in the traditional fishery resources (i.e. *Merluccius hubbsi*, *Micropogonias furnieri*), and increases in crustacean (*Chaceon notilis*), molluscs (*Zygochlamys patagonica*) and some fishes (*Macrodon ancylodon*, *Macruronus magallanicus*, Rajidae). The *mTL* trend reflects the changes in the AUCFZ landing structure. This was characterized by large, slow-growing and late-maturing species during the early 1990s, while during recent years, early 2000s, it was mainly characterized by medium-sized fishes, crustaceans and molluscs. The examination of the *mTL*, FBI, TrC trajectories and LP temporal pattern suggests that new fishery resources are developing or that the fishing effort has been redistributed from overexploited resources to lightly exploited resources. In addition, the examination of discriminator and common species, and the fact that traditional resources are being over-fished support the hypothesis that the *mTL* trend has been influenced more by the impacts of new fishing technologies than the changes in market-driven exploitation and environmental fluctuation. These results provide evidence of the fishing down process along AUCFZ.

Keywords: trophic structure, landing profiles, overfishing, ecosystem management, Argentina, Uruguay.

RESUMEN: EVALUANDO EL ORIGEN DEL PROCESO 'FISHING DOWN MARINE FOOD WEB' EN LA ZONA COMÚN DE PESCA ARGENTINO-URUGUAYA. – La tendencia temporal en el nivel trófico medio (*mTL*), índice de balance de las pesquerías (FIB), desembarques de categorías tróficas (TrC) y perfiles de desembarque (LP) de la comunidad marina explotada (82 especies) en la Zona Común de Pesca Argentino-Uruguaya (ZCPAU) fue examinada entre 1989 y 2003. Los desembarques totales (Y_t) (rs=-0.561; P<0.05) y los desembarques de carnívoros y predadores tope disminuyó, mientras que los desembarques de herbívoros, detritívoros y omnívoros se incrementaron. Consecuentemente, el *mTL* decreció significativamente (rs =-0.88; P<0.01) a una tasa de 0.41 desde 1991 (*mTL* =3.81) a 2003 (*mTL* =3.4), por su parte el índice FIB disminuyó en los últimos 6 años. El patrón temporal de LP presentó cuatro periodos significativamente diferentes en su composición específica y la Producción Primaria Requerida (PPR), con una fuerte caída en los recursos pesqueros tradicionales (i.e. *Merluccius hubbsi*, *Micropogonias furnieri*), y el incremento en crustáceos (*Chaceon notilis*), moluscos (*Zygochlamys patagonica*) y algunos peces (*Macrodon ancylodon*, *Macruronus magallanicus*, Rajidae). La tendencia en el *mTL* refleja cambios en la estructura de los desembarques de la ZCPAU, que fue discriminada por especies grandes, de lento crecimiento y tardía maduración en los inicios de los 90', mientras que durante los años recientes, inicios de los 2000, ellos fueron principalmente discriminados por peces de tallas medianas, crustáceos y moluscos. Las trayectorias de *mTL*, FIB, TrC y el patrón de LP sugieren el desarrollo de nuevos recursos pesqueros o la redistribución del esfuerzo de recursos sobreexplotados a recursos explotados o poco explotados. Asimismo, el análisis de las especies discriminantes y comunes, junto con la sobrepesca de recursos tradicionales, soportan la hipótesis de que la tendencia en el *mTL* ha sido mayormente influenciada por el impacto de nuevas tecnologías de pesca que por cambios en el mercado o fluctuaciones ambientales. Estos resultados evidencian el proceso "Fishing Down" en la ZCPAU.

Palabras claves: estructura trófica, perfil de desembarque, sobrepesca, gestión ecosistémica, Argentina, Uruguay.

INTRODUCTION

Human activities such as fishing and environmental modifications have a wide range of impacts on ecosystems. These impacts are reflected in changes in overall abundance, productivity, and community structure (Hall, 1999; Blaber *et al*., 2000; ICES, 2000; Sinclair *et al*., 2002; Stergiou, 2002). Impacts on fish community structure are widely documented and quantified, including changes in species dominance, slope of the size spectra (e.g. Haedrich and Barnes, 1997; Bianchi *et al*., 2000; Zwanenburg, 2000; Jouffre and Inejih, 2005; Yemane *et al*., 2005), and catch profile (Zwanenburg *et al*., 2002; Sala *et al*., 2004), amongst others. As a consequence, fishery catches have been gradually shifting from long-living and high trophic level species to short-living species located in low trophic levels of the food web. This process has been named "fishing down marine food webs" and has been documented globally (Pauly *et al*., 1998; Pauly and Palomares, 2005) and regionally (Sala *et al*., 2004; Arancibia and Neira, 2005).

The Río de la Plata and adjacent marine waters support one of the traditional fishery activities of the Argentinean and Uruguayan coastal region (Lasta and Acha, 1996; INAPE, 1999). The Argentine trade liberalizing regime in 1989 diversified products and markets and incorporated more efficient technology (Bertolotti *et al*., 2001). As a result, the fishery effort has increased on the Argentina continental shelf (Bertolotti *et al*., 2001) and Northern Argentine Coastal System (NACS), including the Argentinean-Uruguayan Common Fishing Zone (AUCFZ; Carozza *et al*., 2001). During this intensive fishery exploitation period, the NACS fish assemblages showed a relative persistence in the resident species composition (Jaureguizar, 2004; Jaureguizar *et al*., 2006); however, the structure of the assemblages has changed so that it is progressively dominated by younger individuals (Jaureguizar, 2004). Although recent work analyzing the mean Trophic Level (*mTL*) trend, has hypothesized the occurrence of the fishing down marine food web process in AUCFZ (Milessi *et al*., 2005), its sources are not well understood. The *mTL* trend can indicate long-term changes at the community level induced by fishing. In the short and medium term, the trend could be attributed to changes in market demand, fishing technologies, and/or environmental conditions (Caddy and Garibaldi, 2000).

Consequently, the objective of this study was to assess the sources of the fishing down marine food web process in AUCFZ through the relationship between the temporal pattern of landing composition (catch profile) and indirect indicators of that process (mean Trophic Level, Fishing-in-balance index, Trophic categories (herbivores, detritivores and omnivores; mid-level carnivores; high-level carnivores and top predators) and Primary Production Required to sustain fisheries. The *mTL* approach is similar to that of Milessi *et al*. (2005); however, in this study we have added the Argentinean landing data, which represents on average 49.4% of the total landings, plus 20% of years and 37% more species (22 species). In fact, this is the first attempt to estimate the temporal change of the catch profile and the relationship with other indicators of the status of the ecosystem.

