



## Experimental results with a reducing device for juvenile fishes in a tropical shrimp fishery: impact on the invertebrate bycatch

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**Abstract.** The impact of the experimental introduction of a bycatch reduction device for juvenile fish in the shrimp trawl fishery in the Colombian Caribbean was assessed for invertebrates. Four net configurations were compared: no device, turtle excluding device alone, bycatch reduction device for juvenile fish alone and both devices incorporated on the net. This last configuration resulted in the lowest invertebrate mean CPUE but the turtle excluding device also performed well. Response in CPUE and mean size of selected invertebrate taxonomic categories to the device configurations was distinctive but disparate. The thesis is advanced that full report of invertebrates should be made in any study on bycatch even though bycatch reducing devices rarely have invertebrates in focus.

**Key words:** Bycatch reducing devices, tropical invertebrates, Colombia, Caribbean Sea.

**Resumen. Resultados experimentales con un dispositivo reductor de peces juveniles en una pesquería tropical de camarones: Impacto sobre la fauna acompañante de invertebrados.** Se evaluó el impacto sobre la fracción de la pesca acompañante correspondiente a los invertebrados de la introducción experimental de un reductor de juveniles de peces en la pesca de arrastre de camarones en el Caribe colombiano. Cuatro configuraciones en las redes fueron evaluadas: sin dispositivos, solo dispositivo exclusor de tortugas, solo dispositivo exclusor de juveniles de peces, ambos dispositivos incorporados a la red. Esta última configuración resulto en la CPUE mas baja para los invertebrados, pero el exclusor de tortugas mostro igualmente buen desempeño. La respuesta a las configuraciones en CPUE y tamaño medio de categorías taxonómicas seleccionadas de invertebrados fue distintiva pero disparatada. Se plantea la tesis de que en todo estudio sobre la fauna acompañante de la pesca del camarón se debe hacer reporte completo de los invertebrados, aun cuando los dispositivos reductores raramente los tienen como objetivo.

**Palavras claves:** Dispositivos reductores de peces, invertebrados tropicales, Colombia, mar Caribe.

### Introduction

Shrimp trawling not only impacts habitat structure and ecosystem functioning (Watling & Norse 1998, Thrush & Dayton 2002) but it also produces the highest amounts of bycatch (Alverson *et al.* 1994, Hall 1999) which leads to high accounted and unaccounted fishing mortality (Broadhurst *et al.* 2006). Shrimp trawling bycatch is made of non commercial fishes, commercial undersized fishes and invertebrates, some of them of commercial

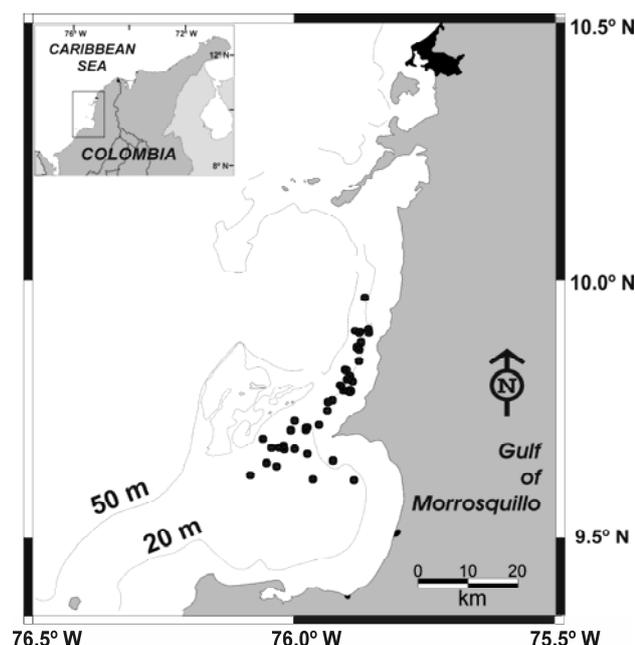
value. Although the invertebrate fraction represent a significant part of the bycatch, most accounts have focused on the fish fraction and have either ignore invertebrates or tended to lump them together with the likely consequence of underreporting, as pointed out by Kelleher (2005). Concomitantly, most of the devices proposed and used to reduce bycatch focus on the escape of individual fish species or groups of fishes (e.g. juveniles) that support fishing elsewhere

