Integrating biological, ecological and socio-economic indicators to assess data-limited, tropical, small-scale fisheries: the case of the Colombian Pacific

Dissertation submitted by

Pilar Adriana Herrón Pérez

to the Faculty 2 (Biology & Chemistry), Bremen University
in partial fulfillment of the requirements for the degree of
Doctor rerum naturalium (Doctor of Natural Sciences)

May 2019, Bremen.

Universität Bremen

ZMT LEIBNIZ CENTRE for Tropical Marine Research

CEMarin

Advisory Committee:

1. Reviewer: Prof. Dr. Matthias Wolff

    University of Bremen, Germany, Leibniz Centre for Tropical Marine Research (ZMT). Bremen, Germany

2. Reviewer: Dr. Maria Lourdes Palomares

    University of British Columbia, Institute for the Oceans and Fisheries, Vancouver, Canada

1. Examiner: Prof. Dr. Wilhelm Hagen. University of Bremen, Bremen, Germany

2. Examiner: Dr. Marc Taylor. Thünen Institute. Bremerhaven, Germany

3. Examiner: Dr. Marie Fujitani. Leibniz Centre for Tropical Marine Research (ZMT). Bremen, Germany

Attending students:

1. Astrid Sánchez-Jiménez
    Ph.D. Student, University of Bremen

2. Ivonne Vivar Linares
    Master Student (ISATEC), University of Bremen

To my father

ABSTRACT

In tropical countries Small-Scale Fisheries (SSF) contribute more than half of the total fisheries catch and provide food security, nutrition, employment and multiplier effects to local coastal economies. Concerns about the sustainability of SSF have frequently been raised mostly in relation to declining trends of both total catch and catch-per-unit-effort (CPUE) in different tropical areas across the world. However, adequate stock assessments of main target species are often hindered by the poor quality and quantity of data available. Even if challenges to conduct reliable stock assessments are overcome, the multi-species, and multi-gear nature of SSF demands a holistic approach that accounts for the impacts that fishing can have on different components of the ecosystems and that acknowledges that SSF exhibit the complexity of social-ecological systems. Using the Colombian Pacific coast as a case study area of tropical, data-limited SSF, this thesis presents a novel and comprehensive assessment that includes: a) the stock condition of the main target species, b) the potential impacts of SSF to the biological communities and ecosystems to which the target species are associated, and (c) the socio-economic drivers of the gear choices made by small-scale fishers.

Two complementary length-frequency-catch-data (LFCD) approaches and two data sources (government and non-government derived) were used to assess the stock condition of three main target species of the SSF in the Colombian Pacific: the Pacific Sierra (*Scomberomorus sierra)*, the Spotted Rose Snapper (*Lutjanus guttatus)* and the Pacific Bearded Brotula (*Brotula clarkae)*. The first LFCD approach followed traditional stock assessment methods that involve estimations of growth and mortality parameters from modal progression of length frequency over time, catch curve analysis and a yield-per-recruit model. The second approach was based on the relative contribution of fish sizes in the catches with regard to proposed reference values for healthy stocks. Growth parameter estimates differed between data sources and exhibited large confidence intervals (estimated through a novel bootstrap routine), which indicated an overall high uncertainty underlying the assessment. Estimated values of stock indicators, i.e. exploitation rate, fishing mortality and size-proportions, converged to suggest a state of heavy to over-exploitation for the three assessed species, although there were differences observed among data sources that were attributed mainly to the fisheries selectivity and sampling design.

Going beyond the single species approach to fisheries management, different ecological indicators of the impact of fisheries were estimated based on the composition of the nominal catch of different gears used in SSF at three coastal zones of the Colombian Pacific. The results showed that taxonomic, size-based, functional and conservation features of the nominal catch vary greatly with geographical location and gear type used. Overall, handlines and longlines tended to select larger sizes and higher trophic level species than nets but they also caught a higher proportion of intrinsically vulnerable species and species of conservation concern. This challenges the idea that more selective gears have overall lower ecological impacts. In contrast, nets targeted a wider range of species and sizes (although focusing on small or medium sized fish) and also caught a higher diversity of trophic and spatial guilds. Bottom trawls exhibited a high percentage of landed by-catch; an undesirable feature for any fisheries in terms of sustainability. These results emphasize the need to consider the potential ecological impacts of the Colombian Pacific SSF which had been mostly ignored in the past.

Finally, a characterization of the socio-economic conditions of small-scale fishers, and an estimation of the different gears' profitability, were carried out at three coastal villages of the central Colombian Pacific. Fish per capita consumption in the studied villages was very high (237 kg*pc*yr^{-1}), something that has been obscured in the national statistics that position Colombia as a country with very low fish consumption rate. The fishers' gear choices were influenced by the value of their target species and potential profits but also by access to markets, access to fishing grounds and the local socio-economic conditions. Overall, a high market demand for shrimp species, coupled with relatively easy access to fishing grounds and easy operation of the gears, drove the majority of fishers of the central Colombian Pacific to use gillnets with small mesh sizes and bottom trawls. Moreover, users of those gears were less likely to make seasonal changes in gear use when compared to other fishers. Highly variable catches and profits, coupled with relatively high entry and operational fishing costs, led to an overall low economic income for small-scale fishers, which inevitably increases their already vulnerable socio-economic condition.

A set of practical recommendations to transition towards more holistic assessments and management of tropical SSF is drawn from the results of this thesis and from consideration of regional and global contexts. Three priorities are highlighted here. First, to increase the reliability of stock condition assessments: i) fisheries data collection schemes should be adjusted based on fishing effort, and ii) fisheries selectivity of the different gears must be estimated to correct LFCD prior to analysis. Second, adoption of ecological indicators, as part of regular SSF monitoring and assessments of temporal trends, will enable the consideration of potential ecosystem impacts of fishing during the decision making processes of SSF management. Third, investments in strengthening the social capital of coastal fishing communities and consideration of local socio-economic and cultural contexts in the design of fisheries management measures, while promoting co-management schemes, will be essential in the path towards sustainable SSF in tropical coastal areas of the world.

Keywords: data-limited fisheries, catch composition, eastern tropical Pacific, ecological indicators, ecosystem-based fisheries management, gear-based management, stock assessment, social-ecological systems.

ZUSAMMENFASSUNG

In den Ländern der Tropen trägt die Kleinfischerei (engl. SSF) mehr als die Hälfte zum gesamten Fischfang bei und sorgt für Ernährungssicherheit, Beschäftigung und Multiplikatoreffekte für die lokale Küstenwirtschaft. Besorgnis über die Nachhaltigkeit von SSF wurde häufig vor allem im Zusammenhang mit rückläufigen Trends bei den Gesamtfangmengen und den Fangmengen je Aufwandseinheit (engl. CPUE) in verschiedenen tropischen Gebieten auf der ganzen Welt laut. Eine angemessene Bestandsabschätzung der wichtigsten Zielarten wird jedoch oft durch die schlechte Qualität und Quantität der verfügbaren Daten erschwert. Selbst wenn die Herausforderungen für die Durchführung zuverlässiger Bestandsabschätzungen überwunden werden, erfordern gemischte Kleinfischereien (mehrere Arten, unterschiedliche Fanggeräte) einen ganzheitlichen Ansatz, der die Auswirkungen der Fischerei auf verschiedene Komponenten der Ökosysteme berücksichtigt und anerkennt, dass Kleinfischereien komplexe sozial-ökologische Systeme sind. Am Beispiel der kolumbianischen Pazifikküste als Fallstudiengebiet für tropische, datenlimitierte SSF stellt diese Arbeit eine neuartige und umfassende Bewertung vor, die folgende Aspekte beinhaltet: a) die Erfassung des Bestandszustandes der wichtigsten Zielarten, b) die Abschätzung potenzieller Auswirkungen von SSF auf die biologischen Gemeinschaften und Ökosysteme, denen die Zielarten zugeordnet sind, und c) die Identifizierung der sozioökonomischen Treiber der von den Kleinfischern gewählten Fangmethoden.

Zwei komplementäre Ansätze zur Analyse von Längenhäufigkeiten in den Fängen (engl. Length-Frequency-Catch-Data, LFCD) und zwei Datenquellen (staatlich und nichtstaatlich) wurden verwendet, um den Bestandszustand von drei Hauptzielarten der SSF im kolumbianischen Pazifik zu bewerten: *Scomberomorus sierra* (engl. Pacific Sierra), *Lutjanus guttatus* (engl. Spotted Rose Snapper) und *Brotula clarkae* (engl. Pacific Bearded Brotula). Der erste LFCD-Ansatz folgte traditionellen Bestandsbewertungsmethoden, und beinhaltet neben Schätzungen von Wachstums- und Sterblichkeitsparametern - ermittelt mittels modaler Progression der Längenhäufigkeiten über Zeit,- eine Analyse der Fangkurve und ein Ertrags pro Rekrut (Yield-per-Recruit)-Modell. Der zweite Ansatz basierte auf der Analyse der Größenverteilung in den Fängen, d.h. des relativen Beitrags der Fischgrößen zu den Fängen hinsichtlich der vorgeschlagenen Referenzwerte für gesunde Bestände. Die Schätzungen der Wachstumsparameter unterschieden sich zwischen den Datenquellen und zeigten große Vertrauensintervalle (geschätzt durch eine neuartige Bootstrap-Routine), was auf eine insgesamt hohe Unsicherheit hinweist, die der Bewertung zugrunde lag. Die geschätzten Werte der Bestandsindikatoren, d.h. Nutzungsrate, fischereiliche Sterblichkeit und Größenverhältnisse, weisen zusammen auf einen Zustand starker bis übermäßiger Ausbeutung für die drei untersuchten Arten hin, derweil Unterschiede zwischen den Datenquellen beobachtet wurden, die hauptsächlich auf die Selektivität der Fischerei und das Stichprobendesign zurückzuführen sind.

Über den Einzelartenansatz des Fischereimanagements hinausgehend wurden verschiedene ökologische Indikatoren für die Auswirkungen der Fischerei anhand der Zusammensetzung des Nominalfangs verschiedener in SSF verwendeter Fanggeräte in drei Küstenzonen des kolumbianischen Pazifiks ermittelt. Die Ergebnisse zeigten, dass die taxonomischen, größenbezogenen, funktionellen und naturschutzbezogenen Merkmale des nominalen Fangs je nach geographischer Lage und verwendeter Ausrüstung stark variieren. Insgesamt tendieren Hand- und Langleinen dazu, größere Individuen und Arten auf höherem trophischen Niveau zu fangen als Netze. Dabei fingen sie allerdings auch einen höheren Anteil an als gefährdet eingestufte Arten. Dies stellt die Vorstellung in Frage, dass selektivere Fanggeräte insgesamt geringere ökologische Auswirkungen haben. Im Gegensatz dazu zielten die verwendeten Netze auf ein breiteres Spektrum von Arten und Größen ab (konzentriert auf Fische kleiner oder mittlerer Größen) und fingen auch eine größere Vielfalt an trophischen und räumlichen Gilden. Grundschleppnetze wiesen einen hohen Prozentsatz angelandeter Beifänge auf, was als ein unerwünschtes Merkmal für jede Fischerei im Hinblick auf ihre Nachhaltigkeit gilt. Diese Ergebnisse unterstreichen die Notwendigkeit, die potenziellen ökologischen Auswirkungen der SSF im kolumbianischen Pazifik zu berücksichtigen, etwas was in der Vergangenheit weitgehend ignoriert wurde.

Abschließend wurde in den drei Küstendörfern des zentralkolumbianischen Pazifiks eine Charakterisierung der sozioökonomischen Bedingungen von Kleinfischern und eine Abschätzung der Rentabilität der verschiedenen Fanggeräte durchgeführt. Der Pro-Kopf-Verbrauch von Fisch in den untersuchten Dörfern war sehr hoch (237 kg*pc*yr-1), was in den nationalen Statistiken, die Kolumbien als ein Land mit sehr niedrigem Fischverbrauch ausweisen, verschleiert wird. Die Wahl der Fanggeräte wurde durch den Wert der Zielarten und der potenziellen Gewinne, aber auch durch den Zugang zu Märkten, den Zugang zu Fischgründen und die lokalen sozioökonomischen Bedingungen beeinflusst. Insgesamt führte eine hohe Marktnachfrage nach Garnelenarten, verbunden mit einem relativ einfachen Zugang zu den Fanggründen und einer einfachen Bedienung der Fanggeräte, dazu, dass die Mehrheit der Fischer im zentralkolumbianischen Pazifik Kiemennetze mit kleinen Maschenweiten und Grundschleppnetze einsetzte. Darüber hinaus war es weniger wahrscheinlich, dass die Nutzer dieser Fanggeräte im Vergleich zu anderen Fischern während der Saison das Fanggerät wechselten. Stark schwankende Fangmengen und Gewinne sowie relativ hohe Einstiegs- und Betriebskosten führten zu einem insgesamt niedrigen wirtschaftlichen Einkommen der Kleinfischer, was ihre ohnehin schon gefährdete sozioökonomische Lage zwangsläufig verschärft.

Eine Reihe von praktischen Empfehlungen hin zu einer ganzheitlicheren Bewertung und Bewirtschaftung tropischer Kleinfischereien wird aus den Ergebnissen dieser Arbeit und aus der Berücksichtigung regionaler und globaler Zusammenhänge gezogen. Drei Prioritäten werden hier hervorgehoben. Erstens, um die Zuverlässigkeit der Bestandsbewertungen zu erhöhen: i) Die Erhebungsmethoden fischereilicher Daten sollten auf der Grundlage des Fischereiaufwands angepasst werden, und ii) die Selektivität der verschiedenen Fanggeräte muss ermittelt werden, um die LFCD vor der Analyse zu korrigieren. Zweitens wird die Anwendung ökologischer Indikatoren als Teil des Monitorings und der Bewertung zeitlicher Trends in der SSF es ermöglichen, die potenziellen Auswirkungen der Fischerei auf das Ökosystem bei den Entscheidungsprozessen des SSF-Managements zu berücksichtigen. Drittens werden Investitionen in die Stärkung des Sozialkapitals der Küstenfischereigemeinden und die Berücksichtigung der lokalen sozioökonomischen und kulturellen Kontexte bei der Gestaltung von Fischereimanagementmaßnahmen unter gleichzeitiger Förderung von Co-Management-Systemen für den Weg zu nachhaltigen SSF in tropischen Küstengebieten der Welt von wesentlicher Bedeutung sein.

Stichworte: datenlimitierte Fischerei, Fangzusammensetzung, östlicher tropischer Pazifik, ökologische Indikatoren, ökosystembasiertes Fischereimanagement, Fanggerätmanagement, Bestandsbewertung, sozial-ökologische Systeme.

RESUMEN

En los países tropicales, la pesca a pequeña escala (ingl. SSF) contribuye con más de la mitad de las capturas pesqueras totales y brinda seguridad alimentaria, nutrición, empleo y múltiples beneficios a la economía local costera. Frecuentemente surgen diversas preocupaciones sobre la sostenibilidad de la SSF, principalmente asociadas a las tendencias observadas de reducción de los volúmenes de captura y de captura por unidad de esfuerzo (CPUE) en diferentes áreas tropicales del mundo. Sin embargo, la escasa calidad y cantidad de datos disponibles a menudo obstaculiza la realización de diagnósticos adecuados sobre el estado de las poblaciones de las principales especies objetivo. Incluso si se superan los desafíos para llevar a cabo dichos diagnósticos de manera confiable, el carácter multi-específico y multi-artes de la SSF demanda un enfoque holístico que considere los impactos que la pesca puede tener sobre diferentes componentes de los ecosistemas y que reconozca que la SSF posee la complejidad de los sistemas socio-ecológicos. Utilizando la costa del Pacífico colombiano como caso de estudio de SSF tropical con limitaciones de datos, esta tesis presenta una evaluación novedosa y exhaustiva que incluye: a) la condición del stock de las principales especies objetivo, b) los impactos potenciales de la SSF sobre las comunidades biológicas y sobre los ecosistemas a los cuales están asociados las especies objetivo, y c) los factores socio-económicos que motivan a los pescadores a elegir sus artes de pesca.

Dos enfoques complementarios de análisis de datos de frecuencia de tallas de captura (ingl. LFCD) y dos fuentes de datos (gubernamentales y no gubernamentales) fueron utilizados para evaluar el estado del stock de tres principales especies objetivo de la SSF en el Pacífico colombiano: la sierra castilla (*Scomberomorus sierra*), el pargo lunarejo (*Lutjanus guttatus*) y la merluza (*Brotula clarkae*). El primer enfoque de análisis de LFCD se basó en métodos tradicionales de evaluación de recursos pesqueros, que incluyen la estimación de parámetros de crecimiento y mortalidad a partir de la progresión modal de la frecuencia de tallas en el tiempo, el análisis de curvas de captura y un modelo de rendimiento por recluta. El segundo enfoque se basó en el aporte relativo de rangos de tallas de los peces capturados, con respecto a valores de referencia propuestos para recursos pesqueros saludables. Los parámetros de crecimientos estimados difirieron entre las fuentes de datos y mostraron grandes intervalos de confianza (estimados a través de una nueva rutina de *bootstrapping*), lo que indica un alto grado de incertidumbre subyacente al diagnóstico. Los valores estimados para los indicadores del estado de recursos pesqueros, como son: la tasa de explotación, la mortalidad por pesca y las proporciones de tallas, convergieron en indicar un estado de plena explotación o de sobreexplotación para las tres especies evaluadas, aunque se observaron diferencias entre las fuentes de datos, las cuales se atribuyen principalmente a la selectividad de las pesquerías y al diseño del muestreo.

Con el fin de ir más allá del enfoque de manejo pesquero basado sólo en las especies objetivo, se estimaron diversos indicadores ecológicos del impacto pesquero con base en la composición de la captura de los diferentes artes de pesca utilizados en la SSF de tres zonas costeras del Pacífico colombiano. Los resultados mostraron que las características taxonómicas, de estructura de tallas, funcionales y de conservación de la captura variaron ampliamente dependiendo de la ubicación geográfica y del tipo de arte de pesca utilizado. En general, las líneas de mano y los espineles tendieron a seleccionar tamaños más grandes y especies de mayor nivel trófico que las redes, pero también capturaron una mayor proporción de especies intrínsecamente vulnerables y de interés para la conservación. Esto pone en tela de juicio la idea de que los artes más selectivos tienen, en general, un menor impacto ecológico. Por el contrario, las redes capturaron un rango más amplio de especies y de tallas (aunque se enfocaron en peces pequeños o medianos) y capturaron también una mayor diversidad de grupos tróficos y funcionales. Las redes de arrastre de fondo tuvieron un alto porcentaje de captura incidental, una característica indeseable para cualquier pesquería en términos de sostenibilidad. Estos resultados enfatizan sobre la necesidad de considerar los potenciales impactos ecológicos de la SSF del Pacífico colombiano, los cuales hasta ahora habían sido ignorados.

Finalmente, se realizó una caracterización de las condiciones socio-económicas de los pescadores de SSF y una estimación de la rentabilidad de los diferentes artes de pesca en tres comunidades costeras del Pacífico central colombiano. El consumo de pescado per cápita en dichas comunidades fue muy alto (237 kg*pc*año^{-1}), lo cual estaba oculto en las estadísticas nacionales que posicionan a Colombia como un país con una tasa de consumo de pescado muy baja. La elección de los artes de pesca por parte de los pescadores es motivada por el valor de las especies objetivo y por las ganancias económicas potenciales, pero también por el acceso que tienen a los mercados, el acceso a los caladeros y por sus condiciones socio-económicas locales. En general, la alta demanda de mercado por especies de camarón, junto con la relativa facilidad de acceso a los caladeros y la facilidad para utilizar los artes de pesca, promueve que la mayoría de los pescadores del Pacífico central colombiano utilice redes de enmalle con ojos de malla pequeño y redes de arrastre de fondo. Además, los usuarios de estos artes tienden menos a realizar cambios estacionales de arte de pesca, en comparación a otros pescadores. Las capturas y las ganancias económicas fueron bastante variables lo cual, sumado a los altos costos de entrada y operativos de la actividad pesquera, resultaron en ingresos económicos bajos para los pescadores, lo que inevitablemente empeora su situación socio-económica, de por sí ya vulnerable.

A partir de los resultados de esta tesis y considerando los contextos regional y global, se presentan aquí un conjunto de recomendaciones prácticas para la transición hacia una evaluación y gestión más holística de las SSF en áreas costeras tropicales. Se destacan aquí tres prioridades. En primer lugar, para aumentar la confiabilidad en los diagnósticos sobre el estado de los recursos pesqueros: i) los sistemas de colecta de datos deben ser ajustados con base en el esfuerzo pesquero, y ii) la selectividad de los diferentes artes debe ser estimada para corregir los LFCD antes de realizar análisis. En segundo lugar, la adopción de indicadores ecológicos, como parte de la evaluación periódica de la SSF, y el monitoreo de tendencias temporales, permitirá tener en cuenta los posibles impactos de la pesca en el ecosistema en los procesos de toma de decisiones de manejo de la SSF. En tercer lugar, las inversiones orientadas a fortalecer el capital social de las comunidades costeras con actividad pesquera y la consideración del contextos socio-económico y cultural local en el diseño de las medidas de manejo pesquero, a la vez que se promueven esquemas de co-manejo, serán esenciales en el camino hacia la sostenibilidad de las SSF en las zonas costeras tropicales del mundo.

Palabras clave: pesquerías con datos limitados, composición de las capturas, Pacífico oriental tropical, indicadores ecológicos, manejo pesquero basado en ecosistemas, manejo basado en artes de pesca, evaluación de recursos pesqueros, sistemas socio-ecológicos.

Content

Table of Figures

List of Tables

Acknowledgements

The journey of a PhD is truly one of intense inner growth; intellectual and academic, but also personal. A growth that, for me, could not have been achieved without the support of many people encountered along the way. First and foremost, my supervisor Prof. Dr. Matthias Wolff, who gave me the opportunity to join his research group. His constant support and trust were essential at each stage of the process. Deep gratitude also to PD. Dr. Marion Glaser, who guided me in exploring the social-ecological angles of marine research and gave me valuable advice throughout the process. All the members of the Resource Management working group at ZMT with whom I had fruitful discussions and who were always willing to share their experiences; in particular thanks to: Gustavo Castellanos-Galindo, Lotta Kluger, Paul Tuda, Seth Abobi, Jennifer Rehren, Moritz Stäbler, Manuel Jänig and Rebeca Borges. Special thanks to Gustavo for reading and commenting drafts of the General Introduction, the General Discussion and the Abstract of this thesis, and to Manuel Jänig for his help with the German translation of the abstract. Immense gratitude goes to Tobias Mildenberger for being such an inspiring research collaborator and for his friendship. Thanks also to Lisa Wels for joining me for six months in the Colombian Pacific to carry out her Master's thesis and for all her support in the field.

Of course, the whole adventure could not have started without the generous scholarship offered by CEMarin to cover my living expenses for three and a half years and a scholarship from the University of Bremen for the last three months. The research project, to collect data in Colombia, was funded by CEMarin and by Rufford Foundation and supported by several government and non-governmental institutions in Colombia, such as: AUNAP (Autoridad Nacional de Acuicultura y Pesca), Fundación Squalus, WWF Colombia, Fundación MarViva and Universidad del Valle. Special thanks to Juan Manuel Díaz, Giovanni Melo, Gloria González and Catalina Sánchez from Fundación MarViva, not only for providing their valuable data sets, but for their help in the process of data curation. Thanks to José Tavera and Juan Felipe Lazarus at Universidad del Valle for their help with species identification. Also, to Juan Carlos Mejía, Carlos Andrés Puentes and Javier Quintero for their support with maps.

Thanks to the coastal communities of Bocana, Pital and Punta Bonita for receiving me in their homes, teaching me about their culture and making my fieldwork much easier and enjoyable. Immense gratitude to my local research team: Wilfrido Angulo, Mary Cruz Clarette and Enier Cuero, who always went the extra mile to engage the fishers and gather as much data as possible. Thanks also to Bernardo Orobio and Yuli Riascos for always being there when I needed, for their friendship and offering me a cozy home in Buenaventura.

My "Bremenian family" was essential along the way for moral support, laughter, bike rides, cooking delicious food and making the most out of the local weather. I will have forever in my heart: Inés Viana, Astrid Sánchez, Daniel Saavedra, Sonia Bejarano, Agustin Moreira, Guilherme Abuchahla, Juan Carlos Mejía and Ernesto Acosta. Many friends and colleagues in different parts of the world followed my progress and encouraged me in the past three and half years; in particular thanks to: Alexandra

Aparicio, Elsa Henao, Valeria Pizarro, Helena Andrade, Fernando Castillo, John Ramirez, Vladimir Puentes, Alberto Campuzano, Daniel Torija, Juan Pablo Quimbayo, and Marianne Copeland. Special thanks to Marianne for proofreading the General Introduction and Abstract.

Last, but not least, my deepest gratitude to all my family for their constant support, unconditional love and patience during this process. To my mom for triggering my life lasting connection with the ocean, for always believing in me and for constantly encourage me to do what I love. To my brother for sharing that connection with the sea, for his creativity, that brought to life our first audiovisual project related to the fishers of the Colombian Pacific, but most of all for his strength and courage during the difficult times we faced while being apart. To my dad, a shining star that has rejoined the Universe, for his nurturing love, his passion for his ideals and his life lessons that were such a driving and decisive force for me, particularly in the last months, to achieve this goal. You are always in my heart.

CHAPTER 1

General Introduction

1.1 SMALL-SCALE FISHERIES: THE GLOBAL CONTEXT

Fishing has been carried out by humans since prehistoric times experiencing exponential growth, as an economic activity, in the 19th century thanks to technological improvements in fishing gears and navigation (Sahrhage and Lundbeck, 2012). Nowadays, fish contribute to 17% of the animal protein consumed worldwide with human fish consumption growing at a faster rate (3.2) than human population itself (1.6) in the past five decades (FAO, 2018a). This growth in fish consumption has mainly been facilitated by the development of the aquaculture industry since the production of capture fisheries appears to have remained unchanged since the late 1980s (FAO, 2018a). Concerns about the sustainability of marine fisheries have been widely exposed in the scientific literature (Costello et al., 2012; Hilborn et al., 2003; Pauly et al., 1998; Worm and Branch, 2012) with currently a third of the assessed stocks considered to be fished at biologically unsustainable levels (FAO, 2018a). However, the global situation is not a generalized one: while in developed countries fisheries management has substantially improved resulting in better conditions of several stocks, in many developing countries, where a higher number of people directly depend on fisheries for their livelihoods (WorldBank, 2012), catch-per-unit-effort has declined and overcapacity has worsened. (Ye and Gutierrez, 2017).

In developing countries, more than half of the fisheries catch is produced by the Small-Scale Fisheries (SSF) subsector (also referred to as artisanal), which provides food security, nutrition, employment and multiplier effects to local coastal communities worldwide (Béné et al., 2007; FAO, 2015a). While encompassing a wide range of features in different national and local contexts, artisanal fisheries have been defined as:

> "*Typically traditional fisheries involving fishing households (as opposed to commercial companies), using relatively small amount of capital, relatively small fishing vessels, making short fishing trips, close to shore, mainly for local consumption. In practice, definition varies between countries, e.g. from hand-collection on the beach or a one-person canoe in poor developing countries, to more than 20 m. trawlers, seiners, or long-liners over 20 m in developed countries. Artisanal fisheries can be subsistence or commercial fisheries, providing for local consumption or export. Sometimes referred to as small-scale fisheries. In general, though by no means always, using relatively low-level technology. Artisanal and industrial fisheries frequently target the same resources that may give rise to conflict*" (FAO, 2015a).

Despite the importance of SSF, global attention and resources given historically to the subsector, by government and academia, have been relatively low in comparison to other food providing activities or to industrial fishing (Purcell and Pomeroy, 2015). Increased recognition of their socio-economic contributions (Béné et al., 2007) and of the potential ecological impacts of the activity on non-target stocks and associated ecosystems (Jennings and Kaiser, 1998), have encouraged a growing number of studies and initiatives in the field of SSF in recent years (Purcell and Pomeroy, 2015). Additionally, linkages between securing sustainable SSF and the achievement of several Sustainable Development Goals (SDG) of the United Nations 2030 Agenda [1], particularly those related to ending poverty (SDG 1), ending hunger (SDG 2), achieving decent work and economic growth (SDG 8), reducing inequalities (SDG 10) and ensuring sustainable use of marine resources (SDG 14), have helped to raise awareness about the importance of adequately assessing and managing SSF (Chuenpagdee et al., 2019; Singh et al., 2018).

A major challenge of managing SSF is the relatively low quantity and often poor quality of data related to their catch compared to that of industrial fisheries, which usually results in under-representation of this subsector in the national fisheries and economic statistics provided by countries to FAO (Food and Agricultural Organization of the United Nations) for periodic global assessments (Pauly and Zeller, 2016). Data limitations are partly related to the fact that coastal villages in developing countries tend to be dispersed over large areas and geographically isolated. This characteristic demands additional financial and human resources from governments in order to record landings. Unfortunately, most governments, especially in developing countries, lack financial and human resources for SSF management (Salas et al., 2007; WorldBank, 2012). The data limitations of the SSF consequently hinder adequate assessment of stocks and estimations of maximum sustainable yields (*MSY*), a key reference point of traditional single-species fisheries management used as a basis to establish limits on fishing effort or to set catch quotas (King, 2007). Whether attempting to use traditional “holistic” assessment methods, based mostly on time series of catch and effort data, or analytical methods based on length frequency data (Sparre and Venema, 1998), temporal sampling gaps, lack of information on fishing effort, poor knowledge of life history characteristics of target species (e.g. growth rate, length at maturity), deficiencies in taxonomic identification and poor sampling design in monitoring schemes, can all lead to biases in the estimation of the stock condition and the derived management measures that are later implemented (Dowling et al., 2019; Omori et al., 2016; Ramírez et al., 2017). In cases of acute data scarcity, some authors have proposed assessing the risk of overexploitation based on stock productivity and stock susceptibility analyses (Milton, 2001; Patrick et al., 2010), which can also be complemented with local ecological knowledge (LEK) derived from resource users (Jara-Baquero, 2018). Nevertheless, such risk-based assessments also require accurate knowledge of basic life history characteristics of the target species as

---

[1] https://sustainabledevelopment.un.org/sdgs

a minimum input (Honey et al., 2010), which is often absent for the target species of tropical SSF (Ramírez et al., 2017).

Even if challenges to conduct reliable stock assessments were overcome, management for sustainable SSF requires going beyond the single species approach, acknowledging that fishing can exert impacts on different components of the ecosystems (Jennings and Kaiser, 1998; Link et al., 2002; Rochet and Trenkel, 2003) and that the small-scale fishing sector exhibits the complexity of social-ecological systems (Kittinger et al., 2013; Ostrom, 2009). The Ecosystem Approach to Fisheries – EAF (Garcia, 2003) and the Ecosystem-Based Fisheries Management – EBFM (Pikitch et al., 2004) are two frameworks commonly used by managers to account for the effects of fishing at the community and ecosystem levels. Due to the inherent taxonomic and/or size range selectivity of fishing, ecological impacts of fishing include reduced biodiversity, reduced abundance of by-catch species, changes in taxonomic composition and size structure of the fish community, and changes in trophic dynamics of the entire ecosystem (Arias-González et al., 2004; Jennings and Kaiser, 1998; Pauly et al., 1998; Pikitch et al., 2004).

Despite the general issues of low quantity and quality of data, recent studies in tropical, developing contexts have begun to incorporate an ecosystem approach in their assessments of SSF (Bacalso and Wolff, 2014; Rehren et al., 2018; Tuda, 2018). However, translation of the results of these assessments into management measures still requires closer collaboration between scientists, decision makers and resource users. Moreover, the inclusion of the human dimension in the assessment of SSF, particularly in developing countries, has lagged behind the aforementioned inclusion of an ecosystem-based approach, with social, economic and cultural indicators related to SSF sustainabilty still being developed (Davies et al., 2009; Edwards et al., 2019; Glaser et al., 2012; Naranjo-Madrigal et al., 2015; Schuhbauer and Sumaila, 2015). Some argue that accounting for the uncertainty in fishers' behaviors can be more important than addressing the scientific uncertainty of environmental and biological processes that influence stock dynamics, as unexpected behavior by resource users can result in unintended outcomes of management interventions (Fulton et al., 2011). Coastal fishing communities in developing countries are often marginalized sectors of the society, belonging to ethnic minority groups with weak participation in decision making (Béné et al., 2007; Salas et al., 2007). Understanding fishers' motivations and hurdles should, therefore, be a key component of SSF assessments as an input to the design of management strategies that aim to ensure long-term sustainability in its three dimensions: biologic, ecologic and socio-economic (Stephenson et al., 2017).

1.2 SMALL-SCALE FISHERIES IN THE COLOMBIAN PACIFIC

Despite being the only South American country with Caribbean and Pacific coasts, with large territorial seas (total of 3,189 km of coastline and 928,660 km^2 of Exclusive Economic zones; (CCO, 2018), Colombia is not a marine fishing nation. The contribution of the fishing sector to the national economy (Gross Domestic Product) is only 0.5% (FAO, 2015b). This is attributed more to its geographical and environmental conditions (e.g. low productivity in the sea) than to the lack of investment in the development of logistical and technological capacities (FAO, 2015b). Total annual landings from marine fisheries, which contribute 82% to total landings in the country (the rest are inland fisheries), have ranged between 40,000 and 80,000 tonnes in recent years (AUNAP and UNIMAGDALENA, 2013a; FAO, 2015b). Such landings are very low when compared to landings of neighbouring countries such as Ecuador (715,357 tonnes) and Perú (3’774,887 tonnes), based on reports from 2016 (FAO, 2018a). Annual fish consumption per capita in Colombia is also relatively low (5 kg) when compared to the average values for Latin America (18 kg) and the world (20 kg) (FAO, 2015b, 2018a).

In Colombia, SSF have many of the characteristics identified as typical of this type of fisheries throughout Latin America and the developing world i.e. multi-gear and multi-species, low capital investment, labor intensive, remote and diverse landing sites and weak market power among fishers (Purcell and Pomeroy, 2015; Salas et al., 2007). SSF are loosely defined by Colombian law as the type of fishing “carried out by individual fishers or fishers organised into enterprises, cooperatives or other asociations, working independently with equipment related to a small-scale productive activity and using small-scale fishing systems, gears and methods” (Law 13 1990 and Decree 2256 of 1991).

Specifically along the Pacific coast of the country, more than 11,000 households of mostly Afro-descendant communities depend on SSF for nutrition, income and employment (Rueda et al., 2010), employing mainly handlines, longlines, gillnets and bottom trawls and using low technologies (Figure 1.1). The relevance of the socio-economic benefits derived from SSF for people on the Pacific coast of Colombia increases when the regional context of relatively high levels of poverty (65%) and illiteracy (30%) are taken into account (Castiblanco et al., 2015). The annual fisheries catch derived from SSF on the Pacific coast is around 5,000 ton. This supplies both local and national markets, and accounts for 15% - 40% of the total landed catch in this coastal region, with industrial fisheries making up the rest (AUNAP and UNIMAGDALENA, 2013a; De la Hoz and Manjarrés-Martínez, 2016). However, the contribution of SSF to the total regional catch increases to 68% - 83% when landings of tuna species from the industrial fishing fleet are excluded from the data (AUNAP and UNIMAGDALENA, 2013a; De la Hoz and Manjarrés-

Martínez, 2016). Furthermore, those landings values are most likely underestimated due to historical weaknesses in the way the national fisheries statistics have been collected. Similar to most other Latin American countries (Salas et al., 2007), the Colombian fisheries authority (AUNAP for its Spanish acronym[2]) is highly centralized and has limited resources to carry out adequate fisheries monitoring programs, which results in a lack of continuity, lack of standard methods and under-representation of rural fishing communities (Ramírez et al., 2017; Saavedra-Diaz, 2012). These problems are exacerbated by several institutional changes that were introduced in the fisheries management institutional structure between 2002 and 2011. Taking into account those difficulties, Wielgus et al. (2010) carried out a reconstruction of the national fisheries statistics from 1950 to 2006 using different secondary sources and estimated that for the Pacific coast of Colombia catches may have been 1.3 times higher than was officially reported by the country to FAO. This adjusted estimate would increase the contribution of SSF to 19% of the total catch in the Pacific coast. Nevertheless, more accurate estimates derived from adequate sampling in rural coastal villages are still needed to estimate the true contribution of SSF, not only to the overall catches but also to food security in the region.

Despite the many limitations of fisheries statistics in the country, there is preliminary evidence of a high proportion (> 50%) of juvenile fish (below the average size at maturity) in the catch of some of the most important commercial species of the Colombian Pacific (AUNAP and UNIMAGDALENA, 2013b), which could be a sign of growth overfishing (Froese et al., 2008). Fisheries authorities have made efforts to assess the stock condition of the main target species at a regional scale, with the purpose of establishing annual catch quotas (Barreto and Borda, 2008; Barreto et al., 2009; Puentes et al., 2014a). One of the most comprehensive technical reports carried out by the national fisheries authority in recent years, based on catch curves and surplus production models, indicated an over-exploitation situation for 66% of the assessed target species (Puentes et al., 2014a), although the same report recognized the limitations of the data on which these assessments were based.

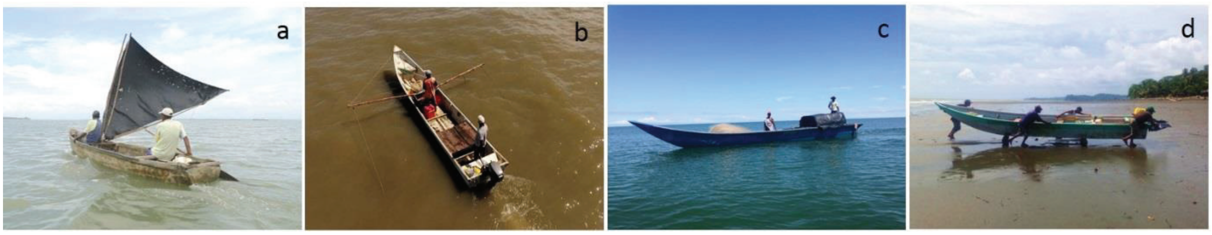


Figure 1.1. *Diversity of boats used in small-scale fishing operations of the Colombian Pacific by fishers using diverse fishing gears, such as: a) lobster nets, b) bottom trawls, c) gillnets and d) longlines.*

---

[2] Autoridad Nacional de Acuicultura y Pesca – AUNAP (www.aunap.gov.co)

One of the main target species of both the industrial and the small-scale fishing fleets, the white shrimp *Penaeus occidentalis*, for which more detailed time series data on catch and effort of the industrial fleet is available, shows a drastic decline in catch per unit effort since 1980 (Figure 1.2). Additionally, this important fishing resource was diagnosed as being in a state of depletion since 1995, based on catch-curve analysis and surplus production models (Rueda et al., 2011, 2014). Besides the evidence derived from fisheries data, there is an overall stakeholders perception of declining abundance of fishing resources and increased fishing effort in the country´s SSF, based on extensive interviews with fishers, community leaders and fisheries experts between 2008 and 2009 along the Pacific coast of Colombia (Saavedra-Diaz, 2012).

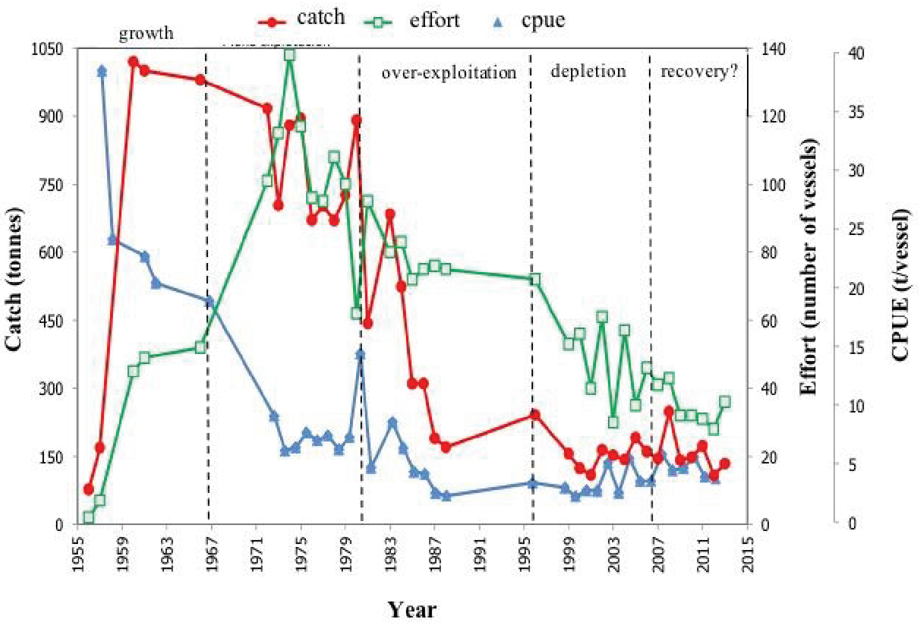


Figure 1.2. *Fishing development phases of white shrimp (<u>Penaeus occidentalis</u>) in the Colombian Pacific by the national industrial fleet. Catch (tonnes) is shown in red related to the left Y axis, fishing effort in green related to values in the immediate right Y axis, and catch-per-unit-efffort (CPUE) in blue related to the far right Y axis. Modified from Rueda et al. (2014)*

A lack of fisheries management regulations for SSF, and a lack of enforcement capacity, may have contributed to the negative trends perceived for many fishing resources in the Colombian Pacific. Current fishing regulations for this region include: establishment of annual catch quotas for main target species or taxonomic groups (AUNAP, 2016), annual seasonal closure for shallow and deep sea shrimp fisheries (mid January to mid March), a minimum size for the manual collection of the mangrove cockle (*Anadara tuberculosa*) established at 5 cm (INPA, 2000), a minimum mesh size for gillnets of 2.75 inches and the prohibition of the use of the small-scale bottom trawling net (locally known as *changa*) (INCODER, 2004). Concerned about the perceived decreasing trend in the abundance of resources, small-scale fishers of some coastal areas have called for additional management measures related to: protection of spawning areas, a maximum number of fishers or boats allowed, a maximum number of users of particular fishing gears, seasonal or temporal closures, and size limits (Saavedra-Díaz et al., 2015).

Partly in response to deficient management capacities from government authorities, several community-driven initiatives to design and implement fisheries management plans have been introducted in recent years supported by environmental non-governmental organizations (NGOs). Particularly in the northern sub-region of the Colombian Pacific (northern Chocó), an inter-institutional initiative has been developed, over the course of more than 10 years, to develop fisheries management measures such as spatial zoning and fishing gear restrictions (Ramírez-Luna and Chuenpagdee, 2019; Vieira et al., 2016). As a result, an Exclusive Artisanal Fisheries Zone (ZEPA for its Spanish acronym) and a regional marine protected area (Regional District of Integrated Management - DRMI “Tribugá”) were recently declared by the fisheries authority and by the regional environmental authority respectively (AUNAP, 2013; Codechoco, 2014). Together, the ZEPA and DRMI encompass a total area of ca. 1,600 km^2 where gear-based fisheries management regulations are being implemented with high levels of local stakeholder participation (Ramírez-Luna and Chuenpagdee, 2019).

However, the implementation of gear-based management measures without specific knowledge on their ecological and socio-economic implications could lead to unexpected and undesired consequences. For example, promoting the massive use of a specific type of fishing gear, based on its higher selectivity (e.g. long-lines instead of gill nets), could create problems of fishing overcapacity by increasing the pressure on certain stocks and certain habitats (Pauly et al., 2002; Pomeroy, 2012). Moreover, the selective fishing of species of higher trophic levels, which are the main target species of long-lines and hand-line gears in the northern Pacific region (MarViva, 2014), could evolve in lower yields, biodiversity loss and alteration of the fish community structure (Breen et al., 2016).

1.3 STUDY AREA

1.3.1 Environmental characteristics

The Pacific coast of Colombia is located within the Panama Bight and belongs to the Eastern Tropical Pacific ecoregion. It stretches for ca. 1,300 km (Correa and Morton, 2010) from the border with Panamá (7° 13' 21”N, 77°53'25”W) to the border with Ecuador (1° 27' 48”N, 78°51'43”W) (Figure 1.3). This coastal region is characterized by high precipitation levels (ranging from 2,500 - 9,000 mm*year^{-1}), abundant rivers that drain from the western Andes and a semi-diurnal tidal range that varies between 3 - 4.5 meters on spring tides and between 2 - 3 meters on neap tides (IDEAM, 2005; Poveda et al., 2006). Sea surface temperatures in the region typically show two distinct periods: a colder one, associated with an upwelling coming from Panama, that lasts from January to March with temperatures averaging 26.5°C, and a warmer one with temperatures increasing up to 28.5°C during the northern summer (Devis-Morales, 2009). However, events associated with the El Niño Southern Oscillation (ENSO) can drastically change this seasonality (Wang and Fiedler, 2006).

The northern Colombian Pacific sub-region extends for ca. 335 km from the border with Panamá (7°12'39” N, 77°53'21” W) to Cabo Corrientes in the south (5°29'50” N, 77°09'23” W). This coastal sub-region is distinguished from the rest of the Colombian Pacific by the predominance of rocky cliffs, sandy beaches and a relatively narrow continental shelf (of 1 - 15 km in width). This contrasts with the predominance of alluvial plains and barrier islands backed by mangroves and estuaries, with an average shelf width of 50 km, in the central and southern sub-regions (Martínez et al., 1995, Castellanos-Galindo and Zapata, 2019).

1.3.2 Socio-economic characteristics

Inhabitants of the Colombian Pacific region are 95% Afro-descendant. They have traditionally used natural resources based on collective work strategies and a collective sense of ownership with livelihoods that depend mostly on agriculture, fishing, timber and gold extraction (Escobar, 2008). Recognizing their ethnic rights in 1993 (Law 70 of 1993), the Colombian government granted the possibility to request collective land titles for organized Afro-Colombian local communities known as Community Councils (Offen, 2003). Currently, collective lands owned by Afro-descendant communities extend to more than 5 million hectares and represent almost 50% of the entire Pacific region (Escobar, 2008; PNUD, 2012). The titles include mainly rainforests, mangroves and farmed lands that surround river basins. However, they exclude marine ecosystems despite the fact that these are also important areas of historic resource usage for Afro-descendant communities living along the Pacific coast (Escobar, 2008).

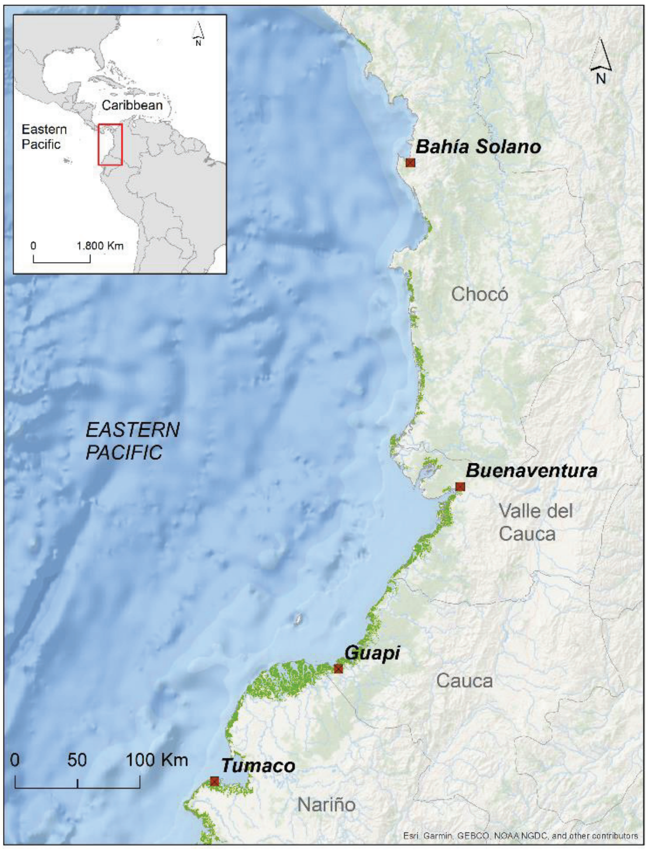


Figure 1.3. *Location of the Colombian Pacific coast indicating main land provinces (i.e. Chocó, Valle del Cauca, Cauca and Nariño) and main coastal cities (i.e. Bahía Solano, Buenaventura, Guapi and Tumaco) along the coast. Mangrove areas are shown in green.*

Even though collective land ownership was an important milestone in the region´s socio-economic development, the Pacific region continues to be one of the most marginalized and poorest regions of the country, with 65% of the population unable to meet their basic needs (Castiblanco et al., 2015). A lack of road infrastructure has kept the region relatively isolated from the rest of the country with only two cities (Buenaventura and Tumaco, Figure 1.1) being connected by road to the inner areas of the country. Rural villages and small towns are only accessible by boats or small planes, which has resulted in relatively low population density in the Pacific region, as a whole, compared to other regions of the country (Etter et al., 2006). More specifically, within the region, population density varies widely between those areas that have a large urban population, like Buenaventura (with approximately 70 people*km^{-2}), and rural coastal areas, such as the northern Pacific coast (with approximately 6 people*km^{-2}) (DANE, 2011).

Besides the historic marginalization by Colombia´s centralized government, the inhabitants of the Pacific region have also suffered the impacts of decades of armed conflict, expansion of illegal economic activities (e.g. cocaine production and distribution), forced displacement and high levels of local government corruption, which have all contributed to the current state of low living standards and high economic dependence on the extraction of natural resources (Castellanos-Galindo and Zapata, 2019; Escobar, 2008; Ibáñez and Vélez, 2008).

1.4 SCOPE OF THESIS

1.4.1 Thesis objectives

Considering the lack of published information available about SSF in the Colombian Pacific, this area is used here as a case study exemplifying data-limited fisheries in tropical developing countries, to apply a holistic approach for SSF assessment based on biological, ecological and socio-economic indicators that can be derived from fisheries landings data. This asssessment considers the natural resource conditions: i) at the population level of single target species through diagnosis of their stocks using a traditional fisheries management approach; and ii) at the ecosystem level, through selected indicators of potential ecological impacts of fishing, using an ecosystem based fisheries management approach – EBFM. Also considered, using a social-ecological systems approach, are the socio-economic factors associated with SSF that help identifying behavioral drivers of small-scale fishers. Variables related to the governance of SSF, another key component for assessing and managing social-ecological systems, are not included in the present research because but they have been examined recently by other researchers (Ramírez-Luna and Chuenpagdee, 2019; Saavedra-Diaz, 2012); the findings of their research are incorporated in the General Discussion section of this thesis.

The research questions (RQ) addressed in Chapters 2 to 4 of this dissertation considered the fact that SSF are complex social-ecological systems (Figure 1.4). These questions are:

> *RQ1 What is the stocks' condition of the three most abundant species landed by the SSF of the Colombian Pacific? (Chapter 2).*
>
> *RQ2 What can catch composition tell us about the potential ecological impacts of SSF in the Colombian Pacific? And how does the composition differ among coastal sub-regions and among types of fishing gears? (Chapter 3).*
>
> *RQ3 What are the socio-economic drivers of gear choices of small-scale fishers of the central Colombian Pacific? (Chapter 4).*

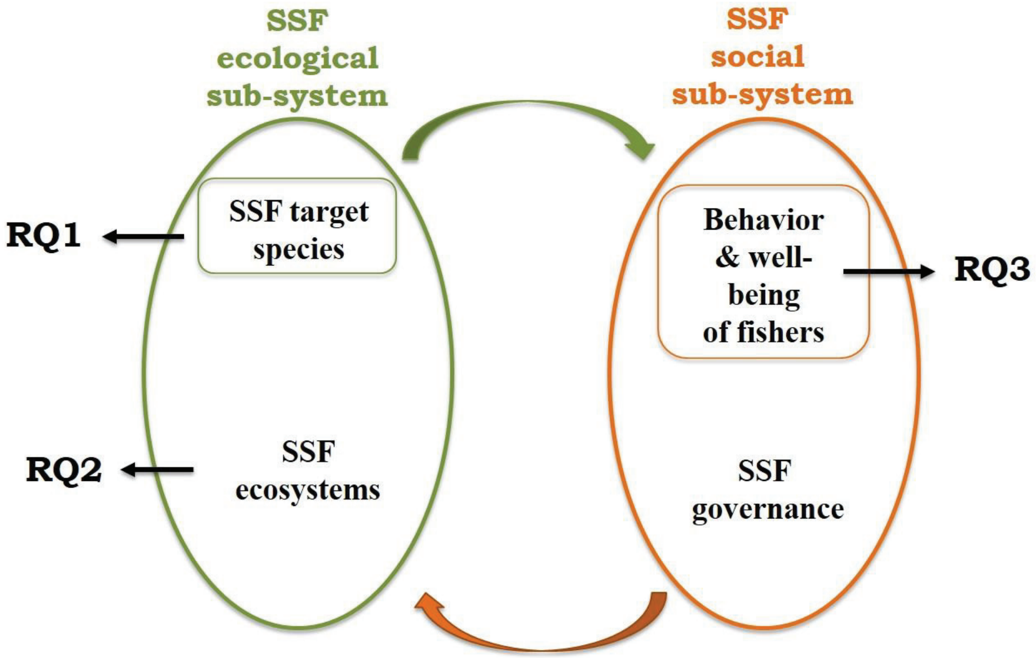


Figure 1.4. *Conceptual diagram of the research questions (RQ) under a holistic assessment approach which takes into account the social-ecological nature of small-scale fisheries. Based on Resilience_Alliance (2010) and Ostrom (2009).*

1.4.2 Thesis outline

The dissertation is divided into five chapters. Chapter 1 provides a general introduction to the research project, contextualising it at global and national levels of knowledge related to the assessment and management of SSF. Emphasis is given to the particular challenges of assessing multi-gear and multi-species SSF in developing countries.

Chapter 2 addresses the first research question (RQ1) and aims to provide the best possible estimates of the stocks' conditions and harvest levels of three main target species of SSF in the Colombian Pacific region. It also explores how assessment results vary with differences in data sources and sampling schemes. The assessment approach adopted is based on two sets of data (government and non-government derived) and two sets of stock condition indicators that are well-suited for data-poor fisheries since they only require representative length-frequency-catch-data of the fisheries and a few external life history parameters that were available in the literature. The first set of indicators follows FAO's traditional stock assessment methods (Sparre and Venema, 1998), which require estimations of growth parameters, mortality rates and biological reference points; for this purpose, a recently developed R package, TropFishR (Mildenberger et al., 2017; R-Core-Team, 2017) was used, which facilitated the estimation of confidence intervals of growth parameters. The second set of indicators used is based on catch proportions related to length-referenced points that have been proposed to assess the sustainability status of the fishery (Cope and Punt, 2009; Froese, 2004). Based on the findings of the two-fold assessment, recommendations on how to improve SSF data collection are given and future research priorities are suggested, that are also applicable to other data-limited fisheries, to increase the accuracy of stock asssessments.

Chapter 3 addresses the second research question (RQ2) and examines the differences in taxonomic, size and functional composition of the nominal catch of the multi-gear SSF of the Colombian Pacific coast. Geographic and gear-related differences in selected ecological indicators are used as proxies of the potential environmental impacts of current SSF practices. The selected indicators are: mean length, maximum body size, mean trophic level, proportion of trophic and spatial guilds, proportion of threatened species and proportion of landed by-catch (Fulton et al., 2005; Jennings, 2005; Jennings and Dulvy, 2005; Link, 2005; Rochet and Trenkel, 2003; Shin et al., 2005). Estimations and analyses are based on landings data from recent years (2011 to 2017), collected by a NGO (Díaz et al., 2016) and by the main author, at three coastal zones of the Colombian Pacific that differ in environmental, socio-economic and fisheries management regimes. Based on the results, potential ecological impact of different fishing gears are discussed, as well as the potential benefits of implementing monitoring of such ecological indicators as part of assessment and management of SSF.

