A Leverage-points Perspective for Sustainability Transformation in Tropical Small-scale Fisheries Systems: Evidence from the Costa Rican Pacific




Dissertation submitted by

Astrid Sánchez Jiménez

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)

December, 2021, Bremen

Universität Bremen

ZMT LEIBNIZ CENTRE for Tropical Marine Research

Advisory Committee

1. Reviewer Prof. Dr. Matthias Wolff

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

2. Reviewer Dr. Maraja Riechers

Department of Sustainability, Leuphana Universität Lüneburg, Germany

1. Examiner: Prof. Dr. Wilhelm Hagen

University of Bremen, Germany

2. Examiner: Prof. Dr. Marie Fujitani

Leibniz Centre for Tropical Marine Research (ZMT), Germany

3. Examiner: Prof. Dr. Douglas MacMillan

Durrell Institute of Conservation and Ecology (DICE), University of Kent, Canterbury, United Kingdom

Attending Students

1. MSc Regina Bacalso. PhD Student, University of Bremen

2. Alice Pohle, MSc Student, University of Bremen

Doctoral defense

Held on February 3, 2022 at 10 a.m. in Bremen

To my mother and my father.

To the women who have paved and illumined my way.

A mi madre y a mi padre.

A las mujeres que han allanado e iluminado mi camino.

“Nature is not a place to visit. It is home”

Gary Snyder

ABSTRACT

Most of the world's fisheries are small-scale fisheries (SSF) which greatly contribute to employment, food security, and poverty alleviation of millions of people. Despite its great importance, conventional fisheries management often does not address the underlying factors of overfishing. Thus rather than incremental change, it is vital to select sustainability interventions that foster transformational change at the systemic level. However, many management interventions do not take into account the fishing impact on ecosystems, or the complexity of SSF as social-ecological systems (SES). In the Anthropocene, humans have become the main driver of change on planet Earth, and although values and mindsets shape environmental decisions, the role of human actors in adopting sustainable behaviors is often overlooked.

Using the Gulf of Nicoya (GoN) SSF as a case study in a tropical coastal area (Costa Rica, Pacific Coast), the main objectives of this dissertation are: to highlight the need for transformational change towards sustainability, to classify management interventions, and to provide a basis for prioritizing research and management in tropical SSF. To classify interventions, a leverage points perspective focused on places in complex systems to intervene and create systemic change was applied. The hypothesis is that GoN fisheries management focuses mainly on shallow leverage points (parameters, feedbacks) that produce little change in the overall functioning of the system, while transformative responses are required at the design/intent level of the system (deep leverage). Three different studies were conducted to investigate deep leverage points: *rethink* knowledge systems, *reconnect* with nature, and *restructure* institutions.

First, *rethinking* the interactions between two ecological knowledge systems. Similarities, complementarities and differences between an EwE trophic model and local ecological knowledge (LEK) were analyzed to examine the impacts of fishing on the ecosystem (1993-2013). The similarities pointed to a severe decrease in the catch of shrimp and corvina, an increase in the impact of gillnet fishing, semi-industrial trawling and in the fishing effort towards larger corvinas. Complementarities suggested significant reductions in the catch of high trophic level species (e.g. mackerel, sharks and rays), economic losses due to the catch of small individuals, catches dominated by sardines (instead of the valuable shrimp) and an increase in the use of illegal gillnets. Finally, the differences indicated that the EwE model showed a reduction in sardine catches, while this was not confirmed by the participants.

Second, in order to *reconnect* human behavior to social-ecological resilience and to nature, it was investigated whether information about the fishery system and the effects of management (conveyed experientially through a trophic model, EwE) influenced ecological norms and beliefs, in the context of environmental education. Based on theories of social psychology, the antecedents of environmental behavior of the participants who deliberated on the EwE model information (treatment) and those who did not (control) were analyzed. Personal norms and altruistic-and-biospheric values significantly explained support to sustainable measures. Educational interventions helped reduce uncertainties, increasing legitimacy, and a perceived behavioral control of fishers to support the measures.

Third, *restructure* fishing institutions was addressed by incorporating heterogeneity in research and management. The ecological and socioeconomic feasibility of policy interventions and the pluralistic motivations underlying fishers' choices were examined using a contingent valuation exercise and deliberation. Underlying support to reduce fishing effort includes intrinsic, instrumental and relational motivations, and a fair compensation in the midst of serious poverty issues. Scientific practices should foster collaborative approaches that integrate multiple values attributed to ecosystems (especially from women and other marginalized groups), thus cultivating trust and commitments. If management is properly oriented, there are already conditions in the GoN to redesign fishing institutions so that rules, regulations and norms allow the expansion of existing values.

Finally, in light of a leverage points perspective, while the solutions are already within the fisheries system of the GoN, conventional fisheries management disregards them. Fisheries management is carried out primarily from a single-species approach, which has its place, but altering the course of the fishing system requires a SES approach focused on the underlying drivers of overfishing and under-researched areas such as: (a) the behavioral (and plural) causes of compliance; (b) values and mindsets that shape emerging goals, norms and institutions; (c) two-way learning processes to foster environmental stewardship and awareness of the ecological impacts of fishing. The results are intended to support the prioritization of research and management efforts in which ecological and social phenomena are understood as a system whose parts only function in relation to the others, and indicate plausible paths to initiate sustainability transformations in tropical SSF.

Keywords: small-scale fisheries (SSF), leverage points for sustainability, Costa Rican Pacific, a plural-values-and-ecosystem-based perspective, sustainability transformations, inter- and transdisciplinary research, behavioral change interventions, social-ecological systems (SES).

ZUSAMMENFASSUNG

Die meisten Fischereien der Welt sind Kleinfischereien (engl. SSF), die einen großen Beitrag zur Beschäftigung, Ernährungssicherheit und Linderung der Armut von Millionen von Menschen leisten. Trotz dieser starken Bedeutung geht das konventionelle Fischereimanagement oft nicht auf die zugrunde liegenden Faktoren der Überfischung ein. Daher ist es sehr wichtig Nachhaltigkeitsinterventionen auszuwählen, die den transformativen Wandel auf systemischer Ebene fördern. Viele Managementinterventionen berücksichtigen jedoch nicht die Auswirkungen der Fischerei auf Ökosysteme oder die Komplexität der SSF als sozial-ökologische Systeme (engl. SES). Im Anthropozän ist der Mensch zum Hauptantrieb des Wandels auf dem Planeten Erde geworden, und obwohl Werte und Denkweisen Umweltentscheidungen prägen, wird die Rolle der menschlichen Akteure bei der Annahme nachhaltiger Verhaltensweisen oft übersehen.

Am Beispiel der GoN Fischerei –SSF- als Fallstudie in einem tropischen Küstengebiet (Costa Rica, Pazifikküste) sind die Hauptziele dieser Dissertation: die Notwendigkeit eines transformativen Wandels in Richtung Nachhaltigkeit hervorzuheben, Managementinterventionen zu klassifizieren und eine Grundlage für die Priorisierung von Forschung und Management in tropischen SSF zu schaffen. Um Interventionen zu klassifizieren, wurde eine „Leverage Points-Perspective“ angewendet, die sich auf Orte in komplexen Systemen konzentriert, um zu intervenieren und systemische Veränderungen herbeizuführen. Die Hypothese ist, dass sich das GoN-Fischereimanagement hauptsächlich auf oberflächennahe Hebelwirkungspunkte (Parameter, Rückkopplungen) konzentriert, die eine geringe Änderung der Gesamtfunktion des Systems bewirken, während transformative Reaktionen auf der Entwurfs-/Intentionsebene des Systems erforderlich sind (tiefe Hebelwirkung). Drei verschiedene Studien wurden durchgeführt, um tiefe Hebelwirkungen zu untersuchen: Wissenssysteme überdenken, sich wieder mit der Natur verbinden und Institutionen neu strukturieren.

Erstens, die Wechselwirkungen zwischen zwei ökologischen Wissenssystemen zu *überdenken*. Ähnlichkeiten, Komplementaritäten und Unterschiede zwischen einem trophischen Modell (EwE-Modell) und lokalem ökologischem Wissen (engl. LEK) wurden analysiert, um die Auswirkungen der Fischerei auf das Ökosystem zu untersuchen (1993-2013). Die Ähnlichkeiten deuteten auf einen starken Rückgang des Fangs von Garnelen und Corvina, eine Zunahme der Auswirkungen der Kiemennetzfischerei, der halbindustriellen

Schleppnetzfischerei und des Fischereiaufwands auf größere Corvinas hin. Komplementaritäten deuteten auf eine deutliche Reduzierung des Fangs von Arten mit hohem trophischen Niveau (z. B. Makrele, Haie und Rochen), wirtschaftliche Verluste durch den Fang kleiner Individuen, von Sardinen (anstelle der wertvollen Garnelen) dominierten Fänge und eine Zunahme der Verwendung illegaler Kiemennetze hin. Schließlich zeigten die Unterschiede, dass das EwE-Modell eine Verringerung der Sardinenfänge zeigte, während die Workshop-Teilnehmern dies nicht bestätigten.

Zweitens wurde, um menschliches Verhalten mit sozial-ökologischer Resilienz und mit der Natur in *Verbindung* zu bringen, untersucht, ob Informationen über das Fischereisystem und die Auswirkungen des Managements (erfahrungsgemäß vermittelt durch ein trophisches Modell, EwE) ökologische Normen und Überzeugungen im Kontext der Umweltbildung beeinflusst haben. Basierend auf Theorien der Sozialpsychologie wurden die Vorläufer des Umweltverhaltens der Teilnehmer, die über die Informationen des EWE-Modells nachdachten (Behandlung) und derjenigen, die dies nicht taten (Kontrolle), analysiert. Persönliche Normen und altruistische und biosphärische Werte erklärten signifikant die Unterstützung zu nachhaltigen Maßnahmen. Bildungsinterventionen trugen dazu bei, Unsicherheiten zu verringern, die Legitimität zu erhöhen und eine wahrgenommene Verhaltenskontrolle der Fischer zu unterstützen, um die Maßnahmen zu unterstützen.

Drittens wurde die *Umstrukturierung* von Fischereiinstitutionen durch Einbeziehung der Heterogenität in Forschung und Management angegangen. Die ökologische und sozioökonomische Machbarkeit politischer Interventionen und die pluralistischen Motivationen, die den Entscheidungen der Fischer zugrunde liegen, wurden anhand einer kontingenten Bewertung und Beratung untersucht. Die zugrunde liegende Unterstützung zur Verringerung des Fischereiaufwands umfasst intrinsische, instrumentelle und relationale Motivationen sowie eine angemessene Entschädigung inmitten schwerwiegender Armutsprobleme. Wissenschaftliche Praktiken sollten kollaborative Ansätze fördern, die vielfältige Werte integrieren, welche Ökosystemen (insbesondere von Frauen und anderen Randgruppen) zugeschrieben werden, und so Vertrauen und Verpflichtungen kultivieren. Wenn das Management richtig ausgerichtet ist, gibt es im GoN bereits Bedingungen, um Fischereiinstitutionen so umzugestalten, dass Regeln, Vorschriften und Normen die Erweiterung bestehender Werte ermöglichen.

Obwohl die Lösungen im Hinblick auf die „leverage points perspective" zwar bereits im Fischereisystem der GoN enthalten sind, werden sie im konventionellen Fischereimanagement ignoriert. Das Fischereimanagement wird in erster Linie nach einem Einzelarten-Ansatz durchgeführt, der seine Berechtigung hat, aber die Änderung des Verlaufs des Fischereisystems erfordert einen SES-Ansatz, der sich auf die zugrunde liegenden Triebkräfte der Überfischung und unzureichend erforschter Gebiete konzentriert, wie zum Beispiel:(a) die Vielzahl der Gründe für die Einhaltung von Regeln und Gesetzen; (b) Werte und Denkweisen, die aufkommende Ziele, Normen und Institutionen prägen; (c) wechselseitige Lernprozesse zur Förderung der Umweltverantwortung und des Bewusstseins für die ökologischen Auswirkungen der Fischerei. Die Ergebnisse sollen die Priorisierung von Forschungs- und Managementbemühungen unterstützen, in denen ökologische und soziale Phänomene als ein System verstanden werden, dessen Teile nur in Relation zu den anderen funktionieren, und plausible Wege aufzeigen, um Nachhaltigkeitstransformationen in tropischen SSF anzustoßen.

Stichworte: Kleinfischerei (engl. SSF), „Leverage Points Perspective" für Nachhaltigkeit, Costaricanischer Pazifik, eine auf pluralen Werten und Ökosystemen basierende Perspektive, Nachhaltigkeitstransformationen, inter-und-transdisziplinäre Forschung, Interventionen zur Verhaltensänderung, sozial-ökologische Systeme (engl. SES).

RESUMEN

La mayoría de las pesquerías del mundo son pesquerías en pequeña escala (ing. SSF) que contribuyen en gran medida al empleo, la seguridad alimentaria y el alivio de la pobreza de millones de personas. A pesar de esta gran importancia, la ordenación pesquera convencional suele ignorar los factores subyacentes de la sobrepesca. Por lo tanto, en lugar de cambios incrementales, es vital seleccionar intervenciones de sostenibilidad que fomenten el cambio transformacional a nivel sistémico. Sin embargo, muchas intervenciones de ordenación no tienen en cuenta el impacto de la pesca en los ecosistemas o la complejidad de las SSF como sistemas social-ecológicos (ing. SES). En el Antropoceno, los seres humanos se han convertido en el principal impulsor del cambio en el planeta Tierra y, aunque los valores y la mentalidad dan forma a las decisiones ambientales, a menudo se pasa por alto el papel de los (as) actores humanos en la adopción de comportamientos sostenibles.

Utilizando las SSF del Golfo de Nicoya (GoN) como estudio de caso en una zona costera tropical (Costa Rica, Costa del Pacífico), los principales objetivos de esta tesis son: destacar la necesidad de un cambio transformador hacia la sostenibilidad, clasificar las intervenciones de gestión y proporcionar una base para priorizar la investigación y el manejo en las SSF tropical. Para clasificar las intervenciones, se aplicó una perspectiva de puntos de apalancamiento centrada en lugares en sistemas complejos para intervenir y generar un cambio sistémico. La hipótesis es que la ordenación pesquera del GoN se centra principalmente en puntos de apalancamiento poco profundos (parámetros, retroalimentaciones) que producen pocos cambios en el funcionamiento general del sistema, mientras que se requieren respuestas transformadoras en el nivel de diseño/intención del sistema (apalancamiento profundo). Se llevaron a cabo tres estudios diferentes para investigar puntos de influencia profundos: *repensar* los sistemas de conocimiento, *reconectarse* con la naturaleza y *reestructurar* las instituciones.

Primero, *repensar* las interacciones entre dos sistemas de conocimiento ecológico. Se analizaron las similitudes, complementariedades y diferencias entre un modelo trófico EwE y el conocimiento ecológico local (ing. LEK) para examinar los impactos de la pesca en el ecosistema (1993-2013). Las similitudes apuntaban hacia una fuerte disminución en la captura de camarón y corvina, un aumento en el impacto de la pesca con redes de enmalle, el arrastre semi-industrial y en el esfuerzo de pesca hacia corvinas de mayor tamaño. Las complementariedades sugirieron reducciones significativas en la captura de especies de alto nivel trófico (por ejemplo, caballa, tiburones y rayas), pérdidas económicas debido a la captura de individuos pequeños, capturas dominadas por sardinas (en lugar de camarones valiosos) y

un aumento en el uso de redes de enmalle de camarones ilegales. Finalmente, las diferencias indicaron que el modelo EwE mostró una reducción en las capturas de sardina, mientras que esto no fue confirmado por los participantes.

En segundo lugar, con el fin de *reconectar* el comportamiento humano con la resiliencia social-ecológica y con la naturaleza, se investigó si la información sobre el sistema pesquero y los efectos de la ordenación (transmitidos experimentalmente a través de un modelo trófico, EwE) influían en las normas y creencias ecológicas, en el contexto de la educación ambiental. Con base en teorías de la psicología social, se analizaron los antecedentes de comportamiento ambiental de los participantes que deliberaron sobre la información del modelo EwE (tratamiento) y los que no (control). Las normas personales y los valores altruistas y biosféricos explicaron significativamente el apoyo a las medidas sostenibles. Las intervenciones educativas ayudaron a reducir las incertidumbres, aumentar la legitimidad y la percepción de un control del comportamiento de los pescadores para respaldar las medidas.

