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Research Article

Using trophic modeling: evaluating fisheries discard effect on the Río de la Plata Estuary and coastal shelf

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ABSTRACT. While fishing discards and bycatch are worrisome for fisheries management, research has been mainly focused on commercial or threatened species, while the ecosystem effects were largely neglected. In this work, the effects of discard and fishing efforts on the structure and the functioning of the food web of the Río de la Plata (RdlP) were analyzed using mass balance and dynamic trophic modeling. Discard is consumed almost entirely by several species with a large preference for it, producing mixed trophic impacts. The role of discard on the global attributes of the RdlP ecosystem does not seem important, resulting in a low incidence in trophic flows, growth, and development of the trophic web. Dynamic simulations showed a mixed response to variations of discards, with some groups responding positively and others negatively. For example, a decrease in discards would produce a slight decrease in the biomass of most functional groups, being more pronounced in the predators of the system. Variations in biomass produced by discards are more sensitive under the assumption of bottom-up ecosystem control than mixed control and to a lesser extent under top-down control. Our work confirms a complex relationship between discards and ecosystem functioning, warning about the beneficial result of discard reduction policies.

Keywords: ecosystem approach; fisheries; discard; Ecopath with Ecosim; Río de la Plata; Uruguay

INTRODUCTION

Discard and bycatch are the main problems produced by marine fishing activities. Discard is considered the portion of the catch that returned to the sea due to economic, legal, or personal considerations. The incidental catch is the retained catch of non-target species captured. At the same time, the term bycatch refers to the summation of discard and incidental catch (Alverson et al. 1994).

Discarding is a common practice in most fisheries worldwide, reaching more than a third of the world's catch (Davies et al. 2009, Zeller et al. 2018). In the late 80s, 27 million tons of fish discards were produced annually (Atar & Malal 2010). However, after major efforts to reduce discard practices, the most recent estimates mention a total volume of 10 million tons (Gilman et al. 2020).

Indeed, that non-target fishing can rise to 40% in some fisheries (Cressey 2015), and the southwest Atlantic (FAO Area 41) had the highest mean discard rate, contributing 7% of the total annual global discards (Pérez-Roda 2019).

Since the beginning of the fishing activity, discards and incidental catches have been generated mainly due to the lack of knowledge of the species' potential for consumption or the inability to select the target species (Hall 1999, Kelleher 2005). Trawl fishing fleets (with less selectivity) cause high impacts across all trophic levels. In contrast, artisanal and recreational fishing causes specific effects that generally affect a minimal number of species (Defeo et al. 2011, Comesaña & Nogueira 2013, Lercari et al. 2015).

Fishing discard is considered morally wrong on many occasions due to the waste of millions of tons of protein thrown into the sea (Hall et al. 2000, Hall &

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Mainprize 2005). It may have strong socio-economic implications and cause negative consequences for the harvested stock and the ecosystem organizational level (Harrington et al. 2005, Tsagarakis et al. 2013, Costello et al. 2020). These negative consequences may reduce fish stocks and alterations in the flow of energy in trophic networks (Tudela 2004, Bellido et al. 2011, Hilborn et al. 2020). In addition, discarding produces changes in the diversity and abundance of species (Bozzano & Sardà 2002, Newsome et al. 2014), with direct consequences on the fitness of individuals, the dynamics and composition of the communities, and their interactions. (Mallol 2005, Fondo et al. 2015).

Decades ago, discarding and incidental fishing was not seen as a relevant problem since it was considered inevitable in the fishing process (Mallol 2005, Arreguín-Sánchez 2011). However, the management objectives currently tend to promote more selective, participatory, and co-managed fishing activities to achieve greater effectiveness and efficiency, favoring discards reduction and bycatch (Carranza & Horta 2008, Gelcich et al. 2009, FAO 2020).

The global trend in fisheries is geared toward implementing ecosystem management (EM), an approach that considers social, political, and economic factors, the technologies used, and the impact they cause on the habitat (Defeo 2015, Sanchirico & Essington 2021). Changing discards rates will potentially impact organisms throughout the food web (Bozzano & Sardá 2002, Bicknell et al. 2013, García et al. 2015). Therefore, the reduction of discards is a primary objective of this management strategy, and the efforts to achieve it have been diverse (Valeiras 2015, Gasco et al. 2018). However, management measures focused on reducing discards "as much as possible" must first consider the trade-offs at socio-economic and ecosystem levels (Heath et al. 2014). Then, the analysis of the effects of fisheries discards should be an integral part of EM. This approach requires evaluations of direct and indirect effects of an activity on individual components, global properties, and the sustainability of ecosystem services (Christensen & Walters 2000, Raby et al. 2011, Fondo et al. 2015).

Models and simulations constitute a common tool used to analyze fisheries management strategies. Its implementation is a complex process; however, there is a large number of articles that apply multispecies modeling to consider the multiple users of the marine ecosystem, seeking to represent the complexity of interactions of natural and anthropogenic origin into an EM framework (Milessi et al. 2010, Arreguín-Sánchez et al. 2015, Vögler et al. 2015). In particular, ecosystem models hypothesize how ecosystems function explicitly through computational algorithms, incorporating ecological, social, and economic variables and processes (Hollowed et al. 2000, Christensen & Pauly 2004, Sturludottir 2018).

In this context, the objective of the present work is to analyze the possible effects that changes in discard rates and fishing efforts would produce on the ecosystem structure and functioning of the estuary of the Río de la Plata and the contiguous Atlantic oceanic shelf.

MATERIALS AND METHODS

Study area

The RdlP estuary is located on the east coast of South America, covering an area of 36×10^3 km^2, forming the second-largest basin on the continent (Framiñan et al. 1999). It is one of the largest estuarine environments on Earth, with high productivity, supporting artisanal and industrial fisheries of Uruguay and Argentina (Acha et al. 2008). Following geographical, environmental, and institutional criteria (Lercari et al. 2009), the study area comprises the outer and middle zone of the RdlP and the adjacent Atlantic coastal platform, with a surface of 70,500 km^2, delimited on the southeast by the 50 m isobath and by the Uruguay-Brazil border on the northeast (Fig. 1).

Fisheries activities and analysis strategy

The fisheries in the study area are carried out by Uruguayan and Argentine small-scale (artisanal) and industrial fleets operating up to 50 m deep, where *Cynoscion guatucupa* and *Micropogonias furnieri* are the main fishing targets (Rey 2010, Marín et al. 2020). There were considered four fishing fleets belonging to Uruguay and Argentina, grouped according to the location of their base port; these fleets operate mainly in the study area.

The fishing fleets considered were: North Buenos Aires artisanal coastal fleet (AA): about 200 artisanal vessels and approximately 10 semi-industrial vessels were considered. They operate mainly on the north coast of the province of Buenos Aires. The information corresponding to catches by fleet comes from Carroza et al. (2004), Colautti & Suquele (2006), and data provided by the Secretary of Fisheries of the province of Buenos Aires (www.sagpya.mecon.gov.ar). Mar del Plata coastal fleet (AI): 14 vessels that have a port in the study area were included (Contín & Colautti 2008). The demersal catch data by species and ports are taken from Carroza et al. (2001). Uruguayan industrial fleet (UI): this fleet operates almost in the entire study area; it is composed mainly of bottom trawling fishing comprising 33 vessels. The catch data for the period 1999

