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Ecosystem impacts of the introduction of bycatch reduction devices in a tropical shrimp trawl fishery: Insights through simulation

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Abstract

ECOSIM simulations of the introduction of bycatch reduction devices (BRD) to a tropical industrial shrimp fishery resulted in moderate to strong positive changes of biomass of selected bycatch functional groups, depending on the position of the BRD in the trawl net. The highest increases in biomass after 20 years of simulation were predicted in the scenario with 12.70 cm × 30.48 cm football-shaped steel fisheye BRD positioned with its center 15 meshes to the outside of top center and 30 meshes from the opening of the bag. In general, results are encouraging both in terms of protection of selected functional groups and in socio-economic terms. Croakers, a group that in the Ecopath base model was heavily impacted as part of bycatch in shrimp trawling, show significant rebuilding of biomass without substantially affecting shrimp yield at the base fishing effort level. Similar rebuilding was also observed in other economically relevant groups, such as snappers. Predicted biomass increments are conducive to larger captures by the long-line and artisanal fleets operating in the area. The results stress the potential benefits of the implementation of BRD and encourage its testing in Colombian waters. They also stress the need for careful choice of functional groups to be protected.

Keywords: Bycatch; Tropical fish; Fisheries management; Simulation; Ecopath with ECOSIM; Caribbean Sea; Colombia

1. Introduction

Ecosystems subject to active fishery exploitation typically suffer changes in structure and function. Most often expressed as changes in their food webs. Consequently, ecosystem responses to exploitation are usually complex (Jennings and Kaiser, 1998; Hall, 1999). In this context, the main concern is to assess the extent to which the fishery is jeopardizing the long-term viability of both affected populations and fishery yield. From a conservationist point view, the goal is to maintain biodiversity and ecosystem integrity despite exploitation, as to maintain ecosystem functioning into the future (Pauly et al., 2002). Thus, new approaches at the ecosystem scale have been invoked for fisheries management, with a change of paradigm from building "sustainable" fisheries to "rebuilding" of biomass within ecosystems (Pitcher, 2001).

The upwelling ecosystem in the Caribbean off Colombia (Fig. 1; Cabrera and Donoso, 1993; Andrade, 2000), sustains industrial shrimp trawling (Viaña et al., 2004), semi-industrial long-lining (boats of intermediate size and autonomy between the industrial and the artisanal ones (Arévalo et al., 2004) and artisanal fisheries (Correa and Manjarrés, 2004a). These fisheries are mainly targeting shrimps, lobsters, pelagic and demersal fishes (Manjarrés, 2004).

The industrial shrimp fleet exerts particular pressure on the demersal community of the area not only due to the extraction of relatively substantial amounts of shrimp (annual catch during 2000 of 337.3 ± 36.1 t, $P = 95\%$, Viaña et al., 2004), but also because of the high level of bycatch. Thus, for the period 2000–2001, the target resource of the fleet represented

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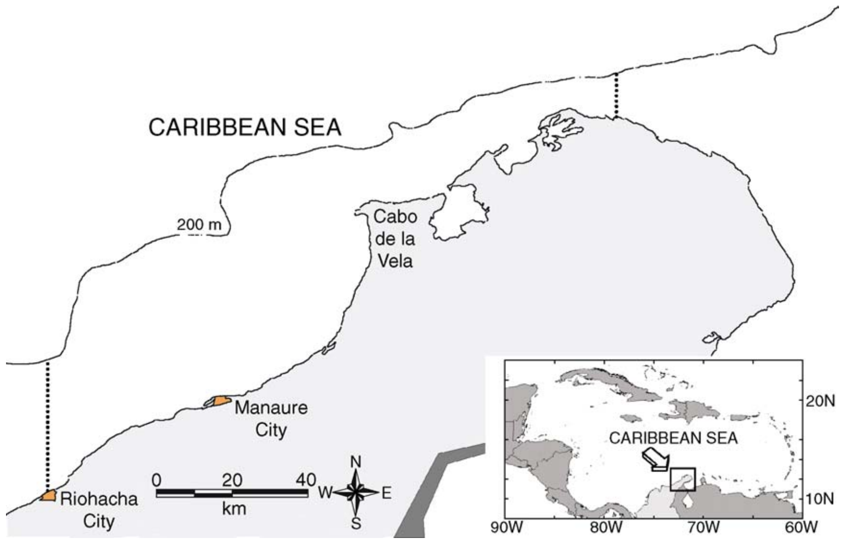

Fig. 1. Upwelling ecosystem off northern Colombia, Caribbean Sea. Study area comprises 4220 km^2 of continental shelf indicated by the segmented lines.

only 11% of total catch by weight. Of the remaining 89%, 28% were fishes and the rest invertebrates and algae (Viaña et al., 2004). The bycatch problem is a recurrent issue in worldwide trawl fisheries (Alverson et al., 1994), calling for action to reduce this collateral mortality imposed on non-target populations (FAO, 1996). A number of technological innovations to alleviate this problem in trawl capture systems have been proposed (Kennelly and Broadhurst, 2002), including, in particular, bycatch reduction devices (BRDs) that operate fitted anterior to ahead of the codend of shrimp trawls. Indeed, it has been found that BRDs can reduce bycatch of tropical shrimp trawling by as much as 40–50% (Branstetter, 1997).