MATERIALS AND METHODS

We analyzed the landings (Y_i) and trophic levels (TL_i) of 82 species captured in AUCFZ waters (Fig. 1) to define the temporal pattern in the landing composition and the trend in *mTL* and FIB between 1989 and 2003. These 82 species comprised 85%-98% of the total annual landings in the study period. Landing statistics were obtained from the Annual Statistical Yearbook of the Comisión Técnica Mixta del Frente Marítimo (CTMFM) (Binational Technical Commission for the Maritim Front). Freshwater fish species (e.g. catfish *Pimelodus* spp., characin *Leporinus obtusidens*) and cultured fish species (e.g. Siberian sturgeon *Acipenser baeri*, common carp *Cyprinus carpio*) were not included in this analysis because they inhabit inland ecosystems and/or they are artificially fed. The data set was analyzed as follows:

a) The mean trophic level (TL_j) for a given year j was estimated by multiplying the landing (Y_i) by the trophic levels of individual species/groups i, then taking a weighted mean (Pauly *et al*., 1998). That is,

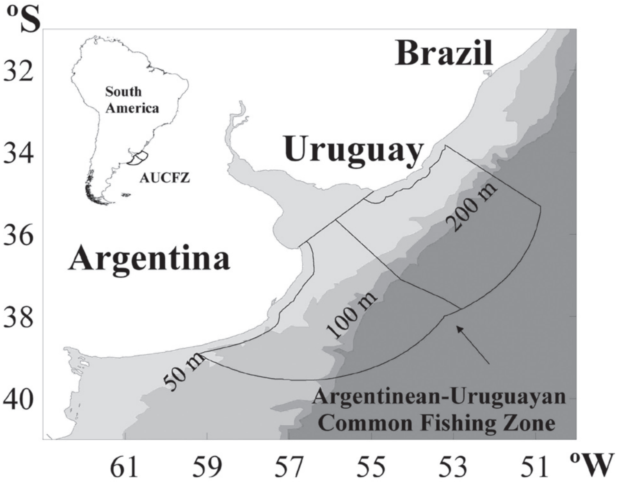

FIG. 1. – Location and bathymetry of the study area.

$$\overline{TL}_j = \frac{\sum TL_{ij} * Y_{ij}}{\sum Y_{ij}}$$

where TL_j = mean trophic level of landings in year *j*; Y_{ij} = landings of species *i* in year *j* and TL_i = trophic level of species *i*. Trophic levels of the 82 species (TL_i) were obtained from FishBase (Froese and Pauly, 2000) (Table 1). In the case of species grouped under a common name in the CTMFM Annual Statistical Yearbook (e.g. flounders), we considered the trophic information for the genus (i.e. *Paralichthys*) as representative of those single species (i.e. *Paralichthys orbignyanus, P. patagonicus,* and *P. isosceles* Table 1). The *mTL* trend was interpreted by plotting the *mTL* against years.

TABLE 1. – List of species used in the analysis. The TL values were derived from Fishbase with the exception of those marked with (a) which were derived from Cortés (1999). TL (Trophic level), CB (Chondrichthyan Benthic), CD (Chondrichthyan Demersal), CP (Chondrichthyan Pelagic), C (Crustaceans), LD (Large Demersal), LP (Large Pelagic), MD (Medium Demersal), MP (Medium Pelagic), M (Molluscs), SD (Small Demersal), SP (Small Pelagic).

Herbivores. detritivores and omnivores (TLC1)			
M	Scallop	*Aequipecten tehuelchus*	a2.00
SP	Brazilian menhaden	*Brevoortia* spp.	2.75
C	Red crab	*Chaceon notialis*	a2.52
M	Cockle	*Donax hanleyanus*	a2.00
SP	Argentine anchovy	*Engraulis anchoita*	2.48
C	Shrimp	*Farfantepenaus paulensis*	a2.52
C	False Southern King crab	*Lithodes santolla*	2.52
MD	Whitemouth croaker	*Micropogonias furnieri*	2.63
MP	Mullet	*Mugil* spp.	2.00
M	Blue mussel	*Mytilus edulis*	a2.00
SP	Silverside	*Odontesthes* spp.	2.57
MP	Parona leatherjacket	*Parona signata*	2.52
C	Shrimp	*Pleoticus muelleri*	a2.40
M	Scallop	*Zygochlamys patagonica*	a2.00
Mid-level carnivores (TLC2)			
DC	Elephantfish	*Callorhinchus callorhynchus*	3.23
MD	Hawkfish	*Cheilodactylus bergi*	3.18
LD	Argentine conger	*Conger orbignyanus*	3.4
SD	South american silver porgy	*Diplodus argenteus*	3.13
SD	Blackbelly rosefish	*H. dactylopterus lahillei*	3.4
M	Squid	*Loligo sanpaulensis*	a3.80
MD	Southern kingcroaker	*Menticirrhus americanus*	3.5
M	Octopuses	*Octopus* spp.	a3.20
SD	Black southern cod	*Patagonotothen* spp.	3.4
MD	Brazilian flathead	*Percophis brasiliensis*	3.49
MP	Chub mackerel	*Scomber japonicus*	3.00
MP	Yellowtail amberjack	*Seriola lalandei*	3.09
MP	Choicy ruff	*Seriolella porosa*	3.41
MD	Common seabream	*Sparus pagrus*	3.4
SP	Falkland sprat	*Sprattus fuegensis*	3.4
High-level carnivores and top predators (TL C3)			
MD	Sea bass	*Acanthistius brasilianus*	4.01
PC	Sandbar shark	*Carcharhinus plumbeus*	4.1
PC	Night shark	*Carcharhinus signatus*	4.5
PC	Sand tiger shark	*Carcharias taurus*	4.5
LP	Dolphinfish	*Coryphaena hippurus*	4.37
MD	Thornfish	*Cottoperca gobio*	4.26
MD	Stripped weakfish	*Cynoscion guatucupa*	3.9
MP	Little tuny	*Euthynnus alleteratus*	3.98
DC	Soupfin shark	*Galeorhinus galeus*	4.21
LP	Butterfly kingfish	*Gasterochisma melampus*	4.35
High-level carnivores and top predators (TL C3) (continued)			
LD	Pink cusk-eel	*Genypterus* spp.	4.34
M	Squid	*Illex argentinus*	4.1
PC	Shortfin mako	*Isurus oxyrhinchus*	4.5
LP	Skipjack	*Katsuwonus pelamis*	4.35
PC	Porbeagle	*Lamna nasus*	4.5
LP	Oil fish	*Lepidocybium flavobruneum*	4.34
SD	King weakfish	*Macrodon ancylodon*	3.9
LD	Grenadier	*Macrourus holotrachys*	3.71
LD	Patagonian toothfish	*Macruronus magellanicus*	3.93
LP	Billfish	*Makaira* spp.. *Tetrapturus* spp.	4.5
LD	Southern hake	*Merluccius australis*	4.45
LD	Argentine hake	*Merluccius hubbsi*	4.08
LD	Southern blue whiting	*Micromesistius australis*	3.79
BC	Southern eagle ray	*Milyobatis goodei*	3.55
DC	Narrownose shark	*Mustelus schmitthi*	3.6
MD	Flounders	*Paralichthys* spp.	3.65
C	Southern King crab	*Paralomis granulosa*	4.5
LD	Black drum	*Pogonias cromis*	3.89
MD	Wreckfish	*Polyprion americanus*	3.89
MP	Bluefish	*Pomatomus saltatrix*	3.83
PC	Blue shark	*Prionace glauca*	4.5
SD	Searobin	*Prionotus sp.*	4.3
LD	Sandperch	*Pseudopercis semifasciata*	3.98
BC	Rays	Rajidae	3.88
BC	Brazilian guitarfish	*Rhinobatos* spp.	3.67
MD	Tadpole codling	*Salilota australis*	3.6
MP	Atlantic bonito	*Sarda sarda*	4.43
SP	Round sardinella	*Sardinella aurita*	4.5
DC	Spotted dogfish	*Squalus acanthias*	4.00
DC	Angel shark	*Squatina* spp.	4.1
LP	Albacore	*Thunnus alalunga*	4.5
LP	Southern Bluefin tuna	*Thunnus maccoyii*	3.93
LP	Bigeye tuna	*Thunnus obesus*	4.3
LP	Others tunas	*Thunnus* spp.	4.5
LP	Yellowfin tuna	*Thunus albacares*	4.45
MP	Snoek	*Thyrsites atun*	3.74
MP	White snake mackerel	*Thyrsitops lepidopoides*	4.5
MD	Plata pompano	*Trachinotus marginatus*	3.74
SP	Rough scad	*Trachurus lathami*	3.99
MP	Largehead hairtail	*Trichiurus lepturus*	4.45
MD	Argentine croaker	*Umbrina canosai*	4.2
MD	Brazilian codling	*Urophycis brasiliensis*	3.79
LP	Swordfish	*Xiphias gladius*	4.5