Chapter 4 addresses research question 3 (RQ3) and examines the socio-economic conditions of fishers from the central Pacific coast of Colombia based on data from interviews with small-scale fishers at three selected coastal villages. The coastal villages selected for the study share many environmental features but differ by their distance to the main fish markets and by the social and economic infrastructure available to the fishers' and their families. The chapter also includes an assessment of the profitability of different fishing gears based on landings data collected by the main author over a period of 12 months (2016-2017) and on market prices of the different species recorded monthly at main fish markets used by local fishers to sell their catch. Based on the results, an assessment of potential drivers of gear choices is carried out to explore whether fishers' preferences for a certain type of gear are more related to catch, profit maximization or other socio-economic criteria such as: (a) dependence on SSF, (b) fishing skills and technical capacities, (c) fishing access and risks, or (d) economic well-being. The implications of the findings for fisheries management in Colombia and for multi-gear SSF in similar tropical contexts elsewhere are discussed.

Chapter 5 summarizes the main findings of the preceeding chapters and provides a comprehensive analysis of the results obtained with special emphasis on the implications for fisheries management in Colombia. This synthesis is followed by critical reflection upon the methological approach used and the limitations of the data, resulting in the identification of future research needs in the country.The final part of this final chapter presents an intepretation of the main findings of the thesis considering a regional and global context, through a comparison with case studies from other tropical SSF, followed by a summary of practical recommendations derived from this thesis to facilitate the required transition towards more holistic assessment and management of tropical SSF.

1.4.3 Manuscripts and contribution of doctoral candidate

Manuscript 1. Herrón, P., Mildenberger, T. K., Díaz, J. M., & Wolff, M. (2018). Assessment of the stock status of small-scale and multi-gear fisheries resources in the tropical Eastern Pacific region. Regional Studies in Marine Science, 24, 311-323. (Chapter 2)

> Experimental concept and design (50%), experimental work and/or acquisition of data (50%), data analyses and interpretation (60%), preparation of figures and tables (80%), drafting of manuscript (90%).

Manuscript 2. Herrón, P., Castellanos-Galindo, G., Stäbler, M., Díaz, J. M., & Wolff, M. (2019). Towards ecosystem-based assessment and management of small-scale and multi-gear fisheries: insights from the tropical eastern Pacific. Frontiers in Marine Science, 6, 127. (Chapter 3)

> Experimental concept and design (80%), experimental work and/or acquisition of data (60%), data analyses and interpretation (80%), preparation of figures and tables (80%), drafting of manuscript (80%).

Manuscript 3**.** Herrón, P., Kluger, L. Castellanos-Galindo, Wolff, M. & Glaser M. (Manuscript submitted). Understanding gear choices and identifying leverage points for sustainable tropical small-scale marine fisheries. Submitted on May 7th 2019 to Ocean and Coastal Management. Currently under review.

> Experimental concept and design (60%), experimental work and/or acquisition of data (100%), data analyses and interpretation (80%), preparation of figures and tables (80%), drafting of manuscript (80%).

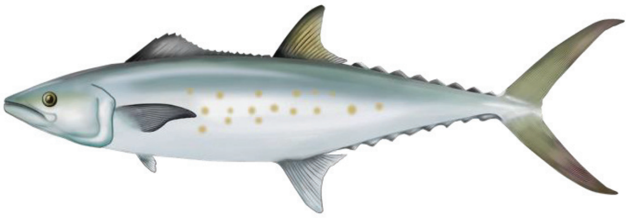
Besides the publication of manuscripts, the doctoral candidate attented the following academic events to present preliminary results of the dissertation:

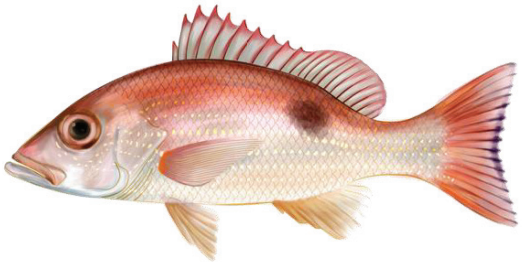
- International workshop *Tropical Fisheries in a Changing World*. Oral presentation: “Artisanal fisheries in an under-developed area of South America: the Colombian Pacific coast”. February 2017. Bremen, Germany. P. Herrón & G. Castellanos-Galindo.
- Rufford Colombia Meeting. Oral presentation: “Evaluando la pesca artesanal multi-artes y multi-específica del Pacífico Colombiano”. April 2017. Bogotá, Colombia. P. Herrón.

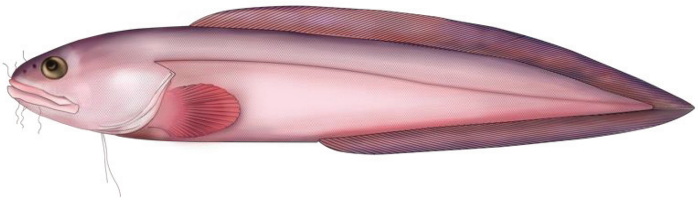
- International Congress of Conservation Biology (ICCB). Oral presentation: “Assessing the multi-gear and multi-species artisanal fisheries of the Colombian Pacific coast”. July, 2017. Cartagena, Colombia. P. Herrón, G. Melo, J.M. Díaz & M. Wolff.
- XIV Colombian Congress of Ichthyology and V Meeting of South-American Ichthyologists. Poster presentation: “Evaluación de la pesca artesanal multi-artes y multi-específica del Pacífico colombiano”. August 2017. Cali – Colombia. P. Herrón, G. Castellanos-Galindo, J. M. Díaz & M. Wolff.

CHAPTER 2

Stock status of target species







CHAPTER 2

Assessment of the stock status of small-scale and multi-gear fisheries resources in the tropical Eastern Pacific region

Pilar Herrón, Tobias K. Mildenberger, Juan Manuel Díaz and Matthias Wolff

This is the author´s version of the work. Please cite the final version as:

Herrón, P., Mildenberger, T. K., Díaz, J. M., & Wolff, M. (2018). Assessment of the stock status of small-scale and multi-gear fisheries resources in the tropical Eastern Pacific region. *Regional Studies in Marine Science*, 24, 311-323. doi.org/10.1016/j.rsma.2018.09.008

Article submitted on May 8th 2018, accepted September 17th 2018 and published online on October 5th 2018.

ABSTRACT

Small-scale multi-gear fisheries contribute half of global fisheries landings but are generally data-poor, hindering their assessment and management. Aiming to overcome various existing challenges, we used two complementary length-based approaches to assess the status of three main target species in the small-scale fisheries of Eastern Pacific countries: Spotted Rose Snapper *Lutjanus guttatus*, Pacific sierra *Scomberomorus sierra*, and Pacific Bearded Brotula *Brotula clarkae*, using length-frequency catch data (LFCD) from the Colombian Pacific coast. Two data sources – official governmental data and community-based monitoring from a non-government organization – were used to estimate two sets of stock indicators: one based on the derivation of growth and mortality parameters from modal progression, catch curve analysis and a yield-per-recruit model using TropFishR; and the second based on the relative contribution of fish sizes with regard to proposed reference values for healthy stocks. Growth estimates differed between data sources and exhibited large confidence intervals, indicating an overall high uncertainty underlying the LFCD revealed through a novel bootstrapped approach. Estimated values of stock indicators, exploitation rate, fishing mortality and size-proportions converged in suggesting a state of heavy to over-exploitation for the three assessed species, although differences were observed among data sources that we attribute mainly to fisheries selectivity and sampling design. In order to improve future assessments of stocks in multi-gear and data-poor contexts, estimations of fleet-specific selectivity should be used to reconstruct LFCD prior to analyses. Additionally, sampling design should be based on fishing effort distribution among gears and areas and, when feasible, fishery-independent data on stock conditions should be included.

Keywords: Colombia, Data-poor stocks, Fisheries management, Length-based indicators, Length-frequency data, TropFishR.

2.1 INTRODUCTION

Small-scale fisheries are recognized as an “economic and social engine, providing food and nutrition security, employment and other multiplier effects” to local communities worldwide and contribute to nearly half of reported global fish catches (FAO, 2015a). Moreover, when direct human consumption of fisheries products is included, the contribution of small-scale fisheries to global catch increases to two-thirds (FAO, 2015a). This is particularly true for developing countries, where conditions of social inequity and poverty in rural communities increase the degree of dependence and the synergetic benefits derived from small-scale fisheries by coastal households (Béné et al., 2010).

Considering the socio-economic importance of small-scale fisheries, knowledge about the stock condition and future potential for exploitation of target species is essential for both users and managers of fishing resources. However, multiple sources of uncertainty impinge on traditional stock assessment methods (Hilborn and Walters, 1992; Scott et al., 2016). This uncertainty is amplified in data-poor contexts where unreported catches can lead to underestimation of the fishing impact on natural populations and to bias in temporal trends of total annual landings (Jacquet et al., 2010; Pauly and Zeller, 2016; Pitcher et al., 2002). Limited human and financial resources for fisheries management in developing countries often result in lack of continuity of fisheries statistics, lack of standardized data collection methods and under-representation of landing sites (Saavedra-Diaz, 2012; Salas et al., 2007; Zeller et al., 2006). In such contexts, incorporating data from participatory fisheries monitoring has the potential of improving the assessment of stock condition (Ramírez et al., 2017), by including less accessible landing sites and increasing the frequency of sampling and the overall sample sizes.

Small-scale fisheries of Colombia share many of the characteristics identified for this type of fisheries in Latin America: multi-gear and multi-species, low capital investment, labor intensive, remote and diverse landing sites and low management capacities from government authorities (Castellanos-Galindo and Zapata, 2019; Salas et al., 2007). In the Colombian Pacific coast, small-scale fisheries provide food, income and employment to at least 11,000 households of Afro-Colombian communities (Rueda et al., 2010). According to latest government fisheries statistics, they contribute 15 - 40% of total landed catch in this coastal region, and this contribution increases to 68 - 83% when landings of tuna species from the industrial fishing fleet are excluded (De la Hoz and Manjarrés-Martínez, 2016). Preliminary stock assessments, carried out as part of the national fisheries authority’s duties to assess fisheries resources and establish annual catch quotas, indicate a status of over-exploitation of 50 - 67% of main target species in the Colombian Pacific

(Barreto and Borda, 2008; Barreto et al., 2010; Puentes et al., 2014a). Additionally, a high proportion (>50%) of juvenile fish - below the length at maturity - are reported in the catch of most of those species (AUNAP and UNIMAGDALENA, 2013b), which could be a sign of growth and recruitment overfishing (Froese et al., 2008). However, these government reports acknowledge limitations in the data they had available for analysis, linked to the lack of funding to carry out continuous and systematic fisheries monitoring and to adequately quantify fishing effort. Besides the recurrent funding constraints, fisheries statistics in Colombia have also been affected by institutional changes that occurred between 2002 and 2011, in which fisheries management and enforcement responsibilities were transferred three times from one government authority to another (Saavedra-Diaz, 2012; Wielgus et al., 2010).

In this study, we carry out an assessment of the stock condition of three commercially important target species of the Colombian Pacific coast, that contribute about one third to the total annual landings of small-scale fisheries in this coastal area (De la Hoz and Manjarrés-Martínez, 2016) . Our approach is based on two set of indicators of stock condition that are well suited for data-poor fisheries since they require only length-frequency catch data, that is representative of the fisheries, and few external life history parameters that are generally available in the literature. The first set of indicators follows FAO's traditional stock assessment methods (Sparre and Venema, 1998) by estimating growth parameters, mortality rates and biological reference points but incorporates new procedures aimed at assessing the degree of uncertainty in the estimation of growth parameters using the recently developed R package TropFishR (Mildenberger et al., 2017; R-Core-Team, 2018). The second set of indicators uses catch proportions related to length-referenced points to assess the sustainability status of the fishery (Cope and Punt, 2009; Froese, 2004). We used official fisheries data collected by the national government (GOV) between 2013 and 2015 using a consistent sampling scheme carried out by the same institutional bodies (www.sepec.aunap.gov.co). Additionally, we carried out parallel stock assessments for the three species using data from a participatory fisheries monitoring program carried out by a non-government organization (NGO) in the northern sub-region of the Pacific coast from 2011 to 2013 (see Methods section). Our aim was to provide the best possible estimate of stock condition of the selected target species with the data currently available and explore differences among outcomes from different data sources that vary in the sampling scheme used and in their geographical extent.

2.2 METHODS

2.2.1 Study area

The Pacific coast of Colombia is located within the Panama Bight and belongs to the Eastern Tropical Pacific ecoregion. It stretches for ca. 1,300 km (Correa and Morton, 2010) from the border with Panamá (7° 13' 21"N, 77°53'25"W) to the border with Ecuador (1° 27' 48"N, 78°51'43"W) (Fig. 2.1). This coastal region is characterized by high precipitation levels ranging 2,500 - 9,000 mm*year^{-1}, abundant rivers that drain from the western Andes and a semi-diurnal tidal range, which varies between 3 and 4.5 meters on spring tides and between 2 and 3 meters on neap tides (IDEAM, 2005; Poveda et al., 2006). Sea surface temperatures in the region typically show two distinct periods, a colder one - associated to upwelling periods - from January to March, with temperatures averaging 26.5°C, and a warmer part of the year with temperatures increasing up to 28.5°C during the northern summer (Devis-Morales, 2009). However, events associated with El Niño Southern Oscillation can drastically change this seasonality (Wang and Fiedler, 2006). The northern Colombian Pacific sub-region extends for ca. 335 km from the border with Panamá (7°12'39" N, 77°53'21" W) to Cabo Corrientes in the south (5°29'50" N, 77°09'23" W). This coastal sub-region is distinguished from the rest of the Colombian Pacific by the predominance of rocky cliffs and sandy beaches and a relatively narrow continental shelf (1 - 15 km) which contrasts with the predominance of mangroves and estuaries, and average shelf width of 50 km in the central and southern sub-regions (Castellanos-Galindo and Zapata, 2019; Martínez et al., 1995). Additionally, the predominance of hook-based fishing gears in the northern sub-region contrasts with the predominance of gillnets in the rest of the Pacific coast, a situation that has been enhanced in recent years by community-driven management initiatives that aim to protect the rights of small-scale fishers (Díaz et al., 2016; Ramírez-Luna and Chuenpagdee, 2019).

On the other hand, the Colombian Pacific region has a relatively low population density ranging from 5 to 17 people*km^{-2} (Etter et al., 2006) and a low infrastructure development compared to the Caribbean coast of the country (Castellanos-Galindo and Zapata, 2019). There are only two large urban centers, one located in the center (Buenaventura) and the other one in the southern end of the coast (Tumaco), with several small rural villages scattered along the coastline and river basins.

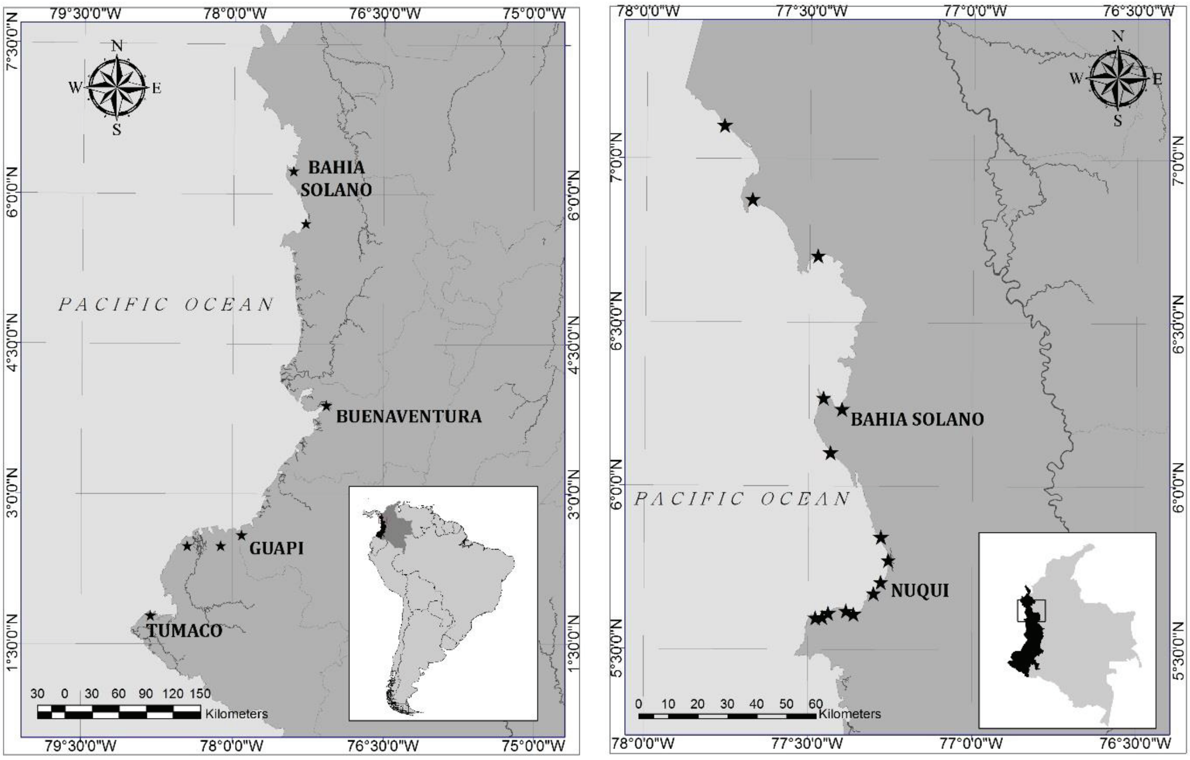


Figure 2.1. *Pacific coast of Colombia indicating the location of sampling sites included in the government - GOV - sampling scheme (left), and sampling sites included by the non-government organization - NGO - sampling scheme (right) during the study period. Names of main urban centers are included.*

2.2.2 Selected target species

The stock assessment was carried out for the species Pacific Sierra *Scomberomorus sierra* (Jordan and Starks, 1895), Spotted Rose Snapper *Lutjanus guttatus* (Steindachner, 1869) and Pacific Bearded Brotula *Brotula clarkae* (Hubbs, 1944), which together contribute to more than 30% of the total biomass landed by the small-scale fisheries in the Colombian Pacific (De la Hoz and Manjarrés-Martínez, 2016). All three species are distributed along the entire range of the Eastern Tropical Pacific, i.e. from the Gulf of California to the northern coast of Peru (Froese and Pauly, 2017), and have also been recognized as important species in the fisheries landings of other countries in the region such as: Costa Rica (Bystrom et al., 2017; Herrera et al., 2016; Naranjo-Elizondo et al., 2016), Panama (Vega et al., 2013) and Mexico (Amezcua et al., 2006; Espino-Barr et al., 2012). Despite their importance, very few assessments about the condition of their stocks have been published as peer-reviewed literature and, so far, none of them for the Colombian Pacific region (Amezcua et al., 2006; Espino-Barr et al., 2012). Table 2.1 summarizes biological and ecological features of the species as well as information related to their landings from small-scale fisheries in Colombia.

Table 2.1. *Ecological characteristics of selected target species included in the present study, based on Froese and Pauly (2007), Robertson and Allen (2015) and Nielsen et al. (1999). Information on landings by the small-scale artisanal fisheries is also presented based on AUNAP and UNIMAGDALENA (2013a)*

Species	**Habitat**	**Maximum depth (m)**	**Key ecological features**	**Biomass landed (ton*yr^{-1})**	**Main fishing gears**	**% total biomass landed**
S. sierra	Pelagic-neritic	15	Swims in schools	634	Gillnets, handlines	17
L. guttatus	Demersal	120	Inhabits reefs (adults) and estuaries (juveniles)	272	Gillnets, handlines	7
B. clarkae	Bentho-pelagic	650	Inhabits soft-bottoms and rocky reefs	311	Longlines, handlines	8

2.2.3 Data collection

Length-frequency catch data (LFCD) from 2013 to 2015 was obtained from GOV data, based on sampling carried out at seven landing sites distributed along the Pacific coast (Fig. 2.1). GOV sampling scheme included length measurements of random samples of fish at commercial landing sites, to the nearest 0.1 cm. Data from NGO was collected from 2011 to 2013 through a community-based fisheries monitoring program implemented by MarViva Foundation in the northern Pacific sub-region (Díaz et al., 2016), including 13 rural and 2 urban landing sites (Fig. 2.1). Total length of all fish arriving at each landing site was measured to the nearest 0.5 cm, two to three times per week. For both GOV and NGO, budget constraints, religious holidays or extreme weather conditions prevented data collection in some instances. Total number of sampling days per month and year in GOV and NGO data sets is included as part of Annex I (Table S2.1).

2.2.4 Stock assessment indicators

Assessment of the stock condition for the three selected species was carried out using two sets of indicators: (a) exploitation rate (*E*) and fishing mortality (*F*) relative to biological reference points, based on linearized catch curves and the yield per recruit (YPR) model, as described in Sparre and Venema (1998), and (b) length-based indicators of fishing sustainability, related to target points, as described in (Froese, 2004).

2.2.4.1 Growth parameters

Von Bertalanffy's growth parameters (VBGP) were estimated for each species, applying the seasonalised von Bertalanffy´s growth function to the LFCD (Somers, 1988):

$$Lt = L\infty * \left(1 - e - \left(K(t - t0) + S(t) - S(t0)\right)\right)$$

where Lt is the length of the fish at a particular age t, $L\infty$ is the asymptotic length in cm, K is the growth rate coefficient in year^{-1}, t_0 is a theoretical age at which length is zero, $S(t)=(CK/2\pi)*\sin 2\pi(t-ts)$, C is a constant indicating the amplitude of the oscillation, typically ranging from 0 to 1, and ts is the fraction of a year (relative to the age of recruitment, t = 0) where the sine wave oscillation begins (i.e. turns positive) (Somers, 1988; Sparre and Venema, 1998). A bootstrapped version of the Electronic Length Frequency Analysis (ELEFAN) (Pauly, 1982; Pauly and David, 1980, 1981; Schwamborn et al., 2018) was used for the fitting process. In ELEFAN within TropFishR the parameter t_{anchor} is used to describe the fraction of the year where the von Bertalanffy growth function crosses length = 0 for a given cohort (Taylor and Mildenberger, 2017). Additionally, the growth performance index (Φ') was also estimated as: $\Phi' = \log(K) + 2 * \log(L\infty)$, based on Pauly (1984). An initial seed value of $L\infty$ was estimated based on $Lmax$, derived from the mean of the 1% largest fish in the sample and following the formula from Pauly (1984): $L\infty = Lmax/0.95$.

In order to improve cohort visualization, LFCD was filtered to 14-day periods within each month based on target days that were selected for each species and data source through an application developed using the shiny R-package (https://shiny.rstudio.com) (Chang et al., 2017). The use of this application allowed us to readily quantify and visualize the sample size per day of the month (1 to 31), for each combination of species, year and data source. A table summarizing the target days selected for each species and data source is included in Annex I (Table S2.2). The most suitable moving average (MA) value for each data source was determined by restructuring the data based on different MA values and the rule of thumb established in Taylor and Mildenberger (2017) concerning the number of bins spanning the youngest cohorts. The initial seed value $L\infty$ ± 20%, and a K range between 0.01 and 2 defined the search space for the 500 resamples of the bootstrapped ELEFAN. For all additional parameters (t_{anchor}, C, t_s), which are bound between 0 and 1, the search space was not further limited but spanned the whole unit interval. Maximum density estimates and 95% confidence intervals for all VBGP were obtained for each species and data set, based on the 500 resamples of the bootstrapping procedure.

2.2.4.2 Exploitation rate and fishing mortality

Once VBGP were estimated, the entire data (i.e. not filtered) was used for subsequent analysis. In order to account for missing data and make LFCD more representative of real catches, raising factors, as defined in Sparre and Venema (1998), were estimated for each species and data source based on: (a) days not-sampled in any given month, taking into account monthly variations in the catch of each species, (b) catch used for local consumption, based on the estimates made by Wielgus et al. (2010), and (c) proportion of fishing trips sampled versus total fishing trips per day based on data recorded by MarViva Foundation at each landing sites. A table summarizing the end value and the method to calculate raising factors used for each species and data set source presented in Annex I (Table S2.3).

Using raised LFCD and previously estimated VBGP, linearized length-converted catch curves were produced for each species and data source taking into account growth seasonality. Catch curves were applied to the average catch numbers per length class across all years, and for the year 2013 only, being this the only common year between the data sources. Total instantaneous mortality rate (Z) was estimated by calculating the slope of the regression line of the descending part of the catch curve. The selection of points for the regression line was based on the age (length-derived) classes represented in the catch in each case (i.e. species/data-source combination).

The rate of natural mortality (M) was estimated using the empirical formula developed by Then et al. (2015): $M = 4.118K^{0.73}L_{\infty}{}^{-0.33}$

This formula was preferred over the wide range of available empirical formulas for estimating M, since it yielded better prediction power for more than 200 species of fish with different life histories, when accurate estimations of maximum age are not readily available. Based on the estimated Z and M values, fishing mortality (F) and exploitation rate (E) were estimated from: $F = Z - M$ and $E = F/Z$, respectively. Estimated values of E were then compared to a reference value of 0.5, which has been proposed as an upper level of sustainable exploitation for fish species (Gulland, 1971). Estimated F values were also compared against reference points derived from the YPR prediction model of Beverton and Holt (1957): (a) the highest biomass per recruit (F_{max}), (b) a 50% reduction of the biomass of unexploited population ($F_{0.5}$), and (c) a fishing mortality which corresponds to 10% of the slope of the yield per recruit curve in the origin ($F_{0.1}$). Parameters of the length-weight relationship, a and b, required as inputs for the YPR model, were obtained from recent estimations carried out by the Colombian fisheries authority (Puentes et al., 2014a) that can be found in FishBase (Froese and Pauly, 2017).

2.2.4.3 Length-based indicators for fishing sustainability

The second set of indicators for the assessment of stock condition are the simple three length-based indicators (LBI) for fisheries sustainability and their associated reference points synthesized as “let them spawn, let them grow and let the mega-spawners live” (Froese, 2004). These LBI are based on previous studies that have documented links between the variables involved in the estimation of the LBI with recruitment overfishing and/or growth overfishing (Barneche et al., 2018; Berkeley et al., 2004; Beverton, 1992; Myers and Mertz, 1998).The LBI used here are:

(a) *Pmat*, the proportion of mature fish in the catch, with 100% as the reference target point, based on the formula: *Pmat* = % fish in sample > *Lm*; where *Lm* is the length at maturity. *Lm* values used here were derived from a relatively recent assessment carried out by Colombia´s fisheries authority, where they estimated median length at maturity (estimated length at which 50% of the fish are mature) for several target species in the country, based on visual assessment of gonads stage of maturity and the use of a logistic model to assess proportion of mature fish per length class, based on data collected in 2013 (Puentes et al., 2014a). Total length *Lm* values used here were: 58.8 cm for *S. sierra*; 35.3 cm for *L. guttatus* and 75.4 cm for *B. clarkae*.

(b) *Popt*, the proportion of fish within a 10% range around the optimum length (*Lopt*) in the catch, with 100% as the reference target, based on the formula: *Popt* = % fish $\geq$ *Lopt*-10% and $\leq$ *Lopt*+10%; where: log(*Lopt*) = 1.053*log(*Lm*) – 0.0565, based on Froese and Binohlan (2000). Estimated *Lopt* for the selected target species, based on this formula, were: 63.6 cm for *S. sierra*; 37.2 cm for *L. guttatus* and 82.7 cm for *B. clarkae*.

(c) *Pmega*, the proportion of “mega-spawners” in the catch, with 30 - 40% considered acceptable percentages in the catch when no specific management strategy is in place, based on the formula: *Pmega* = % fish > *Lopt* + 10% (Froese, 2004).

The three proportions, or LBI, were then summed (*Pmat* + *Popt* + *Pmega*) to obtain *Pobj*, a combined indicator used to follow a decision-tree designed by (Cope and Punt, 2009), which could prove useful in multi-gear fisheries where the assumption of trawl-like selectivity is often not fulfilled. This decision tree is based on the results of a deterministic population dynamics model developed by the authors to explore the effects of different fishery selectivity patterns, different recruitment compensation rates and different life history traits, on the outputs of the LBI proposed by (Froese, 2004). Through their model, the authors found that *Pobj* had a more consistent relationship with spawning biomass (SB) than any of the individual LBI (*Pmat, Popt* or *Pmega*), and that different selectivity patterns in the fishery were associated to range of values of *Pobj*. Once a selectivity pattern is established based on *Pobj*, threshold values of *Pmat, Pobj* and/or the *Lopt*/*Lm* ratio point to an estimated probability of the stock spawning biomass (SB) being below established reference points, either 40% or 20% of the unfished spawning biomass (0.4SB or 0.2SB). For further details please refer to Fig. 10 and Table 5 in Cope and Punt (2009).

2.3 RESULTS

A total of 135,002 fish were included in the analysis: 37,177 for *S. sierra*, 74,978 for *L. guttatus* and 22,847 for *B. clarkae*. Gillnets of varied mesh sizes (2.5 – 20 cm), hand lines and longlines with hooks of different sizes (to #9), were the predominant gears employed in the fisheries, although their proportions differed among the two data sources (Table 2.2). As described above, hand lines and longlines are more commonly used in the northern sub-region of the Colombian Pacific (NGO data) than in the rest of the coast.

Table 2.2. *Total number of fish measured by the government (GOV) sampling scheme from 2011 to 2013 and by the non-government organization (NGO) sampling scheme from 2013 to 2015. Size range, mean length and percentage (%) of fish landed, according to the type of fishing gear used, are also presented.*

					% per gear type			
Species	**Data source**	**Total *n***	**Size range (cm)**	**Mean length (cm)**	**Gillnet**	**Hand line**	**Longline**	**Others**
S. sierra	GOV	16531	11 - 110	46.2	89.6	8	0.2	2.2
	NGO	20646	14 – 99.5	53.2	70.2	29.3	0.3	0.2
L. guttatus	GOV	16952	9 - 99	35.9	55.3	34.7	8.0	2.1
	NGO	58026	6.5 - 89.5	35.1	55.6	43	1.4	0
B. clarkae	GOV	4273	6.5 - 100	71.7	0.4	52.5	47.2	0
	NGO	18574	17.5 - 130	73.4	0.0	2.7	97.3	0

2.3.1 Growth parameters

Estimated VBGP and confidence intervals (CI) were obtained through the bootstrapped ELEFAN based on 500 resamples (Fig. 2.2, Table 2.3). An MA of 9 was selected for all three species. Growth curves obtained through ELEFAN using two additional MA values are included in Annex I (Fig S2.1). Estimated confidence intervals cover a wide range indicating an overall high uncertainty in the estimations. Particularly, upper CI bounds show a larger deviation from the estimated values (maximum density result after 500 resamples) than lower bounds. However, results based on GOV data showed narrower confidence intervals than those from NGO for *S. sierra* and *L. guttatus,* whereas NGO results had narrower intervals for *B. clarkae* (Table 2.3). Differences are also observed between the VBGP estimated from GOV and NGO data, with largest differences found for *S. sierra*. For this species GOV data resulted in substantially higher values of $L\infty$, K and Φ'. For *L. guttatus* and *B. clarkae* Φ' was similar between data sources, while $L\infty$, K values also differed.

Estimated C values were similar between the two data sources for the three species (Table 2.3), which suggests seasonal oscillations in growth rate for all of them. Estimated t_s values ranged from 0.5 to 0.7 for *S. sierra* and *L. guttatus* and between 0.2 and 0.4 for *B. clarkae* (Table 2.3). These periods correspond to June-August and February-May, respectively. It must be noted that parameters t_{anchor} and t_s are defined in the unit interval (i.e. range from 0 to 1) and due to the yearly repeating pattern of the growth curves, a growth curve with a t_{anchor} or t_s value of 0.01 is similar to one with a value of 0.99. This is reflected in the large confidence intervals that resulted in the estimation of those two parameters and of parameter C, which is strongly dependent on t_s.

Table 2.3. *Estimated values for VBGP (maximum density: max. dens.) and confidence intervals (upper interval and lower interval) resulting from bootstrapped ELEFAN analysis for the three selected target species, based on government (GOV) and non-government (NGO) data sources.*

Species	**Parameters**	**GOV**			**NGO**		
		Max. dens.	Lower int.	Upper int.	Max. dens.	Lower int.	Upper int.
S. sierra	$L\infty$	88.97	81.92	113.60	74.89	72.07	105.24
	K	0.41	0.08	0.56	0.22	0.06	0.53
	t_{anchor}	0.45	0.03	0.91	0.53	0.06	0.92
	C	0.34	0.09	0.98	0.34	0.09	1.00
	ts	0.66	0.02	0.99	0.63	0.00	0.95
	Φ'	3.51	2.73	3.86	3.09	2.49	3.77
L. guttatus	$L\infty$	59.61	54.73	77.63	65.85	50.12	73.73
	K	0.57	0.34	1.22	0.47	0.14	1.78
	t_{anchor}	0.44	0.15	0.92	0.47	0.01	0.97
	C	0.49	0.05	0.99	0.63	0.18	1.00
	ts	0.52	0.04	1.00	0.72	0.01	0.98
	Φ'	3.31	3.01	3.87	3.31	2.55	3.99
B. clarkae	$L\infty$	90.65	83.25	119.78	88.32	86.25	91.39
	K	0.23	0.07	0.97	0.25	0.14	0.41
	t_{anchor}	0.50	0.10	0.94	0.59	0.03	0.88
	C	0.57	0.01	0.99	0.63	0.12	1.00
	ts	0.38	0.02	1.00	0.24	0.01	1.00
	Φ'	3.28	2.69	4.14	3.29	3.01	3.54

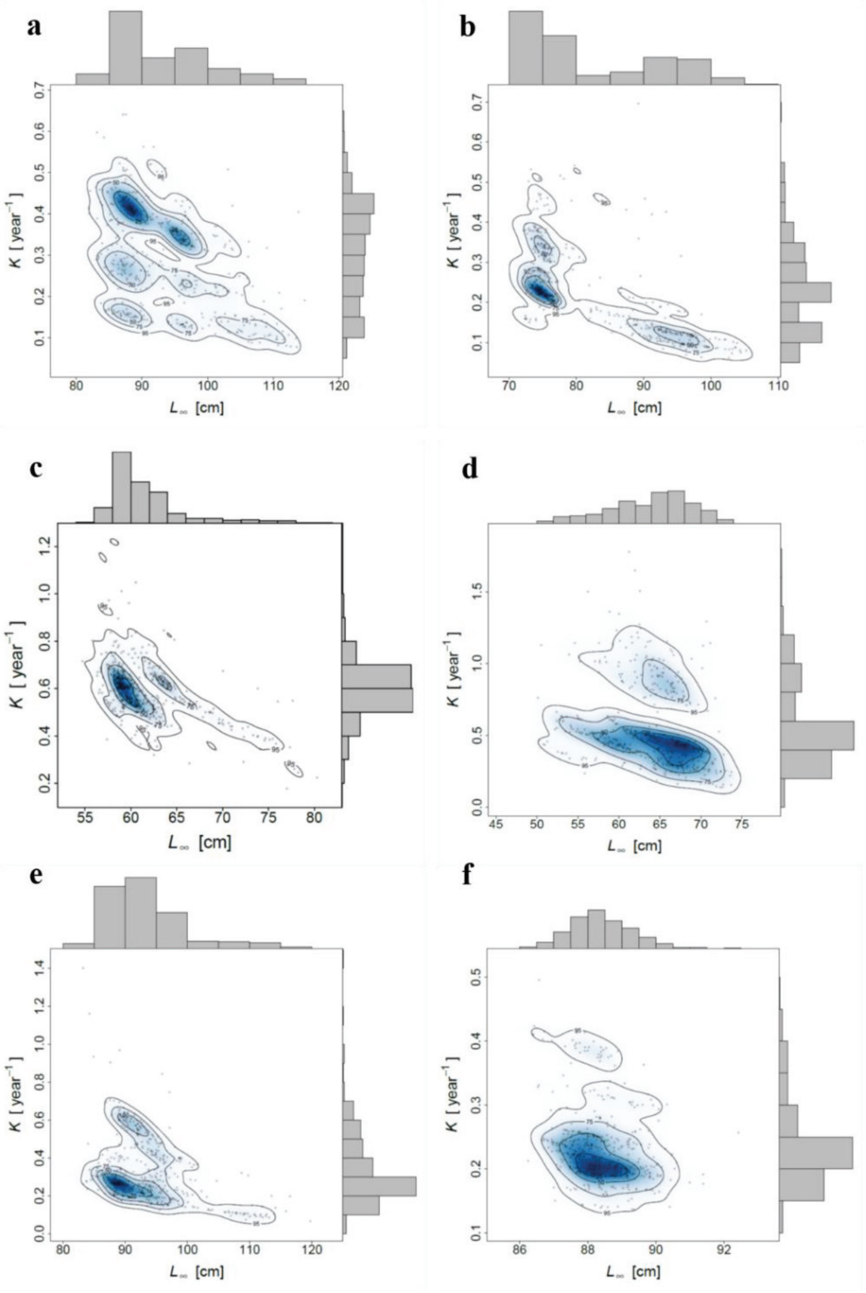


Figure 2.2. *Graphic outcome of bootstrapped ELEFAN for the three selected species and the two data sources (government data - GOV) and non-government data - NGO), using TropFishR. Dots represent estimated L∞ and K (growth parameters of the von Bertalanffy´s equation) per resampled length-frequency catch data. Marginal histograms show univariate density for both parameters, while density lines and color intensity indicate the multivariate density. a) S. sierra - GOV, b) S. sierra - NGO, c) L. guttatus - GOV, d) L. guttatus - NGO, e) B. clarkae - GOV, f) B. clarkae – NGO.*

2.3.2 Fishing mortality and exploitation rate

Only one set of the previously estimated VBGP - either GOV or NGO derived - was selected as input for the linearized length-converted catch curve and YPR analyses for each species. Preference was given to: smaller variation in outputs across different moving averages, narrower range of confidence intervals and larger sample size. Therefore, VBGP estimated values derived from GOV were used for *S. sierra* and *L. guttatus*, whereas VBGP estimated values derived from NGO were used for *B. clarkae*. Table 2.4 summarizes the estimated values of *M, Z, F, E* and biological reference levels of fishing mortality (F_{max}, $F_{0.1}$ and $F_{0.5}$) estimated for each species, data source and time period. Graphical outputs of all catch curves produced are included in Annex I (Fig. S2.2 and S2.3).

The estimated *M* value was constant for each species since only one set of estimated VBGP was selected and used for its calculation from the selected empirical formula (Then et al., 2015). *Z* values were very similar between time periods (i.e. average catch of three years versus catch of 2013) within each combination of species/data source, which suggests little or no variation in *F* among years. A higher *E* was observed in the values estimated from NGO for *S. sierra* and *L. guttatus*, compared to those estimated from GOV. In the case of *S. sierra*, estimated values of *E* derived from both data sources are above the threshold of $E = 0.5$, used as an indicator of over-exploitation (Gulland, 1971). In contrast, estimated values of *E* for *L. guttatus* indicate an over-exploitation status based on NGO, but an under-exploited status based on GOV (Table 2.4).

Table 2.4. *Estimated values of natural mortality (M), fishing mortality (F), biological reference points of fishing mortality (F_{max}, $F_{0.1}$, $F_{0.5}$) and exploitation rate (E) for the selected target species, based on government (GOV) and non-government (NGO) data sources. Estimations were carried out for the average catch of three years within each data source and for 2013 only.*

		GOV		**NGO**	
Species	**Parameters**	**2013-2015**	**2013**	**2011-2013**	**2013**
S. sierra	*M*	0.49	0.49	0.49	0.49
	Z	1.04	1.06	1.43	1.41
	F	0.55	0.57	0.95	0.92
	E	0.53	0.54	0.66	0.65
	$F_{0.1}$	0.29	0.29	1.01	1.04
	F_{max}	0.54	0.55	1.01	1.35
	$F_{0.5}$	0.20	0.20	0.17	0.17
L. guttatus	*M*	0.71	0.71	0.71	0.71
	Z	1.01	1.05	1.78	1.76
	F	0.30	0.34	1.07	1.05
	E	0.30	0.32	0.60	0.60
	$F_{0.1}$	0.62	0.74	0.70	0.91
	F_{max}	0.87	1.02	0.97	1.23
	$F_{0.5}$	0.29	0.29	0.29	0.29
B. clarkae	*M*	0.34	0.34	0.34	0.34
	Z	0.23	0.26	0.29	0.28
	F	-0.11	-0.08	-0.05	-0.06
	E				
	$F_{0.1}$	0.20	0.22	0.20	0.20
	F_{max}	0.63	0.67	0.59	0.61
	$F_{0.5}$	0.14	0.14	0.14	0.14

Comparisons of estimated *F* values with regard to biological reference points show a similar diagnosis of stock condition to *E* results for *L. guttatus* but not so for *S. sierra* (Table 2.4). Estimated *F* for *S. sierra* derived from GOV is above the biological reference points of fishing mortality F_{max} and $F_{0.1}$, suggesting over-exploitation. However, NGO derived results for this species, indicate that *F* is close to, but still lower than, the F_{max} and $F_{0.1}$ estimated through YPR analysis, which would indicate a fully exploited, but not yet over-exploited, stock. Unexpectedly, estimated *Z* for *B. clarkae* based on both data sources had a lower or similar value than *M*, resulting in negative *F* values close to 0. This is not realistic and believed to be an artifact of the methods used and quality and quantity of the data (see Discussion). Therefore, no real diagnosis can be made at this point about the stock condition of this species based on the first set of indicators and the data available, other than the fishing mortality might be relatively low.

2.3.3 Length-based indicators of fishing sustainability

Table 2.5 summarizes the estimated *Pmat*, *Popt* and *Pmega* in the catch for each species and data source. None of the estimated proportions comply with the individual reference target values proposed by Froese (2004) for this indicators. Nevertheless, results derived from NGO data might be interpreted as suggesting a better condition of the stocks than results from GOV, since *Pmat* and *Popt* values were higher in the former than in the latter. Specifically, *L. guttatus* and *B. clarkae* show more than 50% of mature and optimum-sized fish based on NGO data. On the other hand, *Pmega* values are very low for *S. sierra* and *B. clarkae*, which could be interpreted as desired values in a healthy fisheries that is “letting” the older or mega-spawners out of the catch (Barneche et al., 2018; Mora et al., 2009; Myers and Mertz, 1998). However, after applying the decision-tree proposed by (Cope and Punt, 2009), which accounts for the intrinsic selectivity pattern of the fisheries, results indicate that stocks of *L. guttatus* and *B. clarkae* have spawning biomass below target reference point of 0.4 SB with a probability of 100%. In the case of *S. sierra*, results are quite ambiguous since those derived from NGO indicate that the stock is in good condition but results from GOV indicate that there is a 52% probability that the spawning biomass is below the target reference point of 0.4 SB.

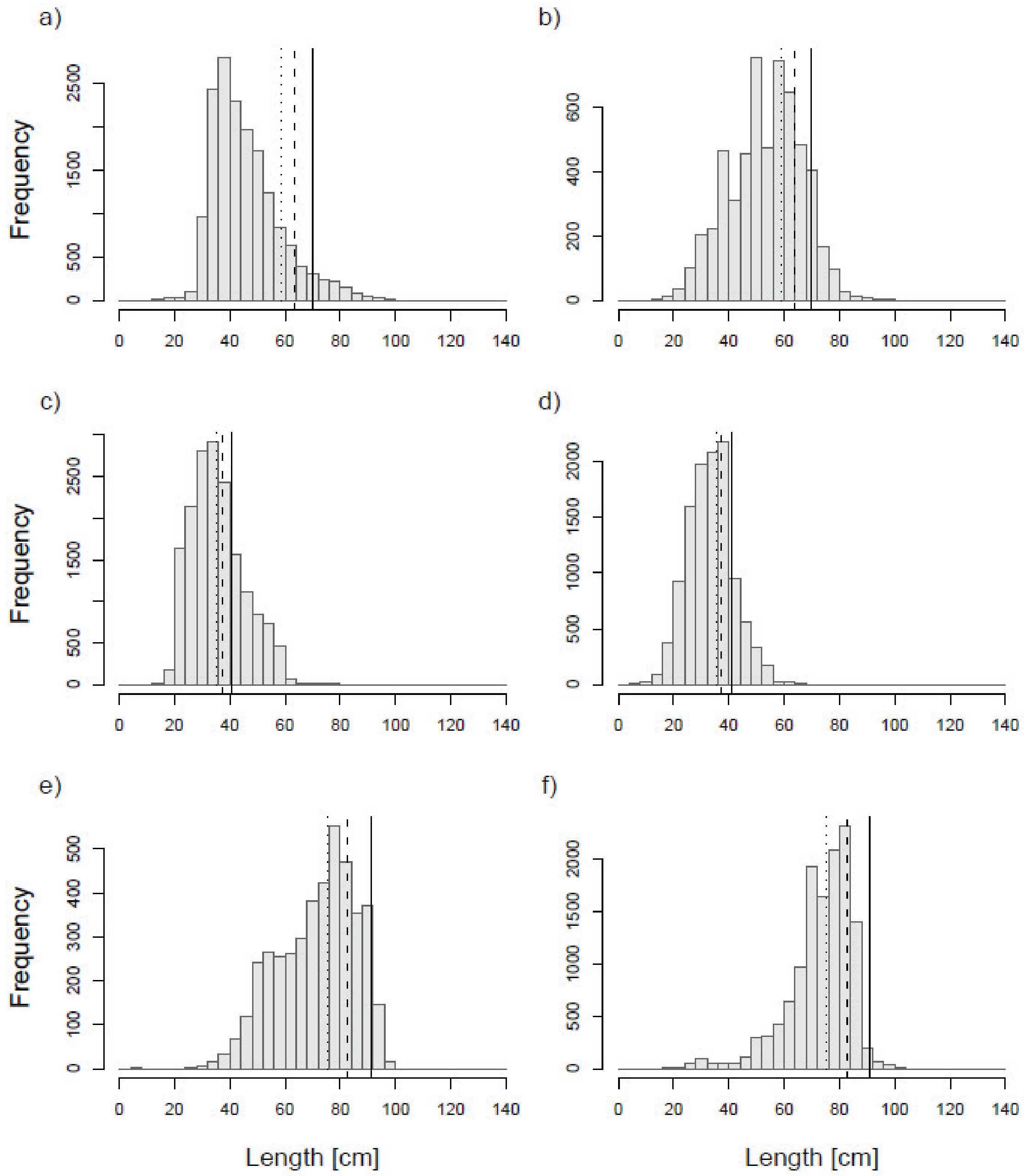


Figure 2.3. *Size distribution of landed fish of the three target species assessed here based on two data sources: government data (GOV) and data from a non-government organization (NGO). Vertical lines indicate length-based reference values of: length at maturity Lm (dotted line), optimum length Lopt (dashed line) and 10% above the optimum length Lopt+10%, (solid line). a) S. sierra - GOV, b) S. sierra - NGO, c) L. guttatus - GOV, d) L. guttatus - NGO, e) B. clarkae - GOV, f) B. clarkae – NGO.*

Table 2.5. *Proportions of mature fish (Pmat), optimum-sized fish (Popt), larger than optimum size fish (Pmega) and Pobj (= Pmat + Popt + Pmega) for each species and data source (government – GOV - or non-government organization - NGO), based on the indicators proposed by Froese (2004) and the formulas described in Methods. Stock condition interpretation is based on a decision tree proposed by Cope and Punt (2009), aimed to assess whether spawning biomass (SB) is above (>) or below (<) a reference point (RP) of 0.4 unfished biomass. The last column indicates the estimated probability of SB being lower than 0.4 of unfished biomass based on the same authors.*

Species	**Data source**	***Pmat***	***Popt***	***Pmega***	***Pobj***	**Stock condition interpretation**	**Probability**
S. sierra	GOV	0.15	0.11	0.06	0.32	SB < RP	52%
	NGO	0.38	0.38	0.06	0.82	SB ≥ RP	0%
L. guttatus	GOV	0.47	0.28	0.27	1.02	SB < RP	100%
	NGO	0.56	0.52	0.15	1.23	SB < RP	100%
B. clarkae	GOV	0.48	0.44	0.05	0.97	SB < RP	100%
	NGO	0.51	0.53	0.01	1.05	SB < RP	100%

2.4 DISCUSSION

In many tropical developing countries small-scale fisheries do not play a significant role in the national economic performance, despite their high importance in terms of local income, employment and food security for coastal communities - and therefore government allocation of resources for fisheries management is very scarce (Kato et al., 2012; Purcell and Pomeroy, 2015). This often results in a very limited quantity and quality of data available for adequate assessments of the status of fisheries resources, and managers are faced with the challenge of making decisions, with very limited information, for nearly 99% of the species reported in the worldwide catch (Costello et al., 2012; Honey et al., 2010). In this study, we attempted to provide the best assessment possible for three target species of the small-scale fisheries in the Eastern Tropical Pacific, using LFCD collected in Colombia, a country with all of the fisheries management constraints and the data limitations described above (Castellanos-Galindo and Zapata, 2019; Saavedra-Diaz, 2012). We did so, combining two methodological approaches suited for data-poor contexts, taking into account that a single biological reference point is not sufficient in providing an unequivocal diagnosis of stock condition, particularly when dealing with several sources of uncertainty (Erisman et al., 2014; Ramírez et al., 2017). In the following paragraphs, we discuss the outcomes of the assessment routines and their implications for fisheries management.

2.4.1 Growth parameters

Our estimation of growth parameters based on von Bertalanffy´s growth equation followed traditional methods of length frequency stock assessments (Sparre and Venema, 1998) but incorporated novel steps to improve the precision of the estimates and to measure the degree of uncertainty. The new procedures comprised: (1) an initial "seed" $L\infty$ input value estimated using the 1% largest fish in the catch, with the aim of reducing the effect of outliers in the sample; (2) an active selection of the length group´s moving average value to enhance cohorts' visualization in the reconstructed length-frequency plots, and (3) the application of ELEFAN with improved optimization routines within a bootstrapping framework that allows to estimate confidence intervals of growth parameters estimations (Mildenberger et al., 2017; Schwamborn et al., 2018; Taylor and Mildenberger, 2017).

Our estimated values of $L\infty$, K and Φ' fall within the range of previous estimations made for the three target species (Table 2.6), with two exceptions. First, the estimated asymptotic length for *B. clarkae* was lower than previously estimated in Colombia by the national fisheries authority, even though the search range input used for the bootstrapped ELEFAN analysis (81–121 cm) was wide and covered most previous literature estimates (Table 2.6). The second exception was the estimated K value for *L. guttatus* which was higher than previously estimated from fisheries targeting this species in the Eastern Tropical Pacific. In the case of *B. clarkae*, fishes are predominantly caught by hook-based gears (hand lines and longlines) that impose a specific type of selectivity reflected in the size distribution of the catch, which influence the visualization of cohort progression in the ELEFAN analysis (Fig. 2.3, Fig. S2.1). Previous studies carried out for this species in Colombia included catches from industrial shrimp-trawling fisheries, which might have resulted in different size distributions and therefore different estimations of VBGP (Angulo, 1995; Angulo and Zapata, 1997).

On the other hand, the relatively high value estimated for K in *L. guttatus* seems to compensate for a relatively low $L\infty$ estimated for this species, which is below the maximum reported length for this species (80cm) (Froese and Pauly, 2017). Despite the existing records of large individuals of *L. guttatus* in the wider Eastern Pacific region that are close, or even >80cm, several studies carried out on this species, that were based on catch data, show maximum lengths of 50 - 60 cm (Andrade-Rodriguez, 2003; Barreto and Borda, 2008; Sarabia-Méndez et al., 2010; Soto Rojas et al., 2009), which suggests that either the selectivity imposed by the fisheries exclude the largest size classes or that those large individuals (>60cm) are now rare cases or "outliers" in the natural population, due to historical fishing impact. Our estimated $L\infty$ value is similar to those estimated using otolith-derived age-frequency data from catch data from the Mexican Pacific (Amezcua et al., 2006; Andrade-

Rodriguez, 2003; Soto Rojas et al., 2009), that could also support the “outliers” hypothesis.

Table 2.6. *Comparison of estimated values of growth parameters* L∞*, K and Φ’ for the three target species assessed here. All studies were carried using length-frequency catch data, except those indicated (†), based on age.*

Species	***L∞***	***K***	**Φ’**	**Source**	**Country**
S. sierra	88.97	0.41	3.51	Present study (GOV)	Colombia
	74.89	0.22	3.09	Present study (NGO)	Colombia
	85.81	0.37	3.44	Puentes et al. (2014a)	Colombia
	108.3	0.15	3.25	Aguirre-Villaseñor et al. (2006)	Mexico
	111.3	0.16	3.30	Barreto et al. (2010)	Colombia
	111.2	0.16	3.30	Barreto and Borda (2008)	Colombia
	75.10	0.19	3.03	Medina Gomez (2006)[†]	Mexico
	99.54	0.21	3.31	Nava-Ortega et al. (2012)[†]	Mexico
	81.00	0.6	3.60	Castillo (1998)	Colombia
L. guttatus	59.61	0.57	3.31	Present study (GOV)	Colombia
	65.85	0.47	3.31	Present study (NGO)	Colombia
	79.50	0.4	3.40	Puentes et al. (2014a)	Colombia
	66.19	0.13	2.76	Amezcua et al. (2006)[†]	Mexico
	139.00	0.28	3.73	Barreto et al. (2010)	Colombia
	87.5	0.24	3.26	Barreto and Borda (2008)	Colombia
	64.58	0.21	2.94	Bystrom et al. (2017)	Costa Rica
	66.40	0.13	2.76	Andrade-Rodriguez (2003)[†]	Guatemala
	96.60	0.26	3.38	Sarabia-Méndez et al. (2010)	Mexico
	65.90	0.13	2.75	Soto Rojas et al. (2009)[†]	Costa Rica
	55.10	0.40	3.08	Suárez (1992)	Colombia
B. clarkae	90.65	0.23	3.28	Present study (GOV)	Colombia
	88.32	0.25	3.29	Present study (NGO)	Colombia
	103.80	0.50	3.73	Puentes et al. (2014a)	Colombia
	119.20	0.20	3.45	Barreto et al. (2010)	Colombia
	118.00	0.70	3.99	Angulo (1995)	Colombia
	130.00	0.50	3.93	Angulo and Zapata (1997)	Colombia
	105.20	0.45	3.70	Muñoz (1999)	Colombia

Our results show very large confidence intervals in estimated growth parameters, particularly in the estimation of *K*, the growth coefficient. A wide range of estimated values of *L*∞ and *K* parameters have also been observed in previous studies carried out for these species in Colombia and in other countries of the Eastern Tropical Pacific (Table 2.6). These studies have shown that estimations of length-derived VBGP can be highly influenced by the bias imposed by the selectivity of fisheries (either gear imposed, spatial or temporally driven), since the catches do not necessarily represent the size structure of the natural populations (Maunder et al., 2014; Punt et al., 2014; Sampson, 2014; Taylor et al., 2005). Using otolith-derived size at age estimates, Medina Gomez (2006) found different values of growth parameters of *S. sierra* from different coastal zones within the Gulf of California in the Pacific coast of Mexico and related these findings to the selectivity of fishing gears used in the different zones, but not excluding the potential existence of sub-populations along the coastal region. Different stocks of the same species had been identified within a single coastal region, such as the case of the congeneric *S. cavalla* in the Gulf of Mexico (Johnson et al., 1994). In our case, the northern sub-region of the Colombian Pacific presents particular environmental features compared to the rest of the coast (see section 2.2.1), and there are also differences in the proportion of fishing gears reported in the landings of the two geographical areas included in the present study (Table 2.2). Therefore, both factors – gear imposed differences in selectivity between zones and spatial differences of size distribution among subpopulations - could contribute to the different patterns of size structure and related cohort’s progression observed in the two data sources (Fig. 2.3, Fig. S2.1).

Another difference between our VBGP estimation method and others previously carried out for these species, is the fact that we used the seasonalised growth function for the ELEFAN analysis. While the main VBGF parameters (*L*∞, *K*) and associated confidence intervals presented here are not substantially different from those derived from the non-seasonal approach (Table S2.4, Annex I), our results suggest that there are seasonal changes in the growth rates of the three species, which could be related to changes in water temperature, precipitation and/or to the availability of food in the coastal shelf zone (Morales-Nin and Panfili, 2005). In the case of *S. sierra* and *L. guttatus*, results indicate that the period with the highest growth rate falls between the months of June and August, which could be due to the period of warmer sea-surface temperatures in the Colombian Pacific (Devis-Morales, 2009). In the case of *B. clarkae*, a species that inhabits deeper water habitats, different environmental factors could be influencing the growth rate during the first months of the year (Feb-Mar), but these factors are currently unknown.