Introduction of BRDs in the shrimp trawl industry in Colombian Caribbean waters is a foreseeable scenario in the near future. Thus, it is of utmost interest to anticipate the ecosystem effects of such a management action in terms of expected biomass restoration and to contrast this forecasting with subsequent monitoring. The aim of this paper is to test whether the implementation of BRDs is a useful management alternative in the restoration of non-target populations affected by industrial shrimp trawling in the upwelling ecosystem off Colombia. In order to anticipate and explore plausible ecosystem responses, a dynamic trophic model (ECOSIM, Walters et al., 1997) was used to simulate putative long-term dynamic changes in biomass levels of selected functional groups within the ecosystem after insertion of BRDs in the shrimp trawling gears.

2. Study area

The tropical upwelling ecosystem at La Guajira (Caribbean Sea, Colombia) covers an area of 4220.66 km^2 (Fig. 1). An Ekman-type coastal upwelling forced by the Northeastern trade winds characterize the system and the wind driven circulation dominates the flows of the area, i.e. the Caribbean Current (Andrade, 2000). The shelf is wide between Cabo de La Vela and Riohacha and narrow in front of Punta Gallinas. Sediments are sand–muddy from Cabo de la Vela to Punta Gallinas, and sandy with shells off Cabo de la Vela to Riohacha (Álvarez-León et al., 1995). This system is characterized by enhanced primary productivity in upwelled waters (Andrade, 2000), and supports the largest seagrass beds of the Colombian Caribbean Sea between Cabo de la Vela to South of Riohacha (Díaz et al., 2003). The ecosystem supports around 900 different species, some of which are exploited by fisheries, such as shrimps, lobsters, snappers, groupers, croakers, pompanos, jacks and bonitos. Oceanographic and meteorological conditions show very marked changes due to the occurrence of Northeastern trade winds and the migration of the intertropical convergence zone (ITCZ) (Muller-Karger and Aparicio, 1994).

3. Ecopath base model

Various data were gathered from a several projects, such as the Catalogue of Macrofauna of INVEMAR 2001–2002, distribution and structure of seagrass (Díaz et al., 2003), and used to construct this base model with Ecopath of the tropical upwelling ecosystem. Data published in papers, books, reports, and theses were used for the diet matrix (e.g. Bitter, 1984; Cortes and Criales, 1990; Duarte et al., 1999; De La Cruz-Agüero, 1993; Mendoza, 1993; Opitz, 1996; Penchaszadeh and Lera, 1983; Sedberry and Cuellar, 1993; Sierra et al., 1994). Fisheries statistics in the upwelling area were collected during 1999–2000 for demersal resources (Manjarrés, 2004) and for small pelagics during 1997–1998 (Viaña et al., 1999). These data provided species composition lists, trawlable biomass, length and weight of fishes, fish landings, fishing effort, and use and details on fishing long-lines.