b) In order to observe changes in the contributions of each group to the total landings (Pauly *et al*., 2002), the exploited species were separated into three trophic categories: herbivores, detritivores and omnivores (TrC1: *TL* 2.0-3.0), mid-level carnivores (TrC2: *TL* 3.01-3.50), and high-level carnivores and top predators (TrC3: *TL*>3.51). Declines in the percentage of higher categories can be a result of the fishing down marine food web process (Caddy and Garibaldi, 2000; Pauly *et al*., 2002).

c) The fishing-in-balance index (FIB, Pauly *et al*., 2000) was used to indicate whether fisheries in AUFCZ are balanced in ecological terms. The FIB index for any year *i* in a series was estimated as follows:

$$FIB = \log (Y_i*(1/TE)^{TL_i}) - \log (Y_0*(1/TE)^{TL_0})$$

where Y_i is the landings in year *i*, TL_i is the mean *TL* of the landings in year *i*, *TE* is the trophic efficiency (here set at 0.10 following Pauly *et al*., 2000), and Y_0 and TL_0 are the landings and mean *TL* of the first year of the series. An increase in FIB indicates expansion of a fishery (geographical or expansion beyond the initial ecosystem to stocks not previously exploited or only lightly exploited) or that bottom-up effects have occurred. Conversely, a decrease indicates geographical contraction of the fisheries or a collapse in the underlying food web leading to the "backward-bending" plots of *TL* vs. Catch, which were originally presented in Pauly *et al*. (1998). Values of FIB<0 may be associated with unbalanced fisheries, i.e. a lower current catch than the theoretical catch based on the productivity of the food web (Pauly *et al*., 2000).

d) Changes in the landing profiles (LP) over time (year groups) were determined using two statistical techniques (cluster analysis and non-metric multidimensional scaling [nMDS]) that allow significant patterns in the data to be identified (Clarke and Warwick, 2001). These methods were carried out using the Bray-Curtis similarity index. Prior to calculating the Bray Curtis index, the landing catches (Y_i) were log (x+1) transformed to reduce the contribution of the more abundant species to *Yt*. Significant differences in catch profiles over time, between year groups identified by Cluster and nMDS analysis, were tested using the Analysis of similarity (ANOSIM, Clarke and Warwick, 2001), whose null hypothesis is no changes in landing profiles between year groups. Significant level and R-statistic values for pair-wise comparisons provided by ANOSIM were used to detect dissimilarity between year groups. R-statistic values near 1 indicate significant differences in species composition, while values near 0 indicate no significant difference (Clarke and Warwick, 2001). Finally, to see the changes in landing profiles over time we identified the species in the landings that were responsible for these differences. For each year group we categorized target species as common (if they contributed to the top 50% of the average similarity within the year group), or discriminators (if they contributed to the top 70% of dissimilarity between year groups, and had a low ratio of average dissimilarity to its standard deviation). The method is based on analyzing Bray-Curtis (dis) similarity matrices derived from year species compositions. Species that on average contributed strongly to the year group were quantified and ranked using the similarity percentage procedure (SIMPER) (Clarke, 1993). This procedure uses the standard deviation of the Bray-Curtis dissimilarity matrix attributed to a species for all species pairs, and compares it with the average contribution of a species to the dissimilarity. In addition, it allows the average contribution of a species to the measure of dissimilarity between time year groups to be quantified (Clarke and Warwick, 2001).

e) The exploited species were also categorized into elasmobranchs (benthic, demersal, pelagic), demersal teleosts (large, medium, small), pelagic teleosts (large, medium, small), crustaceans and molluscs, in order to observe changes in the contribution of each group to the total landings of the defined period in point d).

f) Primary Production Required (PPR, Pauly and Christensen, 1995) to sustain fisheries according to fish categories in each period defined in point d) was estimated as follows:

$$PPR = Y * TE^{(TL-1)}$$

where, *PPR* is the Primary Production Required (gC m^{-2} $year^{-1}$), Y is the landings (gC m^{-2} $year^{-1}$) and *TE* is the mean trophic transfer efficiency between consecutive trophic levels (*TLs*). *PPR* estimates are based on a conversion factor of 0.06 g carbon:1 g wet weight of catches, and on the *TE* per trophic level being 10%. *PPR* is commonly expressed as a percentage of the total primary production (%*PP*). Primary production estimates (min: 112.74; max: 1214.13 gC m^{-2} $year^{-1}$) for AUCFZ (total area: 218718 km^2) were obtained from (Gómez-Erache *et al*., 2002).