2.4.2 Stock condition based on estimates of E and F

Confidence intervals for VBGP are not yet routinely incorporated into length-based stock assessments and it is probable that the high uncertainty in the VBGP found in our study may also be underlying many past length-based stock assessments. This quantified uncertainty provides helpful guidance on the interpretation of the result of subsequent analyses; due to the wide confidence intervals around the VBGP, resulting estimates of *E*, *F* and biological reference levels should be regarded as a first approximation to the current stock condition of the target species assessed here.

Our results suggest that different sampling schemes could lead to different outcomes of stock condition and may end up giving contrasting guidelines to managers. Estimated values of *E* and F/F_{max} for *S. sierra* and *L. guttatus* differed somewhat between the two data sources used. For *S. sierra*, results derived from both data sets suggest a status of overexploitation, although NGO estimates were higher. Also in *L. guttatus*, NGO data provided higher estimates for *E* and *F* but in this case those data suggested overexploitation, while the far lower estimates derived from the GOV data rather indicated under-exploitation (Table 2.4). In the case of *B. clarkae*, estimated *Z* was very close to or even lower than *M*, which could imply that fishing mortality is almost negligible for this species and that the existing biomass is under-exploited. However, from the catch curves (Fig. S2.2 and S2.3) it seems that the regression line and thus *Z* does not represent well the entire data, since it might be overestimating mortality for smaller individuals and underestimating it for larger ones. This unusual pattern of the catch curve can most probably be attributed to different gears (and/or mesh and hook sizes) and associated selectivities (Table 2.4), but could also have resulted from differences in the availability of different cohorts at a particular time or place. Since the catch curve method is based on the assumption that beyond a critical size, all larger fish are fully retained, catch-at-length matrices should ideally be corrected before running the catch curve analysis, based on the knowledge of the selectivity curves of each fishing fleet involved (Punt et al., 2014; Sampson, 2014). Unfortunately, the lack of knowledge on the selectivity features of the different fleets involved in the fisheries, and the unavailability of fisheries-independent data on natural abundance and/or reproductive processes did not allow us to correct catch-at-length data in the present study.

Stock assessments carried out by Colombia´s fisheries authority from 2008 to 2016, based on catch curves and surplus production models, reported an overexploitation status for the three target species assessed here (AUNAP, 2016; Barreto and Borda, 2008; Barreto et al., 2009, 2010; Puentes et al., 2014a). The most comprehensive of those assessments - based on data collected in 2013 during the entire year - reported *E* values of 0.59, 0.72 and 0.76 for *S. sierra*, *L. guttatus* and *B. clarkae,* respectively (Puentes et al., 2014a). Official total landings data for each species from 2006 to 2017 do not show a clear trend of relative stock abundance (Fig. S2.4), but it must be noted that these data are not readily comparable because of the lack of information on fishing effort and the lack of consistency in sampling frequency and spatial stratification (www.sepec.gov.co). As described above, these inconsistencies are mainly linked to budget constraints and drastic institutional changes that occurred within the fisheries government sector of the country between 2002 and 2011.

Besides the technical reports produced by the Colombian fisheries authority, very few stock assessments have been published in the literature for the three target species. Even though the stocks of neighboring countries within the Eastern Tropical Pacific could be different from the ones exploited in the Colombian Pacific, their assessments could provide another reference. In the central Pacific of Mexico, Espino-Barr et al. (2012) found an exploitation rate of 0.74 for *S. sierra* based on catch data, with a higher F than F_{max} (0.57 vs 0.42), indicating a status of overexploitation of this species in this country. On the other hand, for *L. guttatus*, Amezcua et al. (2006) reported an E between 0.19 and 0.43 for the southern Gulf of California in Mexico and Bystrom et al. (2017) reported an exploitation rate of 0.44 based on samples taken from the northern coast of Costa Rica. Both studies found exploitation rates slightly below the threshold of $E = 0.5$, which resembles the output of our assessment for the Colombian Pacific based on GOV data.

2.4.3 Stock condition based on LBI

Even though the final stock diagnosis based on LBI showed more consistent results among the two data sources than the outputs of E and F, there were also slight variations between the estimates derived from the two data sources, which further suggests that different sampling schemes may lead to different management advice. Particularly, in the case of *S. sierra* the diagnosis was not consistent, since results from NGO data gave a picture of a healthy stock, while GOV data indicate a 52% probability that the spawning biomass is below the reference target level. A key difference observed among the two data sources for *S. sierra* was the higher proportion of mature fish (*Pmat*) in NGO data compared to GOV data (Table 2.5). This difference in *Pmat* results in two different diagnosis of stock condition when applying the decision tree that, in this case, requires a *Pmat* >0.25 to conclude that the spawning biomass is above the target level (Cope and Punt, 2009). In contrast, for both *L. guttatus* and *B. clarkae* the combined indicator *Pobj* and the final diagnosis indicate that there is a 100% probability that the spawning biomass is below the reference target level (0.4SB).

Table 2.7. *Estimated values for length at maturity (Lm) and proportion of mature fish in the catch (Pmat) for S. sierra, L. guttatus and B. clarkae. Case where studies were performed separately for female (F) or male (M) fishes are indicated. All values refer to total length, except where indicated (†).*

Species	**Lm (cm)**	***Pmat***	**Source**	**Country**
S. sierra	58.80	0.15	Present study (GOV)	Colombia
	58.80	0.38	Present study (NGO)	Colombia
	58.50	0.05	AUNAP and UNIMAGDALENA (2013b)	Colombia
	57.50		Barreto and Borda (2008)	Colombia
	58.9 (F)		Ordoñez et al. (2017.)	Colombia
	44.3† (F)	0.3	Aguirre-Villaseñor et al. (2016)	Mexico
	56.4 (M)	0.26 – 0.29	Lucano-Ramírez et al. (2011)	Mexico
	59.3 (F)	0.26 – 0.29	Lucano-Ramírez et al. (2011)	
L. guttatus	35.30	0.47	Present study (GOV)	Colombia
	35.30	0.56	Present study (NGO)	Colombia
	41.3	0.17	AUNAP and UNIMAGDALENA (2013b)	Colombia
	30.6	0.39	Sarabia-Méndez et al. (2010.)	Mexico
	33		Rojas (1997)	Costa Rica
B. clarkae	75.40	0.48	Present study (GOV)	Colombia
	75.40	0.51	Present study (NGO)	Colombia
	73	0.49	AUNAP and UNIMAGDALENA (2013b)	Colombia
	71		Muñoz (1999)	Colombia
	62.3		Acevedo et al. (2007) ††	Colombia
	71.9	0.13	Herrera et al. (2006)	Costa Rica

† Furcal length used, instead of total length. †† Based on data collected from 1994 to 1996

All LBI used here as a second set of indicators to assess the stock condition of the target species were based on *Lm* values previously estimated in the country (see Methods) and therefore were not influenced by our estimated VBGP. The estimation of the combined indicator *Pobj* and the application of the decision tree – as proposed by Cope and Punt (2009) - have not been previously carried out before for the three selected target species. Nonetheless, it is possible to compare our estimated proportions of mature individuals (*Pmat*) in the catch with previous estimates made in Colombia and in other countries of the

Eastern Tropical Pacific. This comparison, though, must consider the existing variations in the estimated *Lm* used as reference value in different studies (Table 2.7). It has been shown that differences in *Lm* within the same species can be related to environmental or latitudinal factors, genotype, stock size and/or historic fishing pressure (Cardinale and Modin, 1999; Heibo et al., 2005; Rowell, 1993). Differences observed in *Pmat* estimates are influenced not only by their reference *Lm* value but also by the type of fisheries involved in the sampling. For example, estimated *Pmat* for *B. clarkae* derived from industrial trawling shrimp fisheries in Costa Rica (Herrera et al., 2016) is much lower than *Pmat* values estimated in Colombia where most catches come from longlines and hand lines. Thus, gear selectivity, habitats used as fishing grounds and environmental factors that could trigger ontogenetic movements impose a bias in the size distribution of the catch and in turn a bias on the estimation of parameters of stock condition (Maunder et al., 2014; Sampson, 2014).

2.4.4 Conclusions and outlook

A general pattern of declining stocks has not only been presented by reports made by Colombia´s fisheries authority in the past years, but it is the perception shared by different stakeholders in the country. Extensive interviews carried out with fishers, community leaders in coastal areas and fisheries experts from government and academic institutions between 2008 and 2009, revealed a general perception of declining fishing resources and of increasing fishing effort in the country´s small-scale fisheries (Saavedra-Diaz, 2012).

Despite the limitations to adequately estimate the indicators of stock condition based on length-frequency data only, most of our results are consistent with those obtained by previous assessments in Colombia and neighboring countries for the three selected target species but, moreover, highlight the value that length-based methods still have to assess stocks in data-poor contexts around the world where modern population dynamics models or integrated approaches cannot be applied due to lack of available data (Cope and Punt, 2009).

Our study shows how differences in sampling schemes to collect LFCD in a fairly delimited coastal zone can impose different degrees of uncertainty to data analyses and, more importantly, may even lead to different management conclusions. A higher uncertainty was observed in estimates derived from NGO data, which we attribute to a very specific and selective type of fisheries in the northern sub-region of the Pacific coast. While GOV data included a wider range of fleets and gears (e.g. gillnets of different mesh sizes and other type of nets) that are used along the entire coast, NGO data was dominated by catches made with hooks in more offshore pelagic or deeper environments, given by the particular environmental characteristics of that sub-region. In this sense, our estimated VBGP, as well as their related *E* and *F* values, could be biased due to using non-corrected LFCD that did not account for the intrinsic selectivity of the fisheries (Taylor et al., 2005). In order to improve future stock assessments and reduce the underlying uncertainty of LFCD in multi-gear and small-scale fisheries settings, a stratified random sampling should be designed (Sparre and Venema, 1998) based on a previous assessment of current fishing effort and how it changes spatially, temporally and among the different gears (McCluskey and Lewison, 2008). In the case of Colombia, this change would not necessarily mean additional costs compared to the current sampling scheme but a redistribution of the current sampling effort.

On the other hand, taking into account the large influence that the selectivity of the fisheries has on the estimation of VBGP, natural mortality and fisheries mortality parameters, specific research on estimates of gear selectivity is highly recommended to be able to correct LFCD before conducting analyses. Selectivity studies should differentiate not only among main type of gears but also among the more common mesh sizes and hook sizes that are used by fishers (Millar and Fryer, 1999; Millar and Holst, 1997). A complementary analysis of the influence of different fishing grounds on the size distribution of the catch will also help to refine stock assessments and their interpretation (Punt et al., 2014; Sampson, 2014).

Despite the appealing nature of LBI to managers and other stakeholders, due to their ease of calculation and interpretation (i.e. no need for complex calculations of growth and mortality parameters), caution must be taken to draw conclusions out of “snap-shot” data or when estimated values of *Lm* do not correspond to the stock assessed. Even though the *Pobj* indicator and the decision-tree used here (Cope and Punt, 2009) infers and takes into account a selectivity pattern of the fisheries, improvements in the sampling scheme as those described above and acquiring longer time series data will increase reliability of results of stock assessments based on LBI. Participative monitoring in rural coastal areas could greatly improve landing sites coverage and help the implementation of the new sampling design (Díaz et al., 2016; Ramírez et al., 2017), but overall control and supervision from the fisheries authority is recommended so that there is a single handler and curator of the database. Finally, tropical developing countries, like Colombia, will also greatly benefit from investing in acquiring fisheries-independent data to increase the knowledge about the status of the populations and their life cycles. This could be a joint effort with neighboring countries that share the use and management responsibilities of the fished stocks.

ACKNOWLEDGEMENTS

We thank the National Authority of Fishing and Aquaculture in Colombia (AUNAP) for kindly providing data collected between 2013 and 2015, as part of their fisheries monitoring program carried out in agreement with Universidad del Magdalena. We also thank local communities and fishers from the municipalities of Nuquí, Bahía Solano and Juradó in the Colombian Pacific coast, for supporting data collection between 2011 and 2013, carried out by MarViva Foundation. Financial support to MarViva Foundation for fisheries monitoring was provided by USAID (Cooperation Agreement #49-2012 through their BIOREDD+ Program), AUNAP (Cooperation Agreement #65-2012), the European Union (Cooperation Agreement #75-2013) and INVEMAR (Cooperation Agreement #009-2015). P. H. received financial support from CEMarin (Call # 5 of 2015) during the process of writing this paper. Thanks to J. Quintero for producing the maps used for Fig. 2.1. Thanks to G. Castellanos-Galindo, M. Stäbler, C. McLaverty and J.G. Ramírez for valuable inputs throughout the process of writing this paper.

CHAPTER 3

Assessing potential ecological fishing impacts

CHAPTER 3

Towards ecosystem-based assessment and management of small-scale and multi-gear fisheries: insights from the tropical eastern Pacific

Pilar Herrón, Gustavo A. Castellanos-Galindo, Moritz Stäbler, Juan Manuel Díaz & Matthias Wolff

This is the author´s version of the work. Please cite the final version as:

Herrón, P., Stäbler, M., Castellanos-Galindo, G., Díaz, J. M., & Wolff, M. (2019). Towards ecosystem-based assessment and management of small-scale and multi-gear fisheries: insights from the tropical eastern Pacific. *Frontiers in Marine Science*, 6, 127. doi.org/10.3389/fmars.2019.00127

Article submitted on May 6th Nov 2018, accepted March 01st 2019 and published online on March 19th 2019.

ABSTRACT

Small-scale fisheries (SSF) remain a largely under-assessed and overlooked sector by governments and researchers, despite contributing approximately 50% to global fish landings and providing food and income for millions of people. The multi-species, multi-gear and data-poor nature of SSF makes implementation of traditional single-species management approaches - like catch-quotas or size limits - particularly challenging and insufficient. A more holistic approach is thus required, which demands assessment of ecological impacts. Here we carried out an estimation of selected ecological indicators of the impact of fisheries (mean length, maximum body size, mean trophic level, trophic and spatial guilds, threatened species and landed by-catch) based on the nominal catch of different gears in three representative SSF along the Colombian Pacific using landings data collected in multiple years (2011 – 2017). Results showed that taxonomic, size-based, functional and conservation features of the nominal catch vary greatly with geographical location and gear type used. Overall, handlines and longlines tend to select larger sizes and higher trophic levels than nets, but they also catch a higher proportion of intrinsically vulnerable species and species of conservation concern. This challenges the idea that more selective gears have overall lower ecological impacts. In contrast, nets target a wider size range – although focusing on small or medium sized fish - and include a higher diversity of trophic and spatial guilds, which could arguably be considered a more “balanced harvest” type of fishing that retains ecosystem structure and functionality. Bottom trawls, though, exhibited a relatively high percentage of landed by-catch, an undesirable feature for any fisheries in terms of sustainability. We propose that the assessment of a suite of ecological indicators, like those implemented here, should be included as part of periodic evaluations of multi-gear and multi-species SSF in tropical coastal areas, as a practical step towards ecosystem-based fisheries management.

Keywords: Colombia, catch composition, ecological indicators, ecosystem approach to fisheries, gear-based management.

3.1 INTRODUCTION

Small-scale fisheries (SSF) are widely recognized for their contribution to nearly half of global landings and for the multiple socio-economic benefits they provide to coastal communities (Andrew et al., 2007; Béné et al., 2010; FAO, 2015a). However, this fisheries sector remains largely under-assessed and overlooked by governments and researchers (FAO, 2015a; Purcell and Pomeroy, 2015; Salas et al., 2019; Salas et al., 2007). Management of SSF in tropical developing countries is generally constrained by insufficient government funding, lack of political will, open access regimes, multiple and scattered landing sites and low participation of resource users in decision making (Andrew et al., 2007; Kato et al., 2012; Salas et al., 2007). Traditional management approaches like catch-quotas and size limits for target species exhibit several practical difficulties when tried to be implemented in multi-gear and multi-species tropical SSF (Purcell and Pomeroy, 2015; Salas et al., 2007). Furthermore, the establishment of catch-quotas, one of the most common management measures, depends on reliable assessments of the target stock size and condition of main target species but these type of assessments are often hindered by low quality of the data available, high uncertainties underlying length-frequency catch data and lack of knowledge of basic growth and reproduction features of target species (Cope and Punt, 2009; Froese, 2004; Herrón et al., 2018; Ramírez et al., 2017).

In the past two decades a shift in fisheries management has been observed from a single-species approach - in which the main objective was to obtain maximum sustainable yields (*MSY*) of target species - to a more holistic approach that also considers the impacts of fishing at the community and ecosystem level, for which two main frameworks are commonly used: the Ecosystem Approach to Fisheries – EAF (Garcia, 2003) and the Ecosystem-Based Fisheries Management - EBFM (Pikitch et al., 2004). Both frameworks take into account the undesired effects of fishing on ecosystems due to the inherent selectivity of the fisheries for a particular size range and/or taxonomic group; these effects may include impacts on biodiversity, taxonomic composition, population abundance, size structure, trophic structure and trophic dynamics of biological communities (Arias-González et al., 2004; Jennings et al., 1998; Pauly et al., 1998; Pikitch et al., 2004). To detect such impacts, several ecological indicators have been proposed based on empirical or model-derived evidence of their potential to adequately inform of fishing 34 impacts. These indicators often relate to basic ecosystem´s attributes such as: species richness and diversity, biomass, relative 36 abundance of specific target or non-target groups, size structure, trophic level, structure and dynamics of the food web (Fulton et al., 2005; Jennings, 2005; Jennings and Dulvy, 2005; Link, 2005; Rochet and Trenkel, 2003; Shin et al., 2005). Current scientific advice for fisheries management in the European

Union, for example, incorporates assessment of indicators such as: mean length of the fish community, proportion of predatory fish in the community, catch-based marine trophic index, proportion of discards in the fishery, among others (“IndiSeas” project, Coll et al. (2016)). Other approaches to holistically assess fisheries and examine fishing impacts at the ecosystem level are mass-balanced trophic models, which require knowledge of trophic relations, as well as detailed data on diet composition and fishing effort that are not always available for coastal tropical systems (but see for example: Bacalso and Wolff (2014); Rehren et al. (2018); Tesfaye and Wolff (2018)).

Here we examine the composition of the nominal catch of the multi-gear and multi specific SSF of the Colombian Pacific coast to assess geographic or gear-related differences in selected indicators used as proxies of the potential ecological impacts of current fishing practices. Our analyses used a unique set of landings data from recent years (from 2011 to 2017) collected at three coastal zones of the Colombian Pacific with different environmental, socio-economic and fisheries management regimes. Finally, we discuss the potential benefit of implementing a periodic monitoring of ecological indicators to assess and manage SSF under an ecosystem-based approach.

3.2 METHODS

3.2.1 Study area

The Colombian Pacific coast is part of the tropical eastern Pacific region and it is located in the western side of the country bordering with Panama (7° 13' 21”N, 77°53'25”W) and Ecuador (1° 27' 48”N, 78°51'43”W), and stretching for approximately 1.300 km (Correa and Morton, 2010) (Figure 3.1). The northern coastal sub-region extends for approximately 335 km of coastline south of the Panama border and is characterized by rocky and sandy shores, and relatively small mangrove forests (ca. 50 km2, Velandia et al. (2016)). This sub-region has a narrow continental shelf (1-15 km) and a low human population density (6 people*km-2, DANE (2011)). In contrast, 67 the central coastal sub-region of Buenaventura, which encompasses approximately 150 km of coastline south and north of the city of Buenaventura, is dominated by mangrove forests (ca. 220 km2; Mejía-Rentería et al. (2018)), alluvial plains, river deltas and estuaries. These seascapes are also the dominant ones in the remaining Colombian Pacific southern coast up to the border with Ecuador. The Buenaventura sub-region has a wider continental shelf (32-52 km) and a higher human population density (70 people*km-2, DANE (2011)) mainly due to the presence of the main city port of the entire Colombian Pacific (Buenaventura city).

Within the northern sub-region, there are two management areas declared in recent years: 1) an Exclusive Artisanal Fisheries Zone or ZEPA, for its Spanish acronym, and 2) a regional marine protected area (Tribugá - Integrated Regional Management District or DRMI for its Spanish acronym), declared recently by the Colombian fisheries authority and by the regional environmental authority, respectively (AUNAP, 2013; Codechoco, 2014) (Figure 3.1). These two management zones cover ca. 1.600 km2 of coastal and marine habitats (Velandia and Díaz, 2016) and complement conservation efforts by the adjacent National Natural Park Utría established in 1987 (PNN, 2006), which includes a marine area of ca. 132 km2. Current fishing practices inside the marine area of the National Park are similar to those within the DRMI (PNN, 2011) and therefore we considered the Park´s area as part of the same coastal zone, referred to hereafter as Tribugá.

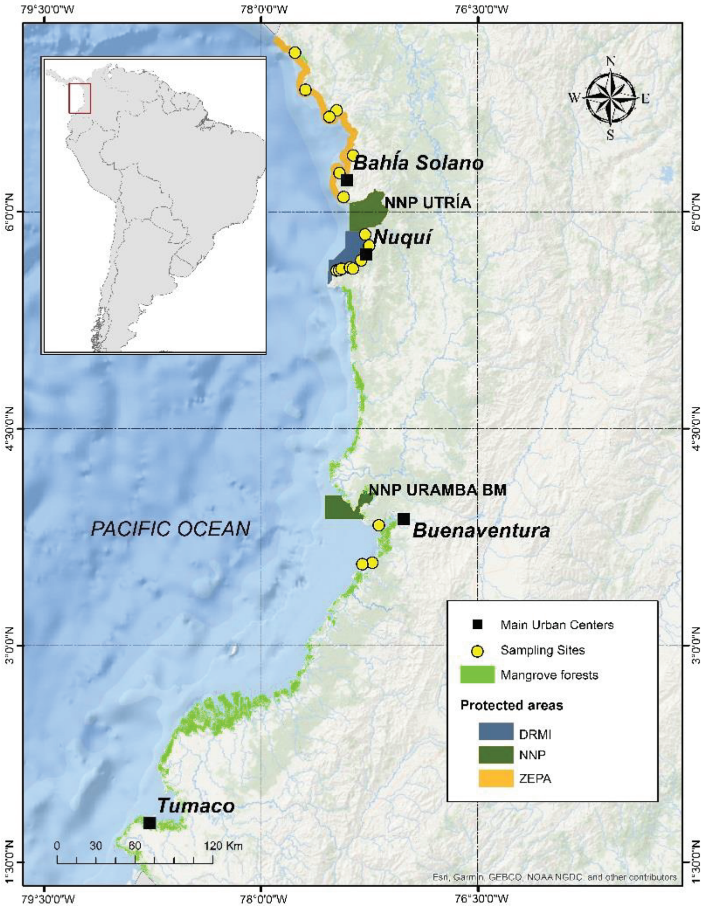


Figure 3.1. *Colombian Pacific coast with location of the coastal zones included in this study: ZEPA, Tribugá (DRMI and National Natural Park Utría) and Buenaventura. Location of sampled landing sites, mangrove forests and National Natural Parks within the coastal zones are also shown.*

3.2.2 Fishing gears

At least 13 different main types of fishing gears have been reported in the Colombian Pacific SSF (Saavedra-Diaz, 2012) and eight of those are used by fishers at some or all of the three coastal zones studied here. These eight gears are: handlines, longlines (bottom), gillnets (including lobster nets), bottom trawls, purse seines, beach seines, cast nets and spear guns. Cast nets are mostly used to collect bait (such as sardines or anchovies) used in longlines or handlines and therefore the catch derived from this gear is rarely landed. Spear guns are used by a very low number of fishers while beach seines are more commonly used by family groups in the coastal communities. However, these two gears (spear guns and beach seines) contributed to < 1% of the nominal catch recorded within each zone (Figure 3.2) and therefore were not included in further analyses. The main characteristics of the five gears that account for most of the catch are summarized in Table 3.1, including a sub-classification of gillnets based on the net material and on their mesh size. Given that lobster nets are a type of gillnet targeted on a specific taxonomic group (Palinuridae) and include the use of bait, we treat them here as a separate type of gear. Detailed technical specifications of these gears and how they are used in the Colombian Pacific can be found in Saavedra-Diaz (2012) and Puentes et al. (2014b).

3.2.3 Data collection

In the ZEPA and Tribugá coastal zones, a community-based fisheries monitoring program was implemented from 2011 to 2016 by the regional non-government organization (NGO) MarViva Foundation (www.marviva.net). Local observers were trained and hired to collect data at landing sites within each coastal community (Díaz et al., 2016; López-Angarita et al., 2018). Monthly visits were made by staff from the NGO to verify data quality and species identification. Data gathered through this monitoring program and used in the present study include data from nine landing sites located in ZEPA (2011-2013) and nine landing sites located in Tribugá (2011-2013 and 2016). At the Buenaventura coastal zone a similar community-based monitoring scheme was adopted by the authors of this study to collect data from August 2016 to July 2017 at three representative landing sites (Figure 3.1). Data gathered at landing sites included: date, common name of landed species, weight landed per taxa to the nearest 0.05 kg, catch status (e.g. whole, gutted), fishing gear type and fishing method. Also, total length of fish (or disc width in rays) and total length of invertebrates to the nearest 0.5 cm were measured in a representative sample of the catch (20-30%). All fish species were identified to the lowest taxonomic level possible following identification guides available for the region (Acero, 2004; Fisher et al., 1995; Keen, 1971; Marceniuk and Acero, 2009; Robertson and Allen, 2015).

Taking into account the collective ownership and management of the land occupied by Afro-descendant communities along the Pacific coast of Colombia (Law 70 of 1993), formal agreements with the Boards of the Community Councils Los Riscales, Los Delfines, Cupica, Juradó, Cajambre and Bazán-Bocana (in charge of the coastal areas where this study took place) were made by either MarViva Foundation or by the first author, whereby written informed consent was obtained. Additionally, meetings with fishers' representatives (locally elected leaders of fishers associations) were held at each coastal community to explain the objectives and methods of the project prior to the beginning of field activities. Approval from an external ethical committee was not required by local legislation for research collecting fisheries data at landing sites.

Table 3.1. *Characteristics of gear types and subtypes that contribute most to total SSF landings at the three zones of the Colombian Pacific included in the present study*

Gear type	**Gear subtype**	**Hook / Mesh size**	**Number of fishers**	**Main features**
Handlines		5 - 9	1 - 2	1 to 10 hooks. Use bait.
Longlines		5 - 10	2 - 3	Bottom longlines. 500 - 2,000 hooks. Use bait.
Gillnets	Small-mesh	≤ 2.75”	2	1 to 12 pieces of nylon net (each piece: 180*1.8m), used drifting or fixed to bottom.
	Medium-mesh	3 - 5”	2	
	Large mesh	≥ 5”	2 - 3	
	Lobster net	4”	1 - 2	2 to 6 pieces of multifilament net (each piece: 150-180*1.8m). Use bait.
Bottom trawls		0.5 - 1”	2	Multifilament net of 8-10*2-3m dragged over the sea floor at shallow areas. Small-scale equivalent of industrial otter-trawler.
Purse seines		2 - 2.5”	10 - 14	Small-scale encircling multifilament net, operated by 2 boats. Used only in the first three to four months of the year. Fishing grounds located 8-10 nautical miles from the coast.

3.2.4 Data processing and analyses

Considering that 80% of fish were not landed whole, but gutted (42.6%), beheaded (2.2%), gutted and beheaded (31.4%) or as trunks (3.4%), weight corrections factors based on FAO (2000) were applied to landed weight for more accurate estimates of live weight removed per taxon. For some taxonomic families of small-sized species of relatively low market value (e.g. Acanthuridae, Muraenidae) there was partial or no data available on conversion factors. We assigned a conversion factor of 1.1 to those cases, being this value the most common reported as conversion factor for gutted weight across taxa (FAO, 2000). Large sting rays (*Hypanus* spp.) that could not be weighted were measured and disc-widths were later converted to total weight based on literature values for the two species involved (Ehemann et al., 2017). A table with all correction factors used per taxon is included in Annex II (Table S3.1). Landings data converted to live weight is technically known as “nominal catch” (FAO, 2018b) which does not include discarded specimens (live or dead) that are not brought to landing sites. For practical reasons we will refer here to the nominal catch as “catch”. After weight conversion was performed, as described above, relative weight per taxa (species, genus or family) was calculated based on the catch (kg) per taxon divided by the total catch (all taxa combined) within each coastal zone.

To explore potential inter-annual differences in the catch composition of the coastal zones of Tribugá and ZEPA, we carried out cluster and non-metric multi-dimensional scaling analyses (nMDS) to compare relative weight within landing sites among years of those species that contributed to 95% of the catch at each landing site.

Size-based, functional and conservation indicators related to the composition of the catch were estimated and assessed among coastal zones and fishing gears. A list of the selected indicators is presented in Table 3.2, along with a brief description and the rationale behind their current global use as proxies of ecological fishing impacts. Mean total length (cm) in the catch was estimated 166 across taxa for each gear within each coastal zone and visualized through violin plots. Maximum body size (cm), trophic level, trophic guild and spatial guild were assigned to all species registered in the landings based on data available on FishBase (Froese and Pauly, 2017), the Smithsonian Tropical Eastern Pacific Fish Guide (Robertson and Allen, 2015) and SeaLifeBase (Palomares and Pauly, 2018). Additionally, published values from local studies (Castellanos-Galindo et al., 2017; Criales-Hernandez et al., 2006) were used to assign trophic levels to some invertebrate species for which information could not be found on international databases. Trophic guilds categories used were: herbivore, invertivore, omnivore, piscivore and planktivore, while categories of spatial guilds used were: demersal, bentho-pelagic and pelagic.

Conservation threat status was assigned to species based on regional and national assessments that follow the International Union for the Conservation of Nature’s (IUCN) Red List standards (IUCN, 2017). National assessments used are those carried out in Colombia in recent years for marine fish species (Chasqui et al., 2017), marine invertebrates (Ardila et al., 2002) and reptiles (Morales-Betancourt et al., 2015); the last one was included taking into account the rare occurrence of some species of sea turtles in the catch. Information on regional assessments was based on Polidoro et al. (2012). The categories used are: Not Evaluated (NE), Data Deficient (DD), Least Concern

(LC), Near Threatened (NT), Vulnerable (Kronen et al.), Endangered (EN) and Critically Endangered (CR). Definitions and criteria used for each category can be found at www.iucnredlist.org.

An additional classification of the taxa registered in the catch was made based on their current use or importance to fishers and markets. Three categories were considered for this purpose: “commercial”, for those species of commercial interest, “local use” for those species that are not sold to external markets but are locally consumed or used as bait, and “by-catch” for those species that are not intentionally targeted and are usually discarded before reaching the landing site. However, when the size of the individuals was not so small (approximately >25 cm) or when fishers did not carry out the sorting process of the catch while they were on-board, some of that by-catch made it to the landing site and we will refer to that portion of the catch as “landed by-catch”. In the case of bottom trawlers, fishers generally brought the last haul completely unsorted and separated from the rest of the catch, so 200 we could use that haul to estimate landed by catch. The classification of species in the above mentioned categories was based on Díaz et al. (2016) and on interviews made to local fishers of the coastal zone of Buenaventura by the first author (unpublished data).

Mean trophic level (*MTL*) of the catch for each gear category (*g*) at each coastal zone was estimated using the formula described by Pauly et al. (1998):

$$MTL(g) = \sum_{s=i}^{n} Wig * TLi \Big/ \sum Wig$$

Where *Wig* is the biomass (total weight) of species *i* caught by gear *g*, and *TLi* is the trophic level of species *i* for *n* species. In a similar way we estimated mean maximum body size (*MBS*) per gear type at each zone, replacing *TL* in the previous formula for *MBS*. Generalized linear models (GLMs), using a logarithmic link function and a quasipoisson distribution, were used to assess differences in mean length, *MTL* and mean *MBS* among gear types and zones. When statistical differences were detected within either factor or their interaction, pairwise comparisons were carried out using the “emmeans” R Package, based on least-square means and adjusted *p* values following Tukey tests (R-Core-Team, 2018; Russell, 2018).

Table 3.2. *Size-based, functional and conservation indicators used here for the assessment of the catch of SSF in the Colombian Pacific. Rationale for its use as proxies of ecological fishing impacts and related literature are also indicated.*

Indicator	**Description**	**Rationale**	**Associated references**
Mean length	Mean length of all species in the catch	Given that fisheries is size selective and normally targets the adult phase of target species, it is expected that mean length in the catch decreases with increased fishing effort.	Jennings (2005); Jennings and Dulvy (2005); Link (2005); Rochet and Trenkel (2003); Shin et al. (2005)
Mean maximum body size (*MBS*)	Weighted mean of the maximum size that the species in the catch can have in their lifetime.	Species with larger body size, higher longevity and age at maturity and lower growth rates have higher vulnerability to fishing and therefore are more likely to experience overfishing under sustained or increased fishing effort.	Cheung (2007); Denney et al. (2002); Dulvy and Reynolds (2002); Greenstreet and Rogers (2006); Jennings et al. (1999); Pitcher and Preikshot (2001); Smith et al. (1998)
Mean trophic level (*MTL*)	Weighted mean of the trophic level of the species in the catch (*sensu* Pauly et al. 1998)	Given that fisheries tend to target larger fish/species with high trophic levels it is expected that mean trophic level in the catch will decreased with increased effort.	Gascuel et al. (2016); Guénette and Gascuel (2012); Jennings et al. (2002); Pauly et al. (1998); Pinnegar et al. (2002); Shannon et al. (2014)
Trophic guilds	Relative abundance of species belonging to these trophic guilds: herbivore, invertivore, omnivore, piscivore and planktivore	Following the rationale for MTL, it is expected that increased fishing will lead to a decrease in the proportion of piscivore species (or other guilds) in the catch.	Caddy and Garibaldi (2000); Link et al. (2002); Rochet and Trenkel (2003)

Table 3.2. (continued)

Indicator	**Description**	**Rationale**	**Associated references**
Spatial guilds	Relative abundance of species associated to a habitat in the water column: demersal, bentho-pelagic and pelagic	Given the intrinsic selectivity of the fisheries (gear, season or spatially induced) it is expected that the proportion of pelagic and/or demersal species will change with increased fishing effort.	Caddy (2000); Caddy and Garibaldi (2000); Fulton et al. (2005); Link et al. (2002); Pitcher and Preikshot (2001); Rochet and Trenkel (2003)
Threatened categories	Relative abundance of endangered species based on categories established by IUCN (www.iucnredlist.org)	Endangered species should be avoided as target or by-catch of commercial fisheries to allow their populations to recover.	Degnbol and Jarre (2004); Rochet and Rice (2005); Shin et al. (2010)
Landed by-catch	Relative abundance of species that are not intentionally targeted and usually discarded	Removal of non-target species can cause a decrease in the population abundance of those species but also ecological effects on the ecosystem such as food-web disruption or habitat destruction	Alverson et al. (1994); Collie et al. (2017); Fulton et al. (2005); Link (2005); Rochet and Trenkel (2003); Shin et al. (2010)

3.3 RESULTS

A total of 40,035 one-day fishing trips were sampled accounting for 1,823.2 tons of estimated biomass in the catch and 515,243 specimens measured. The proportion of the catch contributed by each fishing gear differed among ZEPA, Tribugá and Buenaventura (Figure 3.2). Hook-based gears contributed the most to the catch in ZEPA and Tribugá, while net-based gears dominated in Buenaventura. The relative contribution made by each gear to the total biomass was similar to the proportion of fishing trips per gear in ZEPA and Tribugá, but not so in Buenaventura, where a very large biomass contribution was made by purse seine nets despite the relatively low number of fishing trips recorded for that gear type (Figure 3.2). Total biomass (kg), number and estimated percentage of fishing trips sampled per gear type at each zone are presented in Table 3.3.

3.3.1 Taxonomic composition of the catch

179+ species belonging to 80 families 232 were identified as part of the catch of the SSF of the three coastal zones of the Colombian Pacific. However, this number of species is probably an under-estimation of the richness of the catch considering that 66 common names of mostly rare species (i.e. low relative abundance in the catch) were not assigned to any taxonomic category and 31 of them were only identified to genus or family level, resulting in a total of 276 different common names registered in the catch of the three coastal zones.

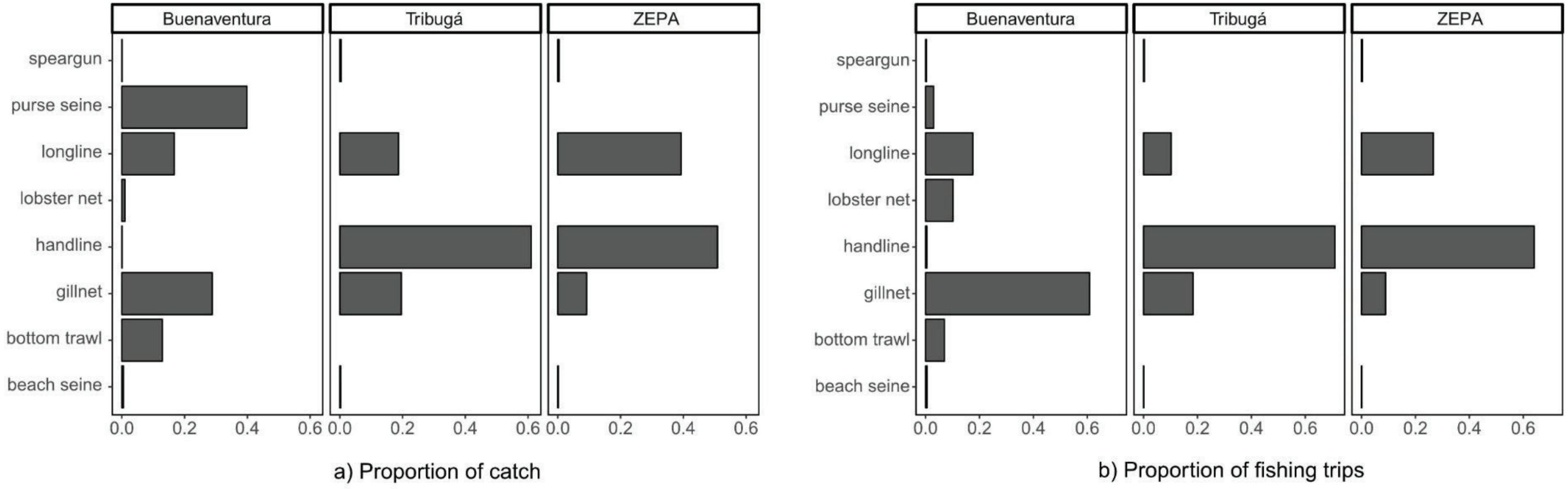
95% of the biomass in the catch was accounted for by 24 families and 72 species (Figure 3.3 and Figure S3.1 in Annex II). Mackerels, tunas and bonitos (Scombridae) contributed between 20 and 30% of the annual catch at all zones, indicating an overall importance of this family in the SSF of the entire Colombian Pacific coast. Jacks (Carangidae), cusk eels (Ophidiidae), groupers (Serranidae) and snappers (Lutjanidae) were also important in the landings of ZEPA and Tribugá while in Buenaventura, catfishes (Ariidae), whiptail stingrays (Dasyatidae) and drums or croakers (Sciaenidae) followed Scombridae in the relative abundance ranking (Figure S3.1 in Annex II). A higher number of species (41) accounted for 95% of the catch in Tribugá than in Buenaventura and ZEPA (35 species each) (Figure 3.3). The distribution of the relative abundance of species shows a more even pattern in the catch of Tribugá than that of ZEPA, where two dominant species (*Thunnus albacares* – Scombridae and *Brotula clarkae* – Ophidiidae) contributed to 35% of the catch. Invertebrate species, mainly shrimps (Penaeidae) and lobsters (Palinuridae), were abundant in Buenaventura, but not so in ZEPA or Tribugá. Additionally, several shark species were relatively abundant in ZEPA and Tribugá compared to Buenaventura (Figure 3.3). A complete list of the taxa recorded in the catch of each zone, with their absolute and relative weight, can be seen in the supplementary material of Herrón et al. (2019a)[3].

Table 3.3. *Total biomass in the nominal catch (i.e. live weight converted from landed weight, as described in Methods) of SSF, number of fishing trips sampled and estimated percentage of trips sampled per gear type at landing sites of the three coastal zones of the Colombian Pacific included in the present study (n.d. = no data available on total number of trips).*

Zone	Gear type	Biomass (kg)	Number of fishing trips sampled	Percentage of fishing trips sampled
ZEPA	Beach seine	2,057.6	7	n.d.
	Gillnet	86,435.7	875	87%
	Handline	481,009.8	6,302	78%
	Longline	370,961.4	2,620	67%
	Spear gun	3,951.5	32	n.d.
Tribugá	Bbeach seine	1,383.9	21	n.d.
	Gillnet	158,752.0	5,345	92%
	Handline	493,520.3	20,672	76%
	Longline	151,412.0	2,974	70%
	Spear gun	3,476.2	95	n.d.
Buenaventura	Beach seine	343.8	6	n.d.
	Bottom trawl	9,358.8	77	21%
	Gillnet	20,799.7	669	42%
	Handline	77.5	5	n.d.
	Lobster net	750.9	112	45%
	Longline	12,068.7	193	62%
	Purse seine	28,835.5	33	47%
	Spear gun	77.7	4	n.d.

---

[3] www.frontiersin.org/articles/10.3389/fmars.2019.00127/full#supplementary-material



a) Proportion of catch

b) Proportion of fishing trips

Figure 3.2. *Relative contribution to the catch in terms of biomass (A) and to the number of sampled fishing trips (B) by each gear type used in the SSF at three coastal zones of the Colombian Pacific. Sampling periods and landing sites included in each coastal zone are described in Section 3.2.3*

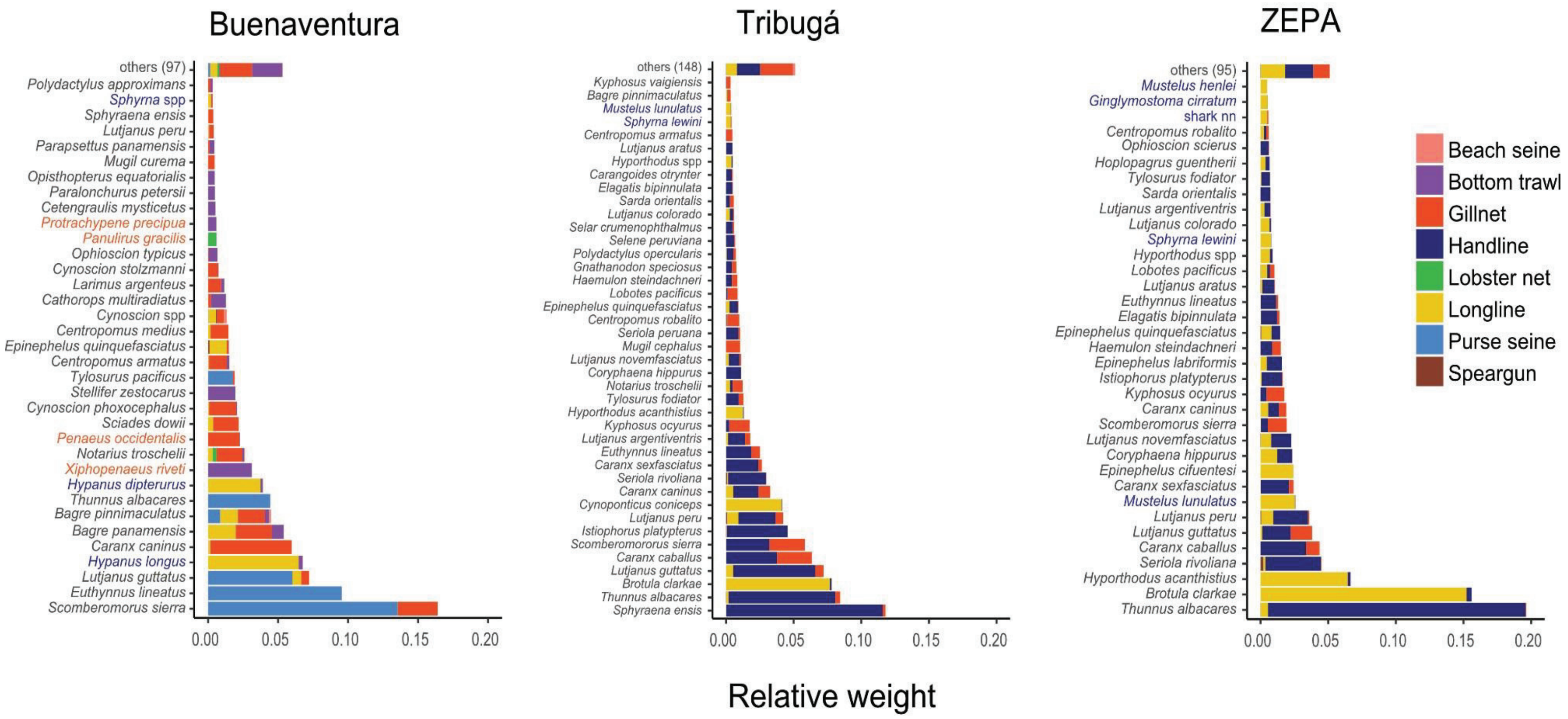


Figure 3.3. *Relative weight of taxa in the catch of the SSF at three coastal zones of the Colombian Pacific: ZEPA, Tribugá, and Buenaventura. Taxonomic identity is indicated for those taxa that contributed 95% to total catch and relative catch contribution by each gear type is illustrated. Elasmobranch species (sharks and rays) are shown in blue font, crustaceans in orange and bony fish in black.*

Table 3.4. *Mean estimated values ± standard deviation for total length, maximum body size and trophic level of the catch at the three geographical zones studied here: Buenaventura, Tribugá and ZEPA.*

		All species in the catch			Only fish species in the catch		
Zone	**Gear**	**Total length**	**Max. body size**	**Mean trophic level**	**Total length**	**Max. body size**	**Mean trophic level**
Buenaventura	Bottom trawl	11.26 ± 4.89	33.26 ± 39.01	3.24 ± 0.70	11.99 ± 5.20	41.96 ± 45.26	3.63 ± 0.48
	Gillnet	31.18 ± 13.18	77.02 ± 33.91	3.88 ± 0.59	35.35 ± 12.75	81.66 ± 31.12	4.00 ± 0.42
	Lobster net	23.61 ± 11.50	55.70 ± 51.88	3.78 ± 0.51	36.08 ± 14.09	86.47 ± 68.76	4.3 ± 0.34
	Longline	46.93 ± 21.94	169.93 ± 85.65	3.75 ± 0.35	47.01 ± 21.92	169.93 ± 85.65	3.75 ± 0.35
	Purse seine	54.48 ± 14.18	119.53 ± 63.67	4.21 ± 0.31	54.48 ± 14.18	119.53 ± 63.67	4.21 ± 0.30
Tribugá	Gillnet	32.03 ± 15.67	86.02 ± 47.89	3.91 ± 0.56	32.03 ± 15.67	86.47 ± 68.76	3.91 ± 0.56
	Handline	39.77 ± 23.80	151.16 ± 95.65	4.17 ± 0.27	39.77 ± 23.80	151.16 ± 95.65	4.17 ± 0.27
	Longline	60.66 ± 21.91	141.64 ± 64.44	3.91 ± 0.20	60.66 ± 21.91	141.69 ± 64.44	3.91 ± 0.20

Table 3.4 *(continued)*

ZEPA	Gillnet	38.43 ± 10.73	83.24 ± 46.29	3.98 ± 0.38	38.43 ± 10.73	83.24 ± 46.29	3.98 ± 0.38
	Handline	42.73 ± 18.10	184.57 ± 97.55	4.25 ± 0.26	42.73 ± 18.10	184.57 ± 97.55	4.25 ± 0.26
	Longline	73.86 ± 14.05	133.35 ± 72.27	3.90 ± 0.21	73.86 ± 14.05	133.53 ± 72.60	3.90 ± 0.21

Table 3.5. *Proportions of threatened or non-threatened taxa in the catch of SSF of the Colombian Pacific Species classification were based on regional assessments (Polidoro et al., 2012) (Reg) and national assessments produced by the Colombian government (Col) for marine fish species (Chasqui et al., 2017), marine invertebrates (Ardila et al., 2002) and reptiles (Morales-Betancourt et al., 2015). Categories used are: Not Evaluated (NE), Data Deficient (DD), Least Concern (LC), Near Threatened (NT), Vulnerable (Kronen et al.), Endangered (EN), and Critically Endangered (CR), based on: www.iucnredlist.org.*

		Not classified				**Non-threatened categories**						**Threatened categories**					
		unknown		**NE**		**DD**		**LC**		**NT**		**VU**		**EN**		**CR**	
Zones	**Gears**	**Reg**	**Col**	**Reg**	**Col**	**Reg**	**Col**	**Reg**	**Col**	**Reg**	**Col**	**Reg**	**Col**	**Reg**	**Col**	**Reg**	**Col**
Buenaventura	Bottom trawl	0.02	0.02	0.33	0.90	0.03	0.01	0.62	0.04	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
	Gillnet	0.03	0.03	0.08	0.66	0.01	0.05	0.88	0.00	0.00	0.12	0.00	0.14	0.00	0.00	0.00	0.00
	Lobster net	0.02	0.02	0.01	0.96	0.55	0.00	0.38	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.01
	Longline	0.05	0.05	0.00	0.47	0.65	0.07	0.30	0.00	0.01	0.04	0.00	0.37	0.00	0.00	0.00	0.00
	Purse seine	0.00	0.00	0.00	0.29	0.00	0.05	0.88	0.00	0.12	0.66	0.00	0.00	0.00	0.00	0.00	0.00
Tribugá	Gillnet	0.04	0.04	0.10	0.69	0.01	0.03	0.83	0.02	0.02	0.21	0.00	0.01	0.00	0.00	0.00	0.00
	Handline	0.01	0.01	0.02	0.63	0.01	0.02	0.83	0.02	0.13	0.33	0.01	0.00	0.00	0.00	0.00	0.00
	Longline	0.03	0.03	0.00	0.34	0.65	0.01	0.29	0.01	0.01	0.56	0.00	0.05	0.02	0.00	0.00	0.00
ZEPA	Gillnet	0.07	0.07	0.14	0.58	0.00	0.01	0.78	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00
	Handline	0.01	0.01	0.03	0.48	0.02	0.02	0.57	0.01	0.37	0.49	0.00	0.00	0.00	0.00	0.00	0.00
	Longline	0.03	0.03	0.00	0.17	0.43	0.02	0.44	0.01	0.08	0.59	0.00	0.17	0.02	0.00	0.00	0.00

Results from the cluster and the nMDS analyses showed that there were not distinctive inter-annual differences related to species composition of the catch at the landing sites sampled in ZEPA and Tribugá (Figure S3.2 in Annex II). Based on records of daily fishing activity in Tribugá and ZEPA collected by MarViva during their monitoring program (Díaz et al., 2016) and the information available from the Colombian fisheries authority (http://sepec.aunap.gov.co/), there was no evidence of changes in fishing effort made by the small-scale fleet in those areas during the past ten years. We thus used the combined catch data for all years of each of these coastal zones for subsequent analyses.

3.3.2 Size-based indicators of the catch

Overall, most specimens at all zones were < 100 cm of total length (Figure 3.4) with longlines in ZEPA capturing on average larger size classes (Table 3.4), even though the largest specimens were caught by handlines in Tribugá (e.g. the sailfish species *Istiophorus platypterus* reaching > 400 cm TL; Figure S3.3 in Annex II). In contrast, bottom trawls in Buenaventura exhibited a high relative abundance of small-sized individuals with a narrow unimodal distribution of length. The catch of this gear was composed mainly of the target small shrimps species Pacific seabob - *Xiphopenaeus riveti* and titi shrimp - *Protrachypene precipua*, and other non-target small-sized invertebrates and juvenile fish of several species (Figure 3.3 and Figure 3.4). Lobster nets and gillnets in Buenaventura had most of their catch towards the lower side of the overall length range observed in this study (Figure 3.4 and Table 3.4). Results from the GLM conducted with the entire catch (all species included) showed that mean length in the catch within the same gear type was statistically different among zones, with ZEPA showing higher mean length in the catch than Tribugá and Buenaventura for gillnets and longlines, and also for handlines when compared to Tribugá ($p<0.001$ in all cases). Mean length was also statistically different among gears within the same zone: in Buenaventura, mean length of purse seines was higher than that of all other gears whereas mean length of bottom trawls was lower than all the other gears ($p<0.001$ in all cases). In Tribugá and ZEPA, longlines had a significantly higher mean length in their catch compared to handlines and gillnets ($p<0.001$ in all cases).

Handlines and longlines showed the largest maximum body size (*MBS*) of the species in the catch, with mean values above 130 cm in all cases (Figure 3.5 and Table 3.4). Mean *MBS* of the entire catch of handlines was statistically higher ($p<0.001$) in ZEPA than in Tribugá. In the case of longlines, Buenaventura showed higher mean *MBS* than ZEPA and Tribugá, related to the high relative abundance of stingrays (*Hypanus* spp) in the catch of longlines of that central coastal zone, although the mean *MBS* was only statistically different when compared to ZEPA ($p = 0.02$). On the other hand, gillnets appear to target species of medium *MBS* at all three zones with mean values close to 80 cm and statistical differences found between Tribugá and Buenaventura ($p = 0.01$). Bottom trawls had a significantly 298 smaller mean *MBS* than all other gears except for lobster nets ($p<0.01$ in all cases).

Paired comparisons based on the entire catch within each coastal zone revealed that in Buenaventura, longlines had higher *MBS* than all other gears, except for purse seines ($p<0.001$ in all cases), while bottom trawl had lower *MBS* than all other gears except for lobster nets ($p<0.01$ in all cases); none of the other paired comparisons was statistically significant in Buenaventura. In ZEPA, handlines exhibited a significantly higher *MBS* than longlines and gillnets ($p<0.001$ in both cases). In Tribugá mean *MBS* of gillnets was lower than that of handlines and longlines ($p<0.001$ in both cases), but mean *MBS* values of the two hook-based gears, i.e. longlines and handlines, were not significantly different between each other.

