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Towards sustainable fisheries in the colombian Pacific coast: economic performance of a new shrimp trawl net

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Abstract. Bottom shrimp trawling is considered one of the fishing practices with higher bycatch and habitat impact, generally adjudged to technological factors. Based upon this, the REBYC-II LAC project in Colombia developed with fishermen, prototype trawl nets to reduce bycatch in both shallow-water and deep-water shrimp fisheries. In 2018, experimental trials were conducted to test differences in shrimp bycatch between traditional and prototype nets, resulting in a significant reduction of the bycatch and a substantial reduction in fuel consumption. This paper seeks to identify whether the use of the prototype net represents a potentially higher profit to fleet owners, by analysing three profitability indicators: Net Present Value (NPV), Benefit-Cost Ratio (BCR) and Internal Rate of Return (IRR). All the economic and financial indicators for both fisheries presented better results for the prototype net compared to the traditional one. Our results contribute to support the potential development and adoption of low impact and fuel-efficient trawl fishing gear in Colombia.

Key words: Economic viability, shrimp trawl fisheries, fishing technology, fuel efficiency, sustainable fishing practices.

Resumen. Hacia pesquerías sostenibles en la costa Pacífica colombiana: Desempeño económico de una nueva red de arrastre para camarón. El arrastre de fondo de camarón es considerado una de las prácticas de pesca con mayor capturas incidentales e impacto en el hábitat, debido generalmente a factores tecnológicos. Basado en esto, el proyecto REBYC-II LAC en Colombia desarrolló con los pescadores redes de arrastre prototipo para reducir capturas incidentales en las pesquerías de camarón de aguas someras y profundas. En 2018, se realizaron pruebas experimentales para evaluar diferencias en las capturas incidentales entre los dos tipos de redes, demostrando que la red prototipo redujo significativamente las capturas incidentales y el consumo de combustible. Este estudio busca identificar si el uso de las redes prototipo representa potencialmente una rentabilidad más alta para los armadores pesqueros, a través de tres indicadores: Valor Presente Neto, Relación Costo-Beneficio y Tasa Interna de Retorno. Todos los indicadores económicos y financieros para ambos tipos de pesquerías, presentaron mejores resultados para la red prototipo. Nuestros resultados respaldan el potencial desarrollo y adopción de una red de arrastre de bajo impacto y más eficiente en consumo de combustible en Colombia.

Palabras clave: Viabilidad económica, pesquerías de arrastre de camarón, tecnología de pesca, eficiencia en uso de combustible, prácticas de pesca sostenible.

Introduction

Industrial shrimp trawling is an important fishing activity on the Colombian Pacific coast. Started in the late fifties it reached its peak in the seventies. In the eighties a decrease in fishing yields and revenues was observed due to artisanal and industrial fishing occurring simultaneously, high volatility in international prices, and a high fuel price (Mora-Lara, 1988; Escobar & Rueda, 2018). As a result, the fleet number has decreased over the last decades. However, industrial and artisanal shrimp fisheries are still of great economic and social importance in the Pacific coast, providing food security and livelihood to fishing communities. Together they are responsible for more than 13000 employees, they represent a traditional way in which people relate to nature, and a cultural expression (Rueda & Escobar, 2014).

According to the target catch, there are two kinds of trawling fleet: shallow and deep-water shrimp fisheries (Fig. 1). Since 2000, approximately 40 vessels operate in the shallow water shrimp (SWS) in a depth between 5 and 60 meters and their main target in the Pacific Ocean is the western white shrimp (*Penaeus occidentalis* Streets, 1871).

The deep-water shrimp (DWS) operates with no more than 25 vessels per year in depths ranging from 60 to 300 meters, mainly targeting crystal shrimp (*Penaeus brevirostris* Kingsley, 1878), yellow leg shrimp (*Penaeus californiensis* Holmes, 1900) and Kolibri shrimp (*Solenocera agassizii* Faxon, 1893) (Rodríguez et al., 2012; Girón et al., 2016).