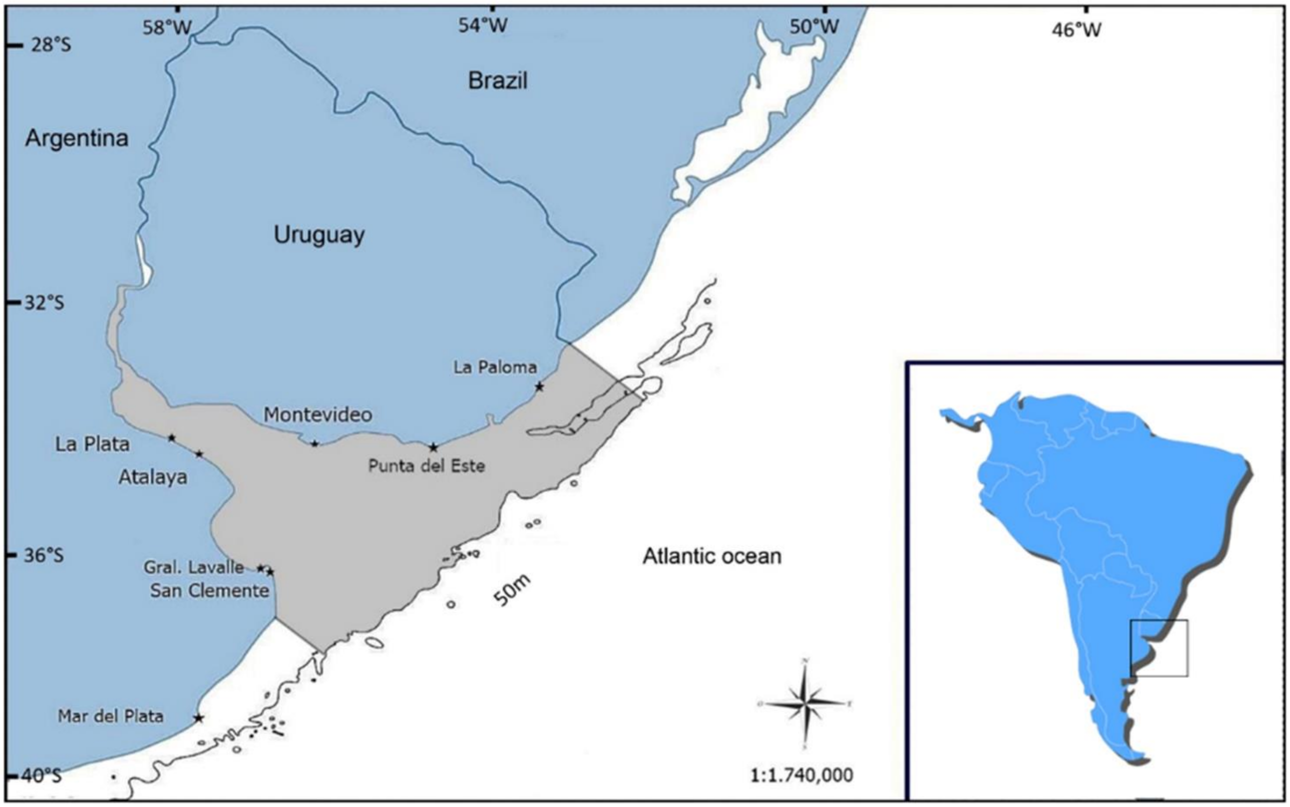

Figure 1. Río de la Plata and its adjacent platform map. The shadow zone represents the modeled area; the stars show the main fishing ports.

and 2000 come from official data from DINARA (www.dinara.org.uy), and for the period 2000-2001 come from the fisheries sector report *(DINARA 2003)*. *Uruguayan artisan fleet (UA): this* small-scale fleet includes 315 vessels with activity comprised 7 nm away from the coast. Data from 48 fishing ports along the coast were used. The catch information is relative to 2002 taken from official DINARA data (www. dinara.gub.uy).

The most important species are mainly whitemouth croakers (*M. furnieri*), Brazilian codling (*Urophycis brasiliensis*) and stripped weakfish (*C. guatucupa*), the argentine hake (*Merluccius hubbsi*), and argentine shortfin squid (*Illex argentinus*) (Rey et al. 2000, Milessi et al. 2005, Horta & Defeo 2012). These species have shown a decreasing trend in their yields since the '80s, showing signs of overexploitation (Pin & Defeo 2000, Defeo et al. 2011).

Trophic models: representation of biomass flows in the ecosystem

The Ecopath approach represents an ecosystem's energy and biomass fluxes (Pauly et al. 2000, Christensen et al. 2008). The mass balance state model is made up of a set of coupled linear equations (Eq. 1) that represent the production of each of the functional groups in the ecosystem and describe the balance between the increase in biomass from production and the losses from predation and exploitation, including fishing (Polovina 1984, Christensen & Pauly 2004):

$$\mathrm{B}i^{*}\,(\mathrm{P/B})i^{*}\mathrm{EE}i = \mathrm{Y}i + \sum_{j=1}^{n} Bj\,(B/Q)j\,\mathrm{DC}ji \quad \text{(Eq. 1)}$$

where *Bi* is the functional group *i* biomass in a given period, for *i* = 1...n functional groups; *(P/B) i* is the production/biomass ratio for *i* (Ricker 1946); EEi is the ecotrophic efficiency (fraction of the production used in the system); *Yi* is the fishing yield for *i*; *Bj* is the biomass of predator *j*; *(Q / B) j* is the consumption/ biomass ratio of group *j*, and *DCji* is the fraction of *i* in *j's* diet. The static Ecopath model is the base for dynamic simulations using the Ecosim model (see below).

This study relies on a previously implemented Ecopath-Ecosim trophic model of the studied area (Lercari et al. 2009, 2014), representing the ecosystem in the period (2000-2006). The basic structure of this model has been used with different modifications to address diverse questions (Bergamino et al. 2012, Vögler et al. 2015). On this occasion, as we specifically seek to analyze the role of discards, modifications to the basic model were made, creating a new group of detritus (discards) to receive the flow of discards produced by the fleet. Information on catches and discard was updated with recent estimates for the study area (Lorenzo et al. 2015). Information by functional groups that make up the structure of the trophic model is shown in Table 1, along with catch and discards estimates for each of the five defined fleets. These represent approximately 10% of the catch in the four fleets considered. Because there is no updated information, the discard values assigned to each fleet were estimated from the percentages calculated by Rey et al. (2000) and subsequently evaluated by Lorenzo et al. (2015). For this research, it is assumed that the discard of the artisanal fleet is negligible compared to the values of the industrial fleets. Finally, it is considered that all the organisms discarded have a mortality rate of 100%, even when they are returned to the sea and have a chance of survival. In the Ecopath model, discards are assigned to a specific trophic group of detritus. Primary input data (B, P/B, and Q/B), including the diet assignation matrix, is provided as Supplementary Files (Tables 1A-2A). Detailed information on the input data sources of the mass balanced model can be found in (Lercari et al. 2014, Vögler et al. 2015).

Mass balance model analysis

Electivity indices measure food utilization about their abundance or availability in the environment. First, the consumption of discard by the diverse trophic groups was assessed, and the electivity of each group for discard was estimated. The electivity index provided by Ecopath (Ivlev 1961) describes a consumer's preference for their prey (in this case, discards). Its scale ranges from -1, which represents the total evasion of the prey, to 1, total preference for the prey (Ivlev 1961).

Trophic structure (trophic levels and biomass of each group) was analyzed, and discards were contextualized. The effects of discard on trophic interactions were evaluated using mixed trophic impacts analysis (Ulanowicz & Puccia 1990). This method makes it possible to observe the type of impact (positive or negative) that each functional group has on the other ecosystem components. Regarding the effects at ecosystem level attributes, the contribution of discards to the total flows of the system (T) and their organization in terms of ascendency, overhead, and development capacity was estimated. Ascendency (A) measures system information derived from information theory (Ulanowicz 1986). It quantifies the activity level and the degree of organization, a key index that characterizes the system's development and maturity (Monaco & Ulanowicz 1997). Because ecosystems cannot grow indefinitely, there is a limit to this growth called the development capacity (DC) (Arreguín-Sánchez et al. 2002). Ecosystems maintain a positive difference between development capacity and the ascendency called overhead. Indirect flows provide limits on the increase in the ascendency and reflect the "reserve strength" of the system, from where they can satisfy unexpected shocks (Ulanowicz 1986). A system with low ascendency and sufficient overhead can respond effectively to the demands of its environment.