En tercer lugar, se abordó la reestructuración de las instituciones pesqueras incorporando la heterogeneidad en la investigación y la ordenación. La viabilidad ecológica y socioeconómica de las intervenciones de política y las motivaciones pluralistas que subyacen a las elecciones de los pescadores se examinaron mediante un ejercicio de valoración contingente y deliberación. El apoyo subyacente para reducir el esfuerzo pesquero incluye motivaciones intrínsecas, instrumentales y relacionales, y una compensación justa en medio de graves problemas de pobreza. Las prácticas científicas deben fomentar enfoques colaborativos que integren múltiples valores atribuidos a los ecosistemas (especialmente de mujeres y otros grupos marginados), cultivando así la confianza y los compromisos. Si el manejo se orienta adecuadamente, ya existen condiciones en el GoN para rediseñar las instituciones pesqueras para que las reglas, regulaciones y normas permitan la expansión de los valores existentes.

Finalmente, a la luz de una perspectiva de puntos de apalancamiento, mientras que las soluciones ya están dentro del sistema pesquero del GoN, la ordenación pesquera convencional las ignora. La ordenación pesquera se lleva a cabo principalmente desde un enfoque de una sola especie, lo cual tiene su lugar, pero alterar el curso del sistema de pesca requiere un enfoque de SES centrado en los impulsores subyacentes de la sobrepesca y en áreas poco investigadas, tales como: (a) los factores conductuales (y plurales) de cumplimiento; (b) valores y mentalidades que dan forma a las metas, normas e instituciones emergentes; (c) procesos de aprendizaje bidireccional para fomentar la gestión ambiental y la conciencia de los impactos ecológicos de

la pesca. Los resultados están destinados a apoyar la priorización de esfuerzos de investigación y manejo en los que los fenómenos ecológicos y sociales se entienden como un sistema cuyas partes solo funcionan en relación con las demás, y a indicar caminos plausibles para iniciar transformaciones de sustentabilidad en las SSF tropicales.

Palabras clave: pesquerías en pequeña escala (ing. SSF), puntos de apalancamiento para la sostenibilidad, Pacífico tropical, una perspectiva basada en valores plurales y ecosistemas, transformaciones hacia la sostenibilidad, investigación inter-y-trans-disciplinaria, intervenciones de cambio de comportamiento, sistemas social-ecológicos (ing. SES).

Content

Table of Figures

List of Tables

Acknowledgements

This PhD has been a deep inner journey and a dance of intellect and heart. I express gratitude to many people who crossed my path and have made this possible. First of all, I sincerely thank my supervisors, Prof. Dr. Matthias Wolff and Prof. Dr. Douglas Macmillan, for giving me the opportunity to join this incredible project in the Gulf of Nicoya. Their support, trust and guidance throughout the entire process have been fundamental. I am also deeply grateful to my co-supervisor, Prof. Dr. Marie Fujitani, for teaching me so much with patience and kindness, as well as for always being there to discuss ideas. Appreciations to Prof. Dr. Achim Schlüter for co-creating this project and for his constructive comments. I am very grateful to Dr. Maraja Riechers and Prof. Dr. Wilhem Hagen for evaluating this thesis.

I appreciate the presence and the experiences shared, brief and extensive, with the members of my lab, such as MSc Manuel Jänig, MSc Michael Kriegl, Dr. Paul Tuda and Dr. Cand. Giovani Romagnoni. I especially appreciate the fruitful discussions and interdisciplinary collaboration with Dr. Cand. Viola Alms, and support of dear friends Dr. Pilar Herrrón and Dr. Rebecca Borges for reading and commenting on the drafts of the general discussion. Similarly thanks to Dr. Jennifer Rehren for providing timely comments to my German version of the abstract. To the Dr. Cand. Regina Bacalso for kindly participate in my defense committee, and to Dr. Cand. Alonso del Solar for offering a friendly and needed hand on the way to my defense.

Without support from Leibniz Center for Tropical Marine Research (ZMT), Germany, through the project 3601, Leibniz Chair of Environment, this dissertation would not have been possible, so I thank ZMT for offering me a position as a doctoral researcher, as well to Mercè Sánchez and Jody S. for the logistical support. I am grateful with the University of Bremen for the open-access publishing support and for the three month scholarship STIBET that helped me finish this dissertation. Furthermore thanks to several colleagues with whom I shared nice time: such as Daniel Saavedra., Ivonne V., Lotta K., Gustavo C., Juan Carlos M., Agustin M., Sonia B., Theresa S., Sofia S. Guilherme A. Ernesto A., Jonas L., Vignesh, S. and Stephan P. As well to Annette B. for friendly welcoming me to their home during my first weeks in Germany.

Data collection in Costa Rica had the support of governmental and non-governmental institutions, such as the Marine Science and Limnology Research Center, University of Costa Rica (CIMAR), within the which I wholeheartedly appreciate the constant mentoring and humanity of Dr. Álvaro Morales and my master's supervisor, Dr. Jorge Cortés, both for preparing me for a PhD, and I am also grateful to Dr. Ingo Wehrtmann for fostering my connection with the tropical sea and CIMAR. As well want to thank other researchers who offered their time to discuss ideas, including Berny Marín (INCOPESCA, Costa Rican Institute of Fisheries and Aquaculture), Dr. Cindy Fernández, Dr. Jeffrey Sibaja, MSc. Ana Gloria Guzmán and Dr. Erick Ross. Genuine thanks to my dear friend MSc Grettel Ulate (ECMAR, National University) and the esteemed biologist Randall Arauz for always supporting my work.

I am forever indebted to the fishing communities of the Gulf of Nicoya for sharing so much wisdom with me and especially thanks to Sandra Cruz and Ester Ledezma for welcoming me into their homes. Besides thanks to Ezequiel Alvarez, Deyler Ledezma, Damaris Pérez, Luis Marín, V. Luis Pérez, Olger Quesada, Greivin Pérez, Albanis Montiel and Lucas, for their help with the logistics of the workshops and interviews. Similarly to Karen Quirós for helping me with data collection and for introducing me to the natural gems of Isla Chira. A heartfelt thanks to very dear friends and colleagues Bárbara Escobar, Talía Chamorro, and Gleice Alves for the application of the surveys, photographic documentation and even for driving to the study area, also to Luis Artavia for the maps used in this thesis.

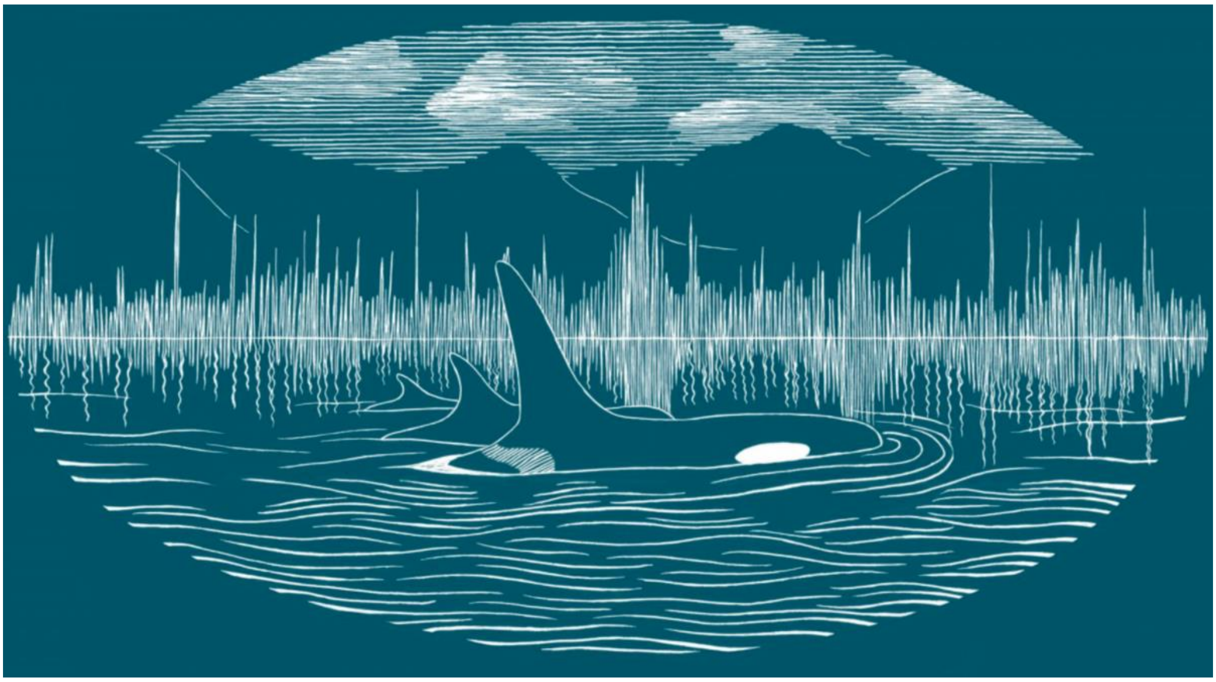
Bremen became my second home thanks to shared laughter, bike rides and Bürgerpark walks. Forever grateful for the friendship of Rebecca Borges, Pilar Herrón, Vanessa Burgos, Sara Méndez, Inés Viana, Azucena V., women whom I carry in my heart. Thanks also to those who made my stay in this country more joyful such as Arelly Quirós (unforgettable cycling adventure to the North Sea with summer hail), Daniel Torija (hundreds of memorable journeys), Bettina Lüschen (help finding the perfect bike), Raquel D. and Dharma R. (for sharing a cat world). Thanks to friends, citizens of the world, who have also encouraged me such as Johnny Rosales, Fernando H., Claudia Maztdorf, Lisa Carrillo, Coralia Chamorro, Lara Solórzano Dalia N. and Griselda A. I also treasure my friendship with Karem Aguirre, Carlos Paniagua and Daniel Campos for the amazing bond and for sharing a connection with our adored sea.

Last but not least, my appreciation to all my family who during these PhD years have not been near physically, but who are close to my heart, such as David Rojas for our wonderful friendship and unconditional support, and Lilliana (and Carlos) for their love. To Betty, Aida, Carmen, Mayela, Stephanie, Jennifer, Ruth, Olga for being women that I admire. To Geiner for our friendship since childhood, to José (Beto) -Vanessa (& family) for our meeting in Bremen. Thanks my beloved sister also to Jimmy and Luis for always been kind and caring to my parents. My deepest gratitude to my mom, dad, sister and nephew (his heart) for their unconditional love and for being my inspiration. To my dad for always believing in me and advise me with amorous wisdom. To my mom for having always been there for me and each time listening me with infinite patience and compassion. My endless gratitude for their existence.

CHAPTER 1. General Introduction

"Humboldt was ready to formulate his new vision of nature. In the Andean foothills, he began to sketch his so-called 'Naturgemälde' – an untranslatable German term that can mean 'painting of nature' but which also implies a sense of unity or wholeness. […] 'Nature was a living whole,' he later said […].Individual phenomena were important 'in their relation to the whole'. The 'Naturgemälde' strikingly illustrated nature as a web in which everything was connected."

—**Andrea Wulf,** The Invention of Nature: Alexander von Humboldt's New World



Illustration, Alex Boersma

1.1. SUSTAINABILITY AND SMALL-SCALE FISHERIES

Small-scale fisheries (SSF) provide the basis for the livelihoods and well-being of many coastal and rural regions around the world (FAO, 2015). The sustainability of the SSF sector faces significant challenges such as overfishing, a substantial loss of marine biodiversity and non-compliance with regulations (Grafton et al., 2006; Lubchenco et al., 2016). Furthermore, many sustainability interventions in traditional fisheries management have only taken gradual steps towards sustainability, as they do not take into account the impact of fishing on ecosystems (Beddington et al., 2007) nor the complexity of SSF as social-ecological systems (SES). Transformative changes are required, at the systems level, in management, governance and research approaches (Chuenpagdee and Jentoft, 2018).

Sustainability is understood in this context as the ability of societies to maintain the health and integrity of the natural system over time, which in turn contributes to the thriving and well-being of society (Folke et al., 2016). FAO member states approved voluntary guidelines to improve fisheries sustainability (FAO, 2015) and encourage the necessary changes to warrant the viability of SSF as a means of food security and poverty eradication. With the adoption of Sustainable Development Goal 14 (SDG 14, "life underwater") of the 2030 Agenda for Sustainable Development (United Nations, 2015), the member countries of the United Nations agreed on the priorities to generate science-based policies, support small-scale fishers, end subsidies that contribute to overfishing and protect/restore marine-coastal ecosystems.

The scale and magnitude of the global environmental emergency require deep sustainability transformations in management methods and tools, in institutions (Chuenpagdee and Jentoft, 2018), and also in the way research is approached (UNESCO, 2019). Conventional fisheries management have focused in many cases on incentives that contribute to overcapacity and overlook individuals' intrinsic motivations to act sustainably (Grafton et al., 2006; Lubchenco et al., 2016). Measures such as the control of catch volumes, the minimum mesh sizes, are useful to address concrete problems, but they lack a holistic approach that also takes into account the interactions of the species, the changes in the structure of the ecosystem (Link, 2002) and human-nature relations.

Sustaining marine diversity and SSF livelihoods requires careful attention to the associations between ecosystems, fishers' behavior and seafood markets (Crona et al., 2020). Yet although behavioral and cognitive aspects such as the values, motivations and ecological knowledge of the people involved in the local adoption of management measures are fundamental for sustainability, have so far been barely linked to fisheries research (Battista et al., 2018). Moreover, the way in which scientific results have routinely been communicated within (e.g., the natural and social sciences) and outside of academic disciplines, has not widely permeated the realm of decision and policy-making to address societal problems in practice (Kittinger et al., 2013).

Sustainability transformations imply fundamental changes in the system, at the structural, functional and relational level, which lead to new patterns of interactions and emergent results throughout the system (Patterson et al., 2017). There has been a shift over the last few years within the SSF, from traditional management approaches aimed at maximizing catches and maintaining the productive capacity of the stocks to a recognition that fisheries are coupled social-ecological systems (SES) composed of multiple subsystems and different levels (Kittinger et al., 2013; Leslie et al., 2009; Ostrom, 2009). Understanding the critical interactions and feedbacks between social, institutional and ecological factors can help explain how these dynamics affect the potential for sustainability (Lindkvist et al., 2020).

1.1.1. System Approach to Fisheries and the Use of Trophic Models

Healthy ecosystems and social justice are foundations on which to build fair economic development (Bennett et al., 2019). The ways in which people relate and interact with nature play a key role in shaping resilience (Folke et al., 2010). Going beyond the single-species management approach recognizes that fishing activity does not only affect target species and their habitats (through the mortality caused by fishing and the gear effects), but also affects biological interactions in the system through a disruption in predator-prey or other, indirect trophic relationships (Pauly et al., 1998). In the past two decades, Ecosystem-based Fisheries Management (EBFM) acknowledged the complex ecological interactions and feedbacks inside a fishing system (Pikitch et al., 2004).

Fishing impacts can cause changes in the overall composition of ecological communities, reduce species richness, and decrease the system's ability to generate ecosystem services (e.g., decreased value of fish catches) (Christensen et al., 2015), similarly they can generate changes in the structure and general function of the ecosystem, affecting its ability to recover from environmental changes (ecological resilience) (Christensen and Pauly, 2004). Within Ecosystems Approach to Fisheries, Ecopath with Ecosim (EwE) has been used as a tool for modeling a great variety of aquatic ecosystems subjected to human use (Christensen and Pauly, 1992; Walters et al., 2008). This free software has been applied in various data contexts around the world to comprehend the fishing impacts on the structure and function of ecosystems (Christensen and Pauly, 2004)

EwE models can assist in better understanding the direct and indirect impacts of fishing on the biological components of the system and their resulting productivity, while facilitating progress towards the integration of more socio-economic dynamics in ecosystem-based modeling (Christensen et al., 2011; Walters et al., 2008). In the context of tropical SSF where poor data availability is a common feature, due to the difficulties in conducting expensive collection of fishery data, the relatively few key data required for EwE modeling (Bacalso and Wolff, 2014) have made this tool very useful to examine the impacts of fishing activities and to explore possible long-term effects of fisheries management policies (Bacalso et al., 2013; Christensen and Walters, 2005; Rehren et al., 2018; Walters et al., 2008).