in the fishery (e.g. Graham 2003, Steele *et al.* 2002) or focus on species like turtles (e.g. Lewison *et al.* 2004), mammals (e.g. Read *et al.* 2006) and birds (e.g. Uhlmann *et al.* 2005) to which humans attach emotional values.

A device aiming to reduce bycatch in shrimp trawling, with focus in juvenile fish, was tested in Colombian Caribbean waters. This device should complement the turtles excluding device which is mandatory but has not been properly tested either, at least in Colombian Caribbean waters. We present and discuss here the results of such tests in regard to the invertebrate fraction of the bycatch as we believe invertebrates deserve closer attention in this context than that they have received so far.

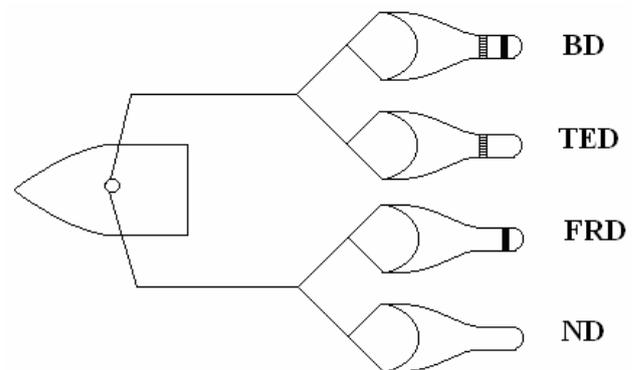
## Materials and Methods

From August to early December 2005 (rainy season) 88 experimental trawls (average speed of 2.5 knots, trawl time between 3.5 and 4.5 h) were carried out off the central Caribbean coast of Colombia in depths from 15 to 37 m. Of the 88 trawls 47 were fit for detailed invertebrate analysis (Fig. 1). Vessels (“Florida” type trawler, 21.3 m in length, 450 hp) used belong to the regular shrimp fleet and the area fished is a traditional shrimp trawling area. The choice of trawling sites and times (at night) was entirely left to the Skipper so as to duplicate the normal activity patterns of vessels. Vessels carry 4 japanese-type polyethylene nets, two per band, each of 12.8 m of head line. The bycatch reducing device tested is of the “fisheye” type (32.0 cm x 22.0 cm x 45.3 cm), with its center 30 meshes from the codend and 15 meshes from the outside top of the codend.



**Figure 1.** Study area showing shrimp trawling locations and 20 m and 50 m depth contours.

We tested the effect on invertebrate bycatch (effects on fish bycatch and a general account can be found in Manjarres *et al.* 2008) in 4 net configurations: one net fitted with only the turtles excluding device, called heretofore, TED configuration; a second net fitted with only the fish bycatch reducing device to be introduced, called heretofore, FRD configuration; a third net fitted with both reducing devices, called heretofore, BD (both devices) configuration, and the fourth one without any reducing devices, called heretofore, ND (no device) configuration (Fig. 2) that acts as control. The configuration order of the nets was arbitrarily set at the beginning of each trip.



**Figure 2.** Experimental net configurations. Order of configuration arbitrary. BD= Both Devices, TED= Turtles Excluding Device, FRD= Fish Reduction Device, ND= No Device