Dynamic simulations

The dynamic simulations were conducted using the Ecosim approach. This routine uses the linear equations (defined on Ecopath) as differential equations that define the variation of the biomass of the functional groups with time (Walters et al. 1997, Christensen & Walters 2004). From Equation 1, the temporal dynamic program Ecosim defines a series of differential equations of the type:

$$\frac{dBi}{dt} = (\mathrm{P/Q})i{*}\sum Q\,ji - \sum Qij + \mathrm{I}i - (\mathrm{M}i + \mathrm{F}i + \mathrm{e}i){*}\mathrm{B}i \quad \text{(Eq. 2)}$$

where dBi / dt is the growth during the interval dt of i in terms of BBi; (P/Q) i is the quotient between production and consumption; Mi is natural mortality not caused by predation; Fi is the fishing mortality; Ei is immigration; II is emigration; and Ei × Bi - Ii is the net migration rate. The consumption calculations (Q) are based on the theory of the "foraging arena," The prey is not available all the time, displaying different behavior patterns that make the prey vulnerable or not for predation. Thus, the biomass of i is divided between a vulnerable fraction and a fraction not vulnerable to predators, and the transfer (v) between the two fractions (vulnerable and not vulnerable to predation) is what determines the control of trophic flow between predators and prey (Walters et al. 1997, Walters & Martell 2004).

In this context, the consumption of i from its predators j is defined as:

$$\mathrm{Q}ij = \frac{aij.vij.Bi.Bj.Ti.Tj.Sij.Mij/Dj}{vij+vij.Ti.Mij+aij.Mij.Bj.Sij.Tj/Dj} \quad \text{(Eq. 3)}$$

where *aij* represents the effective search for prey *i* by predators *j*, *vij* is the transfer of biomass between a vulnerable and invulnerable state to predation, *BBi* and *BjB* are the biomass of prey *i* and predators *j*, *Ti* and *Tj* is the relative time used for feeding, *Sij* is the factor defined by a short or long-term environmental function, *Mij* represents a mediating factor, and *Dj* represents the effects of limiting the consumption rate (Walters et al. 1997, Pauly et al. 2000, Christensen & Walters, 2004).

Table 1. Catch and discard values assigned to the four fleets of the Río de la Plata estuary. UA: Uruguayan artisanal, UI: Uruguayan industrial, AA: Argentinean artisanal, AI: Argentinean industrial, expressed as t km^{-2} yr^{-1} corresponding to 2006 data. Total values by 70,500 km^{2}.

Functional group/ Fleet	UA		UI		AA		AI		Total Discard	Total Catch
	Discard	Catch	Discard	Catch	Discard	Catch	Discard	Catch		
Pontoporia blainvillei	0.00023				0.00023				0.00046	
Galeorhinus galeus		0.00185	0.00002	0.00022					0.00002	0.00207
Urophysis brasiliensis		0.00138	0.00009	0.00091					0.00009	0.00228
Genidens + Porichthys		0.00020	0.00025	0.00245		0.00061	0.00012	0.00051	0.00037	0.00378
Flounders		0.00005	0.00011	0.00106					0.00011	0.00111
Squatina guggenheim		0.00064	0.00036	0.00361					0.00036	0.00425
Prionotus nudigulas									0.00000	0.00000
Mustelus schmitti		0.00276	0.00147	0.01475					0.00147	0.01751
Other marine fishes		0.00003				0.00371	0.00074	0.00307	0.00074	0.00682
Micropogonias furnieri adult		0.06722	0.06059	0.60590		0.22349	0.04445	0.18522	0.10504	1.08182
Micropogonias furnieri youth					0.00120				0.00120	0.00240
Rapana venosa										
Cynoscion guatucupa youth					0.00110				0.00110	0.00220
Cynoscion guatucupa adult		0.00303	0.01703	0.17034		0.01947	0.00387	0.01614	0.02091	0.20898
Hard bottom fishes		0.00005	0.00004	0.00044					0.00004	0.00049
Large gastropods			0.00018	0.00177					0.00018	0.00177
Sciaenidae		0.00688	0.00676	0.06763	0.00032	0.00461	0.00092	0.00383	0.00800	0.08295
Rays		0.00010	0.00005	0.00052	0.00027	0.00042	0.00008	0.00035	0.00041	0.00139
Pelagic fishes		0.00244	0.00173	0.01728	0.00142	0.00397	0.00080	0.00333	0.00395	0.02701
Shrimps		0.00047								0.00047
Mytilidae			0.00150							0.00150
Large bivalves				0.01150					0.00115	0.01150
Sum	0.000230	0.092111	0.089837	0.898373	0.004542	0.256285	0.050986	0.212443	0.145596	1.460713

Thus, the interaction between predators and prey is modeled by imposing an exposure limit of the biomass of the prey to the predator, depending on whether the control of trophic flow is dominated by the prey (bottom-up control) or by the predator (top-down control) (Walters et al. 1997, Christensen & Walters 2004). If the vulnerability parameter is high, the interaction between predator and prey depends largely on the abundance of the predator (top-down) since the passage rate from an invulnerable to a vulnerable state is high. On the contrary, if it presents very little vulnerability, the prey mainly controls the interaction (bottom-up).

Simulation scenarios

Four scenarios were simulated for 25 years to evaluate the consequences of changes in discard rates and the increase in fishing effort by the fleets in the area (Table 2). In the first scenario, the combined effects of increased fishing effort and a lineal decrease to 0 of discards were explored. The consequences of the predominance of ecosystem control top-down, bottom-up, and mixed control in the vulnerability matrices were explicitly considered in this case. Thus, the model's sensitivity to this parameter was explored, allowing us to evaluate the interactions and variations of the biomass of different groups under different predator-prey controls.

A linear decrease in discards was simulated in the second scenario, reaching 0 after 25 years of simulations but maintaining the same fishing effort.

In the third scenario, an increase in the fishing effort was simulated as two times its initial value for the industrial fleets and 1.5 times for the Argentine and

Table 2. Description of the 25-year Ecosim simulation scenarios performed changing discard effort and ecosystem control in the Río de la Plata estuary model. UA: Uruguayan artisanal, NA: not analyzed.

	Stage	Discards UA	Effort others fleets	Ecosystem control	
1	Effort increase Discard decrease	Decrease to 0	Increase × 1.5	Increase × 2	bottom-up mixed top-down
2	Discard decrease	Decrease to 0	=	=	NA
3	Effort increase	=	Increase × 1.5	Increase × 2	NA
4	Discard pulse	1 × 3x increase	=	=	NA

Uruguayan artisanal fleets. Discard rates were maintained unchanged.

In the last scenario, a discard pulse was simulated in year 12, multiplying for three times its initial value, i.e. from 0.145 to 0.437 t km^{-2}. The magnitude of the pulse was evaluated to generate relevant changes in the functional groups. To transfer the scenarios to be simulated to Ecosim, 25-year time series corresponding to the simulated period were created in a .csv file replicating the fishing effort and discard patterns mentioned above. This file was imported into Ecosim, defining the series as forcing functions. In the case of fleet changes in the fishing effort, effort data by gear type (data control # 3: forcing) was applied. For the simulation of changes in discards, force biomass (data control # -1: forcing) was applied.

The results of the temporal simulations are presented in two waysfirst, the temporal trajectory of the initial biomasses (Ecopath input values) along the simulated period. Second, analysis of the final biomass/ initial biomass ratio expressed as a percentage of change at the end of the simulation period.