1.1.2. Integrating Plural Values in Fisheries Decision Making

One remaining challenge is to integrate ecological modeling and social dimensions into the EAF, which calls for collaborative processes between scientists, institutional actors and fishery workers (Bentley et al., 2019; Power et al., 2004; Steenbeek et al., 2020). In most environmental conflicts, stakeholders embrace different values (**Table S1.1** in Annex I) and preferences that are often not well represented in decision-making (Martín-López et al., 2007). It is also essential to understand the role of societies in the adoption of sustainable behaviors (Schwartz and Bilsky, 1987), given that people's values, mindsets and choices shape the decisions involved in the state and future of the ecosystems (Song et al., 2013)

The applied school of integrated valuation (Gómez-Baggethun et al., 2014; Jacobs et al., 2016) and plural valuation e.g., (Arias-Arévalo et al., 2017; Kenter, 2016; Pascual et al., 2017)) emerges from the traditions of ecosystem services (Millenium Ecosystem Assesment, 2005) and ecological economics (Costanza, 1991; Costanza et al., 1997), and aims to bring science to practical applications in society. The plural valuation of nature represents the different ways of perceiving the importance of nature, ecosystems and ecosystem services, which includes multiple values and worldviews in a coherent and operational framework that aims at social impact, in addition to the academic realm (Arias-Arévalo et al., 2018; Jacobs et al., 2016; Kenter, 2018).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) - international body which assesses the state of biodiversity and of the ecosystem services it provides to society-, distinguishes different ways of perceiving the importance of nature (IPBES, 2019b; Pascual et al., 2017), it also takes into account diverse ways of knowing (e.g., scientific knowledge and local ecological knowledge), and includes: (1) intrinsic value or the importance of nature itself; (2) relational values or the significance of nature to foster relationships between people and the environment; and (3) instrumental values or the importance of the benefits of nature for human beings (Pascual et al., 2017).

There is a growing recognition of the need to combine multiple disciplines within and across the natural and social sciences (e.g., social psychology, ecology, sustainability sciences), as well as methods (e.g., plural valuation, contingent valuation, relational values, economic experiments) to represent diverse sets of ecosystem values and to support decision making (Christie et al., 2012; Gómez-Baggethun et al., 2014; Kenter, 2016). The preferences of the stakeholders for designing conservation policies need to be taken into account to ensure successful results both ecologically and socially (Martín-López et al., 2007).

United Nations (UN) declared from 2021 to 2030 the Decade of Ocean Sciences for Sustainable Development (UNESCO, 2019), to improve the health of the oceans by generating the knowledge, data and approaches necessary to support sustainable development in the future. The incorporation of inter- and transdisciplinary teams (Glaeser et al., 2009; Jacobs et al., 2016; Nash et al., 2021) and deliberative methods in plural valuation (Kenter et al., 2011; MacMillan et al., 2006; Spash, 2007, 2008), can serve as open spaces for dialogue and platforms for the integration -in real-world applications- of diverse knowledge and values of the ecosystem, thus opting for transformational research towards sustainability (Folke et al., 2010).

1.2. EXAMINING LEVERAGES FOR SUSTAINABILITY TRANSFORMATION IN SMALL-SCALE FISHERIES

SSF make important contributions to national and regional economies and represent almost half of global fish landings (FAO, 2015). They are an essential source of nutrition, income and employment for millions of people in coastal communities (Crona et al., 2020). SSF have traditionally been defined by technological dimensions such as having relatively limited capital and labor, little production, and reduced fleet size and mobility (Salas et al., 2011). The SSF Guidelines (FAO, 2015) frame these fisheries as “all activities along the value chain: pre-harvest, harvest and post-harvest carried out by men and women in terrestrial and marine systems”.

The term SSF is an evolving and context-dependent concept that begins to more explicitly recognize the health of aquatic ecosystems and biodiversity as a basis of well-being (Smith and Basurto, 2019). The SSF exemplify the unpredictable interdependence between people and nature, characteristic of complex social-ecological systems (Basurto et al., 2013; Leslie et al., 2009, 2015; Ostrom, 2009) that can lead to sustainability or overfishing depending on the management course taken, it can also be driven by external pressures such as climate change and market demands (Salas et al., 2007). New and improved ways to understand, analyze, and govern the fisheries dynamics are needed to enable SSF to become a leverage for sustainability (Crona et al., 2020).

Several policy measures have been promoted to improve the sustainability in fisheries, including rights-based incentives, legally enforceable harvest strategies and marine reserves (Beddington et al., 2007). However, most of the management interventions currently applied in SSF tend to be tangible but with limited potential for transformational change (Meadows, 1999); for instance based on single-species management and relying mainly on economic incentives and perverse subsidies (Grafton et al., 2006). Considering that most of the world's fisheries are small-scale, it is vital to opt for governance transformations, identify successful cases, new tools to facilitate such changes, and implement them more broadly (Beddington et al., 2007; Chuenpagdee and Jentoft, 2018).

For transforming social-ecological systems to a more sustainable state, it is necessary to understand where and how to intervene (Abson et al., 2017; Meadows, 1999), also understanding how this translates into policy and management strategies (Leslie et al., 2015; Schlüter et al., 2021). A noticeable example is represented by systems theory and specifically the work of Meadows, (1999) on leverage points for sustainability. She identified a hierarchy of places, which later (Abson et al., 2017) categorized into four system characteristics (**Table 1.1**). The twelve leverage points range from shallow (e.g. changes in parameters and feedbacks) to deep (e.g. changes in system intent and paradigms). Many interventions are easy to apply but with limited potential for sustainability transformations (shallow leverage) (Meadows, 1999).

Table 1.1. Twelve leverage points (Meadows, 1999) with their corresponding system characteristics (Abson et al., 2017).

Shallow Leverage points	**System characteristics**	**Examples**
12.Constants, parameters, numbers	Parameters: measurable system features	Subsidies, taxes, population age structures; transport networks
11. The size of buffers and other stabilizing stocks, relative to their flows		
10. Structure of material stocks and flows		
9. Length of delays, relative to the rate of system changes	Feedbacks: interaction within the system	Models to predict responses
8. Strength of negative feedback loops, relative to the effect they are trying to correct against		

Table 1.1. Twelve leverage points (Meadows, 1999) with their corresponding system characteristics (Abson et al., 2017).

Shallow Leverage points	**System characteristics**	**Examples**
7. Gain around driving positive feedback loops		
Deep Leverage points	**System characteristics**	**Examples**
6. Structure of information flow	Design: systemic structures	Access to information; type and diversity of information (e.g., cultural or biological); biodiversity to improve genetic information diversity; institutional arrangements; sanctions, controls, incentives; co-management schemes
5. Rules of the system		
4. Power to add, change, evolve, or self-organize system structure		
3. Goals of the system	Intent: long-term trajectory of system behavior	Values, worldviews, beliefs
2. Mindset out of which the system arises (goals, structure, rules)		
1. Power to transcend paradigms		

1.2.1. A Leverage Points Perspective for Sustainability Transformations

Leverage points has been described based on system analysis, "as places within a complex system (a living body, a fishery, a city, an ecosystem) where a small shift in one thing can produce big changes in everything" (Meadows, 1999). There are twelve leverage points identified that influence the behavior of a system, ranging from 'shallow' (places where interventions are relatively easy to implement but produce little change in the overall functioning of the system) to 'deep leverage points more difficult to alter and generally less explored, but that potentially resulting in transformational change (Meadows, 1999). The places correspond to four system characteristics (from shallowest to deepest): *parameters* (mechanist, materials), *feedback* (processes), *design*, and *intent* (Abson et al., 2017) (**Table 1.1**).

Among the "deeper" leverage points that have great potential but are under-investigated (Fischer and Riechers, 2019), *design* has to do with the social structures that manage feedbacks and parameters (Abson et al., 2017). That is, interventions that delve into how information flows (e.g. access, type and diversity of information, whether cultural or biological, such integrating indigenous knowledge or focusing on biodiversity to improve genetic information diversity), and in redefining the rules of the system (for example, sanctions, controls or incentives) which establish the conditions for a self-organized system structure (Meadows, 1999), such is the case of co-management initiatives in fisheries (Herrón et al., 2020).

One deep leverage point to create system-wide change, is at the level of *intent* or the underlying values, goals, and actors worldviews that shape the emerging direction toward which the system is heading (Abson et al., 2017), through interventions that redefine the goals of the system and recognize what purpose is being fulfilled, change mindsets from which the system arises (e.g., values, worldviews, beliefs) and transcend paradigms (Meadows, 1999). While there is an urgent need to focus on less obvious but possibly more effective interventions (Riechers et al., 2021a), there are many conceivable interactions between leverage points (Chan et al., 2020) and the investigation of the interplay between the deep and the shallow leverage points is likely to lead to identifying synergistic benefits (Fischer and Riechers, 2019).

Over the last few years, research on leverage points has been receiving increasing attention within sustainability circles, e.g., (Abson et al., 2017; Chan et al., 2020; Conlon, 2021; Dorninger et al., 2020; Fischer and Riechers, 2019; Jiren et al., 2021; Lam et al., 2021; Riechers et al., 2021a). Two recent examples in fisheries include work on the sustainability of the financial sector of fishery products (Jouffray et al., 2019) and another is in the context of the gear choices in SSF (Herrón et al., 2020). However, despite the growing interest in leverage point investigation, the SSF faces complex social-ecological issues and mainstream fisheries management still lags behind in applying these concepts.

At this time of great challenges and global environmental changes, including the climate emergency (Christensen et al., 2015) and the COVID-19 pandemic (Bennett et al., 2020), achieving the SDGs for the SSF sector will require a fundamental reorganization of the entire system through technological, economic and social factors, including paradigms, objectives and values (Chan et al., 2020). A leverage points perspective (Fischer and Riechers, 2019) in SSF has the potential to identify priority points for intervention and strategic actions which appear to be key to societal transformation.

1.3. A CASE STUDY IN A TROPICAL COASTAL AREA: THE GULF OF NICOYA, COSTA RICA

Costa Rica is a tropical Latin American country located between Nicaragua and Panama, neighboring also Colombia and Ecuador by sea and home to extensive marine biodiversity, approximately 3.5% of all reported marine species (Wehrtmann and Cortés, 2009). While the total continental territory covers a small region of 51,100 km^2, the marine area including territorial seas and Exclusive Economic Zones is more than ten times larger (589,683 km^2). The Exclusive Economic Zone of Costa Rica is significantly extended with 200 miles on the Pacific coast and 200 miles around Isla del Coco (an oceanic island) (Wehrtmann and Cortés, 2009).

The country is surrounded by coasts in both the Pacific Ocean and the Caribbean Sea, the Pacific coastline is approximately six times larger than the Caribbean one (1,016 kilometers and 212 kilometers respectively) (Herrera-Ulloa et al., 2011). In the Pacific Coast, the numerous bays, extended gulfs, upwelling systems and large exclusive economic zone (EEZ) of 589,682.9 influences a high level of fishing productivity. On the other hand, the Caribbean Coast has a narrow continental platform and an EEZ of approximately 24,000 square kilometers, and lower fishing productivity if compared to the Pacific (Wehrtmann and Cortés, 2009).

For decades the national economy focused on agriculture, particularly the export of coffee beans and bananas, then since the mid-1990s it has specialized mainly in services such as tourism (Herrera-Ulloa et al., 2011), including ecotourism and medical tourism, also in finance and pharmaceutical research. In 2010, fishing and aquaculture constituted approximately 1,4 % of GDP (Beltrán-Turriago, 2014); by 2014, tourism revenues represented 5.3% of the country's GDP (Sabau, 2017). Although the share of fishing in GDP is not as significant as tourism, the importance of fishing and aquaculture is better reflected in the generation of employment and contribution to the diet (Beltrán-Turriago, 2014; FAO, 2003)

The fishing fleets operating in Costa Rica entail six sectors, the (1) pelagic and (2) demersal fisheries, (3) shrimp fishery and (4) other invertebrate fisheries; (5) recreational and (6) foreign fisheries (Herrera-Ulloa et al., 2011; Trujillo et al., 2015). The pelagic fisheries (1) catch small pelagics (7% of total landings) such as sardines (*Ophistonema* spp.) and anchovies (Engraulidae) which are fished at an industrial scale, together with large pelagics (50% of reported landings) including Carangidae (*Caranx* spp.), skipjack tuna (*Katsuwonus pelamis*) as well as sharks (15% of reported landings) e.g., silky shark (*Carcharhinus falciformis*) and hammerheads (Sphyrnidae) (Trujillo et al., 2015).

The demersal fisheries consist of drums and croakers Sciaenidae (*Micropogon altipinnis* and *Cynoscion* spp.), snappers (Lutjanidae), groupers (*Epinephelus* spp.) and different rays and sharks (e.g., Rajidae, Torpedinidae and *Alopias* sp) (Herrera-Ulloa et al., 2011). By the 2000s the shrimp fishery comprised 41 shrimp vessels along the Pacific coast, targeting shallow coastal species (e.g., *Litopenaeus* spp., conchudo *Rimapenaeus byrdi* and tití shrimp *Xiphopeneaus kroyeri*), as well as deepwater shrimp fisheries (e.g., *Heterocarpus affinis*, *H. vicarious* known as camello) and *Solenocera agassizii* (fidel) (Wehrtmann and Nielsen Munoz, 2009). The invertebrate fisheries such as bivalves (e.g., the piangua fishery) are central for the small coastal communities but usually underrepresented in fishery statistics (Herrera-Ulloa et al., 2011).

The recreational fishing sector targets many of the species that are also directed by demersal fishing; furthermore, foreign vessels largely target tuna in the EEZ (Trujillo et al., 2015). In general, the six fishing sectors in Costa Rica use different fishing gears and are part of two main fleets, an industrial fleet that operates mainly in marine waters and a small-scale fishery that operates mostly in coastal water which represents approximately 75% of the total fleet (Herrera-Ulloa et al., 2011). Small-scale fishers in 2009 numbered 13,850 living and working in 75 communities in the Pacific and 950 small-scale fishers living and working in 11 communities on the Caribbean coast (Sabau, 2017).

As in other tropical coastal areas of Africa, Asia (Béné et al., 2010), and Latin America, the Costa Rican SSF target multiple species and use multiple gear, tend to have little capital and labor as well as remote landing sites, migrants, seasonal workers, and weak bargaining power on the part of fishers (Herrera-Ulloa et al., 2011; Salas et al., 2011). Poor management and governance, poverty conditions, climate variability and pollution are particularly pressing issues in tropical coastal areas (Purcell and Pomeroy, 2015) affecting also Costa Rican fisheries. One of the main fishing centers of the SSF in this country is represented by the Gulf of Nicoya (GoN), located on the Pacific Coast with an area of 1,500 km² (10 ° 00'N - 85 ° 00'W) (Vargas, 2016). The GoN is a very productive tropical estuary with the highest concentration of fishing communities (Herrera-Ulloa et al., 2011).

1.3.1. Small-Scale Fisheries in the Gulf of Nicoya as a Social-ecological System

The GoN represents a tropical coastal and marine social-ecological system (CM-SES) (Glaeser et al., 2009; Glaser et al., 2012) and consists of multiple levels and scales (Chavez Carrillo et al., 2019). In the ecological subsystem (**Figure 1.1)** and at the biophysical level, both marine currents (Voorhis et al., 1983), wind patterns (Brenes et al., 2003), flow of nutrients and the seasonal discharge of several effluent rivers (e.g., Tárcoles and Tempisque), make the GoN an estuary with high primary productivity (Gocke et al., 2001). These conditions favor a wide biodiversity of fish and benthic invertebrates (Vargas, 1995; Wolff et al., 1998). The coastal ecosystems found in the region include mangrove forests which play a role as breeding and larval development sites for many marine species, similarly rocky reefs, and river estuaries (Vargas, 2016).