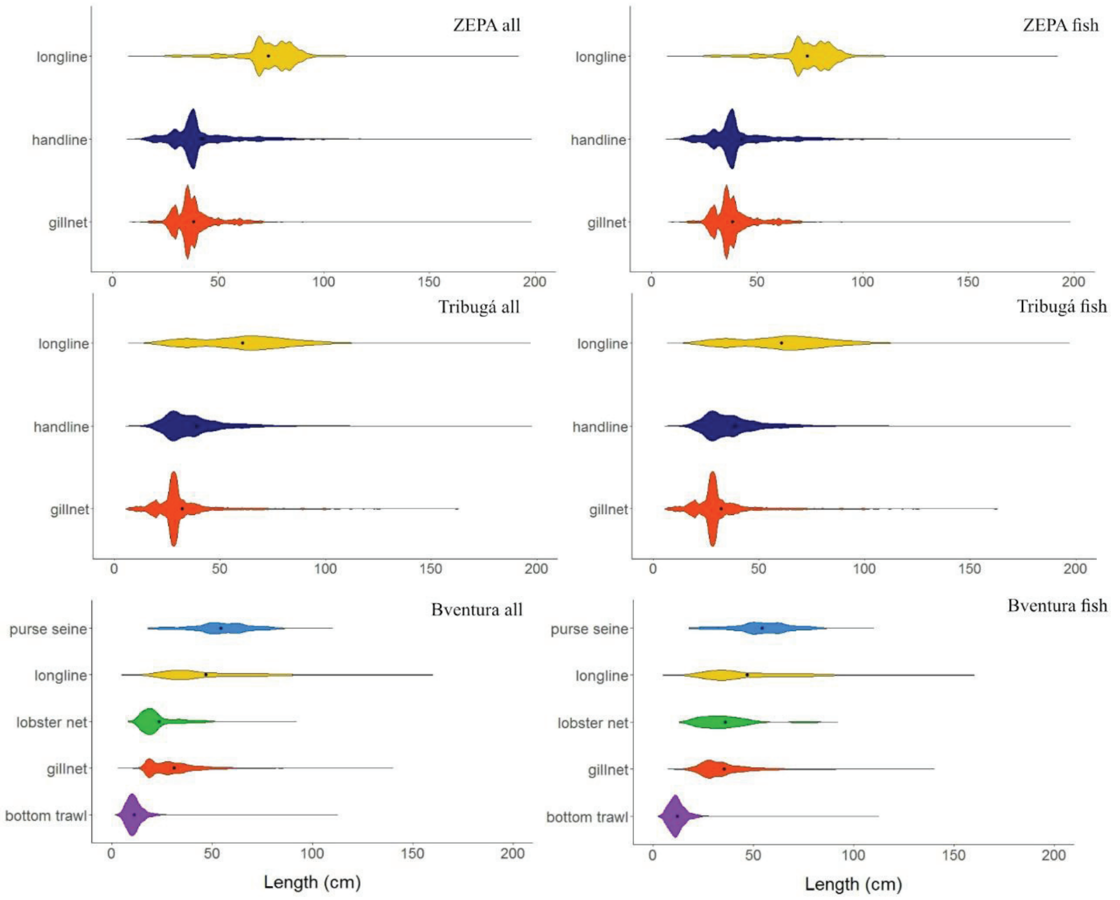


Figure 3.4. *Length distribution of the entire catch (up to 200 cm) and of the fish portion of the catch of SSF per gear type at three coastal zones of the Colombian Pacific: ZEPA, Tribugá, and Buenaventura (abbreviation: Bventura). Black dots indicate mean values.*

For bottom trawls, gillnets and lobster nets in Buenaventura invertebrates accounted for 34%, 8% and 56% of the catch respectively. To assess the influence of shrimp and other small invertebrates on the estimates of size-based indicators, we estimated mean length and mean MBS for the fish portion of the catch, i.e. excluding all invertebrates and other non-fish species (i.e. sea turtles) from the data set prior to analyses. As expected, values of both size-based indicators, especially of *MBS*, increased for bottom trawls, lobster nets and gillnets in Buenaventura (Table 3.4) but had no effect in other gears of that coastal zone nor in the estimates derived from Tribugá and ZEPA, where invertebrates and reptiles accounted for only 0.03% and 0.01% of the catch respectively. GLMs conducted for the fish portion of the catch showed the same statistical differences in total length among zones and/or gears observed previously for the whole catch, except for the difference between gillnets and lobster nets in Buenaventura which was not significant this time (p = 0.98). In contrast, the results of the pairwise comparisons of *MBS* values based on the fish portion of the catch showed that differences among zones or gears previously observed for the entire catch were no longer significant. In particular, mean *MBS* of the fish caught with gillnets was not statistically different between Buenaventura and Tribugá (p = 0.12) and within Buenaventura mean *MBS* of longlines and lobster nets were not statistically different (p = 0.34) from each other.

3.3.3 Functional indicators of the catch

Mean trophic level (*MTL*) of the entire catch 332 (all species included) was very similar across gears and zones, with mean values lying above 3.5 for all cases except for bottom trawls in Buenaventura that exhibited the lowest mean value, while handlines and purse seines exhibited the highest values (Figure 3.6 and Table 3.4). Statistically significant differences among gears within the same coastal zone were only found between *MTL* of handlines and longlines within ZEPA ($p < 0.01$).

Following the rationale explained above for size-based indicators and considering the general positive relationship between a species body size and its trophic level (Romanuk et al., 2011), we also estimated *MTL* for the fish portion of the catch only. Similarly to the findings related to mean length and *MBS*, there was an increase – although relatively smaller – in the estimated values of *MTL* for bottom trawls, gillnets and lobster nets in Buenaventura (Figure 3.6 and Table 3.4). The small increase resulted in the difference between *MTL* of gillnets from Buenaventura and gillnets from Tribugá being no longer significant (p = 0.24).

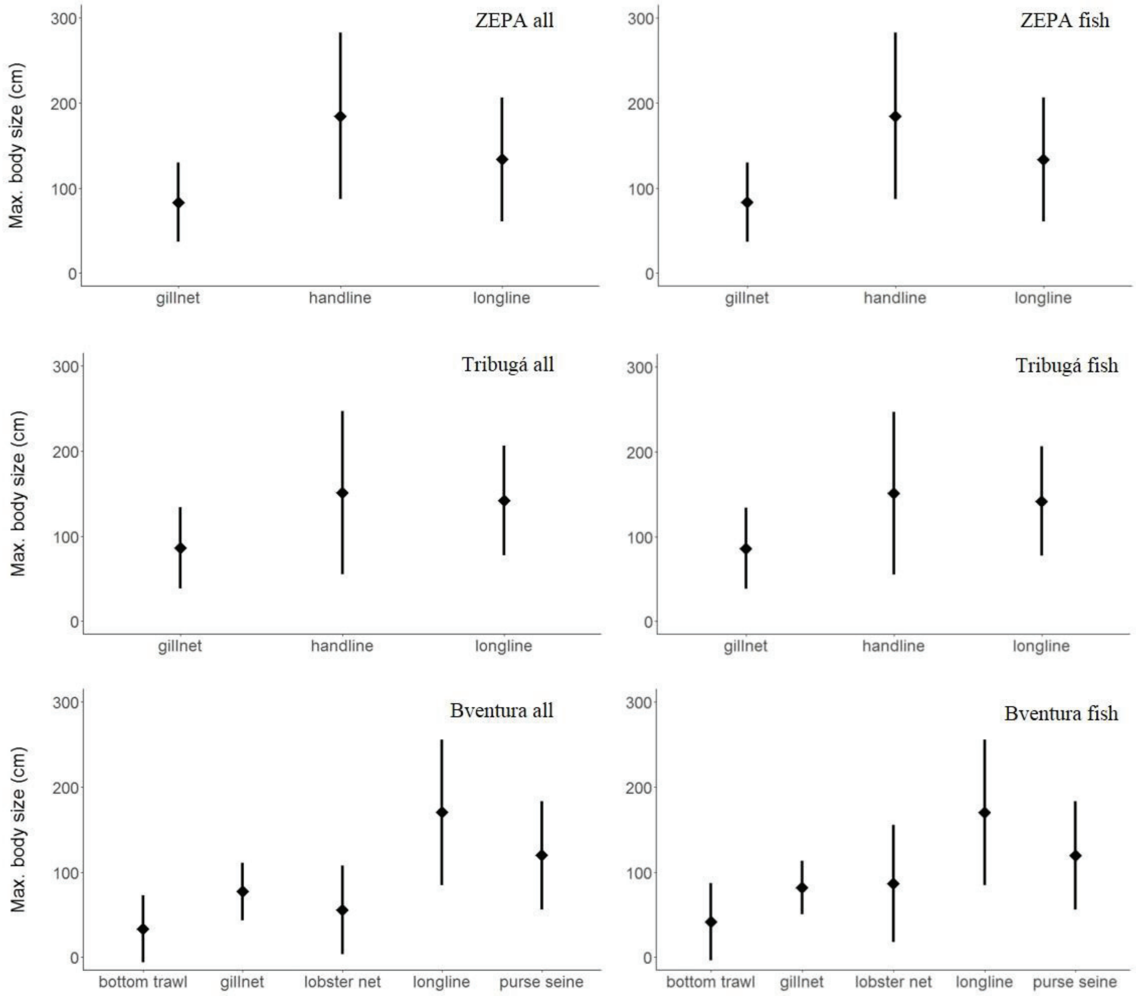


Figure 3.5. *Weighted mean and standard deviation of maximum body size of the entire catch and of the fish portion of the catch of SSF per gear type at three coastal zones of the Colombian Pacific: ZEPA, Tribugá, and Buenaventura (abbreviation: Bventura).*

Results of the relative abundance of trophic guilds corroborated that high trophic level guilds (piscivores and invertivores) are dominant in the catch of most gears across zones, except for bottom trawls, the gear that showed the highest diversity of trophic guilds (Figure 3.7). Also worth noting is the higher relative abundance of invertivores in the catch of longlines in Buenaventura compared to that of Tribugá and ZEPA for the same gear, where piscivores accounted for more than 90% of the catch.

In terms of spatial guilds, demersal species were dominant in Buenaventura for all gears except for purse seines, contrasting with the results from ZEPA and Tribugá where pelagic species had a higher relative abundance in the catch of gillnets and handlines while longlines caught more demersal and bentho-pelagic species (Figure 3.7). The overall proportions of species belonging to different spatial guilds was similar between ZEPA and Tribugá for the same type of gear: gillnets, handlines or longlines.

3.3.4 Conservation indicators of the catch

Based on the regional assessment of IUCN´s Red List, the three coastal zones have Least Concern (LC) as the predominant category of the biomass in the catch (54 to 73%), while threatened categories (Vulnerable – VU, Endangered – EN and Critically Endangered – CR) represented less than 1% of the biomass. The relative weight of species classified as Near Threatened (NT) was higher in ZEPA than in the other two zones with handlines being the gear that contributed most to that difference (Table 3.5).When the same analysis was based on the national assessment (Colombian´s red lists assessments), Not Evaluated (NE) and Near threatened (NT) were the dominant categories in the catch of all zones - with ZEPA exhibiting the highest relative abundance of NT species - while Data Deficient (DD) and LC had overall low values. Based on the national assessments, the relative weight of species under category VU was higher in the catch of ZEPA and Buenaventura, mostly due to the presence of species caught with longlines (e.g. stingrays). Overall, the relative abundance of threatened or near threatened categories in the catch was higher when based on national assessments than when the analysis was based on IUCN´s regional assessments.

Landed by-catch species, those that are not commercialized or locally used, were only a conspicuous proportion of the catch of bottom trawls where they accounted for > 30% of the catch (Table 3.6). For the rest of the gears, landed by-catch was below 3% and more than 75% of the catch corresponded to commercially important species. In ZEPA and Tribugá, 20% of the catch of gillnets is locally consumed or used as bait, instead of sold to local or external markets.

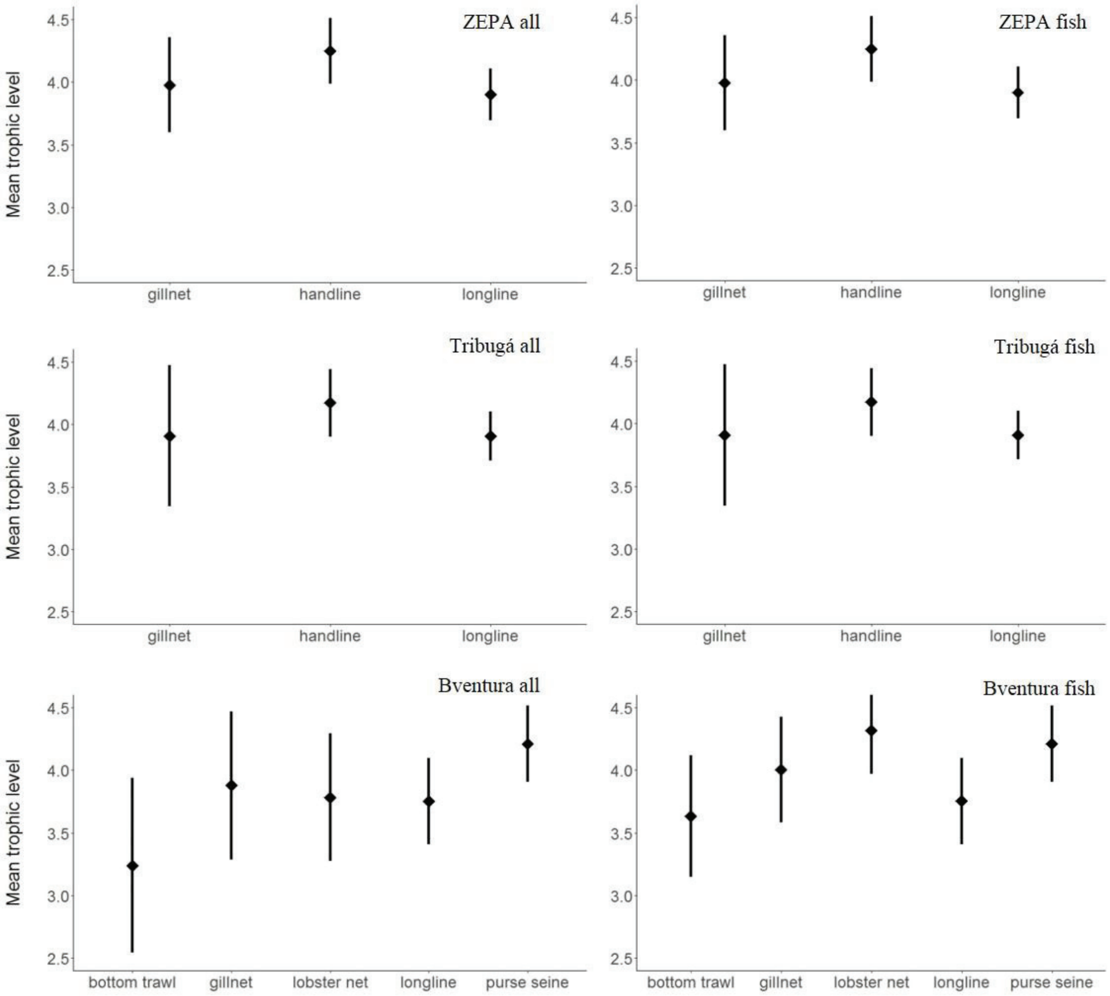


Figure 3.6. *Weighted mean and standard deviation of trophic level of the entire catch and of the fish portion of the catch of SSF per gear type at three coastal zones of the Colombian Pacific: ZEPA, Tribugá, and Buenaventura (abbreviation: Bventura).*

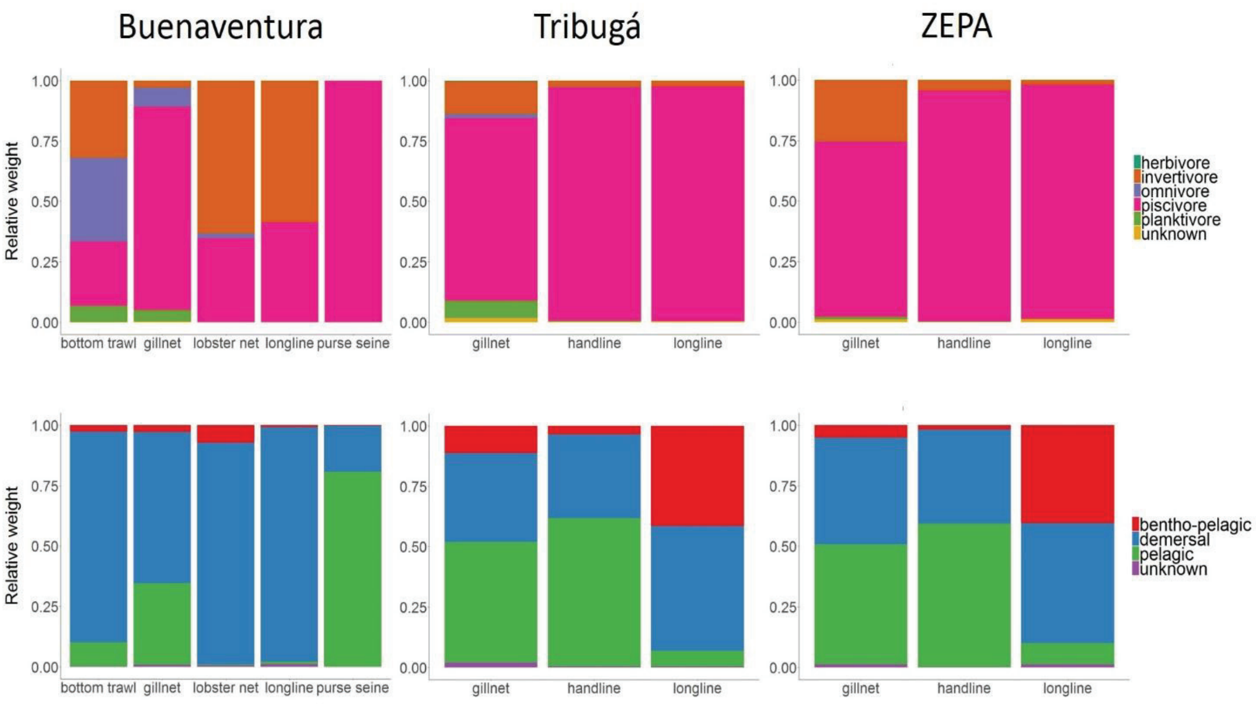


Figure 3.7. *Proportion of trophic guilds and spatial guilds per gear type in the catch of SSF at three coastal zones of the Colombian Pacific: ZEPA, Tribugá, and Buenaventura.*

3.4 DISCUSSION

Our results showed clear differences in the catch composition among the three coastal zones and, particularly, between the northern rocky-dominated coast (Tribugá and ZEPA) and the central estuarine and mangrove-dominated coast (Buenaventura) of the Colombian Pacific. Some of the observed differences were related to the interaction between gear type and geographical location of the coastal zones.

Despite being in a traditionally data-poor tropical SSF context, our data sets, produced by a non-government organization and by an academic research project, included higher sampling frequency, sample size and geographic coverage than normal government fisheries data (Herrón et al., 2018; Ramírez et al., 2017). Community-based fishing monitoring schemes (as those followed in the present study) are therefore useful and likely more effective and less expensive ways of monitoring fisheries resources in typical SSF like the ones evaluated here. Overcoming some limitations in these schemes like the correct differentiation of 400 certain species and common names within certain taxonomic groups, e.g. groupers, sharks, is something that will require further attention in the future (Castellanos-Galindo et al., 2018).

Table 3.6. *Proportions of categories related to fishers' use of the species registered in the catch of SSF in the Colombian Pacific. "Commercial" refers to species that are usually sold to local or external markets, "local use" to those species that are not sold but are locally consumed or used as bait, and "landed by-catch" to those species that are not intentionally targeted and that are usually discarded. Taxa which could not be identified to species level and could not be assigned to a specific category where classified as "unknown".*

Zones	**Gears**	**Commercial**	**Local use**	**Landed by-catch**	**Unknown**
Buenaventura	Bottom trawl	0.55	0.10	0.36	0.00
	Gillnet	0.90	0.09	0.01	0.00
	Lobster net	0.93	0.05	0.02	0.00
	Longline	0.98	0.01	0.01	0.00
	Purse seine	1.00	0.00	0.00	0.00
Tribugá	Gillnet	0.77	0.21	0.00	0.02
	Handline	0.96	0.03	0.00	0.00
	Longline	0.76	0.23	0.00	0.00
ZEPA	Gillnet	0.78	0.21	0.00	0.01
	Handline	0.98	0.02	0.00	0.00
	Longline	0.96	0.03	0.00	0.01

3.4.1 Size-based and functional indicators

In the management areas established in the northern coastal zones, a higher selectivity of fishing gears has been promoted based on the assumption that gillnets tend to catch a higher proportion of immature fish and have higher by-catch rates than hook-based gears (Ramírez-Luna and Chuenpagdee, 2019; Vieira et al., 2016). Our results confirmed a lower mean length in the catch of gillnets when compared to longlines and handlines in ZEPA and Tribugá. However, fisheries selectivity is influenced not only by the gear used but also by spatial and temporal patterns of resource distribution (Maunder et al., 2014; Sampson, 2014). Therefore, the observed differences reflect not only the inherent selectivity of gears but also the location of the fishing grounds used by each gear. Particularly in ZEPA, longline fishers use deeper grounds located at greater distances from the shore, whereas gillnets tend to fish in areas closer to shore (Velandia and Díaz, 2016). A higher abundance of larger/older individuals in deeper habitats has been widely reported for many fish species and has been attributed to ontogenetic changes, although recent evidence indicate that this “deepening” could also be associated to increased fishing pressure in shallower areas (Frank et al., 2018). Distance to shore and depth of fishing grounds could also explain the higher mean length observed in the catch of purse seines in Buenaventura compared to other gears in the same zone (Figure 3.4). Purse seines are used at fishing grounds located further offshore (8-10 nautical miles) than other gears (unpublished data) and target mostly pelagic species (Figure 3.3). Bottom trawls - which exhibited the lowest mean length in the catch of all zones even when invertebrates are removed – have the smallest mesh size of all nets (0.5”) and are used in near-shore, shallow waters (unpublished data), targeting mainly two small-sized shrimp species (*Xiphopenaeus riveti* and *Protrachypene precipua*). Continued monitoring of mean length in the catch complemented by spatial analyses of fishing grounds could provide more information regarding the factors explaining the observed differences and the potential long-term impacts of different gears on the size structure of fish and invertebrate communities.

Our results of maximum body size (*MBS*) in the catch indicate that longlines and handlines are targeting larger body-sized species that are more vulnerable to overfishing due to their life history characteristics (Cheung, 2007; Jennings et al., 1998) (e.g. sailfish, tunas and sharks, Figure 3.3), while bottom trawls are targeting species that could potentially withstand more fishing pressure and/or recover more rapidly (e.g. shrimps, other small invertebrates and small-sized fish species). Particularly in Buenaventura, longlines had a significantly higher *MBS* than the rest of the gears, probably linked to the fact that large-sized stingrays of the genus *Hypanus* were an important part of the catch of this gear (Figure 3.3 and Figure 3.5).

Targeting a relative high proportion of small-sized specimens has been suggested as a way of improving overall yields while maintaining the structure of the natural ecosystem, under the concept of “balanced harvest” (Kolding et al., 2015a), an approach that contradicts traditional management measures like imposing size limits for target species to avoid fishing immature individuals thus preventing growth and recruitment overfishing (Beverton, 1992; Froese, 2004; Myers and Mertz, 1998). Despite being more aligned to the principles of EBFM, critics of the balanced harvest approach have also argued that there are many practical difficulties of implementing such harvest scheme, particularly a drastic shift in consumers’ seafood preferences towards new species and sizes (Charles et al., 2015; Froese et al., 2015; Garcia et al., 2015).

Similarly to size-based indicators, mean trophic Level (*MTL)* of the catch has been used as an indicator of ecological fishing impacts as it is expected to decrease with increasing fishing pressure (Gascuel et al., 2016; Jennings et al., 2002; Pauly et al., 1998; Pinnegar et al., 2002), but see Sethi et al. (2010). However, *MTL* has been criticized as an indicator of ecosystem condition since it can be largely influenced by external economic factors, such as market demands (for species and sizes) and by environmental variability that alters the dynamics of primary productivity and the recruitment of planktivore species (Branch et al., 2010; Caddy et al., 1998; Caddy and Garibaldi, 2000). Nevertheless, *MTL* may still be a suitable indicator for the state of a fishery system, if fishing pattern and external factors remain constant over time and only fishing effort increases (Shannon et al., 2014). Our estimates of *MTL* were fairly similar across gears and coastal zones and showed that SSF in the Colombian Pacific are extracting mainly high trophic level species of the system. This is corroborated by the high proportion of piscivores and invertivores in the catch of most gears across all zones, with the exception of bottom trawls that exhibited the highest diversity of trophic guilds in the catch (Figure 3.7).

These results go in line with a worldwide pattern of fishing that has focused on high trophic levels (Kolding et al., 2015b). *MTL* values observed here (overall mean: 3.9) are higher than *MTL* values reported in tropical SSF of the Western Indian Ocean (2.3 - 3.6, Rehren, 2018); (Tuda et al., 2016)), the Caribbean (3.3 – 3.5, Arias-González et al. (2004)), the Indo-Pacific (2.4 – 3.7, Bacalso and Wolff (2014)) and other localities in the tropical eastern Pacific (2.5 – 2.9, Díaz-Uribe et al. (2007); Zetina-Rejon et al. (2003)). However, values of trophic level per species used in this study correspond to the adult phase of the species (Froese and Pauly, 2017) and do not necessarily correspond to the actual trophic level of the size classes harvested per species. This can impose biases in the estimates of mean *MTL* of the catch (Caddy et al., 1998; Reed et al., 2016). In the future, local studies on the diet composition of target species should be conducted and used to estimate trophic levels per size class of main target species.

Differences observed in the proportion of spatial guilds across zones and gears seem best explained by location and habitat type. In ZEPA and Tribugá, coastal zones characterized by narrow continental shelves and few estuaries, pelagic and bentho-pelagic species dominated the catch (Figure 3.7). In contrast, fishing gears in the mangrove dominated and estuarine area of Buenaventura caught mainly demersal species, except for purse seines, the only gear that operates further off-shore. Therefore, observed differences in proportions of spatial guilds do not seem to offer at this point an unequivocal indication of potential geographical or gear-based differences in fishing impacts but future assessments of temporal trends of this indicator might indicate changes in fishing effort or in the natural abundance of the resources (Caddy, 2000; Link et al., 2002; Pitcher and Preikshot, 2001).

3.4.2 Conservation indicators

Based on regional assessments of the threatened status of species (Polidoro et al., 2012), most of the catch of SSF in the Colombian Pacific does not currently face major extinction risks, which could be interpreted as a sign of a sustainable fishery. However, the diagnosis is different when the national assessments are used (Ardila et al., 2002; Chasqui et al., 2017; Morales-Betancourt et al., 2015), since a large proportion of the biomass in the catch corresponds to Nearly Threatened (NT) species (Table 3.5). Based on the national red lists, longlines' catch is conformed partly by species classified as Vulnerable in Buenaventura (37%) and in ZEPA (17%), mainly attributed to the presence of rays, stingrays and sharks. However, national assessments of commercially important species have generally been based on stock assessments with limited landings time-series or with poor spatial coverage. This could impose biases and is a common situation in data limited tropical small-scale fisheries assessments (Costello et al., 2012; Herrón et al., 2018; Ramírez et al., 2017). On the other hand, the high proportion of Not Evaluated (NE) species in the catch of SSF, based on national assessments (Table 3.5), highlights the need to collect data on the status of natural populations based also on fishery independent surveys.

By-catch and discards have also been considered to be meaningful indicators of the potential ecosystem impacts of fishing (Fulton et al., 2005; Link, 2005). They are increasingly being monitored and regulated in fisheries of developed countries (e.g. Landings:Discards ratio from the IndiSeas project, Coll et al., (2016). The high proportion of landed by-catch of bottom trawls observed here (36%) suggests a higher ecosystem impact of this fishing gear compared to other gears currently used. Bottom trawling has long been identified as a fishing method that can cause a variety of ecological impacts, such as: reduced abundance of non-target species, reduced diversity of the benthic community, sediment resuspension, disruption of nutrients cycles, changes in primary productivity, destruction of habitat and changes in trophic dynamics of the demersal and benthic communities (Collie et al., 2017; Collie et al., 2000; Dell et al., 2013; Olsgard et al., 2008). Fisheries authorities in Colombia banned the use of bottom trawls more than ten years ago (INCODER, 2004) but fishers continue to use it since there is low enforcement capacity and high market demand for the main target species (small-sized shrimp species). On the other hand, a recent study on the effects of small-scale bottom trawling in similar estuarine environments in Brazil found that observed differences in the structure of macrofaunal communities seemed to be more related to natural variability than to the degree of trawling impact (Ortega et al., 2018). These authors discussed whether those communities could be adapted to a highly dynamic and frequently disturbed estuarine environment, which could also be the case of the benthic communities in Buenaventura that have sustained a bottom trawl fishery for more than 30 years. Specific studies on the dynamics of the catch of bottom trawls involving on-board monitoring and surveys of natural benthic communities will provide valuable inputs for management decisions regarding the continuation of the ban currently established on this gear or, perhaps, a transition towards fishing effort regulation.

3.4.3 Conclusions and outlook

Analyses of the catch through the lens of ecological indicators provide alternative paths for the assessment and monitoring of SSF that complement the traditional single-species assessment methods and provide insights into potential ecological impacts of fishing. Observed differences in taxonomic composition of the catch and in the proportion of gears used among coastal zones most likely reflect the deep knowledge of small-scale fishers about the temporal and spatial distribution of resources (Purcell et al., 2018; Saavedra-Diaz, 2012). Hook-based gears (handlines and longlines) tend to catch larger sizes and higher trophic levels than nets, but they also include a higher proportion of species that are more vulnerable to fishing impacts and/or have higher conservation concerns. These findings challenge the generalized notion that more selective gears have overall lower ecological impacts. In contrast, net-based gears catch wider size ranges – although tend to focus on small-size classes - and include a wider representation of species, trophic and spatial guilds, which could arguably be considered a more “balanced harvest” type of fishing that retains ecosystem functionality (Garcia et al., 2015). Using the data presented here, a preliminary snap-shot assessment of the gears (Annex II, Table S3.2,) suggests that there is not one ideal or “green” fishing gear since each gear harvests a specific size and/or functional component of the system and therefore will affect that component more severely than other gears. The rapid assessment also shows that the same type of gear can have different ecological impacts when used in different environmental contexts, e.g. the differences in the proportion of trophic and spatial guilds in the catch of longlines in Buenaventura compared to that in ZEPA.

Ecological indicators to assess the impacts of fisheries are most useful when assessed on a temporal timeframe and used simultaneously, taking into account that no single indicator can adequately inform on its own about the status or trends of a complex ecological system (Coll et al., 2016; Link et al., 2002; Shin et al., 2010). Additionally, the criteria to assess the degree of ecological impact of the gears must be aligned with fisheries management and conservation objectives that sometimes have conflicting long-term goals (Link et al., 2002). For example, targeting large individuals is usually considered a sound fisheries management measure on the basis of avoiding juveniles in the catch and allowing individuals to reproduce prior to being harvested. However, fish species that attain large body sizes are generally those that are more fecund (Barneche et al., 2018) and more vulnerable to overfishing compared to small-sized fish species, potentially facing higher extinction risks (Cheung, 2007; Cheung et al., 2005; Jennings et al., 1998).

In order to better inform management decisions related to ecological impacts imposed by different fishing gears, medium to long-term monitoring of the relative effort of each gear and of the metrics associated to ecological indicators is needed. We propose that simple ecological indicators, such as those used in this study, be included as part of annual assessments of multi-gear SSF in tropical countries where data and management capacities are limited. In this way, a systematic evaluation of the potential impacts of fishing at the community and ecosystem level could be developed and facilitate the transition towards EBFM.

ACKNOWLEDGMENTS

We thank the local communities and fishers from the municipalities of Juradó, Bahía Solano, Nuquí and Buenaventura in the Colombian Pacific coast for allowing and supporting data collection at different landing sites between 2011 and 2017. Thanks to C.A. Puentes for producing the map for Figure 3.1. MarViva Foundation received financial support from USAID (Cooperation Agreement #49-2012 of their BIOREDD+ Program), AUNAP (Cooperation Agreement #65-2012), the European Union (Cooperation Agreement #75-2013) and INVEMAR (Cooperation Agreement #009- 2015). P. H. received financial support from CEMarin (Call # 5 of 2015) and from Rufford Foundation (RSG 19522-1).

CHAPTER 4

Understanding drivers of gear choices

CHAPTER 4

Understanding gear choices and identifying leverage points for sustainable tropical small-scale marine fisheries

Pilar Herrón, Lotta C. Kluger, Gustavo A. Castellanos-Galindo, Matthias Wolff & Marion Glaser.

This is the author´s version of the work. Please cite the final version as:

Herrón, P., Kluger, L.C., Castellanos-Galindo G., Wolff, M. & Marion Glaser. (Manuscript submitted). Understanding gear choices and identifying leverage points for sustainable tropical small-scale marine fisheries.

Submitted on May 7th 2019 to *Ocean and Coastal Management.* The manuscript was under review at the moment of presenting this dissertation.

ABSTRACT

In rural coastal areas of most countries of the global South small-scale fisheries (SSF) are the main source of food and income, and a key driver of the local economy. Ensuring sustainability of SSF requires an understanding of socio-economic and cultural contexts and consideration of drivers of fishers' behaviour with respect to spatial and temporal fishing pattern and gear choice. In this study, we characterize the socio-economic settings of SSF in three villages of the central Colombian Pacific coast and compare the profitability of different fishing gears, providing context to a discussion on drivers behind fishers' gear choice and fishing strategies. We estimate a mean annual fish consumption of 237 kg per capita in the study area, which is higher than most estimates from coastal communities worldwide. Bottom trawls, a gear type banned by the fishing authority, had appealing characteristics for young and less experienced fishers with limited income opportunities: low investment and maintenance costs, low operational risks, high value of target species and high profitability. Users of gillnets of small mesh size ($\leq$2.75") targeted the most valuable species in the market, white shrimp *(Penaeus occidentalis*), but their catch-per-unit-effort (CPUE) and associated profit varied between villages, something that is potentially related to spatial patterns of resource abundance and fishing effort. Longlines were used by a small percentage of fishers, generally older and more experienced, who perceived theft risks to be higher than other gear user groups. Commonly used leverage points for SSF sustainability, such as as economic compensation to fishers or redistribution of fishing effort among gears, could also be combined with more impactful ones, such as facilitating fishers' organization and empowerment towards co-management schemes. Our results provide an essential, and often overlooked, socio-economic perspective for managers in tropical SSF pursuing a holistic approach to fisheries management, based on an improved understanding of fishers' incentives and constraints that influence the way they fish.

Keywords: behavioural drivers, food security, coastal social-ecological systems, Colombian Pacific, tropical eastern Pacific, socio-economic drivers

4.1 INTRODUCTION

Small-scale fisheries (SSF) contribute nearly half of global fishing landings (FAO, 2015a) and are an essential source of protein, income and jobs for coastal communities (Béné et al., 2010; Davies et al., 2009). Their relevance is particularly large in Africa, Asia and Latin America where 95% of fishers and fish-farmers of the world live (Béné et al., 2007). In isolated coastal rural communities SSF constitute not only a significant source of income but also the main driver of associated economic activities that provide essential materials for fishing (e.g. fuel, boats, ice) and those that deal with post-harvest operations (e.g. maintenance, processing labour, transport to markets). In such way, SSF are a pivotal contributor to poverty prevention and alleviation in those coastal areas (Béné et al., 2007).

SSF managers face not only the challenge of the declining trend reported for most fishing stocks worldwide (Costello et al., 2012; Ye et al., 2013), but also that of dealing with “the dynamic and unpredictable interdependence of people and nature” (Andrew and Evans, 2009), which is characteristic of social-ecological systems (Ostrom, 2009). In recent years, a transition has been taking place from traditional fisheries management approaches, that aimed to maximize catch while maintaining the health of stocks (King, 2007), to more holistic approaches which consider socio-economic and cultural contexts towards achieving both ecological sustainability and human well-being (Kittinger et al., 2013; Purcell and Pomeroy, 2015; Salas et al., 2007). Such holistic approaches require identifying and understanding the drivers behind resource use patterns, such as fishers’ choices on when, how or where to fish (Fulton et al., 2011; Kronen et al., 2010). Since SSF are such an important source of income in most coastal rural communities, one might expect that fishers always try to maximise profits through a constant trade-off between incentives (e.g. market prices, catch volumes) and constraints (e.g. weather conditions, existing rules) (Saldaña et al., 2017). However, many studies have found that fishers are also driven by factors that are not directly associated to profit or catch maximisation such as traditional values, social obligations, age, skills, level of education, risk aversion, peer pressure and leisure time availability (Abernethy et al., 2007; Kronen, 2004; Naranjo-Madrigal et al., 2015; Torres-Guevara et al., 2016). Moreover, when offered more profitable economic activities fishers can be reluctant to leave the occupation because they appreciate the adventurous and unconventional nature of fishing as a lifestyle (Pollnac and Poggie, 2006, 2008).

Understanding fishers’ gear choice has become increasingly important since gear-based management approaches have gained popularity for managing SSF (McClanahan and Mangi, 2004; Naranjo-Madrigal et al., 2015; Purcell et al., 2018; Selgrath et al., 2018). Gear-based management measures that seek positive effects on the abundance and sustainability of fisheries resources can also have socio-economic consequences for fishers, such as short-term economic losses (Condy et al., 2015) or social conflicts related to increased fishing overcapacity (Pomeroy, 2012). For example, the prohibition of a specific fishing gear could result in immediate benefits to the ecosystem but could also generate social resistance due to a long tradition in the use of that gear or to short-term economic losses (Condy et al., 2015; Kittinger et al., 2013). The variety and impact of such consequences could vary among fishing villages or between gear-users (Arias et al., 2015; Purcell et al., 2018).

In Colombia, a tropical country of the global South where multi-gear and multi-species SSF face most of the management challenges described above, more than 11,000 households of Afro-descendant communities rely on SSF for nutrition, income and employment (Rueda et al., 2010). Small-scale fishers employ mainly gillnets, bottom trawls, longlines, beach seines and purse seines, with catch composition varying greatly among coastal sub-regions and between gears (Herrón et al., 2019a). Taking the central Pacific coast of Colombia as a case study, here we examine the socio-economic settings of SSF fisheries in three coastal villages and compare the profitability of different fishing gears, based on landings data and interviews with fishers. The selected coastal villages share many environmental features (estuarine, mangrove-dominated seascape), but differ in their distance to the main fish markets, access to fishing grounds, social and economic infrastructure. We explored how gear preferences relate to catch or profit maximization and to variables related to: dependence on SSF, individual skills, technical capacities, access to fish markets or fishing grounds, safety considerations and perceptions of fishers. Finally, we discuss the implications of our findings for identifying leverage points (Meadows, 1999) for management of multi-gear marine SSF in Colombia which could be applicable to other similar tropical contexts.

4.2 METHODS

4.2.1 Study area

The Buenaventura coastal sub-region, named after the large port city it includes, is located in the centre of the Colombian Pacific and stretches for ca. 150 km of coastline dominated by mangrove forests and estuaries (Figure 4.1). SSF landings in this sub-region contribute 56.9% to total landings of the entire Pacific coast (AUNAP and UNIMAGDALENA, 2013a), which is probably linked to a higher human population density and number of fishers (approximately 70 people*km^{-2} (DANE, 2011)) in this coastal sub-region, compared to other sub-regions of the Pacific (e.g. the northern Pacific sub-region has 6 people*km^{-2} (DANE, 2011)). The Buenaventura sub-region is also characterized by relatively high unemployment rates (only 13% formally employed), high poverty[4] levels (66.5%) and low education levels (67% of people attend only primary school), when compared to the national averages (DNP, 2019). Three rural coastal villages located at different distances from the port city of Buenaventura were selected for this study based on previous knowledge of their use of fishing gear, which are representative of the central and southern sub-regions of the Colombian Pacific coast (Castellanos-Galindo and Zapata, 2019; Tilley et al., 2018). Demographic information, distance to the city port and key features of the social and economic infrastructure in the three villages are summarized in Table 4.1. No roads connect either of the villages with the city of Buenaventura nor to other areas of the country so that these villages can only be accessed with small boats. Due to its proximity to the city, the village *Bocana* is connected to the urban electrical network and has full-time electricity. *Bocana* also has a basic tourism infrastructure (small hotels and restaurants) that accommodates mostly local and national visitors. The villages of *Pital* and *Punta Bonita* are more distant from the city and not connected to the urban electrical network, depending on diesel generators for electricity supply. In these two villages electricity is generally only available from 18 to 22 h. *Punta Bonita*, despite being geographically the most remote of the villages (Figure 4.1), has infrastructure for ice production and refrigeration storage facilities powered by a solar energy system. This infrastructure, recently provided by development cooperation projects (USAID, 2015, 2017), allows fishers to store fishing products and reduces the need to travel to the city for ice provision. Considering the differences among the three villages (Table 4.1) we will refer hereafter to them as: near-urban (*Bocana*), remote (*Pital*) and remote-equipped (*Punta Bonita).*

The villages are inhabited by Afro-descendant communities that have been granted collective land titles and management rights over their ancestrally occupied lands (Law 70 of 1993), as it is the case for most Afro-descendant communities in the Colombian Pacific region (Escobar, 2008; Offen, 2003). Before data was collected for this study, formal agreements were signed with the elected management boards (locally known as *Juntas*) of the Community Councils Cajambre and Bazán-Bocana, to which the selected villages belong. Several meetings with elected leaders of the local fishers associations at each site were also held to present the objectives, methodology, progress and preliminary results of the research project.

---

[4] Based on the Multidimensional Poverty Index which includes 10 indicators beyond economic income based on health, education and standard of living. People who experience deprivation in at least one third of the weighted indicators fall into the category of multidimensionally poor (http://hdr.undp.org/en/2018-MPI).

Table 4.1. *Demographics, social and economic infrastructure at the three coastal villages included in this study. Data were obtained from local censuses made by Community Councils of Bazán-Bocana and Cajambre, and through field observations made by the first author.*

	Coastal villages		
Socio-economic characteristics	**Bocana (Near-urban)**	**Pital (Remote)**	**Punta Bonita (Remote-equipped)**
Distance to port city (km)	13	45	54
Population (number of families)	361	93	88
% families with fishers	37.1	53.8	76.1
Electricity - main network	Yes	No	No
Water sanitation	Partial†	No	No
Access to internet and cell signal	Yes	Partial††	Partial††
Fish storage facilities	No	No	Yes
Ice production	No	No	Yes
Health center	Yes	No	No
Tourism infrastructure	Yes	No	No

†Water supply and sewage network available for approximately 50% of the population.
††Internet access at schools. Cell signal only through private antennas at local stores

4.2.2 Data collection

At SSF landing sites in each village data on weight landed per species (to the nearest 0.05 kg), type of fishing gear used[5], name of fishing ground visited, time to access fishing ground, total trip duration and crew size was collected three days per week between August 2016 and August 2017 (Herrón et al., 2019a). Sampled fishing trips were randomly selected within gear categories, aiming to record landings data proportionally to fishing effort per gear. However, this was not always possible due to the often simultaneous arrival of fishing boats and to the sample processing time (identification and weighing of species) which varied depending on the abundance and diversity of the catch. During the final months of field work (July-August 2017), the fishing grounds that had been reported by fishers during the sampling period were georeferenced using a Garmin GPS device with the guidance of two experienced fishers from each village.

---

[5] Manual collection of mangrove cockle (*Anadara tuberculosa*), another important type of SSF in the Colombian Pacific region, was undertaken in the study area but not included in this study.

Information on fishers' socio-economic characteristics and on their gear preferences was collected through a structured questionnaire (Annex III, Text S4.1) applied in Spanish. Interviewees were selected using a lottery system from a full list of each type of gear-user group within the respective village, aiming to interview at least 50% of active fishers from each village. Interviews were conducted with those fishers who gave their consent with a no response rate of 3.8%. First-sale prices of commercially important species were obtained once a month from three fish buyers in the city of Buenaventura, where many interviewed fishers sold their catch.

4.2.3 Data processing and analyses

Based on previous studies related to the economic and social drivers of fishers' choices (Davies et al., 2009; Glaser et al., 2012; McClanahan and Mangi, 2004; Naranjo-Madrigal et al., 2015; Torres-Guevara et al., 2016) interview data were assigned to indicators related to fishing operational aspects, fishers' preferences or perceptions, and then grouped according to four criteria: (a) dependence on SSF, (b) fishing skills and technical capacities, (c) fishing access and risks, and (d) economic well-being. The indicators used for each criterion are defined in Table 4.2. Data from grouped variables were used to create radar plots which allow comparison of the performance of the four criteria between the three villages and among users of different types of gears. Using the geo-referenced data of most common fishing grounds, minimum and maximum latitudinal and longitudinal points per fishing gear in each village were extracted and plotted as polygons to locate the main fishing areas used (Figure 4.1).

We estimated annual per capita fish consumption (*AFC*) for each village, using the following formula:

$$AFC = \big((c * af) \div p\big) * fd * 52$$

where c is the mean amount of fish (kg) left for consumption per fisher after one fishing trip based on interview data, *af* is the estimated number of full-time active fishers in the village, p is the estimated population living in the village (for the remote and the remote-equipped villages) or in fishers' neighbourhoods (for the near-urban village) based on Community Councils' census data, fd is the average number of fishing days per week based on interview data and 52 is the total number of weeks in one year. Table S4.1 (Annex III) shows the values used for each parameter in each of the three villages. This formula is based on field observations made by the first author where village households without active fishers also received benefits from the catch, via their family or community relations.

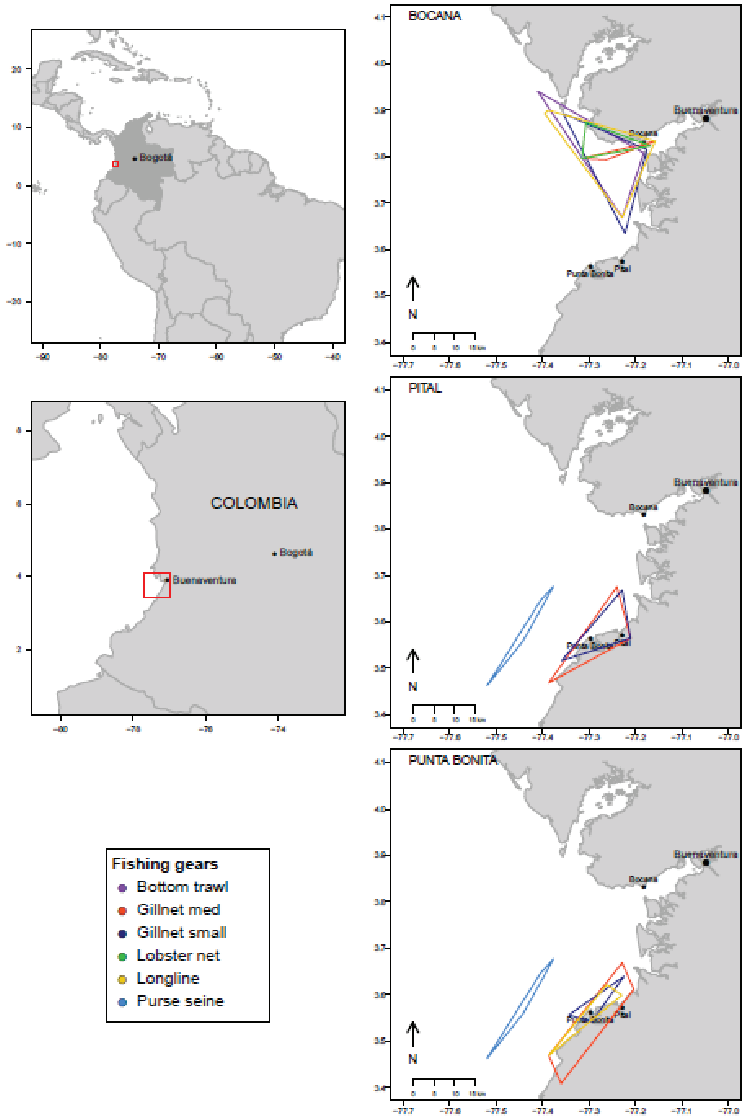


Figure 4.1. *Location of the study area on the Colombian Pacific coast (left panel) and location of fishing areas used by fishers with different fishing gears from the three coastal villages in this study (right panel): Bocana (near-urban village), Pital (remote village), and Punta Bonita (remote-equipped village).*

Annual mean price per species was estimated based on market prices obtained for commercially important species. For species for which we could not obtain market prices, values of similar species or related taxa (genus or family) were assigned. An exchange rate of 1 US$: $ 2,957.6 COP (Colombian pesos) was used, based on the average official conversion rate between August 2016 and August 2017[6]. Based on mean annual price, we assigned each species to one of four price categories that we defined based on adjoining price ranges, with arbitrarily chosen boundaries: a) Low: $\leq$ 1 US$/kg, (b) Medium: >1 and $\leq$ 2.5 US$/kg, (c) High: > 2.5 and $\leq$ 5 US$/kg, and (d) Very high: > 5 US$/kg. The

---

[6] www.banrep.gov.co/es/tasa-cambio-del-peso-colombiano-trm

proportions of landed weight per price category were then estimated for each gear type in each village.

Mean costs of purchase, monthly maintenance and daily fishing operation were estimated for each type of gear based on interview data. Based on landed weight per species collected for sampled fishing trips and on mean market price per species, we estimated mean catch-per-unit-effort - CPUE (kg/fishing day) and mean value of the catch-per-unit-effort - VPUE (US$/fishing day); the latter derived from multiplying CPUE times market price for each species. Landed weight per fish species[7] was used, regardless of state (e.g. gutted, beheaded or whole), as that is the relevant variable that determines market price and is therefore used in fisheries economic analyses (FAO, 2018b). Daily maintenance and purchase costs were estimated based on the information provided by interviewed fishers on the average durability of gear (one year for longlines, two years for bottom trawls and three years for gillnets) and on the average number of fishing days per month (23.4 days). Potential gear-related or village-related differences in CPUE and VPUE were analysed through linear models after log-transformation of the data. Estimates of monthly income for users of different gear types in each village were based on mean VPUE, percentage distribution of profit shares and daily costs of operation, gear maintenance and purchase.

---

[7] Species refers to the lowest taxonomic category assigned to the different fishes and invertebrates recorded in the catch, which was species, genus or family.

Table 4.2. *Criteria and indicators used to assess potential incentives or constraints for fishers in their daily fishing operations and their gear choices. Measure units and the scales used in radar plots (Figures 4.3, 4.4, 4.5 and 4.6) are also indicated. More details in section 4.2.1*

Criteria	**Indicator**	**Definition and scale used for radar plots**
Dependence on SSF	Sole income ind.	Proportion of fishers without other income than fishing (0-1).
	Sole income house	Proportion of fishers without additional household income other than fishing (0-1).
	Consumption	Amount of fish left for local consumption after a fishing trip (0-7 kg/day).
	Illiteracy	Proportion of fishers that did not attend high school (0-1).
	Household size	Number of people in household that depend on fisher´s income (0-7 people).
Fishing skills & technical capacities	Age	Average age of fishers (10-50 years).
	Experience	Average experience working as fisher (1-35 years).
	Other gears	Proportion of fishers that use more than one gear along the year (0-1).
	Boat size	Average weight capacity of the boat used for fishing (0.6-5 t)
	Engine power	Average engine power of the boat used for fishing (0-40 HP).
Fishing access and risks	Ground access	Average time needed to access fishing grounds (0-1.5 h).
	Market access	Average time needed to access most commonly used markets (0-2 h).
	Damage risks	Proportion of fishers perceiving gear damages as a risk (0-1).
	Weather risks	Proportion of fishers perceiving extreme weather conditions (i.e. wind, rain, currents) as a risk (0-1).
	Theft risks	Proportion of fishers perceiving theft as a risk (0-1).
Economic well-being	House own	Proportion of fishers who own the house they live in (0-1).
	Boat own	Proportion of fishers who own the boat used (0-1).
	Gear own	Proportion of fishers who own the gear used (0-1).
	Perception 1	Average perception of own fishing economic performance nowadays. Likert scale from 1 (very bad) to 5 (very good).
	Perception 2	Average perception of own economic performance nowadays compared to five years ago. Likert scale from 1 (much worse) to 5 (much better)

Due to the relatively small sample size of fishing trips and interviewed fishers using purse seines and lobster nets, these two gear types were excluded from gear-based analyses. Users of beach seines had different landing sites than the other gears so that catch and effort data from this type of fishery could not be collected. All figures and analyses were developed using the software R version 3.5.0 (R-Core-Team, 2018) and the packages: 'tidyverse' (Wickham, 2017), 'fmsb' (Nakazawa, 2018), 'emmeans' (Russell, 2018), "sp" (Bivand et al., 2013; Pebesma and Bivand, 2005), "sf" (Pebesma, 2018), "scales" (Wickham, 2018) , "rgdal" (Bivand et al., 2019), "maps" and "mapsdata" (Brownrigg, 2018a, b).

4.3 RESULTS

Catch and effort data from 1,083 fishing trips were recorded at landing sites located in the three selected coastal villages between August 2016 and August 2017, and 127 fishers were interviewed (Table S4.2, Annex III). Five main gear types were used in those fishing trips: bottom trawls, gillnets, lobster nets, bottom longlines and purse seines. Considering that there were large differences in target species between small-mesh gillnets (≤2.75") and medium-mesh gillnets (≥3"), we treat them here as two different type of gears: 'gillnet-small' and 'gillnet-med'. Table 4.3 summarizes the main characteristics of the sampled fishing gears and their most common target species (see also Herrón et al. (2019a)).

Users of all gears, except for purse seines, fished mainly in near-shore and shallow areas (1-5 km) while users of purse seines fished furthest from the shore (13-15 km) (Figure 4.1). Fishers using gillnets and longlines used relatively large fishing areas and there were spatial overlaps among users of different gears from the same village. Interviewed fishers did not mention conflicts related to within-villages overlap of fishing grounds but a small percentage (9%) complained about fishers from neighbouring villages increasingly using their fishing areas, which is not reflected in our results.

Figure 4.2 shows the distribution of main gear choice (the gear they use most of the year) among interviewed fishers and their choice of secondary gear (the gear they turn to as an alternative) in each village. Overall, the main choice of gear at the three villages were gillnets: 'gillnet-small' in the near-urban and remote village, and 'gillnet-med' in the remote-equipped village. When asked for the reasons behind their choice of main gear, most fishers (82.3%, n = 127) pointed out that their choice enabled them to catch their target species. The second most common reason for main gear choice for fishers using bottom trawls was profitability (35% of fishers, n = 23), while for users of longline (12%, n = 15) and 'gillnet-small' (13%, n= 52) it was the ease of using the gear. Overall, less than half of the fishers (43%, n = 127) used a secondary gear but with differences between villages. In the remote-equipped village, over twice the percentage of fishers (68%, n = 38) changed gear during the course of the year, compared to the remote (32%, n = 22) and near-urban villages (31%, n = 67). Purse seines, a seasonal gear used only during three to four months of the year (Table 4.3), was the first choice of secondary gear in the remote-equipped village while bottom trawls and lobster nets were used exclusively in the near-urban village (Figure 4.2), due to the vicinity of adequate fishing grounds for their target species (e.g. small-sized shrimps and lobsters). Only 9% of interviewed fishers (n = 127) mentioned a third choice of gear: either purse seines or beach seines.

Table 4.3. *Characteristics of gear types used at the three coastal villages of the central Colombian Pacific studied here. Modified from Herrón et al. (2019a).*

Gear type	Number hooks / Mesh size	Number of fishers	Main features	Main target species
Bottom trawl[†]	0.5 - 1"	2	Multifilament net of 8-10*2-3m dragged over the sea floor at shallow areas.	Pacific seabob (Spanish “camarón tití”; *Xiphopenaeus riveti),* titi shrimp (Spanish “camarón pomada”; *Protrachypene precipua),* Carabali shrimp (Spanish “camarón tigre”; *Rimapenaeus byrdi*)
Longline	4, 5, 7, 8, 9	2 - 3	Bottom longlines using 500 - 2,000 baited hooks.	Snappers *(Lutjanus* spp), groupers *(Epinephelus* spp), catfishes *(Bagre* spp, *Notarius* spp), sting-rays *(Hypanus* spp)
Gillnet-small[††]	≤ 2.75"	2	5 to 12 pieces of nylon net (each piece: 180*1.8m) used drifting or fixed to bottom.	Western white shrimp o “camarón blanco” (*Penaeus occidentalis*), Pacific sierra (*Scomberomorus sierra),* drums or croakers *(Cynoscion* spp, *Menticirrhus* spp., *Larimus* spp), snooks (*Centropomus* spp)
Gillnet-med	3" - 6"	2 - 3		Jacks *(Caranx* spp), snappers *(Lutjanus* spp), snooks *(Centropomus* spp), drums or croakers *(Cynoscion* spp, *Ophioscion* spp)
Lobster net	4"	1 - 2	2 to 6 pieces of multifilament net (each piece: 150-180*1.8m). Use bait.	Green spiny lobster (*Panulirus gracilis*)
Purse seine	2 - 2.5"	12 - 15	Small-scale encircling multifilament net, operated by 2 boats. Used only from January to March - April each year.	Tunas (*Thunnus albacares, Euthynnus lineatus*), Pacific sierra (*Scomberomorus sierra*).

