REDUCING BYCATCH WITH BETTER TECHNOLOGY IN THE GULF OF CALIFORNIA SHRIMP FISHERY

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I N D E X

I. INTRODUCTION AND PROJECT SUMMARY

Many experts believe that the most ecologically damaging fishery in the Gulf of California is the shrimp trawl fishery. Antiquated gear and overcapacity in the shrimp trawl fishery results in very high bycatch rates that take a heavy toll on the Gulf ecosystem. Furthermore, the potential catch killed through trawling is income taken away from artisanal and other fishers and represents high volumes of wasted biomass. Although part of the bycatch is commonly kept by crews of industrial shrimpers as an extra income, if juvenile organisms would be allowed to grow to maturity, its commercial value would surely twice that of the shrimp harvest[1].

This project attempts to address the above concerns by testing the effectiveness and efficiency of the industrial and artisanal versions of a bycatch reduction device, the "RS-INP" trawling prototype, in the Gulf of California. The "RS-INP" trawling prototype has been developed by the National Fisheries Institute of Mexico (INAPESCA) during the past 20 years and previous tests performed with this gear in the southern Mexican Pacific revealed that shrimp catches were cleaner and that the prototype also eliminated the bycatch risk for endangered species such as sea turtles and vaquita (*Phocoena sinus*). Through additional testing, the project evaluated: i) the effectiveness and efficiency of the industrial and artisanal versions of the "RS-INP" trawling prototype in the Gulf of California; ii) operational and economic merits; and iii) possibilities for a widespread regional adoption.
Fishing trials were undertaken test the gear on board two different types of vessels: commercial industrial vessels and artisanal shrimpers of the Mexican Pacific. The industrial

[1] Garcia, J.M. and Gomez Palafox, J.V. La pesca industrial de camarón en el Golfo de California: situación economico-financiera e impactos socio-ambientales. Conservation International: 2005.

and artisanal versions of the “RS-INP” prototype were compared to their traditional counterparts in terms of bycatch-to-shrimp ratios, catch efficiency, indicators of drag resistance, fuel consumption rate and selectivity. The industrial fishing effort took place between Sonoran and Sinaloan waters, while the artisanal testing occurred in Sinaloa, Southern Baja California and the Upper Gulf of California.

We found that the industrial version of the “RS-INP” prototype reduced bycatch-to-shrimp ratios between 20-50%, without reducing shrimp production. Trials undertaken with artisanal fleets from Magdalena-Almejas Bay revealed a higher performance of the “RS-INP” for reducing bycatch-to-shrimp ratios in comparison to the traditional trawling gear, even under conditions of naturally low shrimp availability. Artisanal trials performed in the Upper Gulf revealed that comparisons between the “RS-INP” prototype and drift gillnets are complicated given the drastic differences between the prototype and drift gillnets, the gear traditionally used for shrimp fishing in that area. The analysis of trials undertaken on board the “Mario Moreno I” and “Mario Moreno III” industrial trawlers demonstrated the absence of significant differences between the prototype and the traditional gear in terms of catching shrimp, while at the same time, the trials showed that the traditional gear resulted in a significantly higher amount of fish bycatch, while the prototype resulted in a significantly higher proportion of shrimp in the total catch.

In general terms, catch efficiency indicators for the industrial prototype were higher than the traditional trawling system and the prototype offered less resistance to drag forces than the traditional system. Furthermore, industrial trawlers consumed less fuel when using the “RS-INP” prototype. The industrial and artisanal versions of the prototype and traditional gears caught similar sizes of shrimp, but with artisanal gear, the size selectivity for the prototype was higher. The typical total catch obtained by the industrial prototype and the industrial traditional gear showed practically the same taxonomic composition.

Detailed statistical analyses[2] were performed on data obtained onboard industrial trawlers and artisanal boats of Magdalena-Almeja Bay (Southern Baja, California) and Dautillos (Sinaloa), to determine whether a discard effect in species or sizes was detectable comparing the catch of the prototype and the traditional gear during trails on board the industrial fleet. According to tests[3], significant differences between the prototype and the traditional gear were absent in terms of the size structure of shrimp and bycatch species, relative abundance of shrimp and bycatch, and shrimp and bycatch yields. The moment of the commercial season at which trials are performed is crucial, because the combination of high efficiency of commercial fleets for reducing shrimp stocks and high spatial and temporal variability in occurrence and abundance of shrimp and bycatch affect the statistical significance of the results.

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[2] Statistical analyses included: Cohort Analyses; ANOVAs after application of the Pennington statistic for reducing the variance of means; Wilcoxon rank tests and Discriminant Analysis using Wilks Lambda and total percentages as performance indicators.

[3] Tests were undertaken considering delta, normal, free and Kappenman statistic distributions.

We estimated the need of capital and cash flow along the season for a typical industrial trawler under the scenario of using the traditional trawling system and using the "RS-INP" trawling prototype. We also estimated interim return rates and actual net values at successive seasons, for defining the economic profitability of continuously using the industrial version of the prototype. Even though we assumed that both trawling systems were equally efficient and that neither differed in their catch quality (shrimp sizes), the use of the prototype reduced the work capital by ≈17% and increased the seasonal balance. When using the traditional trawling system, the interim return rate is negative 26.3% and after five seasons it would have been necessary to again invest USD $4,140. When using the prototype, the interim return rate goes to 85.4% and at the investment necessary for acquiring the prototype would have been recovered (approximately USD $171,875) after three fishing seasons. The residual value of the prototype would also be higher.

At the present, there are positive signals regarding conditions and interest for massively adopting the "RS-INP" trawling prototype by regional industrial and artisanal fleets. Nevertheless, costs related to necessary training for fishers and netters on construction, use and maintenance of the prototype have not yet been estimated. Due to the experimental nature of catch technologies, we discussed the disconnect between obtaining selectivity and performance results with sound statistical significance for convincing decision makers and the importance of excusing statistics and promoting the change based on economic reasons and the precautionary principle.

During the project, INAPESCA promoted the prototype at national and international scientific meetings and submitted the prototype to the 2009 International Smart Gear competition. INAPESCA is also requesting an international institutional patent for the prototype through the Mexican Institute of Intellectual Property. The project was useful also for other Mexican federal institutions, such as the National Commissions of Fisheries and Aquaculture and Natural Protected Areas, since the prototype was tested as an alternative for replacing drift gillnets in the Upper Gulf of California.

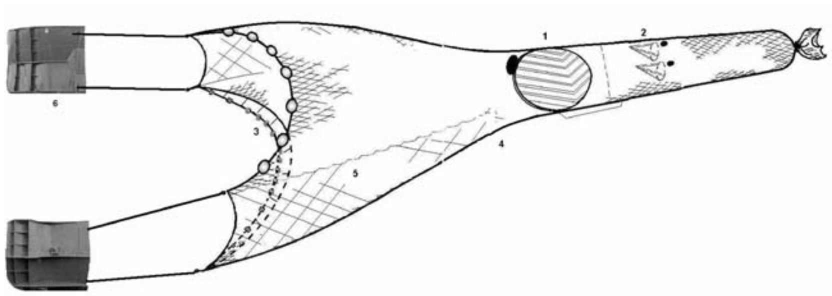
INAPESCA also agreed with the U.S. National Oceanic and Atmospheric Administration (NOAA) Southeast Fisheries Science Center on testing the artisanal and industrial prototypes with US-shrimpers from the Gulf of Mexico. With support of the United Nations Food and Agriculture Organization (FAO), INAPESCA now plans to test the prototype with industrial and artisanal Mexican fleets from Campeche and Tamaulipas (Gulf of Mexico). Sinaloan representatives of the National Chamber of Fisheries of Mexico (CANAINPESCA) have requested that INAPESCA continue the experiments with the prototype. In response, INAPESCA will undertake training workshops on the construction and operation of the prototype for local fishers and netters. WWF is currently evaluating the possibility of continuing to support INAPESCA in its next enterprises with the "RS-INP" prototype in the Gulf of Mexico and Sinaloa, through its fisheries program for the Mexican Caribbean and the WWF-Carlos Slim Foundation Alliance.

II. PROJECT BACKGROUND

The Mexican government, shrimp producers and civil society are interested in developing and testing technologies for reducing bycatch and fishing costs within the Gulf of California shrimp trawl fishery. Bycatch reduction devices have been tested for several years in the Gulf with varied effectiveness (e.g. reductions between 7-40% of bycatch volumes with minor losses in shrimp catch[1]). Nevertheless, at the present only sea turtle excluding devices are mandatory.

Over the past 20 years, INAPESCA has developed the prototype trawling net, “RS-INP”. A partial result of that process has been the “Magdalena I” trawling net, widely used in the Magdalena-Almejas Bay (Southern Baja, California). Based on this initial design, the “RS-INP” industrial and artisanal prototype was developed in 2001 with support of the Global Environment Facility and the United Nations Food and Agriculture Organization[4]. Previous trials of the prototype suggested that shrimp production was clean and that the device eliminated the bycatch risk for endangered species such as sea turtles and vaquita.

Industrial and artisanal versions of the “RS-INP” prototype share the same general configuration (Fig 1), but the industrial prototype uses hydrodynamic steel trawling doors, while the artisanal version uses fiberglass trawling doors. SPECTRA mesh is the standard net material for both versions.



1. "Super Shooter" turtle excluder devise
2. "Fish Eye" bycatch reduction devise
3. Second footrope lader with rubber rollers
4. Knotless webbing pannel made of polyethylene high tenacity fibres
5. Mesh size gradient along the net (wing=3", body=2 1/4"; end= 2")
6. Hydrodynamic stainless steel trawl doors

Fig. 1. Configuration of the “RS-INP” prototype trawling net.