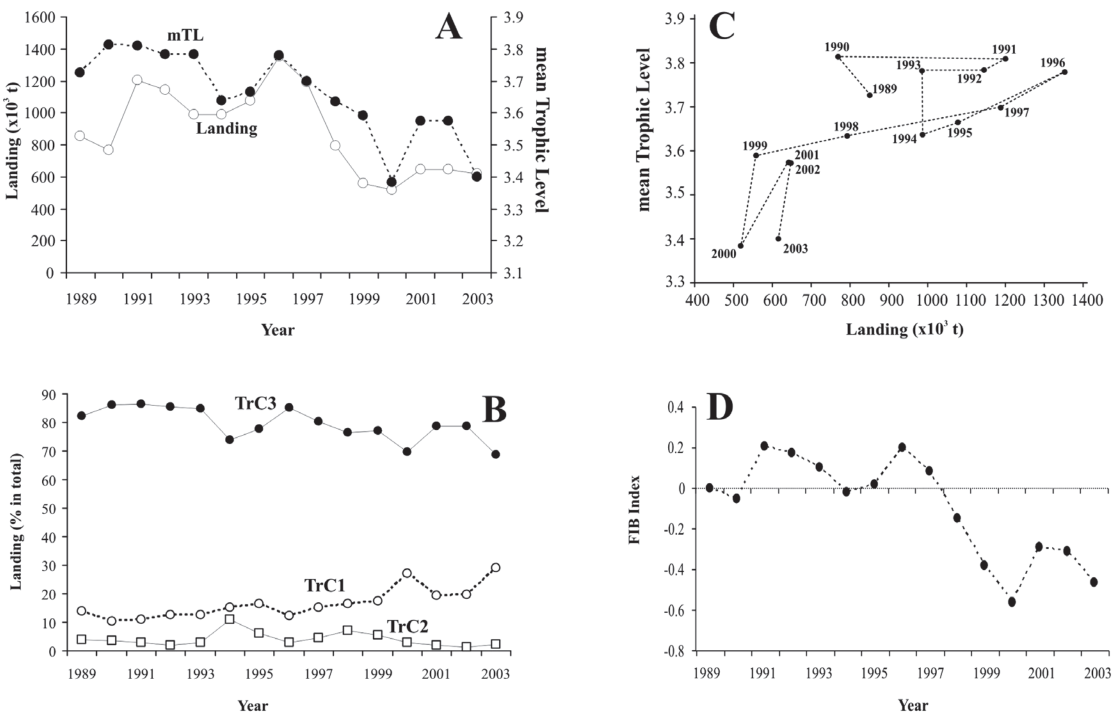

FIG. 2. – Trends in parameters related to fishing the food webs along AUCFZ in the period 1989-2003. A) Landings and mean trophic level (mTL), B) landings according to trophic categories, C) mTL against landings, D) FIB index.

Our estimates could be conservative considering that discards were not included in the calculations, and that part of the catches may have remained unreported in official fisheries statistics. Both unreported catches and discards can cause the footprint of fisheries to be underestimated, and bias the estimated *mTL* of landings, *FIB, LP* and *PPR*.

RESULTS

Temporal trend in landing, *mTL* and FIB index

Landings along AUCFZ increased considerably from 851000 t in 1989 to 1353000 t in 1996 (Fig. 2a). After that the landings decrease constantly and significantly (rs=-0.561; P<0.05) to 616000 t in 2003 (Fig. 2a). The *mTL* of landings significantly decreased from 1989 to 2003 (rs=-0.88; P<0.01) with a decline of 0.03 *TL* year^{-1}. We can observe that the *mTL* has shown a variable decline since 1996 (Fig. 2a). The high-level carnivores and top predators (TrC3) make higher contributions to the total landings than detritivores and omnivores (TrC1) and mid-level carnivores (TrC2) (Fig. 2b). The landings of high-level carnivores and top predators (TrC3) have decreased substantially, and the landings of herbivores, detritivores and omnivores have increased (TrC1) (Fig. 2b). The plot of *mTL* against landings has a signature marked by abrupt phase shifts. The time series tend

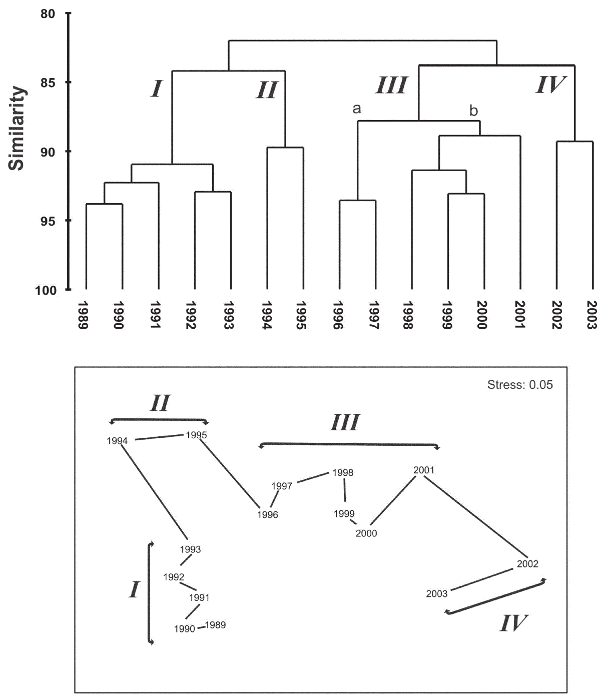

FIG. 3. – Dendrogram of the cluster analysis and nMDS two dimensional diagram showing resulting time blocks.

TABLE 2. – R-statistic values and their significance levels for pair-wise comparisons of species landing composition in the time blocks (ANOSIM).

Time blocks	R statistic	Significance level
1989-1993 vs. 1994-1995	1	0.048
1989-1993 vs. 1996-2001	0.915	0.002
1989-1993 vs. 2002-2003	1	0.048
1994-1998 vs. 1996-2001	0.875	0.036
1994-1998 vs. 2002-2003	1	0.333
1996-2001 vs. 2002-2003	0.865	0.036

to bend backwards and then after 1996 the trophic level and landings decreased together (Fig. 2c). The FIB index showed a variable value between 1989 and 1996 and then a sharp decline to 2000. After this the index continued with negative values (Fig. 2d).

Temporal pattern in landing profile

Four main year groups were delineated at a high similarity level (85%) in the cluster analysis in the landing profile for AUCFZ. The nMDS showed a low stress (0.05), which was sufficient to provide useful representation of the data. In two dimensions it gave the same picture as the dendogram (Fig. 3). The agreement in the results of these two methods confirms the validity of year groups that define a clear temporal trend in the landing composition from 1989 to 2003 (Fig. 3).

The species composition was significantly different between most year groups (ANOSIM, $P<0.05$). Although the time block comparison between 1994-1995 and 2002-2003 did not show significant differ-

TABLE 3. – Average landing (Av. Land., t), percentage of landing contributions (Contr. %) and cumulative percentage of landing contributions (Cum. %) for each species within the time blocks.