RESULTS

Mass balance model analysis

It was observed that the groups that consumed the most discards were *Otaria flavescens*, seabirds and bentophagous fish, *Urophycis brasiliensis*, Flat fishes, and, to a lesser extent, *Mustelus schmitti* (Table 3). Furthermore, these results agree with the selection index (electivity) for *O. flavescens*, seabirds, *U. brasiliensis*, and flat fishes, close to 1 in these cases. Discards have a TL = 1, as detritus and phytoplankton. Discards interact mainly with top predators, including marine mammals (*O. flavescens*), narrownose smoothhound (*Mustelus schmitti*), and *Squatina guggenheim*, seabirds, and fishes (*U. brasiliensis*) (Supplementary File, Table 2A).

Ecotrophic efficiency values were close to 1 (0.95) for discards, indicating that the discard would be consumed almost entirely in the system; the amount that flows to the detritus or is exported outside the ecosystem is scarce (0.007 t km^{-2}). Regarding the ecosystem statistics derived from the network analysis, specifically referring to discard, the contribution to the ascendency was 1.86 flowbits and development capacity 2.97 flowbits. Their contribution to the total trophic flows (TST) represents 0.0003% and to the growth and development of the trophic web 0.003% (ascendency).

Table 3. Consumption and electivity values for major consuming discard in the ecosystem of the Río de la Plata estuary.

	Consumption (t km^{-2} yr^{-1})	Electivity
Otaria flavescens	0.0163	0.9434
Seabirds	0.0692	0.9688
Urophycis brasiliensis	0.0148	0.9385
Flounders	0.0257	0.7222
Mustelus schmitti	0.0124	0.3184

Discards represent 10% of the total catches estimated at 1.46 t km^{-2} yr^{-1}, of which 61.56% correspond to the UI, and 6.3% to the UA, the AA represents 17.56% and the AI 14.58%. Mixed trophic analysis showed that a positive impact of the discard is observed mainly on seabirds, *O. flavescens*, the flat fishes, *U. brasiliensis*, and, to a lesser extent, *S. guggenheim*. The negative impacts were produced on functional groups of the genus *Genidens* and *Porichthys* (fraile, white sea catfish, and lucerna), *Galeorhinus galeus*, and to a lesser extent on various groups of commercially important fish (*Micropogonias furnieri* and *Cynoscion guatucupa*) (Fig. 2).

Dynamic model analysis

Increase in fishing effort and decrease in discards

In the first scenario tested, the increase in fishing effort and the decrease in discards were jointly evaluated under three vulnerability values (ecosystem control). At a general level, it was shown that the type of ecosystem

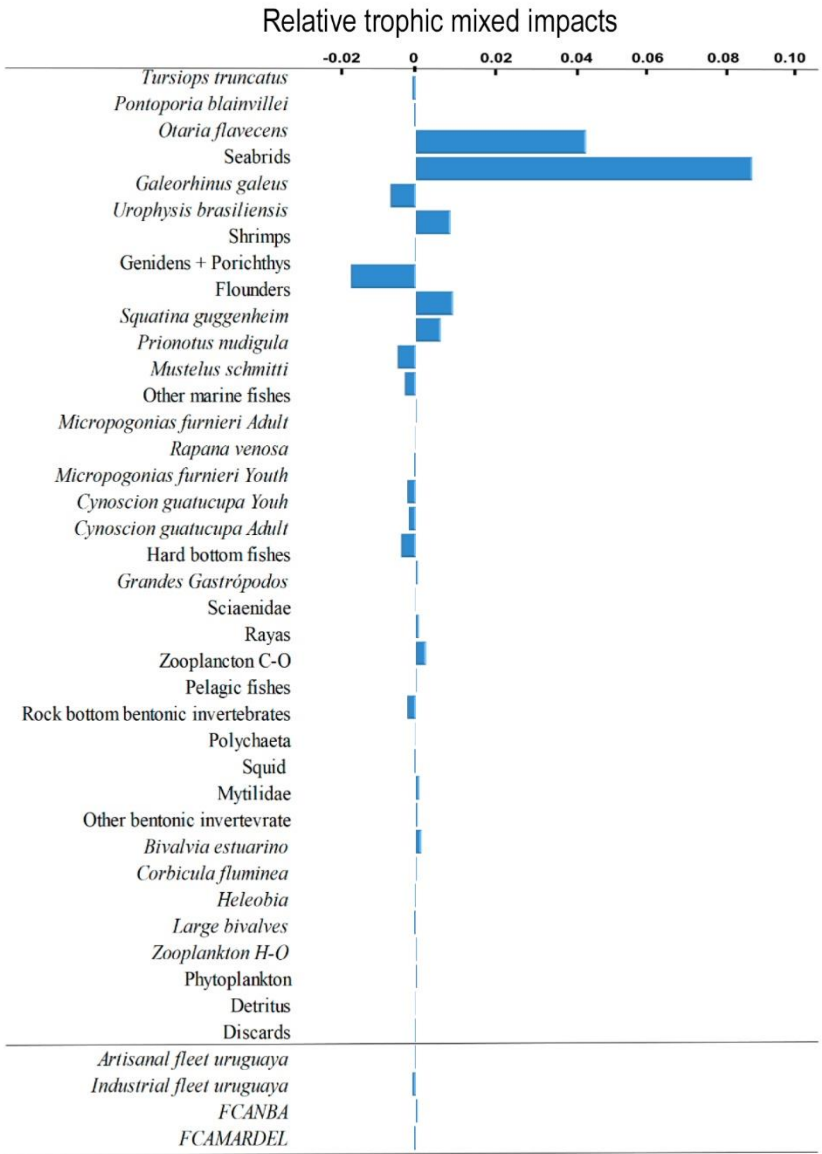

Figure 2. Mixed trophic impacts in the Río de la Plata estuary and its adjacent shelf. The bars quantify the direct and indirect trophic impact of fisheries discards. FCAMDEL: Mar del Plata coastal fleet, FCANBA: artisanal fleet of the north of Buenos Aires.

control largely influences the behavior of functional groups. Changes in biomass are more pronounced under the assumption of ecosystem control bottom-up than under mixed and top-down (Fig. 3). A decrease in the biomass of all the groups evaluated was observed in the case of top-down control. Such decrease is more evident in the functional higher trophic level groups *(Pontoporia blainvillei* and *Tursiops truncatus*) and some fishery target species such as *M. furnieri* and *U. brasiliensis*. Under the mixed ecosystem control, the general tendency is to decrease the biomass of most functional groups. However, this decreasing tendency is less pronounced than in top-down control. As an exception to these behaviors, the *U. brasiliensis* group would remain almost stable and recover its initial value at the end of the simulation. In the simulation under control bottom-up, it would produce, as in the other situations, a decrease in biomass at higher trophic levels (seabirds, *P. blainvillei*, and *T. truncatus*).