On deck the complete bycatch of each net configuration was weighted. A sample of at least 25% in weight of bycatch from each net configuration and trawl was stored in the freezing room and subsequently sorted, and identified to the lowest taxonomic level possible in the laboratory. Individuals were weighted and measured as follows: carapace width (carapace length for *Iliacantha liodactylus* Rathbun, 1898 and *Pseudorhombila quadridentata* (Latreille, 1828)) for crab like crustaceans (*Calappa* sp., *Callinectes* sp., *Hepatus pudibundus* (Herbst, 1785), *Leiolanbrus nitidus* Rathbun, 1901, *Lupella forceps* (Fabricius, 1793), *Persephona punctata* (Linnaeus, 1758), *Pilumnus sayi* Rathbun, 1897, *Portunus gibbesii* (Stimpson, 1859), *Stenorhyncus seticornis* (Herbst, 1788)); total length for Stomatopoda and *Xiphopenaeus kroyeri* (Heller, 1862)/*Farfantepenaeus notialis* (Pérez-Farfante, 1967); cephalothorax length for *Palinurus argus* (Latreille, 1804) and *Sicyonia typica*, (Boeck, 1864); valve length for bivalves (*Aequipecten lineolaris* (Lamarck, 1819), *Atrina seminuda* (Lamarck, 1819), *Euvola ziczac* (Linnaeus, 1758), *Laevicardium laevigatum*, (Linnaeus, 1758)); disc diameter for asteroidea (*Astropecten* sp., *Luidia*

*clathrata* (Say, 1825), *L. senegalensis* (Lamarck, 1816)); and plume length for the cephalopod *Loligo* sp.

For total bycatch and selected taxonomic categories a paired test comparing mean CPUE (kg/h) of net configurations against the ND configuration were conducted. In this approach each trawl is viewed as one and the same subject under four treatments (net configurations). It is assumed that the underlying composition and abundance of invertebrate fauna for a given trawl path is the same for all net configurations and thus differences in CPUE are due to the different net configurations only. Mean size of selected taxonomic categories was also compared the same way but in this case regardless of the identity of the trawl. Resampling routines (Good 2005) were written for the effect with the program Statistics 101, v. 1.0.6 (<http://www.statistics101.net/>).

Bootstrap-t 95% confidence intervals (CI) were fitted to mean CPUE and mean size of selected taxonomic categories per net configuration (Manly 1997).

## Results

Mean CPUE per net configuration and mean size for selected taxonomic categories and net configuration are shown in Tables I and II, respectively. Results of the tests are shown in Tables III and IV for CPUE and size, respectively. All net configurations retained significantly less total invertebrate bycatch than the control (ND configuration). Their performance was not even, however. Interestingly, the TED configuration was superior to the FRD configuration in that it retained significantly less biomass in quite more instances (selected taxonomic categories), 16 versus 9, respectively, when compared to the ND configuration (Table III). The response of the taxonomic categories to the net configurations also varied ranging from significant reduction in all net configurations, for instance, the asteroidea *Astropecten* sp., to insensitivity to all net configurations, for instance, the cephalopod *Loligo* sp., to responses to only one or two particular net configurations (Table III) always in relation to the ND configuration.

Porifera and the crab *Lupella forceps* illustrate two opposite cases of synergic interactions between devices. Interestingly the TED configuration retains significantly less Porifera than the control but when both devices are present (BD configuration) mean CPUE becomes indistinguishable from the control. In contrast, mean

CPUE of *L. forceps* is indistinguishable from the control for both TED and FRD configurations, but when both devices are present (BD configuration) mean CPUE significantly drops with respect to control (Table III).

In two instances the presence of excluding devices increased CPUE. The crab *Portunus gibessi* showed significantly higher CPUE in trawling nets fitted with the FRD compared with nets with no devices (Table III); the bivalve *Atrina seminuda* showed significantly higher CPUE when both devices are present than when either the TED or the FRD are present (Table III) compared to control.

For most taxonomic categories mean size was not different among net configurations (Table IV). Instances of increased or decreased mean size with respect to control were, however, present. That is the case, for example, of the bivalve *Aequipecten lineolaris* (Table IV).