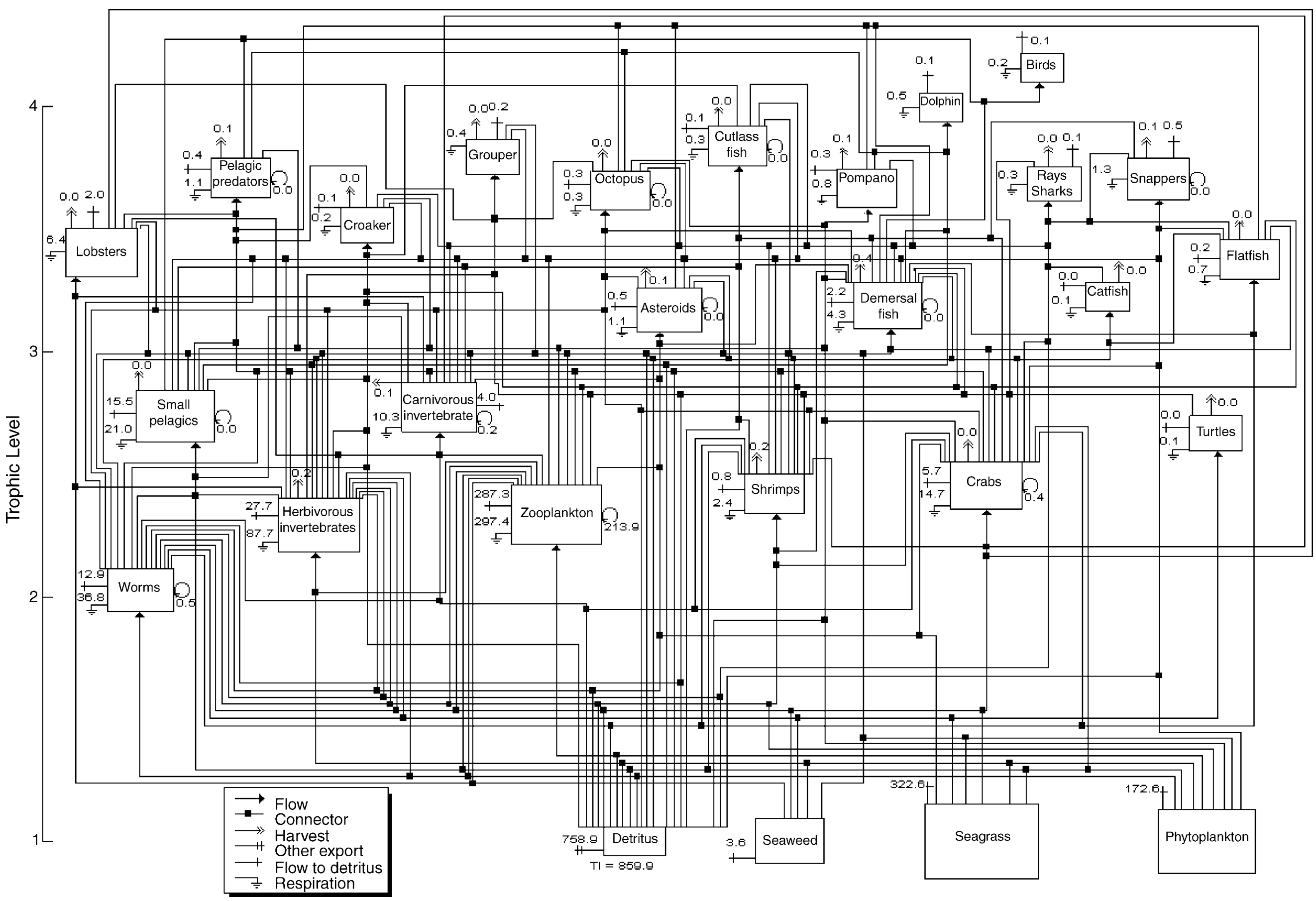

Fig. 2. Biomass flow diagram of the upwelling ecosystem off northern Colombia, Caribbean Sea. Flows are in t km^{-2} year^{-1}. The surface area of the boxes is proportional to the logarithm of the biomass. The components of the system are structured along the vertical axis according to their trophic level defined as 1 for primary producers and detritus and as 1 plus the weighted average of the prey's trophic level for consumers.

Twenty-seven functional groups were defined in the system, including dolphins; sea birds; marine turtles; 11 groups of fish include rays and sharks: 9 invertebrate groups; 3 primary producers (phytoplankton, macro-algae and seagrasses); and detritus (Fig. 2; Table 1). Fishing fleets were included as predators groups within the model. The pedigree of the model was 0.549, i.e. intermediary between data not rooted locally (0) and data fully rooted locally (1) (Christensen et al., 2000). The fisheries were divided into industrial trawling, semi-industrial long-lining and artisanal fisheries (Table 2). The balance model represents the structure and potential dynamics of ecosystem. The groupings, parameterizations and assessments of sources for this Ecopath base model are fully described in Criales-Hernández (2004). The model was built using the Ecopath with ECOSIM (EwE) modeling approach (Christensen and Pauly, 1992; Walters et al., 1997) and describes the interactions between different components within the ecosystem (Fig. 2). The major part of the energy throughout is achieved from trophic levels I to II (69.93%), where an important proportion of the total flow originates from detritus (32%). Artisanal fleets had a special impact on trophic levels II and III, and they impact on Pompano/Bonito/Jacks, while the semi-industrial long-lines affected snapper and groupers (trophic level III), and the industrial shrimp trawling impacted specially the croakers group (trophic levels II and III).

The size of the ecosystem is moderate in terms of total biomass and total system throughput (68.3 t km^{-2} and 3275 t km^{-2} year^{-1}, respectively) compared to upwelling areas in subtropical and temperate waters, e.g. Benguela 1990s, 231 t km^{-2} and 39304 t km^{-2} year^{-1} (Shannon et al., 2003), and California 1977–1985, 63.09 t km^{-2} and 7621 t km^{-2} year^{-1} (Jarre-Teichmann, 1998), but it is comparable to other upwelling ecosystems in the tropics, e.g. Northeastern Venezuela, 122.1 t km^{-2} and 7621 t km^{-2} year^{-1} (Mendoza, 1993), and Gulf of Salamanca, Colombia, 42.2 t km^{-2} and 3038 t km^{-2} year^{-1} (Duarte and García, 2002, 2004).

4. Material and methods

Mortality reduction due to the implementation of BRDs on shrimp trawling gears has been documented for Gulf of

Table 1
Basic input parameters of the mass balance model of the tropical upwelling ecosystem off northern Colombia, Caribbean Sea