Shallow water fisheries are fully exploited or even overexploited (Rueda et al., 2018), because of an uncontrolled fishing effort of a sequential fishery between artisanal and industrial fleets (Alcocer et al., 2014; Rueda et al., 2018). Moreover, bottom trawling fishing is considered one of the methods with higher bycatch and habitat impact (Alverson et al., 1994; Bianchi et al., 2000; Hall et al., 2000; Kaiser et al., 2002; Eayrs, 2007; Escobar-Toledo et al., 2014; Pérez et al., 2019). Bycatch can be classified in incidental catch and discards. While incidental catch refers to the specimens valued by the market, the discarded bycatch includes those without commercial value that tend to be thrown overboard (Pascoe, 1997). Currently, in shallow waters of the Colombian Pacific Ocean, the proportion of target catches and bycatch is up to 1:20, meaning that for every 1 kilogram of target catch, there are 20 kilograms of bycatch. Regarding

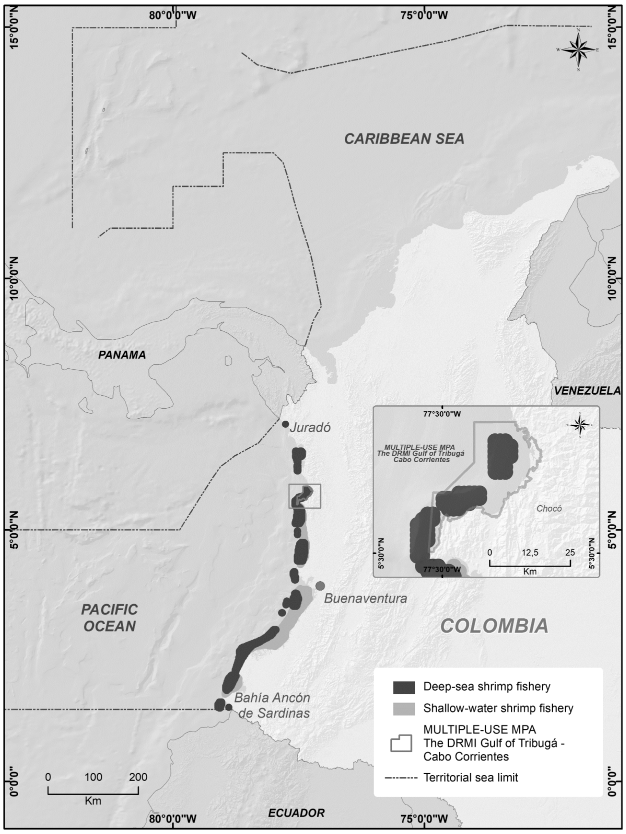

Figure 1. Distribution of the shrimp fishing grounds in the Colombian Pacific. Shades of grey indicate type of fishing fleet.

deep water, the proportion is substantially below 1:1 (Rueda et al. 2018; Escobar & Rueda, 2018).

Most of the capture methods used for fishing are heavily dependent on the use of fossil fuels (Suuronen et al. 2012). For fisheries like shrimp trawling in Colombia, high consumption of fuel constitutes a major constraint to its economic viability, and also represents a significant source of greenhouse gas emissions. Technological factors are one of the main drivers of bycatch, due mainly to the nets' low selectivity capacity (Knudsen et al., 2010; Jenkins & Garrison, 2013 and Guanais et al., 2015). As a result, The Food and Agricultural Organization of the United Nations (FAO) and the Marine and Coastal Research Institute in Colombia, INVEMAR, joined efforts under a project named REBYC-II LAC, seeking to promote the sustainable management of bycatch in Latin American and Caribbean Trawl Fisheries. Prototypes trawl nets were developed by different stakeholders including trawling shrimp fishermen, considering the objective of reducing bycatch and fuel-consumption (Marco et al., 2021). The use of thinner and stronger twines, square mesh netting, less netting and larger mesh size appear among the modifications made (Escobar & Rueda, 2018).

In 2018, fishing experiments were performed to evaluate differences in catch per unit effort of bycatch and target catch, between the prototype and traditional trawl nets per fleet. In the SWS fishery, results showed that the prototype trawl net increased target-catch by 118% and reduced incidental catch by 21% compared to traditional trawl nets. In the DWS fishery, the use of prototype net showed discards decreased up to 47% and there was no statistically significant difference between the target catch and incidental catch for prototype and traditional nets in this fishery. For both the DWS and SWS fisheries, prototype nets showed a 24% reduction in fuel consumption (Escobar & Rueda, 2018).