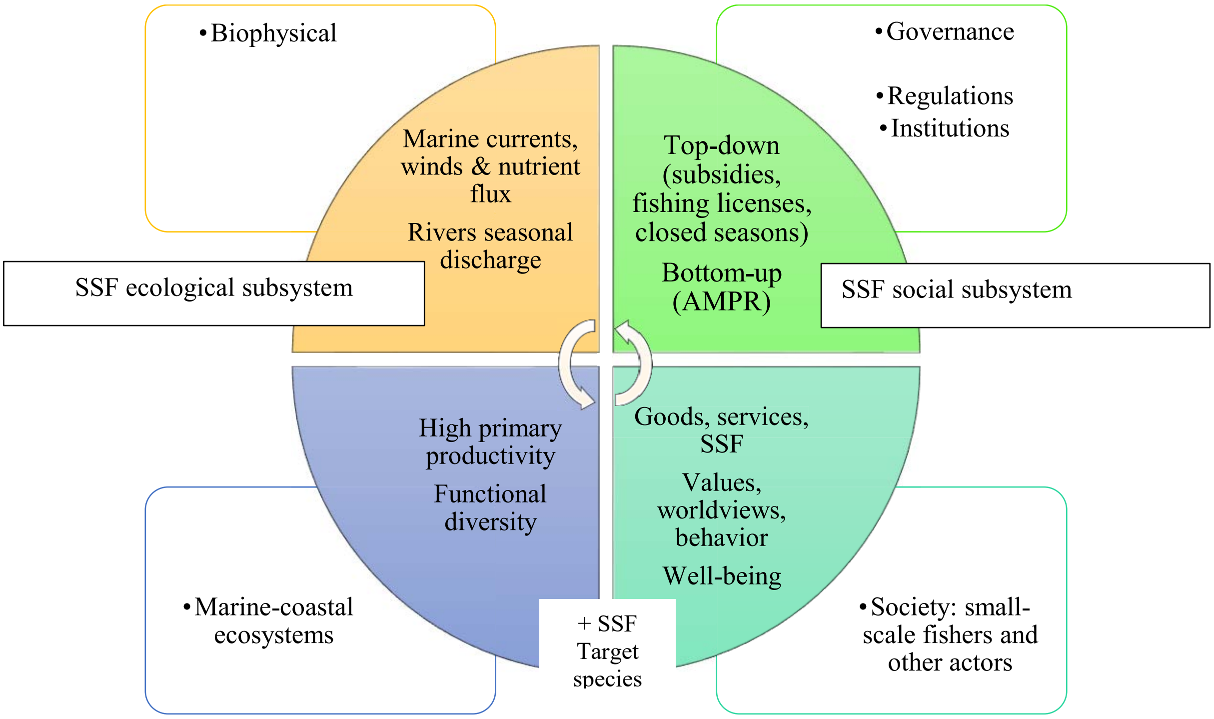


Figure 1.1. Social-ecological system of small-scales fisheries in the Gulf of Nicoya. The ecological subsystem at the biophysical and ecosystems levels, along with the social subsystem at the level of society, management and governance.

The mangrove forest contributes to primary productivity by providing organic matter and improving the functional diversity of fish and invertebrates (Stern-Pirlot and Wolff, 2006; Wolff, 2006) as well as redundancy between groups to maintain the basic functions of the ecosystem(**Table S1.2** in Annex I), in which shrimp are food key to a wide variety of species (Alms and Wolff, 2019; Wolff et al., 1998). In addition to fish, other species are also present, including seabirds, cetaceans and critically endangered sea turtles (e.g., the hawksbill turtle) (CREMA, 2014).

Regarding the social subsystem (**Figure 1.1**), coastal and marine ecosystems of the GoN make available numerous goods, services and cultural values. For example, has been suggested an approximate value of USD 408 million per year for the contributions of the GoN mangroves in processes of climate regulation, coastal protection and fishing activity (Hernández-Blanco et al., 2021). Within the SSF sector (2,700 licensed fishers for 2014) the activity is a fundamental support for food security (Beltrán-Turriago, 2014; FAO, 2003) and represents not only the livelihood of thousands of fishers but also a deeply rooted tradition (Fernández-Carvajal, 2013) in at least 16 communities (Beltrán-Turriago, 2014).

Concerning the management level, top-down regulations predominate (Lozano and Heinen, 2016a) such as control of fishing effort through the allocation of permits/licenses by the Costa Rican Institute of Fisheries and Aquaculture (INCOPESCA), gear size control, fishing closures and a subsidy system in the main areas of the Gulf during the peak of the shrimp reproduction period when the fishery is closed (BIOMARCC et al., 2013). Moreover due to a bottom-up community initiative, a type of marine protected area of co-management, the Marine Area for Responsible Fishing (AMPR for its Spanish acronym) was legally recognized in 2019 (Lozano and Heinen, 2016a).

SSF in the GoN are diverse, with multi-gear boats including gillnets, lines (bottom longlines and drifting longlines), handlines and manual gear (traps and mollusk extraction) (BIOMARCC et al., 2013), and multispecies fisheries (Herrera-Ulloa et al., 2011). The whiteleg shrimp (*Litopenaeus vannamei*) is one of the main resources of the local economy and, together with the corvina reina (*Cynoscion albus*), characterizes over 50% percent of the catch in the inner Gulf (Marín-Alpízar, B. and Vásquez, 2014). There is high demand for corvina reina and whiteleg shrimp in the domestic market (Proyecto Golfos, 2012) with a preferential pricing for larger individuals (Marín-Alpízar and Alfaro-Rodríguez, 2019). Gillnet is the most common gear for both corvina and shrimp, and therefore represents the focus of this study.

1.3.2. Inner, middle and outer Gulf

Due to the need for zoning for the implementation of fishing closures, the GoN has been administratively divided by INCOPESCA into three zones: 201 or internal Gulf, 202 middle part and 203 at the mouth of the Gulf (Vargas, 2016) (**Figure 1.2**). Isla de Chira is an example within zone 201, made up of small-scale fishing communities, where several hand line fishers committed to sustainability have created a Marine Area for Responsible Fishing (AMPR) (Ulate-Garita, 2020). Despite the lack of adequate State support, the fishers of Isla Chira maintain a monitoring program to avoid the use of gillnets within the AMPR.

Islanders tend to recognize the need and benefits of AMPR and help monitor and enforce the area (Ulate-Garita, 2020), but it is still common to use gillnets to catch shrimp outside the AMPR, due to the price of shrimp can be more favorable than that of other species. Some NGOs, the national university (UNA) and the INA (the national learning institute) have provided support to these fishers with technical courses and in finding diversification alternatives to fishing (Beltrán-Turriago, 2014).

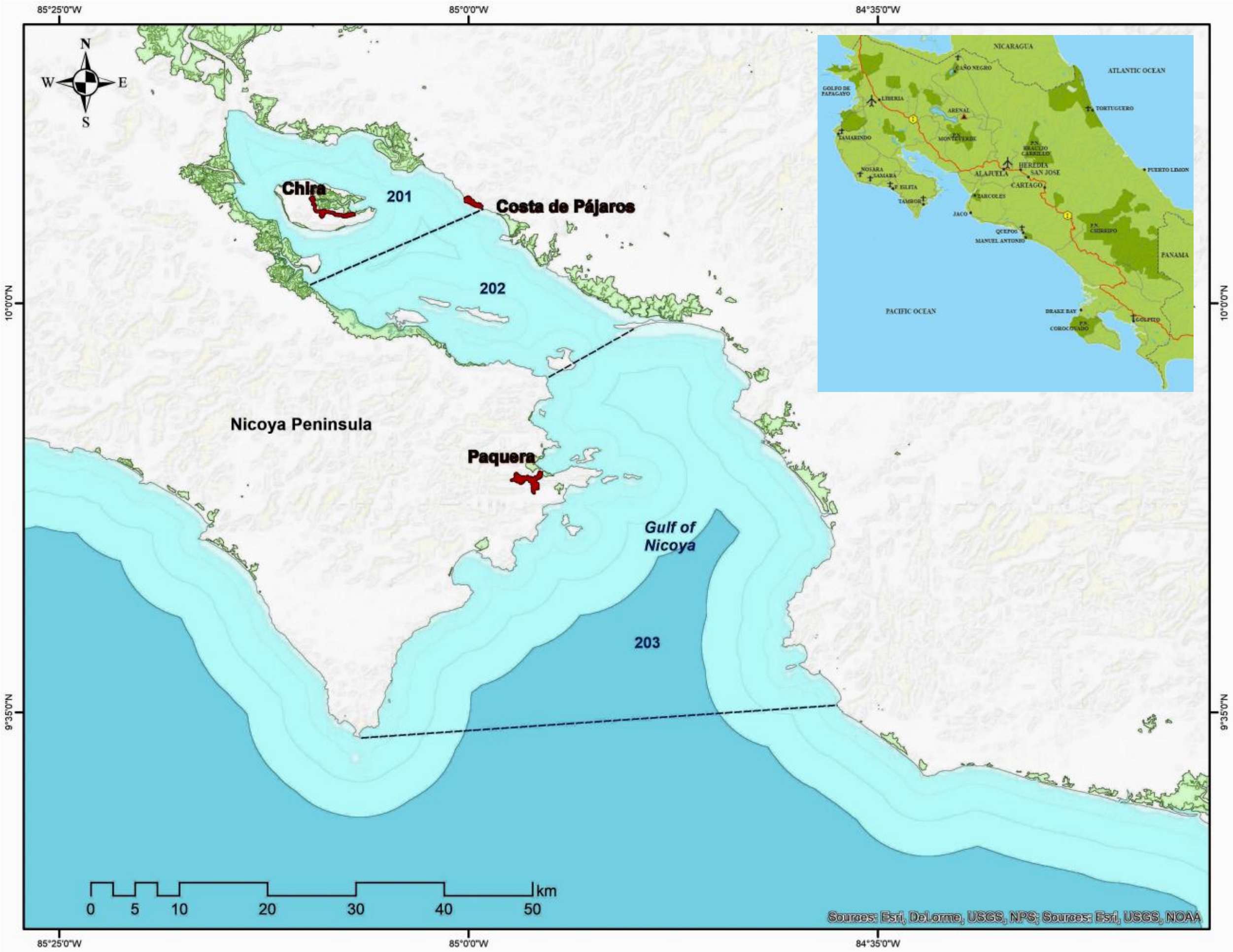


Figure 1.2. Study area in the Gulf of Nicoya. Zone 201 or internal gulf, area 202 corresponds to the middle part and the 203 sector is located at the mouth of the gulf.

In area 202 (**Figure 1.2**), a representative community is that of Costa de Pájaros (CP), where an AMPR has been created by a popular initiative. In this sector, fishers can operate different fishing gears. The majority use shrimp gillnets, followed by those using finfish gillnets and a low percentage using bottom lines and hand lines (Pacheco-Urpí, 2013). Gillnet fishing gear consists of a nylon net or mesh with a height of 1.5 meters and a length of approx. 500 meters. The legally allowed mesh size is 3 inches for shrimp and 3.5-8 inches for finfish (Fernández-Carvajal, 2013). Poverty issues are prevalent in CP and there is widespread use of illegal fishing gears (the most extensive in the Gulf), (Pacheco-Urpí, 2013) including dragnets, the 2.75-inch gillnet and the 2.5-inch gillnet mesh.

Communities such as La Leona and Playa Blanca are important representatives of the outer zone (203) (**Figure 1.2**), home to dispersed groups of small-scale fishers who predominantly use gillnets and depend heavily on fishing, though some community members alternate with touristic activities. In this sector, the AMPR Paquera-Tambor has been created and various fishing, tourism and university sectors have contributed to its creation (Chavez Carrillo et al., 2019).

1.3.3. Towards a Systems Management of Small-scale Fisheries in the Gulf of Nicoya

In the 1990s an ecosystem approach to fisheries was applied through the development of an Ecopath model of the Gulf to analyze the interactions of multiple species, as well as the system impacts of fish landings (Wolff et al., 1998). The model revealed that: (1) shrimps occupy a central position in the food web as a diet item for many groups of fish; (2) overexploitation of shrimp seriously affects the food web of the entire system; and (3) that sustainable levels of catches could be achieved if a significant reduction in fishing effort were implemented to allow shrimp and fishery resources to recover (Wolff et al., 1998).

An updated version of this model (Alms and Wolff, 2019) (**Figure 1.3**) show that the general structure and functionality of the ecosystem has been maintained over the years, but only due to the redundancy between some low trophic level species that dominate the catches, such as shrimps, small pelagic fish, crabs and small demersal fish. While the catch of shrimp (of high economic value) and of predators of higher trophic levels such as rays, sharks, mackerel and barracuda, has suffered a considerable decrease, translating into significant economic losses (around 50%), the catch volume of sardines has greatly compensated the loss in catch volume.

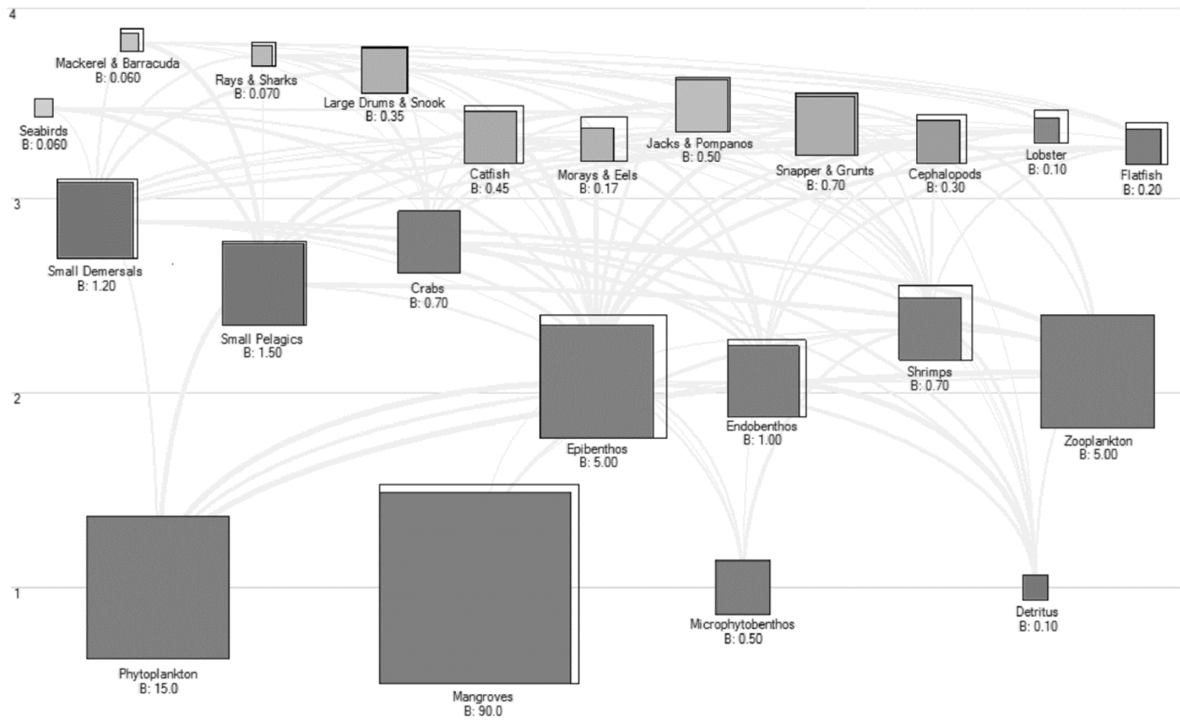


Figure 1.3. Biomass changes of the compartments in the Gulf of Nicoya ecosystem along two decades. The vertical position of boxes mark their trophic level in the system. Catches at the lowest and highest trophic levels decreased from 1993-2013. The mean trophic level (MTL) of the catch remained at a low value ~2.8. Adapted from Alms & Wolff, 2019 with permission of the authors.

The predominance of high trophic level species can be considered as an indicator of the health of an ecosystem (Pauly et al., 1998), thus the reduction in catches at the highest trophic level in the 1993-2013 period, is a sign of the unsustainable route taken by GoN fisheries that is undermining its own means. With the strong pressure and reduction on shrimp over the last decades, the economy and the ecosystem have been affected, since the different life stages of shrimp are key foods for a wide variety of species, including commercial ones (Alms and Wolff, 2019; Wolff et al., 1998). Furthermore, in many cases, regulation through mesh size control (gears and individuals), as is the case of the GoN, does not necessarily address ecological impact in tropical SSFs with multiple gears and numerous species (Herrón et al., 2020).