1989-1993 Average similarity: 91.83 Species	Av. Land.	Contr. %	Cum. %	1994-1995 Average similarity: 89.91 Species	Av. Land.	Contr. %	Cum. %
Merluccius hubbsi	138672.96	3.95	3.95	*Merluccius hubbsi*	115463.27	4.36	4.36
Micropogonias furnieri	29386.11	3.43	7.39	*Micropogonias furnieri*	45105.76	3.98	8.34
Engraulis anchoita	14900.69	3.21	10.60	*Cynoscion guatucupa*	25044.37	3.76	12.10
Cynoscion guatucupa	15102.33	3.2	13.80	*Engraulis anchoita*	16426.2	3.63	15.73
Paralichthys spp.	6728.12	2.97	16.77	*Cheilodactylus bergi*	16867.3	3.53	19.26
Mustelus schmitthi	6949.33	2.95	19.72	*Mustelus schmitthi*	8427.3	3.33	22.59
Illex argentinus	11132.41	2.87	22.59	*Paralichthys* spp.	7165.91	3.27	25.87
Scomber japonicus	5040.65	2.82	25.42	*Genypterus* spp.	4438.93	3.14	29.00
Percophis brasiliensis	3716.53	2.73	28.15	*Scomber japonicus*	4520.6	3.10	32.10
Acanthistius brasilianus	3415.43	2.73	30.88	*Acanthistius brasilianus*	4143.61	3.08	35.18
Squatina spp.	3043.84	2.69	33.57	*Squatina* spp.	3231.95	3.03	38.21
Genypterus spp.	4336.61	2.64	36.21	*Helicolenus dactylopterus lahillei*	3816.05	2.97	41.17
Helicolenus dactylopterus lahillei	2386.35	2.55	38.76	*Lamna nasus*	3816.05	2.97	44.14
Lamna nasus	2386.35	2.55	41.31	*Umbrina canosai*	3395.37	2.91	47.05
Sparus pagrus	2838.99	2.55	43.85	*Illex argentinus*	3101.8	2.85	49.90
Umbrina canosai	1378.74	2.42	46.27	*Parona signata*	1521.16	2.64	52.54
Pseudopercis semifasciata	1294.23	2.38	48.65				
Sarda sarda	1269.62	2.29	50.93				

1996-2001 Average similarity: 89.4 Species	Av. Land.	Contr. %	Cum. %	2002-2003 Average similarity: 89.48 Species	Av. Land.	Contr. %	Cum. %
Merluccius hubbsi	73564.72	3.47	3.47	*Merluccius hubbsi*	38659.89	3.94	3.94
Micropogonias furnieri	35228.27	3.32	6.79	*Micropogonias furnieri*	33682.67	3.90	7.84
Illex argentinus	26964.67	3.15	9.94	*Engraulis anchoita*	15542.82	3.54	11.38
Cynoscion guatucupa	20616.1	3.13	13.08	*Cynoscion guatucupa*	11252.07	3.51	14.89
Rajidae	7089.1	2.81	15.89	*Aequipecten tehuelchus*	9057.88	3.44	18.33
Mustelus schmitthi	5279.67	2.74	18.63	*Illex argentinus*	15644.54	3.38	21.71
Engraulis anchoita	7576.87	2.74	21.37	Rajidae	9042.74	3.37	25.08
Percophis brasiliensis	5341.1	2.69	24.06	*Mustelus schmitthi*	4239.24	3.12	28.20
Paralichthys spp.	4580.2	2.64	26.71	*Percophis brasiliensis*	3298.6	3.06	31.26
Helicolenus dactylopterus lahillei	3624.35	2.56	29.26	*Paralichthys* spp.	3026.72	2.97	34.23
Lamna nasus	3624.35	2.56	31.82	*Macruronus magellanicus*	14749.86	2.97	37.20
Squatina spp.	2682.37	2.50	34.33	*Umbrina canosai*	2606.25	2.90	40.09
Chaceon notialis	3071.03	2.50	36.83	*Chaceon notialis*	2493.22	2.88	42.98
Cheilodactylus bergi	4089.13	2.46	39.28	*Squatina* spp.	2047.69	2.81	45.79
Umbrina canosai	2931.08	2.46	41.74	*Macrodon ancylodon*	1627.28	2.70	48.49
Aequipecten tehuelchus	8877.37	2.38	44.12	*Helicolenus dactylopterus lahillei*	1290.78	2.63	51.12
Macrodon ancylodon	1613.38	2.31	46.43				
Acanthistius brasilianus	1633.78	2.16	48.59				
Parona signata	937.03	2.12	50.71				

TABLE 4. – Average landing (Av. Land., t) and average landing contributions (Av. Contr. %) of species groups within each time block (Chon, Chondrichthyan).

	1989-1993 Av. Land	(Contr. %)	1994-1995 Av. Land	(Contr. %)	1996-2001 Av. Land	(Contr. %)	2002-2003 Av. Land	(Contr. %)
Benthic Chond	140.4	*(0.9)*	2122.3	*(8.1)*	1890.7	*(10.7)*	2325.2	*(15.3)*
Demersal Chond	2196.9	*(13.9)*	2634.2	*(10.1)*	1815.6	*(10.3)*	1291.9	*(8.5)*
Pelagic Chond	411.42	*(2.6)*	1281.0	*(4.9)*	617.3	*(3.5)*	286.4	*(1.9)*
Crustaceans	60.7	*(0.4)*	881.0	*(3.4)*	630.5	*(3.6)*	504.9	*(3.3)*
Molluscs	1675.1	*(10.6)*	1671.2	*(6.4)*	5197.1	*(29.4)*	3560.6	*(23.4)*
Small Pelagic	2650.0	*(16.8)*	4239.0	*(16.3)*	1363.2	*(7.7)*	2610.0	*(17.1)*
Medium Pelagic	717.9	*(4.5)*	1313.3	*(5.0)*	316.0	*(1.8)*	320.4	*(2.1)*
Large Pelagic	82.9	*(0.5)*	65.3	*(0.3)*	102.4	*(0.6)*	27.1	*(0.2)*
Demersals	7881.3	*(49.8)*	11858.1	*(45.5)*	5766.1	*(32.6)*	4295.3	*(28.2)*