## Discussion

It is not straightforward to assimilate CPUE to biological impact, as this depends on the natural history (abundance, distribution pattern, reproduction, etc) of the species involved and more subtle, on the survival rate of discards and escapees (see review by Broadhursts *et al.* 2006). Nevertheless, however natural history mediates the impact of fishing on populations, it is common sense that the highest the CPUE so the potential of an impact increases. We have shown that the incorporation on shrimp trawling nets of bycatch reducing devices affects CPUE of invertebrates in the bycatch in a variety of ways, even though the reduction devices by design focus on other species or groups of species different from invertebrates.

The response to net configurations of invertebrate species is far from uniform. This presents us with a difficult challenge: not matter what we do, species different than the target species will be affected in a number of ways by fishing. The total eradication of bycatch (invertebrate or finfish) in the shrimp fishery may turn out to be an impossible task at least in our tropical context. Nevertheless, it is clear that applied research should be directed to how to reduce both invertebrate and finfish bycatch simultaneously while the shrimp fishery is still economically viable (Kennelly & Broadhurst 2002).

The good performance of the TED configuration excluding invertebrates in this study is probably related to the position at the bottom of the net used by fishers in Colombian waters, which is contrary to what is customary. The results presented

**Table I.** Mean CPUE (kg/h) values and inferior/superior bootstrap confidence intervals (CIi/ CIs). TED= Turtles excluding device configuration; FRD= Fish reducing device configuration; BD= Both devices configuration; ND= No device configuration.

Taxonomic Category	TED			FRD			BD			ND		
	Mean	CIi	CIs									
Total Bycatch	2.633	1.992	3.351	2.754	2.334	3.207	2.128	1.675	2.570	3.091	2.653	3.528
<i>Aequipecten lineolaris</i>	0.006	0.003	0.010	0.016	0.009	0.024	0.004	0.002	0.006	0.012	0.006	0.019
<i>Astropecten</i> sp.	0.019	0.011	0.033	0.040	0.029	0.051	0.020	0.012	0.030	0.065	0.036	0.105
<i>Atrina seminuda</i>	0.002	4E-4	0.005	0.003	0.001	0.005	3E-4	0.000	8E-4	0.001	1E-4	0.003
<i>Calappa</i> sp.	0.017	0.000	0.052	0.040	0.003	0.096	0.056	0.000	0.132	0.268	0.134	0.420
<i>Callinectes</i> sp.	0.049	0.026	0.077	0.067	0.039	0.100	0.054	0.030	0.081	0.116	0.072	0.160
<i>Euvola ziczac</i>	0.025	0.016	0.037	0.038	0.026	0.051	0.014	0.006	0.025	0.046	0.028	0.067
<i>Hepatus pudibundus</i>	0.006	0.000	0.016	0.043	0.009	0.082	0.005	0.000	0.014	0.044	0.019	0.069
<i>Iliacantha liodactylus</i>	0.002	5E-4	0.004	0.005	0.003	0.007	0.002	7E-4	0.004	0.008	0.005	0.011
<i>Laevicardium laevigatum</i>	0.056	0.036	0.081	0.119	0.086	0.165	0.086	0.048	0.139	0.136	0.103	0.174
<i>Leiolumbrus nitidus</i>	7E-4	1E-4	0.002	6E-4	2E-4	9E-4	1E-4	0.000	3E-4	2E-4	0.000	6E-4
<i>Loligo</i> sp.	0.087	0.065	0.111	0.099	0.076	0.124	0.107	0.084	0.133	0.092	0.070	0.117
<i>Luidia clathrata</i>	0.026	0.014	0.042	0.035	0.023	0.047	0.020	0.014	0.028	0.043	0.027	0.062
<i>Luidia senegalensis</i>	0.014	0.004	0.027	0.042	0.017	0.017	0.011	0.001	0.023	0.037	0.016	0.063
<i>Lupella forceps</i>	1.254	0.852	1.720	1.130	0.860	1.409	0.928	0.704	1.181	1.110	0.884	1.372
Octocorallia	0.051	0.022	0.085	0.073	0.051	0.100	0.059	0.032	0.094	0.096	0.066	0.134
<i>Palinurus argus</i>	0.020	0.000	0.048	0.046	0.021	0.075	0.084	0.020	0.198	0.044	0.009	0.086
<i>Persephona punctata</i>	0.008	0.005	0.012	0.011	0.006	0.017	0.005	0.002	0.008	0.017	0.012	0.021
<i>Pilumnus sayi</i>	0.001	5E-5	0.003	0.005	0.002	0.010	0.003	2E-4	0.007	0.003	0.001	0.006
Porifera	0.094	0.057	0.139	0.126	0.083	0.177	0.113	0.071	0.161	0.146	0.100	0.197
<i>Portunus gibbesii</i>	0.171	0.113	0.238	0.196	0.143	0.252	0.154	0.110	0.203	0.161	0.115	0.205
<i>Pseudorhombila quadridentata</i>	0.004	0.000	0.009	0.009	0.003	0.015	0.006	0.000	0.015	0.007	0.002	0.014
<i>Sicyonia typica</i>	0.529	0.351	0.729	0.540	0.372	0.730	0.432	0.281	0.592	0.585	0.423	0.745
<i>Stenorhynchus seticornis</i>	5E-4	1E-4	9E-4	4E-4	1E-4	9E-4	3E-4	0.000	7E-4	9E-4	5E-4	0.001
Stomatopoda	0.070	0.050	0.093	0.048	0.036	0.060	0.041	0.029	0.054	0.074	0.048	0.113
<i>Xiphopenaeus kroyeri</i> / <i>Farfantepenaeus notialis</i>	0.171	0.124	0.225	0.172	0.126	0.226	0.074	0.053	0.097	0.249	0.199	0.307