With support from the Walton Family Foundation, INAPESCA and WWF evaluated the effectiveness and efficiency of the industrial and artisanal versions of the “RS-INP” trawling prototype in the Gulf of California, as well as its operational and economic merits. We also evaluated possibilities for widespread regional adoption. This project formed a key part of WWF’s “Gulf of California Sustainable Shrimp Initiative,” a regional and multi-institutional

[4] ftp://ftp.fao.org/FI/DOCUMENT/rebyc/BycatchBook_Final_05.pdf

effort supported by several foundations which aims to reduce the ecological impact of shrimp trawl fisheries and optimize their economic value.

III. MATERIALS AND METHODS

Nets for the industrial version of the prototype were 110 feet long and those of the artisanal nets were 50 feet long (please see the appendix for detailed designs for both versions). Additional instruments were used for monitoring the efficiency of excluding devices and measuring drag forces and fuel consumption. Nets were tested on board industrial and artisanal vessels representative of the commercial shrimp fleets of the Pacific Ocean (Table I, Fig. 2).

Table I. Main features of industrial trawlers used in the project.

Name	Year of construction	Material	Total length	Total width	Engine power (HP)
“BIP-XI”	1980	Steel	22.6	7.32	500
“Mario Moreno I”	1989	Steel	20.0	6.0	402
“Mario Moreno III”	1989	Steel	20	6.0	402
“GEOMAR IV”	1973	Steel	22.3	6.0	400

Industrial and artisanal versions of the “RS-INP” prototype were compared to their traditional counterparts in terms of bycatch-to-shrimp ratios, catch efficiency[5,6,7], indicators for drag resistance, fuel consumption rates[8,9] and selectivity[10]. The effort applied with industrial trawlers in Sonoran and Sinaloan waters is summarized in Table II.

Fig. 2. Industrial shrimp trawlers used in the project. a) “BIP XI”, b) “Mario Moreno III”, c) “Marion Moreno I”.

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5 Gulland, J.A 1983 Fish Stock Assessment A Manual of Basic Methods Vol. 1 John Wiley & Sons.

6 Fridman, A. 1973 Theory and Design of Commercial Fishing Gear. 489 p.

7 Fridman, A. I. 1986 Calculations for Fishing Gear Designs. Fishing News Books, Ltd.241 p.

8 Tait, D. 2002, Improving Economic Viability on Offshore Shrimp Trawlers by Gear and Fuel Efficiency. Dep. Fish. Oc. Responsible Fish. Oper. US Program of Energy Research and Development.

9 McIlwaine, R. and M. Borstad, 2003. Energy efficient twin trawl system for the British Columbia Trawl Fishery. Natural Resources Canada (PERD) Energy Efficiency Task.

10 Pope, J.A.; A.R. Margetts; J.M. Hamley and E.F. Akyüz, 1983. Manual de métodos para la evaluación de las poblaciones de peces. Parte 3. Selectividad del arte de pesca. FAO. Doc. Téc. Pesca, (41) Rev. 1:56 p.

Table II. Effort applied on board industrial trawlers.

Campaign/Date	Description	Number of fishing trials	Accumulated trawling time (hrs)	Average duration of a single fishing trial (hrs)	Average depth (fathoms)
A (Oct 9-25, 2007)	Simultaneous comparisons between the “Phantom” net and the RS-INP prototype on board the “BIP XI”	38	254.6	2.9	11.6 (min= 6.5, max=16.5)
B (Jan30 – Feb 8, 2008)	Single trials with the “Phantom” net on board the “Mario Moreno I”	36	269.1	3.7	9.6 (min=5.4, max=18.0)
C (Jan 30 – Feb 8, 2008)	Single trials with the RS-INP prototype on board the “Mario Moreno III”	32	120.5	3.4	9.6 (min=2.0, max=18.5)
D (Feb 15-23, 2008)	Simultaneous comparisons between the “Phantom” net and the RS-INP prototype on board the “Mario Moreno III”	30	73.2	2.1	8.1 (min=4.9, max=19.0)
E (Feb 14-Mar 6, 2008)	Single trials with the RS-INP prototype v.1.0 (110 ft long, 2.5 m2 trawling doors) on board the “GEOMAR”	22	87	3.8	
	Single trials with the RS-INP prototype v.1.1 (120 ft long, 2.5 m2 trawling doors) on board the “GEOMAR”	14	52		
	Single trials with the RS-INP prototype v.1.2 (110 ft long, 3.0 m2 trawling doors) on board the “GEOMAR”	18	71		
	Simultaneous comparisons with the RS-INP prototype v.1.3 (120 ft long, 3.0 m2 trawling doors) and the Phantom 1.0 (120 ft long, Spectra, 3.0 m2 trawling doors) on board the “GEOMAR”	6	25		
	Single trials with the Phantom 1.1 (110 ft long, 450 Kg. trawling doors) on board the “GEOMAR”	5	13		

Table III. Effort applied on board artisanal fleets.

Location	Date	Number of trials (paired)	Accumulated trawling time (hrs)
La Reforma (Sinaloa)	Feb 18-22, 2008	80	46
Magdalena-Almejas Bay (Southern Baja, California)	Sep 14-Oct 2, 2008	243	558
Upper Gulf of California (Golfo de Santa Clara, Sonora and San Felipe, Baja, California)	Nov 17-Dec 21, 2008	296	-

Figures 3 and 4 provide a general visual description of the field activities of the project.

The testing onboard the industrial trawler “BIP XI” demonstrated that trawling simultaneously with traditional and prototype gears is challenging, since weight differences and drag forces distort the underwater geometry of both gears. In successive tests, parallel comparisons (two individual trawlers operating simultaneously in the same fishing ground) or sequential comparisons (a single trawler separately using both gears in the same fishing ground) were preferred.

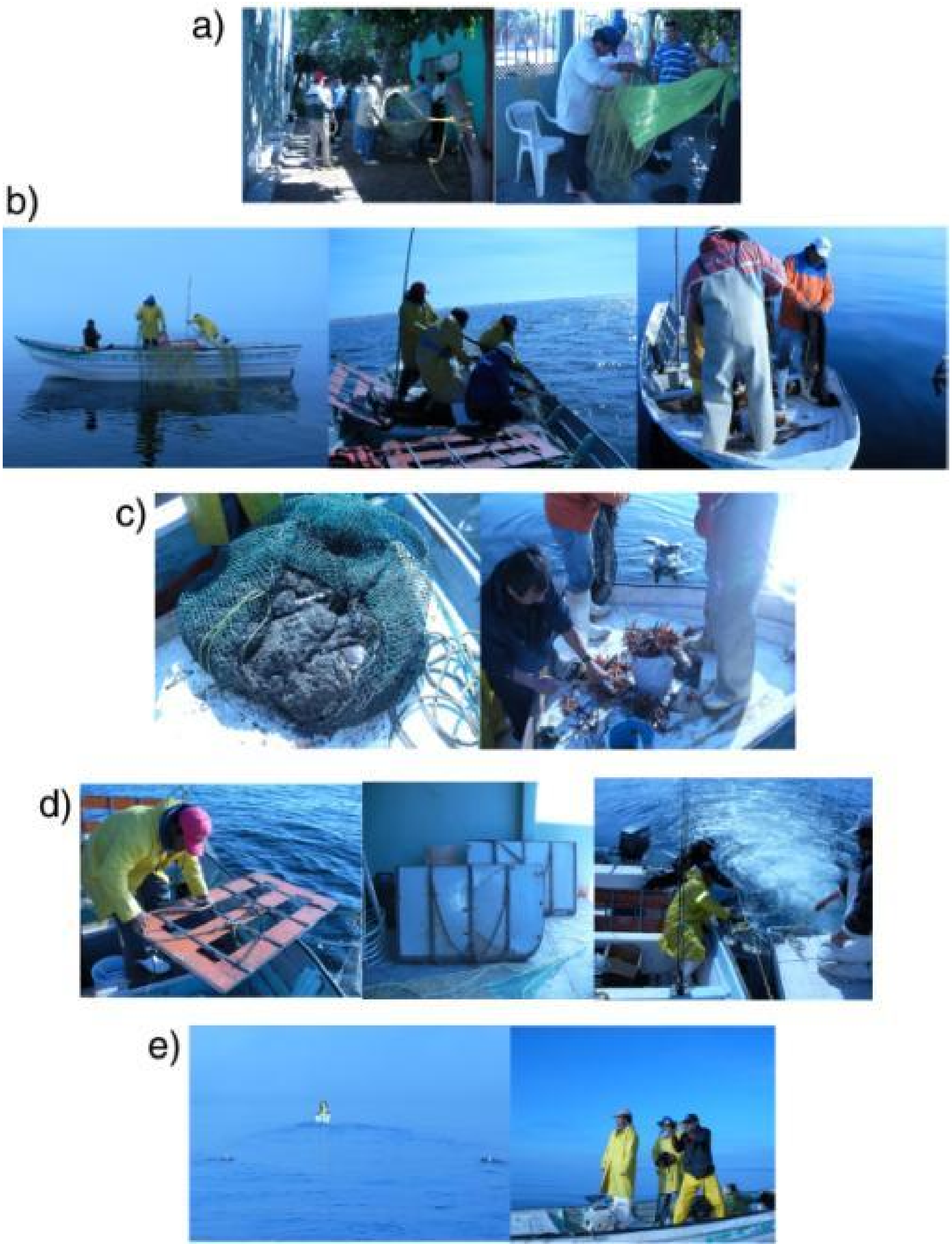

Fig. 3. Activities performed on board artisanal fleets. a) Preparation of the "RS-INP" prototype with fishers from Sinaloa; b) Deployment and recovery of the traditional trawling

gear used in Sinaloa; c) Mud and a sample of bycatch collected by the traditional trawling gear; d) Traditional (left) and prototype (center) trawling doors and measurement of the drag tension during the trawling (right); e) Calibration of the trawling gear: buoys are used as geometry indicators and sextants measure operation angles.