There are key aspects that are not being adequately addressed in the management of the fisheries in the GoN, including overcapacity issues (Beddington et al., 2007), underlying causes of non-compliance and the allocation of subsidies that can promote fishing pressure (Grafton et al., 2006). For example, in the past years, subsidized (fuel) shrimp trawling vessels contributed to overcapacity (Lozano and Heinen, 2016a) and a strong impact on the ecosystem (Alms and Wolff, 2019) with high levels of bycatch and discarded individuals (Arana et al., 2013; Trujillo et al., 2015). Alternative strategies to standard fisheries management are needed to move from targeting the maintenance of the stocks productive capacity to a social-ecological systems management that ensures the integrity and sustainability of SSF in the Gulf.

1.4. RATIONALE AND SCOPE OF THESIS

If sustainable fisheries management is the desired state for the GoN, there should be an intentional focus on deep leverage points (Meadows, 1999; Riechers et al., 2021b) i.e., interventions that examine flows of information and knowledge, the system norms and conditions for a self-organizing system structure. Also at the level of intent, i.e., the underlying values and stakeholder mindsets that shape the emerging behaviors and goals of the system (Meadows, 1999). The fundamental hypothesis of this dissertation is that fisheries policy interventions in the GoN, have traditionally focused on shallow leverage points (parameters and feedbacks) that produce minor change in the overall functioning of the system. SSF management needs a social-ecological approach with transformative responses at the level of design and system intent.

To find answers regarding the overarching hypothesis, three different studies are conducted (with specific research questions, shown below in the thesis outline) and a leverage points perspective (Abson et al., 2017; Fischer and Riechers, 2019; Meadows, 1999) is used as a framework and as a tool of analysis. The aims are to: (1) investigate less evident but potentially more influential areas of intervention for the sustainability of the SSF in the GoN (chapters 2-4); (2) analyze these results and existing literature to uncover current state of sustainability interventions in the GoN, along with the interaction between deep and shallow points of intervention (Chapter 5); likewise (3) identify specific deep leverage points with the potential of a transformative change for the GoN SSF (Chapter 5).

The GoN has been extensively investigated in recent decades (Vargas, 2016) and the social-ecological interdependence of the fishing system is being increasingly recognized by researchers over the last few years (Chavez Carrillo et al., 2019; García-Lozano and Heinen, 2016; Lozano and Heinen, 2016b; Partelow et al., 2021). However, there is still a separation in the way in which the natural and social areas of knowledge conduct and communicate their results within and outside the academic disciplines. It is essential to guide interdisciplinary scientific practices for the solution of applied social problems and to promote inter-sectoral collaborations e.g., (Pacheco-Urpí, 2000; Ulate-Garita, 2020).

Some areas of influential intervention for sustainability or deep leverage points (Abson et al., 2017): include (1) *rethink* how different types of knowledge, sources of information and participatory approaches can help guide scientific information and management to solve applied social problems (Kittinger et al., 2013); (2) *reconnect* and reorient human behavior to nature, resilience and with the capacity of ecosystems to support life (Folke et al., 2016); and (3) *restructure* institutions by improving the way in which heterogeneity in behavior and human values can be incorporated into research and management of SSF (Abson et al., 2017; Jacobs et al., 2016; Lindkvist et al., 2020).

Of interest here is to shed light on "deep" leverage points under-investigated and overlooked by traditional fisheries management in the GoN SSF. The characterization of the GoN as a social-ecological system is providing context for examining three sites which although presenting differences, are all integrated into the same larger system and face similar challenges. Given the importance of gillnet fisheries in the GoN our study focuses on small-scale gillnet fishers from Isla Chira (Palito, Montero, Bocana), Costa de Pájaros and Paquera-Tambor (La Leona and Playa Blanca) (**Figure 1.2**., areas 201, 202 and 203 along the GoN) (1) whose fishing targets include predominantly corvina and shrimp and (2) are familiar with the fishing closure system, receive or have received economic subsidy during the closed season

1.4.1. Thesis Outline

Small-scale fisheries of the Gulf of Nicoya in Costa Rica's Pacific Coast are investigated as case study in a tropical context. The research presented in chapters 2-5 (**Figure S1.1** in Annex I) of this dissertation is developed from an ecosystem-based perspective, makes use of ecological modeling information generated within an interdisciplinary team (Alms and Wolff, 2019) and considers the fact that SSF are complex social-ecological systems. A leverage-points perspective is applied as a coherent framework and as a lens to understand the dynamics of the system. Immersed in this perspective, some specific approaches are used along the thesis chapters and the questions addressed within three different studies are shown below:

Chapter 2, RQ1 (*rethink ecological knowledge and information flows)*: this chapter asks what are the interactions between different types of knowledge (a trophic model and local ecological knowledge), and how this knowledge can be merged to promote sustainability and improve fisheries management.

Chapter 3, RQ2 (*reconnect with nature and ecosystem resilience)*: this chapter investigates the importance of universal values and ecosystem-based education interventions (using EwE modeling information) in predicting and encouraging environmental behavior (Value, Belief, Norm theory; Stern, 2000). It asks how to reconnect human behavior with nature and social-ecological resilience. Can a deliberation about a trophic model (EwE) produce effects on ecological norms and beliefs, in the context of environmental education and management? What are the changes in the behavioral intentions of the participants receiving and deliberating on EwE model information from the ecosystem?"

Chapter 4, RQ3 (restructure institutions): This chapter delves into how to improve the way in which heterogeneity in human behavior, values and worldviews of different actors and institutions can be incorporated into (inter-and-transdisciplinary) research and ecosystem-based management for improving SSF management (*restructure* institutions). "Do plural values and plural motivations influence a fisher's willingness to accept (WTA) reductions in fishing effort? How interdisciplinary and transdisciplinary research can help incorporate heterogeneity in ecosystem-based management for sustainability transformations in SSF?

Chapter 5: The general discussion analyzes the results of the previous chapters in light of a leverage point perspective, to uncover current sustainability interventions in the SSF of the GoN and enabling the examination of the interplay between shallow and deep systemic changes, as well as helping to provide a basis for prioritizing tropical SSF research, management efforts and transformative changes towards sustainability.

1.4.2. Manuscripts and Contribution of Doctoral Candidate

The articles included in this dissertation have been or will be published as follows:

Manuscript 1: Sánchez-Jiménez, A., Fujitani, M., MacMillan, D., Schlüter, A., and Wolff, M. (2019). *Connecting a trophic model and local ecological knowledge to improve fisheries management: The case of Gulf of Nicoya, Costa Rica*. *Front. Mar. Sci.* 6. https://doi.org/10.3389/fmars.2019.00126 (Chapter 2).

Experimental concept and design (90%), acquisition of data (95%) data analysis and interpretation (80%), preparation of figures and tables (90%), drafting of manuscript (90%).

Manuscript 2: Sánchez-Jiménez, A., MacMillan, D., Wolff, M., Schlüter, A., and Fujitani, M. (2021). *The Importance of Values in Predicting and Encouraging Environmental Behavior: Reflections From a Costa Rican Small-Scale Fishery. Front. Mar. Sci.* 8, 137. https://doi.org/10.3389/fmars.2021.543075 (Chapter 3).

Experimental concept and design (70%), acquisition of data (95%), data analysis and interpretation (80%), preparation of figures and tables (90%), drafting of manuscript (80%).

Manuscript 3: Sánchez-Jiménez, A., Wolff, M., Fujitani, M., and MacMillan, D. *Plural-values-and-ecosystem-based-Approach to Examine Policy Feasibility: a Leverage Point for Sustainability in Tropical Small-scale Fisheries* [Submitted to *Ecology and Society*]. Currently under review. (Chapter 4).

Experimental concept and design (80%), acquisition of data (95%), data analysis and interpretation (80%), preparation of figures and tables (90%), drafting of manuscript (90%).

Manuscript 4: Sánchez-Jiménez, A., Fujitani, M., MacMillan, and Wolff, M. *Interplay between Leverage Points for Transforming Sustainability: evidence from a Tropical Small-Scale Fishing System* [Sumitted to *People & Nature*]. Currently under review. (Chapter 5).

Experimental concept and design (80%), acquisition of data (95%), data analysis and interpretation (85%), preparation of figures and tables (100%), drafting of manuscript (90%).

Besides the publications of manuscripts, the doctoral candidate attended the following academic events to generate collaborations, present aspects of the design of the project and preliminary results of the dissertation

- Bremen, Germany (October, 2015). 11th Meeting of the International Scientific Advisory Board Leibniz Center for Tropical Marine Research (ZMT). Poster presentation: Valuing Marine Ecosystem Services in the Nicoya Gulf, Costa Rica: towards an integrated coastal management approach. A. Sánchez Jiménez, M. Wolff, A. Schlüter and D. MacMillan.

- Florianopolis, Brazil (May, 2016). II Iberoamerican Congress of Integrated Management of Coastal Areas. Oral presentation: "Visión comunitaria sobre la gestión, el uso y aprovechamiento de los recursos marino costeros en el Pacífico de Costa Rica". A. Sánchez Jiménez, Á. Morales Ramírez, J. Samper Villarreal, C. Sánchez Noguera.

- Canterbury, England UK (July, 2016). Valuing nature and participatory decision making conference, University of Kent, Canterbury. Poster presentation: Towards a sustainable use of marine Ecosystem Services in Gulf of Nicoya (Costa Rica) -a study on Deliberative Valuation and adaptation strategies in a tropical context. A. Sánchez Jiménez, M. Wolff, A. Schlüter and D. MacMillan.

CHAPTER 2. Integrating Local Ecological Knowledge and a Trophic Model (*Rethink Systems of Knowledge*)

Photos taken during the workshops entitled "20 years of changes in the ecosystem of the Gulf of Nicoya".

CHAPTER 2

Connecting a Trophic Model and Local Ecological Knowledge to Improve Fisheries Management: The Case of Gulf of Nicoya, Costa Rica

Astrid Sánchez-Jiménez, Marie Fujitani, Douglas MacMillan, Achim Schlüter & Matthias Wolff

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

Sánchez-Jiménez A., Fujitani M., MacMillan D., Schlüter A. and Wolff M. (2019). Connecting a Trophic Model and Local Ecological Knowledge to Improve Fisheries Management: The Case of Gulf of Nicoya, Costa Rica. *Front. Mar. Sci*. 6, 126. https://doi.org/10.3389/fmars.2019.00126

ABSTRACT

Trophic models of the Ecopath with Ecosim (EwE) type and local ecological knowledge (LEK), have widely been applied for fisheries assessment and management. However, there are no specific methodologies describing how (LEK) from local fishers can be incorporated with the scientific data from trophic models in the context of tropical small-scale fisheries management. Here we explored a systematic integration of LEK with EwE modelled output. An EwE food web model of the Nicoya Gulf ecosystem (Costa Rica) constructed 20 years ago and recently re-visited by the authors, was used in workshops to stimulate discussion among local stakeholders regarding changes in the marine ecosystem. For this study, 58 artisanal fishers were recruited to eight workshops. To assess the LEK, we documented the discussions, and the qualitative data were analyzed with quantitative frequency of responses to identify trends. Next, we systematically compared the changes in the fishery over time through an analysis of similar, complementary and contradictory information across knowledge systems. In general, the analysis across systems reflected changes in species composition of the catches, paralleled by a harvest reduction of high trophic level species, as well as economic losses due to a shift to harvesting low value species and due to an increase in operational costs. Overall we identified: (1) similar pieces of information that delivered the same message, providing robust evidence of changes in the social-ecological system; (2) information complementary to each other, that together provided a broader picture (descriptors and attributes) of the changes of some fishing resources; and (3) conflicting pieces of information that indicated mismatches between sources of knowledge, which might suggest the cause of management problems. This study demonstrated how integrating knowledge systems can enhance our understanding of the state and changes in ecosystems, helping to improve fisheries management. We also found that an EwE model can be an effective communication tool to be used with fishers, to promote discussion and engagement. Our aspiration is to bring new-and-replicable tools to the policy interface in tropical small-scale fisheries, based on both stakeholder participation (including LEK) and the best scientific information available.

Keywords: small-scale fisheries (SSF), ecosystem based approach for fisheries management, Ecopath with Ecosim (EwE), trophic model, local ecological knowledge (LEK), connecting knowledge systems, Latin-American fisheries, tools for the science-policy interface

2.1. INTRODUCTION

In recent years, resource managers have increasingly focused on fishery-driven changes in ecosystem structures and trophic relations, since fishery-induced changes in biomass at one trophic level have shown to affect the whole ecosystem (Pauly et al., 2000). Food web models of the Ecopath type have been used as efficient tools for presenting the interactions and changes in the food web as a result of fishing (Christensen and Pauly, 2004), and have also allowed managers to predict tentative changes in the future, with the Ecosim tool (Pauly et al., 2000; Christensen and Walters, 2004).

If one seeks to identify feasibility in fisheries management measures, it is important to understand both the ecosystem context in which the fishing activities take place, and the preferences or motivations underlying the fishers' behavior (Bacalso et al., 2013). While EwE modeling tools have widely been applied for ecosystem based fisheries assessment (Christensen and Walters, 2005), there are as yet only a reduced number of examples in the literature of their application with fisher stakeholders (Ainsworth and Pitcher, 2005b, 2005a; Armada et al., 2018; Bacalso et al., 2013; Christie et al., 2009; Paramor et al., 2005; Pitcher, 2001) despite the fact that fishers' participation in the decision-making process has often shown to enhance sustainable management (Leite and Pita, 2016; Pita et al., 2010).

Synergies across scientific and local knowledge systems has been limited in policy making at a global level (Mackinson, 2001; Tengö et al., 2014) including the Latin-American tropical context (Salas et al., 2007; Begossi, 2015; Saavedra-Díaz et al., 2015). Understanding human activities and their impacts on the ecosystem is crucial for societal decisions and for the development of adaptation strategies (Dietz, 2013). However, assessment may be complex and any decision can present uncertainties (Kenter et al., 2011). Scientific data, if communicated adequately, has the potential to inform people and help in the process of weighting alternatives (Dietz, 2013). When scientific knowledge and local perception are disconnected from public policies, it usually leads to management measures that are not complied (Msomphora, 2015).

The scientific findings and local ecological knowledge (LEK) need to be integrated to improve decision making (Mackinson et al., 2011). The same principles apply for the management of fisheries (Mackinson et al., 2011; Saavedra-Díaz et al., 2015; Fujitani et al., 2018). In this way, we use the case study of the small-scale fishery (gillnet) in the Gulf of Nicoya (GoN), Pacific Coast, Costa Rica (**Figure 2.1**), to better understand the interactions between scientific information (EwE modeling) and local ecological knowledge. Most of national catches come from the Pacific Coast (BIOMARCC et al., 2013) and several important fishing grounds are within the GoN (Wolff et al., 1998), supporting thousands of small scale fishers, who mainly use nets to fish and sustain their families (Pachecho-Urpí et al., 2013; Ross-Salazar, 2014).