Despite these experiments showed a considerable bycatch and fuel consumption reduction, the use of this kind of modified net is not yet spread among the fishers due to financial and cultural reasons. According to fleet owners the main reasons why the use of prototype nets is not yet spread (S. Ardila, personal communication, March 2, 2020) are:

- Decreased profit levels, due to high international supply of shrimps and low market prices
- Strong tradition where the use of experimental gears is not as popular as in other industries
- Higher price of the prototype net (compared to the traditional)
- Low netting material availability

Several studies have been done internationally to evaluate economic performance and financial viability of the fishing activity, for instance, studies made by Lery et al. 1999; Tietze et al. 2001 and Eayrs, 2007 contributed importantly to having a better understanding of these variables on vessels and fisheries in different countries around the world. Building on those studies Adeogun et al. (2009) and Ünal and Franquesa (2010) focused on small scale fisheries in Africa and included social variables, under the understanding stated by Schuhbauer & Sumaila (2016) that profit is necessary, but more criteria should be included to evaluate a new technology and make it viable.

Based on the information mentioned above, this study evaluates if the use of the prototype nets represents a potentially higher profit for the industrial Shrimp trawling fleet owners in the Colombian Pacific coast, by assessing three economic indicators: Net Present Value (NPV), Internal Rate of Return (IRR) and Benefit-Cost Ratio (BCR).

Materials and Methods

The analysis was made as follows:

i An income statement was calculated for the traditional net in both fisheries, the value considered was the median of the information reported by the fishery information system of INVEMAR (SIPEIN) in 2017 for all the fleet with the information registered for the Pacific coast in that specific time frame. Then, an income statement was calculated for the prototype trawl net, based on the variation between fuel consumption, target catch, and bycatch shown by the experiment presented in the introduction (Tables I and II). To calculate the gross profit, operating cost and investment were discounted from the revenue, as equation 1 shows, where P corresponds to gross profit, R to revenue and C to the total cost.

$$P = R - C \qquad 1$$

The revenue (R) corresponds to the amount of product captured by its price per kilogram, this was calculated to each specie with commercial value. On the other hand, the total cost (C) includes operating costs and investment.

To simplify the model some assumptions were made. Eight fishing operation during a year were considered: three DWS and five SWS. To calculate values in US dollars, the official rate of exchange provided by the Central Bank of Colombia in 2017 was used (COP 2951.32). A crew consisting of six members was considered for the SWS fishing operation, one skipper, one vessel operator, one stevedore, one cook, one sailor in charge of net maintenance and one first mate. For the DWS fishing operation, the crew included also an additional sailor, as a higher volume of target catch needs to be handled. Its salary is defined in terms of the revenue and variable cost (the ones related to fuel consumption and maintenance), consequently, if revenue increases or variable cost decreases, the retribution perceived by the crew will increase.

ii Next, a five-year cash flow was calculated for traditional and prototype trawl nets. Here, investment cost corresponds to four fishing nets, two of them for replacement. Accelerated depreciation of the fishing gear was taken, accounted for one year of useful life. Finally, the inflationary goal of the central bank in 2017 was the inflation rate

Table I. Income statement comparison for traditional and prototype nets - SWS fishery 2017 (USD)

	Traditional nets	Prototype nets
Concept	**USD**	**USD**
REVENUE	**136705**	**145956**
Target catch	27309	59533
Incidental catch	109396	86423
EXPENSES	**131758**	**123222**
Fixed cost	**17609**	**17609**
Social benefits	6468	6468
Management/services	10268	10268
Licenses	872	872
Variable cost	**114149**	**105613**
Fuel	75475	57361
Maintenance and supplies	20313	20313
Procedures and services	1728	1728
Others	3558	3558
Staff	13076	22654
GROSS PROFIT	**4947**	**22734**
Gross profit margin	**4%**	**16%**

Table II. Income statement comparison for traditional and prototype nets – DWS fishery 2017 (USD)

	Traditional nets	Prototype nets
Concept	**USD**	**USD**
REVENUE	**127667**	**127667**
Target catch	127207	127207
Incidental catch	461	461
EXPENSES	**111183**	**103241**
Fixed cost	**18533**	**18533**
Social benefits	7392	7392
Management/services	10268	10268
Licenses	872	872
Variable cost	**92650**	**84708**
Fuel	50907	38689
Maintenance and supplies	19343	19343
Procedures and services	1016	1016
Others	1981	1981
Staff	19403	23679
GROSS PROFIT	**16485**	**24426**
Gross Profit Margin	**13%**	**19%**

considered for revenues and cost increments, 3% and 4% respectively (Table III and IV).