[†] *Bottom trawls are currently banned by the national fisheries authority of Colombia (INCODER, 2004).*

[††] *Only gillnets of mesh-sizes ≥2.75" are allowed by the fisheries national fisheries authority in Colombia (INCODER, 2004).*

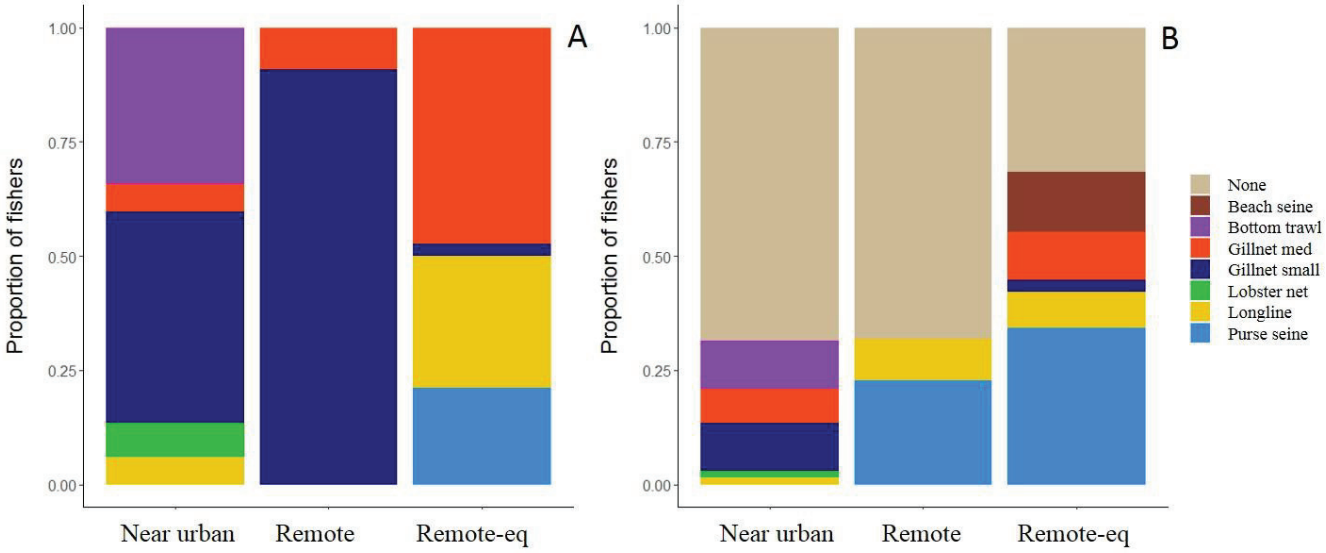


Figure 4.2. *Proportion of interviewed fishers using different fishing gears as main gear (A) or secondary gear (B) in three villages of the central Colombian Pacific coast. Remote-eq = remote-equipped.*

4.3.1 Dependence on SSF

Fishers in the near-urban village were more dependent on SSF than fishers in the remote and the remote-equipped villages, and this higher dependence is mostly associated to the lack of alternative income (Figure 4.3a). Fishers in the remote village had an average larger “household size” (5.5. ± 0.4 people) and left a higher amount of fish for local “consumption” after a daily fishing trip (6.8 ± 0.8 kg) than the other two villages (refer to Table 4.2 for indicators definitions). Annual fish consumption per capita (*AFC*) was estimated as 231.7 kg in the near-urban village, 216.1 kg in the remote village and 254.5 kg in the remote-equipped village. Overall mean of *AFC* for the three villages combined was 236.6 kg per capita.

When the indicators linked to the criterion of dependence on SSF were assessed for users of different gears (Figure 4.3b), bottom trawl users showed relatively high values for three of the five indicators, suggesting that a higher dependence on SSF compared to other gear users was driven mostly by the lack of alternative income. In contrast, users of ‘gillnet med’ appeared to be less dependent on SSF, with a higher proportion of fishers with alternative income sources at the individual (45%, n = 24) and at the household level (75%, n = 24). Users of longlines showed the highest levels of “illiteracy” (100% attended only primary school, n = 15) and also the lowest amount of fish left for local “consumption” (3.7 ± 0.3 kg/day).

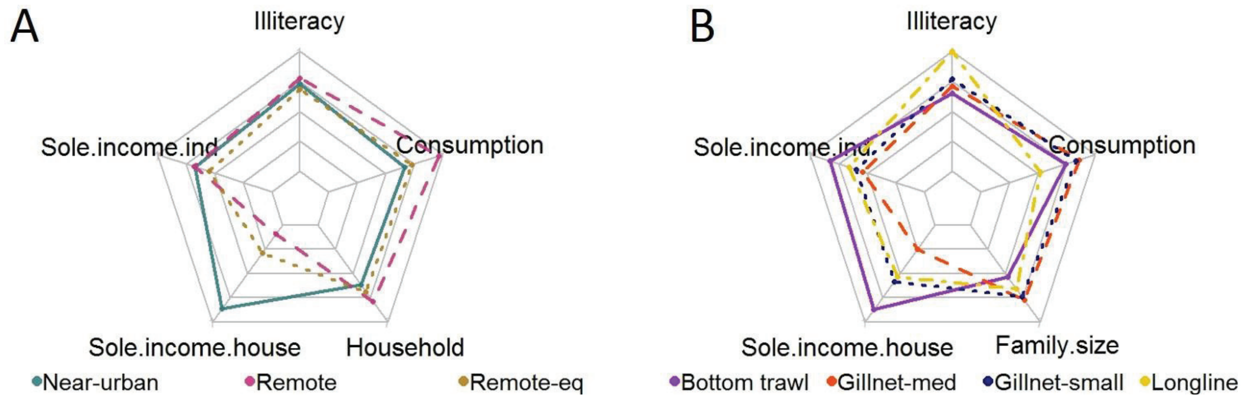


Figure 4.3. *Radar plots synthesizing indicators related to the criterion "Dependence on SSF" for fishers from different coastal villages (A) and for users of different types of fishing gear (B). Remote-eq = remote-equipped. Indicator's definitions and scales are included in Table 4.2.*

The activities mentioned by fishers as providing alternative income for themselves (i.e. individual alternative income) included tourism (only mentioned in the near-urban village), patching gillnets for other fishers, local business initiatives, logging (only mentioned in the remote village) and agriculture. Local businesses included stores of miscellaneous products, fuel stores, baking bread, woodwork, building or repairing houses and building or repairing boats.

Activities that provided alternative household income were performed by fishers' wives and involved mostly the collection and commercialization of mangrove cockles (*Anadara tuberculosa*), teaching at local schools and running small restaurants. Mangrove cockle collection, which involved children during off-school periods, was more important for fishers' households in the remote (100% of fishers, n = 22) and remote-equipped villages (71%, n = 38) than for those in the near-urban village (3%, n= 67).

4.3.2 Fishing skills and technical capacities

Most fishers were taught how to fish by their fathers or uncles during childhood or adolescence and on average at age 13.3 ± 0.4 (mean ± SE). Most fishers reported that they had first learnt to use cast nets and handlines but later on also learnt how to use "more modern" gears, like gillnets or bottom trawls. Overall, fishers from the remote and remote-equipped villages showed more skills and technical capacities than fishers from the near-urban village. This outcome was related to boat size, engine power and/or fishing experience (Figure 4.4a). Fishers in the remote village were older (42.6 ± 3.0 years old, mean ± SE), more experienced (25.3 ± 2.2 years) and used larger boats (3.3 ± 0.3 ton), while fishers from the remote-equipped village had more powerful engines (33.0 ± 5.6 horse power) and the majority used more than one gear (68.4%, n = 38).

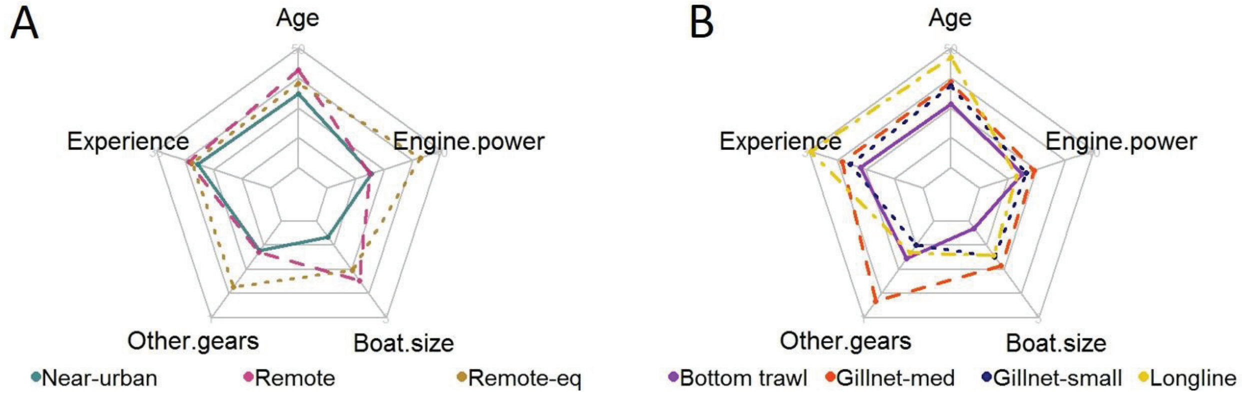


Figure 4.4. *Radar plots synthesizing indicators related to the criteria "Skills and technical capacities" estimated for fishers from different coastal villages (A) and for users of different fishing gears (B). Remote-eq = remote-equipped. Indicator's definitions and scales are included in Table 4.2.*

Bottom trawl' fishers were younger (31.1 ± 3.0 years old) and less experienced (19.7 ± 3.0 years) than other user groups. They also used the smallest boats (0.9 ± 0.1 ton) and relatively small engines (15.0 ± 0.0 horse power), suggesting that their fishing capacities were lower than those fishers using other gears (Figure 4.4b). In contrast, fishers using longlines were older (47.0 ± 3.1 years old) and more experienced (34.7 ± 3.2 years). A higher proportion of 'gillnet med' fishers (83.3%, n = 24) used different gears throughout the year than any other user group.

4.3.3 Fishing access and risks

Fishers from the remote-equipped village were most vulnerable in terms of risks and access issues (Figure 4.5a). Its more isolated geographical location implies a greater distance to reach the main markets (1.3 ± 0.1 hours) and fishing grounds (1.1 ± 0.02 hours) which may explain the higher proportion of fishers perceiving theft risks (44.7%, n = 38) (Figure 4.5a). In contrast, fishers from the near-urban village were closer to main markets in the port city (0.3 ± 0.01 hours) and also often able to sell part or all of their catch within the same village due to the demand from local hotels and restaurants that serve tourists.

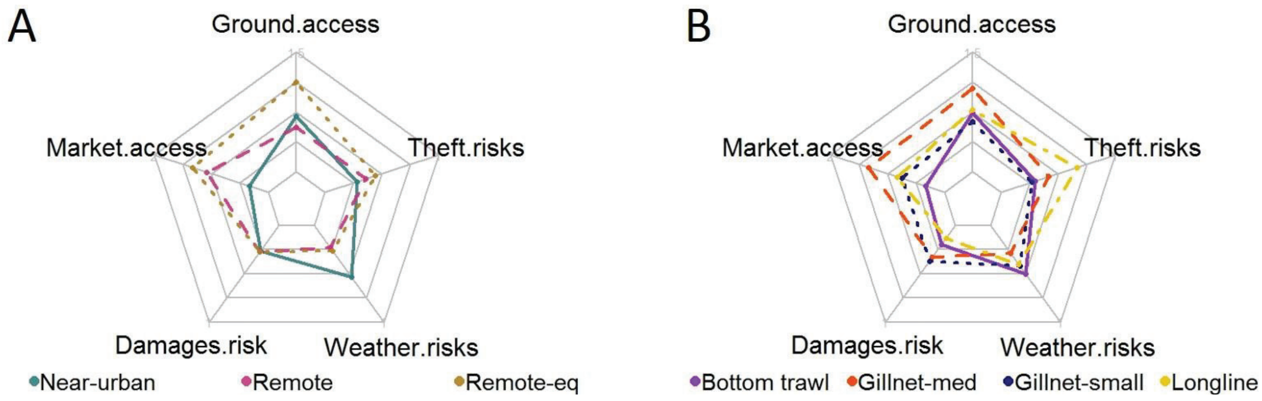


Figure 4.5. *Radar plots synthesizing indicators for "Fishing access and risks" estimated for fishers from different coastal villages (A) and different fishing gear users (B). Remote-eq = remote-equipped. Indicator's definitions and scales are included in Table 4.2.*

Users of bottom trawls showed the highest percentage of fishers (50%, n = 23) perceiving risks related to weather conditions (e.g. strong winds, strong current, torrential rain) but relatively a low percentage of bottom-trawl fishers perceived risks related to theft (30%) or gear-damage (20%) (Figure 4.5b). They were also closer to their fishing grounds (0.74 ± 0.02 hours) and to main markets (0.3 ± 0.01 hours), since bottom trawls in this sub-region are only used by fishers from the near-urban village (Figure 4.2). Gillnet users, both small and medium mesh sizes, perceived more risk of gear damages than other users (33%, n= 52 and 37%, n= 24 respectively), while longline fishers perceived more risks of engine thefts (67%, n = 15).

4.3.4 Economic well-being

Almost half of all interviewed fishers in all three villages (47%, n = 127) considered the current economic performance of fishing as "reasonable" even though catches and profits were highly variable. As one of the fishers described it: "*Sometimes we lose, sometimes we win*". Perception of improving or worsening economic performance in the past five years (Perception 2 in Table 4.2) varied greatly between villages and gear user types. Fishers that considered the current performance to be 'worse' or 'much worse' (33% and 14% respectively) argued that current catches were lower while fuel prices were higher than in the past. Others argued that more fishers were competing for the same resources and that dredging activities by port authorities were negatively impacting fishing grounds. Nevertheless, some fishers perceived their current economic performance as 'better' or 'much better' than in the past (19% and 6% respectively); these fishers stated that commercialization opportunities had improved or that they had been able to acquire new gears or engines. Some of the fishers that perceived the situation as 'the same' (28%)

mentioned that they were grateful to still be able to support and feed their families through fishing.

Fishers from the remote village showed higher economic well-being than fishers from the other two villages, as indicated by a higher percentage interviewees owning a house (82%), fishing gear (55%) and boat (45%, n = 22), and also by their more positive perception of their economic performance in SSF (as defined in Table 4.2) (Figure 4.6a). In the remote-equipped village fewer fishers owned boat or gear (29%, n = 38 in both cases) and in the near-urban village fewer fishers owned their house (51%, n = 67).

Among users of different gears, bottom trawlers exhibited less favourable economic conditions than the other groups of gear users, given that they had the lowest percentage of house owners (48%) and a relatively low percentage of boat and gear owners (39%, n = 23 in both cases) (Figure 4.6b). Nevertheless, most users of bottom trawls had the most positive perception of their current economic performance (3.5 ± 0.1, in a scale from 1 to 5) when compared to all other gear-user groups. In contrast, longline fishers had the most negative perception of current (2.8 ± 0.2) and progressive economic performance (2.3 ± 0.3).

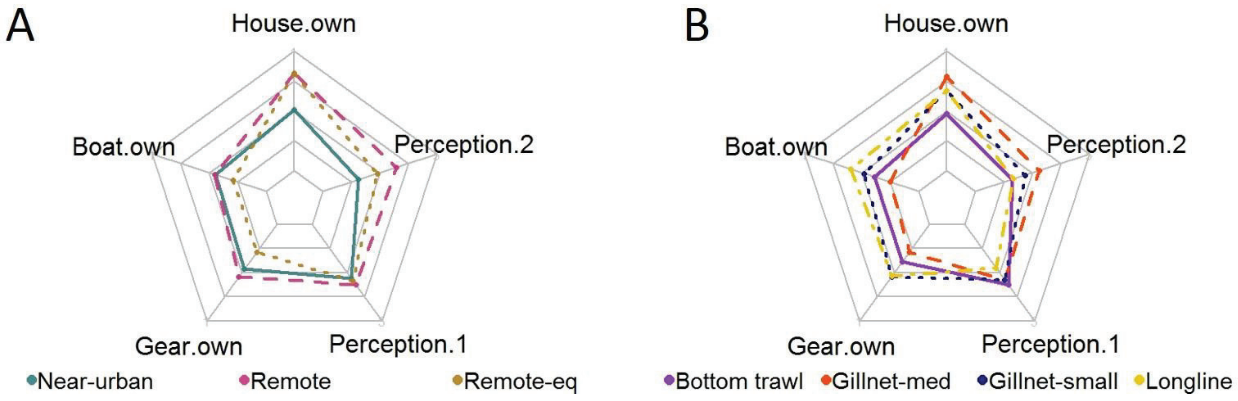


Figure 4.6. *Radar plots synthesizing indicators for "Economic well-being" estimated for fishers from different coastal villages (A) and different gear users (B). Remote-eq = remote-equipped. Indicator's definitions and scales are included in Table 4.2.*

4.3.5 Catch and profitability

Mean catch-per-unit-effort, CPUE (kg/day) calculated per gear type in each village showed that CPUE was highest for users of longlines in the near-urban village and lowest for fishers using 'gillnet–small' in the remote village (Figure 4.7a). Annual mean CPUE of longlines in the near-urban village was significantly higher than mean CPUE of the other gears used in that village and also higher than CPUE of longlines in the remote village ($p < 0.001$ in all four cases). There were also differences among villages in the mean CPUE of 'gillnet-small': this was lower in the remote village than in the other two villages. The difference between the remote and the near-urban village was statistically significant ($p < 0.001$).

Mean value of the catch-per-unit-effort - VPUE (US$/day) was highest for bottom trawls and lowest for 'gillnet-small' in the remote village (Figure 4.7b). Within the near-urban village, the difference between VPUE of bottom trawls and that of longlines and 'gillnet med' was statistically significant ($p< 0.05$ and $p< 0.01$, respectively). VPUE by gear type varied also among villages, but the pattern was different than that for CPUE (Figure 4.7). 'Gillnet-small' from the near-urban village had a higher mean VPUE than 'gillnet-small' from the other two villages, but the difference was only significant when compared to the remote village ($p < 0.01$). In the case of longlines, mean VPUE in the near-urban village was also slightly higher than in the remote-equipped village, but the difference was not statistically significant.

The contrasting patterns of CPUE and VPUE between villages and gears relates to different price categories of the species in the catch. Even though the main target species of all gears generally had medium, high or very high value in the market, the composition of price categories of the resulting catch varied between gears and villages (Figure 4.8). Longlines in the near-urban village predominantly caught species with low market value (e.g. stingrays, catfishes) while the same gear in the remote village caught mostly species of medium market value (e.g. snappers, groupers). The catch of gillnets was mainly composed of species of medium market value (e.g. jacks, snooks, drums) except for 'gillnet-small' in the remote village where high and very high value species (e.g. White Shrimp, Pacific Sierra) were more frequent.

Using 'gillnet-small' required the highest initial investment and the highest costs of monthly gear maintenance among all the gears (Table 4.4), followed by 'gillnet-med', longlines and bottom trawls. According to field observations made by the first author, gillnets were prone to breaking from floating logs or trash, to entangling with bottom rocks and to suffering accidents with boat propellers. In the case of longlines, individual hooks can be lost while fishing and entire sections of the longline can get accidentally cut by boat propellers or strong currents. Purchase prices for bottom trawls did not show large variations among respondent fishers while those of longlines and gillnets were highly variable (Table 4.4), which is probably related to different total sizes of the gear (i.e. meters of net or number of hooks used) or to specific characteristics of the gear such as mesh or hook size and nylon resistance. In contrast to their low purchase and maintenance costs, bottom trawls had the highest mean cost for a one-day fishing trip. This is related to the relatively high fuel consumption when operating dragging gears (Parker and Tyedmers, 2015). The mean cost of a one-day fishing trip for users of gillnets and longlines varied between villages, with fishers from the remote village spending more per fishing trip than fishers from the other two villages (Table 4.4).

Table 4.4. *Estimated mean costs (US$) ± standard error (SE) of gear purchase and maintenance and of daily fishing trips based on interviews made to fishers at three selected coastal villages of the Colombian Pacific coast.*

Costs	**Gear type**	**Coastal village**		
		Near-urban	**Remote**	**Remote-equipped**
Purchase	Bottom trawl	183.02 ± 7.14		
	Gillnet-med	684.82 ± 279.00	2,570.17 ± 135.27	1,145.82 ± 197.75
	Gillnet-small	1,504.90 ± 188.00	2,120.93 ± 154.87	2,739.26 ± 0.00
	Longline	220.94 ± 109.50		275.62 ± 22.27
Monthly mantainence	Bottom trawl	11.39 ± 1.69		
	Gillnet-med	50.73 ± 16.91	96.38 ± 16.74	90.18 ± 51.92
	Gillnet-small	80.12 ± 8.87	89.24 ± 25.78	30.44 ± 0.00
	Longline	11.02 ± 0.49		30.81 ± 9.63
One-day fishing trip	Bottom trawl	36.32 ± 1.77		
	Gillnet-med	31.65 ± 3.63	29.76 ± 9.47	53.33 ± 7.40
	Gillnet-small	24.26 ± 2.24	29.39 ± 3.41	42.27 ± 0.00
	Longline	25.03 ± 1.89		34.83 ± 0.98

Interviewed fishers reported that 50% of the profit from fishing day-trips belonged to the owner of the gear and boat, while the remaining 50% was equally distributed among the fishing labourers participating in the trip. Preliminary estimates of monthly income per fisher (gear-owners and non-owners), according to their village and main choice of gear, suggests that bottom trawls are the most profitable type of gear, while the profitability of gillnets (small or medium mesh sized) and longlines varied among villages

(Table 4.5). Estimates are based on a two-person crew which was the most common crew observed during the sampling period.

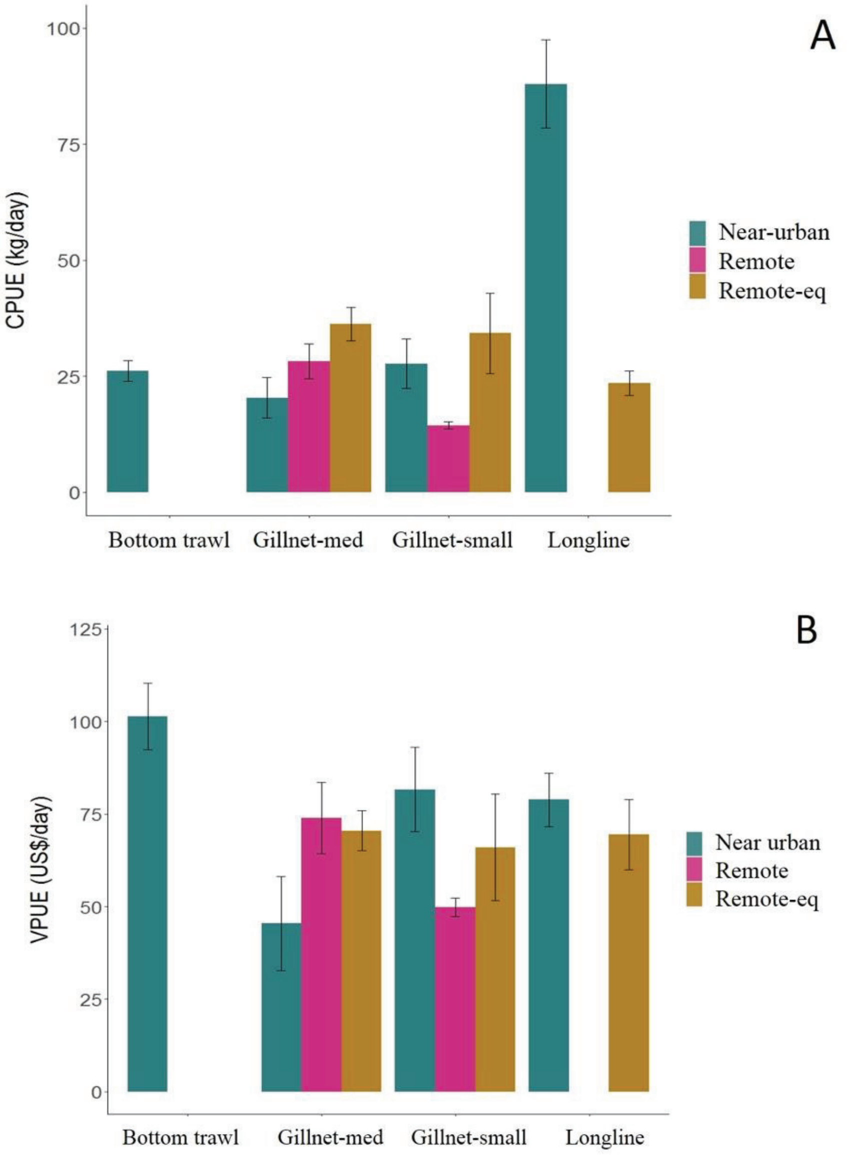


Figure 4.7. *Mean catch-per-unit-effort (CPUE) in kg/day (A) and mean value-per-effort (VPUE) in US$/day of main fishing gears in three coastal villages of the central Colombian Pacific coast (landings data collected between August 2016 and August 2017). Remote-eq = remote-equipped*

Table 4.5. *Estimated mean monthly income (US$) derived from small-scale fisheries in the study region based on: (a) mean value of the catch-per-unit-effort (VPUE) derived from landings data, (b) mean daily costs of gear investment, maintenance and fishing trips derived from interviews and (c) distribution of gross profits (VPUE minus daily operational costs) between owner and non-owner of gears for an usual two-person-crew fishing trip (75% and 25% respectively). As described in section 3.5, gear owners assume maintenance and purchase costs, while non-owners assume only their share of daily operational costs.*

Gear type	**Fisher type**	**Coastal village**		
		Near-urban	**Remote**	**Remote-equipped**
Bottom trawl	gear owner	1,009.74		
	non-owner	342.33		
Gillnet-med	gear owner	164.86	653.04	184.33
	non-owner	80.95	258.89	100.59
Gillnet-small	gear owner	888.72	231.02	347.52
	non-owner	336.17	119.98	139.21
Longline	gear owner	918.96		560.29
	non-owner	315.70		202.66

4.4 DISCUSSION

Our findings highlight the vast importance of SSF for the livelihoods and food security of coastal inhabitants of the Colombian Pacific coast. Fish per capita consumption in the studied villages is very high, something that is obscured in the national statistics that position Colombia as a country with very low fish consumption rate (FAO, 2015b), due to the reduced fish consumption in the main cities located far from the sea. Fishers' gear choices are influenced by the value of target species and potential profits but also by access to markets, access to fishing grounds and socio-economic local conditions. Overall, the high market demand for shrimp species, coupled with accessible fishing grounds and the easiness to operate the gears ('gillnet-small' and bottom trawls), drive the majority of fishers of the central Pacific sub-region to use gillnets with small mesh size and bottom trawls. Users of those gears were less likely to make seasonal changes in gear use when compared to other fishers. Highly variable CPUE and VPUE, coupled with relatively high entry and operational fishing costs, result in an overall low economic income for small-scale fishers, which increases the already vulnerable socio-economic status of these people (Benítez and Flores-Nava, 2019; DNP, 2019).

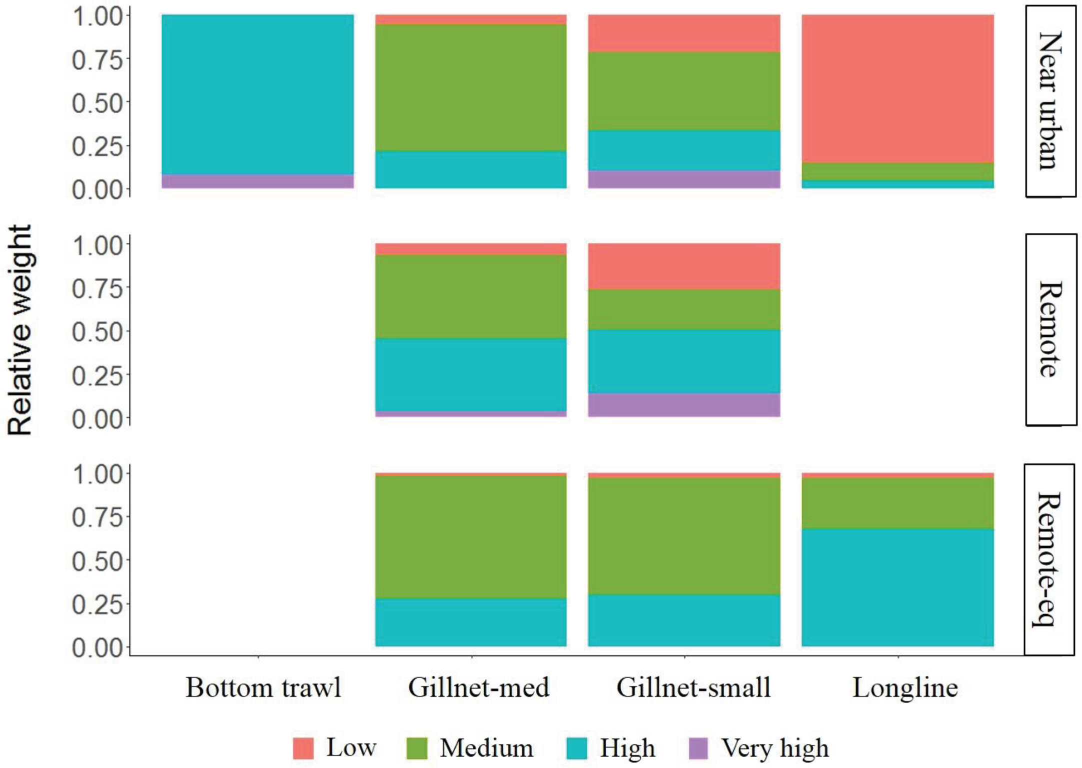


Figure 4.8. *Proportion of the catch (landed weight) in four price categories: Low: ≤ 1 US$/kg, (b) Medium: >1 and ≤ 2.5 US$/kg, (c) High: > 2.5 and ≤ 5 US$/kg, and (d) Very high: > 5 US$/kg for different fishing gears commonly used at three villages of the central Pacific coast of Colombia. Remote-eq = remote-equipped.*

4.4.1 SSF as a major contributor to local nutrition and livelihoods

The relevance of SSF as a food source for Afro-descendant coastal communities of the central Colombian Pacific is best illustrated when the national average of *AFC* (annual fish consumption per capita) of 4.7 kg (FAO, 2015b) is compared to the overall mean of 236.6 kg *AFC* estimated for the coastal villages studied here. Our *AFC* values are very similar to recent estimates made for the entire Colombian Pacific coast (250 to 291 kg) (Benítez and Flores-Nava, 2019) but higher than estimates from a major South American fishing country like Chile where an *AFC* of 104-156 kg for fisheries-dependent families was estimated by the same authors (Benítez and Flores-Nava, 2019). The higher *AFC* in the Colombian Pacific coast when compared to Chile could be due to the relative isolation of most villages on the Colombian coast that limits access to animal protein from the interior of the country. Our estimated *AFC* is also higher than the average (74 kg) and the maximum values (164 kg) reported in a global assessment of fish consumption in coastal indigenous communities (Cisneros-Montemayor et al., 2016). These differences could be generated by a lack of local data on fish consumption for

84% by coastal indigenous groups in the global assessment and the consequent need to make extrapolations, as stated by the authors of that study (Cisneros-Montemayor et al., 2016). Nevertheless, the *AFC* we report in this study could also be overestimated because a correction factor could be applied to the variable fishing days (*fd*) used in the formula to calculate *AFC* (see section 2.2) to account for days of bad weather, sickness or other reasons for which the fishers cannot go out to fish every planned day of the week. Further studies that include detailed records of daily fishing activity and the precise amount of fish left for consumption after a sample of fishing trips (i.e. not derived only from interviews), would refine estimates of *AFC* in rural villages of the Colombian Pacific coast.

Our results suggest SSF to be a more essential source of income for fishers in the near-urban village than for those in the two remote villages (Figure 4.3a). This outcome is related to lack of alternative income and more marginalized living conditions for fishers in the near-urban village than other inhabitants of the same village. For example, fishers' neighbourhood in the near-urban village do not share the housing conditions found in the touristic and central areas, but rather resemble the housing conditions seen at the remote and remote-equipped villages, e.g. houses on wooden stilts without water sanitation systems (first author, personal observations). Most of the fishers interviewed in the near-urban village also reported that they were not born in that village but migrated from other rural villages along the Colombian Pacific coast. It is likely that these migrations were linked to the armed conflict in Colombia during past decades (Ibáñez and Vélez, 2008) and that migrating households had resort to SSF as their main livelihood, probably as a conscious choice of specialisation in fisheries in near-urban contexts with more demand for their products. In contrast, fishers from the two remote villages – equipped and not equipped – had more diverse livelihoods and sources of income (Figure 4.3b), probably as a result of a longer history of inhabiting those territories. Such income source diversity in the remote and remote-equipped villages reduce household vulnerability. Manual collection of mangrove cockles (a type of SSF performed predominantly by women and not assessed in this study) provided important alternative income in fishers' households in the two remote villages, as it is the case in many coastal rural areas along the Colombian Pacific coast (Espinosa et al., 2010). Both the remote and the remote-equipped villages have larger mangrove forests in their surrounding areas than the near-urban village. Mangroves around the near-urban village, due to its proximity to the main city port, had suffered more from human interventions than more rural mangrove areas (INVEMAR-CVC, 2007; Mejía-Rentería et al., 2018). A larger mangrove area could allow a higher CPUE and profit levels for mangrove cockle collectors from the remote and remote-equipped villages compared to that obtained by cockle collectors in the mangroves surrounding the near-urban village (INVEMAR, 2010).

Monthly income per fisher showed large differences among gear users and villages, ranging from US$ 81 to US$ 342 per month for fishers that do not own fishing gears (Table 4.5), with many non-owner fishers earning less than the national minimum wage of US$ 249 in 2017[8]. These results are similar to previous estimated monthly income for fishers of the Colombian Pacific coast that ranged between US$200 and 250 (Benítez and Flores-Nava, 2019) and technical reports that indicated that more than half of the people involved in aquaculture and fisheries production in the country earned less than a minimum wage (OECD, 2016). Our results imply that a non-owner fisher was earning between US$ 3.5 and US$ 14.6 per fishing day, resembling daily income of small-scale fishers in other tropical coastal areas, such as US$ 9.5 per day in the Philippines (Anticamara and Go, 2016) and US$5.3 per day in India (Willmann and Kelleher, 2009). In both cases, the daily income for a small-scale fisher are near the minimum wage level established in each of the countries (US$ 4.6 – 10.16 and US$ 2.4 – 11.31, respectively[9])

Estimated monthly income for fishers who owned fishing gears (ranging from 164.8 to 1009.7 US$, Table 4.5) are likely overestimations since our calculations assumed the owner to take part in all fishing trips during the year (which is not always the case) and did not take into account potential investment and maintenance of boat or engines. Costs related to boat and engine purchases were also left out of our analyses because they were often bought as family investments that involved more than one household and were used for purposes other than fishing (e.g. transport to city).

4.4.2 Socio-economic drivers of fishing gear choice

The estuarine and mangrove dominated coastline surrounded by shallow soft-bottom habitats in the central and southern Colombian Pacific are the preferred habitats for penaeid shrimp species (Castellanos-Galindo and Zapata, 2019; Primavera, 1998). Considering the high market value and demand of shrimp, many fishers in the coastal villages studied here chose ‘gillnet-small’ and bottom trawls as their primary gear to target these shrimp species (Figure 4.2). The importance of habitat for fishing gear choice is confirmed when this central sub-region is compared to the northern, rocky-dominated coast of the Colombian Pacific where, due to the absence of shallow soft bottom habitats, there is no artisanal shrimp fleet (Castellanos-Galindo and Zapata, 2019; Herrón et al., 2019a).

Even though artisanal bottom trawls were banned in the Colombian Pacific by the Colombian fishing authority (INCODER, 2004), their comparatively lower investment and maintenance costs (Table 4.4), higher profitability (Table 4.5) and poor enforcement of the prohibition, make them an appealing gear choice

---

[8] www.salariominimocolombia.net/2017

[9] en.wikipedia.org/wiki/List_of_minimum_wages_by_country

for young, unexperienced fishers with relatively low material wealth (i.e. non-owners of house, boat or gears). A similar situation was observed in southern villages of the Colombian Pacific coast where young fishers with little fishing experience are normally operating bottom trawls (third author, personal observations). It also resembles the situation of beach seines in the coast of Kenya where this banned fishing gear continues to be used by young unexperienced fishers because of the low initial investment, low individual economic responsibility and low risks to the crew, since the gear is operated from shore (Mangi et al., 2007; Obura, 2001; Tuda et al., 2016). Fishers in the near-urban village in our study, where all bottom trawl users lived, are closer to the main markets and closer to fishing grounds rich in their target species (i.e. small-sized shrimps; Figure 4.1) than the other two villages. Also, users of bottom trawls perceived a lower risk of theft and gear damage than other gear user groups (Figure 4.5b), all of which add up as additional incentives for using bottom trawls despite their illegal status.

Users of longlines, who were on average older and more experienced than other gear users, had the highest mean CPUE in the near-urban village (Figure 4.7a). However, such large catch was not reflected in a high mean VPUE (Figure 4.7b). This contrast is attributable to the comparatively high catch contributions of species with low market value (85.1%, Figure 4.8), mainly stingrays of the genus *Hypanus* and catfishes of the family Ariidae (Herrón et al., 2019a). Longlines are considered a more traditional type of gear which requires the prior catching of bait. In addition, a specific set of skills is required (e.g. knowing how to deploy and retrieve 1,000 to 3,000 hooks manually, manipulating live stingrays and eels aboard), with danger of serious injuries for unexperienced fishers. These aspects make entry of new fishers difficult, with one longline fisher commenting on the difficulties of finding a suitable crew member replacing his usual fishing partner in case of sickness (fisher #74, August 2017). It is likely that longline users value the adventure and risky side of SSF more than a high income (Pollnac and Poggie, 2008), though other factors, beyond those assessed here, might also influence the preferential behaviour of longline fishers.

Gillnets are among the easiest gear types to use, according to interviewed fishers. Users of 'gillnet-small' target the most valuable species in the market: the white shrimp (*Penaeus occidentalis*), whereas 'gillnet-med' target several fish species mostly of intermediate market value (Figure 4.8). The disadvantage of their relatively high investment costs (Table 4.4) is often compensated by government or non-government gear subsidies distributed in many of these fishing villages (MADR, 2015; USAID, 2015). Despite the high market value of white shrimp (annual mean: US$ 13.8/kg), VPUE of 'gillnet-small' varied greatly between our three study villages, probably due to differences in species abundance in different fishing grounds and to fishing effort variables not recorded in this study (e.g. number of boats using the same fishing grounds, number of net pieces used). Further studies that include seasonal analyses of CPUE derived from 'gillnet-small' at different fishing grounds, coupled with a more precise characterization of fishing effort, would improve understanding of the factors influencing the highly variable CPUE and related VPUE for this type of gear.

4.4.3 Leverage points for SSF management

Leverage points refer to places in a complex systems where relatively small changes may lead to drastic changes in the entire system (*sensu* Meadows (1999)). We adopt here the hierarchy of leverage points proposed by Abson et al. (2017) who defined as "shallow" leverage points those interventions that are "easy to implement yet bring about little change to the overall functioning of the system" and "deep" leverage points those that are "more difficult to alter but potentially result in transformational change". A range of leverage points for SSF management and sustainability can be deducted from this study.

A first and relatively "shallow" leverage point (Abson et al., 2017) is that of providing direct financial compensations to fishers that are willing to stop using illegal gears to fishers that are impacted by the seasonal shrimp-fishing closures (i.e. bottom trawls and gillnets of mesh size < 2.75", INCODER (2004). Such financial compensation would require a full enforcement of the regulations in place (e.g. fishers using illegal gears are prevented from landing their catch, collecting fines from fishers encountered with illegal fishing gear). A full enforcement of the ban on bottom trawls in the Colombian Pacific could have positive ecological impacts associated to, for example, the reduction of its high percentage of by-catch (37%) which includes juveniles or small-sized fish and invertebrate of several non-target species (Herrón et al., 2019a). In similar contexts of tropical multi-gear SSF, enforcing bans of unselective dragnets, a type of beach seines, have shown positive ecological and economic effects, with increased CPUE and profits per fisher (McClanahan, 2010; Rehren et al., 2018). However, the frequent lack of financial and enforcement capacity of fisheries authorities in the global South and the high potential for fraud and political corruption - as observed in a similar context of shrimp SSF on the coast of Brazil (Musiello-Fernandes et al., 2017) - renders this management intervention (i.e. financial compensation coupled with full enforcement) infeasible for our study region. Nevertheless, compensation schemes that involve the development of locally acceptable and feasible alternative livelihoods that relate to local lifestyles and cultural choices might be viable and should be explored (Daw et al., 2012).

A less "shallow" leverage point (Abson et al., 2017) relates to the redistribution of fishing effort invested in illegal gear types into legal gears (Bacalso et al., 2016). However, such management intervention demands detailed assessment of potential ecological and social impacts in these villages, since the redistribution could lead to overfishing of other target species and/or to social conflicts due to an increased number of boats using the same fishing grounds (Rehren et al., 2018). Considering that the bottom trawl fleet employs mainly young fishers with relatively little alternative income, alternatives to render this fleet more ecologically sustainable (e.g. reducing bycatch and reducing damage to benthic habitats) could also be explored. Such potential solutions, which involve changes in the net design, the ground gears or the spreading mechanisms, are already being applied in many penaeid-trawl fisheries (see review in McHugh et al. (2017)). Exploration of these alternatives would require that fishers, fisheries authorities and other stakeholders join efforts and financial resources for pioneering experiments in order to assess potential changes.

Finally, a potentially “deeper” leverage point (Abson et al., 2017) is to promote stronger local governance structures that help integrate the local ecological knowledge (LEK) about the temporal and spatial dynamics of resource abundance and environmental variations, which can influence spatially different choices of fishing gears and fishing grounds (Herrón et al., 2019a; Purcell et al., 2018). Particularly in data-limited SSF, the fishers, as direct users of the resources and keepers of historic environmental knowledge, could provide essential information for fisheries management (Kolding et al., 2014; Sánchez Jiménez et al., 2019) and thus play an active role in the design of ecologically sound management measures that also consider the socio-economic and cultural local contexts (Cinner et al., 2011; Kittinger et al., 2013). Moreover, future research on the social processes related to SSF need to move beyond the economic focus and better include behavioral aspects that influence resource use patterns and thus the ways management or conservation goals are best pursued (Aswani et al., 2018).

4.4.4 Conclusions

SSF are essential for nutrition, employment and income for rural coastal communities in the Colombian Pacific, as in many other tropical countries of the global South (Béné et al., 2007). Ensuring their sustainability must be therefore a priority for governance at the local, national and international level. The methodological approach employed here offers a new approach to move towards more holistic assessment and management of SSF as complex social-ecological systems with important functions for both conservation and human well-being.

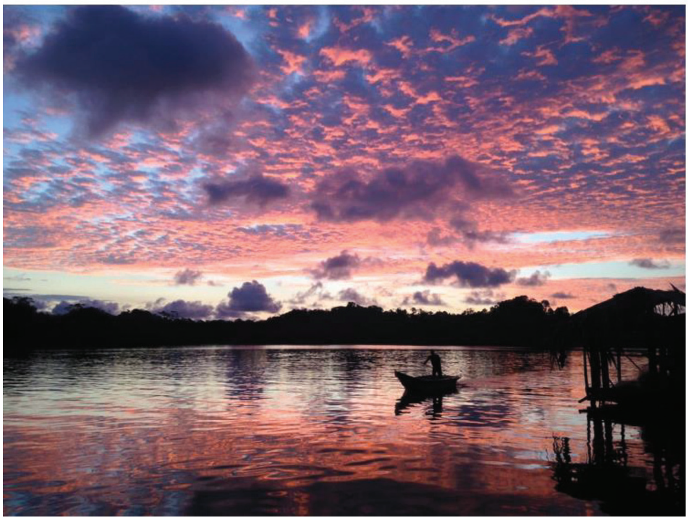
The strikingly high annual fish consumption found in our study villages (237 kg*pc*year^{-1}) emphasizes the importance of SSF as a protein source especially for rural coastal communities of the Colombian Pacific. Besides food provision, small-scale fishers’ households are also dependent on the income provided by the commercialization of the catch derived from SSF. However, estimated monthly incomes are relatively low and widely variable depending on the type of fishing gear used, the location of fishing grounds and on seasonal dynamics beyond the scope of this paper. Fishers' gear choices are influenced by the value of target species and potential profits but also by access to markets, access to fishing grounds and by local socio-economic conditions, e.g. lack of alternative income, low fishing experience. Management measures aiming for SSF sustainability range from relatively "shallow" leverage points (*sensu* Abson et al., 2017), such as economic compensation to fishers or redistribution of fishing effort among gears, to "deeper" leverage points, such as facilitating fishers' local organization and empowerment towards increasing their participation in knowledge production, interpretation and in the co-design of management and implementation. Addressing deeper leverage points is most likely bring about the changes needed to achieve a holistic form of sustainability in human-nature relations in the small-scale fisheries of these coastal social-ecological systems.

ACKNOWLEDGMENTS

We thank the local communities and fishers from the coastal villages of the Community Councils of Bazán-Bocana and Cajambre, municipality of Buenaventura, in the Colombian Pacific coast for allowing and supporting data collection at different landing sites between 2016 and 2017. PH received financial support from CEMarin (Call # 5 of 2015) and from Rufford Foundation (RSG 19522-1).

CHAPTER 5

General Discussion



5.1 MAIN FINDINGS

Using the small-scale fisheries (SSF) of the central Colombian Pacific as a case study area of tropical marine SSF this dissertation took elements from the traditional single-species fisheries management approach (Sparre and Venema, 1998), the ecosystem-based-fisheries-management (EBFM) approach (Pikitch et al., 2004) and the social-ecological system approach (Ostrom, 2009) to carry out a threefold assessmente of: a) the stock condition of main resources under exploitation (i.e. target species) (Chapter 2), b) the potential impacts of SSF to the biological communities and ecosystems in which the target species are embedded (Chapter 3), and (c) the socio-economic drivers of gear choices made by small-scale fishers (Chapter 4).

The key findings were: (a) the three main target species of the Colombian Pacific SSF showed signs of over-exploitation but, given the high uncertainties surrounding the stock diagnosis, more emphasis should be given to improve the data collection schemes in place; (b) the potential ecological impacts of SSF vary greatly with the type of habitats in the fishing areas, the type of fishing gear used and the interaction between those two factors; (c) fishers' choice of gear are mainly driven by profit maximization and expected catch composition. However, access to fishing grounds, access to markets, alternative income and risk aversion also influence gear choices; and d) coastal villagers are extremely dependent on SSF for income and food provision making them vulnerable to environemental and market dynamics. A synthesis of the main findings related to each research question is given hereafter (sections *5.1.1* to *5.1.3*), followed by an analysis of the implications of those findings for future assessment and management of the SSF in the Colombian Pacific (section *5.1.4*). Section *5.2* presents the strengths and limitations of the methodological approach used in this thesis, identifying areas where further research is needed. Finally, section *5.3* provides an intepretation of the main findings of the thesis considering a regional and global context, finishing with a summary of recommendations derived from this thesis aiming at facilitating the required transition towards more holistic assessments and management of tropical SSF.

5.1.1 Stock condition of main target species

In Chapter 2, the research question addressed was: "what is the stock condition of the three most abundant species landed by the SSF of the Colombian Pacific?" The species assessed were: Pacific Sierra *Scomberomorus sierra* (Jordan and Starks, 1895), Spotted Rose Snapper *Lutjanus guttatus* (Steindachner, 1869) and Pacific Bearded Brotula *Brotula clarkae* (Hubbs, 1944), which together contribute to more than 30% of the total biomass landed by the SSF in the Colombian Pacific (De la Hoz and Manjarrés-Martínez, 2016). Despite limitations of the lenght-frequency-catch-data (LFCD) used for analyses, our results confirmed previous diagnosis carried out by the fisheries authority in Colombia (Barreto and Borda, 2008; Barreto et al., 2010; Puentes et al., 2014a), indicating that the three species were either fully exploited or over-exploited. The resulting diagnosis also resembled stock assessments for the same target species carried out in other countries of the Tropical Eastern Pacific that may be sharing some stocks (Amezcua et al., 2006; Bystrom et al., 2017; Espino-Barr et al., 2012).

However, the major relevance of the findings goes beyond providing an updated diagnosis of the stock condition of target species and lies in unveiling the high uncertainties underlying the estimation of growth and mortality parameters, that are the basis of most length-based assessments methods (Maunder and Piner, 2014; Sparre and Venema, 1998). Such uncertainties were revealed through the novel methodological approach used here which consisted of incorporating a bootstrapping ELEFAN (Electronic Length Frequency Analysis) routine, by means of the recently developed TropFishR package (Mildenberger et al., 2017). The observed uncertainties had to do mostly with limitations in the sampling scheme that is currently in place and with fisheries selectivity, which can be imposed by the type of fishing gear used, but can also be associated to spatial and/or temporal patterns of abundance of specific size-classes (Maunder et al., 2014; Sampson, 2014). Thus, it is likely that not only the diagnosis of stock condition included in this study but also previous stock assessments carried out in Colombia based on the same type of LFCD included similar biases. There is thus an urgent need of making adjustments to the fisheries data collection scheme used in Colombia, of consolidating longer time series data using the same methodological approach and of acquiring data on fisheries selectivity.

By conducting parallel stock assessments for each of the selected target species using two different data sources (government and non-government derived), it was shown that different sampling schemes and different distribution of fishing effort per gear can result in very different structures of LFCD and consequently in different values of growth and mortality parameters, which in turn lead to different diagnosis of stock condition (Herrón et al., 2018). A stratified sampling design based on fishing effort (McCluskey and Lewison, 2008) and reconstruction of LFCD based on knowledge of fisheries selectivity is thus essential to obtain more reliable estimates of stock condition in Colombia and in similar SSF settings (Maunder et al., 2014; Punt et al., 2014).

The application of the relatively simple length-based-indicators (LBI) proposed by Froese (2004), combined with the decision tree developed by Cope and Punt (2009), show some appealing characteristics to managers of data-limited SSF, namely: (a) not relying on growth and mortality estimates that may exhibit large uncertainties, (b) taking into account the general pattern of fisheries selectivity and (c) being much easier to calculate and interpret than traditional stock assessment parameters. However, the adoption of LBI does not replace a detailed stock assessment which allows to estimate the adequate level of fishing effort (e.g. Sparre and Venema (1998)) to provide direct input for the design of input control management measures. Additionally, LBI require reliable estimates of length at maturity (*Lm*), a parameter that shows intraspecific variations associated to environmental or latitudinal factors, genotype, stock size and/or historic fishing pressure (Cardinale and Modin, 1999; Heibo et al., 2005; Rowell, 1993). As shown in Chapter 2, *Lm* estimates for the target species asssessed varied among different research studies. Particularly, for *Brotula clarkae* estimated values of *Lm* varied from 62.3 cm (Acevedo et al. (2007), based on catch data collected between 1994 and 1996) to 75.4 cm (Puentes et al. (2014a), based on catch data collected in 2013). Therefore, continuos research on reproductive and biological processes of main target species is required for reliable outcomes when using LBI (Froese, 2004). Finally, management decisions derived from LBI should ideally be based on temporal trends of the indicators and not on snapshot assessments (Froese, 2004).

5.1.2 Potential ecological impacts of SSF

The research questions addressed in Chapter 3 were: “what can catch composition tell us about the potential ecological impacts of SSF in the Colombian Pacific? And does the composition (and associated potential ecological impacts) differ among coastal sub-regions and types of fishing gears?” The assessment of the catch composition of SSF at three coastal zones of the Colombian Pacific revealed taxonomic, size and functional differences related to both the environmental context of each coastal zone and to the gear types used (Herrón et al., 2019a). A preliminary assessment based on the outcomes of the selected ecological indicators suggested that there is not one “ecologically ideal” fishing gear since each type of gear harvests a specific size and/or functional component of the system. Moreover, the same type of gear can have different ecological effects in different environmental contexts. These findings challenge the notion that more selective gears (in terms of size and species targeted) have overall lower ecological impacts; a notion mostly derived from a the traditional fisheries management goal of reducing by-catch and discards (FAO, 1995). This research showed that hook-based gears (i.e. handlines and longlines), which are the predominant gear type used by fishers in the northern Colombian Pacific, caught larger sizes and higher trophic level species than nets, but they also included a higher proportion of species that are considered more vulnerable to fishing impacts due to their life history traits such as high longevity, late maturity and/or slow growth (e.g. sailfish, tunas, sharks, Herrón et al. (2019)). However, the observed differences in mean length of the catch were associated not only to the inherent size selectivity of the gears but also to the location of fishing grounds used by the different gears, since selectivity is also influenced by the spatial and temporal distribution of the fisheries resources (Maunder et al., 2014; Sampson, 2014). Although a spatial analysis of the catch composition in terms of size-based indicators was beyond the scope of the study in Chapter 3, the results showed that, in general, gears used in more pelagic and deeper fishing grounds (e.g. purse seines in the central Colombian Pacific or longlines in the northern Colombian Pacific) caught larger fish sizes than gears used in shallow, near-shore areas (e.g. gillnets and bottom trawls).

In the estuarine and mangrove dominated coastal sub-region of the central Colombian Pacific a wide variety of nets were used by small-scale fishers (i.e. gillnets, bottom-trawls, lobster nets, purse seines) while hook-based gears were less commonly used. Such pattern might reflects the local knowledge of fishers regarding seasonal and spatial patterns of abundance of target species and size classes (Herrón et al., 2019a; Purcell et al., 2018). Among the nets used, bottom trawls are a gear type banned since 2004 by the Colombian fisheries authority (INCODER, 2004) since they have been identified as destructive due to their dragging nature (Olsgard et al., 2008). Results showed that bottom trawls had the highest percentage of landed by-catch among all gears (36%) and the by-catch included species from a wide range of taxonomic groups, such as: octocorals (Octocorallia spp.), sponges (Demospongiae spp.), sea stars (Astropectinidae spp.), sea snails (e.g. Muricidae spp,. Conidae), crabs (Leucosiidae spp., Xanthidae spp.) and many juvenile fish species. Most of that by-catch is later discarded due to a lack of market or consumption value of the species involved. So, although the biomass and energy associated to by-catch organisms is not entirely removed from the system, there is induced fishing mortality to those by-catch species with potential negative effects on their population dynamics (Harrington et al., 2005; Sardà et al., 2015). Even though further studies are required to assess the actual impacts of bottom trawls in near-shore habitats of the Colombian Pacific, a high rate of discarded by-catch remains an undesired characteristic in any type of fishery, not only for ecological considerations but also for ethical ones, as they are seen as “a waste” of natural resources (Kelleher, 2005).

Estimated mean trophic level of the catch and proportions of trophic guilds showed that most fishing gears in the Colombian Pacific target mainly high trophic levels (i.e. piscivore and invertivore species), which could be interpreted as a sign of healthy fish communities where top predators have as yet not been fished out (Stevenson et al., 2007). However, a high mean trophic level in the catch could also reflect an inefficient fishing strategy in terms of the amount of energy harvested from the system, which is lower at high trophic guilds due to the lossess in metabolic costs along the food web and to lower productivity per biomass unit at higher trophic levels (Kolding et al., 2015b). Future analyses of temporal trends in trophic indicators of the catch per gear will allow better assessment of potential trophic impacts of SSF in the fish community and to detect early signs of changes in the ecosystems.

5.1.3 Socio-economic drivers of fishing gear choices

The research question addressed in Chapter 4 was: "what are the socio-economic drivers of gear choices of small-scale fishers of the central Colombian Pacific?" Based on the analysis of interviews with fishers and landings data collected at three coastal villages over the course of one year, the results showed that the high market demand for shrimps and the easy access to suitable habitats for those species drove most of the small-scale fishers to use gillnets and bottom trawls in the study area (Herrón et al., 2019b). These drivers could also help explain the predominance of gillnets in most fishing villages of the central and southern Colombian Pacific (Castellanos-Galindo and Zapata, 2019).