**Table II.** Mean size values (cm) and inferior/superior bootstrap confidence intervals (CIi/ CIs). TED= Turtles excluding device configuration; FRD= Fish reducing device configuration; BD= Both devices configuration; ND= No device configuration.

Taxonomic Category	TED			FRD			BD			ND		
	Mean	CIi	CIs									
<i>Aequipecten lineolaris</i>	3.41	3.23	3.56	3.60	3.51	3.70	3.61	3.48	3.76	3.49	3.40	3.57
<i>Astropecten</i> sp.	0.58	0.56	0.60	0.58	0.56	0.60	0.59	0.55	0.63	0.59	0.56	0.62
<i>Callinectes</i> sp.	6.64	6.20	7.09	6.93	6.64	7.22	7.03	6.64	7.41	6.50	6.13	6.87
<i>Euvola ziczac</i>	5.25	4.97	5.51	5.13	4.93	5.33	4.94	4.61	5.29	5.14	4.96	5.30
<i>Iliacantha liodactylus</i>	2.62	2.35	2.84	2.35	2.24	2.46	2.47	2.24	2.62	2.47	2.35	2.57
<i>Laevicardium laevigatum</i>	2.94	2.87	3.02	2.96	2.89	3.04	3.17	3.10	3.25	3.07	3.00	3.15
<i>Loligo</i> sp.	4.83	4.48	5.19	5.26	4.68	5.85	4.78	4.32	5.31	5.18	4.78	5.60
<i>Luidia clathrata</i>	0.83	0.78	0.87	0.82	0.78	0.85	0.85	0.81	0.90	0.81	0.77	0.84
<i>Lupella forceps</i>	3.22	3.17	3.28	3.25	3.18	3.31	3.18	3.13	3.24	3.28	3.22	3.34
<i>Palinurus argus</i>	14.27	11.18	18.09	13.17	11.44	15.20	18.50	16.00	21.03	18.26	15.15	21.22
<i>Persephona punctata</i>	2.68	2.57	2.78	2.58	2.49	2.65	2.69	2.57	2.82	2.59	2.51	2.68
<i>Portunus gibbesii</i>	3.55	3.49	3.61	3.70	3.63	3.77	3.64	3.57	3.70	3.69	3.61	3.77
<i>Sicyonia typica</i>	6.30	6.21	6.39	6.28	6.19	6.36	6.51	6.42	6.58	6.45	6.37	6.53
Stomatopoda	7.68	7.41	7.95	8.46	8.17	8.75	7.61	7.36	7.89	8.25	7.97	8.54
<i>Xiphopenaeus kroyeri</i> / <i>Farfantepenaeus notialis</i>	7.08	6.90	7.27	7.28	7.07	7.52	6.77	6.55	6.99	7.18	6.98	7.41

here are one more powerful reason for enforcement of present regulations with regard to TEDs: even if there are no more turtles to protect, TEDs will reduce the bycatch of a number of invertebrates.