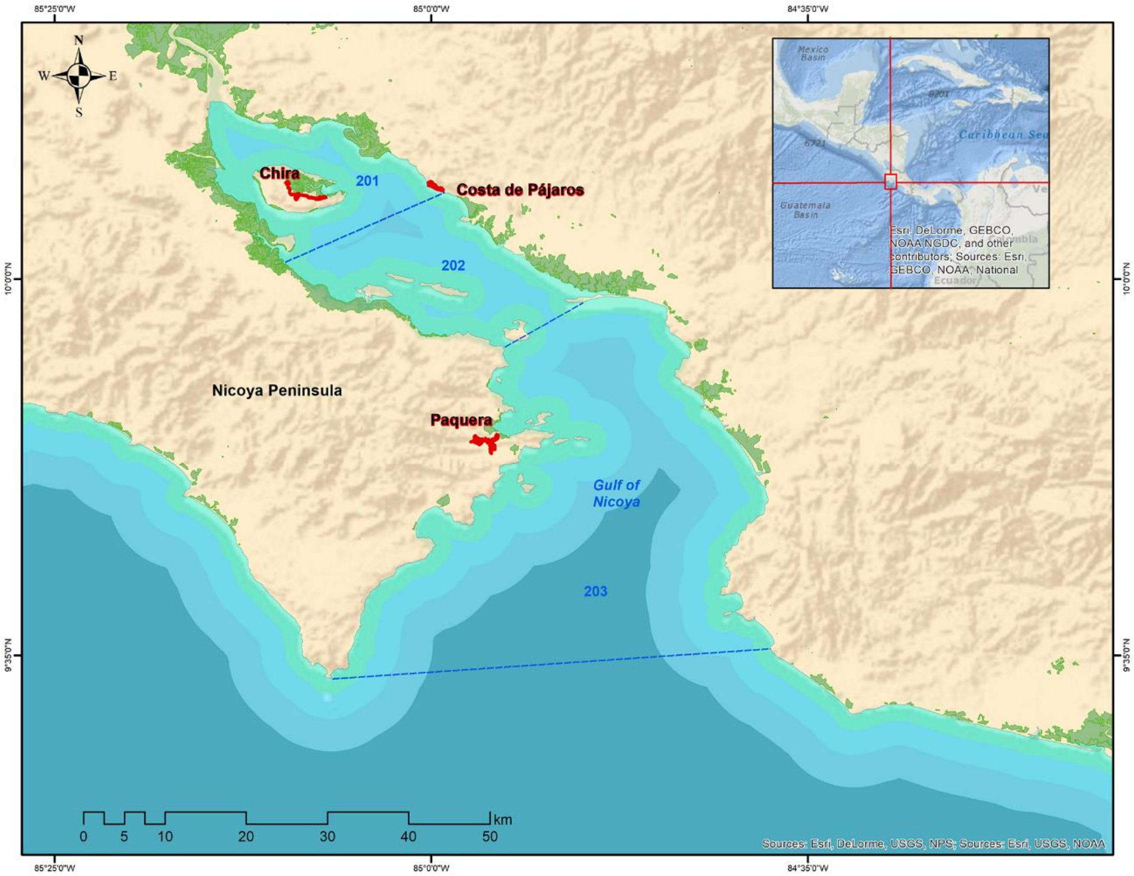


Figure 2.1. Gulf of Nicoya located on the Pacific coast of Costa Rica. The Gulf is sectored by INCOPESCA into areas 201, 202 and 203 based on species composition and fishing gears used (Marín-Alpízar, B. and Vásquez, 2014). The three focal points selected for this study, along the gulf were: Isla Chira (inner area), Costa de Pájaros (inner-intermediate area) and Paquera-Tambor (outer area).

The GoN has exhibited different forms of fishery management, including spatial and temporal closures (Salas et al., 2007), such as a seasonal fishing closure of three-four months, for the protection of small pelagic species' reproductive peak events: Whiteleg shrimps (*Litopenaeus* spp.), small pelagic fish species (Cupleiformes) snapper (*Lutjanus* spp.) and corvinas (*Cynoscion* spp. and other species); also feeding grounds for barracudas (*Sphyraena ensis*) (Proyecto Golfos, 2012). Other management tools used are licenses, fishing permits, and gear restrictions (Salas et al., 2007) and the so called "marine responsible fishing areas" (AMPRs for its Spanish acronym). The latter were implemented in response to local initiatives of co-management (García-Lozano and Heinen, 2016).

Despite the management measures in place, challenges persist, such as fishing without a license, the use of prohibited mesh sizes by gillnet fishers (<3 inches) (Ross-Salazar, 2014), illegal small-scale bottom trawls, and the bycatch associated with both small-scale and semi-industrial trawling. Illegal fishing during closures is also common (Proyecto Golfos, 2012) and the limited government participation in surveillance activities complicate the condition (Salas et al., 2007). There are recent efforts to control minimum catch sizes (of the individuals) for target species to protect juveniles. In tropical contexts it has been observed that this measure can be advantageous since it can potentially be controlled at the markets, with the difficulty that the great variety of species caught is confusing for fishers and for law enforcement (Purcell and Pomeroy, 2015).

Fishing data such as catches, fishing gear, recruitment, reproduction and diet analysis are present for some commercial species in the GoN fisheries, some of this information has been summarized in technical reports (BIOMARCC et al., 2013; Marín-Alpízar, B. and Vásquez, 2014). However, there are important inconsistencies in data collection and other data limitations in time series that make difficult the elaboration of complex population dynamic models of traditional fisheries stock assessments. In addition, as Marín-Alpízar, B. and Vásquez, (2014) stated, few efforts have been made to develop a holistic description and understanding of the ecosystem (Alms and Wolff, 2019; Wolff et al., 1998). The lack of coordinated effort between fishery stakeholders, researchers and decision makers exacerbates the situation (Proyecto Golfos, 2012).

The fishing effort dynamics in other regions of the Costa Rican Pacific is driven by ecological factors such as the catches composition and environmental changes, in addition to social influences such as the fishers behavior, cultural and economic aspects (Naranjo-Madrigal and Bystrom, 2019). It is expected that the disconnect between social and ecological elements will be reflected in poor policy measures; the fishing overexploitation is also a result of the limited coordination among societal actors and the corresponding systematic integration of their knowledge and available information (Mackinson, 2001; Salas et al., 2007). At large, overfishing is a great threat in the GoN rooted in the high fishing pressure and in the lack of an integrated management that adequately incorporates ecological aspects and social elements (Pachecho-Urpí et al., 2013) .

A portrayal and modeling of the GoN ecosystem and its fisheries has been described about 20 years ago by Wolff et al., (1998) who used a functional trophic modeling (EwE) approach to integrate ecological and fisheries data of the Gulf. Recently, the GoN has been re-visited by the authors and collaborators to update the model with current data (Alms and Wolff, 2019) and to contrast the state of the GoN ecosystem between these two decades. The basic input parameter gathered to create the model (Alms and Wolff, 2019), are from the Costa Rican monthly small-scale landings statistics (INOPESCA), for the main target groups of fisheries. In fishing contexts with data limitations, such as the GoN, an EwE trophic model represents an advantage due to the relatively few key data required (Bacalso and Wolff, 2014).

When comparing the system models 20 years apart, some changes could be clearly distinguished: 1) Species composition of the catches has changed significantly over the years, paralleled by a harvest reduction of high trophic level species; 2) economic losses have increased due to a shift to harvesting low value species and due to an increase in operational costs. The EwE models are based on the available ecological and fisheries information (Pauly et al., 2000) and they are a promising starting point for taking management decisions in the Gulf of Nicoya (Alms and Wolff, 2019). However it is also important to evaluate and consider the state of the LEK with regards to the fishing system to link and better understand the social and ecological drivers involved in the fishing effort dynamics and fishers' choices.

Connecting LEK and scientific knowledge rests under the assumption that different knowledge systems can contribute to an enriched picture, useful for sustainable management of ecosystems (Tengö et al., 2014). The aim of this study was to apply EwE information in participatory workshops to integrate fisher's LEK with modelled output for GoN, with the premise that connecting these two knowledge systems can enhance our understanding of the state and changes in the ecosystem and help to improve fisheries management. Fishers were asked about how they perceive the state of the local living marine organisms, which of them are important for their livelihoods and how the ecosystem have changed (1990-2010), what are the fishing impacts on the ecosystem, following similar applications of LEK in the Latin-American region (Begossi, 2015).

Particularly, EwE results were used to stimulate discussion among local stakeholders regarding observed changes in the marine ecosystem. The discussions were documented, the qualitative data were analyzed and presented by frequency of responses, to identify the predominant topics and trends while assessing the LEK. Systematically and qualitatively, we compared the changes in the fishery over time through an analysis of similarities, complementarities and contradictions across knowledge systems (Tengö et al., 2014). The outcomes of this study are expected to contribute to new narratives for decision making in fisheries management, based on both stakeholder participation and scientific evidence.

2.2. MATERIALS AND METHODS

2.2.1. Study site

The Gulf of Nicoya, located on the Pacific coast of Costa Rica, has an area of 1550 km^2, a length of 80 km and a width of 50 km. The Gulf contains several islands, mangrove areas and biodiversity spots. Of the 214 species of fish (Proyecto Golfos, 2012) more than 50 are commercially important (Lobo-Calderón et al., 2012). Proyecto Golfos, (2012) summarizes a list of coastal-marine species reported in the GoN, including 200 species of polychaetes, 10 species of stomatopods, 95 species of decapods, 37 species of copepods, five species of cetaceans, and breeding areas for hammer-head shark (*Sphyrna lewini*), among other species. The nesting beaches for the ridley sea turtle (*Lepidochelys olivacea*) and feeding grounds for hawksbill turtles (*Eretmochelys imbricata*) and green turtles (*Chelonia mydas*) also give the GoN a conservation value (CREMA, 2014).

Due to the high productivity of the Gulf of Nicoya, it is considered one of the most important estuaries in the region (Wolff et al., 1998; Alms and Wolff, 2018), and the fisheries are a very important economic activity (Wolff et al., 1998). Costa Rica's small-scale fishers use mainly fishing nets, but also bottom and drifting longlines and handline (Marín-Cabrera, 2012). An additional sector of the Gulf`s fishers generate their income from manual shellfish harvesting (Marín-Cabrera, 2012). Moreover, two semi-industrial fleets operate in the gulf (sardine purse-seiners and shrimp trawlers) (Ross-Salazar, 2014).

According to its bathymetry, the GoN can be divided into three different sectors, the inner, middle and outer Gulf (Marín-Alpízar, B. and Vásquez, 2014) (**Figure 2.1**), named zones 201, 202, and 203, respectively by the Costa Rican institute of fisheries, INCOPESCA. The division is based on species composition and fishing gears used. Some species have reproductive sites in well-developed mangrove inner and middle areas of the GoN (e.g., croakers and shrimps) from where they migrate to external areas when maturing; there are movements in the opposite direction of certain species as well (Proyecto Golfos, 2012). The inner GoN is defined as an area of priority by INCOPESCA, for its importance in the reproduction and nursery of commercially important fish species and shrimps (Marín-Cabrera, 2012; Proyecto Golfos, 2012).

Considering the diverse conditions within the GoN, for this study, three focal points were selected along the Gulf of Nicoya (**Figure 2.1**): (1) Isla Chira (North internal region, 10°05'33,84"N-85°09'01,07"W); (2) Costa de Pájaros (North intermediate region, 10°06'02,66"N-84°59'42,68"W); (3) Paquera-Tambor (South-West external region, 9°49'05, 53"N-84°56'00, 51"W). The inner, middle and outer sites (areas 201, 202 and 203 respectively) were considered to geographically represent the diversity of extended SSF communities located along the GoN, and at the same time to effectively embody common aspects among the sites, for example similar target resources such as corvinas and shrimps (Alms and Wolff, 2019), and the generalized use of gillnet as a fishing gear.

2.2.2. Study Overview

First, we conducted a pre-workshop where a questionnaire was applied and artisanal gillnet fishers were recruited to workshops. Next, we conducted workshops using the information from the EwE model of Gulf of Nicoya as input for discussion of the changes in the fishing system over time, and for assessing LEK. Data from the workshops were analyzed by coding into individual themes the most frequent words used by respondents, to identify trends and relevant topics. Finally, we qualitatively compared the state of the resources according to EwE model output and LEK of the fishers. Evidence from the model and LEK were compared in terms of the interactions found across both sources of knowledge, as information that is similar, complementary or contradictory to each other (Tengö et al., 2014).

The core of the study was conducted from May to July, 2017, as this is a 3-month period of fishing closure in the inner and intermediate zones of the GoN, created for the protection of the reproductive peak events of target resources (small pelagic fish species, shrimps, snapper, and corvinas). Given that fishers from internal zones are usually not involved in any fishing activity during the closure, it was expected that fishers would have more availability to participate and engage. Before running the official survey, exploratory visits to the study sites were performed during January-March, 2017, to establish contacts with community leaders and fishing association presidents.

In each community we sought and obtained authorization from the fishing associations for conducting the interviews and workshops. Participants were asked for prior informed consent and we explained them the project and the data uses. Their responses were voluntary and confidential, and all people involved in the study had the possibility to drop out at any time. Data handling took place in an anonymized form and it was made sure that it is impossible to identify particular individuals. The focus of the study was small scale fishers who used gillnet gears, having more than five years living in the area and about five years of experience as a fisher. An official INCOPESCA list of fishers' names matching these criteria was provided by the fishing associations' representatives, so it was possible to contact participants during the study in their houses or at the local fish buyers.

2.2.3. Pre-Workshop Questionnaire Administration

The questionnaire was pretested with fisher community leaders to measure the performance of the instrument. This allowed our team to reformulate some sections for language, precision, and clarity. During the questionnaire administration, a minimum of 10 people were interviewed per community in the expectation that at least five participants would be attending the workshops. In small groups the conversations are facilitated (Macmillan et al., 2002). The general characteristics of small-scale gillnet fishers interviewed and their availability to be part of a workshop, were examined via the questionnaire included in Annex II (**Text S.2.1**).

The first part of the questionnaire was designed to obtain information on socio-economic and demographic characteristics and fishing practices of the respondents. The second part of the questionnaire identified the willingness of the fishers to participate along the entire process. Each interview session lasted an average of 30 minutes (Leite and Gasalla, 2013) with 86 questionnaires performed; 34.5% of the fishers interviewed were from Costa de Pájaros, 32.8% from Isla Chira and 32.7 from Paquera-Tambor. In this study we presented results for the three sites and for the fishers who met our selection criteria and attended the workshops (N=58). Most of the attendees were male (82.8%) with an average age of 41 years, the age of the majority (24.1%) range from 26-32 years.

2.2.4. An Ecopath with Ecosim Model to Assess Local Ecological Knowledge

To assess local fishers' knowledge about changes in the fishing ecosystem over time, workshops were held in each focal area (**Figure 2.1**). Seven workshops were conducted and 58 fishers participated. In order to adequately communicate information to the fishers, the understanding of the EwE model output by the moderators was essential. Our interdisciplinary team (EwE modeling, behavioral economics, integrated coastal management and fisheries ecology) met to address this aspect and to plan the sessions that would be presented in the workshops.

The lectures and activities were pretested in a pilot workshop (Leite and Gasalla, 2013) with small-scale fishers in the Gulf, and it was found that the simulations of the models needed to be translated into basic graphs and illustrations, to facilitate participants' interaction, as other authors have also pointed out (Armada et al., 2018). In the official workshops, the major findings of the study were explained by a facilitator and an assistant using visual aids, via graphs and illustrations. Likewise, the names of the species were presented to fishers using common names and images to confirm recognition (Leite and Gasalla, 2013). The lecture slides used in the workshops are provided in the Annex II (**Figures S2.1, S2.2**).

For the purpose of this paper, the following changes in the fishery over time (1990s-2010s; (Alms and Wolff, 2019), were explained to participants: (1) an overall increase of 20.9% in the total fishing catches, for both small-scale and semi-industrial catches; (2) a severe decrease in the catches of shrimps and corvinas (60% and 35% respectively) in the 2010s; (3) changes from shrimp dominated catches (1990s) to sardine dominated catches and small demersal fish (e.g., small corvinas, small sharks, among others). We encouraged participants to reflect on the information received and on the changes in the fishery system, to discuss it in groups (Power et al., 2004) and to make a presentation with an overview of their perceptions, to the rest of the participants.

Attendees were stimulated to participate equally during the activities. Their opinions and comments were registered through photographs, notes, recording relevant discussions, and collecting the materials used in the presentations (Saavedra-Díaz et al., 2015). Workshops were conducted at sites of easy access to participants, such as community centers, restaurants, and schools (Sánchez-Jiménez et al., 2014), and were based on previous published methodologies for consultation processes (Paramor et al., 2005; Power et al., 2004).

2.2.5. Data Analysis and Interactions between Scientific information and Local Ecological Knowledge

The data of the questionnaires was used to create a respondents' profile in terms of socio-economic, demographic characteristics and fishing practices of the participants (**Tables S2.1, S.2.2** in Annex II). Later, the qualitative data from workshops were coded into individual themes according to the most frequent words used by respondents (Paramor et al., 2005), and presented with the percentage (%) of people referencing key subjects, along with specific quotes (Ward et al., 2017). The most recurrent topics mentioned was catch, abundance of fishing resources (mainly shrimps, corvinas and large predatory species), fishing effort, economic efficiency, and impact of fishing fleets on the marine resources. Then, we used the key themes identified to explore interactions between the two sources of knowledge (scientific and local).

We followed a modified version of the concepts described in Tengö et al., (2014), and focused on the state and changes over time of the resources shrimps, corvinas, sardines and large predators. Systematically and qualitatively, we compared (Gilchrist et al., 2005) the changes in the fishery over time, through an analysis of similar, complementary and contradictory information across knowledge systems. Similarity in information is understood here as two sources of knowledge that provide the same message with the exact same or very similar words. We defined complementary as different pieces of information that are unique to each knowledge system, but when combined, can better describe a situation or enrich a message. Information that is contradictory to another piece of information, presents opposite messages on the same topic.