Despite being a gear banned by the Colombian fisheries authority more than ten years ago (INCODER, 2004), bottom trawls continued to be used due to the lack of enforcement and the high market price of the small-sized shrimps, which are the main target species of fishers that use that gear (Herrón et al., 2019b). Besides the market incentives, bottom trawls had low entry and maintenance costs which also makes this fishing gear very appealing to young fishers that live close to suitable fishing grounds. In contrast, gillnets had the highest initial investment and maintenance costs, which ideally should have been compensated by a high value of the catch per effort (VPUE) and a related high profit. However, users of gillnets of small mesh size who target the most expensive species in the market (i.e. the white shrimp, *Penaeus occidentalis*), showed widely variable VPUE, which is probably linked to spatial and temporal dynamics of resource abundance. Such a variable VPUE results in very unstable income to fishers who got relatively small profit margins (between US$ 3.5 and US$ 14.6 per fishing day) when they do not own the gear used. Such low income derived from SSF adds to the already vulnerable socio-economic situation of local communities living along the central Pacific coast, where the percentage of the population living in poverty has been estimated as 66% (DNP, 2019) and could be even higher in rural villages (Escobar, 2008). Additionally, large differences in catch and value per unit effort were observed among coastal villages for the same type of gear, probably linked to the use of different fishing grounds, different taxonomic composition of the resulting catch and different market prices of taxonomic groups. For example, fishers using longlines in a near-urban village caught predominantly species with low market value (e.g. stingrays, catfishes) while fishers using the same gear in a more remote village caught mostly species of medium market value (e.g. snappers, groupers).

Besides the high dependence on SSF for basic economic income, households in coastal villages of the central Colombian Pacific also showed high dependence on SSF as a protein source, evidenced by a relatively high annual fish consumption per capita (average 237 kg*pc*yr^{-1}) when compared to global assessments (Cisneros-Montemayor et al., 2016). Although more precise estimates of local fish consumption are needed (e.g. detailed records of monthly fishing effort along the year and of the precise amount of fish left for consumption after a representative sample of fishing trips) the high fish consumption rate estimated here, derived from interviews to fishers, emphasizes the vast importance of SSF for food security and nutrition in rural coastal areas of the Colombian Pacific and calls for increased government attention to all aspects of SSF management and sustainability.

5.1.4 Management implications for SSF in the Colombian Pacific

By consolidating the information presented in chapters 2, 3 and 4 of this dissertation, a picture of the SSF in the Colombian Pacific emerges, which presents novel and important information from three out of four core subsystems that compose any social-ecological system (Ostrom, 2009). These are: (a) the resource unit, through the stock diagnosis of target species, (b) the resource system, through the assessment of potential ecological impacts of SSF at the community and ecosystem levels, and (c) the resource users, through the assessment of socio-economic drivers of fishers, with relation to their gear choices. The implications of the main findings of this thesis for SSF management will be now discussed considering the Colombian context.

As Jentoft (2000) argued: not only “viable fisheries communities require viable fish stocks” but also “viable fish stocks require viable fisheries communities”. Although the here presented research did not include an assessment of the governance of SSF, the fourth core subsytem of social-ecological systems (Ostrom, 2009), some of the results presented in Chapters 2 and 4 point to the need of promoting a more active participation of fishers and fishing communities in different aspects of SSF management. A transition towards co-management schemes for SSF is in fact a vision shared by most fishers, local community leaders of different coastal villages and fisheries experts in Colombia (Saavedra-Díaz et al., 2016). Co-management of fisheries resources has also been identified as a promising strategy to solve many of the existing problems in fisheries worldwide (Gutiérrez et al., 2011). Government investments in promoting organization and empowerment of fishing communities could facilitate the inclusion and use of valuable local ecological knowledge about natural dynamics of resource abundance and consideration of socio-economic and cultural factors in all stages of SSF management (Cinner et al., 2011; Kittinger et al., 2013).

An important feature of SSF in the Colombian Pacific is that they are mostly near-shore, since most of the fishing activity is carried out within the first 5 kilometres off the coastline (Chapter 4, Fig 4.1). This contrats with the situation in neighboring countries in South América, like Ecuador or Perú, where many SSF are carried out further off-shore, exploiting more pelagic resources and using fishing methods with higher technological invesment (Arellano and Swartzman, 2010; Martínez-Ortiz et al., 2015). Such development of SSF in Ecuador and Peru is linked to highly dynamic and more productive pelagic habitats related to the presence of the Humboldt Current and the Galápagos Archipelago (Martínez-Ortiz et al., 2015). Despite the relative low productivity of the marine waters off the Colombian coast (Pennington et al., 2006), the spatially confined development of SSF in near-shore habitats could constitute an advantage for management and enforcement. Considering the difficulties of fully enforcing top-bottom fisheries management measures in isolated rural environments and the potential ecological and socio-economic benefits of adopting a co-management approach for multi-gear SSF (de Oliveira Leis et al., 2019; Gelcich et al., 2012), right-based management schemes could be explored. Territorial User Rights in Fisheries (TURFs), whereby fishing access privileges are given to a community or a specific user group (Christy, 1982), is a management strategy that has gained support in recent years (Fujita and Bonzon, 2005; Quynh et al., 2017). TURFs, and other similar right-based or fisheries management approaches, e.g. locally-managed marine areas LMMA in the South Pacific (Jupiter et al., 2014), follow the rationale that transfering some of the responsabilities of management to direct resource users will eliminate conflicts among individual fishers that are all trying to maximize their catch, while increasing compliance and reducing the costs of management and enforcement (Fujita and Bonzon, 2005). Even though positive ecological, economic, social and management outcomes have been reported linked to properly implemented right-based management strategies (Fujita and Bonzon, 2005; Gelcich et al., 2019), negative outcomes can emerge due to lack of consideration of socio-economic and cultural contexts, lack of legal support, inadequate infrastructure or lack of understanding of the impact of larger scale processes in local dynamics (Aburto et al., 2013; Gelcich et al., 2019). Future explorations of the feasibilty of adopting right-based management approaches in the Colombia Pacific could take advantage of Community Councils that are already established as ethnic and territorial managing authorities, and the traditional sense of collective ownership of natural resources shared by Afro-descendant communities (Escobar, 2008).

Beyond the governance framework, SSF management objectives in Colombia should be revised to account for the potential ecological fishing impacts and take the first steps to transition from single species management towards an EBFM approach (Pikitch et al., 2004). Most SSF managers in developing countries, as it is the case in Colombia, have excesivelly relied on output controls management measures (e.g. catch quotas and size limits) that were originally designed for monospecific industrial fisheries and are very difficult to implement in multi-gear, multi-species SSF (Purcell and Pomeroy, 2015).

On the other hand, the implementation of gear-based management measures, like those recenltly established in the northern Colombian Pacific (Ramírez-Luna and Chuenpagdee, 2019; Vieira et al., 2016), demand proper assessment of their ecological and socio-economic implications to prevent unexpected and undesired consequences. For example, promoting the generalized use of a specific type of fishing gear based on its higher selectivity (e.g. hook-based gears instead of nets) could create a problem of fishing overcapacity, by increasing the pressure on certain stocks and on certain habitats (Pauly et al., 2002; Pomeroy, 2012). The selective fishing of species of higher trophic levels, which are the main target species of long-lines and hand-line gears in that sub-region (Herrón et al., 2019a), could result in lower yields, biodiversity loss and alteration of the fish community structure (Breen et al., 2016). Moreover, fishers' specialization for particular stocks could reduce the capacity of local communities to adapt to changing environmental conditions that affect the dynamics of stocks (Kittinger et al., 2013; Kluger et al., 2019; Sampson et al., 2015). In contrast, the catches of gillnets and other types of nets assessed here showed a wider representation of sizes, species and trophic guilds, potentially more similar to what is been proposed as a "balanced harvest" (BH) approach to fisheries, whereby the size spectrum and the species composition reflect that of the natural structure of the system (Garcia et al., 2012). Several model-based analyses have shown that adopting a BH approach to fisheries would increase yields, reduce the impacts on community structure and increase ecosystem resilience (Jacobsen et al., 2014; Kolding et al., 2015a; Law et al., 2012). However, the only real examples where the BH approach has been examined come from inland SSF in Africa (Kolding et al., 2015a) that are subject to different environmental dynamics than coastal and marine habitats. Proper implementation of a BH approach would require that all stocks are in healthy condition (Garcia et al., 2015) which is not the case in the SSF in the Colombian Pacific, as described in Chapter 2 (Herrón et al., 2018), nor in most of the fisheries worlwide (Ye and Gutierrez, 2017). BH also requires knowledge of the productivity-at-size for all species (Froese et al., 2015) and drastic changes in markets preferences to incorporate sizes and species that are not currently commercialized (Charles et al., 2015).

Considering that neither the single-species management approach, nor the BH approach are currently viable for SSF in the Colombian Pacific, it is worth considering a revision of the fisheries assessment scheme currently used and incorporate indicators related to ecological impacts. Several suites of ecological indicators have been proposed in the literature based on empirical evidence or on the results of modelling analyses (Coll et al., 2016; Cury and Christensen, 2005; Fulton et al., 2005; Rochet and Trenkel, 2003). Current scientific advice for fisheries management in the European Union, for example, incorporates assessment of indicators such as: mean length of the fish community, proportion of predatory fish in the community, catch-based marine trophic index, proportion of discards in the fishery, among others ("IndiSeas" project , Coll et al. (2016)). Systematic monitoring and assessment of a suite of ecological indicators, like those presented in Chapter 3, could be relatively easy to include as part of periodic evaluations of SSF in the country, as a practical step toward EBFM (Herrón et al., 2019a; Pikitch et al., 2004). Future evaluation of temporal trends of the selected indicators will inform about the impacts of fishing practices in different environmental contexts and facilitate the critical revision of fisheries management and conservation objectives that sometimes have conflicting long-term goals (Link et al., 2002).

Finally, the adoption of an EBFM to SSF management must also aim for healthy and viable stocks of those species mostly contributing to annual landings (Fulton et al., 2005; Rochet and Trenkel, 2003). Therefore, periodic assessment of the stock condition of main target species remains a very important task for SSF managers. As shown in Chapter 2, a large uncertainty underlying the data used for analyses can result in contradictory stock diagnosis depending on the data sources used (Herrón et al., 2018). The results presented in Chapter 2 highlighted the urgent need of making adjustments to the fisheries data collection scheme used in Colombia, the importance of using a consistent methodological approach to consolidate longer time series data and the need to acquire data on fisheries selectivity. In the case of Colombia, changes in the sampling scheme would not necessarily mean additional costs, compared to the current scheme costs, but mainly a redistribution of the current sampling effort. A stratified random sampling should be designed (Sparre and Venema, 1998) based on a previous assessment of current fishing effort and how it changes spatially, temporally and among the different gears (McCluskey and Lewison, 2008). Additionnally, community-based fisheries monitoring, which could be included as part of a co-management arrangements, could increase landing sites coverage and maintain sampling frequency over time (Ramírez et al., 2017). Nevertheless, overall coordination and supervision of the scheme should be carried out by AUNAP, as the national fisheries authority, to maintain methodological consistency and to avoid potential errors caused by different handlers of the data.

5.2 CRITICAL ASSESSMENT OF THE METHODOLOGICAL APPROACH

Research on SSF in the Colombian Pacific is limited and most of it is embedded in the grey literature, i.e. technical reports by government institutions or by non-governmental organizations. A simple search on the database 'Web of Science' (www.webofknowledge.com) using the keywords "fisheries" + "Colombia" and "Pacific" carried out in April 2019 resulted in only 32 publications, out of which two were produced during the course of this thesis. Acknowledging the lack of scientific production for the region and the country, the main objective of this research was to characterize the SSF in terms of previously established indicators linked to fisheries sustainability, using the best available data and a holistic approach that included different components of the social-ecological system. The final aim was to provide essential inputs for managers and resource users that are faced with the challenge of making decisions related to the sustainable use of fishing resources while constrained with insufficient data. Even though the novel information presented here constitutes a snapshot assessment, in the sense that it did not include temporal or spatial dynamics of resource abundance or of fishing effort, it sets a very important baseline for future research in those areas.

Taking into account the recognized weaknesses of the fisheries data collection scheme carried out by the Colombian government, a strategic alliance was made with MarViva Foundation at the start of this research project. MarViva is a regional non-governmental organization (NGO) that at the time had compiled the most complete data sets of small-scale fisheries landings (catch, effort and length frequency data) in the northern Colombian Pacific, using a consistent sampling methodology (Díaz et al., 2016). Besides length-frequency-catch-data (LFCD) from the government and MarViva's data set, additional landings data was collected by the author and collaborators in the field over the course of one year in the central sub-region of the Colombian Pacific using the same methodological approach of MarViva. Results shown here (Chapter 2), in other studies carried out in Colombia (López-Angarita et al., 2018; Ramírez et al., 2017) and in other tropical countries (e.g. Previero et al. (2013); Ticheler et al. (1998)) provide evidence that community-based fishing monitoring schemes can be very useful (and likely more effective and less expensive) than traditional government monitoring programs implemented in tropical SSF. However, identification of all species in the catch and detailed knowledge of the diversity of local common names through ethno-taxonomic studies are important steps prior to implementing similar community-based monitoring programs (Previero et al., 2013). In the data sets used here, some of the rare species in the catch could not be identified to species level (Chapter 3, Herrón et al. (2019a)), which could influence the estimation of some of the catch-based ecological indicators. Nevertheless, due to the low contribution of those species to the total biomass landed, general patterns observed among gears and among geographical zones were likely not significantly affected.

To answer the research question related to the stock condition of main target species of SSF in the Colombian Pacific, potential methods to be used were restricted to those that only require LFCD. Additional data available was restricted to those from a few biological studies on main commercial species and monthly catch landed per species (or higher level taxonomic groups). However, total catch (biomass) data collected by government authorities was not readily comparable since sampling effort varied among years and no fishing effort data was available for SSF (Herrón et al., 2018). The application of more accurate models that have been developed in the past decades (e.g. Stock Synthesis (Methot and Wetzel, 2013); Bayesian analysis (McAllister et al., 1994), that have greatly improved the precision in the diagnosis of stock status, was constrained by the data-limited condition of the SSF in Colombia. Other LFCD-based stock assessments methods developed in recent years, such as the length-based Spawning Potential Ratio (SPR) proposed by (Hordyk et al., 2016), the Length-based-Integrated Mixed Effects (LIME) developed by Rudd and Thorson (2017) and the Length-Based Risk Analysis (LBRA) proposed by Ault et al. (2018), rely on more detailed knowledge of maximum age, selectivity ogives and/or maturity ogives, which were not all available for the species assessed.

One of the methodological approaches used in Chapter 2 was based on traditional stock assessment methods that follow a sequence of: estimation of growth and mortality parameters from modal cohort progression, catch curve analysis and a yield-per-recruit model (Sparre and Venema, 1998). These methods are based on rigourous assumptions, such as: (a) constant recruitment, (b) constant natural mortality rates over the expoited lifespan of the species and (c) trawl-like selectivity of the fisheries, which were not met here. The first two assumptions are considered problematic since recruitment seems to be variable for most species and natural mortality to vary among size-classes (Gislason et al., 2010; Sparre and Venema, 1998). Regarding the assumption on selectivity, the lack of information in the data set related to specific characteristics of the gears (e.g. mesh size or hook size) used during the sampled fishing trips and the lack of previous research on selectivity features of the different gears involved in the fisheries, hindered the attempts made to correct catch-at-length data to account for the non-trawl-like selectivity of the fisheries. The violations of these key assumptions of one of the methodological approaches used, could have imposed additional biases into the parameters estimated to assess the status of the stocks. Nevertheless, the data sets used here were the “best scientific evidence available” (FAO, 1995) at the time of this research to evaluate the status of the fisheries resources under exploitation.

A widely used approach to holistically assess fisheries and examine fishing impacts at the ecosystem level is the use of mass-balanced trophic models, e.g. Ecopath with Ecosim - *EwE* (Christensen et al., 2008). Based on an ecological network analysis derived from trophic interactions, this methodological approach allows to assess the ecological fishing impacts of different gears and different levels of fishing effort on target species and on the fish community and the entire ecosystem. Moreover, it allows to include costs and profit variables to assess economic consequences of specific changes in the system. Thanks to those comprehensive features, *EwE* models have been used to assess potential impacts of fisheries management measures in different coastal systems around the world, many of them focusing on tropical systems (e.g. Bacalso and Wolff (2014); Castellanos-Galindo et al. (2017); Ortiz and Wolff (2002); Rehren et al., (2018); Tesfaye and Wolff (2018); Wolff et al. (2000). For the Colombian Pacific coast, a recent study characterized the trophic flow structure in a well-studied and confined mangrove bay system in the central Pacific sub-region using an *EwE* model (Castellanos-Galindo et al., 2017). The results revealed a relatively low productive system, with low human intervention and low fishing effort; the latter associated to the low human population density inside the bay, which is not necessarily characteristic for the entire central sub-region of the Colombian Pacific (Castellanos-Galindo et al., 2017; Castellanos-Galindo and Zapata, 2019), as shown in Chapter 4. Further research on diet and natural abundance of target and non-target species is needed to be able to develop similar trophic models for other coastal zones of the Colombian Pacific and use them to explore the potential ecological effects of different exploitation and management scenarios.

Even though the evaluation of seasonal or spatial patterns within each of the coastal zones of the Colombian Pacific was beyond the scope of the thesis, some of the obtained results pointed to spatial differences in catch composition (Chapter 3), catch volumes and catch value (Chapter 4), that were likely related to the use of different fishing grounds and/or to seasonal environmental variations. A relatively novel approach that has been incorporated into the ecosystem approach to fisheries management is the métier-based assessment of fisheries (Reeves et al., 2008; Ulrich et al., 2012). A métier has been defined as “a group of fishing operations targeting a similar (assemblage of) species, using similar gear, during the same period of the year and/or within the same area and which are characterized by a similar exploitation pattern” (Ulrich et al., 2012). This management approach considers that fishing trips undertaken by nominally equivalent vessels and/or gears might still produce different catches (García-Rodríguez et al., 2006; Pelletier and Ferraris, 2000; Tzanatos et al., 2005). Taking into account métiers into the decision making process allows, for example, to consider the use of different habitats and/or seasons by users of the same type of gear, as input for the design of fishing effort regulations (Tzanatos et al., 2005). Therefore, future identification of existing métiers in the SSF of the Colombian Pacific and their characterization in terms of spatial and temporal patterns of fishing effort, could be another important step for the transition to a more holistic approach to fisheries assessment and management.

5.3 SSF MANAGEMENT IN TROPICAL COASTAL AREAS

5.3.1 The regional and global context

The SSF of the Colombian Pacific share many characteristics of this type of social-ecological system in tropical developing countries of Africa, Asia and Latin America, where they contribute to poverty alleviation and prevention for coastal communities that often have limited income opportunities and are usually neglected by centralized governments (Béné et al., 2007). The high levels of socio-economic dependence on SSF contrasts with the numerous management challenges encountered, such as the high diversity of species in the catch, the use of multiple gears, remote landing sites, low technological development and weak market power by fishers (Salas et al., 2007). Although tropical SSF share many characteristics that hinder their assessment and management, intrinsic features of each social-ecological system that relate mostly to their resource units, resource systems and resource users (*sensu* Ostrom, 2009) can have a strong influence on the outcome of certain management strategies (Kittinger et al., 2013). Hereafter, results from one of the coastal sub-regions of the Colombian Pacific are compared to selected local case studies from different tropical coastal areas in the world (Figure 5.1), where holistic assessment of SSF have been recently carried out. The selected case studies come from: Costa Rica, in the Tropical Eastern Pacific (Alms and Wolff, 2019; Nielsen-Muñoz and Quesada-Alpízar, 2006; Sánchez Jiménez et al., 2019), Kenya and Tanzania, in the Western Indo-Pacific (Rehren, 2017; Rehren et al., 2018; Tuda, 2018; Tuda et al., 2016) and Philippines, in the Central Indo-Pacific (Bacalso and Wolff, 2014; Bacalso et al., 2016).

One SSF system within the Tropical Eastern Pacific that resembles that of the central Colombian Pacific (chapters 3 and 4) is located in the Gulf of Nicoya, Costa Rica. This highly dynamic estuarine area is the most productive coastal zone in that country in terms of fishing, with fishers traditionally targeting shrimp and mangrove-associated fish species, such as drums and croakers, snooks and catfishes (Alms and Wolff, 2019; Nielsen-Muñoz and Quesada-Alpízar, 2006). A difference between the two systems is that the fishing industry is more developed in the Gulf of Nicoya, compared to the central Colombian Pacific, with small-scale, semi-industrial and industrial fleets actively operating. Another difference is the mean trophic level of the catch (*MTL*), which is one trophic level lower in the Gulf of Nicoya (2.8, Alms et al. (2019)) than the estimated *MTL* for the central Pacific coast (3.8, Herrón et al (2019a)). A recent assessment of changes in the trophic structure of the Gulf of Nicoya system in the past 20 years found that despite no change was observed in mean trophic level (*MTL*) of the catch, there was a drastic reduction of catches of low and high trophic levels, related to the reduced abundance of shrimps and large predators, with mid-trophic level species dominating current catches (Alms and Wolff, 2019). The drastic changes in catch composition have in turn triggered changes in the choices of fishers: the semi-industrial fleet has focused now on small pelagic species of lower market value, and the small-scale fleet has increased effort with illegal small-mesh size gillnets with a consequent reduction of the average size of specimens in the catch (Alms and Wolff, 2019). Even though the predominance in the catch of high level trophic species in the central Colombian Pacific could be interpreted as a sign of a healthy fish community, where top predators have not been fished out (Stevenson et al., 2007), the trend observed in the Gulf of Nicoya could constitute a warning sign of similar future ecological changes for fisheries managers in the Colombian Pacific, where a collapse of the shrimp industrial fishing fleet that operates in shallow waters has already ocurred (Rueda et al., 2014).

Lower values of *MTL* in the catch of SSF, compared to the Colombian Pacific, have also been observed in tropical coastal zones of the Western and Central Indo Pacific; Tuda (2018) reported a *MTL* of 2.4 in SSF of the southern coast of Kenya, Rehren (2017) found a *MTL* of 2.8 in SSF of Zanzibar, Tanzania and Bacalso and Wolff (2014) reported a *MTL* of 3.0 in Danajon Bank, Philippines. In these areas, herbivore and corallivore species contributed an important portion of the catch, which is related to the predominance of coral reefs and seagrasses as near-shore habitats, but also probably linked to the reduced abundance of piscivore species due to historic fishing pressure on top predators (Bacalso and Wolff, 2014; McClanahan and Muthiga, 1988). Also, in these coastal areas of the Indian Ocean the mean length of the catch was lower than the mean value observed in the central Colombian Pacific (32 cm). In the case of Zanzibar the most abundant size class in the catch was 11 -21 cm with juvenile retention rates higher than 82% in five of the six target species (Rehren, 2017), while in southern Kenya the mean length of the catch was 21.1 cm with juvenile retention rates higher than 65% in three of four target species assessed (Tuda et al., 2016). In the case of Philippines, a very low mean length of the catch was observed, 13.6 cm, which is attributed to overfishing and to the overall coral reef degradation linked to both natural and anthropogenic factors (Bacalso and Wolff, 2014). It is thus clear that different ecosystems and different histories of resource exploitation have shaped the current ecological characteristics of the SSF in the case study areas compared here, which further emphasize the importance of not relying on single-species management approaches to manage multi-gear and multi-species fisheries that do not account for the complex dynamics of social-ecological systems.

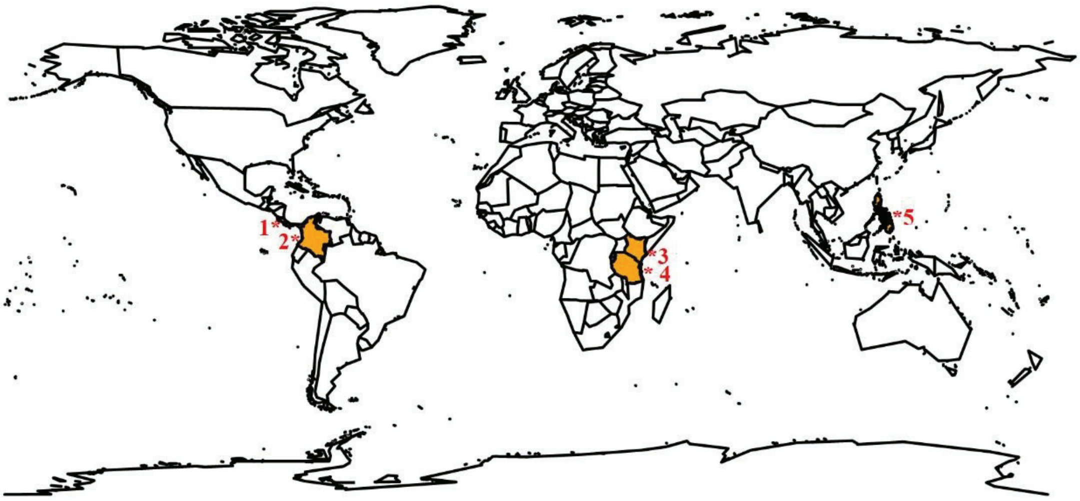


Figure 5.1. *Location of case study areas used to compare ecological characteristics of tropical small-scale fisheries systems: 1) Gulf of Nicoya, Costa Rica; 2) Buenaventura, Colombia; 3) Southern Kenya; 4) Chwaka Bay, Zanzibar-Tanzania; 5) Danajon Bank, Philippines.*

On the other hand, the persistent use of destructive fishing gears that have been banned by the respective fisheries authority is reported in many tropical SSF of developing countries, as it was described here for bottom trawls in the central Colombian Pacific (Chapter 4). This is also the case of beach seines in coastal Kenya (Tuda, 2018), of dragnets in Tanzania (similar to beach seines but used with boats in intertidal areas) (Rehren, 2017), bottom trawls and gillnets with mesh size <3” in the Gulf of Nicoya, Costa Rica (Sánchez-Jiménez et al., 2019) and six different type of gears (beach seines, bottom trawls, Danish seines, round haul seines, small mesh nets and spear gun using compressors) in Danajon Bank, Philippines. In the case of Colombia and Kenya, users of such type of gears are in general in poorer economic conditions compared to other fishers, lack alternative income and/or have little fishing experience (Herrón et al., 2019b; Tuda, 2018). A thorough evaluation of ecological and economic consequences of effort reallocation into other fishing gears using trophic modelling techniques, as it was carried out for the systems of Zanzibar (Rehren, 2017) and Danajon Bank (Bacalso et al., 2016), can be very helpful to discuss and reach consensus with stakeholders on the best course of management actions. Additionally, identifying and understanding the drivers of fishers’ behavior, in particular regarding their decisions on where and how to fish (Fulton et al., 2011; Kronen et al., 2010), similarly to the methodological approach shown in Chapter 4, will facilitate the identification of leverage points for SSF management and ensure higher degree of compliance to new regulations established.

Similarly to the findings described in Chapter 2, signs of over-exploitation of main target species have also been reported in some of the SSF from the selected case studies, in particular in the Pacific coast of Costa Rica (Nielsen-Muñoz and Quesada-Alpízar, 2006), the southern coast of Kenya (Tuda, 2018) and the eastern coast of Zanzibar in Tanzania (Rehren, 2017). Resembling the situation seen in the central Colombian Pacific, a high diversity of species in the SSF catch in the southern coast of Kenya (138 species, (Tuda, 2018)), coupled with the use of nine different type of fishing gears (i.e. the same number of gears seen in the central Colombian Pacific) make enforcement of output control management measures, such as size limits per species almost impossible to achieve (Purcell and Pomeroy, 2015; Tuda et al., 2016). Even though input control management measures, such as gear regulations or maximum number of boats, have better chances of being successfully implemented in multi-gear and multi-species fisheries, constant monitoring of the stock condition of the most impacted species is always required to prevent overfishing (King, 2007). Considering that fisheries data-limitations are common in SSF worldwide (Costello et al., 2012), improvements not only in data collection schemes but also in methodological approaches suited for data-limited fisheries are urgently needed to help bridging that existing gap of stock assessments between developing and developed countries (Ye and Gutierrez, 2017).

5.3.2 Recommendations for management of tropical SSF

Based on the key findings of this research and on the lessons learnt from similar – yet different - SSF systems in tropical coastal areas in different parts of the world, a set of recommendations to transition towards more holistic assessments and management of SSF in tropical contexts is presented here.

- Improving the quality of catch-data collection, so that analyses at the population or ecosystem level are more reliable, is an urgent first step in most tropical SSF. This step implies the design of a stratified sampling scheme to systematically gather information on at least the following variables: catch and effort per gear (or métier, if possible), length frequency of representative samples of the catch, reproductive period of main target and by-catch composition (Sparre and Venema, 1998). The stratification should consider spatial and temporal patterns of fishing effort and how those vary among gears/métiers (McCluskey and Lewison, 2008). Community-based monitoring programs can greatly improve spatial coverage and frequency of fisheries data collection (Herrón et al., 2018; Ramírez et al., 2017) but they require clarifying taxonomic identity of common names used for species found in the catch (Herrón et al., 2019a; Previero et al., 2013).
- In cases where the fishing gears used have a specific pattern of selectivity (i.e. other than trawl-like), specific research on fisheries

selectivity should be conducted in order to correct LFCD before conducting stock assessment analysis (Maunder et al., 2014; Punt et al., 2014). Taking into account that fisheries selectivity is influenced also by spatial and temporal dynamics of the species (e.g. juveniles using shallower inshore habitats, seasonal migrations), assessments of fisheries selectivity based on métiers rather than gears could be more valuable for LFCD correction and for future management decisions (Sampson, 2014; Ulrich et al., 2012).

- Considering the multi-gear and multi-species nature of tropical SSF, gear-based management regulations, along with other input control measures, have higher chances of being sucessfully implemented than output control measures, such as species-specific catch quotas or size limits (Purcell and Pomeroy, 2015). However, assessment of the potential ecological and socio-economic impacts of different gears (or métiers) is required to prevent unintended and undesired outcomes. It should also be considered that not always the more selective gears have lower ecological impacts and that the same type of gear can have different ecological impacts when used in different environmental contexts (Herrón et al., 2019a).
- A set of ecological indicators could be adopted as part of regular monitoring and assessment of SSF, as a practical step to move forward an EBFM approach (Coll et al., 2016; Herrón et al., 2019a; Rochet and Trenkel, 2003). Selection of indicators must consider fisheries management and conservation objectives, as those can have conflicting goals (Link et al., 2002), particularly in areas of high biodiversity (e.g. endemisms, endangered species) or social vulnerability (e.g. growing populations in poverty conditions). Overall, management decisions should not be based on single snapshot assessments but should rely on observed temporal trends of minimum five years (Link, 2005).
- When data on species diets and natural abundance of main trophic components is available, mass-balanced trophic models could greatly improve holistic assessments of ecosystem impacts of fishing and allow more detailed explorations of ecological and economic consequences of input control management measures, such as gear-restrictions or gear effort reallocation (Bacalso and Wolff, 2014; Rehren et al., 2018).
- Research focused on acquiring non-fisheries data related to the status and dynamics of natural populations (e.g. recruitment variability), natural communities (e.g. structure of natural benthic communities) and habitats used by fishers should be promoted. Considering that many governmental institutions in developing countries have limited financial and human resources to carry out comprehensive fisheries research, strategic alliances with academic institutions, non-governmental organizations and development projects should be

developed. Also, international cooperation agreements with neighboring countries that potentially share some exploited stocks could facilitate funding for such research initiatives.

- Considering that local data on fish consumption is absent from many rural coastal areas of developing countries inhabited by indigenous communities (Cisneros-Montemayor et al., 2016), further research is needed on this topic so that global assessments can be based on local realities. Such information will allow not only to accurately value the importance of SSF to local food security but also to correct country´s fishing statistics related to annual catches per species or taxonomic groups, based on more reliable data of the consumed portion of the catch (Pauly and Zeller, 2016).
- In cases of non-compliance by fishers with relation to fisheries regulations such as specific fishing gear restrictions, it must be considered that profitability and lack of alternative income are important drivers of fishers' choices of gear. A common management strategy that involves financial compensation to impacted fishers, coupled with more strict enforcement, has an overall low viability in developing countries given the financial limitations and common institutional weaknesses (Musiello-Fernandes et al., 2017). Compensation schemes, based on the development of locally acceptable and feasible alternative livelihoods that relate to local lifestyles and cultural choices, might be a more viable approach to be explored.
- A potentially more sustainable approach is to promote local governance structures that facilitate the creation of co-management schemes for SSF. Such schemes would help integrate valuable local ecological knowledge (LEK) about the dynamics of resource abundance and environmental variation (Kolding et al., 2014; Sánchez Jiménez et al., 2019) and may allow fishers to play an active role in the design of fisheries management measures that consider the socio-economic and cultural local contexts (Cinner et al., 2011; Kittinger et al., 2013). Considering that strong local leadership and social-cohesion are key attributes of successful fisheries co-management intiatives (Gutiérrez et al., 2011) and taking into account the socio-economic vulnerable conditions of most small-scale fishers in developing countries (Béné et al., 2010), an increased and permanent investment in the strengthening of the social capital of coastal fishing communities would seem to be essential in the path towards sustainable SSF.

LITERATURE CITED

Abernethy, K.E., Allison, E.H., Molloy, P.P., Côté, I.M., 2007. Why do fishers fish where they fish? Using the ideal free distribution to understand the behaviour of artisanal reef fishers. *Canadian Journal of Fisheries and Aquatic Sciences* 64, 1595-1604.

Abson, D.J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., von Wehrden, H., Abernethy, P., Ives, C.D., Jager, N.W., 2017. Leverage points for sustainability transformation. *Ambio* 46, 30-39.

Aburto, J., Gallardo, G., Stotz, W., Cerda, C., Mondaca-Schachermayer, C., Vera, K., 2013. Territorial user rights for artisanal fisheries in Chile–intended and unintended outcomes. *Ocean & Coastal Management* 71, 284-295.

Acero, A., 2004. Systematics and biogeography of the tropical sea catfishes of the New World (Siluriformes: Ariidae) (Ph.D. thesis). Ecology and Evolutionary Biology. University of Arizona, Tucson, U.S:

Acevedo, J., Angulo, W., Ramírez, M., Zapata, L.A., 2007. Reproducción del pez *Brotula clarkae* (Pisces: Ophidiidae) en el Pacífico colombiano. *Revista de Biología Tropical* 55, 957-967.

Aguirre-Villaseñor, H., Morales-Bojórquez, E., Morán-Angulo, R., Madrid-Vera, J., Valdez-Pineda, M., 2006. Biological indicators for the Pacific Sierra (*Scomberomorus sierra*) fishery in the southern Gulf of California, Mexico. *Ciencias Marinas* 32, 471-484.

Alms, V., Wolff, M., 2019. The Gulf of Nicoya (Costa Rica) fisheries system: two decades of change. *Marine and Coastal Fisheries* 11, 139-161.

Alverson, D.L., Freeberg, M.H., Murawski, S.A., Pope, J.G., 1994. A global assessment of fisheries bycatch and discards. Food and Agriculture Organization of the United Nations (FAO) Fisheries Technical Paper No. 339. Rome, FAO. 233 p.

Amezcua, F., Soto-Avila, C., Green-Ruiz, Y., 2006. Age, growth, and mortality of the Spotted Rose Snapper *Lutjanus guttatus* from the southeastern Gulf of California. *Fisheries Research* 77, 293-300.

Andrade-Rodriguez, H.A., 2003. Age determination in the snapper *Lutjanus guttatus* (Pisces, Lutjanidae) and investigation of fishery management strategies in the Pacific Coast of Guatemala (M.Sc. thesis). University of Tromsø, Tromsø, Norway.

Andrew, N.L., Béné, C., Hall, S.J., Allison, E.H., Heck, S., Ratner, B.D., 2007. Diagnosis and management of small-scale fisheries in developing countries. *Fish and Fisheries* 8, 227-240.

Andrew, N.L., Evans, L., 2009. Small-scale fisheries management: frameworks and approaches for the developing world. The WorldFish Center Working Paper 1914. The WorldFish Center, Penang, Malaysia, 29 p.

Angulo, W., 1995. Evaluación de la fauna acompañante del camarón de aguas profundas *Pennaeus brevirostris*, *P. californiensis* y *Solenocera agassizi* en el Pacifico Colombiano. Informe Final. Ministerio de Agricultura, Instituto Nacional de Pesca y Acuicultura - INPA.

Angulo, W., Zapata, L.A., 1997. Evaluación biológico-pesquera de la merluza *Brotula clarkae* (pisces: ophidiidae) en el Pacifico Colombiano. Informe Técnico Final. Ministerio de Agricultura, Instituto Nacional de Pesca y Acuicultura - INPA. Colombia, 80 p.

Anticamara, J.A., Go, K.T., 2016. Spatio-temporal declines in Philippine fisheries and its implications to coastal municipal fishers' catch and income. *Frontiers in Marine Science* 3, 21.

Ardila, N., Navas, G.R., Reyes, J., 2002. Libro Rojo de Invertebrados Marinos de Colombia. INVEMAR. Ministerio de Medio Ambiente. La serie Libros rojos de especies amenazadas de Colombia. Bogotá, Colombia.

Arellano, C.E., Swartzman, G., 2010. The Peruvian artisanal fishery: changes in patterns and distribution over time. *Fisheries Research* 101, 133-145.

Arias-González, J.E., Nuñez-Lara, E., González-Salas, C., Galzin, R., 2004. Trophic models for investigation of fishing effect on coral reef ecosystems. *Ecological Modelling* 172, 197-212.

Arias, A., Cinner, J.E., Jones, R.E., Pressey, R.L., 2015. Levels and drivers of fishers’ compliance with marine protected areas. *Ecology and Society* 20, 1-14.

Aswani, S., Basurto, X., Ferse, S., Glaser, M., Campbell, L., Cinner, J.E., Dalton, T., Jenkins, L.D., Miller, M.L., Pollnac, R. 2018. Marine resource management and conservation in the Anthropocene. *Environmental Conservation* 45, 192-202.

Ault, J.S., Smith, S.G., Bohnsack, J.A., Luo, J., Stevens, M.H., DiNardo, G.T., Johnson, M.W., Bryan, D.R., Jardim, H.e.E., 2018. Length-based risk analysis for assessing sustainability of data-limited tropical reef fisheries. *ICES Journal of Marine Science* 76, 165-180.

AUNAP, 2013. Resolución 899 de 2013. Por la cual se establecen una zona exclusiva de pesca artesanal (ZEPA), una zona especial de manejo pesquero (ZEMP), en el departamento del Chocó y se adoptan otras medidas. Autoridad Nacional de Acuicultura y Pesca - AUNAP, Resolución 899 de 2013, Bogotá.

AUNAP, 2016. Propuesta de cuotas globales de pesca 2017. Autoridad Nacional de Acuicultura y Pesca - AUNAP. Ministerio de Agricultura y Desarrollo Rural. 129 p.

AUNAP, UNIMAGDALENA, 2013a. Boletín estadístico SEPEC. Enero - Diciembre 2013. Convenio de cooperación No. 0058 de 2013 entre la Universidad del Magdalena y la AUNAP. 84 p.

AUNAP, UNIMAGDALENA, 2013b. Tallas mínimas de captura para el aprovechamiento sostenible de las principales especies de peces, crustáceos y moluscos comerciales de Colombia. Convenio 058 de 2013 entre la Autoridad Nacional de Acuicultura y Pesca – AUNAP y la Universidad del Magdalena. 58 p.

Bacalso, R.T.M., Wolff, M., 2014. Trophic flow structure of the Danajon ecosystem (Central Philippines) and impacts of illegal and destructive fishing practices. *Journal of Marine Systems* 139, 103-118.

Bacalso, R.T.M., Wolff, M., Rosales, R.M., Armada, N.B., 2016. Effort reallocation of illegal fishing operations: A profitable scenario for the municipal fisheries of Danajon Bank, Central Philippines. *Ecological modelling* 331, 5-16.

Barneche, D.R., Robertson, D.R., White, C.R., Marshall, D.J., 2018. Fish reproductive-energy output increases disproportionately with body size. *Science* 360, 642-645.

Barreto, C., Borda, C., 2008. Evaluación de recursos pesqueros colombianos. Boletín técnico. Instituto Colombiano Agropecuario. Subgerencia de Pesca y Acuicultura. Bogotá, 132 p.

Barreto, C., Borda, C., Duarte, C.B., Guillot, L., Sánchez, C.L., Maldonado, L.F., 2010. Documento técnico para la propuesta de cuotas globales de pesca para la vigencia 2011. Subgerencia de Acuicultura y Pesca – INCODER. Bogotá, 348 p.

Barreto, C., Borda, C., Rehder, J., Sánchez, C., 2009. Propuesta de cuotas para el provechamiento de los recursos pesqueros colombianos y ornamentales para la vigencia 2010. Instituto Colombiano Agropecuario - ICA. Dirección de Pesca y Acuicultura, Bogotá, 143 p.

Béné, C., Hersoug, B., Allison, E.H., 2010. Not by rent alone: analysing the pro-poor functions of small-scale fisheries in developing countries. *Development Policy Review* 28, 325-358.

Béné, C., Macfadyen, G., Allison, E.H., 2007. Increasing the contribution of small-scale fisheries to poverty alleviation and food security. Food and Agriculture Organization (FAO). Rome, 126 p.

Benítez, J.V.G., Flores-Nava, A., 2019. The contribution of small-scale fisheries to food security and family income in Chile, Colombia, and Peru, in: Salas, S., Barragan-Paladines, M.J., Chuenpagdee, R. (Eds.), Viability and Sustainability of Small-Scale Fisheries in Latin America and The Caribbean. pp. 329-352. Springer International Publishing, Cham.

Berkeley, S.A., Hixon, M.A., Larson, R.J., Love, M.S., 2004. Fisheries sustainability via protection of age structure and spatial distribution of fish populations. *Fisheries* 29, 23-32.

Berkes, F., 2001. Managing small-scale fisheries: alternative directions and methods. International Development Research Center. – IDRC, Ottawa.

Beverton, R., 1992. Patterns of reproductive strategy parameters in some marine teleost fishes. *Journal of Fish Biology* 41, 137-160.

Beverton, R., Holt, S., 1957. On the dynamics of exploited fish populations, Fishery Investigations Series II, Vol. XIX, Ministry of Agriculture. *Fisheries and Food* 1, 957.

Bivand, R., Keitt, T., Rowlingson, R., 2019. rgdal: Bindings for the 'Geospatial' Data Abstraction Library. R package version 1.4-3. https://CRAN.R-project.org/package/rgdal.

Bivand, R.S., Pebesma, E., Gomez-Rubio, V., 2013. Applied spatial data analysis with R. Second edition. Springer, NY. http://www.asdar-book.org/.

Branch, T.A., Watson, R., Fulton, E.A., Jennings, S., McGilliard, C.R., Pablico, G.T., Ricard, D., Tracey, S.R., 2010. The trophic fingerprint of marine fisheries. *Nature* 468, 431-435.

Breen, M., Graham, N., Pol, M., He, P., Reid, D., Suuronen, P., 2016. Selective fishing and balanced harvesting. *Fisheries Research*, 184, 2-8.

Brownrigg, R., 2018a. Extra Map Databases. Version 2.3.0. Original S code by Richard A. Becker and Allan R. Wilks. R version by Ray Brownrigg. https://cran.r-project.org/web/packages/mapdata/.

Brownrigg, R., 2018b. maps: Draw Geographical Maps. R. Original S code by Richard A. Becker, Allan R. Wilks. Enhancements by Thomas P Minka and Alex Deckmy. package version 3.3.0. https://CRAN.R-project.org/package/maps.

Bystrom, A.B., Naranjo-Madrigal, H., Wehrtmann, I.S., 2017. Indicator-based management recommendations for an artisanal bottom-longline fishery in Costa Rica, Central America. *Revista de Biología Tropical* 65, 475-492.

Caddy, J., 2000. Marine catchment basin effects versus impacts of fisheries on semi-enclosed seas. *ICES Journal of Marine Science* 57, 628-640.

Caddy, J., Csirke, J., Garcia, S., Grainger, R., 1998. How pervasive is “fishing down marine food webs”? *Science* 282, 1383-1383.

Caddy, J.F., Garibaldi, L., 2000. Apparent changes in the trophic composition of world marine harvests: the perspective from the FAO capture database. *Ocean & Coastal Management* 43, 615-655.

Cardinale, M., Modin, J., 1999. Changes in size-at-maturity of Baltic cod (*Gadus morhua*) during a period of large variations in stock size and environmental conditions. *Fisheries Research* 41, 285-295.

Castellanos-Galindo, G.A., Cantera, J., Valencia, N., Giraldo, S., Peña, E., Kluger, L.C., Wolff, M., 2017. Modeling trophic flows in the wettest mangroves of the world: the case of Bahía Málaga in the Colombian Pacific coast. *Hydrobiologia* 803, 13-27.

Castellanos-Galindo, G.A., Zapata, L.A., 2019. Small-scale fisheries on the Pacific coast of Colombia: historical context, current situation, and future challenges, in: Salas, S., Barragan-Paladines, M.J., Chuenpagdee, R. (Eds.), Viability and Sustainability of Small-Scale Fisheries in Latin America and The Caribbean. pp. 79-100. Springer International Publishing, Cham.

Castellanos-Galindo, G.A., Chong-Montenegro, C., Baos E, R.A., Zapata, L.A., Tompkins, P., Graham, R.T., Craig, M., 2018. Using landing statistics and fishers’ traditional ecological knowledge to assess conservation threats to Pacific goliath grouper in Colombia. *Aquatic Conservation: Marine and Freshwater Ecosystems* 28, 305-314.

Castiblanco, C., Etter, A., Ramirez, A., 2015. Impacts of oil palm expansion in Colombia: What do socioeconomic indicators show? *Land Use Policy* 44, 31-43.

Castillo, L.F., 1998. Fluctución poblacional (composición y abundancia) de la ictiofauna acompanante del camarón en el Golfo de Tortugas, Pacífico Colombiano (B.Sc. thesis). Universidad del Valle, Cali, Colombia.

CCO, 2018. Política Nacional del Océano y de los Espacios Costeros - PNOEC. Comisión Colombiana del Océano - CCO, Bogotá, D.C. 96 p.

Chang, W., Cheng, J., Allaire, J., Xie, Y., McPherson, J., 2017. Shiny: web application framework for R., R package version 1.0.5., https://shiny.rstudio.com/.

Charles, A., Garcia, S., Rice, J., 2015. Balanced harvesting in fisheries: economic considerations. *ICES Journal of Marine Science* 73, 1679-1689.

Chasqui, L., Polanco, A., Acero, A., Mejía- Falla, P.A., Navia, A., Zapata, L.A., Caldas, J.P.E., 2017. Libro rojo de peces marinos de Colombia. Instituto de Investigaciones Marinas y Costeras Invemar, Ministerio de Ambiente y

Desarrollo Sostenible. Serie de Publicaciones Generales de INVEMAR No. 93. Santa Marta, Colombia.

Cheung, W.L., 2007. Vulnerability of marine fishes to fishing: from global overview to the Northern South China Sea (Ph.D. thesis). University of British Columbia, Vancouver, Canada.

Cheung, W.W., Pitcher, T.J., Pauly, D., 2005. A fuzzy logic expert system to estimate intrinsic extinction vulnerabilities of marine fishes to fishing. *Biological Conservation* 124, 97-111.

Christensen, V., Walters, C., Pauly, D., Forrest, R., 2008. Ecopath with Ecosim 6: A user's guide. Fisheries Centre, University of British Columbia, Vancouver.

Christy, F.T., 1982. Territorial use rights in marine fisheries: definitions and conditions. Food and Agriculture Organization - FAO. FAO Fisheries Technical Papers 227. 10 p.

Chuenpagdee, R., Salas, S., Barragán-Paladines, M.J., 2019. Big questions about sustainability and viability in: Salas, S., Barragan-Paladines, M.J., Chuenpagdee, R. (Eds.), Viability and Sustainability of Small-Scale Fisheries in Latin America and The Caribbean. pp. 3-13. Springer International Publishing, Cham.

Cinner, J.E., Folke, C., Daw, T., Hicks, C.C., 2011. Responding to change: using scenarios to understand how socioeconomic factors may influence amplifying or dampening exploitation feedbacks among Tanzanian fishers. *Global Environmental Change* 21, 7-12.

Cisneros-Montemayor, A.M., Pauly, D., Weatherdon, L.V., Ota, Y., 2016. A global estimate of seafood consumption by coastal indigenous peoples. *PloS one* 11 (12), e0166681.

Codechoco, 2014. Acuerdo 011 de 2014 del Consejo Directivo de Codechoco - Corporación Autónoma Regional para el Desarrollo Sostenible del Chocó, Quibdó.

Coll, M., Shannon, L., Kleisner, K., Juan-Jordá, M., Bundy, A., Akoglu, A., Banaru, D., Boldt, J., Borges, M., Cook, A., 2016. Ecological indicators to capture the effects of fishing on biodiversity and conservation status of marine ecosystems. *Ecological Indicators* 60, 947-962.

Collie, J., Hiddink, J.G., van Kooten, T., Rijnsdorp, A.D., Kaiser, M.J., Jennings, S., Hilborn, R., 2017. Indirect effects of bottom fishing on the productivity of marine fish. *Fish and Fisheries* 18, 619-637.

Collie, J.S., Hall, S.J., Kaiser, M.J., Poiner, I.R., 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. *Journal of Animal Ecology* 69, 785-798.

Condy, M., Cinner, J.E., McClanahan, T.R., Bellwood, D.R., 2015. Projections of the impacts of gear-modification on the recovery of fish catches and ecosystem function in an impoverished fishery. *Aquatic Conservation: Marine and Freshwater Ecosystems* 25, 396-410.

Cope, J.M., Punt, A.E., 2009. Length-based reference points for data-limited situations: applications and restrictions. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 1, 169-186.

Correa, I., Morton, R., 2010. Pacific coast of Colombia. Encyclopedia of the World's Coastal Landforms. Springer, pp. 193-198.

Costello, C., Ovando, D., Hilborn, R., Gaines, S.D., Deschenes, O., Lester, S.E., 2012. Status and solutions for the world's anassessed fisheries. *Science* 338, 517 – 520.

Criales-Hernandez, M.I., Duarte, L.O., García, C.B., Manjarrés, 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.

Cury, P.M., Christensen, V., 2005. Quantitative ecosystem indicators for fisheries management. *ICES Journal of Marine Science*, Volume 62 (3), 307–310.

DANE, 2011. Estimación y proyección de población nacional, departamental y municipal total por área 1985-2020, Proyecciones de población, www.dane.gov.co/index.php/estadisticas-por-tema/demografia-y-poblacion/proyecciones-de-poblacion.

Davies, T., Beanjara, N., Tregenza, T., 2009. A socio-economic perspective on gear-based management in an artisanal fishery in south-west Madagascar. *Fisheries Management and Ecology* 16, 279-289.

Daw, T.M., Cinner, J.E., McClanahan, T.R., Brown, K., Stead, S.M., Graham, N.A., Maina, J., 2012. To fish or not to fish: factors at multiple scales affecting artisanal fishers' readiness to exit a declining fishery. *PLoS One* 7 (2), e31460.

De la Hoz, M., Manjarrés-Martínez, L., 2016. Estadísticas de desembarco y esfuerzo de las pesquerías artesanales e industriales de Colombia en los sitios y puertos pesqueros monitoreados por el SEPEC durante el período Julio a Diciembre de 2016. 60 p.

de Oliveira Leis, M., Barragán-Paladines, M.J., Saldaña, A., Bishop, D., Jin, J.H., Kereži, V., Agapito, M., Chuenpagdee, R., 2019. Overview of small-scale fisheries in latin america and the caribbean, in: Salas, S., Barragan-Paladines, M.J., Chuenpagdee, R. (Eds.), Viability and Sustainability of

Small-Scale Fisheries in Latin America and The Caribbean. pp. 15-47. Springer International Publishing, Cham.

Dell, Q., Griffiths, S., Tonks, M., Rochester, W., Miller, M., Duggan, M., Van Der Velde, T., Pillans, R., Coman, G., Bustamante, R., 2013. Effects of trawling on the diets of common demersal fish by-catch of a tropical prawn trawl fishery. *Journal of Fish Biology* 82, 907-926.

Degnbol, P., Jarre, A., 2004. Review of indicators in fisheries management–a development perspective. *African Journal of Marine Science* 26, 303-326.

Denney, N.H., Jennings, S., Reynolds, J.D., 2002. Life–history correlates of maximum population growth rates in marine fishes. *Proceedings of the Royal Society of London B: Biological Sciences* 269, 2229-2237.

Devis-Morales, A., 2009. Ciclo anual de temperatura, salinidad y circulación en la cuenca pacífica colombiana con énfasis en su región costera y respuesta de la cuenca a eventos El Niño/La Niña recientes (Ph.D. thesis). Universidad de Concepción, Concepción, Chile.

Díaz, J.M., Guillot, L., Velandia-Diaz, M.C., 2016. La pesca artesanal en la costa norte del Pacífico colombiano: un horizonte ambivalente. Fundación MarViva. Bogotá, 158 p.

Díaz-Uribe, J. G., Arreguín-Sánchez, F., Cisneros-Mata, M. A., 2007. Multispecies perspective for small-scale fisheries management: a trophic analysis of La Paz Bay in the Gulf of California, Mexico. *Ecological modelling*, 201(2), 205-222.

DNP, 2019. TerriData - Sistema de estadísticas territoriales. Indicadores de pobreza, educación y empleo para Buenaventura. DNP - Departamento Nacional de Planeación, https://terridata.dnp.gov.co/.

Dowling, N.A., Smith, A.D., Smith, D.C., Parma, A.M., Dichmont, C.M., Sainsbury, K., Wilson, J.R., Dougherty, D.T., Cope, J.M., 2019. Generic solutions for data-limited fishery assessments are not so simple. *Fish and Fisheries* 20, 174-188.

Dulvy, N.K., Reynolds, J.D., 2002. Predicting extinction vulnerability in skates. *Conservation Biology* 16, 440-450.

Edwards, P., Pena, M., Medeiros, R.P., McConney, P., 2019. Socioeconomic monitoring for sustainable small-scale fisheries: lessons from Brazil, Jamaica, and St. Vincent and the Grenadines, in: Salas, S., Barragan-Paladines, M.J., Chuenpagdee, R. (Eds.), Viability and Sustainability of Small-Scale Fisheries in Latin America and The Caribbean. pp. 267-293. Springer International Publishing, Cham.

Ehemann, N., Pérez-Palafox, X., Mora-Zamacona, P., Burgos-Vázquez, M., Navia, A., Mejía-Falla, P., Cruz-Escalona, V., 2017. Size–weight relationships of batoids captured by artisanal fishery in the southern Gulf of California, Mexico. *Journal of Applied Ichthyology* 33, 1051-1054.

Erisman, B.E., Apel, A.M., MacCall, A.D., Román, M.J., Fujita, R., 2014. The influence of gear selectivity and spawning behavior on a data-poor assessment of a spawning aggregation fishery. *Fisheries Research* 159, 75-87.

Escobar, A., 2008. Territories of difference: place, movements, life, redes. Duke University Press. Durham, 437 p.

Espino-Barr, E., Nava Ortega, R.A., Gallardo-Cabello, M., Cabral-Solís, E.G., Puente-Gómez, M., García-Boa, A., 2012. Aspects of *Scomberomorus sierra* fishery from the coast of Colima, Mexico. *Cienc. Pesq.* 20, 77-88.

Espinosa, S., Delgado, M., Orobio, B., Mejía-Ladino, L., Gil-Agudelo, D., 2010. Estado de la población y valoración de algunas estrategias de conservación del recurso piangua *Anadara tuberculosa* (Sowerby) en sectores de Bazán y Nerete, costa Pacífica nariñense de Colombia. *Boletín de Investigaciones Marinas y Costeras* 39, 161-176.

Etter, A., McAlpine, C., Wilson, K., Phinn, S., Possingham, H., 2006. Regional patterns of agricultural land use and deforestation in Colombia. *Agriculture, Ecosystems & Environment* 114, 369-386.