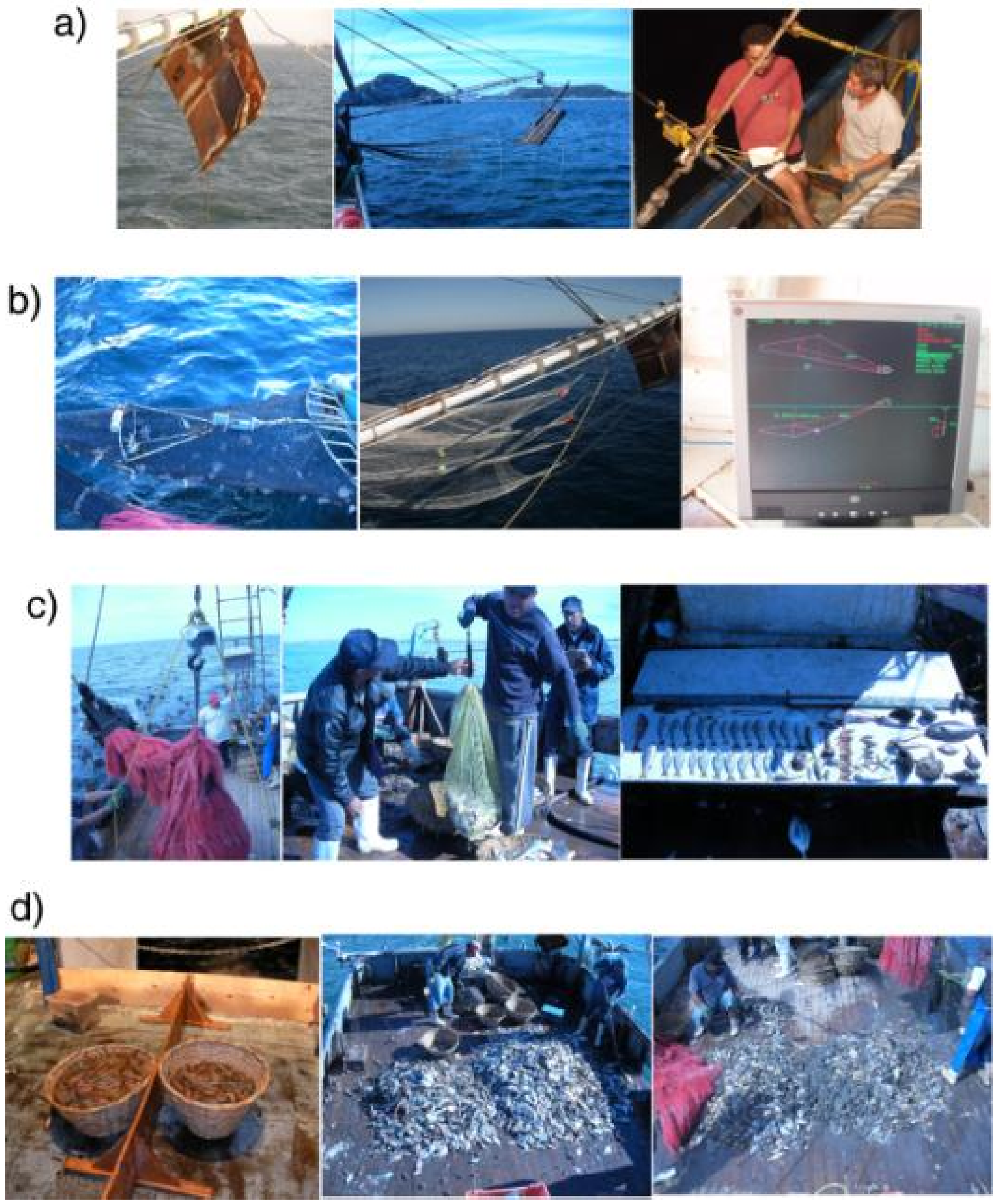

Fig. 4. Activities performed on board industrial trawlers. a) Steel hydrodynamic trawling doors (left) used with the prototype, traditional wood trawling doors (center) and measurement of drag forces during a fishing trial; b) Underwater video camera used for monitoring the effectiveness of fish excluding devices (left), and underwater sensors used for defining the

underwater geometry of the trawling gear (center and right); c) Weighting of the total catch (left) and bycatch (center), and sorting of bycatch samples (right); d) Some qualitative advantages of the "RS-INP" prototype over the traditional gear: Higher volumes of shrimp (left), minor total catch volumes (center) and mud free catch (right).

IV. RESULTS

IV.1. Bycatch-to-shrimp ratios.

The industrial version of the "RS-INP" prototype reduced bycatch-to-shrimp ratios between 20-50%, without reducing shrimp productions (Table IV). A similar performance was observed during campaign E (Fig. 5).

Table IV. Comparative advantages of the RS-INP prototype over the traditional industrial nets.

TESTING	TRADITIONAL NET			RS-INP PROTOTYPE		
	Total catch of shrimp (Kg)	Shrimp-to-Bycatch ratio	Proportion of economically valuable bycatch (%)	Total catch of shrimp (Kg)	Shrimp-to-Bycatch ratio	Proportion of economically valuable bycatch (%)
B vs. C	239	69:1	66.6	433	33:1	56.2
D	134	46:1	-	139	38:1	-

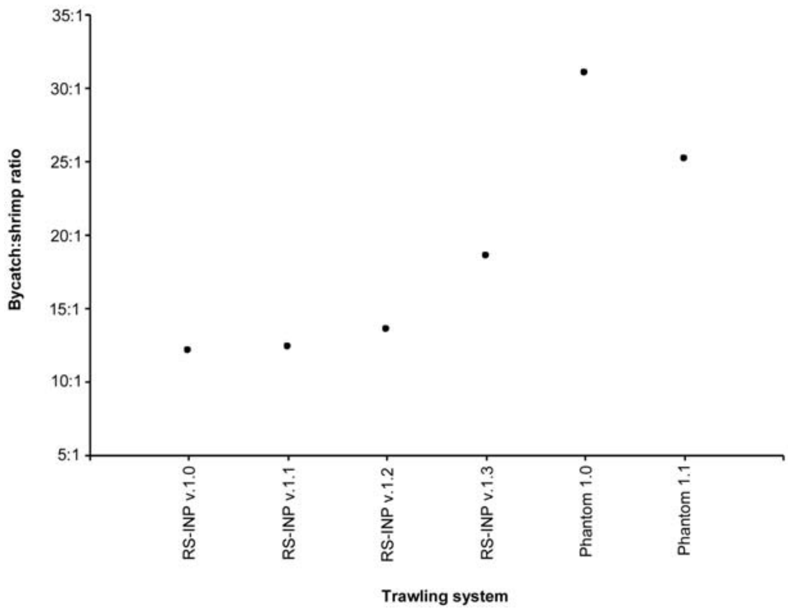

Fig. 5. Bycatch-to-shrimp ratios obtained during the "Test E" with different trawling systems.

The moment of the commercial season when bycatch-to-shrimp ratio comparisons are made is critical. For example, during artisanal fishing trials undertaken in Sinaloa, the natural availability of shrimp was extremely low and only six kilograms of shrimp were obtained from a total catch of 440 Kg (bycatch-to-shrimp ratio= 69:1). Commercial fleets are extremely efficient and reduce shrimp stocks rapidly during the first weeks of the season. In some areas, such as the Upper Gulf, frequent rough sea conditions further reduce the natural availability of shrimp through bathymetric migrations.

Under conditions of low shrimp availability, comparison between traditional gears such as drift gillnets and the prototype are complicated due to differences in operation of the two types of gear, and the related differences in the shrimp vulnerability resulting from usage of each type of gear. For example, due to its dimensions, the artisanal "RS-INP" prototype can trawl up to three hectares/hour, while a 1.3 Km long drifting gillnet used by artisanal fishers at the Upper Gulf covers 1,690 hectares/hour. A drift gillnet covers 563 times more area than the "RS-INP" prototype and its probabilities of catching shrimp (even under natural low availability) are obviously much higher. During the tests performed in the Upper Gulf with artisanal fishers, drift gillnets caught 900 Kg of shrimp, while the "RS-INP" prototype only obtained 100 Kg of shrimp.

IV.2. Catch efficiency

In general terms, catch efficiency indicators for the industrial prototype were higher than the traditional trawling system (Table V). It is worth noting that the indicator "Shrimp Kg/hectare (Ha)" is similar for the traditional trawling system and the prototype. Despite the prototype's smaller dimensions, its mouth tends to open wider which enables it to compensates and cover a wide area. The prototype offered less resistance to drag forces than the traditional system (Table VI).

Table V. Averaged catch performance indicators for the traditional industrial trawling system and the industrial version of the "RS-INP" prototype.

CATCH EFFICIENCY INDICATOR	"PHANTOM" SYSTEM	"RS-INP" PROTOTYPE
Shrimp Kg/fishing trial	6.6	13.5
Shrimp Kg/hr	0.9	3.6
Shrimp Kg/Ha	0.35	0.31
Bycatch Kg/Ha	1.4	0.5

Table VI. Drag force indicators for the traditional and prototype trawling systems.

INDICATORS	"PHANTOM" SYSTEM	"RS-INP" PROTOTYPE
Average trawling speed	2.1	2.3
Max. trawling speed	2.2	3.0
Min. trawling speed	1.9	1.6
Average RPM	1412	1402
Max. RPM	3400	1440
Min. RPM	1300	1340
Drag force (KgF)	1150-1194	871-730

Industrial trawlers consumed less fuel when using the “RS-INP” prototype (Table VII). A comparison between different configurations of the prototype revealed the most efficient configurations: 110 ft and 2.5-3.0 meters^2 trawling doors; 120 ft and 2.5meters^2 trawling doors.