For the analysis of similarities, complementarities, and contradictions across knowledge systems, descriptors and attributes (information derived from the LEK and the model), were used to describe the state and changes of resources (Mackinson et al., 2011). Attributes such as biomass, catch per unit effort (CPUE), and abundance were used to create a descriptor for the state of the marine resources. CPUE, an index of the amount of fish caught per unit time spent fishing using a particular gear, was calculated from data reported in workshops, using the kilograms catch per day with one gillnet. Economic descriptions were elicited using attributes like profits, commercial importance, and prices. Other descriptors such as fishing effort and the impact of fishing gears on species were included.

2.3. RESULTS

The respondents' profiles are summarized in tables (**Tables S2.1, S2.2** in Annex II), revealing that the income for most of the interviewees, lays between ₡200,000 and 300,000 Costa Rican colones (1 EUR: 611 Costa Rican colones as of survey year), 36.8% stated they earn ₡200,000. This amount oscillates around the minimum monthly salary for Costa Rica in 2017 (₡256,000: EUR 419.10). Importantly, most respondents (81%) depend solely on fishing, while the remaining combine fishing with other activities, specifically tourism, which suggest that there is a vast number of fishers with monthly salaries below the minimum.

In the range of ₡80,000 to 110,000 falls the basic expenses (monthly bills and food) of 23.6% interviewees, but is noteworthy that the expenses varied among fishers, and for example 18.2% require a minimum of 200-300 thousand to cover their basic needs. The balance between income and expenses seems to be influenced by the number of family dependents (between 0 and 7 with an average of 3.3 dependents) and other expenditures beyond the basics (e.g., formal or informal loans to buy a fishing boat). Gillnet is the primary fishing activity for 66.7% of the respondents, while 26.3% interlaces gillnet with hook fishing, and 7% interchanges it with line fishing. Corvinas fishing is the main activity and usually is combined with fishing for shrimps (20%) and snappers (15%), and a 40.4% of people are fishing 6-9 hours per day almost daily (56.9%).

Deliberation in workshops concerning changes in the fishing ecosystem over time were used to understand the LEK. The qualitative data helped to identify dominant topics and trends, in relation to abundance of fishery resources (shrimps, corvinas and large predatory species), fishing effort, profitability, and impact of fishing fleets on the marine resources. Then the key themes identified in workshops were used to examine the interactions across LEK and the food web EwE model. We focused on the state and changes over time of the resources shrimps, corvinas, sardines, and large predators, and we compared the information of both systems of knowledge considering the similarities, complementarities and contradictions.

2.3.1. Trends with Shrimps and Corvinas (Local Ecological Knowledge)

The resources shrimps and corvinas were indicated as highly abundant in the past, while their abundance has decreased over the course of time (**Figure 2.2A**). This is nicely summarized by the following statements from a fisher: “in old times, there were more croakers, you could hear them everywhere” (Isla Chira-workshop, 17th June 2017). A participant in the same workshop specified that at around 1993 “a shrimp fever took place all over the island” because of its great abundance and the high fishing activity. In the case of corvinas, data for the 2010s show that certain species of this family were not present any longer while others had recovered.

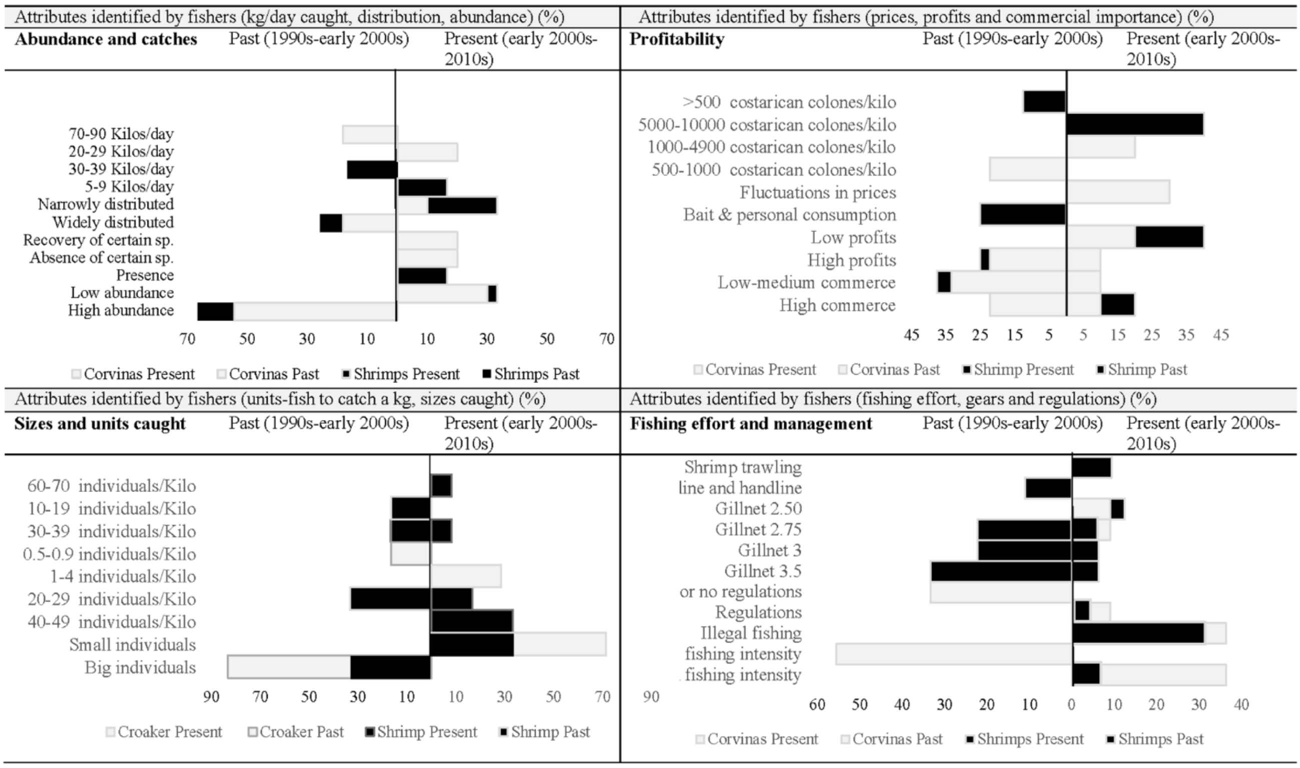


Figure 2.2. Predominant topics and attributes identified in the focus groups, related to the state of shrimps and corvinas (1990s and (or) 2000s). Percentage of responses (%). Topics: **(A)** abundance/catches, **(B)** profitability, **(C)** sizes, **(D)** fishing effort /management.

A significant reduction in catches of corvinas was reported, ranging from 70-90 kg in the 1990s, to only 20-30 kilograms in the 2010s for a single day of fishing. A reduction was also reported for shrimps, from 30-39 Kg in the past to only 5-9 kg today per day of fishing. Participants indicated that shrimps and corvinas were geographically widely distributed in the past, contrasting with the restricted distribution reported for present times (**Figure 2.2.A**): "In the past you could fish shrimps and corvinas everywhere, now you have to go to deeper waters and different places to find them" (Isla Chira-workshop, 8th June 2017). With respect to shrimps, their current distribution is restricted. Low abundance for certain species of shrimps was also mentioned.

In terms of commercial aspects, the answers of participants reflect a medium use intensity of commercial species and low to medium prices of corvinas/shrimps in the earlier 1990s, and a greater commercial use and higher prices for both groups at the end of the1990s and during the 2010s (**Figure 2.2.B**). Fishers reported that at the beginning of the 1990s, and in earlier times, shrimps were so abundant that they were also used as bait. The valuable corvinas were directly sold or were exchanged for plantains, a crop grown in other distant areas, and particularly difficult to find on the islands.

In the 2010s, despite the increased commercial use and higher prices for both species, the profits were reported as relatively low. If one considers the reported size reductions of corvinas and shrimps caught (**Figure 2.2.C**), low incomes can be more easily explained, since small specimens do not receive as high prices in the market as large ones. In line with their perceptions, only 20-29 individual shrimp were needed in the 1990s to make a kilogram, while 40-49 individuals are needed currently. Corvinas were commonly around 2 Kg in size in the 1990s, while currently, one to four individuals are necessary to obtain a kilogram of corvina.

In the 1990s, the most commonly used gillnets mentioned by fishers had mesh sizes of 3.5 and 3.0 inches (**Figure 2.2.D**). During the 2000s, 2.75 and 2.5 inches were the most commonly used gillnet mesh sizes (especially after 2005), even though they are illegal. In general, illegal fishing, through the use of gillnets with mesh sizes of 2.5 inches and "rastras" (a type of artisanal trawling), was widely reported in the early 2010s up to now. Another widely used fishing gear reported during the 2010s is the semi-industrial trawl, labeled as a non-selective method with high levels of bycatch.

As stated by fishers, in the 1990s there were almost no fishing regulations compared to the 2000s (**Figure 2.2.D**) when Marine Areas of Responsible Fishing (AMPRs) and minimum landing sizes (larger than the size at first maturity) were created with the aim of sustaining the fishing resources and ecosystems. However, the fishers still expressed that there are high levels of illegal fishing and confusion with regard to the legal size limits of species, since there are multiple species caught, each with different size regulations.

2.3.2. Trends with other Living Organisms and Large Predatory Species (Local Ecological Knowledge)

For several large predators, fishers' reports point to a great decrease or absence in the waters of the GoN (**Figure 2.3**). This is also the case for the sierra fish (ray, *Pristis* spp.) and hammerhead sharks (*Sphyrna lewini*); however, some fishers still indicate the presence of sierra fishes in coastal waters. Barracuda (*Sphyraena ensis*) was mentioned as a highly abundant species in the 1990s and a low abundance species in the 2010s. In the case of jacks (*Caranx* sp.), the reports went from high to low abundance. In the case of groupers, the picture is diffuse with the presence of cabrilla species (*Epinephelus* spp.) barely mentioned. Also one species that hold no commercial appeal for which information was provided, is the bottlenose dolphin (*Tursiops truncatus*), reported as practically absent at present.

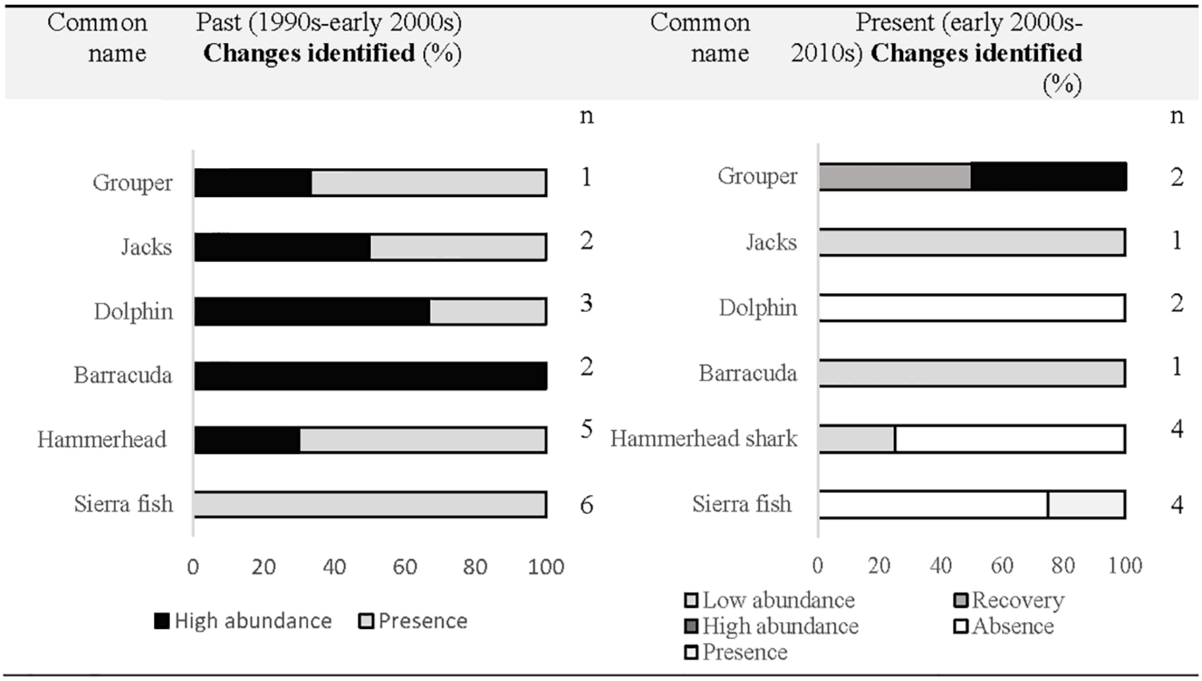


Figure 2.3. Local ecological knowledge (LEK) about temporal changes in the state of large predatory species. According to small-scale fishers consulted in Gulf of Nicoya (% of responses).

As indicated by fishers consulted, mackerel (*Scomberomorus sierra*) was classified as almost absent in the areas where they fished in the 2010s. Participants mentioned that gillnet fisheries generate less profits out of the harvest of this species. For the 1990s, it was suggested that there was a high abundance but low commercial importance of mackerel for gillnet fisheries as well (**Figure 2.4.D**).

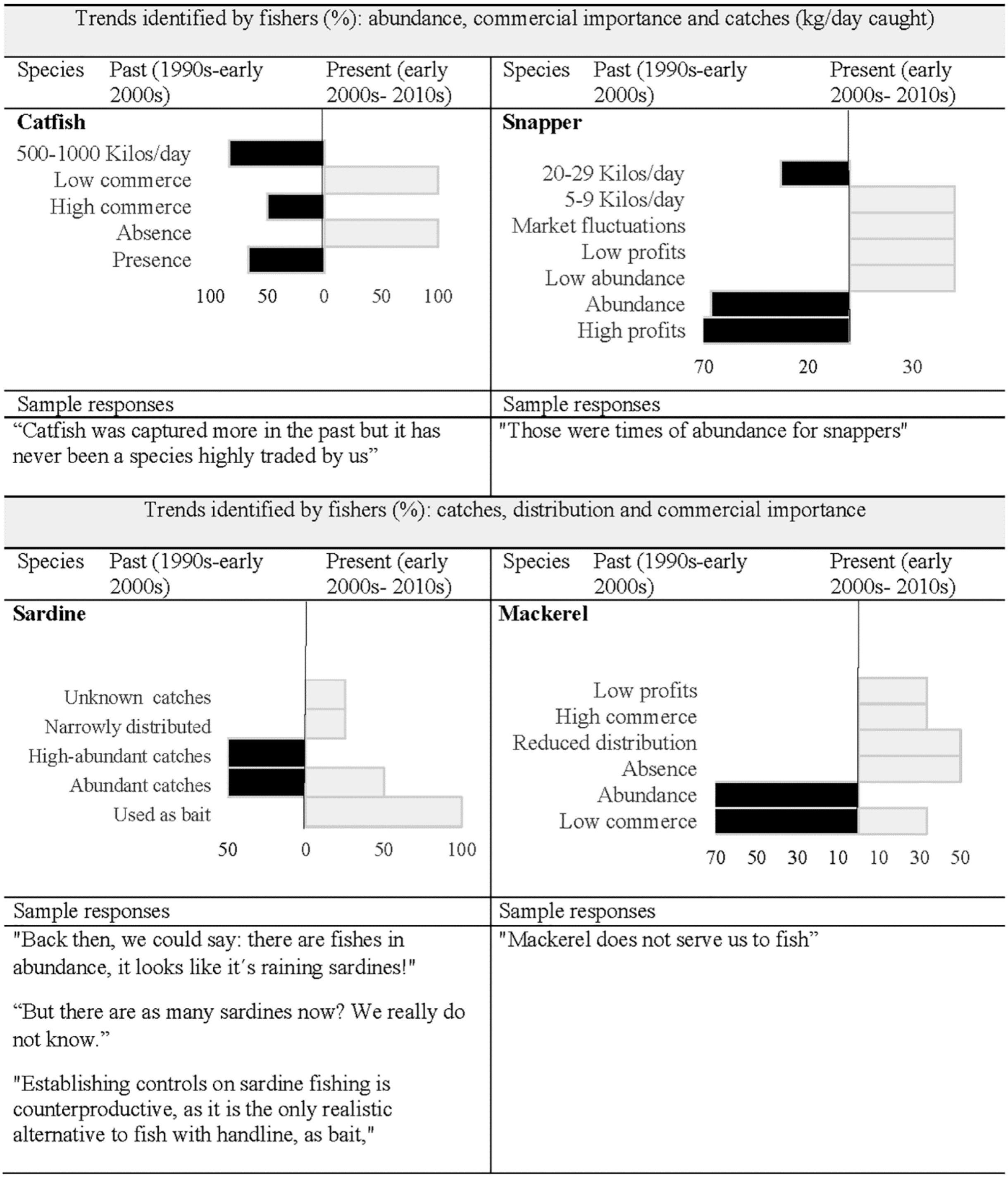


Figure 2.4. Summary trends reported in focus groups by participants, of four important commercial species in Gulf of Nicoya: **(A)** catfish, **(B)** snapper, **(C)** sardine and **(D)** mackerel (% of responses).