Group	Trophic level	Biomass (t km^{-2})	*P*/*B* (year^{-1})	*Q*/*B* (year^{-1})	Ecotrophic efficiency
Phytoplankton	1.00	(12.328)	70.000	–	0.800
Seaweed	1.00	1.102	17.000	–	(0.806)
Seagrass	1.00	28.657	12.800	–	(0.121)
Worms	2.03	(0.751)	15.000	80.000	0.919
Herbivorous invertebrates	2.29	4.500	3.800	29.100	(0.914)
Zooplankton	2.33	9.680	40.000	(88.404)	0.700
Crabs/others crustaceans	2.45	1.580	3.500	16.000	(0.881)
Shrimps	2.42	0.160	5.100	25.000	(0.988)
Turtles	2.67	0.040	0.300	3.500	(0.839)
Small pelagic fish	2.74	2.730	4.00	14.600	(0.311)
Carnivorous invertebrates	2.77	2.500	2.300	8.000	(0.992)
Asteroids/ophiuroids	3.17	0.750	0.900	3.000	(0.961)
Demersal fish	3.19	0.880	3.170	10.000	(0.849)
Catfish	3.22	(0.013)	1.300	7.000	0.950
Flatfish	3.38	0.140	0.830	7.500	(0.931)
Lobsters	3.40	(1.404)	1.020	7.000	0.960
Croakers	3.51	0.030	(1.830)	9.150	(0.622)
Octopus/squids	3.66	0.110	2.300	8.000	(0.957)
Pampano/jacks/bonitos	3.67	0.130	(2.412)	10.300	0.950
Rays/sharks	3.68	0.090	0.620	5.300	(0.858)
Snappers	3.70	0.430	0.560	4.500	(0.561)
Pelagic predatory fish	3.71	0.170	1.950	10.300	(0.774)
Groupers/large demersal fish	3.79	0.092	(1.320)	6.600	(0.616)
Cutlassfish/anguilliformes	3.84	0.110	(0.749)	4.800	0.940
Dolphins	4.00	0.021	0.050	28.000	0.000
Birds	4.16	0.006	0.700	39.330	0.000
Detritus	1.00	–	–	–	0.117

Values in brackets were estimated trough the Ecopath model.

Mexico waters (Branstetter, 1997; Rogers et al., 1997; Engaas et al., 1999). BRDs fitted in several positions on gear have been tested, and results are available in terms of percentage of reduction in bycatch (Branstetter, 1997; Table 3). The BRD-type likely to be tested in Colombian Caribbean waters is the ‘fisheye’. Thus, relative reductions observed in Gulf of Mexico bycatch by others using a 12.70 cm × 30.48 cm football-shaped steel fish-eye BRD fitted on the gear in four selected positions (Fig. 3), was applied to our model and used to simulate the ecological effects of those reductions in

Table 2
Catches (t km^{-2} year^{-1}) by functional group and fleet in the upwelling ecosystem off northern Colombia, Caribbean Sea

Group name	Industrial shrimp trawling fleet	Semi-industrial long-line fleet	Artisanal fleet
Herbivorous invertebrates	0.176	–	0.001
Shrimps	0.152	–	0.008
Crabs/other crustaceans	0.030	–	–
Turtles	–	–	0.004
Small pelagic fish	0.004	–	0.005
Carnivorous invertebrates	0.061	–	0.003
Asteroids/ophiuroids	0.090	–	–
Demersal fish	0.213	0.002	0.182
Catfish	–	–	0.006
Flatfish	0.036	–	–
Lobsters	0.004	–	0.044
Croakers	0.017	–	0.001
Octopus/squids	0.032	–	–
Pompanos/jacks/bonitos	–	–	0.130
Rays/sharks	0.022	–	0.021
Snappers	0.033	0.016	0.041
Pelagic predatory fish	0.005	–	0.060
Groupers/large demersal fish	0.003	0.009	0.011
Cutlassfish/anguilliformes	0.007	–	0.003
Sum	0.885	0.027	0.520
Average trophic level	2.89	3.69	3.43

Average trophic level is indicated for each fleet.

Table 3
Fishing mortality included in the mass balanced model (F_{base}), relative change in industrial fishing mortality due to the use of BRD's ($\%fI_k$) as derived in Eq. (2) and fishing mortality rate (F_i) as derived in Eq. (3) per functional group after catch change from Branstetter (1997)Branstetter (1997, Gulf of Mexico) used in simulations of four different positions of BRDs in the trawl net (see Fig. 3) in the upwelling ecosystem off northern Colombia, Caribbean Sea

Group name	F_{base}	Setting A		Setting B		Setting C		Setting D	
		$\%fI_k$	F_i	$\%fI_k$	F_i	$\%fI_k$	F_i	$\%fI_k$	F_i
Herbivorous invertebrates	0.039	6.0	0.041	−10.0	0.035	−15.0	0.033	22.0	0.048
Shrimps	0.998	−6.0	0.941	−7.0	0.932	−8.0	0.922	−16.0	0.846
Crabs/others crustaceans	0.019	2.0	0.019	1.0	0.019	−2.0	0.019	0.0	0.019
Turtles	0.100	–	0.100	–	0.100	–	0.100	–	0.100
Small pelagic fishes	0.003	−59.0	0.003	−56.0	0.366	−82.0	0.358	−38.0	0.003
Carnivorous invertebrates	0.026	6.0	0.027	−10.0	0.024	−15.0	0.022	22.0	0.031
Asteroids/ophiuroids	0.121	6.0	0.128	−10.0	0.109	−15.0	0.103	22.0	0.148
Demersal fish	0.451	−23.0	0.395	−33.0	0.371	−19.0	0.405	−40.0	0.354
Catfishes	0.463	−76.0	0.463	−57.0	0.463	−97.0	0.463	−100.0	0.463
Flatfishes	0.257	−74.0	0.067	−17.0	0.213	223.0	0.830	−26.0	0.190
Lobsters	0.034	–	0.034	–	0.034	–	0.034	–	0.034
Croakers	0.593	−22.9	0.465	−73.5	0.181	−66.6	0.220	−88.9	0.095
Octopus/squids	0.291	6.0	0.308	−10.0	0.262	−15.0	0.247	22.0	0.355
Pompanos/jacks/bonitos	1.000	–	1.000	–	1.000	–	1.000	–	1.000
Rays/sharks	0.478	–	0.478	–	0.478	–	0.478	–	0.478
Snappers	0.209	−51.9	0.169	−43.0	0.176	−61.6	0.162	−61.0	0.162
Pelagic predatory fish	0.382	16.0	0.409	−79.0	0.002	−37.0	0.003	−100.0	0.212
Groupers/big demersal fish	0.250	–	0.250	–	0.250	–	0.250	–	0.250
Cutlassfish/anguilliformes	0.088	−3.0	0.086	9.0	0.094	−41.0	0.063	95.0	0.147