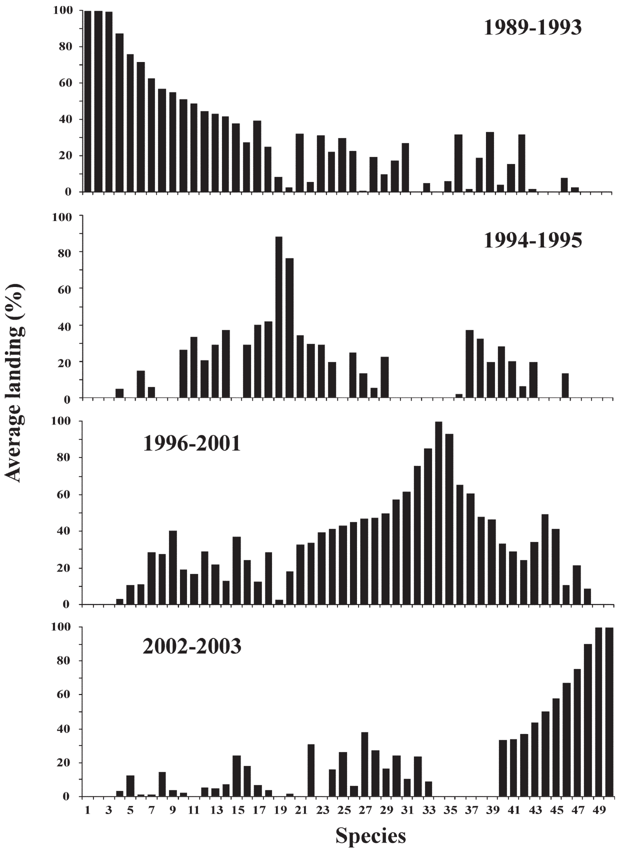

FIG. 4. – Average landings of discriminator species determined using SIMPER for each time block. 1, *Cottoperca gobio*; 2, *Carcharhinus plumbeus*; 3, *Katsuwonus pelamis*; 4, *Sarda sarda*; 5, *Pleoticus muelleri*; 6, *Seriola lalandi*; 7, *Thunnus alalunga*; 8, *Pseudopercis semifasciata*; 9, *Farfantepeneaus paulensis*; 10, *Odontesthes* spp.; 11, *Carcharias taurus*; 12, *Brevoortia* spp.; 13, *Trachurus lathami*; 14, *Scomber japonicus*; 15, *Loligo sanpaulensis*; 16, *Thunnus* spp.; 17, *Genypterus* spp.; 18, *Galleorhinus galeus*; 19, *Thunnus maccoyii*; 20 *Cheilodactylus bergi*; 21, *Thunnus obesus*; 22, *Conger orbignyanus*; 23, *Merluccius australis*; 24, *Xiphias gladius*; 25, *Percophis brasiliensis*; 26, *Diplodus argenteus*; 27, *Chaceon notialis*; 28, *Illex argentinus*; 29, *Menticirrhus americanus*; 30, *Seriolella porosa*; 31, *Octopus* spp.; 32, *Trachinotus marginatus*; 33, *Micromesistius australis*; 34, *Milyobatis* spp.; 35, *Salilota australis*; 36, *Makaira* spp. and *Tetrapturus* spp.; 37, *Lepidocybium flavobruneum*; 38, *Squalus acanthias*; 39, *Thunnus albacares*; 40, *Macrodon ancylodon*; 41, *Mytilus edulis*; 42, *Isurus oxyrhinchus*; 43, Rajidae; 44, *Zygochlamys patagonica*; 45, *Macrourus holotrachys*; 46, *Pogonias cromis*; 47, *Trichiurus lepturus*, 48, *Macruronus magellanicus*; 49, *Patagonotothen* spp.; 50, *Prionace glauca*.

ences, the R-statistic values (R=1, Table 2) indicated a very different species composition. The year groups showed a similarity range between 89.4% and 91.8% (SIMPER, Table 3), and were characterized by several common and diagnostic species (SIMPER, Table 3 and 4).

Year Group *I* defined the period from 1989 to 1993 (Fig 3), with a landing composition average similarity of 91.8% (Table 3), and an average *mTL* of 3.78 (Fig. 2a). The species that most contributed to the similarity of catch landing composition were *Merluccius hubbsi*, *Micropogonias furnieri*, *Engraulis anchoita*, *Cynoscion guatucupa*, *Paralichthys* spp. and *Mustelus schmitti* (Table 3). This time block was mainly discriminated by *Seriola lalandi*, *Katsuwonus pelamis*, *Sarda sarda*, *Carcharias taurus* and *Thunnus alalunga* (Fig. 4). The large demersal species (55.3%), followed by medium demersal species (23.6%), small pelagic species (6.1%), molluscs and demersal chondrichthyans dominated the average landing (Fig. 5). The benthic chondrichthyans and crustaceans made the lowest contribution to the total landing catch. Most of the species groups had the lowest landings during this time block (Fig. 5, Table 4). The primary production required (*PPR*) to sustain catches for this period was 21.803 gC m^{-2} $year^{-1}$, which represents 88.42% (at minimum PP) or 8.21% (at maximum PP) of the total primary production (Table 5).

Year Group *II*, (1994-1995) (Fig. 3), had an average similarity of 89.9% (Table 3) and an average *mTL* of 3.65 (Fig. 2a), *M. hubbsi*, *M. furnieri*, *C. guatucupa*, *E. anchoita*, *Cheilodactilus bergi* and *M. schmitti* were the top common species (Table 3), and these year groups were discriminated by the landing of *C. bergi*, *Thunnus maccoyii* and *Galeorhinus galeus* (Fig. 4). The species groups that contributed most to the average landings were large demersal species (42.6%), followed by me-

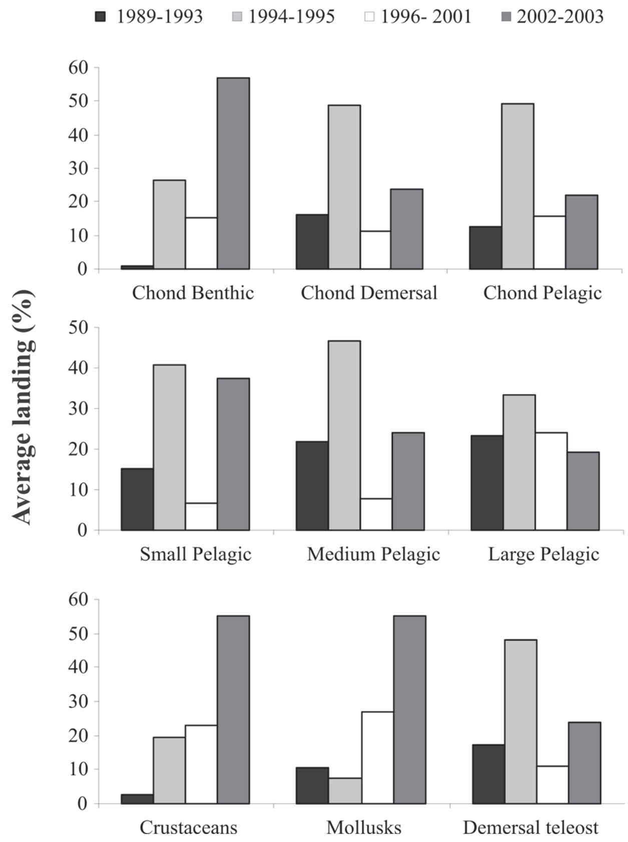

FIG. 5. – Average landing (t in %) of species groups (Chon: chondricthyes; Dem: demersal teleost,) within the main time blocks defined (black, 1989-1993; light grey, 1994-1995; white, 1996-2001; grey 2002-2003).

dium demersal species (30.8%), small demersal species (9.0%), small pelagic species (6.0%) and demersal chondrichthyans (4.7%) (Fig. 5; Table 4). This year group shows a *PPR* value of 23.568 gC m^{-2} year^{-1}, which represents 95.58% (at minimum PP) or 8.88% (at maximum PP) of the total primary production (Table 5).

Year Group *III*, which had an average similarity of 89.4% (Table 3) and an average *mTL* of 3.61 (Fig. 2a), defined the period from 1996 to 2001 (Fig. 3).

It was mainly typified by *M. hubbsi*, *M. furnieri*, *Illex argentinus*, *C. guatucupa,* Rajidae and *M. schmitti* (Table 3). *Myliobatis* spp., *Thunnus albacares*, *Micromesistius australis*, *Merluccius australis*, *Trachinotus marginatus*, *Chaceon notialis* and *Salilota australis* were the main discriminator species (Fig. 4). The landings were dominated by large and medium demersal species, with average landings of 33.6 and 29.6% respectively, followed by molluscs (15.7%) and small demersal species (5.3%) (Fig. 5; Table 4). The *PPR* for this period was 16.739 gC m^{-2} year^{-1}, which represents 67.89% (at minimum PP) or 6.30% (at maximum PP) of the total primary production (Table 5).