On the other hand, the decrease in the biomass of *M. furnieri* is notable. Under this control type, it is simulated that there would be no variations in the biomass of the group "other marine fish" (e.g. *Conger orbignyanus*, *Merluccius hubbsi*, and *Percophis*

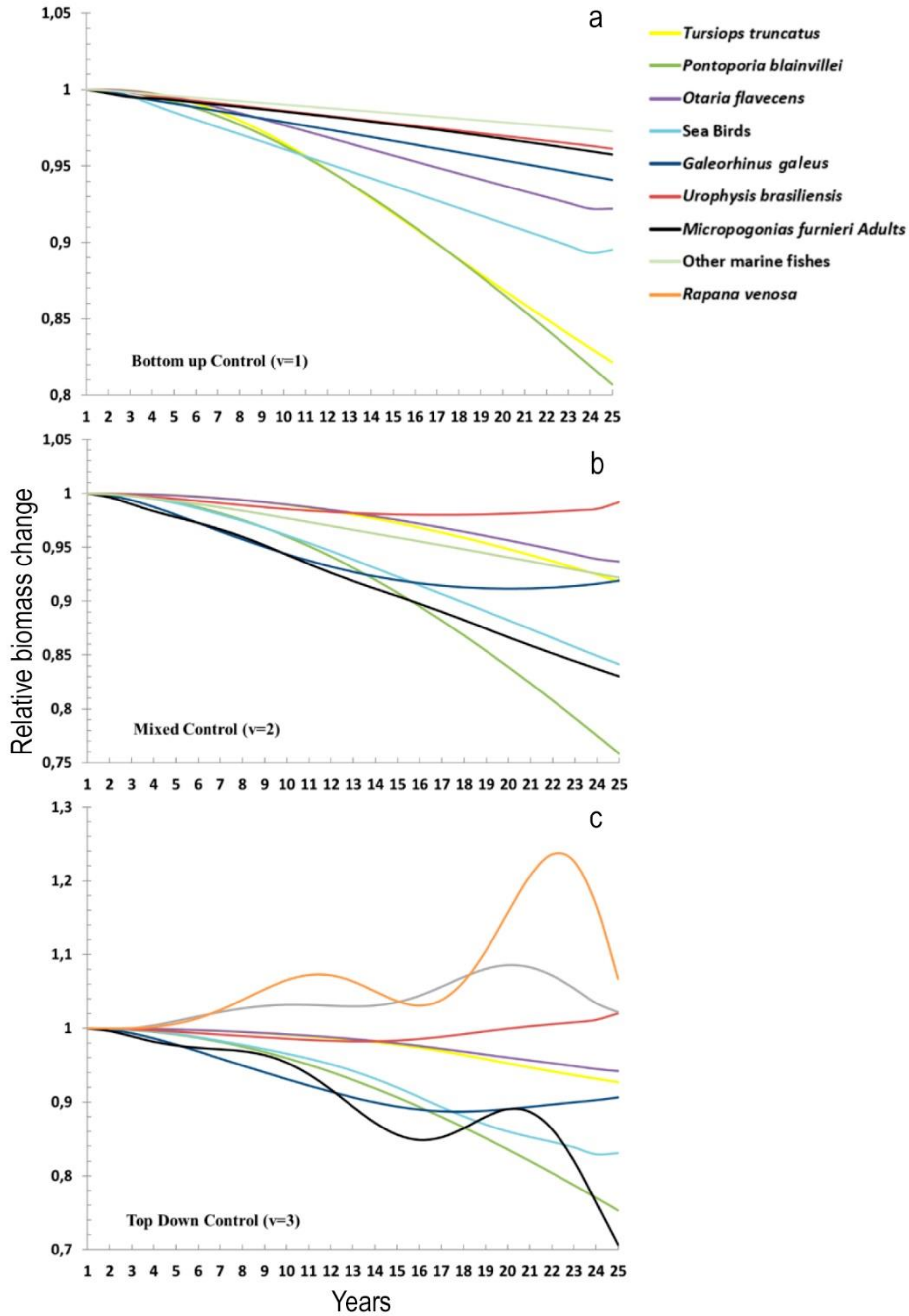

Figure 3. Results of the Ecosim scenario: effort increase, discard decrease. The y axis shows the changes in biomass relative to the initial year under the three ecosystem controls. a) bottom-up, b) mixed, and c) top-down. The figure only shows the functional groups that present a remarkable variation in their biomass.

brasiliensis), which is observed under the previous controls. There are also variations in the biomass of species at intermediate levels that are not present in the previous scenarios. For example, *Rapana venosa* would present an oscillating increase in its biomass with maximum amplitude in year 22 and *M. schmitti*, a minimum tendency to increase its biomass.

Zero discard

In the second scenario, the gradual decrease to zero of the discards would produce a linear increase in the biomass of two functional groups, squids and *M. schmitti*. However, several groups showed a decreasing trend under this scenario (e.g. *P. blainvillei*, in juveniles of *M. furnier*i, in seabirds, members of the group "other marine fish", *T. truncatus)* (Fig. 4).

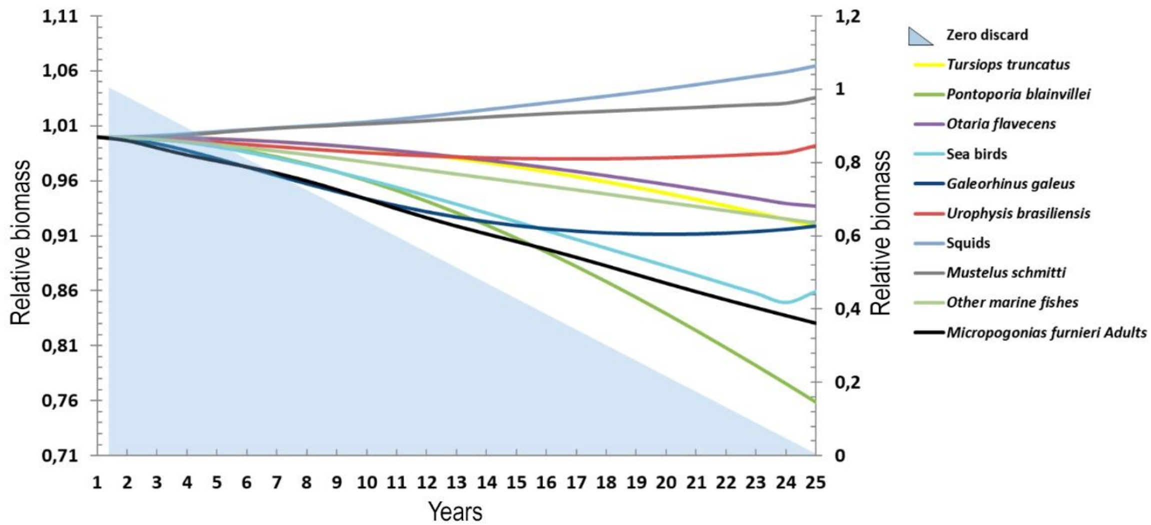

Figure 4. Results of the Ecosim scenario: discard decrease. The values of the changes in relative biomass during the simulation are represented on the left y-axis. The relative biomass of discard (shadowed area) changes is represented on the right y-axis. The figure only shows the functional groups that present a notable variation in their biomass (shadow area).

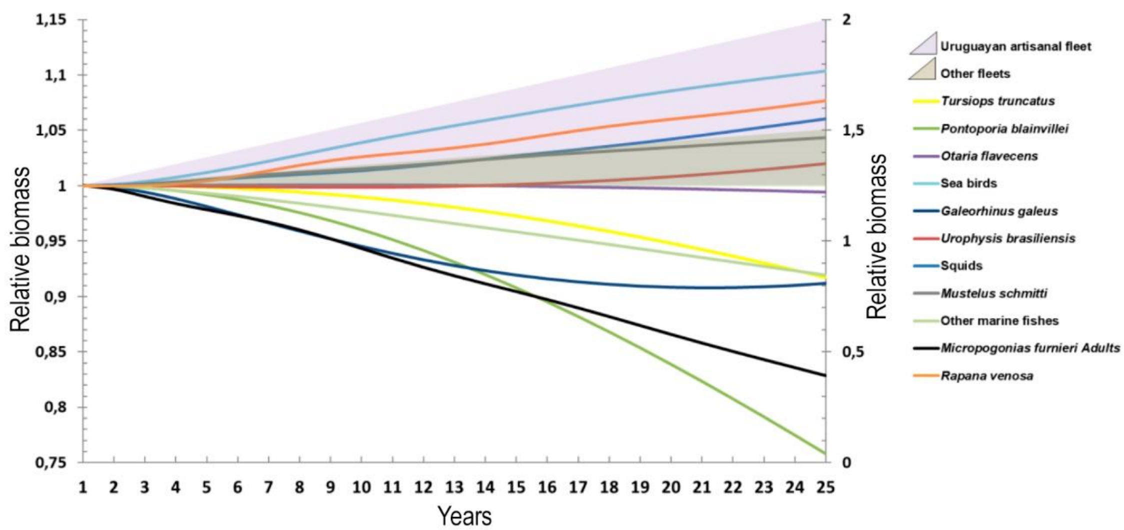

Figure 5. Results of the Ecosim scenario: increase in fishing effort. The values changes in relative biomass during the simulation are represented on the left y-axis. The changes in the relative biomass of fishing effort are represented on the right y-axis. The figure only shows the functional groups that present a remarkable variation in their biomass.