iii Three profitability indicators were calculated: Net Present Value (NPV), Benefit-Cost Ratio (BCR) and Internal Rate of Return (IRR). NPV is the value of all future cash flows (positive and negative) over the evaluation life of an investment discounted to the present, in this case 5 years (t=5). As equation 2 shows, it is defined as the difference between revenue and total cost. For its calculation, it is necessary to use a discount rate (d) which represents the preference current consumption has over future consumption. In this study, three discount rates were used to exemplify different social preferences in terms of money expenditure (Seijo et al., 1997). The first one is an approximation of the market rate given by the central bank (5%), the second one is considered as a social rate (9%) (Herrera et al., 2013; Piraquive et al., 2018) and the third one is a higher discount rate to evaluate projects with a higher return in the midterm, as some authors explains is the case of fisheries (12%) (Mete, 2014).

$$NPV = \sum \frac{Rt - Ct}{(1+d)^t} \qquad 2$$

The BCR (equation 3) is an expression of the relationship between revenues and total cost in present value. It is also understood as the recovery capacity of the investment (Sapag Chain & Sapag Chain,1995: Seijo et al. 1997).

$$BCR = \sum \frac{Rt/(1+d)^t}{Ct/(1+d)^t} \qquad 3$$

The equation 4 shows the IRR, which is a discount rate that makes the NPV of all cash flow (positive and negative) of the project equal to zero (Mete, 2014).

$$0 = NPV = \sum_{t=0}^{T} \frac{Rt - Ct}{(1-IRR)^t} \qquad 4$$

Table III. Five years' cash flow projection- traditional and prototype nets – SWS fishery (USD).

Traditional nets	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
REVENUE		136705	140806	145030	149381	153863
EXPENSES	- 4066	132775	137899	143224	148755	154502
Fixed cost		17609	18137	18681	19242	19819
Investment- Nets	- 4066	1016	1047	1078	1111	1144
Variable cost		114149	118715	123464	128403	133539
Net Cash Flow	**- 4066**	**3930**	**2907**	**1807**	**627**	**- 639**

Prototype nets	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
REVENUE		145956	150335	154845	159490	164275
EXPENSES	6230	126337	131183	136217	141446	146877
Fixed cost		17609	18137	18681	19242	19819
Investment- Nets	6230	3115	3209	3305	3404	3506
Variable cost		105613	109838	114231	118800	123552
Net Cash Flow	**- 6.230**	**19.619**	**19151**	**18.628**	**18044**	**17397**

Table IV. Five years' cash flow projection- traditional and prototype nets – DWS fishery (USD)

Traditional nets	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
REVENUE		127667	131497	135442	139506	143691
EXPENSES	- 4066	112199	116492	120950	125580	130390
Fixed cost		18533	19089	19661	20251	20859
Investment- Nets	- 4066	1016	1047	1078	1111	1144
Variable cost		92650	96356	100210	104218	108387
Net Cash Flow	- 4066	15468	15006	14493	13925	13301

Prototype nets	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
REVENUE		127667	131497	135442	139506	143691
EXPENSES	6230	104799	108790	112934	117239	121709
Fixed cost		18533	19089	19661	20251	20859
Investment- Nets	6230	1558	1604	1652	1702	1753
Variable cost		84708	88097	91621	95285	99097
Net Cash Flow	- 6230	22869	22708	22508	22267	21982

Here, an assumption was made, and it was to consider that the annual net cash flow was reinvested on the operation process for each period.

iv Finally, three hypothetical scenarios were created for the prototype net implementation in the SWS fishery and two for the DWS. Less scenarios were stated for the DWS fishery as for this the prototype net implementation does not present such variation as the implementation of the prototype net in the SWS fishery. The hypothetical variations are presented in Table V and VI.

Results

Regarding the annual income statement for both fisheries, the cost structure showed high participation of variable cost which represented 87% and 83% of the total cost, for SWS and DWS fisheries respectively. Particularly, fuel consumption was 57% and 46%. Based upon the results obtained in the experiment, for the SWS fishery the prototype net showed a target catch increase of 118% and 24% reduction of fuel consumption, 7% increase in revenues and 7% reduction in variable cost compared to traditional nets implementation, leading to an increase in gross profit margin, from 4% with traditional nets to 16% with prototype (Table I). For the DWS fishery revenues remained the same for traditional and prototype nets. However, as the fuel consumption decreased, variable cost was 9% lower for prototype nets. Consequently, gross profit margin went from 13% to 19% (Table II).