Table VII. Fuel consumes indicators.

Trawling system	Motor power (RPM)	Fuel consume (lt/hr)	Total catch (Kg)
RS-INP v.1.0	909	40.8	4000
RS-INP v.1.1	909	42.8	3000
RS-INP v.1.2	921	43.0	
RS-INP v.1.3	940		2500
Phantom 1.0	940	47.2	1500
Phantom 1.1	950	47.8	1900

Derived from the measurement of shrimp samples obtained during the trials[11], we observed that the industrial and artisanal versions of the prototype and the traditional gears did not differ in size ranges of shrimp caught (140-160 millimeters). Nevertheless, the size selectivity for the artisanal version of the “RS-INP” prototype was higher than that of the industrial version of the prototype (180 mm vs. 150 mm).

The typical total catch obtained by the industrial prototype and the industrial traditional gear showed practically the same taxonomic composition (Table VIII).

Table VIII. Taxonomic compositions of the traditional industrial trawling gear and the industrial “RS-INP” prototype.

TAXONOMIC GROUP	“PHANTOM” SYSTEM	“RS-INP” PROTOTYPE
Fishes	90%	89%
Mollusks	6%	6%
Crustaceans	4%	3%
Others	0%	2%

In order to determine whether a discard effect (particular species or sizes) was detectable in the catch obtained by the prototype when compared to the traditional gear, INAPESCA carried out detailed statistical analyses[12] for the following variables and considered data gathered during trials onboard the industrial trawlers and artisanal trials at Magdalena-Almeja Bay (Southern Baja, California) and Dautillos (Sinaloa):

i) size structure of shrimp species and by caught species;
ii) relative abundance of shrimp and bycatch; and
iii) shrimp and bycatch yields.

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[11] 18,444 shrimp on board industrial trawlers and 13,919 shrimp on board artisanal boats.

[12] Analyses performed were Cohort Analyses; ANOVAs after application of the Pennington statistic for lognormal transformation and reduction of the variance of means12,12; Wilcoxon rank tests and Discriminant Analysis using Wilks Lambda and total percentages as performance indicators12.

Data was managed considering delta, normal, free and Kappenman[13] statistic distributions. All tests for all variables indicated the absence of significant differences between the prototype and the traditional gears. The Kappenman estimator did not detected extreme abundance values for any trial, neither for shrimp nor for bycatch. Extreme values in that estimator are frequent when shrimp abundance is high. This suggests that shrimp and bycatch populations were at similarly depressed levels at the moments that trials were performed[14]. According to the Cohort Analysis, the catch of traditional and prototype gears near coastal lagoons tends to be composed by a single cohort of shrimp and bycatch, but at open waters catches were composed by up to three cohorts. This implies that the operation of both gears at the coastal zone might affect only one age class.

IV.3. Economic performance of the "RS-INP" prototype and strategies for its widespread regional adoption.

Along with this and other projects, we have experienced how difficult it is to obtain information about real operational costs and gains of industrial and artisanal shrimp producers. Producers manage this information as industrial "secrets" and many artisanal fishers lack of the discipline for recording key financial information.

Despite the difficulties and uncertainties surrounding the integrity of the data, INAPESCA collected isolated information from a few collaborative producers, as well as published studies and official statistics. However, the economic analyses undertaken with the information collected have not been finished yet. Thus far, we have constructed a theoretical breakdown of monthly production costs and gains of a typical industrial shrimp trawler[15] during the commercial shrimp fishing season. This enabled us to determine the seasonal need of capital and cash flow when using the traditional gear and when using the prototype. We also estimated interim return rates and actual net values for successive seasons, in order to determine the profitability of continuously using the prototype in successive seasons. All analyses for the artisanal prototype have yet being undertaken.

According to our estimates, accumulated savings derived from the use of the "RS-INP" would increase the profitability of an industrial shrimp trawler in comparison to the use of the traditional trawling system (Table IX). As with the results shown above, we assume that the industrial "RS-INP" prototype and the traditional trawling system catch shrimp with the same sizes (quality), but we were conservative considering that both systems are equally efficient (our results shown that the prototype is more efficient). In spite of this, the use of the prototype reduced the work capital by ≈17% and increased the seasonal balance.

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[13] Kappenman, R.F., 1999. Trawl survey based abundance estimation using data sets with unusually large catches. ICES J. Mar. Sci. 56,28-35.

[14] Gamito, R. and H. Cabral. 2003. Mortality of brown-shrimp discards from the beam trawl fishery in the Tagus estuary, Portugal. Fish. Res. 63:423-427.

[15] Steel trawler (72 feet long), with diesel engine (550 HP), 28 days of effective fishing per month, total shrimp catch of 15 Tons/season (only tails) placing 80% of the catch at international markets.

Table IX. Theoretical comparison of economic performance of a typical industrial shrimp trawler using the traditional trawling system and the "RS-INP" prototype.

	Traditional trawling system US Dollars	"RS-INP" prototype US Dollars
Seasonal incomes	$185,692.89	$185,692.89
Seasonal variable and fixed expenses	$176,109.84	$158,320.16
Seasonal balance	$9,583.05	$27,372.73
Work capital	$24,840.86	$20,703.75

Given this, we estimated the economic viability for a typical trawler for investing in the acquisition and use of the "RS-INP" trawling prototype ($39,062) instead of a traditional trawling system $4,687) in a run of five commercial fishing seasons. We found that in the case of using the traditional trawling system, the interim return rate is -26.3% and the actual net value indicates that, after five seasons, fishers will need to invest another $4,140. When using the prototype, the interim return rate goes to 85.4% and the investments made for acquiring the prototype was easily recovered (approximately $171,875). The residual value of the prototype is higher than that of the traditional trawling system.

Due to the experimental nature of the prototype, there is no real data yet about its economic performance along an entire commercial season, but perspectives are positive. For example, results shown above indicated that the size selectivity for the artisanal prototype was higher than that of the industrial prototype. This means that incomes from the artisanal fishers for using the prototype must be higher, since they would catch shrimp of higher quality (180 mm of length).

The eventual widespread transference of the "RS-INP" prototype technology to regional artisanal and industrial fleets has related costs which have not yet been estimated, but which are associated to the necessary training on construction, use and maintenance of the gear. These costs were incurred by the project particularly during the artisanal trials performed in the Upper Gulf where local fishers are not familiar with the construction and operation of trawling systems. As a result, we had to temporarily hire ten artisanal fishers from Magdalena Bay (Southern Baja, California) to assist in training of local fishers. Two workshops on techniques and tactics for fishing with trawling nets and ten pilot fishing travels were also necessary before having the local fishers were equipped with basic skills needed to use the gear.

In order to modernize the industrial fleet, the Mexican government has supported fishers by providing them with SPECTRA nets (lighter than traditional nets), but an improvement in the mesh material does not necessarily improve selectivity, since all aspects related to design of the net body and coupling of excluding devices and hydrodynamic trawling doors is still missing. Industrial fishers from Sinaloa have shown interest in continuing to be informed about the performance of the prototype and the association has been informed about this type of experiment for improving the selectivity and efficiency of shrimp fleets.

V. DISCUSSION OF DATA

Inefficient fishing gears and the associated detriment to shrimp and fish stocks has resulted not only in negative impacts to fisheries, but also in the depletion of target species and degradation to other components of the marine ecosystem[16,17]. Annex I shows the main bycatch species from this project and illustrates the wide variety of species that eventually die and get discarded[18,19,20]. This justifies the search of technologies for increasing selectivity, reducing ecologic damages and reducing operational costs[21,22,23,24,25,26,27]. Nevertheless, studies involving bycatch are not simple and direct, since bycatch is a complex function of geography, seasonality and fishing gear.

Occurrence and abundance of target and bycatch species fluctuate due to biological processes such as reproduction, migrations, etc[25,28,29]. This has been demonstrated for the coastal lagoons of Sinaloa, where sound time series have been defined for <10 out of hundreds of species composing bycatch, because of their high spatial and seasonal variability[30]. We must bear in mind that experiments reported here were undertaken during one of the worst historical fishing

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16 Pauly, D., V. Christensen, S. Guénette, T. Pitcher, R. Sumaila, C. Walters, R. Watson y D. Zeller. 2002. Towards sustainability in fisheries management. Nature. 418:689-695.

17 Lewinson, R., L. Crowder, A. Read y S. Freeman. 2004. Understanding impacts of fisheries bycatch on marine mega-fauna. Trends Ecol. Evol. 19(11):598-604.

18 Erzini, K., M. Costa, L. Bentes, y T. Borges. 2002. A comparative study of the species composition of discards from five fisheries from Algarve (southern Portugal). Fish Manag. Ecol. 9:31-40

19 Burridge, C.Y., T. Pitcher, T.J. Wassenberg, I.R. Poiner, B.J. Hill. 2003. Measurements of the rate depletion of benthic fauna by prawn (shrimp) otter trawls: an experiment in the Great Barrier reef, Australia. Fish. Res. 60:237-253.

20 Acosta, M.E., K. Erzini y T. Cerveira. 2008. Bycatch of crustacean and fish bottom trawl fisheries from southern Portugal (Algarve). Sci. Mar. 72(4): 801-814.

21 Hannah, R.W., S.A. Jones. 2003. Measuring the height of the fishing line and its effect on shrimp catch and bycath in an ocean shrimp (*Pandalus jordani*) trawl. Fish. Res. 60:427-438.

22 Fonseca, P., A. Campos, R. Larsen, T. Borges y K. Erzini. 2005. Using a modified Nordmore grid for by-catch reduction in the Portuguese crustacean-trawl fishery. Fish. Res. 71(2):223-239.

23 Fonseca, P., A. Campos, B. Mendes y R. Larsen. 2005. Potential use of a Nordmore grid for by-catch reduction in a Portuguese bottom-trawl multispecies fishery. Fish. Res. 71(1-2):49-66.