Incidental catch (the squid *Loligo* sp. and the lobster *Palinurus argus*) that represent extra income for crew members, is globally not sensitive

to the presence of reducing devices, at least in terms of CPUE (Table III). In the case of *P. argus* the use of both devices (BD configuration) yields a mean CPUE not different from the control (Table III). This is encouraging as crews will show less resistance to actually incorporate the reducing devices in their nets.

**Table III.** Paired test results for mean CPUE. Turtles excluding device configuration (TED), fish reduction device configuration (FRD), both devices configuration (BD) and no device configuration (ND). > or < net configuration to the left or to the right retained significantly ( $p < 0.05$ ) more biomass per unit effort.

Taxonomic category	Test Results
Total Bycatch	ND>FRD, BD; ND>TED ( $p=0.07$ )
<i>Aequipecten lineolaris</i>	ND>TED, BD; ND=FRD
<i>Astropecten</i> sp.	ND>TED, FRD, BD
<i>Atrina seminuda</i>	ND=TED, FRD; ND<BD( $p=0.08$ )
<i>Calappa</i> sp.	ND>TED, FRD, BD
<i>Callinectes</i> sp.	ND>TED, FRD, BD
<i>Euvola ziczac</i>	ND>TED, BD; ND=FRD
<i>Hepatus pudibundus</i>	ND>TED, BD; ND=FRD
<i>Iliacantha liodactylus</i>	ND>TED, FRD, BD
<i>Laevicardium laevigatum</i>	ND>TED, BD; ND=FRD
<i>Leiolambrus nitidus</i>	ND= TED, FRD, BD
<i>Loligo</i> sp.	ND= TED, FRD, BD
<i>Luidia clathrata</i>	ND>TED, BD; ND=FRD
<i>Luidia senegalensis</i>	ND>TED, BD; ND=FRD
<i>Lupella forceps</i>	ND= TED, FRD; ND>BD
Octocorallia	ND>TED, BD; ND>FRD( $p=0.07$ )
<i>Palinurus argus</i>	ND>TED; ND=FRD, BD
<i>Persephona punctata</i>	ND>TED, FRD, BD
<i>Pilumnus sayi</i>	ND>TED; ND=FRD, BD
Porifera	ND>TED; ND=FRD, BD
<i>Portunus gibbesii</i>	ND=TED, BD; ND<FRD
<i>Pseudorhombila quadridentata</i>	ND=TED, FRD, BD
<i>Sycionia typica</i>	ND=TED, FRD; ND>BD
<i>Stenorhynchus seticornis</i>	ND=TED; ND>FRD( $p=0.07$ ); ND>BD
Stomatopoda	ND=TED; ND>FRD, BD
<i>Xiphopenaeus kroyeri</i> / <i>Farfantepenaeus notialis</i>	ND>TED, FRD, BD

**Table IV.** Test results for mean size. Turtles excluding device configuration (TED), fish reduction device configuration (FRD), both devices configuration (BD) and no device configuration (ND). > or < net configuration to the left or to the right retained significantly ( $p < 0.05$ ) bigger individuals.