Hyphens indicate that no catch information was recorded in Branstetter (1997).

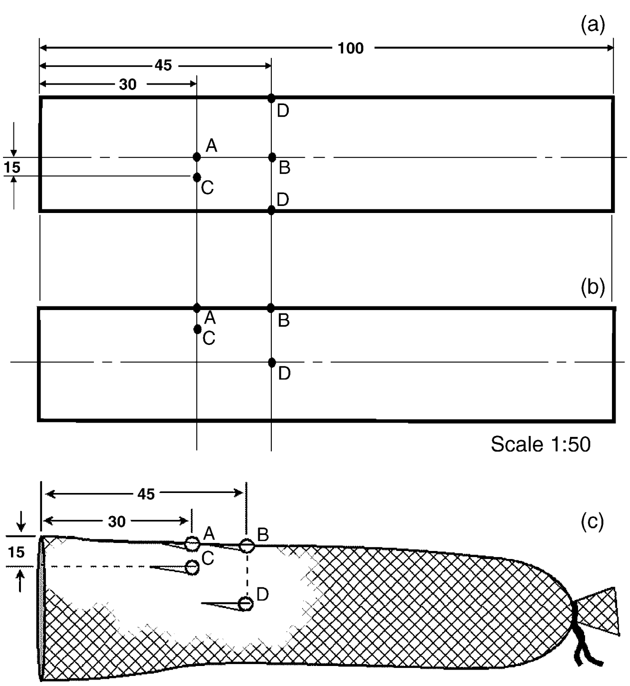

Fig. 3. Diagram of positions of bycatch reduction devices (BRDs) in the trawl net tested in the Gulf of Mexico. Results of the Gulf of Mexico trials, in terms of fishing mortality changes were used to simulate the ecological effects of the use of BRDs in the upwelling ecosystem off northern Colombia. Positions of the center of BRDs (football-shaped steel fish-eye type, size 12.70 cm × 30.48 cm) are indicated by the number of meshes to the outside top center and from the star of the bag of a shrimp trawl net. (a) Upper view, (b) lateral view, (c) schematic drawing.

bycatch along the Columbian Caribbean Coast. In all cases, 100% compliance and correct use of the BRD by fishermen is assumed. The Ecopath base model (Table 3) was used as a starting point for these simulations. We assume that faunal functional setting and responses to fishing gear and BRDs are comparable between the Gulf of Mexico and the upwelling area off Colombia.

Simulations were performed using the ECOSIM approach (Walters et al., 1997), which describes the dynamics of each group through the formulation:

$$\frac{\mathrm{d}B_i}{\mathrm{d}t} = f(B_i) - M_o B_i - F_i B_i - \sum_{j=1}^{n} c_{ij}(B_i, B_j) \quad (1)$$

where $f(B_i)$ is a function of biomass B_i if i is a primary producer, or $f(B_i) = g_i \sum_{j=1}^{n} c_{ij}(B_i, B_j)$ if i is a consumer, where g_i is the net growth efficiency and $c_{ij}(B_i,B_j)$ is the function used to predict consumption rates from B_i to B_j, and represents predator–prey encounter patterns and physiological–behavioral phenomena in predation rates. M_o is the mortality rate not accounted for by predation or fishing and F_i is the fishing mortality rate. The system of Eq. (1) can be integrated with F_i varying in time to provide dynamic biomass predictions for each i as affected directly by fishing, predation and changes in its food availability and indirectly by fishing or predation on other groups with which i interacts.

ECOSIM assumes that the biomasses of the groups in the system are determined by a mix of bottom–up and top–down control with a default vulnerability parameter of 0.3. A number of factors affect the vulnerability parameter including risk sensitive behavior of predators and prey, the availability of refuge, size of prey and mobility (Christensen et al., 2000).

The relative change in industrial fishing mortality applied to the functional group i due to the use of BRDs ($\%fI_i$) was calculated by weighing the relative change in fishing mortality of the individual species that constitute the functional group by their respective biomasses, viz.,

$$\%fI_i = \frac{\sum_{i=1}^{n} \%fI_k B_k}{\sum_{i=1}^{n} B_k} \quad (2)$$

where $\%fI_k$ is the relative change in industrial fishing mortality for species k (belonging to functional group i) in the Gulf of Mexico due to the use of BRDs and B_k is the estimated biomass of species k in the upwelling ecosystem off Colombia.