24 Ye, Y., A.H. Alsaffar, H.M.A. Mohammed. 2000. Bycatch and discards of the Kuwait shrimp fishery. Fish. Res. 45:9-19.

25 Stergiou, K., A. Machias, S. Somarakis y A. Kapantagakis. 2003. Can we define target species in Mediterranean trawl fisheries?. Fish. Res. 59(3):431-435.

26 Sbrana, M.- P. Sartor y P. Belcari. 2003. Analysis of the factors affecting crustacean trawl fishery catch rates in the northern Tyrrhenian Sea (western Mediterranean). Fish. Res. 65(1-3):271-284.

27 Wieland, K., M. Storr-Paulsen. 2006. Effect of tow duration on catch rate and size composition of Northern shrimp (*Pandalus borealis*) and Greenland halibut (*Reinhardtius hippoglossoides*) in the West Greenland bottom trawl survey. Fish. Res. 78:276-285.

28 Gamito, R. and H. Cabral. 2003. Mortality of brown-srimp discards from the beam trawl fishery in the Tagus estuary, Portugal. Fish. Res. 63:423-427.

29 Liggins, G., S. Kennely y M. Broadhurst. 1996. Observer based survey of by-catch from a prawn trawling in Botany Bay and Port Jackson, New South Wales. Mar. Freshw. Res. 47(7): 877-888.

30 Madrid-Vera, J., F. Amezcua and E. Morales-Bojórquez. 2007. An assessment approach to estimate biomass of fish communities from bycatch data in a tropical shrimp-trawl fishery. Fish. Res. 83:81-89.

seasons for shrimp in Mexico (the commercial season 2008-2009), due to the extremely low natural availability of shrimp existing at that time.

Due to the lack of knowledge about stable periods of bycatch abundance and distribution, it is extremely difficult to estimate sound biological reference points[31] as the amount of bycatch obtained by a fishing trial can be the result of natural effects, instead of gear selectivity.

We sought to emphasize advantages of the prototype over the traditional trawling systems, but we only found statistical significance by managing selected pieces of the total generated information (the Magdalena-Almejas Bay and the "Mario Moreno I" and "Mario Moreno III" data sets). However, the extensive statistical analysis we undertook to the complete data collected indicated the absence of significant differences between the prototype and the traditional gear. Strictly speaking, we should conclude that both gears do not differ regarding their effects on bycatch. But, we must bear in mind that seasonality and timing inside the commercial season play an important role, particularly when shrimp and bycatch abundances are rapidly depleted or vary drastically in space and time.
These factors will always hinder compliance with experimental designs and obtaining statistical significance: limited financial resources, high costs of experimenting with catch technologies, wide variability in abundance and distribution of target and bycatch species, as well as the occurrence of accidents and delays.

The existence of statistical significance will always be an obligatory element for decision makers to take action, but under the conditions already described, criteria such as the precautionary approach should also be taken into account, particularly when it is widely recognized that current fishing operations of most of the regional shrimpers are obsolete and only profitable through costly public subsidies. In other words, if the advantages of the prototype are not recognized because of the statistical significance of its selectivity, economic justification and results should be considered.

In addition to the experimenting with catch technologies, INAPESCA and WWF aim to improve the general condition of regional shrimp fisheries by means of another joint ongoing project that designs ecosystem-based management (EBM) schemes for industrial and artisanal fleets. Our EBM approach aims to manage fleets spatially and temporally, so they obtain the highest possible shrimp quality under the majority of economic conditions and with the lowest bycatch levels[32].

VI. PROJECT IMPACT

This project supported the first trials of the current complete version of the prototype within the Gulf of California, Mexico's most important fishing area. Results of our efforts under this

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31 Haddon, M. 2001. Modeling and quantitative methods in fisheries. Chapman & Hall/CRC, New York.

32 "Shrimp fisheries in the Gulf of California: An ecosystem-based management approach: Implementation Phase," supported by the David and Lucile Packard Foundation.

grant were presented at the 5th World Fisheries Congress, held in 2008 in Yokohama, Japan. Encouraged by the feedback from Yokohama, INAPESCA submitted the prototype to WWF´s 2009 International Smart Gear Competition. Although the prototype did not win, it reached the final round of judging.

In October 2008, Mexico's National Commission of Fisheries and Aquaculture (CONAPESCA) identified the need for testing more selective shrimp trawling nets in artisanal fishing fleets from the Upper Gulf of California. This enabled our testing of the "RS-INP" prototype with local artisanal fishers in the Upper Gulf. Though the results of these tests were statistically inconclusive, they were sufficient to generate financial support from the National Commission of Protected Areas (CONANP) for further testing of the prototype in 43 artisanal fishing boats during the 2009-2010 commercial shrimp fishing season[33]. Additionally, CONANP is promoting the use of hook long lines and traps for fishing scale fishes, instead of drift gillnets. Currently, WWF and INAPESCA are undertaking another joint project for testing the effectiveness of fish aggregative devices for concentrating fishing resources and avoid the dispersal of the artisanal fishing effort[34]. WWF and PRONATURA are now (September 2009 -March 2010) funding and operating independent on board observers for documenting the performance of the 43 prototypes, as a result of the mentioned CONANP´s initiative. The information generated by those observers is being provided to INAPESCA for strengthening the decision making process about widespread transference of the prototype to local fishers.

In 2009, INAPESCA also requested an international institutional patent for the "RS-INP" prototype through the Mexican Institute of Intellectual Property of the National Ministry of Economy. The process is expected to be completed by 2011.

Derived from the UC MEXUS-CONACYT agreement, INAPESCA and NOAA Southeast Fisheries Science Center (Panama City, Fla.) agreed in mid 2009 on testing the artisanal and industrial versions of the prototype with US-shrimpers from the Gulf of Mexico. NOAA planed to undertake the tests between November and January 2009, but unexpected factors caused delays and performance reports are now expected by early 2011. NOAA's evaluation will surely support our efforts towards a massive adoption by Mexican fleets.

Results of this project were also useful for to INAPESCA for strengthening its collaboration with the United Nations Food and Agriculture Organization (FAO) and continuing to refine the prototype and test it in other regions of Mexico. By the mid 2010, INAPESCA and FAO will gather in Costa Rica to plan trials with industrial and artisanal fleets from the Gulf of Mexico. WWF will consider additionally supporting those tests as a part of its fisheries program for the Mexican Caribbean.

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33 http://www.conanp.gob.mx/pdf_vaquitamarina/convocatoria_2.pdf

34 Project "Options for Sustainable Artisanal Fisheries in the Upper Gulf of California: "Suripera" nets and other Alternatives", supported by the David and Lucile Packard Foundation.

Based on a request of representatives of CANAINPESCA-Mazatlán that the experiments with the prototype continue, INAPESCA will undertake two training workshops on the construction and operation of the prototype for Sinaloan fishers and netters before the start of the 2010-2011 commercial fishing season. WWF will consider supporting these training efforts through the WWF-Carlos Slim Foundation Alliance.

VII. ACKNOWLEDGMENTS

INAPESCA and WWF would like to thank The Walton Family Foundation for the support you provided for this project.

We also thank Francisca Durazo Reyes, Manuel A. Estrada Elizalde, Jesús Magaña Lozano, Esteban Siqueiros Luque, Gerardo Ulloa Delgado and Reyes Siqueiros Luque for their participation as crew of the "BIP XI". Jesús Ricardo Rojas, Alfredo Zaravia Ponce, Amador Pimentel Muñoz, Ezequiel López Carbajal, Fidel López Orozco, Higinio Robles Arellano, Jesús Roberto Soriano Padilla, Jorge Reyes Olmos, Jorge Sergio Ramírez Estrada, Julio Alfonso García González, Leobardo López and Manuel Villalobos kindly participated as crew for the "Mario Moreno I" and "Mario Moreno III" cruises. We also thank owners of those shrimpers, as well as the owner of "GEOMAR" shrimper for allowing us work on board.

The following staff of INAPESCA kindly participated as technicians in trials performed on board industrial trawlers: Leticia González Ocaranza, Sofía Alida Barón Campis, Adauto Flores, Jorge Luís Oviedo Pérez, Jesús Antonio Virgen Ávila, José Abraham Avilés Burgeño, Valente Matías Sánchez, and Vicente Moreno Borrego.
Raúl Molina, Alejandro Balmori, Luís Belendez, Abraham Navarrete and Miguel A. Cisneros from INAPESCA facilitated many of the official procedures required by the project.

Fernando Domínguez Domínguez, Marco Rafael Pinzón Naranjo, Omar Efrén Zavala Valdéz, Trinidad López Reyes, Armando Flores Uribe, Sergio Macías Aceves, Adauto Flores Uribe, José Luís Fonseca Regalado and Martín Robles Zamora participated as on board observers during the trials undertaken at Magdalena-Almejas Bay.

We acknowledge the collaboration of artisanal fishers from Magdalena-Almejas Bay (Southern Baja, California), Dautillos (Sinaloa), Golfo de Santa Clara (Sonora) and San Felipe (Baja, California) for their collaboration in the artisanal fishing trials. Some artisanal fishers from Puerto San Carlos (Southern Baja, California) agreed to assist with the training to artisanal fishers from the Upper Gulf of California on trawling techniques.

Thanks to Jaime Ventura Machado who constructed the nets used in this project.

Finally, thank you to Ana Tagle, Marisol Plascencia, Adriana Álvarez and Luis Servín (WWF-México) who contributed to the administration of the project.

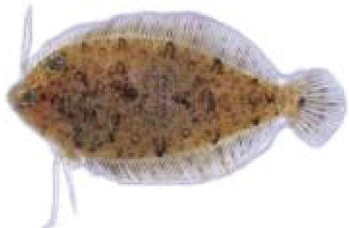
Annex. I. Most frequent bycatch caught during testing.