In terms of cash flow, the 5 years projection for both, traditional and prototype nets, shed light over the profitability of using this new technology in a midterm perspective (Table III and IV). The net cash flow for the SWS and for the DWS fishery showed in Figure 2, reveal that the use of the prototype net in the DWS fishery is the option with the higher net cash flow.

Net Present Value (NPV): For the SWS fishery, the NPV was significantly higher for prototype nets compared to traditional ones for the three discount rates used, showing values of USD 70851, USD 60883 and USD 54600 for discount rates of 5%, 9% and 12% respectively. For instance, for a discount rate of 9%, the NPV for traditional nets was just 5% (USD 3129) of the NPV for prototype gear (USD 60883) (Fig. 3a).

In the case of the DWS fishery, the prototype gear showed higher profitability as well. For instance, considering a 5% discounted rate, the NPV for prototype nets were USD 86792, 55% higher than the NPV for traditional gear (USD 55880) (Fig. 3b).

Internal Rate of Return (IRR): As the NPV, the IRR presented the use of the prototype net as a better investment decision. For the SWS fishery, the IRR was 60% for traditional nets compared to 312% for the prototype ones (Fig. 4a). In the DWS fishery the IRR is similar for both, traditional and prototype nets, showing that in both cases the investment would create value. Actually, it is slightly higher for traditional nets, due to the higher initial investment needed for prototype nets (Figure 4b).

Benefit Cost Ratio (BCR): For both fisheries, this profit indicator is above one for traditional and prototype gear, indicating that the benefits of implementing prototype gear surpassed the costs (Fig. 5).

Given the fact that fisheries are dynamic and complex systems where different factors may vary, an analysis of different possible outcomes with the use of prototype nets was done to enrich the discussion and take into consideration a wider range of options. Table V and VI present three hypothetical scenarios for the SWS fishery and two scenarios for DWS fishery.

For SWS, scenario 1 considers no change in the target catch, it stated that with the use of the prototype net the only changes were in fuel consumption (24% reduction) and in incidental catch (21% reduction). Under this scenario, the NPV of operating with the prototype gear is negative for the three discount rates considered, showing that the reduction in fuel consumption does not compensate the decrease on incidental catch without any increment on target catch. In a more moderate scenario (scenario 3), with an increase in target catch, but not as high as showed in the experiment, the activity is profitable with a NPV far higher than in the case of traditional nets.

In the case of DWS, even in the hypothetical scenario 2 where there is no reduction in fuel consumption and incidental catch decreases 15% the indicators showed that the activity is still profitable.

Discussion

Our results showed that the use of the prototype trawl net represents a potentially higher profit to fleet owners using three profitability indicators. This based upon bycatch, target catch, and fuel consumption levels obtained for traditional and prototype nets on the experiment explained in the introduction. It presented the prototype net as more sustainable due to the results in bycatch reduction and lower levels of fuel consumption. Other similar experiments carried out in Chile and Australia support these results, showing that modified nets managed to cutback incidental catch and discards while target-catch remained at similar levels (Brewer et al., 1998; Queirolo et al., 2009; Courtney et al.,2014). What is more, several modifications have been successfully tested in trawls to reduce bycatch and fuel consumption; reporting reduction of the gear drag between 20% and 35% and fuel saving

Table V. Scenario analysis for prototype net implementation - SWS fishery

Scenario	Interest rate	NPV (USD)	IRR	BCR
Scenario 1	12%	(15819)		1.08
Fuel consumption reduction 24%	9%	(17294)		1.05
Incidental catch reduction 21%	5%	(19644)	—	1.01
Target catch no variation				
Scenario 2	12%	34384		1.21
Fuel consumption reduction 24%	9%	38440		1.18
Incidental catch no variation	5%	44871	213%	1.14
Target catch no variation				
Scenario 3	12%	14020		1.16
Fuel consumption reduction 24%	9%	15832		1.13
Incidental catch reduction 21%			108%	
Target catch increase 50%	5%	18701		1.09