FAO, 1995. Code of conduct for responsible fishing. Fishing and Agriculture Organization of the United Nations (FAO). Rome, 42 p.

FAO, 2000. Conversion factors: landed weigth to live weight. Food and Agricultural Organization of the United Nations (FAO). Fishery Information, Data and Statistic Unit, Rome, 378 p.

FAO, 2015a. Voluntary guidelines for securing sustainable small-scale fisheries in the context of food security and poverty eradication. Food and Agriculture Organization of the United Nations (FAO), Rome, 34 p.

FAO, 2015b. Colombia: Pesca en Cifras 2014. Fishing and Agriculture Organization of the United Nations (FAO). Bogotá, D.C., 52 p.

FAO, 2018a. The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals. Food and Agriculture Organization of the United Nations (FAO), Rome, 210 p.

FAO, 2018b. Handbook of fishery statistical standards. Coordinating Working Party on Fishery Statistics (CWP). Food and Agriculture Organization of the United Nations (FAO). www.fao.org/cwp-on-fishery-statistics/handbook/en/.

Fisher, W., Krupp, F., Schneider, W., Sommer, C., Carpenter, K., Niem, V., 1995. Guía FAO para la identificación de especies para los fines de la pesca: Pacífico Centro-Oriental. Vol. I, II and III. Roma.

Frank, K.T., Petrie, B., Leggett, W.C., Boyce, D.G., 2018. Exploitation drives an ontogenetic-like deepening in marine fish. *Proceedings of the National Academy of Sciences* 115, 6422-6427.

Froese, R., 2004. Keep it simple: three indicators to deal with overfishing. *Fish and Fisheries* 5, 86-91.

Froese, R., Binohlan, C., 2000. Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. *Journal of Fish Biology* 56, 758-773.

Froese, R., Pauly, D., 2017. FishBase. World Wide Web electronic publication. www.fishbase.org, version (10/2017) ed.

Froese, R., Stern-Pirlot, A., Winker, H., Gascuel, D., 2008. Size matters: how single-species management can contribute to ecosystem-based fisheries management. *Fisheries Research* 92, 231-241.

Froese, R., Walters, C., Pauly, D., Winker, H., Weyl, O.L., Demirel, N., Tsikliras, A.C., Holt, S.J., 2015. A critique of the balanced harvesting approach to fishing. *ICES Journal of Marine Science* 73, 1640-1650.

Fujita, R., Bonzon, K., 2005. Rights-based fisheries management: an environmentalist perspective. *Reviews in Fish Biology and Fisheries* 15, 309-312.

Fulton, E.A., Smith, A.D., Punt, A.E., 2005. Which ecological indicators can robustly detect effects of fishing? *ICES Journal of Marine Science* 62, 540-551.

Fulton, E.A., Smith, A.D., Smith, D.C., van Putten, I.E., 2011. Human behaviour: the key source of uncertainty in fisheries management. *Fish and Fisheries* 12, 2-17.

Garcia, S.M., 2003. The ecosystem approach to fisheries: issues, terminology, principles, institutional foundations, implementation and outlook. FAO Fisheries Technical Paper No. 443. Rome, FAO. 2003. 71 p.

García-Rodríguez, M., Fernández, Á.M., Esteban, A., 2006. Characterisation, analysis and catch rates of the small-scale fisheries of the Alicante Gulf (SE Spain) over a 10 years time series. *Fisheries Research* 77, 226-238.

Garcia, S., Kolding, J., Rice, J., Rochet, M.-J., Zhou, S., Arimoto, T., Beyer, J., Borges, L., Bundy, A., Dunn, D., 2012. Reconsidering the consequences of selective fisheries. *Science* 335, 1045-1047.

Garcia, S., Rice, J., Charles, A., 2015. Balanced harvesting in fisheries: a preliminary analysis of management implications. *ICES Journal of Marine Science* 73, 1668-1678.

Gascuel, D., Coll, M., Fox, C., Guénette, S., Guitton, J., Kenny, A., Knittweis, L., Nielsen, J.R., Piet, G., Raid, T., 2016. Fishing impact and environmental status in European seas: a diagnosis from stock assessments and ecosystem indicators. *Fish and Fisheries* 17, 31-55.

Gelcich, S., Fernández, M., Godoy, N., Canepa, A., Prado, L., Castilla, J.C., 2012. Territorial user rights for fisheries as ancillary instruments for marine coastal conservation in Chile. *Conservation Biology* 26, 1005-1015.

Gelcich, S., Martínez-Harms, M.J., Tapia-Lewin, S., Vasquez-Lavin, F., Ruano-Chamorro, C., 2019. Comanagement of small-scale fisheries and ecosystem services. *Conservation Letters*, e12637.

Gislason, H., Daan, N., Rice, J.C., Pope, J.G., 2010. Size, growth, temperature and the natural mortality of marine fish. *Fish and Fisheries* 11, 149-158.

Glaser, M., Christie, P., Diele, K., Dsikowitzky, L., Ferse, S., Nordhaus, I., Schlüter, A., Manez, K.S., Wild, C., 2012. Measuring and understanding sustainability-enhancing processes in tropical coastal and marine social–ecological systems. *Current Opinion in Environmental Sustainability* 4, 300-308.

Greenstreet, S.P., Rogers, S.I., 2006. Indicators of the health of the North Sea fish community: identifying reference levels for an ecosystem approach to management. *ICES Journal of Marine Science* 63, 573-593.

Guénette, S., Gascuel, D., 2012. Shifting baselines in European fisheries: the case of the Celtic Sea and Bay of Biscay. *Ocean & Coastal Management* 70, 10-21.

Gulland, J.A., 1971. The fish resources of the ocean. Fishing News Ltda, Surrey, England. 284 p.

Gutiérrez, N.L., Hilborn, R., Defeo, O., 2011. Leadership, social capital and incentives promote successful fisheries. *Nature* 470, 386.

Harrington, J.M., Myers, R.A., Rosenberg, A.A., 2005. Wasted fishery resources: discarded by-catch in the USA. *Fish and Fisheries* 6, 350-361.

Heibo, E., Magnhagen, C., Vøllestad, L.A., 2005. Latitudinal variation in life-history traits in Eurasian perch. *Ecology* 86, 3377-3386.

Herrera, M., Clarke, T.M., Naranjo-Elizondo, B., Espinoza, M., Wehrtmann, I.S., 2016. Size at maturity of the Pacific Bearded Brotula (Ophidiidae: *Brotula clarkae*): a commercially exploited species in the Pacific of Costa Rica. *Latin American Journal of Aquatic Research* 44, 657.

Herrón, P., Mildenberger, T.K., Diaz, J.M., Wolff, M., 2018. Assessment of the stock status of small-scale and multi-gear fisheries resources in the tropical Eastern Pacific region. *Regional Studies in Marine Science* 24, 311-323.

Herrón, P., Stäbler, M., Castellanos-Galindo, G., Díaz, J.M., Wolff, M., 2019a. Towards ecosystem-based assessment and management of small-scale and multi-gear fisheries: insights from the tropical eastern Pacific. *Frontiers in Marine Science* 6, 127.

Herrón, P., Kluger, L.C., Castellanos-Galindo, G., Wolff, M., Glaser, M., 2019b. Understanding gear choices and identifying leverage points for sustainable tropical small-scale marine fisheries. Manuscript submitted for publication to *Ocean and Coastal Management*.

Hilborn, R., Branch, T.A., Ernst, B., Magnusson, A., Minte-Vera, C.V., Scheuerell, M.D., Valero, J.L., 2003. State of the world's fisheries. *Annual Review of Environment and Resources* 28, 359-399.

Hilborn, R., Walters, C.J., 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Champan and Hall, Inc., New York.

Honey, K.T., Moxley, J.H., Fujita, R.M., 2010. From rags to fishes: data-poor methods for fishery managers. *Managing Data-Poor Fisheries: Case Studies, Models & Solutions* 1, 159-184.

Hordyk, A. R., Ono, K., Prince, J. D., Walters, C. J., 2016. A simple length-structured model based on life history ratios and incorporating size-dependent selectivity: application to spawning potential ratios for data-poor stocks. *Canadian Journal of Fisheries and Aquatic Sciences* 73(12), 1787-1799.

Hubbs, C.L., 1944. Species of the circumtropical fish genus *Brotula*. *Copeia* 3, 162–178.

Ibáñez, A.M., Vélez, C.E., 2008. Civil conflict and forced migration: The micro determinants and welfare losses of displacement in Colombia. *World Development* 36, 659-676.

IDEAM, 2005. Atlas climatológico de Colombia, Bogotá. 217 p.

INCODER, 2004. Resolución 00695. Por la cual se prohíben unos artes de pesca utilizados para la captura del Camarón de Aguas Someras. Instituto Colombiano de Desarrollo Rural - INCODER, Diario Oficial No. 45.545. 11 de Mayo de 2004, Bogotá.

INPA, 2000. Resolución 539 del Instituto Nacional de Pesca y Acuicultura (INPA). Por la cual se regula la talla mínima de captura de la piangua (*Anadara tuberculosa*) en el Pacífico colombiano.

INVEMAR-CVC, 2007. Monitoreo de los manglares del Valle del Cauca y la fauna asociada, con énfasis en las aves y especies de importancia económica como la piangua y el cangrejo azul, Informe Técnico Final. Convenio 174 de 2005 entre INVEMAR y CVC., Buenaventura, 152 p.

INVEMAR, 2010. Potencial productivo de las poblaciones naturales de la piangua *Anadara tuberculosa* y *Anadara similis* dentro de una perspectiva espacio-temporal en la costa Pacífica colombiana. Informe final. Contrato: 161-2008T6344-3459. Instituto de Investigaciones Marinas y Costeras "José Benito Vives de Andréis" - INVEMAR, 283 p.

IUCN, 2017. The IUCN red list of threatened species. Version 2017-3. International Union for Conservation of Nature - IUCN. www.iucnredlist.org.

Jacobsen, N.S., Gislason, H., Andersen, K.H., 2014. The consequences of balanced harvesting of fish communities. *Proceedings of the Royal Society of London B: Biological Sciences* 281, 20132701.

Jacquet, J., Fox, H., Motta, H., Ngusaru, A., Zeller, D., 2010. Few data but many fish: marine small-scale fisheries catches for Mozambique and Tanzania. *African Journal of Marine Science* 32, 197-206.

Jara-Baquero, A.C., 2018. Integration of scientific and local knowledge in data-poor fisheries assessments (Ph.D thesis). Oregon State University. Corvallis, U.S.

Jennings, S., 2005. Indicators to support an ecosystem approach to fisheries. *Fish and Fisheries* 6, 212-232.

Jennings, S., Dulvy, N.K., 2005. Reference points and reference directions for size-based indicators of community structure. *ICES Journal of Marine Science* 62, 397-404.

Jennings, S., Kaiser, M.J., 1998. The effects of fishing on marine ecosystems, in: Blaxter, J.H.S., Southward, A.J., Tyler, P.A. (Eds.), Advances in Marine Biology. Academic Press, pp. 201-352.

Jennings, S., Reynolds, J.D., Mills, S.C., 1998. Life history correlates of responses to fisheries exploitation. *Proceedings of the Royal Society of London B: Biological Sciences* 265, 333-339.

Jennings, S., Reynolds, J.D., Polunin, N.V., 1999. Predicting the vulnerability of tropical reef fishes to exploitation with phylogenies and life histories. *Conservation Biology* 13, 1466-1475.

Jennings, S., Greenstreet, S., Hill, L., Piet, G., Pinnegar, J., Warr, K.J., 2002. Long-term trends in the trophic structure of the North Sea fish community: evidence from stable-isotope analysis, size-spectra and community metrics. *Marine Biology* 141, 1085-1097.

Jentoft, S., 2000. The community: a missing link of fisheries management. *Marine Policy* 24, 53-60.

Johnson, A.G., Fable Jr, W.A., Grimes, C.B., Trent, L., Vasconcelos Perez, J., 1994. Evidence for distinct stocks of king mackerel, *Scomberomorus cavalla*, in the Gulf of Mexico. *Fishery Bulletin* 92, 91-101.

Jordan, D.S., Starks, E.C., 1895. *Scomberomous sierra.* The fishes of Sinaloa. Proceedings of the California Academy of Sciences (Series 2), 5, 377–514.

Jupiter, S. D., Cohen, P. J., Weeks, R., Tawake, A., Govan, H., 2014. Locally-managed marine areas: multiple objectives and diverse strategies. *Pacific Conservation Biology*, 20(2), 165-179.

Kato, Y., Davis, A., Ruddle, K., 2012. Appropriate management for small-scale tropical fisheries. SPC Traditional Marine Resource Management and Knowledge Information Bulletin #30, 13.

Keen, A.M., 1971. Sea shells of tropical west America: Marine Mollusks from Baja California to Peru. Stanford University Press. 1064 p.

Kelleher, K., 2005. Discards in the world's marine fisheries: an update. Food and Agriculture Organization of the United Nations (FAO). FAO Fisheries Technical Paper. Rome, 131 p.

King, M., 2007. Fisheries biology, assessment and management. 2nd edition. Blackwell Publishing. Oxford, 400 p.

Kittinger, J.N., Finkbeiner, E.M., Ban, N.C., Broad, K., Carr, M.H., Cinner, J.E., Gelcich, S., Cornwell, M.L., Koehn, J.Z., Basurto, X., 2013. Emerging frontiers in social-ecological systems research for sustainability of small-scale fisheries. *Current Opinion in Environmental Sustainability* 5, 352-357.

Kluger, L. C., Taylor, M. H., Wolff, M., Stotz, W., Mendo, J., 2019. From an open-access fishery to a regulated aquaculture business: the case of the most important Latin American bay scallop (*Argopecten purpuratus*). *Reviews in Aquaculture*, 11(1), 187-203.

Kolding, J., Béné, C., Bavinck, M., 2014. Small-scale fisheries, in: Garcia, S.M., Rice, J., Charles, A. (Eds.), Governance of Marine Fisheries and Biodiversity Conservation: Interaction and Coevolution, pp. 317-331.

Kolding, J., Jacobsen, N.S., Andersen, K.H., van Zwieten, P.A., 2015a. Maximizing fisheries yields while maintaining community structure. *Canadian Journal of Fisheries and Aquatic Sciences* 73, 644-655.

Kolding, J., Bundy, A., van Zwieten, P.A., Plank, M.J., 2015b. Fisheries, the inverted food pyramid. *ICES Journal of Marine Science* 73, 1697-1713.

Kronen, M., 2004. Fishing for fortunes?: A socio-economic assessment of Tonga's artisanal fisheries. *Fisheries Research* 70, 121-134.

Kronen, M., Vunisea, A., Magron, F., McArdle, B., 2010. Socio-economic drivers and indicators for artisanal coastal fisheries in Pacific island countries and territories and their use for fisheries management strategies. *Marine Policy* 34, 1135-1143.

Law, R., Plank, M.J., Kolding, J., 2012. On balanced exploitation of marine ecosystems: results from dynamic size spectra. *ICES Journal of Marine Science* 69, 602-614.

Link, J.S., 2005. Translating ecosystem indicators into decision criteria. *ICES Journal of Marine Science* 62, 569-576.

Link, J.S., Brodziak, J.K., Edwards, S.F., Overholtz, W.J., Mountain, D., Jossi, J.W., Smith, T.D., Fogarty, M.J., 2002. Marine ecosystem assessment in a fisheries management context. *Canadian Journal of Fisheries and Aquatic Sciences* 59, 1429-1440.

López-Angarita, J., Tilley, A., Díaz, J.M., Hawkins, J.P., Cagua, E.F., Roberts, C.M., 2018. Winners and losers in area-based management of a small-scale fishery in the Colombian Pacific. *Frontiers in Marine Science* 5, 23.

Lucano-Ramírez, G., Ruiz-Ramírez, S., Palomera-Sánchez, F., González-Sansón, G., 2011. Biología reproductiva de la sierra *Scomberomorus sierra* (Pisces, Scombridae) en el Pacífico central mexicano. *Ciencias Marinas* 37, 249-260.

MADR, 2015. Avanza programa de intercambio de artes de pesca no legales por reglamentarias en la costa Pacífica. Ministerio de Agricultura y Desarrollo Rural, Bogotá. www.minagricultura.gov.co/noticias/Paginas/Intercambio-de-artes-de-pesca.aspx.

Mangi, S.C., Roberts, C.M., Rodwell, L.D., 2007. Financial comparisons of fishing gear used in Kenya's coral reef lagoons. *Ambio* 36, 671-677.

Marceniuk, A.P., Acero, P., 2009. A new species of *Cathorops* (Siluriformes; Ariidae) from Mesoamerica, with redescription of four species from the eastern Pacific. *Bulletin of Marine Science* 85, 245-280.

Martínez-Ortiz, J., Aires-da-Silva, A.M., Lennert-Cody, C.E., Maunder, M.N., 2015. The Ecuadorian artisanal fishery for large pelagics: species composition and spatio-temporal dynamics. *PloS one* 10, e0135136.

Martínez, J., González, J., Pilkey, O., Neal, W., 1995. Tropical barrier islands of Colombia's Pacific coast. *Journal of Coastal Research* 11, 432-453.

MarViva, 2014. Monitoreo participativo de la pesca artesanal en la zona exlusiva de pesca artesanal (ZEPA) del norte del Pacífico colombiano (2011-2014). Anexo 1 del Informe Final de Actividades. Convenio de donación No.

BR-GRANT-FOG-003. Programa BIOREDD+ de USAID. Fundación MarViva. Bogotá, 59 p.

Maunder, M., Crone, P., Valero, J., Semmens, B., 2014. Selectivity: theory, estimation, and application in fishery stock assessment models. *Fisheries Research* 158, 1-4.

Maunder, M.N., Piner, K.R., 2014. Contemporary fisheries stock assessment: many issues still remain. *ICES Journal of Marine Science* 72, 7-18.

McAllister, M. K., Pikitch, E. K., Punt, A. E., Hilborn, R., 1994. A Bayesian approach to stock assessment and harvest decisions using the sampling/importance resampling algorithm. *Canadian Journal of Fisheries and Aquatic Sciences* 51(12), 2673-2687.

McClanahan, T., Mangi, S., 2004. Gear-based management of a tropical artisanal fishery based on species selectivity and capture size. *Fisheries Management and Ecology* 11, 51-60.

McClanahan, T.R., 2010. Effects of fisheries closures and gear restrictions on fishing income in a Kenyan coral reef. *Conservation Biology* 24, 1519-1528.

McClanahan, T.R., Muthiga, N.A., 1988. Changes in Kenyan coral reef community structure and function due to exploitation. *Hydrobiologia* 166, 269-276.

McCluskey, S.M., Lewison, R.L., 2008. Quantifying fishing effort: a synthesis of current methods and their applications. *Fish and Fisheries* 9, 188-200.

McHugh, M.J., Broadhurst, M.K., Sterling, D.J., 2017. Choosing anterior-gear modifications to reduce the global environmental impacts of penaeid trawls. *Reviews in Fish Biology and Fisheries* 27, 111-134.

Meadows, D., 1999. Leverage points-places to intervene in a system. The Sustainability Institute, Hartland, Vermont, 21 p.

Medina Gomez, S.P., 2006. Edad y crecimiento de la sierra del Pacifico *Scomberomorus sierra* (Jordan y Starks, 1895), en el Golfo de California, Mexico (M.Sc. thesis). Ciudad de Panamá, Panamá.

Mejía-Rentería, J.C., Castellanos-Galindo, G.A., Cantera-Kintz, J.R., Hamilton, S.E., 2018. A comparison of Colombian Pacific mangrove extent estimations: implications for the conservation of a unique Neotropical tidal forest. *Estuarine, Coastal and Shelf Science* 212, 233-240.

Methot Jr, R. D., Wetzel, C. R., 2013. Stock synthesis: a biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research* 142, 86-99.

Mildenberger, T.K., Taylor, M., Wolff, M., 2017. TropFishR: an R package for fisheries analysis with length-frequency data. *Methods in Ecology and Evolution* 1520-1527.

Millar, R.B., Fryer, R.J., 1999. Estimating the size-selection curves of towed gears, traps, nets and hooks. *Reviews in Fish Biology and Fisheries* 9, 89-116.

Millar, R.B., Holst, R., 1997. Estimation of gillnet and hook selectivity using log-linear models. *ICES Journal of Marine Science* 54, 471-477.

Milton, D.A., 2001. Assessing the susceptibility to fishing of populations of rare trawl bycatch: sea snakes caught by Australia's Northern Prawn Fishery. *Biological Conservation* 101, 281-290.

Mora, C., Myers, R.A., Coll, M., Libralato, S., Pitcher, T.J., Sumaila, R.U., Zeller, D., Watson, R., Gaston, K.J., Worm, B., 2009. Management effectiveness of the world's marine fisheries. *PLoS biology* 7, e1000131.

Morales-Betancourt, M.A., Lasso, C.A., Páez, V.P., Bock, B.C., 2015. Libro Rojo de Reptiles de Colombia. Instituto de Investigación de Recursos Biológicos Alexander von Humboldt (IAvH), Universidad de Antioquia. Bogotá, D. C., Colombia. 258 p.

Morales-Nin, B., Panfili, J., 2005. Seasonality in the deep sea and tropics revisited: what can otoliths tell us? *Marine and Freshwater Research* 56, 585-598.

Muñoz, O.F., 1999. Aspectos de la biología (crecimiento, hábitos alimenticios y reproducción) de *Brotula clarkae* (Pisces: Ophidiidae) en el PNN Gorgona, Colombia (B.Sc. thesis). Universidad del Valle, Cali, Colombia.

Musiello-Fernandes, J., Zappes, C.A., Hostim-Silva, M., 2017. Small-scale shrimp fisheries on the Brazilian coast: stakeholders perceptions of the closed season and integrated management. *Ocean & Coastal Management* 148, 89-96.

Myers, R., Mertz, G., 1998. The limits of exploitation: a precautionary approach. *Ecological Applications* 8, S165-S169.

Nakazawa, M., 2018. fmsb: Functions for medical statistics book with some Demographic Data. R package version 0.6.3.

Naranjo-Madrigal, H., van Putten, I., Norman-López, A., 2015. Understanding socio-ecological drivers of spatial allocation choice in a multi-species artisanal fishery: a Bayesian network modeling approach. *Marine Policy* 62, 102-115.

Naranjo-Elizondo, B., Espinoza, M., Herrera, M., Clarke, T., Wehrtmann, I.S., 2016. Feeding habits of the Pacific Bearded Brotula *Brotula clarkae* Hubbs, 1944 (Ophidiidae) along the Pacific coast of Costa Rica, Central America. *Journal of Applied Ichthyology* 32, 439-447.

Nava-Ortega, R.A., Espino-Barr, E., Gallardo-Cabello, M., Garcia-Boa, A., Puente-Gómez, M., Cabral-Solís, E.G., 2012. Growth analysis of the Pacific sierra *Scomberomorus sierra* in Colima, México. *Revista de Biología Marina y Oceanografía* 47 (2), 273-281.

Nielsen-Muñoz, V., Quesada-Alpízar, M.A., 2006. Informe técnico ambientes marino costeros de Costa Rica. CIMAR - Conservación Internacional - The Nature Conservancy. Comisión Interdisciplinaria Marino Costera de la Zona Económica Exclusiva de Costa Rica, 221 p.

Obura, D.O., 2001. Participatory monitoring of shallow tropical marine fisheries by artisanal fishers in Diani, Kenya. *Bulletin of Marine Science* 69, 777-791.

OECD, 2016. Fisheries and Aquaculture in Colombia. www.oecd.org/countries/colombia/Fisheries_Colombia_2016.pdf.

Offen, K.H., 2003. The territorial turn: making black territories in Pacific Colombia. *Journal of Latin American Geography* 2 (1), 43-73.

Olsgard, F., Schaanning, M.T., Widdicombe, S., Kendall, M.A., Austen, M.C., 2008. Effects of bottom trawling on ecosystem functioning. *Journal of Experimental Marine Biology and Ecology* 366, 123-133.

Omori, K.L., Hoenig, J.M., Luehring, M.A., Baier-Lockhart, K., 2016. Effects of underestimating catch and effort on surplus production models. *Fisheries Research* 183, 138-145.

Ordoñez, J.F.E., Bustos-Montes, D.M., Salas-Castro, S., Girón, A., Rueda, M., 2017. Fecundidad de *Scomberomorus sierra* (Perciformes: Scombridae) en el Pacífico Colombiano. *Boletín de Investigaciones Marinas y Costeras* 46 (1), 29-44.

Ortega, I., Colling, L.A., Dumont, L.F.C., 2018. Response of soft-bottom macrobenthic assemblages to artisanal trawling fisheries in a subtropical estuary. *Estuarine, Coastal and Shelf Science* 207, 142-153.

Ortiz, M., Wolff, M., 2002. Trophic models of four benthic communities in Tongoy Bay (Chile): comparative analysis and preliminary assessment of management strategies. *Journal of Experimental Marine Biology and Ecology* 268, 205-235.

Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. *Science* 325, 419-422.

Palomares, M.L.D., Pauly, D., 2018. SeaLifeBase. World Wide Web electronic publication. www.sealifebase.org. Version (02/2018).

Parker, R.W., Tyedmers, P.H., 2015. Fuel consumption of global fishing fleets: current understanding and knowledge gaps. *Fish and Fisheries* 16, 684-696.

Patrick, W.S., Spencer, P., Link, J., Cope, J., Field, J., Kobayashi, D., Lawson, P., Gedamke, T., Cortés, E., Ormseth, O., 2010. Using productivity and susceptibility indices to assess the vulnerability of United States fish stocks to overfishing. *Fishery Bulletin* 108, 305-322.

Pauly, D., 1982. Studying single-species dynamics in a tropical multispecies context, in: Pauly, D., Murphy, G.I. (Eds.), Theory And Management of Tropical Fisheries. ICLARM Conference Proceedings, vol. 9, International Centre for Living Aquatic Resources., Manila, Philippines, pp. 33-70.

Pauly, D., 1984. Fish population dynamics in tropical waters: a manual for use with programmable calculators. Studies and Reviews (Vol. 8). International Center for Living Aquatic Resource Management (ICLARM) – Studies and Reviews vol. 8, Manila, 325 p.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., Torres, F., 1998. Fishing down marine food webs. *Science* 279, 860-863.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R., Zeller, D., 2002. Towards sustainability in world fisheries. *Nature* 418, 689-695.

Pauly, D., David, N., 1980. An objective method for determining fish growth from length-frequency data. ICLARM Newsletter 3 (3), 13–15.

Pauly, D., David, N., 1981. ELEFAN I, a basic program for the objective extraction of growth parameters from length-frequency data. Ber. Dtsch. Wiss. Kommissuib Meeresforsch. 28 (4), 205–211.

Pauly, D., Zeller, D., 2016. Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nature communications* 7, ncomms10244.

Pebesma, E., 2018. Simple Features for R: Standardized Support for Spatial Vector Data. The R Journal, https://journal.r-project.org/archive/2018/RJ-2018-009/.

Pebesma, E.J., Bivand, R.S., 2005. Classes and methods for spatial data in R. R News 5 (2). https://cran.r-project.org/doc/Rnews/.

Pelletier, D., Ferraris, J., 2000. A multivariate approach for defining fishing tactics from commercial catch and effort data. *Canadian Journal of Fisheries and Aquatic Sciences* 57, 51-65.

Pennington, J.T., Mahoney, K.L., Kuwahara, V.S., Kolber, D.D., Calienes, R., Chavez, F.P., 2006. Primary production in the eastern tropical Pacific: A review. *Progress in Oceanography* 69, 285-317.

Pikitch, E., Santora, C., Babcock, E., Bakun, A., Bonfil, R., Conover, D., Dayton, P., et al., Doukakis, P., Fluharty, D., Heneman, B., 2004. Ecosystem-based fishery management. *Science* 305, 346-347.

Pinnegar, J.K., Jennings, S., O'Brien, C., Polunin, N., 2002. Long-term changes in the trophic level of the Celtic Sea fish community and fish market price distribution. *Journal of Applied Ecology* 39, 377-390.

Pitcher, T.J., Preikshot, D., 2001. RAPFISH: a rapid appraisal technique to evaluate the sustainability status of fisheries. *Fisheries Research* 49, 255-270.

Pitcher, T.J., Watson, R., Forrest, R., Valtýsson, H.Þ., Guénette, S., 2002. Estimating illegal and unreported catches from marine ecosystems: a basis for change. *Fish and Fisheries* 3, 317-339.

PNN, 2006. Plan de manejo Parque Nacional Natural Utria. Parques Nacionales Naturales de Colombia (PNN). Bahia Solano, Colombia, 223 p.

PNN, 2011. Plan de manejo recursos hidrobiologicos y pesqueros Parque Nacional Natural Utría. Parques Nacionales Naturales de Colombia (PNN) - Dirección Territorial Pacifico, El Valle - Chocó, Colombia, 32 p.

PNUD, 2012. Colección cuadernos de informes de desarrollo humano 2011. Afro-Colombianos: sus territorios y condiciones de vida. PNUD - Programa de las Naciones Unidas para el Desarrollo, Bogotá, 112 p.

Polidoro, B.A., Brooks, T., Carpenter, K.E., Edgar, G., Henderson, S., Sanciangco, J., Robertson, D.R., 2012. Patterns of extinction risk and threat for marine vertebrates and habitat-forming species in the Tropical Eastern Pacific. *Marine Ecology Progress Series* 448, 93-104.

Pollnac, R.B., Poggie, J.J., 2006. Job satisfaction in the fishery in two southeast Alaskan towns. *Human Organization* 65, 329.

Pollnac, R.B., Poggie, J.J., 2008. Happiness, well-being and psychocultural adaptation to the stresses associated with marine fishing. *Human Ecology Review* 15, 194-200.

Pomeroy, R.S., 2012. Managing overcapacity in small-scale fisheries in Southeast Asia. *Marine Policy* 36, 520-527.

Poveda, G., Waylen, P.R., Pulwarty, R.S., 2006. Annual and inter-annual variability of the present climate in northern South America and southern Mesoamerica. *Palaeogeography, Palaeoclimatology, Palaeoecology* 234 (1), 3-27.

Previero, M., Minte-Vera, C.V., Moura, R.L.d., 2013. Fisheries monitoring in Babel: fish ethnotaxonomy in a hotspot of common names. *Neotropical Ichthyology* 11, 467-476.

Primavera, J., 1998. Mangroves as nurseries: shrimp populations in mangrove and non-mangrove habitats. *Estuarine, Coastal and Shelf Science* 46, 457-464.

Puentes, V., Escobar, F., Polo, C., Alonso, J.C., 2014a. Estado de los principales recursos pesqueros de Colombia - 2014. Serie Recursos Pesqueros de Colombia. Autoridad Nacional de Acui

cultura y Pesca – AUNAP. Oficina de Generación del Conocimiento y la Información, Bogotá, 244 p.

Puentes, V., Polo, C.J., Roldán, A.M., A., Z.P., 2014b. Artes y métodos de pesca en Colombia. Serie Recursos Pesqueros de Colombia. Autoridad Nacional de Acuicultura y Pesca – AUNAP, Conservación Internacional - CI Colombia, Bogotá, 216 p.

Punt, A.E., Hurtado-Ferro, F., Whitten, A.R., 2014. Model selection for selectivity in fisheries stock assessments. *Fisheries Research* 158, 124-134.

Purcell, S.W., Fraser, N., Tagica, S., Lalavanua, W., Ceccarelli, D.M., 2018. Discriminating catch composition and fishing modes in an artisanal multispecies fishery. *Frontiers in Marine Science* 5, 243.

Purcell, S.W., Pomeroy, R.S., 2015. Driving small-scale fisheries in developing countries. *Frontiers in Marine Science* 2, 1-7.

Quynh, C.N.T., Schilizzi, S., Hailu, A., Iftekhar, S., 2017. Territorial Use Rights for Fisheries (TURFs): State of the art and the road ahead. *Marine Policy* 75, 41-52.

R-Core-Team, 2018. A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Ramírez-Luna, V., Chuenpagdee, R., 2019. Exclusive fishing zone for small-scale fisheries in northern Chocó, Colombia: pre-and post-implementation, in: Salas, S., Barragan-Paladines, M.J., Chuenpagdee, R. (Eds.), Viability and Sustainability of Small-Scale Fisheries in Latin America and The Caribbean. pp. 197-217. Springer International Publishing, Cham.

Ramírez, J.G., Lleonart, J., Coll, M., Reyes, F., Puentes, G.M., 2017. Improving stock assessment and management advice for data-poor small-scale fisheries through participatory monitoring. *Fisheries Research* 190, 71-83.

Reed, J., Shannon, L., Velez, L., Akoglu, E., Bundy, A., Coll, M., Fu, C., Fulton, E.A., Grüss, A., Halouani, G., 2016. Ecosystem indicators - accounting for variability in species' trophic levels. *ICES Journal of Marine Science* 74, 158-169.

Reeves, S.A., Marchal, P., Mardle, S., Pascoe, S., Prellezo, R., Thébaud, O., Travers, M., 2008. From fish to fisheries: the changing focus of management advice. *Advances in Fisheries Science* 50, 135-144.

Rehren, J., 2017. Modelling the multispecies fishery of Chwaka bay, Zanzibar – basis for exploration of use and conservation scenarios (Ph.D. thesis) University of Bremen, Bremen, Germany.

Rehren, J., Wolff, M., Jiddawi, N., 2018. Holistic assessment of Chwaka Bay's multi-gear fishery – Using a trophic modeling approach. *Journal of Marine Systems* 180, 265-278.

Resilience_Alliance, 2010. Assessing and managing resilience in social-ecological systems: A practitioners workbook. Version 2.0. www.resalliance.org/3871.php.

Robertson, D.R., Allen, G.R., 2015. Shorefishes of the Tropical Eastern Pacific: online information system. Smithsonian Tropical Research Institute, Balboa, Panamá. https://biogeodb.stri.si.edu/sftep/

Rochet, M.-J., Trenkel, V.M., 2003. Which community indicators can measure the impact of fishing? A review and proposals. *Canadian Journal of Fisheries and Aquatic Sciences* 60, 86-99.

Rojas, J.R., 1997. Fecundidad y épocas de reproducción del "pargo mancha" *Lutjanus guttatus* (Pisces: Lutjanidae) en el Golfo de Nicoya, Costa Rica. *Revista de Biología Tropical* 44, 477-487.

Romanuk, T.N., Hayward, A., Hutchings, J.A., 2011. Trophic level scales positively with body size in fishes. *Glob. Ecol. Biogeogr.* 20, 231-240.

Rowell, C.A., 1993. The effects of fishing on the timing of maturity in North Sea cod (*Gadus morhua* L.), in: Stokes, K., McGlade, J.M., Law, R. (Eds.), The Exploitation of Evolving Resources. Springer, Berlin, Heidelberg, pp. 44-61.

Rudd, M.B., Thorson, J.T., 2017. Accounting for variable recruitment and fishing mortality in length-based stock assessments for data-limited fisheries. *Canadian Journal of Fisheries and Aquatic Sciences* 75, 1019-1035.

Rueda, M., Bustos, D., Viloria, E., Rodríguez, A., Viaña, J., Girón, A., Correa, J., Romero, J., Chávez, S., 2014. Pesquería Industrial del Camarón de Aguas Someras (CAS) y Camarón de Aguas Profundas (CAP). in: Puentes, V., Escobar, F.D., Polo, C.J., Alonso, J.C. (Eds.), Estado de los Principales Recursos Pesqueros de Colombia - 2014. Serie Recursos Pesqueros de Colombia – AUNAP. Oficina de Generación del Conocimiento y la Información, Autoridad Nacional de Acuicultura y Pesca – AUNAP, Bogotá, D.C., pp. 129 - 142.

Rueda, M., Mármol, D., Viloria, E.A., O., D., Rico- Mejía, F., García, L., Girón, A., 2010. Identificación, ubicación y extensión de caladeros de pesca artesanal e industrial en el territorio marino-costero de Colombia. Informe Técnico Final. INVEMAR, INCODER, AGENCIA NACIONAL DE HIDROCARBUROS-ANH., Santa Marta, 147 p.

Rueda, M., Rico-Mejía, F., Angulo, W., 2011. Evaluación y manejo de la pesquería industrial de camarón de aguas someras en el Pacífico colombiano, in: Diaz, J.M., Vieira, C.A., Melo, G. (Eds.), Diagnóstico de las Principales Pesquerías del Pacífico Colombiano. Fundación MarViva - Colombia, Bogotá, D.C., pp. 91-108.

Russell, L., 2018. emmeans: Estimated Marginal Means, aka Least-Squares Means., R package version 1.2.3. https://CRAN.R-project.org/package/emmeans.

Saavedra-Diaz, L.M., 2012. Towards Colombian small-scale marine fisheries management: hacia un manejo de la pesca marina artesanal en Colombia (Ph.D thesis). University of New Hampshire, Durham, U.S.

Saavedra-Díaz, L.M., Pomeroy, R., Rosenberg, A.A., 2016. Managing small-scale fisheries in Colombia. *Maritime Studies* 15, 6.

Saavedra-Díaz, L.M., Rosenberg, A.A., Martín-López, B., 2015. Social perceptions of Colombian small-scale marine fisheries conflicts: Insights for management. *Marine Policy* 56, 61-70.

Sahrhage, D., Lundbeck, J., 2012. A history of fishing. Springer Science & Business Media. Springer-Verlag Berlin Heidelberg, 348 p.

Salas, S., Barragan-Paladines, M.J., Chuenpagdee, R., 2019. Viability and sustainability of small-scale fisheries in Latin america and the Caribbean. MARE Publications Series, 19. Springer International Publishing, Cham, 574 p.

Salas, S., Chuenpagdee, R., Seijo, J.C., Charles, A., 2007. Challenges in the assessment and management of small-scale fisheries in Latin America and the Caribbean. *Fisheries Research* 87, 5-16.

Saldaña, A., Salas, S., Arce-Ibarra, A., Torres-Irineo, E., 2017. Fishing operations and adaptive strategies of small-scale fishers: insights for fisheries management in data-poor situations. *Fisheries Management and Ecology* 24, 19-32.

Sampson, D.B., 2014. Fishery selection and its relevance to stock assessment and fishery management. *Fisheries Research* 158, 5-14.

Sampson, G.S., Sanchirico, J.N., Roheim, C.A., Bush, S.R., Taylor, J.E., Allison, E.H., Anderson, J.L., Ban, N.C., Fujita, R., Jupiter, S., 2015. Secure sustainable seafood from developing countries. *Science* 348, 504-506.

Sánchez Jiménez, A., Fujitani, M., MacMillan, D., Schlüter, A., Wolff, M., 2019. Connecting a trophic model and local ecological knowledge to improve fisheries management: the case of Gulf of Nicoya, Costa Rica. *Frontiers in Marine Science* 6, 126.

Sarabia-Méndez, M., Gallardo-Cabello, M., Espino-Barr, E., Anislado-Tolentino, V., 2010. Characteristics of population dynamics of *Lutjanus guttatus* (Pisces: Lutjanidae) in Bufadero Bay, Michoacan, Mexico. *Hidrobiológica* 20, 147-157.

Sardà, F., Coll, M., Heymans, J.J., Stergiou, K.I., 2015. Overlooked impacts and challenges of the new European discard ban. *Fish and Fisheries* 16, 175-180.

Schuhbauer, A., Sumaila, R., 2015. Assessing the economic viability of small-scale fisheries – an indicators based framework. Fisheries Economic Research Unit and Too Big To Ignore. The University of British Columbia. 13 p.

Schwamborn, R., Mildenberger, T.K., Taylor, M.H., 2018. Assessing source of uncertainty in length-based estimates of body growth in populations of fishes and macroinvertebrates with bootstrapped ELEFAN. *Ecological Modelling*, 393, 37-51.

Scott, F., Jardim, E., Millar, C.P., Cerviño, S., 2016. An applied framework for incorporating multiple sources of uncertainty in fisheries stock assessments. *PloS one* 11, e0154922.

Selgrath, J.C., Gergel, S.E., Vincent, A.C., 2018. Shifting gears: Diversification, intensification, and effort increases in small-scale fisheries (1950-2010). *PloS one* 13, e0190232.

Sethi, S.A., Branch, T.A., Watson, R., 2010. Global fishery development patterns are driven by profit but not trophic level. *Proceedings of the National Academy of Sciences*, 201003236.

Shannon, L., Coll, M., Bundy, A., Gascuel, D., Heymans, J.J., Kleisner, K., Lynam, C.P., Piroddi, C., Tam, J., Travers-Trolet, M., 2014. Trophic level-based indicators to track fishing impacts across marine ecosystems. *Marine Ecology Progress Series* 512, 115-140.

Shin, Y.-J., Rochet, M.-J., Jennings, S., Field, J.G., Gislason, H., 2005. Using size-based indicators to evaluate the ecosystem effects of fishing. *ICES Journal of Marine Science* 62, 384-396.

Shin, Y.-J., Shannon, L.J., Bundy, A., Coll, M., Aydin, K., Bez, N., Blanchard, J.L., Borges, M.d.F., Diallo, I., Diaz, E., 2010. Using indicators for evaluating, comparing, and communicating the ecological status of exploited marine ecosystems. 2. Setting the scene. *ICES Journal of Marine Science* 67, 692-716.

Singh, G.G., Cisneros-Montemayor, A.M., Swartz, W., Cheung, W., Guy, J.A., Kenny, T.-A., McOwen, C.J., Asch, R., Geffert, J.L., Wabnitz, C.C., 2018. A rapid assessment of co-benefits and trade-offs among Sustainable Development Goals. *Marine Policy* 93, 223-231.

Somers, I., 1988. On a seasonally oscillating growth function. *Fishbyte* 6, 8-11.

Soto Rojas, R.L., Mejía-Arana, F., Palacios, J., Hiramatsu, K., 2009. Reproducción y crecimiento del pargo mancha *Lutjanus guttatus* (Pisces: Lutjanidae) en el Golfo de Nicoya, Costa Rica. *Revista de Biología Tropical* 57, 125-131.

Sparre, P., Venema, S.C., 1998. Introduction to tropical fish stock assessment. Fisheries and Agricultural Organization of the United Nations (FAO) Manual. http://www.fao.org/docrep/w5449e/w5449e00.htm.

Steindachner, F., 1869. Eine Abhandlung über einige neue Fischarten aus den Sammlungen des Wiener-Museums. Anzeiger der Kaiserlichen Akademie der Wissenschaften, Wien, Mathematisch-Naturwissenschaftliche Classe 6 (19), 149-150.

Stephenson, R.L., Benson, A.J., Brooks, K., Charles, A., Degnbol, P., Dichmont, C.M., Kraan, M., Pascoe, S., Paul, S.D., Rindorf, A., 2017. Practical steps toward integrating economic, social and institutional elements in fisheries policy and management. *ICES Journal of Marine Science* 74, 1981-1989.

Stevenson, C., Katz, L.S., Micheli, F., Block, B., Heiman, K.W., Perle, C., Weng, K., Dunbar, R., Witting, J., 2007. High apex predator biomass on remote Pacific islands. *Coral Reefs* 26, 47-51.

Suárez, A., 1992. Contribución al conocimiento biológico (hábitos alimenticios, crecimiento y ciclo sexual) de *Lutjanus guttatus* (Pisces: Lutjanidae) en la costa Pacífica de Colombia (B.Sc. thesis). Universidad del Valle, Cali, Colombia.

Taylor, Walters, C., Martell, S.J.D., 2005. A new likelihood for simultaneously estimating von Bertalanffy growth parameters, gear selectivity, and natural and fishing mortality. *Canadian Journal of Fisheries and Aquatic Sciences* 62, 215-223.

Taylor, M., Mildenberger, T.K., 2017. Extending electronic length frequency analysis in R. *Fisheries Management and Ecology* 24, 330-338.

Tesfaye, G., Wolff, M., 2018. Modeling trophic interactions and the impact of an introduced exotic carp species in the Rift Valley Lake Koka, Ethiopia. *Ecological Modelling* 378, 26-36.

Then, A.Y., Hoenig, J.M., Hall, N.G., Hewitt, D.A., 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. *ICES Journal of Marine Science* 72, 82-92.

Ticheler, H.J, Kolding, J., Chanda, B., 1998. Participation of local fishermen in scientific fisheries data collection: a case study from the Bangweulu Swamps, Zambia. *Fisheries Management and Ecology*, 5, 81-92.

Tilley, A., Herrón, P., Espinosa, S., Angarita, J.L., Box, S., 2018. Predicting vulnerability to management changes in data-limited, small-scale fisheries. *Marine Policy* 94, 39-45.

Torres-Guevara, L., Lopez, M., Schlüter, A., 2016. Understanding artisanal fishers' behaviors: the case of Ciénaga Grande de Santa Marta, Colombia. *Sustainability* 8, 549.

Tuda, P.M., 2018. Assessing the state and impacts of the artisanal reef fisheries and their management implications in Kenyan south coast (Ph.D thesis). University of Bremen, Bremen, Germany.

Tuda, P.M., Wolff, M., Breckwoldt, A., 2016. Size structure and gear selectivity of target species in the multispecies multigear fishery of the Kenyan South Coast. *Ocean & Coastal Management* 130, 95-106.

Tzanatos, E., Dimitriou, E., Katselis, G., Georgiadis, M., Koutsikopoulos, C., 2005. Composition, temporal dynamics and regional characteristics of small-scale fisheries in Greece. *Fisheries Research* 73, 147-158.

Ulrich, C., Wilson, D.C., Nielsen, J.R., Bastardie, F., Reeves, S.A., Andersen, B.S., Eigaard, O.R., 2012. Challenges and opportunities for fleet-and métier-based approaches for fisheries management under the European Common Fishery Policy. *Ocean & Coastal Management* 70, 38-47.

USAID, 2015. Program BIOREDD+. Biodiversity - Reduced Emissions from Deforestation and Forest Degradation. Final Report prepared by Chemonics International Inc. Contract No. AID-EPP-I-00-06-00013-00, Task Order No. AID-514-TO-11-0000, Cali, 58 p.

USAID, 2017. Crónicas de un país en movimiento. Programa de Energía Limpia para Colombia - CCEP. Informe Final (2012-2017) preparado por Tetra Tech Inc. Contrato de USAID N ° AID-514-C-12-00002. Cali, 246 p.

Vega, A., Quezada, F., Robles, Y., 2013. Aspectos biológicos y pesqueros de *Scomberomorus sierra* (Perciformes: Scombridae) en el Golfo de Montijo, Pacífico de Panamá. *Tecnociencia* 15 (2), 53-70.

Velandia, M.C., Díaz, J.M., 2016. Atlas marino-costero del Pacífico norte colombiano. Fundación MarViva., Bogotá.

Vieira, C.A., Díaz-Granados, M.A., Díaz, J.M., 2016. Ordenamiento y manejo pesquero en la costa norte del Pacifico Chocoano, in: Díaz, J.M., Guillot, L., Velandia-Diaz, M.C. (Eds.), La Pesca Artesanal en el Norte del Pacífico Colombiano: Un Horizonte Ambivalente. Fundación MarViva, Bogotá, pp. 45-57.

Wang, C., Fiedler, P.C., 2006. ENSO variability and the eastern tropical Pacific: A review. *Progress in Oceanography* 69, 239-266.

Wickham, H., 2017. tidyverse: Easily Install and Load the 'Tidyverse'. R package version 1.2.1. https://CRAN.R-project.org/package/tidyverse.

Wickham, H., 2018. scales: Scale Functions for Visualization. R package version 1.0.0. https://CRAN.R-project.org/package/scales.

Wielgus, J., Zeller, D., Caicedo-Herrera, D., Sumaila, R., 2010. Estimation of fisheries removals and primary economic impact of the small-scale and industrial marine fisheries in Colombia. *Marine Policy* 34, 506-513.

Willmann, R., Kelleher, K., 2009. The sunken billions: the economic justification for fisheries reform (English). Agriculture and rural development. World Bank, Washington, DC.

Wolff, M., Koch, V., Isaac, V., 2000. A trophic flow model of the Caeté mangrove estuary (North Brazil) with considerations for the sustainable use of its resources. Estuarine, Coastal and Shelf Science 50, 789-803.

WorldBank, 2012. Hidden Harvest: the global contribution of capture fisheries. Report No. 66469-GLB, Washington, 92 p.

Worm, B., Branch, T.A., 2012. The future of fish. *Trends in Ecology & Evolution* 27, 594-599.

Ye, Y., Cochrane, K., Bianchi, G., Willmann, R., Majkowski, J., Tandstad, M., Carocci, F., 2013. Rebuilding global fisheries: the World Summit Goal, costs and benefits. *Fish and Fisheries* 14, 174-185.

Ye, Y., Gutierrez, N.L., 2017. Ending fishery overexploitation by expanding from local successes to globalized solutions. *Nature Ecology & Evolution* 1, 0179.

Zeller, D., Booth, S., Pauly, D., 2006. Fisheries contributions to the gross domestic product: underestimating small-scale fisheries in the Pacific. *Marine Resource Economics* 21, 355-374.

Zetina-Rejon, M.J., Arreguın-Sanchez, F., Chavez, E.A., 2003. Trophic structure and flows of energy in the Huizache–Caimanero lagoon complex on the Pacific coast of Mexico. *Estuarine, Coastal and Shelf Science* 57, 803-815.