SAGARPA

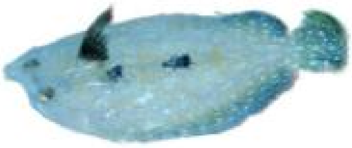
SECRETARÍA DE AGRICULTURA, GANADERÍA, DESARROLLO RURAL, PESCA Y ALIMENTACIÓN

WWF

Platybelone argalus plerura



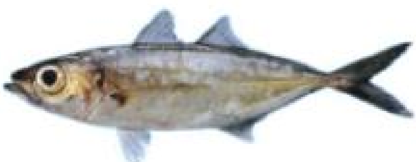
Perissias taeniopterus



Bothus mancus

Oligoplites refulgens

Oligoplites saurus inornatus



Selar crumenophthalmus

Engyophrys sanctilaurentii

Monolene dubiosa

Bothus leopardinus

Oligoplites altus

Trachurus symmetricus

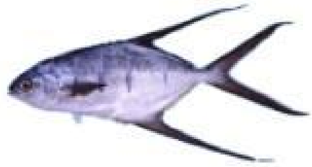

Decapterus macarellus


Decapterus macrosoma

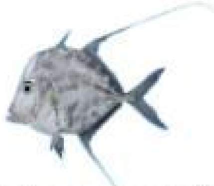

Decapterus muroadsi

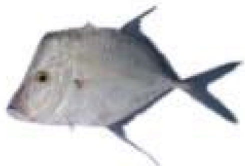

Trachinotus paitensis


Trachinotus kennedy


Trachinotus rhodopus

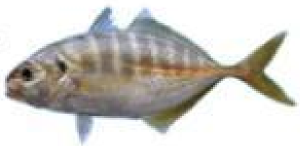

Selene peruviana


Selene oerstedi


Selene brevoortii


Caranx caballus

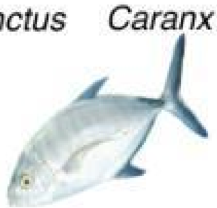

Caranx caninus

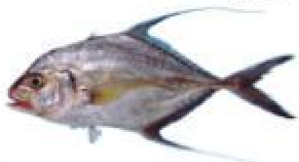

Caranx vinctus


Caranx lugubris


Caranx melampygus

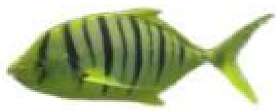

Caranx sexfasciatus


Carrangoides orthogrammus


Carrangoides otrynter

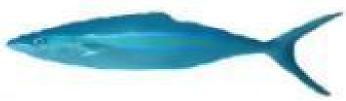

Hemicaranx leucurus


Hemicaranx zelotes


Gnathanodon speciosus


Chloroscombrus orqueta

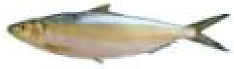

Alectis ciliaris


Elagatis binnipinnulata

Chaetodon humeralis

Oreochromis spp.