Increased fishing effort

The third scenario produces the increase of some groups and the decrease of other ecosystem components such as seabirds and *M. schmitti*, invertebrates, squids, *R. venosa*, and to a lesser extent, *U. brasiliensis* would show an increasing trend in their biomass. However, a downward trend in biomass would occur in *P. blainvillei*, adults of *M. furnieri* (Fig. 5).

Discard pulse

In the final scenario, as a discard pulse occurs, an increasing trend can be observed in the main top predators of the model, where *O. flavescens* would increase its biomass in one year, after which it would decrease steadily until reaching its initial value near the end of the simulation, spreading its effect for more than 10 years. On the other hand, *P. blainville*i would present a minimal increase, tending to keep that increa-

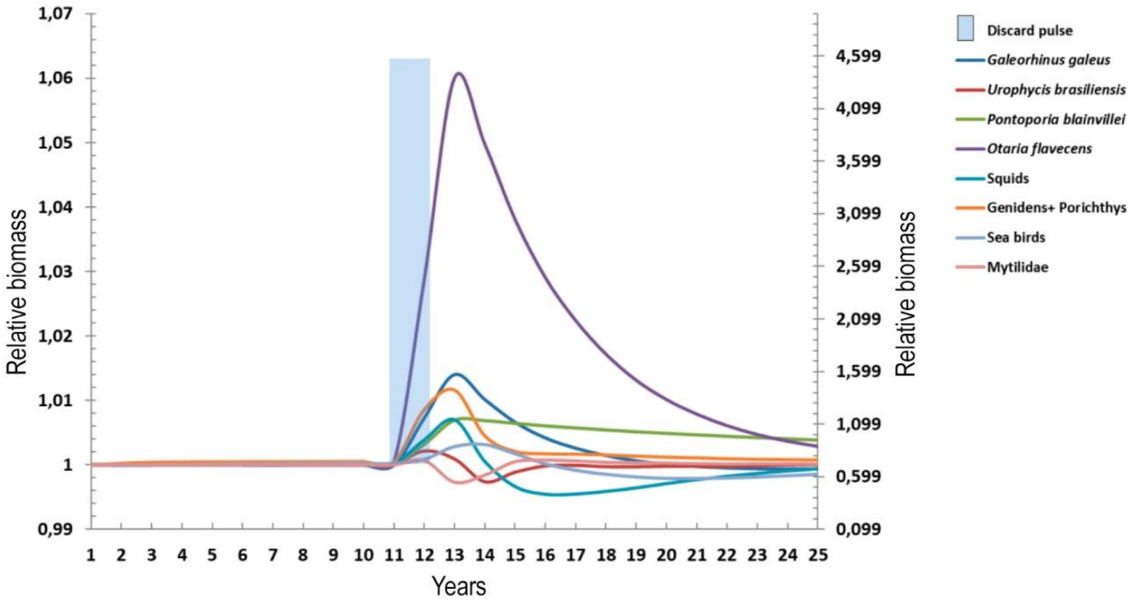

Figure 6. Results of the Ecosim scenario: discard pulse. The values of the changes in relative biomass during the simulation are represented on the left y-axis, and the changes in the relative biomass of discard pulse (shadowed area) are represented on the right y-axis (shadow area). The figure only shows the functional groups that present a remarkable variation in their biomass.

se constant during the remaining 11 years of the simulation. *G. galeus* would present an increase, recovering its initial biomass eight years after the pulse. The squid group will show an increase in the two first years, after which it would decline below its initial value. Regarding the Mytilidae and *U. brasiliensis* groups, they also show a slight decrease in their biomasses after the pulse, for three and four years, respectively, after which they recover their initial value, remaining stable during the rest of the simulation (Fig. 6).

DISCUSSION

In this work, the role of discard on the Río de la Plata (RdlP) estuary ecosystem and its adjacent shelf was evaluated for the first time. The dynamic simulations showed that some groups respond positively and others negatively to the presence of discard. A decrease in discards would produce a slight decrease in most functional groups' biomass, being more pronounced in the predators of the system. Variations in biomass of the ecosystem are more sensitive under the assumption of bottom-up control than under the assumption of mixed control and, to a lesser extent, under top-down control.

Mass balance model

Regarding the role on the ecosystem, although the discard rate is similar to the reported in other marine regions (e.g. Baltic Sea: Zeller et al. 2011; North Sea: Catchpole et al. 2005, Johnsen & Eliasen 2011; and the Mediterranean: Tsagarakis et al. 2013, Piroddi et al. 2015), for the RdlP estuary the influence of discard on the flows and organization of the trophic network (e.g. ascendency) does not seem to be relevant.

The upper and intermediate trophic levels mainly consume the proportion of discard that reaches lower compartments of the system or is exported from the system is scarce. This consumption in upper and intermediate compartments is related to the species' trophic preferences and intrinsic properties of the discard (e.g. does not move to escape consumption) and its flow through the water column. However, fishing discards in our study area seem to be a factor of direct importance for some of the predatory groups (Votier et al. 2004, Galli 2007, Soriano et al. 2016) and some fishing target species (Rey 2000, Dato et al. 2006). Mixed trophic impacts analysis highlight that the effects produced by fishing discards are more pronounced on some components of the system (*Otaria flavescens*, flounder), and there is almost no impact of discards on the fishing fleets (Fig. 2). These observations reaffirm other results that demonstrate the incidence of discards as an easily accessible food source for various marine species (Oro et al. 2013, Fondo et al. 2015, Karris et al. 2018).

Dynamic model

Increase in fishing effort and decrease in discards

In a scenario of increased fishing effort and decreased discards, most groups would generally decrease their biomass; however, the magnitude of change in biomass depends on the type of ecosystem control assumed (Pauly & Palomares 2002). The changes in biomass are more pronounced under bottom-up control than under the assumption of mixed control and, to a lesser extent, under top-down control (Coll et al. 2009).

Tursiops truncatus presents the greatest decrease in its biomass; this species would decrease its biomass mainly due to increased fishing effort. However, combined interactions between discard and effort would also explain the trend (Chilvers & Corkeron 2001, Fruet et al. 2012). Separately these discards and efforts generate similar values in the decline of this species (Figs. 5-6). Considering the other cetacean, *Pontoporia blainvillei* presents a sustained tendency to decrease biomass regardless of the control type. Similarly, previous research (De María et al. 2012) agrees that artisanal fishing is the greatest pressure on these populations (Praderi 2000, Silveira et al. 2018). Also, two important commercial fish species (*Urophysis brasiliensis* and *Micropogonias furnieri*) show a decreasing trend throughout the simulation period, likely related to increased fishing effort (Arena & Rey 2000). However, the possible effects of a decrease in discards (Denadai et al. 2015) on which both species partially feed should also be considered. *Rapan venosa* shows a considerable increase in biomass (particularly in a bottom-up setting). An exception in this scenario, This behavior may directly or indirectly influence the decrease of *M. furnieri* since they present a significant degree of niche overlap that could lead to competition (Lercari & Bergamino 2011, Brugnoli et al. 2014).