Taxonomic category	Test
<i>Aequipecten lineolaris</i>	ND= TED, BD; ND<FRD
<i>Asrtropecten</i> sp.	ND= TED, FRD, BD
<i>Callinectes</i> sp.	ND= TED, FRD; ND<BD( $p=0.06$ )
<i>Euvola ziczac</i>	ND= TED, FRD, BD
<i>Iliacantha liodactylus</i>	ND=TED, FRD, BD
<i>Laevicardium laevigatum</i>	ND>TED, FRD; ND<BD( $p=0.07$ )
<i>Loligo</i> sp.	ND=TED, FRD, BD
<i>Ludia clathrata</i>	ND= TED, FRD; ND<BD( $p=0.08$ )
<i>Lupella forceps</i>	ND=TED, FRD, BD
<i>Palinurus argus</i>	ND>TED( $p=0.06$ ); ND>FRD; ND= BD
<i>Persephona punctata</i>	ND=TED, FRD, BD
<i>Portunus gibbesii</i>	ND=TED, FRD, BD
<i>Sicyonia typica</i>	ND=TED, FRD; ND<BD
Stomatopoda	ND>TED, BD; ND=FRD
<i>Xiphopenaeus kroyeri</i> / <i>Farfantepenaeus notialis</i>	ND=TED; ND<FRD( $p=0.08$ ); ND>BD

This fishery has the shrimp *Farfantepenaeus notialis* as objective species, although the shrimp *X. kroyeri* is also of commercial value. Thus the taxonomic category *F. notialis*/*X. kroyeri* is made of undersized and damaged *F. notialis* and *X. kroyeri* that is discarded because it is not profitable to sort it

out from the mass of the capture. Cleaner captures, i.e less bycatch, would be conducive to better revenues. It follows that the incorporation onto trawling nets of reducing devices, TED and FRD alone or together, opens the opportunity of a more efficient shrimp fishery not only because they

significantly reduce total invertebrate bycatch but because they alone or together directly reduce the bycatch of this taxonomic category (Table III).

In a simulation study on the effect of the introduction of a FRD the same type as here Criales-Hernandez *et al.* (2006, Fig. 3, position C) in the shrimp trawl fishery in northern Colombian Caribbean, a definite response of invertebrate groups was demonstrated. After 20 years simulation some invertebrate groups increased their biomass (crabs/other crustaceans, and carnivorous invertebrates) while other showed slight reductions (worms, herbivorous invertebrates, shrimps, asteroids/ophiuroids, lobsters and octopus/squids). These changes in biomass were mostly explained as the result of increased predatory pressure affecting directly or indirectly medium to low trophic levels. A similar effect is to be expected with the introduction of a FRD in this shrimp fishery. When used together with TED the reduction effects on invertebrate bycatch is enhanced as the BD configuration shows the smallest mean CPUE of total bycatch (Table I). Thus, either via direct or indirect trophic interactions, or reduced fishing mortality or both, the introduction of a FRD will positively affect the invertebrate fraction of shrimp bycatch in this fishery and should be made mandatory.

The size of invertebrates is much less sensitive to net configurations than CPUE (Table IV). Convenience or otherwise of changes in mean size related to TED, FRD or to their simultaneous use is also not as clear cut than the case with CPUE was. Whether populations are better off in the long term if bycatch mortality migrates from small to big individuals or vice versa, is an open question probably to be answered in relation to particular life histories (see, for instance, Young *et al.* 2006). Fact is, however, that a number of species (Table IV) will also be affected in this regard. In the

case of *Loligo* sp. mean size is insensitive to net configurations while mean size of *P. argus* remains statistically unchanged when both excluding devices are used (Table IV), thus fishers would have one argument less to reject the use of both excluding devices.

We believe that aspects like season, depth range and time of the day that do affect abundance, composition and size structure of bycatch (Duarte *et al.* 2006) need not be considered in this study as experimental trawling was conducted in the rainy season and at night only and depth range is short (15 to 37 m). Moreover, Manjarres *et al.* (2008) compared the August and December cruises and found no differences in bycatch CPUE.

The use of reduction devices is no panacea and probably in rich species habitats will never be able to eliminate bycatch totally, but they do help not only in the protection of charismatic species or juveniles of commercial fish species as the case here was (Manjarres *et al.* 2008) but they also help in the protection of invertebrates, although, as shown here, their response is deemed to be complex. At any rate every study on bycatch should report fully on invertebrates.