This year group showed two subgroups. Subgroup "a", with an average similarity of 93.6%, comprises the years 1996 and 1997, while subgroup "b", with an average similarity of 90.6%, clustered the years between 1998 and 2001. Their landing composition did not show significant differences (P=13.3, ANOSIM), but it did show an average dissimilarity of 11.9%. This dissimilarity was explained by the highest landing of *Myliobatis* spp., *M. australis*, *Scomber japonicus* and *S. australis* during 1996-97, and *Zygochlamys patagonica*, *Macrourus holotrachys* and *Micromesistius australis* during 1998-2001 (SIMPER).

Year Group *IV* (2002-2003), with a landing composition average similarity of 89.5% (Table 3) and an average *mTL* of 3.49 (Fig. 2a), was mainly typified by *M. hubbsi*, *M. furnieri*, *E. anchoita*, *C. guatucupa*, *Z. patagonica* and *I. argentinus* (Table 3). *Macruronus magallanicus*, *Trichiurus lepturus*, *Prionace glauca*,

TABLE 5. – Primary Production Required (gC m^{-2} year^{-1}) to sustain the fisheries and % Primary Production, at the minimum (or maximum) PP value, of species groups within each time block (Chon, Chondrichthyan, Demer, Demersal, Pelag, Pelagic).

	Primary Production Required				% Primary Production			
	1989-1993	1994-1995	1996-2001	2002-2003	1989-1993	1994-1995	1996-2001	2002-2003
Benthic Chond	0.019	0.190	0.330	0.406	0.07 (0.01)	0.77 (0.07)	1.34 (0.12)	1.65 (0.15)
Demersal Chond	0.821	0.985	0.679	0.483	3.33 (0.30)	3.99 (0.37)	2.75 (0.26)	1.96 (0.18)
Pelagic Chond	0.689	1.076	1.034	0.480	2.79 (0.26)	4.36 (0.41)	4.19 (0.39)	1.94 (0.18)
Large Demer	14.078	11.723	7.564	5.543	57.09 (5.30)	47.54 (4.41)	30.68 (2.85)	22.48 (2.09)
Medium Demer	5.108	8.604	6.085	4.521	20.71 (1.92)	34.89 (3.24)	24.68 (2.29)	18.33 (1.70)
Small Demer	0.111	0.221	0.223	0.124	0.45 (0.04)	0.89 (0.08)	0.91 (0.08)	0.50 (0.05)
Large Pelag	0.239	0.137	0.295	0.078	0.96 (0.09)	0.55 (0.05)	1.20 (0.11)	0.32 (0.03)
Medium Pelag	0.477	0.407	0.204	0.209	1.94 (0.18)	1.65 (0.15)	0.83 (0.08)	0.85 (0.08)
Small Pelag	0.190	0.203	0.098	0.187	0.77 (0.07)	0.82 (0.08)	0.40 (0.04)	0.76 (0.07)
Crustaceans	0.001	0.003	0.012	0.009	0.004 (0.001)	0.01 (0.001)	0.05 (0.004)	0.04 (0.003)
Molluscs	0.070	0.020	0.216	0.148	0.28 (0.03)	0.08 (0.01)	0.88 (0.08)	0.60 (0.06)
Total	21.803	23.568	16.739	12.188	88.42 (8.21)	95.58 (8.88)	67.89 (6.3)	49.43 (4.59)

Patagonotothen sp. and *M. holotrachys* were identified as discriminator species (Fig. 4). Large (31.6%) and medium (29.6%) demersal species, followed by molluscs (13.8%), small pelagic species (8.7%) and benthic chondrichthyans (5%) contributed most to the landings (Fig. 5; Table 4). The benthic chondrichthyans, crustaceans and small pelagic species made the highest contribution to this year group's landings (Fig. 5). The large pelagic species had the lowest landings while that benthic chondrichthyans, crustaceans and molluscs had the highest landings during this year group (Table 4). This year group shows a PPR value of 12.188 gC m^{-2} $year^{-1}$ which represents 49.43% (at minimum PP) or 4.59% (at maximum PP) of the total primary production (Table 5).

DISCUSSION

The trend over the past 20 years has been a persistent decline in landings, a decrease in *mTL,* FIB indices and PPR, and a change in the species composition of the fishery landings for the Argentinean-Uruguayan Common Fishing Zone (AUCFZ). The decline of 0.03 *TL* $year^{-1}$ for the AUCFZ landings is higher than the trend of 0.1 *TL* per decade estimated on a global scale by Pauly *et al*. (1998) for the last decades. Our rate of decline was higher than that reported at a local scale by Milessi *et al.* (2005) for Uruguayan waters. It was also higher than other regional fisheries, such as the Mediterranean Sea (Pinnegar *et al*., 2003), Gulf of California (Sala *et al*., 2004), and the upwelling system off central Chile (Arancibia and Neira, 2005). The FIB index showed that before 1996 there was a steady upward trend due to increases in both landings and *mTL*, which suggests that the fisheries were expanding to stocks previously not, or only lightly, exploited. After 1996 FIB shows a stepwise decline, which indicates that the fishery is unbalanced in ecological terms. Large, slow growing predators (TrC3), such us hake (*TL*=4.08) and tuna-like species (*TL*≈4.5), have been largely extirpated and replaced by small, fast-growing forage fish and invertebrates (TrC1). The removal of large predators from marine ecosystems has cascade effects on the food webs (Jackson *et al*., 2001). The trophic categories trend became more significant after 1996. As fishery impacts on key elements of the food webs increase, the upward transfer of production becomes impaired and plots of trophic levels versus catch bend backwards as suggested by Pauly *et al*. (2000). Further, not only has the *mTL* decreased, the structure of the landing profile trend denotes that there were changes in the distribution of trophic levels. These results strongly suggest that the "fishing down process" exists in the study area.

The relationship between the dynamic of fisheries landing composition over time and the fishery behaviour allows us to assess specific causes for the observed trend in the *mTL* and FIB indices. More than a few species have been distinguished in different fishery time periods from 1989 to 2003, defining a clear landing profile pattern. These time periods have shown high similarity in species composition and several species have been identified as common or discriminator species. Most common fish species (i.e. *M. hubbsi*, *M. furnieri*, *M. schmitti*) declined in the landings over time. Some fishes (e.g. *C. bergi*) were an important landed resource during the middle period, and other species, mainly crustaceans (*C. notilis*), molluscs (*Z. patagonica*) and other fishes (*M. ancylodon*, *M. magallanicus*, skates), increased in landings during the last years. Although several common species (n=10) were frequent in all time blocks, the dynamic of fisheries landing composition over time, resulted more from changes in the abundance of uncommon species than changes in the common species, which contributed less than 50% of the temporal variations of the fishery landings. The discriminator species and the temporal landing pattern according to species groups indicate that during the early 90s the fisheries was characterized by catches of large, slow growing and late-maturing species, while during later times, early 2000, the landing profile was mainly characterized by medium-sized fishes, crustaceans and molluscs. Our results clearly indicate that changes in *mTL* reflect changes in the community, and this supports the Pauly *et al*. (1998) hypothesis that the landing data can be used as ecosystem indicators at a local scale.