Reducing discards has ecological effects on the food web by reducing the food supply at several trophic levels. Simulating the elimination of discards agrees with Fondo et al. (2015) research. In our study area, primary producers (phytoplankton) and benthic invertebrates with low trophic levels have key groups for the ecosystem (Lercari et al. 2014). Therefore, these trophic interactions show that bottom-up mechanisms play an important role in the estuary of the RdlP and its platform (Vögler et al. 2015).

Zero discard

Under a zero discard scenario, some large predators in the system (*O. flavecens*, *P. blainvillei*, and seabirds) would decrease their biomass because they would use fish discards as freely available food (Oro et al. 2013). Consistent with other studies, it is not observed that these generalist species can show a rapid recovery of their biomass (Fondo et al. 2015) once the discards have been removed. This recovery is observed in *Galeorhinus galeus*, probably directly due to its trophic preferences (Rey 2005), since some of its prey increases in biomass (e.g. squids). Commercial fish species, *M. furnieri,* would show a major decrease in biomass under a zero discard situation. The lack of increase in the biomass of the groups belonging to lower trophic levels may be related to the fact that there is greater pressure from their predators and, in turn, that lower-level groups do not use discard as food (Heath et al. 2014). The exception is the squid group, which presents a considerable increase in its biomass compared to the rest of the groups. Although these statements need another type of research and analysis, this result may be due to their pelagic behavioral and foraging habits (Brunetti & Ivanovic 1992). However, these statements need another type of research and analysis (Heath et al. 2014).

Increased fishing effort

Under an increasing fishing effort scenario, the model predicts contrasting results in functional groups of different trophic levels. There is a tendency to increase the relative biomass of seabirds, *R. venosa*, squids, *Mustelus schmitti*, and to a lesser extent, *U. brasiliensis*. The behavior of commercial species *U. brasiliensis* and *M. schmitti* (i.e. no decrease in its biomass under increasing effort) may be related to the fact that fishing effort does not necessarily lead to a higher percentage of objective catch (Vasconcellos 2007, Coll et al. 2008).

For example, using age-structured biomass models, an increase in mortality can lead to an increase in juvenile biomass through the regulation of reproduction. At the same time, it can increase adult biomass through regulation of maturation (De Roos et al. 2007), which may have direct community consequences because it benefits predator populations that prey on the different life stages. The former could indicate overcompensation mechanisms in these species (Ohlberger et al. 2011).

On the other hand, the highly exploited *M. furnier*i presents a considerable decrease in its biomass, a direct consequence of the increase in fishing pressure since it is the main fishing target of the different fleets. However, the trend may also be influenced by the increase in the biomass of *R. venosa* because this species can generate some overlap effect of the trophic niche (Lercari & Bergamino 2011, Brugnoli et al. 2014). On the other hand, the large predators of the system (*T. truncatus*, *P. blainvillei*, and *G. galeus*) are negatively affected by the increase in fishing effort, as evidenced by previous research (Rosas et al. 2002, Seabra 2018). However, *O. flavescens* and seabirds do not decrease their biomass, possibly because they are species that are not targeted for fishing (Bergamino et al. 2012, Votier et al. 2013). Nevertheless, there are negative interactions between these species and fishing activities that are widely documented (Bicknell et al. 2013, Bombau & Szteren 2017).

Discard pulse

When simulating a pulse in the fisheries discards, the main top predators of the model are immediately positively influenced. These results are consistent with previous research (Hall et al. 2000, Bicknell et al. 2013), which could reflect the incidence of anthropogenic-induced changes in the diets due to the easily accessible food observed on *O. flavescens* and seabirds (Bicknell et al. 2013, Calado et al. 2018, Machado et al. 2018, Szteren et al. 2018). Likewise, some bottom-related groups (such as the *Genidens* + *Porichthys*) tend to increase their biomass, possibly because not all the discard is consumed in the water column and reaches these species at the bottom, forming part of their diet (Stagioni et al. 2012). However, the group's increase in flounder and *U. brasiliensis* is low, presumably due to the trophic pressure exerted by their predators (*O. flavescens, G. galeus*) (Romero et al. 2011), which did show an increase in their biomass.

CONCLUSIONS

The role of discard on the global attributes of the estuary of the RdlP estuary ecosystem does not seem noticeable, resulting in a low incidence in trophic flows, growth, and development of the trophic web. However, discard can be a factor of direct and indirect importance for some of the top predators of the RdlP. The greatest positive effects of fishing discards occur on seabirds, *O. flavescens*, and *U. brasiliensi*s. The negative impacts were produced on functional groups of the genus *Genidens* and *Porichthys* (mochuelo and lucerna), *G. galeus*, and to a lesser extent on various groups of commercially important fish. Dynamic simulations indicate that the decrease in fishing discards would have, consequently, a slight decrease in the biomass of most functional groups, being more pronounced in the predators of the system. In the simulations, the variations in biomass are more sensitive under the assumption of ecosystem control bottom-up than under the assumption of control mixed and, to a lesser extent, control top-down.

Perspectives

Our analysis hopes to contribute to understanding the role of the discards on the ecosystem. Still, our model predictions should not be considered infallible forecasts because of internal (model) constraints and weakness in the data quality used for the simulations. These simulations should be taken as generators of hypotheses to analyze further the functioning and the role of human actions. Discard is considered one of the main problems of the marine ecosystem and fishery sustainability worldwide (Bovcon et al. 2013, FAO 2020). Even when the discard values are considered inside the reported global range, the RdlP is not excluded from this concern (Ehrhardt & Rey 1996, Rey et al. 2000). In this context, implementing zero discard policies and increasing fishing pressures will not represent a relevant benefit for most commercially important groups. To further address these problems, it should be necessary to work more deeply at the academic and management level and promote continuous monitoring of the discard practices. In addition, the type of ecosystem control should be considered when performing the simulations for a complete description of the system's functioning and its impacts.

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Table 1A. Primary input and estimates made by Ecopath for each functional group in the Río de la Plata ecosystem.

Production / Biomass rate (B/P). Consumption / Biomass rate (Q/B). Production / Consumption rate (P/Q). Ecotrophic effiency (EE).

Funcional group	Trophic level	Biomass ($t\ km^{-2}\ yr^{-1}$)	P/B (yr^{-1})	Q/B (yr^{-1})	P/Q (yr^{-1})	EE
Tursiops truncatus	3.9	0.011	0.019	14.585	0.0013	0.00
Pontoporia blainvillei	3.9	0.0142	0.037	27.295	0.0013	0.88
Otaria flavescens	3.7	0.0186	0.058	17.182	0.0034	0.00
Seabirds	3.5	0.0097	0.285	71.678	0.0040	0.00
Galeorhinus galeus	3.7	0.0142	0.532	3.208	0.1657	0.88
Urophycis brasiliensis	3.6	0.1381	0.291	4.119	0.0706	0.97
Squids	3.4	0.0653	5.773	15	0.3849	0.87
Genidens + Porichthys	3.2	0.4308	0.519	4.409	0.1177	0.82
Flat fishes	2.9	0.7651	0.897	2.967	0.3024	0.95
Squatina guggenheim	2.9	1.7128	0.38	3.009	0.1261	0.25
Prionotus	3	0.512	0.272	6.485	0.0420	0.80
Mustelus schmitti	3	0.6772	1.67	4.570	0.3654	0.10
Other marine fishes	3	0.2193	0.374	5.912	0.0633	0.99
Micropogonias furnieri adult	3	6.0159	0.578	3.013	0.1918	0.38
Micropogonias furnieri youth	2.9	4.9077	1.218	6.314	0.1930	0.78
Rapana venosa	3	15.189	0.256	2.824	0.0906	0.19
Cynoscion guatucupa youth	2.9	9.7492	1.167	7.150	0.1632	0.46
Cynoscion guatucupa adult	2.8	7.0798	0.911	3.465	0.2628	0.06
Hard bottom fishes	2.8	0.2079	1.031	8.091	0.1275	0.98
Large Gastropoda	2.7	2.81	0.318	7.587	0.0419	0.78
Sciaenidae	2.7	3.612	0.851	4.012	0.2122	0.93
Rays	2.5	7.1773	0.176	2.857	0.0617	0.21
Zooplankton C-O	2.5	1.1586	22.28	62.305	0.3576	0.61
Pelagic fishes	2.4	4.3807	0.583	6.425	0.0908	0.95
Other freshwater fishes	2.3	0.004	0.9917	7.3039	0.1358	0.87
Rock bottom benthic invertebrates	2.2	0.2304	4.41	14.182	0.3109	0.96
Polychaeta	2	16.422	1.534	17.189	0.0893	0.89
Shrimps	2	46.582	2.736	14.488	0.1889	0.80
Mytilidae	2	27.868	0.543	6.785	0.08	0.34
Other benthic invertebrates	2	1.6838	5.549	16.141	0.3438	0.99
Bivalvia estuarina	2	23.961	2.084	7.873	0.2648	0.93
Corbicula fluminea	2	11.928	0.674	7.418	0.0909	0.80
Heleobia	2	1.718	1.831	8.981	0.2039	0.82
Large bivalves	2	11.476	1.958	7.524	0.2603	0.85
Zooplankton H-O	2	5	114.96	325.089	0.3536	0.12
Phytoplankton	1	42	500			0.08
Detritus	1	191.48				0.05
Discard	1	0.1461				0.94