Table VI. Scenario analysis for prototype net implementation - DWS fishery

Scenario	Interest rate	NPV (USD)	IRR	BCR
Scenario 1	12%	94705	500%	1.40
Fuel consumption reduction 24%	9%	105452		1.36
Incidental catch no variation	5%	122516		1.31
Target catch increase 10%				
Scenario 2	12%	39312	235%	1.23
Fuel consumption no variation	9%	43932		1.20
Incidental catch reduction 15%				
Target catch no variation	5%	51262		1.16

between 23% and 43% in Mexico, Chile and Colombia (Zúñiga, 2006; Rico-Mejía & Rueda, 2007; Melo et al., 2008; Heredia-Quevedo, 2010, Suuronen et al. 2012).

Bottom trawling accounts for almost one quarter of global fish landings but may also have significant and unwanted impacts on seabed habitats and biota (McConnaughey et al., 2019). Management measures (e.g., changes in gear design) and voluntary industry actions can reduce these impacts, helping to meet sustainability objectives for fisheries, conservation and environmental management. Technical changes (use of prototype trawl net) evaluated in shrimp fisheries in Colombia sought to reduce impacts and maintain or increase catchability of target species (Rico-Mejía & Rueda, 2007; Girón et al., 2010). McConnaughey et al. (2019) state that, in addition to an increase of catchability of target species, technical changes show a decrease on depletion of benthic biomass and an improvement in the relative benthic status; such technological changes also proved to be cost-effective. Fleet performance showed reduced operating costs by more selective and energy-efficiency usage, which could contribute towards recovery of capital costs for conversion. In addition, gear modification assessed in this study will also have low environmental impacts per unit catch, due to fuel savings with consequent reductions in greenhouse gas emissions (unpublished data). As a result, and despite the higher price of the prototype net, during the final phase of the project REBYC-II

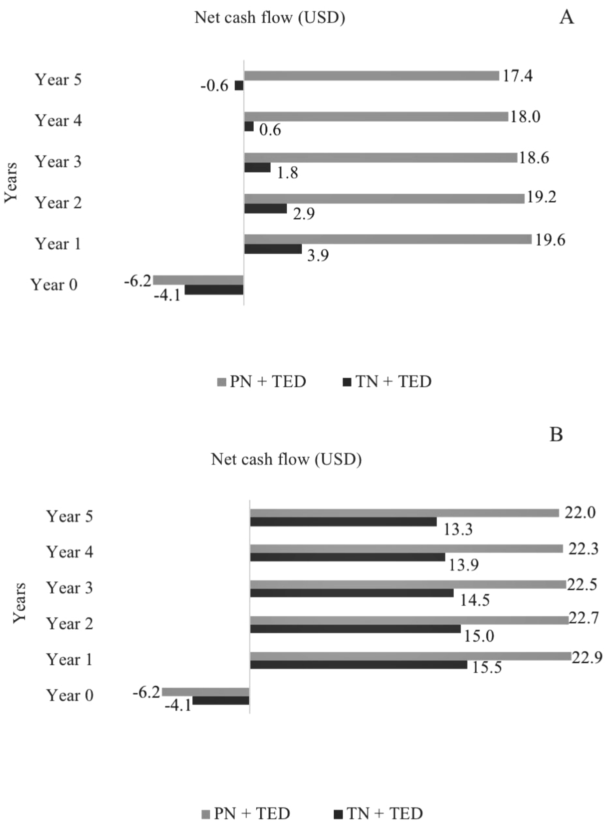

Figure 2. Annual Net cash flow for the SWS (A) and DWS (B) fishery (thousand USD). TN: Traditional Net. PN: Prototype Net. TED: Turtle Excluder Devise.