However, as noted by Caddy and Garibaldi (2000), such a decline in *mTL* of the overall harvest could in some cases be a bottom-up effect due to an increase in nutrients to naturally nutrient-limited marine production systems, even if all levels of the food web are being exploited at a constant rate. In addition, fishing of the food web could be influenced by the impacts of advancements in fishing technologies, and changes in market-driven exploitation (Caddy and Garibaldi, 2000; Stergiou, 2002). Since 1989 as a result of the trade liberalizing regime policy established that year, fishing effort has increased on the Argentinean continental shelf (Bertolotti *et al*., 2001). This led to the highest historical landing of 1372 million t in 1997 and resulted in the exportation rates being doubled from 1990 to 1996. In this period, the fishing industries chose a strategy of diversifying the catches, products and markets, and incorporating more efficient technology, which resulted in unsustainable catch levels (Bertolotti *et al*., 2001).

During the early 90s, in the early stages of fisheries development in AUCFZ, the largest single-species fishery, hake (*M. hubbsi*), influenced not only the total marine landing along AUCFZ, but the mean *mTL* as well. From 1993 to 1997 hake was the most abundant species (in terms of biomass) in AUCFZ. It occupied second position during 1998-1999 and in later years reached third position in abundance during evaluation surveys, with a clear reduction in its spatial distribution (Buratti, 2004). This reflects the observed hake landings along AUCFZ, which decreased from 139000 t in 1989-1993, to 74000 t during 1996-2001, to only 39000 t during the last years (2002-2003). The Chinese market income during 1994 increased the *C. bergi* (Wöhler, 1995), *M. furnieri* and *C. guatucupa* landings (Carozza *et al*., 2001; Lasta *et al*., 2001; Fernández-Aráoz *et al*., 2005), which produced the changes in the landing profile observed in this study. As a consequence of the reduction in hake biomass due to overfishing, during the mid 90s the fishery directed its fishing effort to other fisheries based on coastal species (*M. schmitti* and skates), and austral species (*M. magallanicus*) (Bertolloti *et al*., 2001; Lasta *et al*., 2001; Fernández-Aráoz *et al*., 2005), and during the late 90s on more valuable target species located at low *TL*, such as the red crab *C. notialis*, and the scallop *Z. patagonica* (Lasta and Bremec, 1998; Riestra and Barea, 2000; DINARA, 2003; Gutiérrez and Defeo, 2003). These results clearly indicate that the temporal pattern in the landing profile reflect the changes in the community structure of commercially exploited species, and support the hypothesis that the impacts of improvements in fishing technologies could be more significant in the observed community changes than market-driven exploitation.

Another point to be considered in the *mTL* decrease is the effect of climate on fisheries (Arancibia and Neira, 2005). In the Northern Argentine Coastal System (NACS), between 32 and 41 °S, the regime shifts and the El Niño and La Niña conditions have more influence on the spatial distribution of the fish assemblages than their specific structure (Jaureguizar, 2004). Therefore, changes in the spatial distribution of fish communities could have affected fish susceptibility to the fisheries in AUCFZ and subsequently the *mTL*. However, in this study we do not consider the aggravating effect of a decline in the *mTL* due to a reduction in mean size within species, which is positively related to trophic level (Pauly *et al*., 1998). For example, Jaureguizar (2004) indicated that during intensive fishery exploitation between 1981 and 1999, the NACS fish assemblages changed to a structure which was progressively dominated by younger individuals. This reduction in fish size is related to fishing more than changes in water temperature, since the temperature was almost constant in the study area during that period (Jaureguizar, 2004). Since small individuals tend to have a lower trophic level than large adults (Pauly *et al*., 1998), the decline in *mTL* of the landings in AUCFZ could be greater than reported here.

The present study shows that the fisheries utilized between 95.5% (or 8.88%) and 49.43% (or 4.59%) of the total minimum (or maximum) primary production. This high PPR value corroborates the hypothesis that the AUFCZ fisheries use a large proportion of the productive capacity of the coastal shelf ecosystem. The results indicate a fisheries impact level in the AUCFZ that is comparable to the most intensively exploited temperate shelf ecosystems of the world. Similar systems exhibit PPR values from 24.2 to 35.3% (Pauly and Christensen, 1995), which is from 27 to 53% of the PPR needed to sustain the catches in the southern Brazil shelf (Vasconcellos and Gasalla, 2001), 29% in the North Sea ecosystem (Christensen, 1995) and 36.6% in the Cantabrian Sea (Sánchez and Olaso, 2004). The PPR values estimated decreased ≈55% from the early 90s (1989-1993) to the end of the study (2002-2003). The low PPR value in the last years could be associated with (1) a high level of productivity, (2) large catches at a low trophic level (bivalves, molluscs, crustaceans), and (3) overfishing, which has left the reduced fish biomass unable to use the available production (Pauly and Christensen, 1995). In all periods the major PPR fractions were to sustain the catches of large demersal fish (between 14.078% and 5.543%) and medium demersal fish (between 8.604% and 4.521%). The PPR fractions for sustaining catches of the low trophic level species group (bivalves, molluscs, crustaceans) were less than 1.2%. This result indicates that the decrease in PPR is associated more with overfishing than large catches at low trophic levels.

In conclusion, our analysis shows and strongly confirms that fisheries in AUCFZ have been fishing down the food web as a result of fishery-induced changes rather than other factors (i.e. oceanographic). The overall pattern of shifts in landing profiles, plus the decline in the CPUE of most common species, *Merluccius hubssi* (DINARA, 2003; Renzi and Irusta, 2006) and *Micropogonias furnieri* (Carozza *et al*., 2004; Vasconcellos and Haimovici, 2006), *mTL* and the FIB trend indicate that the fisheries in AUCFZ could have reached an ecologically unsustainable state. Although different management schemes have been applied to AUFCZ (e.g. minimum legal size, quotas by country, seasonal closure zones) they have been insufficient in order to maintain the ecosystem's structure and health. For instance, the implementation of an ecosystem approach to fisheries (EAF, FAO, 2001) seems to be the best alternative to be taken in fishery management in order to rebuild and restore the ecosystem (see Pitcher and Pauly, 1998). EAF needs new models and indicators a well as new tools and methodologies for defining ecosystem reference points and control mechanisms. Although EAF needs much more data than single-species information, and most of this data has yet to be collected, it is possible to adopt some theoretical thresholds from comparative ecosystems that can help in developing a precautionary ecosystem approach (Christensen *et al*., 1996; Latour *et al*., 2003; Pikitch *et al*., 2004; Cury and Christensen, 2005).

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