Opistonema libertate



Opistonema bulleri

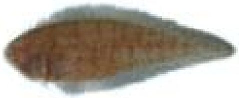
Opistonema medirastre

Sardinops sagax sagax

Neopistoptherus tropicus

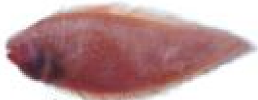
Symphurus fasciolaris

Symphurus chabanaudi



Symphurus prolatinaris

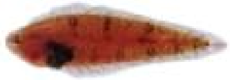
Symphurus atricaudus



Symphurus elongatus

Symphurus atramentalus

Symphurus callopterus



Symphurus gorgonae

Symphurus

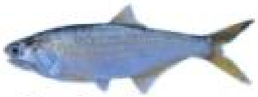
Symphurus melanurus

Symphurus melasmatotheca

Symphurus oligomerus

Elops affinis

Anchoa ischana



Anchovia macrolepidota

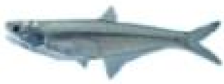
Engraulis mordax

Anchoa walkeri

Anchoa argentivitata

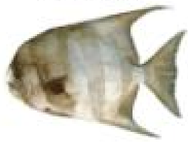
Anchoa nasus

Anchoa lucida



Anchoa mundeola

Catengraulis mysticetus

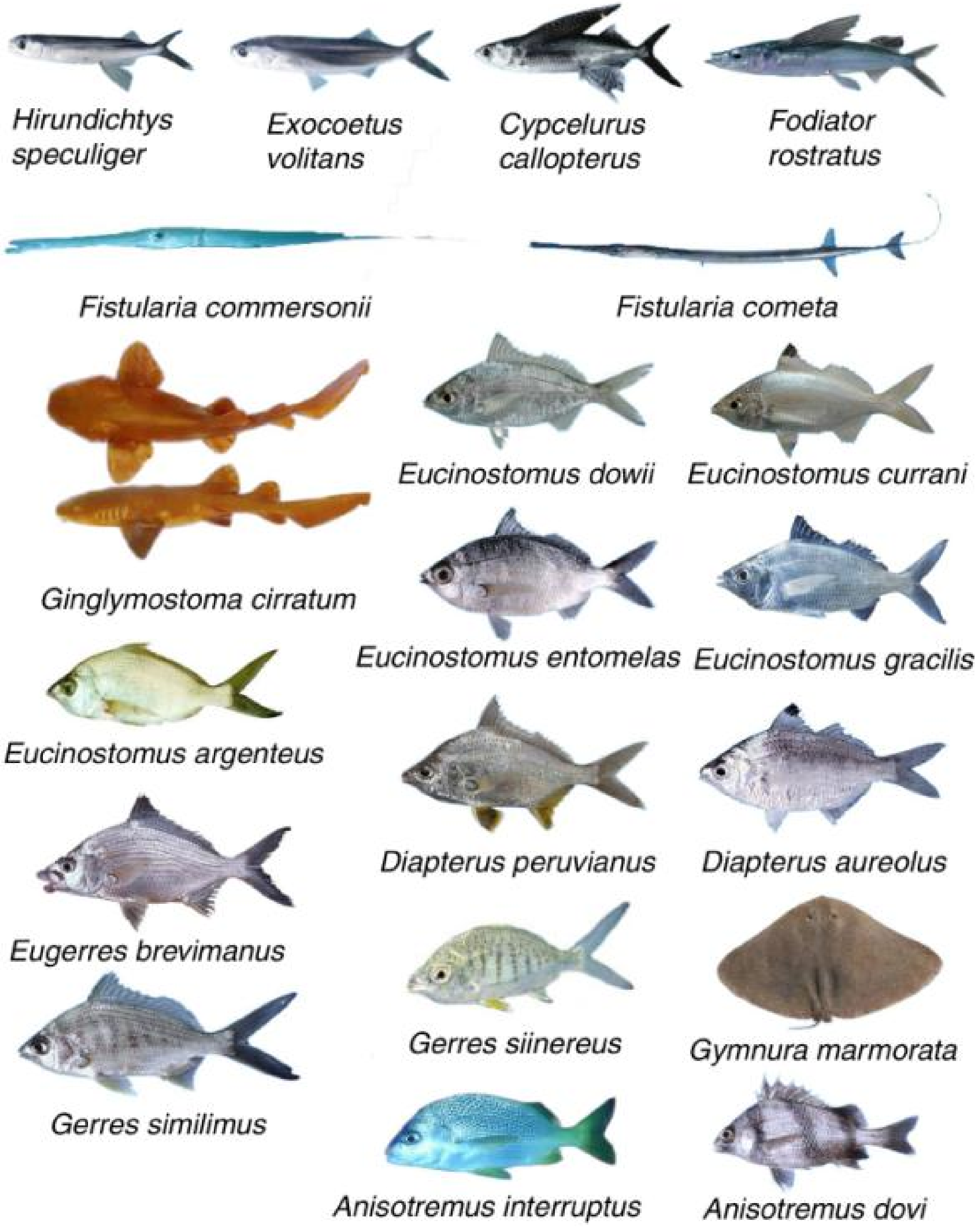


Chaetodipterus zonatus

SAGARPA

SECRETARÍA DE AGRICULTURA, GANADERÍA, DESARROLLO RURAL, PESCA Y ALIMENTACIÓN

WWF




Anisotremus caesius


Anisotremus davidsoni


Anisotremus pacifici


Anisotremus taeniatus


Pomadasys panamensis


Pomadasys bayanus


Pomadasys branickii

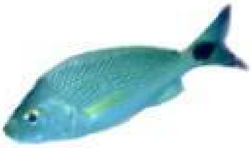

Pomadasys macracanthus


Haemulon flavigattatum


Haemulon maculicauda


Haemulon scuderii


Haemulon sexfasciatum


Haemulon steindachnerii


Haemulopsis leuciscus

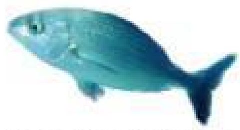

Haemulopsis auxiliaris

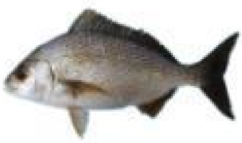

Haemulopsis elongatus


Haemulopsis nitidus


Orthopristis reddingi


Orthopristis calceus

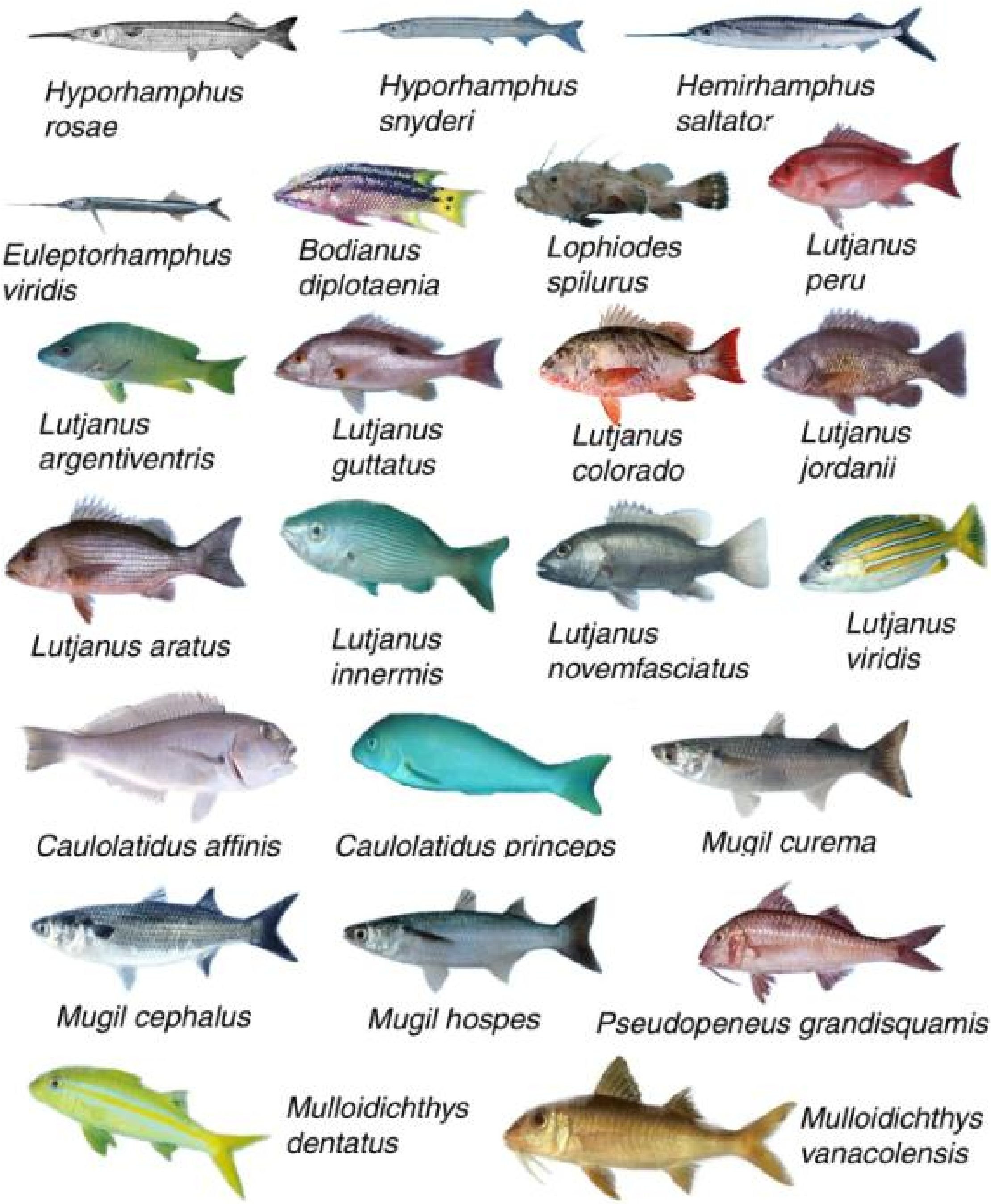

Microlepidotus inornatus


Microlepidotus brevipinnis


Conodon serrifer


Xenichthys xanti

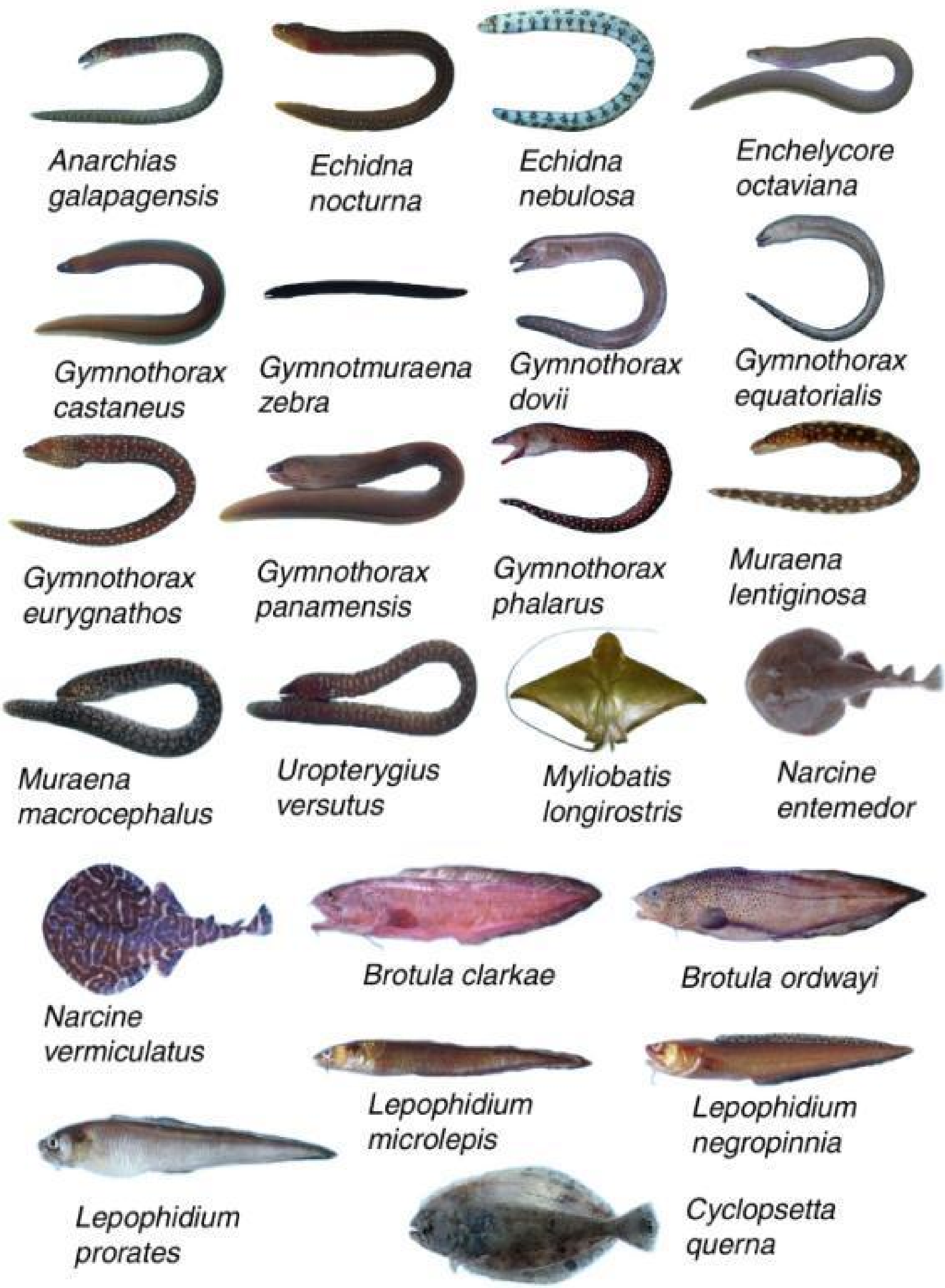

Hyporhamphus naos


Hyporhamphus rosae
Hyporhamphus snyderi
Hemirhamphus saltator
Euleptorhamphus viridis
Bodianus diplotaenia
Lophiodes spilurus
Lutjanus peru
Lutjanus argentiventris
Lutjanus guttatus
Lutjanus colorado
Lutjanus jordanii
Lutjanus aratus
Lutjanus innermis
Lutjanus novemfasciatus
Lutjanus viridis
Caulolatidus affinis
Caulolatidus princeps
Mugil curema
Mugil cephalus
Mugil hospes
Pseudopeneus grandisquamis
Mulloidichthys dentatus
Mulloidichthys vanacolensis