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### References

- Alverson, D. L., Freeberg, M. H., Murawski, S. A. & Pope, J. G. 1994. A global assessment of fisheries bycatch and discards. **FAO Fisheries Technical Papers**, 339: 1–233.
- Broadhurst, M. K., Suunonen, P. & Hulme, A. 2006. Estimating collateral mortality from towed fishing gears. **Fish and Fisheries**, 7: 180–218.
- Criales-Hernandez, M. I., Duarte, L. O., García, C. B. & Manjares, L. 2006. Ecosystem impacts of the introduction of bycatch reduction devices in a tropical shrimp trawl fishery: Insights through simulation. **Fisheries Research**, 77: 333–342.
- Duarte, L. O., Gómez-Canchong, P., Manjarrés, L. M., García, C. B., Escobar, F. D. Altamar, J., Viaña, J. E., Tejada, K., Sánchez, J. & Cuello, F. 2006. Variabilidad circadiana de la tasa de captura y la estructura de tallas en camarones e ictiofauna acompañante en la pesquería de arrastre del Mar Caribe de Colombia. **Investigaciones Marinas (Valparaiso)**, 34(1): 23–42.
- Good, P. I. 2005. **Resampling methods. A practical guide to data analysis**. Birkhäuser. Third Edition, Boston, 219 p.
- Graham, N., 2003. By-catch reduction in the brown

- shrimp, *Crangon crangon*, fisheries using a rigid separation Nordmore grid (grate). **Fisheries Research**, 59: 393-407.
- Hall, S. J., 1999. **The effects of fishing on marine ecosystems and communities**. Blackwell Science, London, 274 p.
- Kelleher, K. 2005. Discards in the world's marine fisheries. An update. **FAO Fisheries Technical Papers**, 470: 1-131.
- Kennelly, S. J. & Broadhurst, M. K. 2002. By-catch begone: changes in the philosophy of fishing technology. **Fish and Fisheries**, 3: 340-355
- Lewis, R., Crowder, L. & Shaver, D. 2004. Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. **Ecological Letters**, 7: 221-231.
- Manjarres, L., Duarte, L. O., Altamar, J., Escobar, F., García, C., Cuello, F., Viaña, J. E., Tejada, K. & Sanchez, J. 2008. Efectos del uso de dispositivos reductores de pesca acompañante en la pesquería de camarón del mar Caribe de Colombia. **Ciencias Marinas**, 34(2): 223-238
- Manly, B. F., 1997. **Randomization, bootstrap and Monte Carlo methods in biology**. Chapman and Hall, Second Edition, London, 399 p.
- Read, A., Drinker, P. & Northridge, S. 2006. Bycatch of marine mammals in U.S. and global fisheries. **Conservation Biology**, 20(1): 163-169.
- Steele, P., Bert, T., Johnstone, K. & Levett, S. 2002. Efficiency of bycatch reduction devices in small otter trawls used in the Florida shrimp fishery. **Fishery Bulletin**, 100(2): 338-351.
- Thrush, S. & Dayton, P. 2002. Disturbance to marine benthic habitats by trawling and dredging. Implications for marine biodiversity. **Annual Review of Ecology and Systematics**, 33: 449-473
- Uhlmann, S., Fletcher, D. & Moller, H. 2005. Estimating incidental takes of shearwaters in driftnet fisheries: lessons for the conservation of seabirds. **Biological Conservation**, 123(2), 151-163
- Watling, L. & Norse, E. 1998. Disturbance of the seabed by mobile fishing gear: a comparison to forest cutting. **Conservation Biology**, 12(6): 1180-1197
- Young, J. L., Bornik, Z. B., Marcotte, M. L., Charlie, K. N., Wagner, G. N., Hinch, S. G & Cooke, S. J. 2006. Integrating physiology and life history to improve fisheries management and conservation. **Fish and Fisheries**, 7: 262-283.

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