For each harvested group i manipulated in the simulations, F_i was computed as:

$$F_i = fI_i \left(1 + \left(\frac{\%fI_i}{100}\right)\right) + fSI_i + fA_i \quad (3)$$

where fI_i, fSI_i and fA_i are fishing mortality rates due to industrial, semi-industrial and artisanal fleets, respectively, in the Ecopath base model.

Simulations were run for a period of 20 years in order to assess the long-term impact of introducing BRDs. We focused particularly on simulating biomass trajectories of shrimps, snappers, croakers, groupers/large demersal fishes, rays/sharks and octopus/squids, since they are either among those groups most impacted by shrimp trawling in the system, or are of particular economic importance.

5. Results

Fig. 4 shows the relative biomass change of functional groups (consumers) after 20 years of simulation of continued, uninterrupted use of BRDs and bycatch reductions associated with their use. Fig. 5 shows the simulated biomass trajectory of selected functional groups and simulated biomass percent

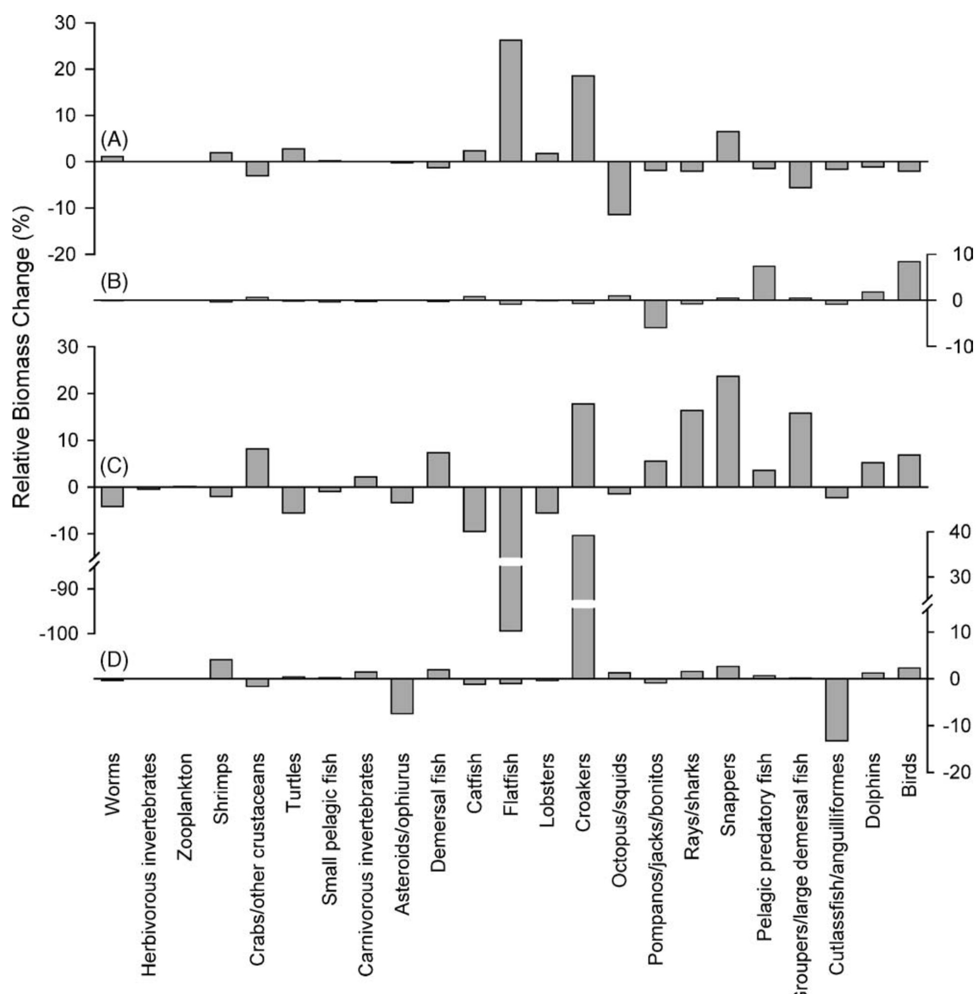

Fig. 4. Relative biomass change of functional groups (consumers) predicted after 20 years of dynamic simulation of the introduction of BRDs in four different positions of the trawl net (see Fig. 3). Simulations refer to the industrial shrimp trawling fleet that operates in the upwelling ecosystem off northern Colombia, Caribbean Sea. Groups are sorted by trophic level. Scales are proportional between cases.