SAGARPA

SECRETARÍA DE AGRICULTURA, GANADERÍA, DESARROLLO RURAL, PESCA Y ALIMENTACIÓN

WWF



SAGARPA

SECRETARÍA DE AGRICULTURA, GANADERÍA, DESARROLLO RURAL, PESCA Y ALIMENTACIÓN

WWF

Cyclopsetta panamensis

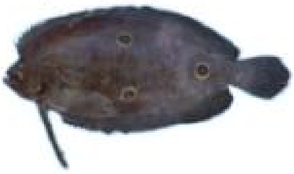
Citharichtys gilberti

Citharichtys platophys

Citharichtys sordidus

Citharichtys xanthostigma

Paralichtys wolmanii



Ancylopsetta dendrittica

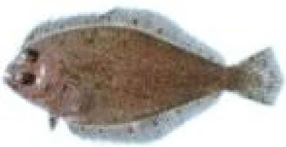
Entropus ciadi

Entropus crossotus

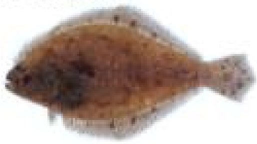
Hyppoglossina bolmani

Hyppoglossina stomata

Hyppoglossina letrophthalma



Syacium latrifrons

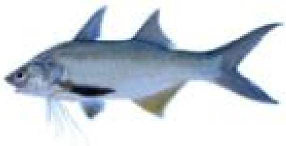


Syacium ovale

Xystreurys liolepis

Pleuronychthys guttulatus

Pleuronychthys ritteri



Polydachtylus approximans

Abudefduf troschelii

Opistoptherus dovii

Rhinobatos glaucostigma

Rhinobatos productus

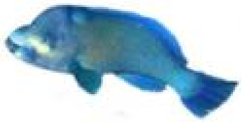
Rhinobatos leuchorrynchus

SAGARPA
SECRETARÍA DE AGRICULTURA, GANADERÍA, DESARROLLO RURAL, PESCA Y ALIMENTACIÓN

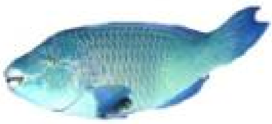
WWF

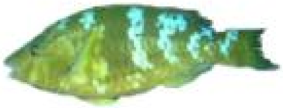

Zapterix xyster


Rhynoptera steindachneri


Scarus perrico


Scarus rubroviolaceus


Scarus compresus


Scarus ghobbari


Umbrina xanti


Umbrina analis


Umbrina bussigni


Umbrina dorsalis


Umbrina roncador


Larimus


Menticirrhus panamensis


Menticirrhus elongatus


Menticirrhus nasus


Menticirrhus paitensis


Menticirrhus undulatus


Cynoscion parvipinnis


Cynoscion reticulatus


Cynoscion albus


Cynoscion squanipinnis


Cynoscion stilzmanni


Cynoscion phoxocephalus


Cynoscion mannus


Cynoscion nobilis

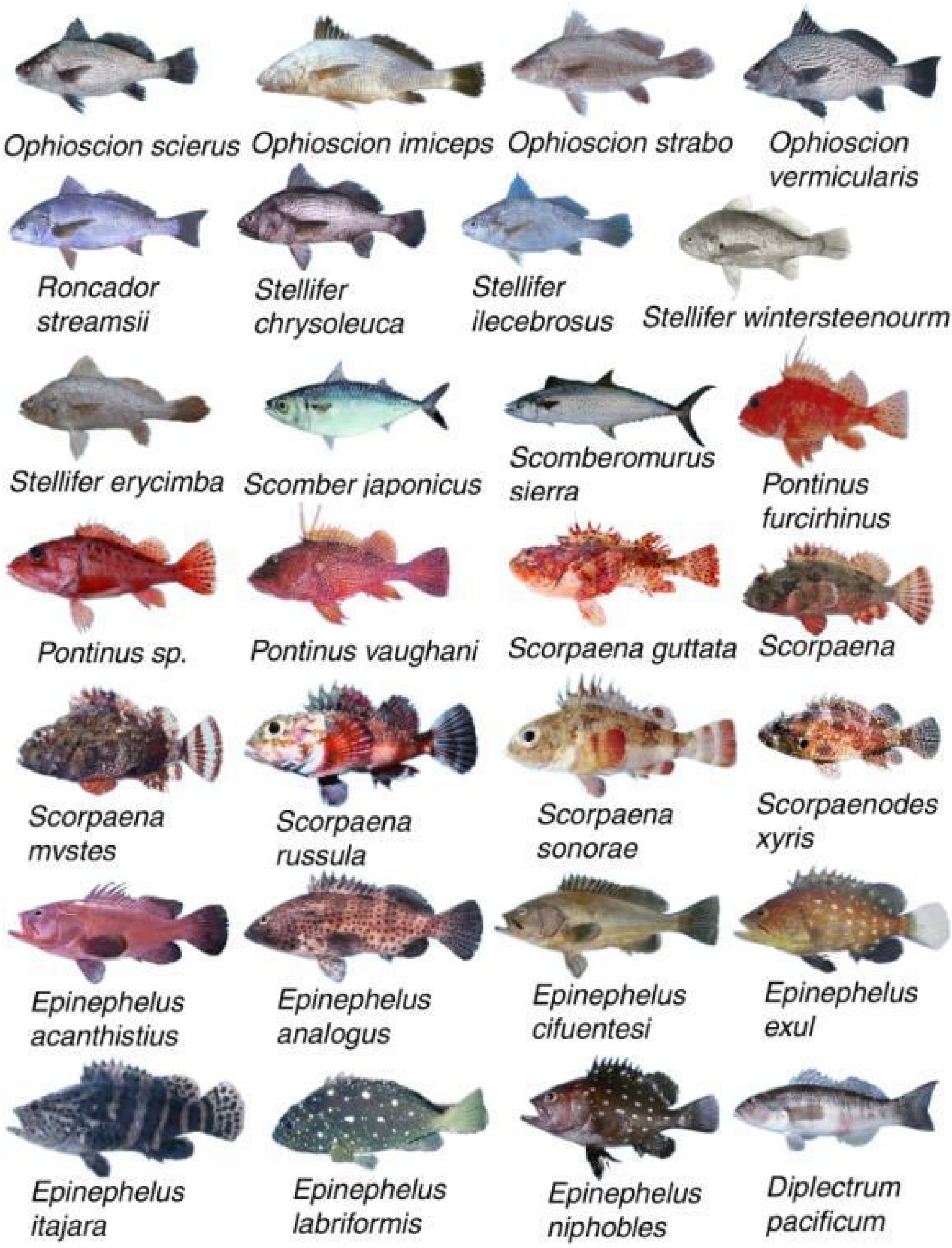

Mycropogonias altipinnis

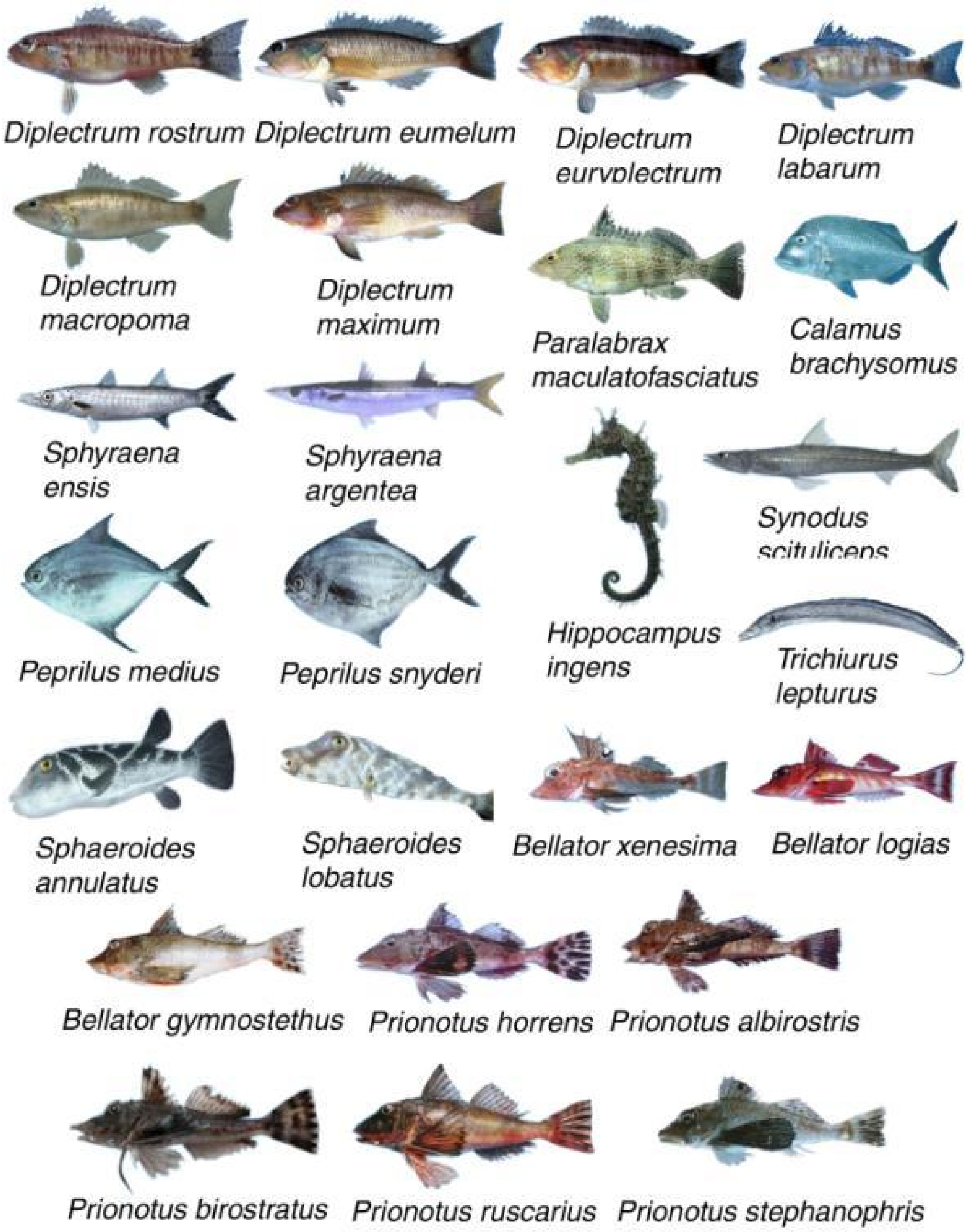

Mycropogonias ectenes


Ophioscion typicus

SAGARPA
SECRETARÍA DE AGRICULTURA, GANADERÍA, DESARROLLO RURAL, PESCA Y ALIMENTACIÓN

WWF





Diplectrum rostrum
Diplectrum eumelum
Diplectrum euryplectrum
Diplectrum labarum
Diplectrum macropoma
Diplectrum maximum
Paralabrax maculatofasciatus
Calamus brachysomus
Sphyraena ensis
Sphyraena argentea
Hippocampus ingens
Synodus scituliceps
Peprilus medius
Peprilus snyderi
Trichiurus lepturus
Sphaeroides annulatus
Sphaeroides lobatus
Bellator xenesima
Bellator logias
Bellator gymnostethus
Prionotus horrens
Prionotus albirostris
Prionotus birostratus
Prionotus ruscarius
Prionotus stephanophris

Urotrygon rogersi

Urolophus maculatus

Family Loginidae

Unidentified decapods

Family Calappidae

Unidentified gastropods

Unidentified echinoderms

Unidentified jellyfish

Megapitaria squalida

Chione californiensis

Hexaplex erithrostomus

Murex recurvirostris