ANNEX

ANNEX I
Supplements for Chapter 2

Table S2.1. *Total number of sampling days across all landing sites for two data sources used in the present study: GOV refers to data collected by the government national fisheries authority – AUNAP - along the entire Colombian Pacific coast, while NGO refers to data collected by MarViva Foundation, a non-government organization, in the northern sub-region of the Colombian Pacific coast.*

month / year	**NGO**			**GOV**		
	2011	**2012**	**2013**	**2013**	**2014**	**2015**
Jan	30	29	31	13	3	2
Feb	26	29	25	6	22	0
Mar	26	31	27	0	28	0
Apr	27	30	30	14	27	17
May	31	31	31	27	29	29
Jun	30	30	30	26	24	27
Jul	30	30	31	27	0	29
Aug	31	30	30	28	0	27
Sep	30	19	29	26	0	28
Oct	31	29	31	30	0	29
Nov	30	30	29	26	27	26
Dec	31	30	30	24	31	22

Table S2.2. *Range of target days per month selected per species and data set (GOV: government, NGO: non-government organization) based on an R-based application designed to readily quantify and visualize the sample size per day of the month (see Methods). The range of target days was used to filter length-frequency catch data as input for the bootstrapped ELEFAN analysis in TropFishR.*

Species	**Data set**	**Target days**
S.sierra	GOV	14:28
	NGO	13:27
L. guttatus	GOV	16:30
	NGO	16:30
B. clarkae	GOV	11:25
	NGO	15:29

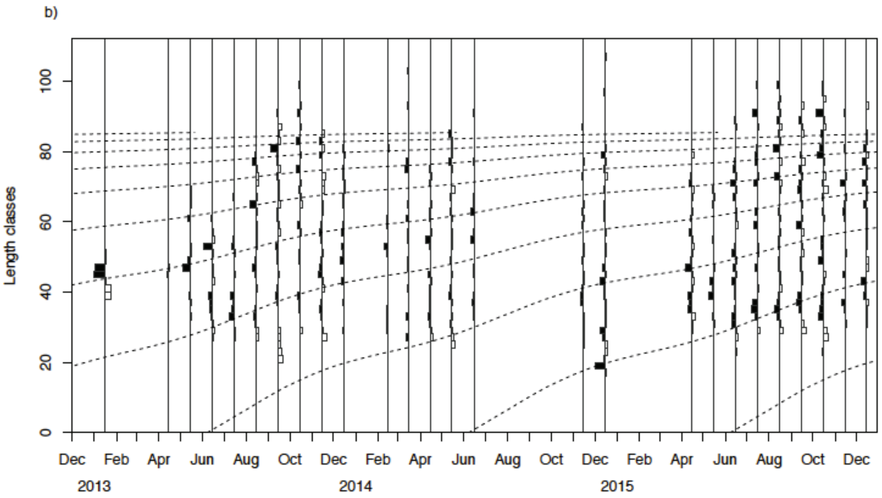
Table S2.3. *Total raising factors used to reconstruct catches (number of fish landed per size class) collected by the government (GOV) and a non-government organization (NGO) in the Colombian Pacific. Total values were the product of three contributing factors: RF1, RF2 and RF3, based on the data available for each data set. Calculations for each factor were based on: RF1:= ((days sampled/total fishing days per month)*(1/proportion of annual catch contributed by sampled month); RF2 = 1.25, based on the estimates made by Wielgus et al. (2010) to account for catch used for local consumption; and RF3 = (sampled fishing trips/total fishing trips per day). NGO data was not corrected for RF2 since sampled catch was measured upon arrival before fishers make their sell.*

	NGO			**GOV**		
Species	**2011**	**2012**	**2013**	**2013**	**2014**	**2015**
S. sierra	1.89	2.04	1.72	2.67	3.92	1.,76
L. guttatus	1.68	1.53	1.75	2.49	3.53	1.70
B. clarkae	2.35	2.43	1.96	12.99	5.18	5.29

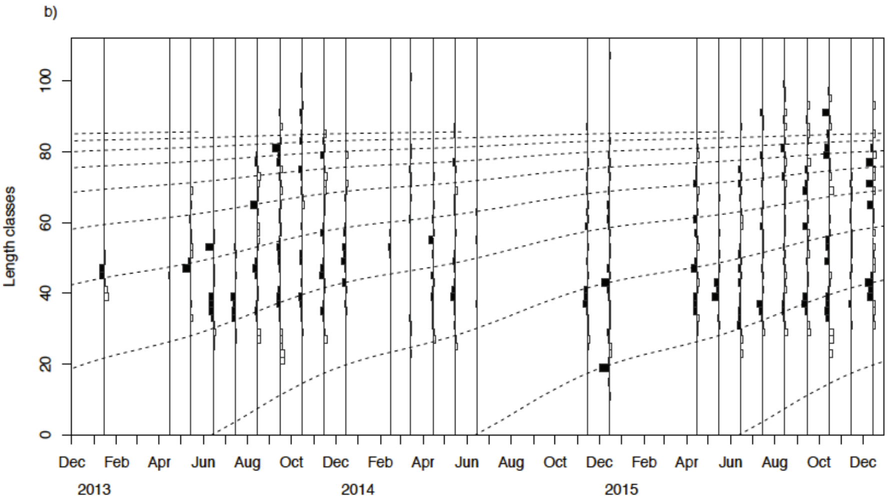
Table S2.4. *Growth parameters from the von Bertallanffy growth function estimated for three selected target species and two data sources included in this study (GOV: government, NGO: non-government organization), with and without the seasonality function of ELEFAN using TropFishR.*

		GOV		**NGO**	
Species	**Parameter**	**ELEFAN with seasonality**	**ELEFAN without seasonality**	**ELEFAN with seasonality**	**ELEFAN without seasonality**
S. sierra	$L\infty$	88.97 (81.92 – 113.60)	86.23 (79.66 – 100.29)	74.89 (72.07 – 105.24)	75.37 (72.07 – 95.69)
	K	0.41 (0.08 – 0.56)	0.44 (0.12 – 0.58)	0.22 (0.06 – 0.53)	0.35 (0.08 – 0.57)
	t_{anchor}	0.45 (0.03 – 0.91)	0.6 (0.25 – 0.96)	0.53 (0.06 – 0.95)	0.84 (0.30 – 0.99)
L. guttatus	$L\infty$	59.61 (54.73 – 77.63)	57.97 (55.70 – 63.81)	65.85 (50.12 – 73.73)	53.88 (50.88 – 71.76)
	K	0.57 (0.34 – 1.22)	0.69 (0.52 – 0.89)	0.47 (0.14 – 1.78)	0.36 (0.10 – 1.2)
	t_{anchor}	0.44 (0.15 – 0.92)	0.59 (0.33 – 0.78)	0.47 (0.01 – 0.97)	0.41 (0.20 – 0.95)
B. clarkae	$L\infty$	90.65 (83.25 – 119.78)	88.89 (82.63 – 96-01)	88.32 (86.25 – 91.39)	88.92 (86.33 – 90.49)
	K	0.23 (0.07 – 0.97)	0.27 (0.16 – 0.71)	0.25 (0.14 – 0.41)	0.25 (0.16 – 0.50)
	t_{anchor}	0.50 (0.10 – 0.94)	0.71 (0.31 – 0.95)	0.59 (0.03 – 0.88)	0.82 (0.38 – 0.99)

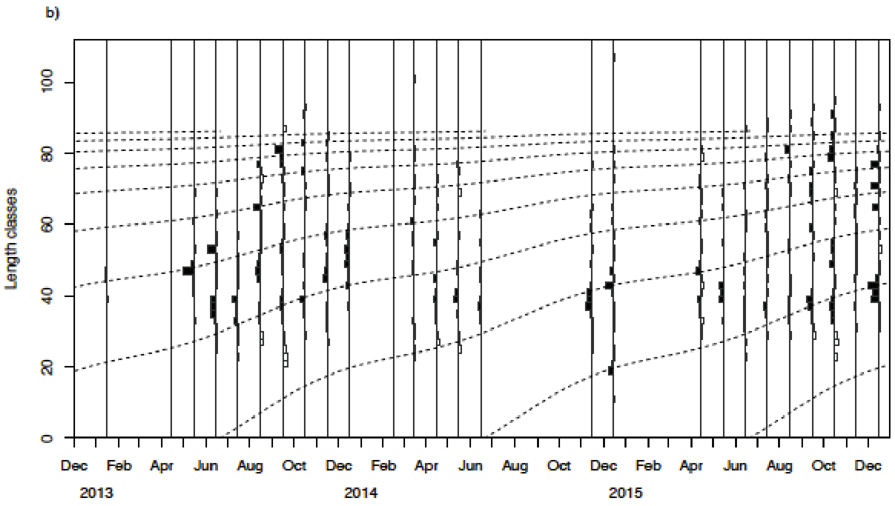
Figure S2.1. *Growth curves obtained through the bootstrapped ELEFAN analysis using three values of moving average (MA) for S. sierra (Ss), L. guttatus (Lg) and B. clarkae (Bc), based on government data (GOV) or non-government data (NGO).*



SsGOV-MA7

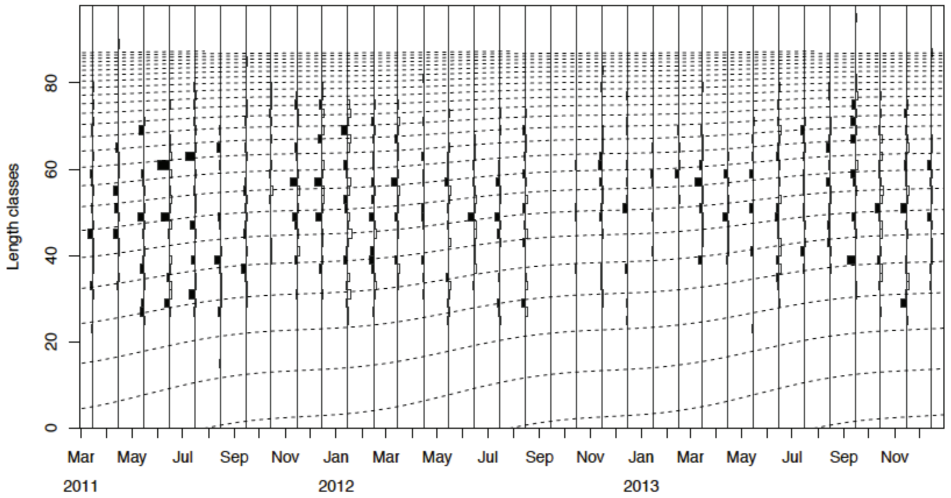


SsGOV-MA9

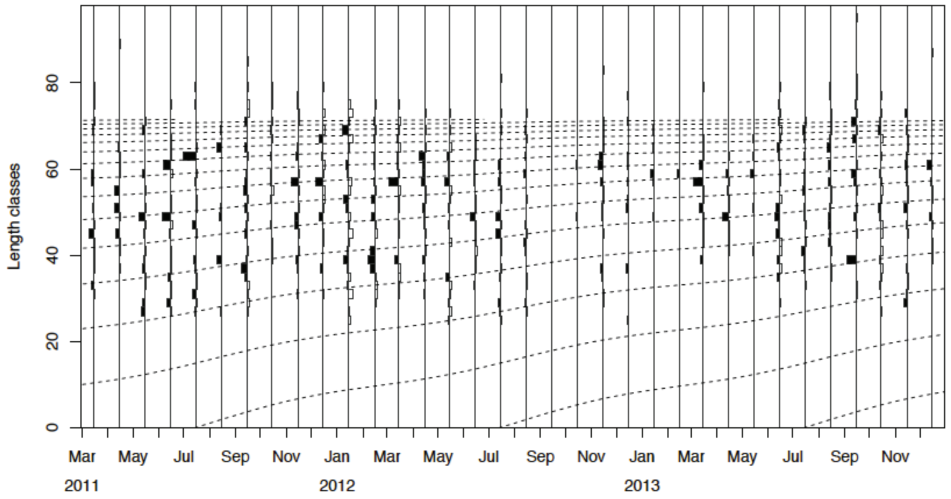


SsGOV-MA11

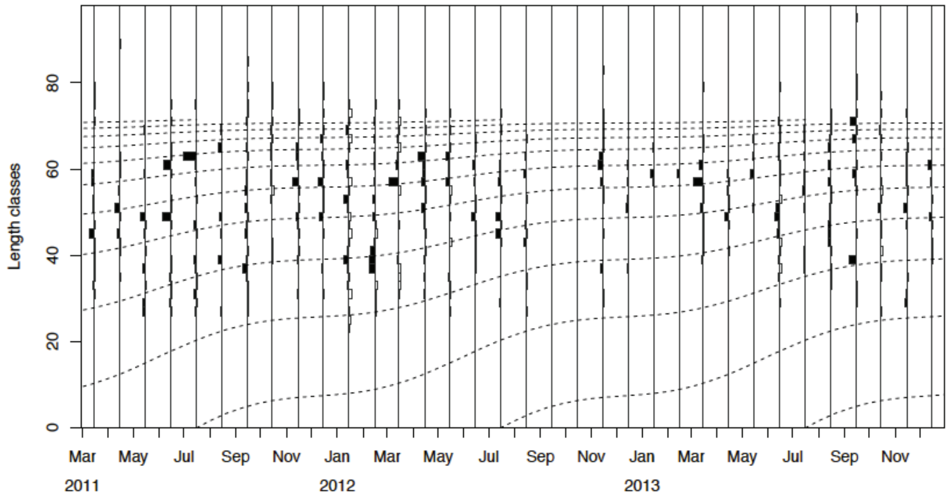
Figure S2.1 *(Continued)*



SsNGO-MA7

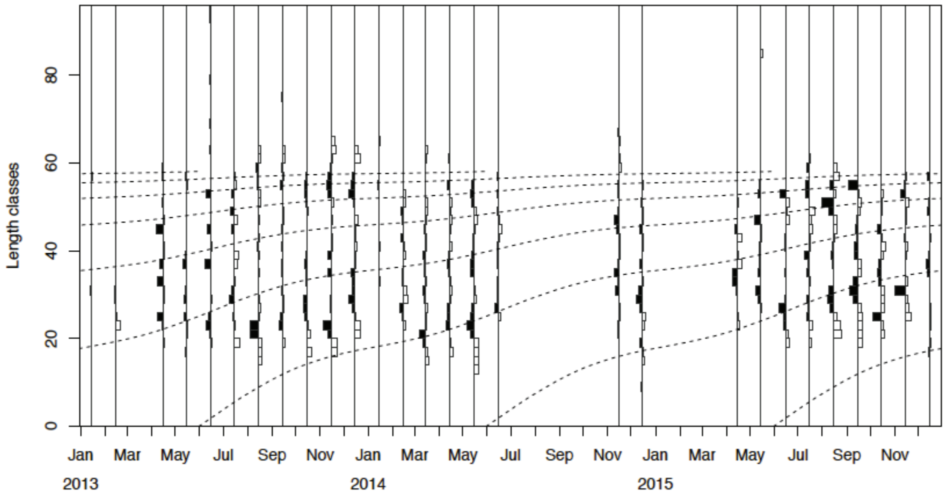


SsNGO-MA9

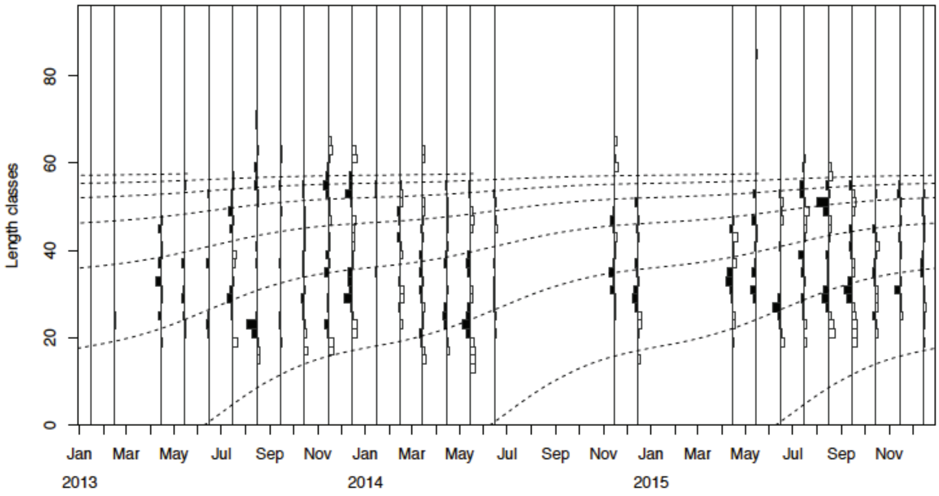


SsNGO-MA11

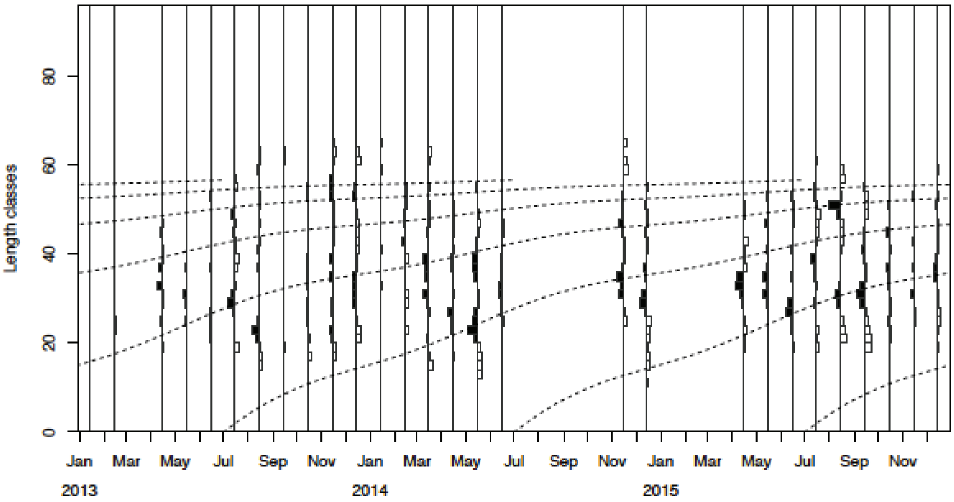
***Figure S2.1** (Continued)*



LgGOV-MA7

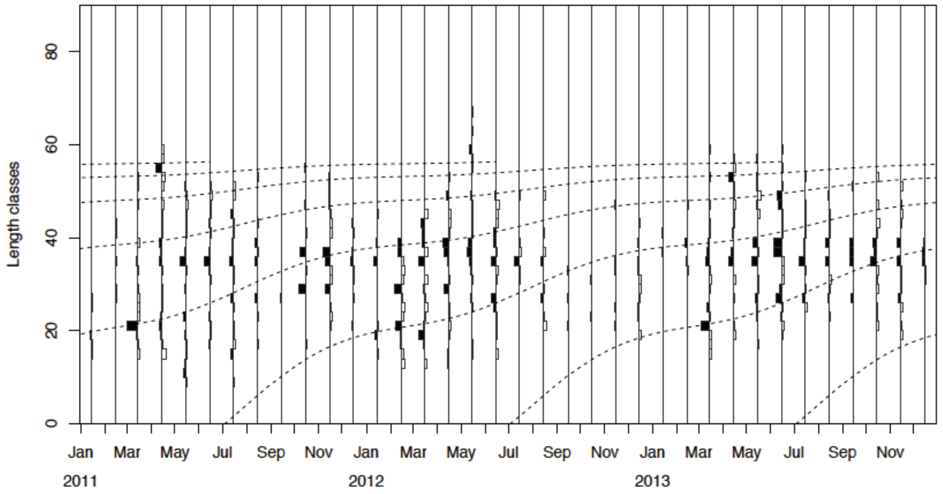


LgGOV-MA9

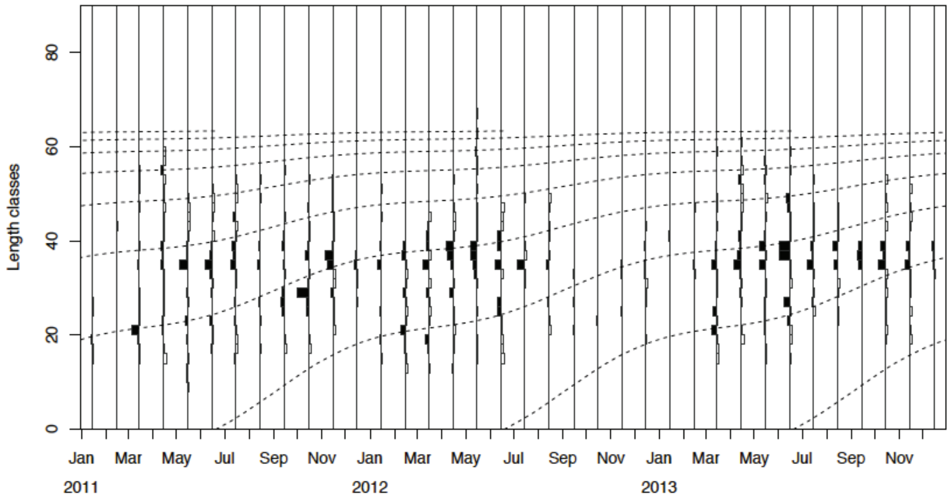


LgGOV-MA11

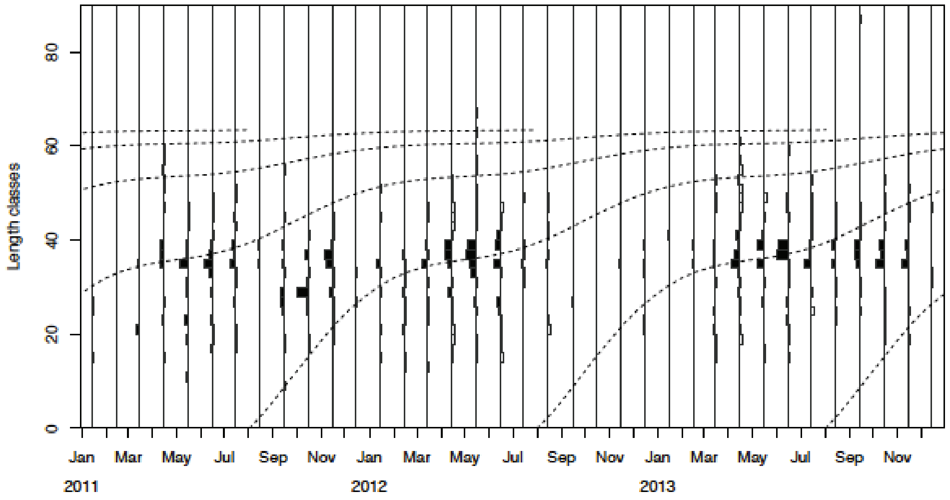
Figure S2.1 *(Continued)*



LgNGO-MA7

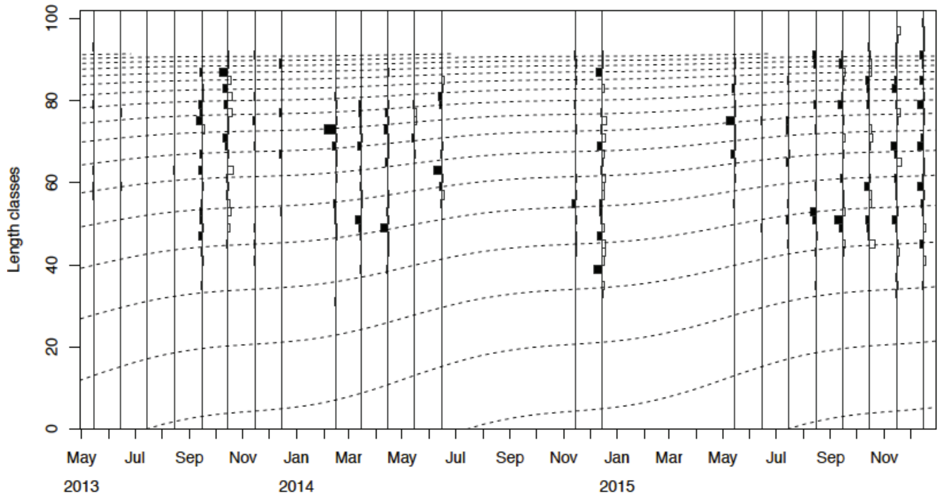


LgNGO-MA9

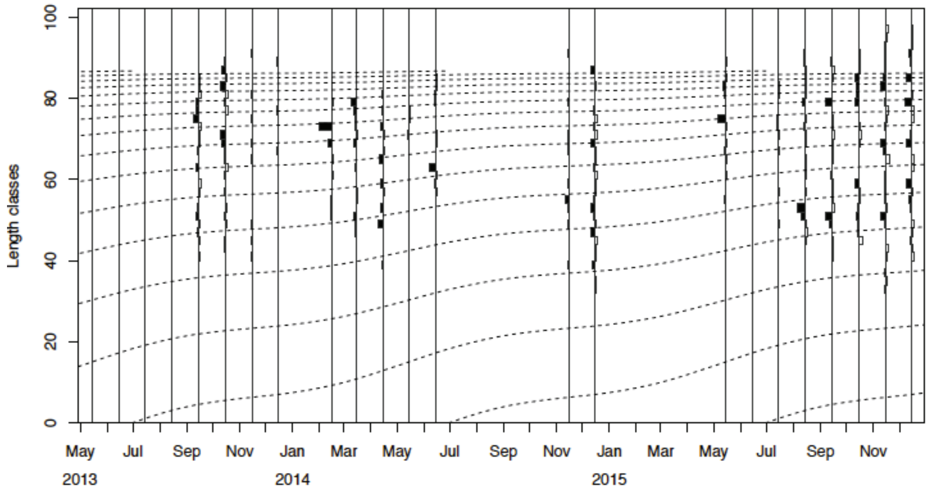


LgNGO-MA11

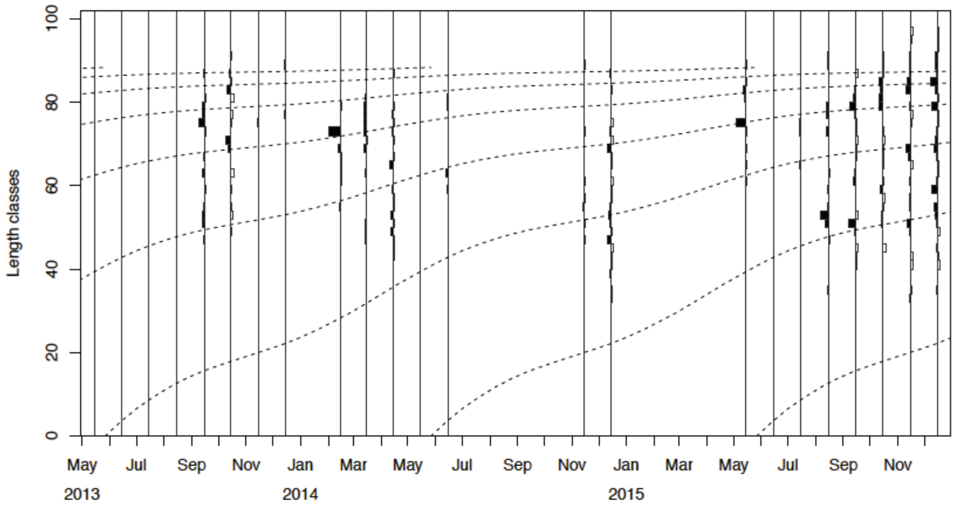
***Figure S2.1** (Continued)*



BcGOV-MA7

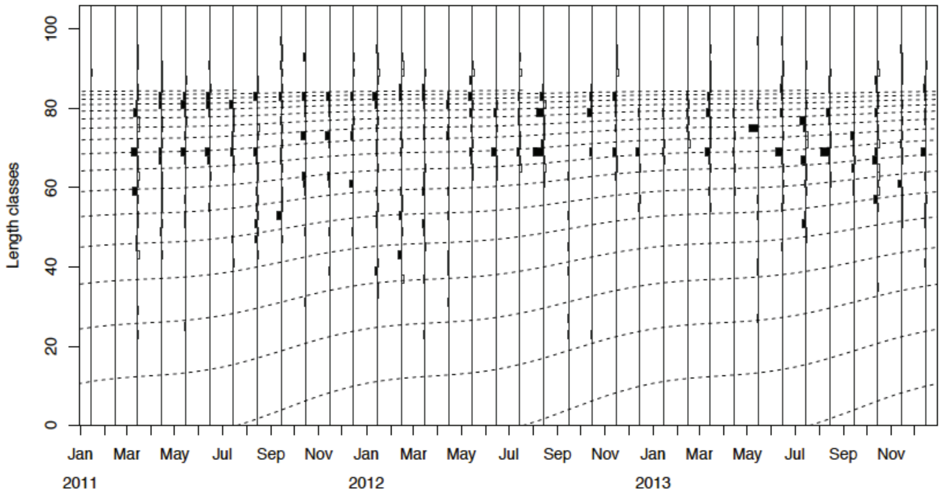


BcGOV-MA9

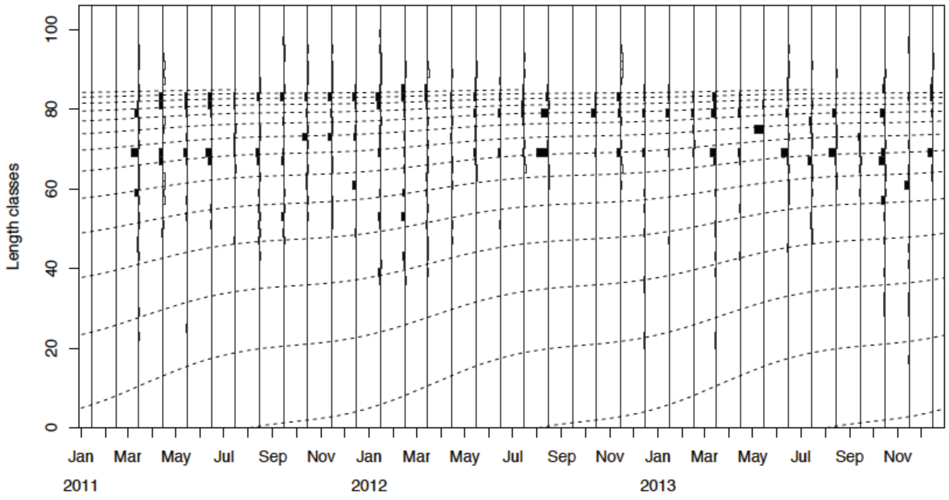


BcGOV-MA11

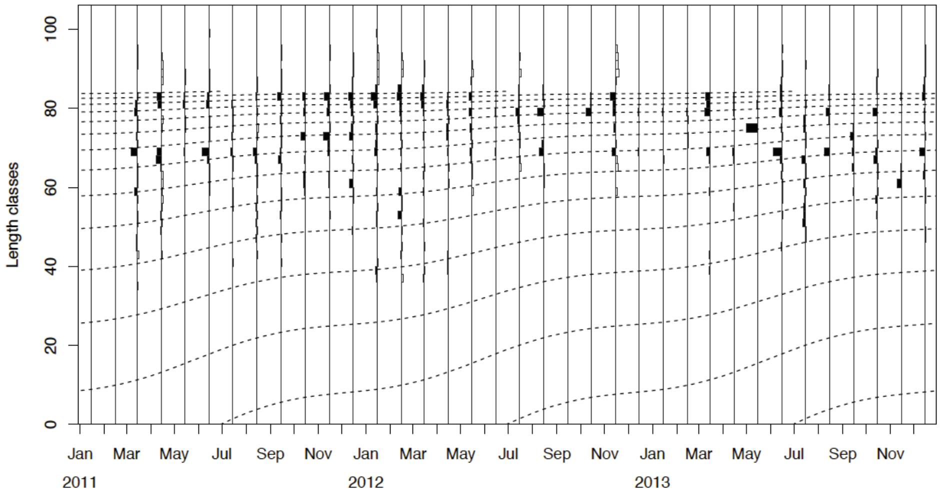
Figure S2.1 *(Continued)*



BcNGO-MA7



BcNGO-MA9



BcNGO-MA11

Figure S2.2. *Catch curves based on the average catch data of three years for the selected target species based on two data sources: government (GOV) data and non-government organization (NGO) data. a) S. sierra GOV, b) S. sierra NGO, c) L. guttatus GOV, d) L. guttatus NGO, e) B. clarkae GOV, f) B. clarkae NGO.*

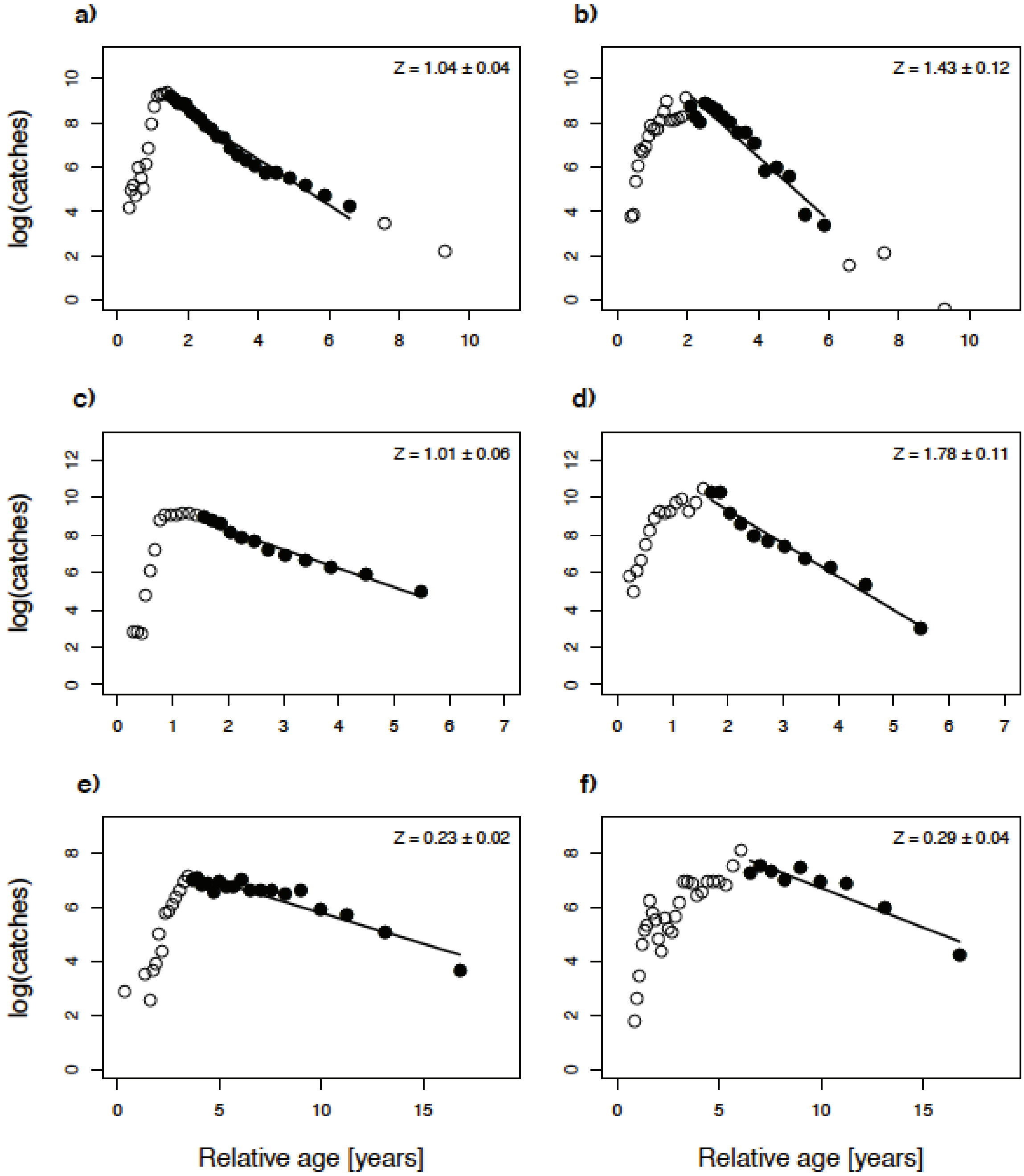
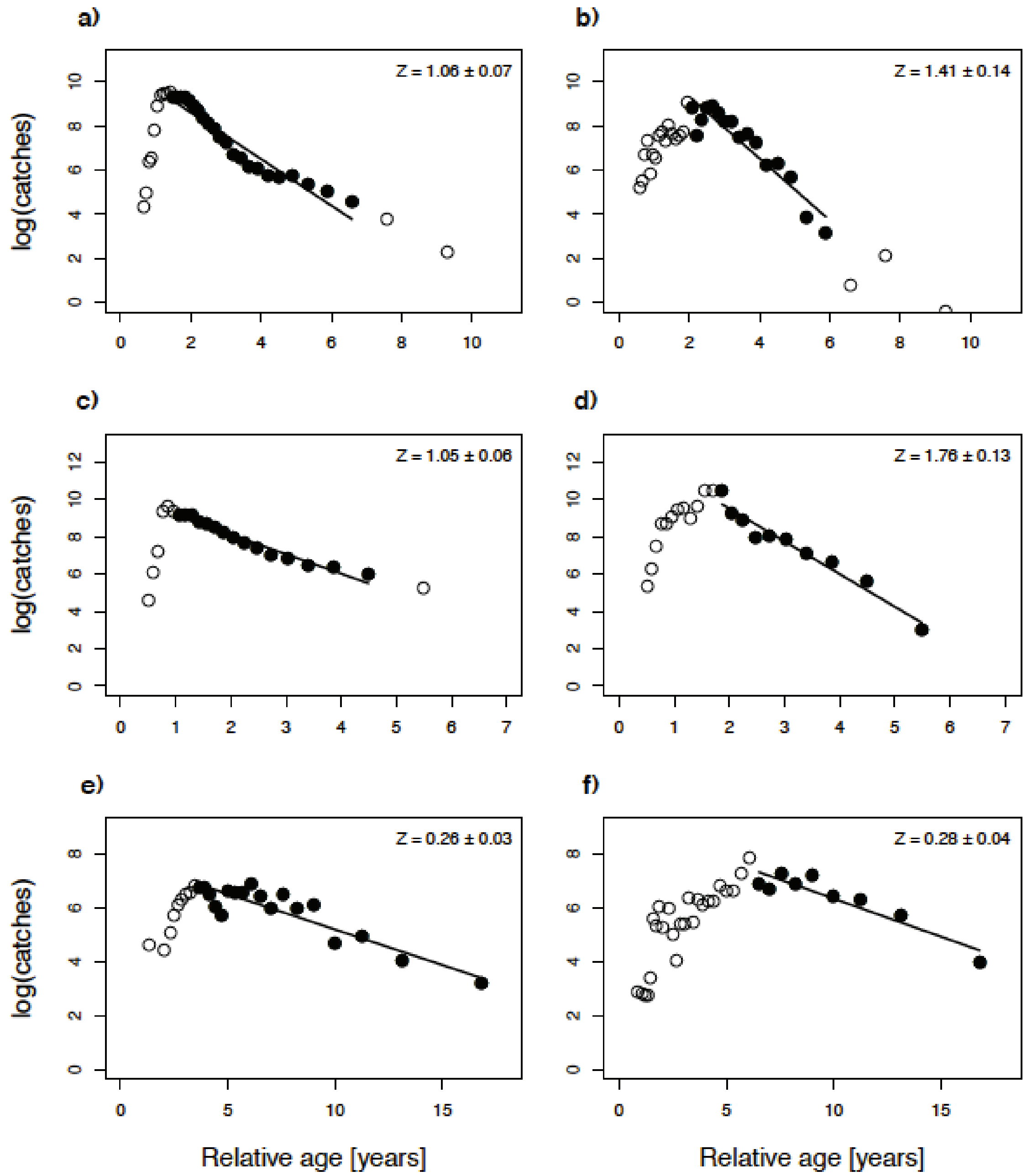


Figure S2.3. *Catch curves based on 2013 catch data for the selected target species based on two data sources: government (GOV) data and non-government organization (NGO) data. a) S. sierra GOV, b) S. sierra NGO, c) L. guttatus GOV, d) L. guttatus NGO, e) B. clarkae GOV, f) B. clarkae NGO.*



ANNEX II
Supplements for Chapter 3

***Table S3.1**. Conversion factors used to estimate total biomass fished at landing sites of the Colombian Pacific coast based on weight status of landed fish and conversion factors established by FAO (2000)[a] for different taxonomic groups and on the relation between disc width (DW) and total weight (W) for two stingray species based on Ehemann et al. (2017)[b]. For families where no data or partial data was available (†) a value of 1.1 was assigned.*

	Weight status				**DW:W**
Taxonomic group	**Gutted**	**Gutted & Head-off**	**Head-off**	**Trunk**	
Hypanus longus					$W = 0.0201*DW^{3.0376}$
Hypanus dipterurus					$W = 0.0175*DW^{3.2418}$
Acanthuridae†	1.1	1.1	1.1	1.1	
Achiridae	1.1	1.2	1.2	1.4	
Albulidae†	1.1	1.1	1.1	1.1	
Alopidae	1.1	1.3	1.2	1.4	
Ariidae	1.1	1.25	1.1	1.25	
Balistidae†	1.1	1.1	1.1	1.1	
Batrachoididae†	1.1	1.1	1.1	1.1	
Belonidae†	1.1	1.1	1.1	1.1	
Carangidae	1.1	1.5	1.4	1.6	
Carcharhinidae	1.25	1.3	1.1	1.4	
Centropomidae	1.1	1.25	1.1	1.4	
Cheloniidae†	1.1	1.1	1.1	1.1	
Cirrhitidae†	1.1	1.1	1.1	1.1	
Clupeidae	1.1	1.2	1.1	1.1	
Coryphaenidae	1.1	1.25	1.1	1.4	
Dasyatidae	1.1	1.25	1.1	1.5	
Elopidae†	1.1	1.1	1.1	1.1	
Engraulidae	1.1	1.4	1.1	1.1	
Ephippidae†	1.1	1.1	1.1	1.1	
Gerreidae†	1.1	1.1	1.1	1.1	
Ginglymostomatidae	1.25	1.3	1.1	1.4	
Haemulidae	1.1	1.25	1.1	1.3	
Holocentridae	1.1	1.25	1.1	1.3	
Istiophoridae	1.1	1.3	1.2	1.4	
Kyphosidae	1.1	1.25	1.1	1.3	
Labridae	1.1	1.25	1.1	1.3	
Lobotidae	1.1	1.25	1.1	1.3	
Lutjanidae	1.1	1.25	1.1	1.3	

Table S3.1 *(continued)*

	Weight status of landed fish				**DW:W**
Taxonomic group	**Gutted**	**Gutted & Head-off**	**Head-off**	**Trunk**	
Malacanthidae	1.1	1.25	1.1	1.3	
Megalopidae	1.1	1.25	1.1	1.3	
Mobulidae	1.1	1.25	1.1	1.5	
Mugilidae	1.1	1.25	1.1	1.3	
Mullidae	1.1	1.25	1.1	1.3	
Muraenesocidae†	1.1	1.1	1.1	1.1	
Muraenidae†	1.1	1.1	1.1	1.1	
Myliobatidae	1.1	1.25	1.1	1.5	
Nematisttidae	1.1	1.25	1.1	1.3	
Ophichthidae†	1.1	1.1	1.1	1.1	
Ophidiidae	1.2	1.4	1.2	1.5	
Paralichthyidae	1.1	1.2	1.1	1.4	
Penaeidae	1.1	1.5	1.5	1	
Polynemidae	1.1	1.25	1.1	1.3	
Portunidae	1.1	1.25	1.1	1.3	
Priacanthidae	1.1	1.25	1.1	1.3	
Scaridae	1.1	1.25	1.1	1.3	
Sciaenidae	1.1	1.25	1.1	1.3	
Scombridae	1.1	1.25	1.15	1.4	
Scorpaenidae	1.1	1.4	1.3	1.1	
Serranidae	1.1	1.5	1.4	1.5	
Sparidae	1.1	1.25	1.1	1.3	
Sphyraenidae	1.1	1.25	1.15	1.4	
Sphyrnidae	1.25	1.3	1.1	1.4	
Stromateidae	1.1	1.25	1.1	1.3	
Tetraodontidae	1.1	1.25	1.1	1.3	
Triakidae	1.1	1.25	1.15	1.4	
unidentified	1.1	1.1	1.1	1.1	

[a] FAO, 2000. Conversion factors: landed weigth to live weight. Food and Agricultural Organization of the United Nations - FAO. Fishery Information, Data and Statistic Unit, Rome, p. 378.

[b] Ehemann, N., Pérez-Palafox, X., Mora-Zamacona, P., Burgos-Vázquez, M., Navia, A., Mejía-Falla, P., Cruz-Escalona, V., 2017. Size–weight relationships of batoids captured by artisanal fishery in the southern Gulf of California, Mexico. Journal of Applied Ichthyology 33, 1051-1054.

Table S3.2. *Preliminary snap-shot assessment of the potential long-term ecological impact of currently used gears in the small-scale fisheries of the Colombian Pacific. Low, Medium or High potential impact categories were assigned to each gear-zone combination based on the relative comparison of the estimated values of the indicators assessed in the present study (Tables 4, 5 and 6, Fig. 7) and on the existing knowledge about the indicators' trend associated to ecological impacts (see Table 2). For example: (a) a gear with a lower mean length in the catch would be associated to a higher ecological impact than a gear with higher mean length in catch, (b) a gear with a higher percentage of threatened species would be associated to a higher ecological impact. In the case of the proportions of trophic and functional guilds, we considered that a higher impact would be caused when a gear has a catch highly dominated by a specific trophic or spatial guild as opposed to a more functionally diverse catch (Rochet and Trenkel, 2003; Caddy and Garibaldi, 2000, Link et al. 2002). Considering the high similarities observed between Tribugá and ZEPA in the values of indicators for the same type of gear, we combined those two zones for the snap-shot assessment.*

		Coastal zones							
		Buenaventura					**Tribugá & ZEPA**		
Type of indicator	**Gear / Indicator**	**Bottom trawl**	**Gillnet**	**Lobster net**	**Longline**	**Purse seine**	**Gillnet**	**Handline**	**Longline**
Size-based	Mean length	High	Medium	Medium	Low	Low	Medium	Medium	Low
	Mean max. body size	Low	Medium	Low	High	High	Medium	High	High
Functional	Mean trophic level	Low	Medium	Medium	Medium	High	Medium	High	Medium
	Trophic guilds	Low	Medium	Medium	Medium	High	Medium	High	High
	Spatial guilds	High	Medium	High	High	Medium	Medium	Medium	Medium
Conservation	Threatened spp	Low	Medium	Low	High	Medium	Medium	Medium	High
	By-catch	High	Low	Low	Low	Low	Low	Low	Low

Figure S3.1. *Relative abundance of families in the nominal catch of the small-scale fisheries at three coastal zones of the Colombian Pacific: ZEPA, Tribugá and Buenaventura (left to right). Family names are included for those taxonomic groups that contributed to 95% of the total catch.*

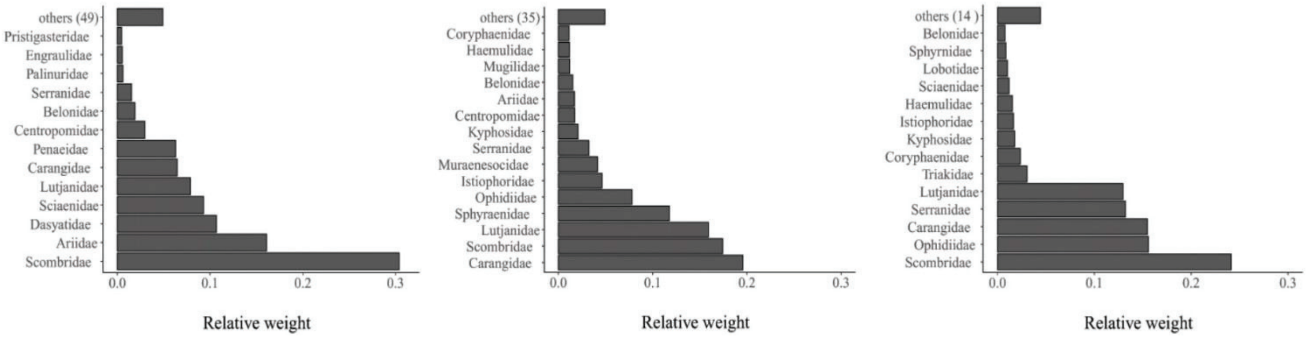
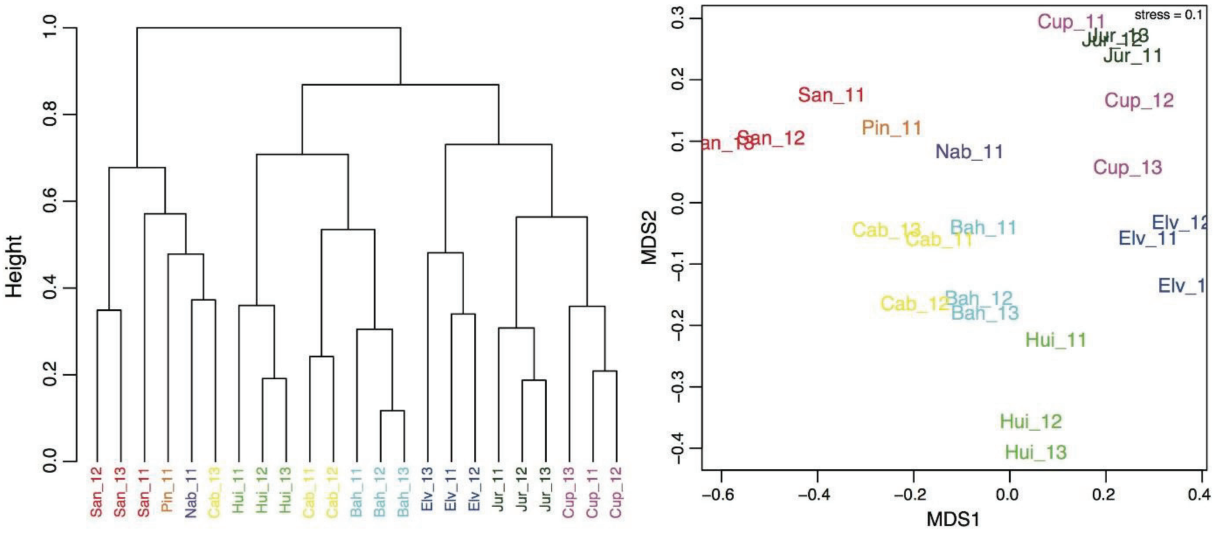


Figure S3.2. *Cluster and non-metric multi-dimensional scaling (nMDS) carried out for ZEPA and Tribugá based on annual relative weight per species at each of the landing sites sampled. Label names correspond to the first three letters of the landing site and the last two digits of the year (e.g. Cup_11 corresponds to the data from Cupica on 2011).*

ZEPA



Tribugá

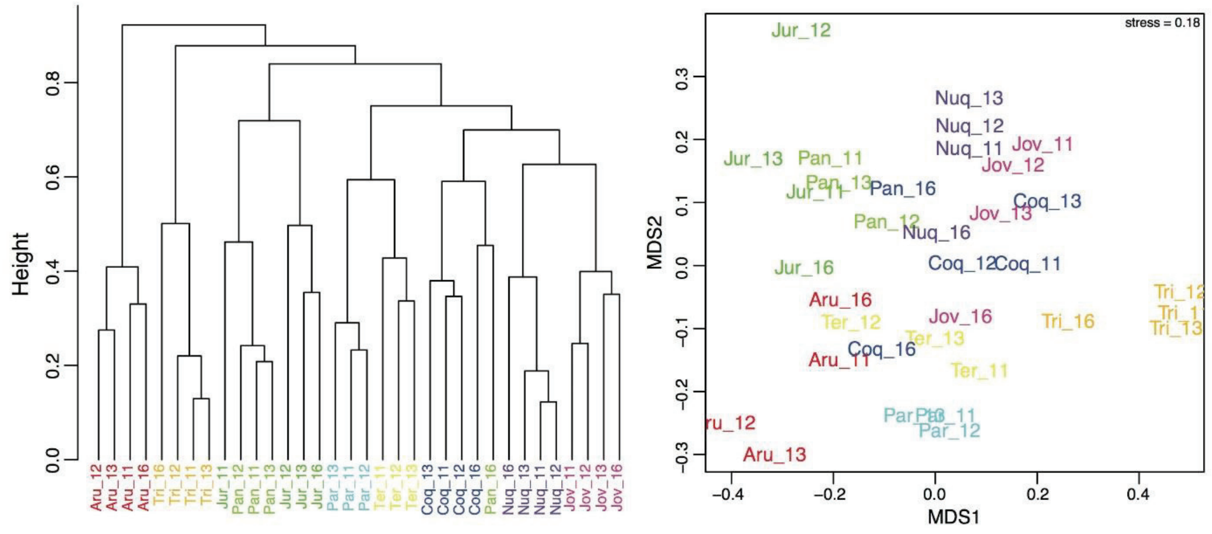
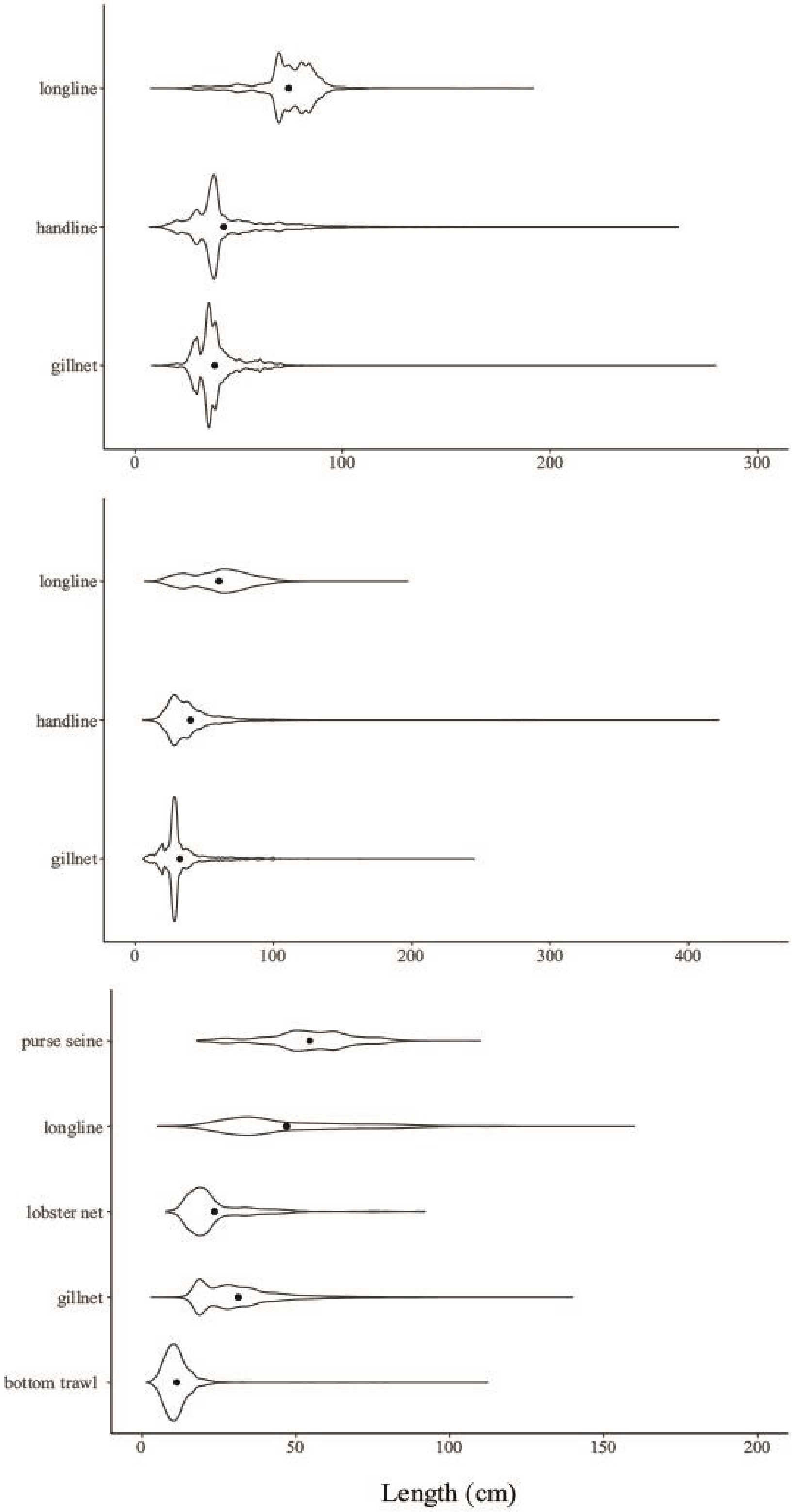


Figure S3.3. *Length distribution per gear type across the entire length range recorded in the catch of small-scale fisheries at three coastal zones of the Colombian Pacific: ZEPA, Tribugá and Buenaventura (top to bottom). Please note differences in scale of the X axis. A similar plot with length distributions up to 200 cm is included as part of the main text to facilitate comparisons.*



ANNEX III
Supplements for Chapter 4

Table S4.1. *Input values for the parameters used here to estimate annual fish consumption per capita (AFC) at each coastal fishing village, where: c is the mean amount of fish left for consumption per fisher after a fishing trip, af is the estimated number of active fishers in each village, p is the total population in the village (for the remote and remote-equipped villages) and in fishers' neighborhood (for the near-urban village) and fd is the number of fishing days per week. Please refer to Chapter 4, section4.2.3 for further details.*

	Coastal villages		
Parameter	**Near-urban**	**Remote**	**Remote-eq**
c	4.5	6.5	5.1
af	134	50	67
p	758	391	370
fd	5.6	5	5.3

Table S4.2. *Number of fishing trips sampled and number of interviews made with fishers per gear type and coastal village.*

	Fishing trips			**Interviewed fishers**		
Gear type	**Near-urban**	**Remote**	**Remote-equipped**	**Near-urban**	**Remote**	**Remote-equipped**
Bottom trawl	77			23		
Gillnet-med	14	29	218	4	2	18
Gillnet-small	82	287	39	31	20	1
Lobster net	112			5		
Longline	113		79	4		11
Purse seine		4	29			8
Sub-total	398	320	365	67	22	38
Total	1,083			127		

Text S4.1. Questionnaire applied to fishers as part of the project: “Assessment of small-scale fisheries in the Colombian Pacific”

Introduction to fishers:

My name is _________ and I am part of the research team of this project that aims to learn more about the current status of small-scale fishing, including both status of the fishing resources and socio-economic conditions of fishers in selected coastal villages of the central Pacific. Your contribution answering this questionnaire will help us to understand better that situation. Any information you give us is confidential and will not be given to other people or entities. At the end of the project the general results will be presented to the community and the Board of the Council without specifying names. Your participation is voluntary and you are free to decide not to answer any question. The interview will take approximately 50 min. Would you like to take part of the interview? Do you have any questions before we begin?

Date: __________Village: _______________ Interviewer: __________________

A. Personal information

1. Full name:__________________________________
2. Age: _____________
3. Birth place:_____________________________________
4. Education level: _________________________(primary school, secondary school, other)
5. How many people in your household economically depend on you: _____________
6. Do you own the house you currently live in? YES___ NO___

B. Fishing activity

7. How old where you when you started fishing? _________

8. How long ago have you been fishing as a subsistence or economic activity? __________

9. How many days per week do you go fishing during fishing months? _________

10. Are there any months of the year that you do not fish? _______
If so, which ones? ______ Why? _______________________________________

11. How long is your fishing trip (total time)? ________(hours)

12. How long does it usually take you to reach your fishing grounds? ________(hours)

13. How do you get to your fishing grounds?

Walking, canoe or boat	Capacity (kg)	Thrust (engine, rows, sail)

14. If boat user, is the boat yours? YES___NO___

15. How many other people do you normally go fishing with? _______

16. How do you distribute the profit of the fishing trip?
Percentage ____ Beneficiary ____; Percentage ____ Beneficiary ____
Percentage ____ Beneficiary ____; Percentage ____ Beneficiary ____

17. Do you carry out other income generating activity? YES___ NO___
If so, what is it (are they)? ____

18. Is there someone else in your household carrying out an income generating activity?
YES___ NO___
If so, what activity (Davies et al.)?
____
Who is involved?
____

C. **Target species and fishing gears**

19. What are your main target species?
____

20. What is the main fishing gear (the one used most of the year)?
____ (gear type and technical specifications)

21. Is the main gear yours? YES___ NO___

22. Do you use more than one fishing gear along the year?
YES ___ NO____ If so,
Why? ____

23. If answered YES in #22, which other gears do you use in order of importance?
____

24. What would you say is the main advantage of the main gear you use, compared to other gears?
____
_

25. What would you say is the main disadvantage of the main gear you use, compared to other gears?
____
_

26. What are the main problems or risks do you perceive when you go out to fish?
____
__

D. **Costs and profitability**

27. How much does it currently cost to buy the main gear you use?
____________ COP[10]

28. How long does the gear last until you have to get another new one?
____________ COP

29. How much do you spend monthly to repair the gear? ____________ COP

30. On average, how much does it cost one of your daily fishing trips?
Fuel __________ COP
Food __________ COP
Ice __________ COP
Other costs __________ COP

---

[10] COP = Colombian Pesos. 1 US$: $ 2,957.6 COP

31. How much of the daily catch do you usually leave for local consumption? ______ (kg/trip)

32. How do you perceive is your economic performance with fishing nowadays?

Very good ___Good ___Reasonable ___Bad ___Very bad ___

Why? ____

33. How do you perceive is your economic performance with fishing nowadays, compared to five years ago?

Much better ___ Better ___ The same ___ Worse ___ Much worse ___

Why? ____

Additional information or comments provided by the fisher:

Ort, Datum: ______________________________

Versicherung an Eides Statt

.

Ich, Pilar Adriana Herrón Pérez, Fehrfeld 13, Bremen 28203. Matr. Nr. 3056606

versichere an Eides Statt durch meine Unterschrift, dass ich die vorstehende Arbeit selbständig und ohne fremde Hilfe angefertigt und alle Stellen, die ich wörtlich dem Sinne nach aus Veröffentlichungen entnommen habe, als solche kenntlich gemacht habe, mich auch keiner anderen als der angegebenen Literatur oder sonstiger Hilfsmittel bedient habe.

Ich versichere an Eides Statt, dass ich die vorgenannten Angaben nach bestem Wissen und Gewissen gemacht habe und dass die Angaben der Wahrheit entsprechen und ich nichts verschwiegen habe.

Die Strafbarkeit einer falschen eidesstattlichen Versicherung ist mir bekannt, namentlich die Strafandrohung gemäß § 156 StGB bis zu drei Jahren Freiheitsstrafe oder Geldstrafe bei vorsätzlicher Begehung der Tat bzw. gemäß § 161 Abs. 1 StGB bis zu einem Jahr Freiheitsstrafe oder Geldstrafe bei fahrlässiger Begehung.

____

Ort, Datum Unterschrift