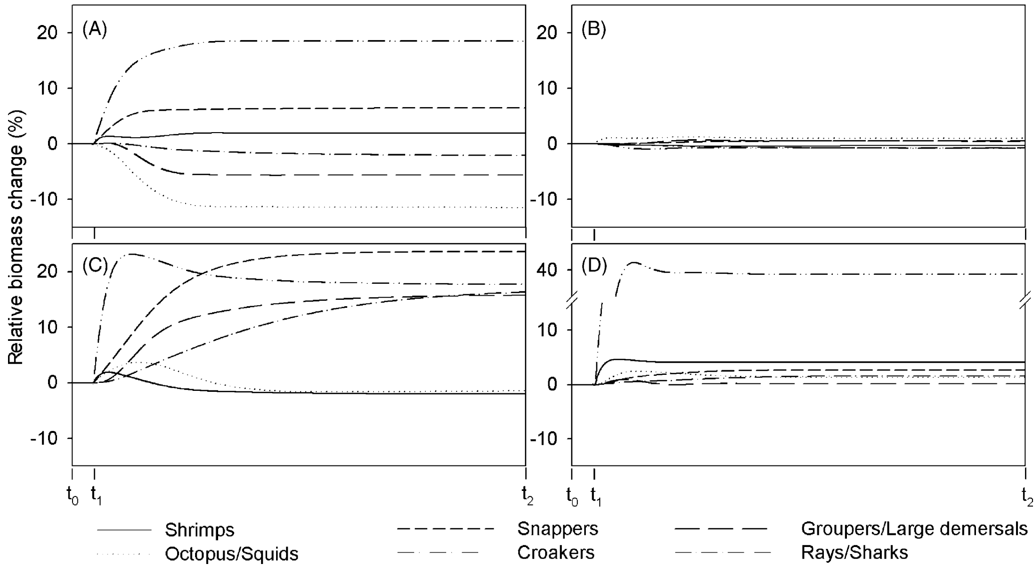

Fig. 5. Simulated relative changes in biomass over time for selected functional groups following the introduction of BRDs in different positions of the trawl net (see Fig. 3). In these simulations, the first year ($t_0 - t_1$) was run under base fishing mortality. In the period $t_1 - t_2$ (20 years), the change in fishing mortality due to the introduction of BRDs was applied.

change of selected functional groups resulting from the use of BRDs placed in the different positions on the net. The Position A (Fig. 3) scenario elicits marginal increase in shrimps and snappers biomasses and a substantial increase in croakers biomass (Figs. 4 and 5). Biomass levels of rays/sharks and groupers/large demersal fishes are reduced moderately, while biomass of octopus/squids is reduced significantly (Figs. 4 and 5). The changes in biomass levels occur in the first 5 years of simulation, then stabilize from there on (Fig. 5). It is interesting that this configuration favours the restoration of croakers biomass over other functional groups, and is surpassed only by the build up of flatfishes (Fig. 4).

Position B (Fig. 3) simulation is conductive to marginal or null changes in the biomass of shrimps, snappers, groupers/large demersals, rays/sharks and octopus/squids, whereas the biomass levels of croakers, flatfishes and pompano/jack/bonitos (*Trachinotus carolinus*, *Euthynnus alleteratus* and *Caranx hippos*) reduce slightly (Figs. 4 and 5). Most other functional groups remain rather unchanged but there is a noticeably large increase in the biomass of birds and pelagic predator fishes (Fig. 4).

Position C (Fig. 3) shows the biggest predicted changes in biomass levels of all most functional groups during simulations. Biomass trajectories stabilize only after a decade has elapsed (Fig. 5). Snappers, rays/sharks, groupers/large demersal fishes and croakers increase their biomass by more than 10%, whereas shrimps and octopus/squids biomasses decrease marginally (Figs. 4 and 5). This setting is especially favourable for snappers, an important harvest group, and for rays/sharks, a group with known vulnerability to overfishing (Fig. 4).

Setting D (Fig. 3) was very positive for croakers, whose biomass increased substantially in the first years of simulation (Fig. 5). The other functional groups were rather insensitive to this setting, except for cutlassfish/anguilliformes, which lost biomass in the simulation (Fig. 4). Biomasses under this configuration stabilized rapidly (Fig. 5).

Fig. 6 shows the predicted distribution of total (multispecies) catches among the industrial shrimp trawling fleet, the semi-industrial long-line fleet and the artisanal fleet for each scenario. Clearly reductions in bycatch in the industrial fleet, predicted particularly for setting C, favour increased catches in the other fleets as well.

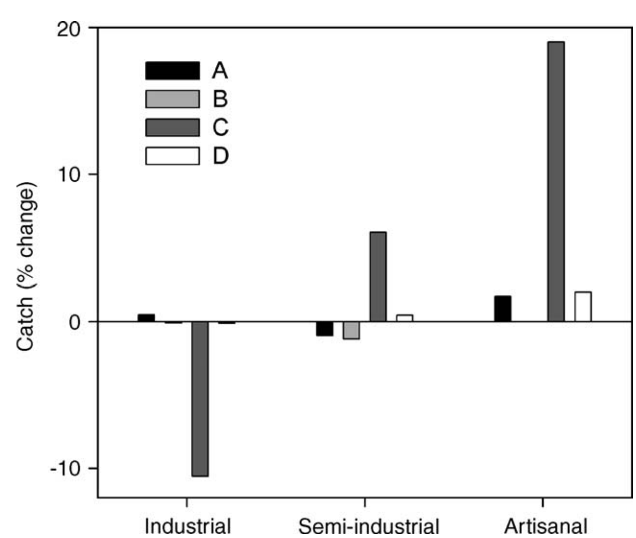

Fig. 6. Predicted relative change in total (multispecies) catches by fishing fleet after the simulated introduction of BRDs in different positions of the trawl net (Fig. 3). Simulations refer to the industrial shrimp trawling fleet that operates in the upwelling ecosystem off northern Colombia, Caribbean Sea.