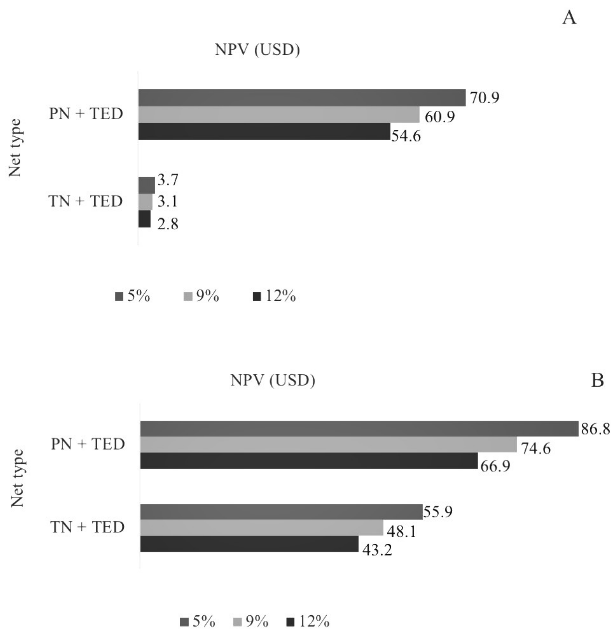

Figure 3. NPV for the SWS (A) and DWS (B) fishery (thousand USD). TN: Traditional Net. PN: Prototype Net. TED: Turtle Excluder Devise.

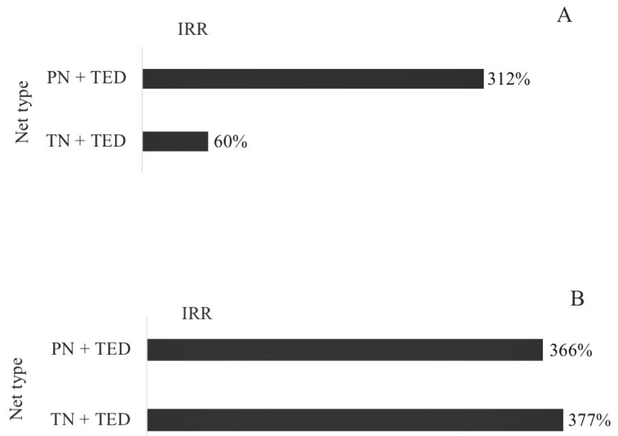

Figure 4. IRR for the SWS (A) and DWS (B) fishery. TN: Traditional Net. PN: Prototype Net. TED: Turtle Excluder Devise.

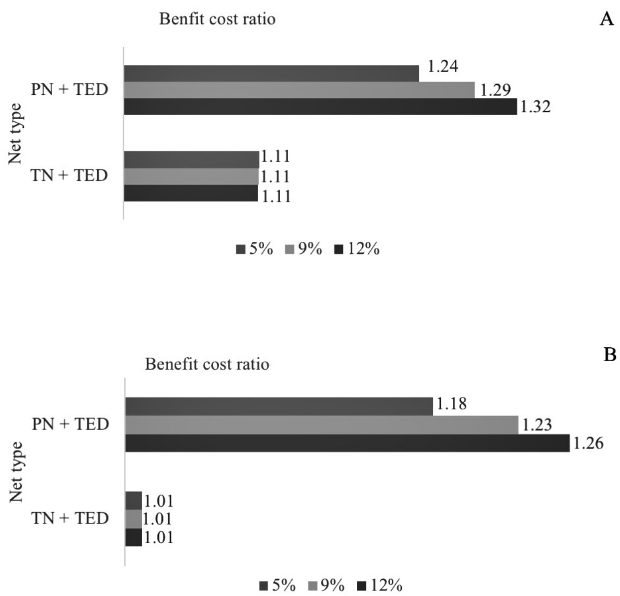

Figure 5. BCR for the SWS (A) and DWS (B) fishery, TN: Traditional Net. PN: Prototype Net. TED: Turtle Excluder Devise.

LAC in Colombia, some industrial fishermen took the initiative to adopt the prototype nets on their own, without government intervention. Currently 30% of the fleet (12 vessels) are using the prototype trawl net (com pers). This fishermen's behaviour has been observed in the Portuguese trawl fishery, where the performance demonstration of the new trawls, resulted in vessel skippers subsequently adopting the new design for commercial fishing (Parente et al., 2008).

This study completed a current assessment of this fishery (Marco et al. 2021), which revealed that regulatory reforms such as: defining marine protected areas, limiting access to the resources, determining fishing effort, allowable catch and fishing technology, in the shrimp trawling on the Pacific coast from Colombia, improved ecological performance through increases in stock size and reduction of bycatch. However, the economic performance is still constrained by high operating costs, inefficient harvest technologies and low product value. In effect, the low economic performance of the fishery may be overcome with the introduction of new fishing technologies, as demonstrated in this research.