Table 2A. Diet matrix showing proportion of the diet biomass used in the balance on Ecopath model.

Prey \ Predator	*Tursiops truncatus*	*Pontoporia blainvillei*	*Otaria flavecens*	Seabirds	*Galeorhinus galeus*	*Urophysis brasiliensis*	Squids	Genidens + Porichthys	Flat fishes	*Squatina guggenheim*	Prionotus	*Mustelus schmitti*	Other marine fishes	*Micropogonias furnieri* adult	*Rapana venosa*	*Micropogonias* furnieri youth	*Cynoscion guatucupa* youth
Tursiops truncatus																	
Pontoporia blainvillei																	
Otaria flavecens																	
Seabirds																	
Galeorhinus galeus																	
Urophysis brasiliensis	0.00400	0.01996	0.00202	0.00802		0.00200		0.00100		0.00091		0.00100	0.00095				
Squids		0.18164	0.00404	0.00501	0.01602		0.06306	0.02498	0.00596	0.00501			0.02298				0.00044
Genidens + Porichthys	0.00020			0.06414	0.22122	0.02098		0.02697		0.00501			0.02697				
Flat fishes			0.00505	0.00200	0.01301			0.05195	0.09443	0.02004		0.01097	0.02997			0.00501	
Squatina guggenheim			0.02119					0.04296	0.00000	0.00501		0.01196					
Prionotus			0.02119	0.00100					0.00000	0.01002		0.01196	0.00999				0.00037
Mustelus schmitti			0.02119		0.01201				0.00000	0.01603							
Other marine fishes		0.00096	0.00010	0.00911	0.00501	0.00999		0.00989	0.00000	0.00095	0.00055	0.01097	0.01998				
Micropogonias furnieri adult	0.65934	0.01098	0.10495														
Rapana venosa																	
Micropogonias furnieri youth	0.20380	0.22855	0.21899	0.30465				0.04795	0.10040	0.02906	0.02497	0.01097	0.12298			0.00060	0.01907
Cynoscion guatucupa youth	0.00200	0.23853	0.26945	0.12427	0.10310	0.45557		0.04096	0.00000	0.22047	0.02697	0.01196	0.03297			0.02005	0.02108
Cynoscion guatucupa adult	0.06394	0.01098	0.05248		0.31131	0.20081											
Hard bottom fishes					0.00200							0.01196	0.00999			0.00100	
Large Gastropoda					0.00200							0.01296					
Sciaenidae	0.00599	0.08583	0.02018	0.05311	0.07407	0.00300		0.05300		0.04810	0.10189	0.01097	0.05795	0.01401		0.01203	0.00095
Rays			0.02119		0.02603	0.01199		0.04985		0.01904		0.01196	0.00999				
Zooplankton C-O								0.00100					0.00200	0.01201		0.00010	0.01004
Pelagic fishes	0.06094	0.06587	0.13624	0.08420	0.05105	0.01499	0.68268	0.04795	0.11531	0.00902	0.04695	0.00120	0.03597	0.00601		0.00902	0.00088
Rock bottom benthic invertebrates																	
Polychaeta		0.00200					0.01101	0.00999	0.00895		0.04895	0.08574	0.19391	0.02703		0.09021	
Shrimps		0.06887		0.00075	0.00701	0.20780				0.05111	0.19679		0.15186	0.05606		0.60740	0.56205
Mytilidae															0.11111		
Other benthic invertebrates				0.00975	0.03804	0.01998	0.24324	0.40360	0.33400	0.00301	0.22876	0.58225	0.04596	0.07007		0.00401	0.00089
Bivalvia estuarina						0.00095							0.06594	0.79079	0.61428		
Corbicula fluminea															0.10794		
Heleobia						0.00500					0.04995			0.00100			0.00502
Large bivalves															0.16667		
Zooplankton H-O								0.00300					0.00200	0.01301		0.04510	0.09033
Phytoplankton																	
Detritus				0.05310	0.10611	0.02098		0.11389	0.33000	0.40200	0.11088	0.10000				0.14333	0.09434
Discard			0.05100	0.10000		0.02600			0.01130			0.00400					
Import		**0.07485**	**0.05000**	**0.19000**	**0.01201**			**0.07100**		**0.15500**	**0.16383**	**0.11000**	**0.11489**			**0.06214**	**0.19571**
Sum	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Cynoscion guatucupa adult	Hard bottom fishes	*Large Gastropoda*	Sciaenidae	Rays	Zooplankton C-O	Pelagic fishes	Rock bottom benthic invertebrates	Polychaeta	Shrimps	Mytilidae	Other benthic invertebrates	*Bivalvia estuarin*	*Corbicula fluminea*	Heleobia	Large bivalves	Zooplankton H-O	Phytoplankton	Detritus	Discard
						0.00035													
0.00090				0.00092		0.00878													
0.00010	0.00013																		
0.00190						0.00097													
	0.03610		0.04709																
0.08016			0.00501	0.01204															
0.03607			0.00501	0.01204		0.00040													
	0.07621																		
		0.02792		0.00301															
0.03807			0.00501	0.01003															
			0.00802		0.10030	0.00997	0.01491	0.01502	0.00299										
0.00902	0.00060		0.00200	0.01892		0.00897													
	0.34597						0.04374	0.00087											
			0.22946	0.13944				0.02203	0.00898										
0.17133			0.09719	0.10433		0.01396			0.04991										
	0.05716						0.12940												
0.00902		0.02193	0.00902	0.00903		0.00299		0.00400	0.00088	0.00000	0.02196								
0.00095		0.10469	0.00020	0.15549															
			0.05210	0.05516															
			0.04709	0.00208				0.00092	0.00092										
		0.56032	0.00000	0.00301															
			0.00802		0.30090	0.38989	0.03479	0.03504	0.02296	0.04500									
					0.20060	0.20542	0.30080	0.30637	0.12378	0.70000	0.42515	0.80000	0.80000		0.80000	0.59702			
0.25750	0.28580	0.28500	0.35671	0.47400	0.10030	0.26524	0.47575	0.61600	0.64983	0.25000	0.48000	0.20000	0.20000	1.00000	0.20000	0.09950			
0.39677	**0.19856**		**0.12826**		**0.29789**	**0.10271**			**0.13975**		**0.07300**					**0.30348**			
1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**			