6. Discussion

According to the simulations, the introduction of BRDs to the shrimp trawling fleet is conductive to long-term build up of biomass levels of selected functional bycatch groups in the upwelling ecosystem off Colombia. Thus, their implementation is desirable, and we reasonably expect that they will favour the non-target populations while marginally affecting shrimp catches, assuming everything else (for instance, fishing effort) remains the same. Biomass rebuilding due to bycatch control has relevant socio-economical implications beyond that of mere conservation, as shown by the predicted increase in catches by the artisanal and semi-industrial long-lining fleets. This occurs with no increase in fishing effort, and just as a consequence of unchanged fishing mortality rates exerted on higher biomass trophic levels.

However, results varied with position of the BRD in the gear and this aspect seems crucial in the effectiveness of BRDs. The simulations provide guidance in this respect. Position C (Fig. 3) appears to have the most extended beneficial results as to enhancing biomass of snappers, croakers, groupers/large demersal fishes and rays/sharks. The slight long-term reduction in shrimp biomass is the result of increased predation by the benefited functional groups, snappers in particular. Such reduction of shrimp biomass is consistent with small reductions in shrimp catches observed after field implementation of BRDs elsewhere (e.g. Steele et al., 2002), and in octopus/squids biomass in this simulation. The most dramatic case, however, is that of flatfishes that see their biomass reduced in 99% at the end of simulation time (Fig. 4). This result is the consequence of an extraordinary catch of flatfishes in the Mexican work (Table 3; Branstetter, 1997) plus the added predation exerted on them by increasing populations of rays/sharks, among others.

The smaller share of shrimp biomass available to shrimp trawlers under setting C, which probably would marginally reduces catches, is broadly compensated by the positive effects on the biomass levels of selected functional groups in the simulations and the positive potential socio-economical benefits for the artisanal fleet operating in the area, with 791 economic fishing units and 2657 fishers (Correa and Manjarrés, 2004a), most of them natives with no alternative sources for both food and income (CORPES, 1992; Manjarrés, 2004).

According to the mass balance base model, mean trophic level of industrial shrimp trawling catch, i.e. including bycatch is 2.89, of the semi-industrial long-lining is 3.69 and of the artisanal fleet is 3.43 (Table 2), as assessed by the trophic level of their catches (see Christensen and Pauly (1992) for a detailed description of the calculation of mean trophic levels). Thus, shrimp trawling is focused on the low-medium trophic levels. According to mixed trophic impacts calculations (i.e. direct and indirect trophic interactions, see Ulanowicz and Puccia, 1990), shrimp trawling is negatively impacting croakers and rays/sharks and positively octopus/squids. In the Ecopath base model, croakers are being heavily impacted as part of the bycatch of the shrimp trawlers. Three of the four configurations of the BRD are conductive to strong biomass build up in this group that is well represented in fish demersal assemblages in the Caribbean waters off Colombia (García et al., 1998; Manjarrés et al., 2001). Thus, BRD implementation seems to be an effective management measure in the protection of selected groups as well, notwithstanding the general importance of protecting species richness in the context of the postulated stabilizing role of the biodiversity in the ecosystems, since declines in biodiversity would accelerate the simplification of ecological communities (McCann, 2000). Non-target species, such as croakers, may play a crucial role in restructuring the architecture of habitats and in maintaining ecosystem processes (Coleman and Williams, 2002).

An increase in biomass due to the inclusion of BRDs into the shrimp trawl nets was predicted for snappers (Fig. 4) as a consequence of both the reduction in their fishing mortality and the enhanced availability of their prey. Since this is a fish group of high economic value, distributed throughout tropical and subtropical waters of the world, there has been concern about the impacts of shrimp trawling upon these populations. Therefore, specific bycatch reduction programmes for snappers have been developed (e.g. Gallaway and Cole, 1999). Snappers (*Lutjanus synagris*, *L. analis*) are historically one of the most abundant and commercially valuable groups in the upwelling ecosystem off Colombia. These species are caught by industrial, semi-industrial and artisanal fisheries (Arévalo et al., 2004; Correa and Manjarrés, 2004b; Viaña et al., 2004). Thus, management actions to ensure their long-term viability and to reduce the conflict between snapper fishermen and shrimp trawlers should be applied. The results of the simulations suggest that the inclusion of BRDs in the trawl fleet can be a successful management strategy for this resource.

Increased biomass of middle-low level consumers that make up most of the bycatch, when accomodated by trophic flows within the ecosystem, will favour some groups and disfavour others, as shown here. More biomass will be available for higher consumers, but higher predation pressure will be exerted on lower trophic levels. This appears to be the case for the octopus/squids group in scenario A, for instance. On the other hand, by reducing bycatch levels, species that feed on discards will be disfavoured, as found by Gribble (2003) in Australia using ECOSIM simulations.

The results presented here should be taken with caution, as is the case for all simulations. The Ecopath base model represents a possible but not unique configuration of the ecosystem and the input changes in bycatch mortality were taken from a study in another similar geographic area (Gulf of Mexico), and applied to the Caribbean. There may be factors not accounted for in the base model and simulations that may affect the response of biomasses and the ecosystem in face of the introduction of BRDs. However, this exercise reveals useful insights as it stresses the potential positive effect of management tools like BRDs not only in the protection of biodiversity but also in socio-economic terms. It also highlights the need for careful definition of objectives as to which functional groups should be enhanced or protected with measures like the introduction of BRDs.

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