In terms of the economic results, there is no reference to a similar study made in the country. However, several studies have been done internationally aiming to support the fisheries' level of profitability, analyzing variables like net profit, total earnings and return on investment. In all cases the importance of having a perspective where the benefit goes beyond economic profitability and includes social and environmental gains and losses, is highlighted (Lery et al., 1999; Tietze et al., 2001; Ünal and Franquesa, 2010; Adeogun et al., 2009).

All the economic and financial indicators for both fisheries presented better results for prototype gear compared to traditional. In this respect, it could be said that the prototype net has the potential to create higher value for the fleet owners, backing a possible investment decision. Nevertheless, it has to be considered that due to the complexity of fisheries the results of a fishing operation could change substantially. Not only biological and environmental factors may change the amount of product captured, but also market and technological factors could have an outstanding impact on revenues and cost structure changes. Lery et al., (1999) and Tietze et al., (2001) found that financial viability was affected in semi-industrial and industrial trawlers in the Caribbean due to limited resource attributed to overfishing. These authors also presented that operating costs heavily participate in the cost structure of fisheries and this feature is particularly deeper in fisheries in developing countries, which is consistent with the results presented here.

Based upon the sensitive analysis exposed above, the high participation of variable costs in the cost structure leaves the industry exposed to variations on this type of cost, which is what is happening with fuel consumption decreasing with the prototype gear use. Different authors state that fuel prices continue to be a major cost and with a high volatility of its price, the fishing industry will continue to suffer a loss in profitability, highlighting the need to reduce impacts and energy consumption throughout the product chain (Suuronen et al. 2012; Parker & Tyedmers, 2015). It is also important to bear in mind the revenue structure for both fisheries. For the SWS fishery using traditional nets, 80,0% of the revenues are due to incidental catch, however, when using prototype nets this percentage goes down to 59,2%. Conversely, for both kinds of nets in the DWS fishery, the revenue structure is the same: 99,6% of the total revenue is result of target catch. These figures elucidate the heavy dependence the SWS fishery has on bycatch products. As a result, reduction in incidental capture diminished the SWS fishery capacity to be profitable. This condition, alongside, with the better profitability indicators for the use of the prototype net in the DWS fishery, and the difference in the ratio between target catch and bycatch for SWS and DWS, (1:20 for SWS and around 1:1 for DWS), lead to consider the later more suitable for fishermen in terms of economic and environmental performance.

Having in mind that the shrimps of deep-water fisheries are in high demand by international markets (S. Ardila, personal communication, March 2, 2020), it would be recommended to work towards creating differentiation from the one captured in shallow waters. This differentiation could be based upon the low target catch and bycatch ratio the DWS presents, the low level of discard due to the use of prototype nets and the governance and control done in the Pacific coast since 1991, factors that could guarantee extraction at sustainable levels (Marco et al., 2021). Here fisheries certification and ecolabelling gain value as a way for harnessing market forces to create an incentive through price premium for sustainable fisheries (Gutierrez et al. 2016). In this vein, different gears are designed to have different levels of seabed contact or penetration depending on the target species and seabed type, and these factors will influence mortality (Hiddink et al. 2017). Consequently, we assessed the economic performance of changes in the design of the trawl net that included improving its selectivity to reduce the impact on biodiversity and habitat. Predictions of trawling impacts for other trawls, such as those used on the Pacific coast of Colombia, showed relative low impact e.g., removal of 6% faunal biomass per trawl haul and recovery times post trawling of around 1,9 years (Hiddink et al. 2017). These results are relevant for the fishing industry, conservation, management, and certification bodies.

The modifications of the prototype net (see introduction section), in addition to allowing the escape of unwanted species or sizes of fish, reduced the amount, weight and surface area of netting and increased water flow through the net, thereby reducing the overall drag. Our results support the potential development and adoption of low impact and fuel efficient (LIFE: Suuronen et al. 2012) fishing in the country. LIFE fishing addresses shrimp trawling, the complex dynamic energy consumption and environmental impacts with the objective of improving the economic viability and environmental sustainability of fishing operations. One management implication of this study is that an improvement in fuel efficiency in the shrimp trawl fishery will not necessarily lead to a sustained reduction in total fuel consumption because higher yields may attract new entrants to the fishery. Therefore, the adoption of prototype trawl nets must be conditional on the non-increase in fishing effort within a management system based on the ecosystem approach for fishing (balancing ecological well-being and good human well-being through new governance).

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