Species of catfish (*Bagre panamensis*) were reported as present in the 1990s and of high commercial importance while they were almost absent and slightly commercially important in the 2010s (**Figure 2.4.A**). Snappers (*Lutjanus* spp.) were identified as highly abundant and profitable in the past. However, catch went down from 20 to 29 Kg in the early 1990s to 5-9 Kg per day in the 2010s (**Figure 2.4.B**). Moreover, fluctuations in the market have been influencing low profits associated with the commercial importance of snappers, according to the majority of fishers consulted.

We found in sardines (*Opisthonema* spp.) an interesting case, since according to the fishers, its catches were abundant in the past (1990s) but the current state in the 2010s is unknown for participants (**Figure 2.4.C**). Fishers mentioned that INCOPESCA authorities suggested to significant reduce sardine fishing. Some people assumed that the management measure was proposed due to a decrease in the catches of the species; however, there was no agreement and certainty among participants regarding this affirmation. Currently sardines are widely used as bait by the fishers, therefore, some other fishers consider that the catches of sardines remain as abundant as in the past

2.3.3. Similarities across Systems of Knowledge

Similar information (**Table 2.1**) is reflected in the reports that indicate peaks in the catches of shrimps and corvinas in the 1990s with a severe decrease (60 and 35%, respectively) in the 2010s. First signals of stock reductions of large corvinas and shrimps were observed in the 1990s, associated to a growing commercial importance of the species at the end of the decade. For both sources of knowledge in the 2010s, fishing effort of corvinas increased while the fishing effort for shrimps decreased.

TABLE 2.1 | Similarities across two knowledge systems. Local ecological Knowledge -LEK- (this study) and scientific information -EwE- (Alms and Wolff, 2019).

Descriptor	Shrimps		Corvinas		Sardines		Large predators	
	1990s-2000s	2000s- 2010s	1990s-2000s	2000s- 2010s	1990s-2000s	2000s-2010s	1990s-2000s	2000s- 2010s
Catches	-Peaks in catches, 30-39 kg/day [EwE & LEK] -Dominate overall catches	-Severe decline catches (+60%, 5-9 kg/day), specially pacific sea bob [EwE & LEK]	-Peak in catches, 70-90 kg/day [EwE & LEK]	-Decline in the catches, (20-29 kg/day) [EwE & LEK]				
Fishing effort		Fishing effort (-) [EwE & LEK]		Fishing effort (+) in the intermediate area [EwE & LEK]				

2.3.4. *Complementarities across Systems of Knowledge*

It was possible to identify descriptors of abundance by integrating different attributes from the two systems of knowledge (from LEK and EwE), such as biomass (from EwE), catch per unit effort (from LEK), individuals size (LEK) and subjective abundance (from LEK). The descriptor of profitability was created using attributes such as profits, level of commercial importance and prices. The combination of data thus provides evidence of changes in the abundance of shrimps and corvinas from a high (1990s) to a low abundance (2010s), and economic changes from high (1990s) to low profitability (2010s) of its fishing activity. The increasing pressure of gillnet fishing on the resources, explained by the expanding illegal fishery, negatively impacted the resources in the 2010s. The impact of semi-industrial trawling on shrimps and corvinas due to bycatch was also identified (**Table 2.2**).

TABLE 2.2 | Complementarities across two knowledge systems. LEK (this study) and scientific information -EwE- (Alms and Wolff, 2019)**.** Abundance descriptor: biomass (b), catches per unit of effort (c), size (s) and abundance (a). Profitability descriptor: profits (pro), level of commercial importance (lc) and prices (pri).

Descriptor	Shrimps		Corvinas		Sardines		Large predators	
	1990s-2000s	2000s- 2010s	1990s-2000s	2000s- 2010s	1990s-2000s	2000s-2010s	1990s-2000s	2000s- 2010s
Abundance	Prominent EwE[b] LEK[c] LEK[a]	Visible reduction EwE[b], LEK[b] EwE[c], LEK[c] LEK[a]	High EwE[b] LEK[c] LEK[s] LEK[a]	Low EwE[b] LEK[c] LEK[s],EwE[s] LEK[a]			Presence, high LEK[a]	-Reduction high trophic levels: mackerel, barracudas, sharks and rays EwE[b] LEK[a] predators
Catches			-Catches rely on five commercial species of corvinas[EwE]	-Corvinas *Cynoscion albus* and *C. stolzmanni* are the largest catch contribution [LEK] -Five commercial species of corvinas declined in 35% [EwE & LEK]				Less large predators (EwE[c]).
Profitability	High profitability EwE[pro], LEK[pro] LEK[ci], LEK[pri]	Low profitability EwE[pro], LEK[pro] LEK[ci] LEK[pri]	High profitability LEK[pro] LEK[ci], LEK[pri]	Low profitability LEK[pro], EwE[pro] LEK[lc], LEK[pri]				

TABLE 2.2 | Complementarities across two knowledge systems. LEK (this study) and scientific information -EwE- (Alms and Wolff, 2019)**.** Abundance descriptor: biomass (b), catches per unit of effort (c), size (s) and abundance (a). Profitability descriptor: profits (pro), level of commercial importance (lc) and prices (pri).

Descriptor	Shrimps		Corvinas		Sardines	Large predators	
Fishing fleets impact on the ecosystem	-SSF gillnets impact on shrimps[EwE] particularly 3-3.5 inches[LEK] -Semi-industrial shrimp fleet impact on shrimp[EwE]	-SSF fleet impact on shrimps [EwE] particularly Illegal nets 2.5-2.75 inches [LEK]	-SSF gillnets impact on corvinas [EwE], particularly 3-3.5 inches[LEK]	Illegal nets 2.5, 2.75 and 3 inches impact on corvinas[LEK]	-Semi-industrial fleet impact on sardine[EwE]	Large predators impacted by SSF gillnet, longline and semi industrial shrimp fleets [EwE]	-SSF fleets reduce impact on sharks/rays [EwE] -Longline and semi industrial shrimp fleets impact on large predators EwE

The two sources of information combined suggest significant reductions in the harvest of high trophic level species (mackerel, barracudas, sharks and rays) in the 2010s. LEK revealed a restricted distribution of catches for both shrimps and sardine in the 2010s with most of the catch originating in the outer part of the gulf (zone 203). Similarly, the fishers indicated that the inshore resources have been decreasing, greatly affecting the SSF, since this fleet is not able to compete with the semi-industrial fishing fleet, which has larger vessels and capacities to go fishing further out to sea.

For the description of the profitability (shrimp and corvina), the two knowledge systems integrated point to the economic losses in the 2010s paralleled by a shift in the harvest from high to low value species. According to the EwE model, shrimps accounted for the vast majority of the total value of small-scale and semi-industrial fleets in the 1990s, and still represented the largest contribution to the SSF fleets in the 2000s but experienced a strong decline in the total catch and value (**Table 2.2**). For the fishers, small corvinas represent the largest contribution in the catch, and currently just two species are sold as a high quality product, whitefin weakfish (*Cynoscion albus*) and the Stolzmann weakfish (*Cynoscion stolzmanni*), compared to seven species in the 1990s. The rest of the species are small and sold in low value classes, from large to small demersal individuals.

For the 1990s, the EwE model alone shows the impact of different fishing fleets on large predators, including a negative impact by small-scale gillnet, longline, and semi-industrial shrimp fleets. However, the specifics of the gillnet' impact on shrimps and corvinas were provided by the fishers since the model does not differentiate at the level of size-class reductions of the species nor does the net sizes used, or the spatial distribution of the catches. Fishers identified a growing commercial importance of the corvinas and shrimps at the end of the 1990s with the extensive use of gillnets with mesh sizes of 3 and 3.5 inches, and an increase of gillnet impact on the resources in the 2010s, especially illegal fishing with mesh sizes of 2.5 and 2.75 inches. The temporal impact (1990s-2010s) of fishing fleets is better explained when the two knowledge systems are complemented.

2.3.5. Contradictions across Systems of Knowledge

There are also contradictory pieces of information between the EwE and LEK (**Table 2.3**). For example, the model shows considerably higher catches of sardines in the 2010s than in 1990s, with a change from shrimp dominated catches in the 1990s to sardine dominated, and a peak of the catches in the early 2000s. The EwE model detects as well a declining trend in the catch of sardines since 2008. Whereas, the LEK is unclear about the current state of the sardine catches, with some fishers believing that its catches are abundant as is commonly seen and used as a bait to fish corvinas.

TABLE 2.3 | Contradictions across two knowledge systems. Local ecological Knowledge -LEK- (this study) and scientific information -EwE- (Alms and Wolff, 2019).

Descriptor	Shrimps		Corvinas		Sardines	
	1990s-2000s	2000s-2010s	1990s-2000s	2000s-2010s	1990s- 2000s	2000s- 2010s
Catches					-Medium catches (shrimp dominated)[EwE] -Peak catches in early 2000s[EwE]	-Higher catches (change to a sardine dominated)[EwE] -Declining trend in catch-2008[EwE] -Unknown / abundant [LEK]

2.4. DISCUSSION

Little effort has been made to address the lack of data integration within the SSF of the GoN in Costa Rica. There is a dissociation between available knowledge and information held by local stakeholders, scientists and decision makers. The approach followed here examined the potential of using the information from the EwE model to stimulate discussion among fishers regarding observed changes in the marine ecosystem and thus identify their perceptions and knowledge on the subject (LEK). Later, scientific information and LEK were systematically compared to identify similarities, complementarities and contradictions to improve understanding of the state and changes in the ecosystem and to make this information available to management. Additionally, we identify other advantages derived from this systematization related with the engagement of the participants.

2.4.1. Connecting Systems of Knowledge

Multiple examples in the academic literature show how synergies across knowledge systems have allowed for a better understanding of ecosystem and natural resources management (Beaudreau and Levin, 2014; Danielsen et al., 2014; Fujitani et al., 2018; Gilchrist et al., 2005; Leite and Gasalla, 2013; Mackinson, 2001). As a first step, the scientific findings of the EwE model of the GoN were presented and discussed among local fishers; illustrating a process of integration of knowledge through a validation, whereby one knowledge system is incorporated into another (Msomphora, 2015). As it has been demonstrated that both types of knowledge can augment each other, the step taken later was to assess interactions across systems (Mackinson et al., 2011), as an example of cross-fertilization of knowledge (Tengö et al., 2014).

The analysis of the interactions across systems of knowledge (**Table 2.1**) demonstrates that the fishers' perceptions about the past and current state of the fisheries-ecosystem (1993-2013) presented strong similarities with the core findings of the EwE model and fisheries data, such as: (1) shrimp dominated catches in the 1990s; (2) a severe decrease in the catch of shrimps and corvinas in the 2000s; (3) an increasing impact of gillnet fisheries and semi-industrial trawling; (4) an increase in fishing effort towards corvinas in the 2010s and a decrease for shrimps . As similar pieces of information from the LEK and the trophic model delivered the same message, this helped to foster stronger confidence in the conclusions and provide robust evidence of changes in the social–ecological system of the GoN.

There is information identified as complementary to each other, because together provide a broader picture (descriptors and attributes) of the changes of some fishing species. The examination across the model and the LEK revealed that it was possible to generate descriptors of abundance and profitability for specific fishing resources, using and combining attributes informed by both sources of knowledge (Ainsworth and Pitcher, 2005b; Mackinson, 2001). Characteristics such as abundance, biomass, catch per unit effort and profits, commercial importance and prices, seems to be adequate attributes when comparing changes in a fishery system.

When complementing the LEK and the EwE model, the following changes in the fishing system were highlighted: (1) significant reductions in the harvest of high trophic level species (mackerel, barracudas, sharks and rays); (2) changes over time in the abundance of shrimps and corvinas from high to low abundance; (3) economic losses due to a shift to harvesting low value species (predominance of small corvinas/shrimps individuals and changes from shrimp to sardine dominated catches); (4) revenues decreased due to higher operational costs to catch offshore resources; the inshore resources diminished, and the small-scale fishers were not able to compete with the semi-industrial fishing fleet and (5) the use of illegal gillnets increased from the early 2000s up to 2010s.

With respect to the temporal changes (1993-2013) caused by fishing fleets on the ecosystem, most of the information was provided by the model. However, the model does not account for the possible size-class reductions of the species within the biomass compartments, while the fishers indicated changes in species composition and size reduction for corvinas and shrimps. Which suggests that there are elements of information more suited to a specific knowledge system and when scientific information and the LEK are complemented, it is possible to see and enriched image. The use of illegal gillnets is one of the factors contributing to the greater fishing intensity that has led to a depletion of larger specimens, resulting in the predominance of smaller individuals in the catches or the so-called fishing down the web (Pauly et al., 1998). The responses suggest that fishers perceive illegal fishing as a key factor in generating conflict.

It is important to acknowledge disagreements between the knowledge held by diverse stakeholders, to avoid reaching artificial consensus (Leite and Gasalla, 2013). Contradictory information was detected between the EwE model and the perceptions of the fishers. The EwE model shows considerably higher sardine catches in the 2010s than in the 1990s, with a shift from shrimp-dominated catches in the 1990s to sardine-dominated catches (peaking in the early 2000s). The EwE model also detects a downward trend in sardine catches since 2008, while the LEK is unclear on the current status of sardine catches, with some fishers believing that their catches are abundant, as is commonly seen and used as bait to fish for corvina. The mismatches between LEK and the EwE could indicate the source of enforcement problems, as fishers do not clearly identify the need to take measures to protect or rebuild the sardine.

In light of the results it is possible to note how using multiple evidence types can generate different useful knowledge, but together improve our understanding of the state and changes in the fisheries systems. Another area where connecting knowledge systems could potentially be fruitful is in relation to controlling the minimum catch size (of individuals) for target species. This is an ongoing effort in the GoN to protect juveniles. Fishers expressed confusion about the legal size limits due to the large number of species caught and the different regulations of current size for each. The measure may be creating a regulatory environment where compliance is high, but the reason for complex regulations involving multiple species is unclear to some fishers, there is a need for better communication about the rationale behind ecosystem-based management alternatives.

2.4.2. General Conclusions and Management Implications for Gulf of Nicoya

Scientific practice needs to involve more directly with fisheries management (Purcell and Pomeroy, 2015). The integration of knowledge systems is complex and requires specific communication strategies, tools and methods (Leite and Gasalla, 2013). Despite the extensive literature on the importance of LEK in fisheries (Fischer et al., 2015) and the multiple examples that use food web models in management schemes (Christensen and Walters, 2004a, 2005; Pauly et al., 2000) , there are only a few practical examples that describe how LEK can be systematically incorporated with ecosystem data for fisheries management (Ainsworth and Pitcher, 2005b, 2005a; Pauly et al., 2002). The method we propose is a novel contribution for the GoN and tropical SSF to explore a systematic integration of an EwE-type food web model with the LEK.

EwE trophic model can be an interactive and effective communication tool to be used with fishers (Armada et al., 2018) to promote discussions on changes in the fishing ecosystem and to gather perceptions about it. The primary purpose in this study was the systematic connection of two systems of knowledge to improve fisheries management, the added advantage was the fishers' engagement. Most of the participants stressed the importance of the current participatory process regarding the information received and the consideration of their perspectives. The representation of local stakeholders in the management process can help to contribute to two-way knowledge exchange, and legitimacy in developing sustainable fishing options (Fujitani et al., 2017) including transparent and more streamlined regulations.

Fishery management in the GoN has not followed an explicit ecosystem approach, and the interaction between species as well as the effect of the different fishing fleets (and fishing effort) on the ecosystem has not been adequately considered (Alms and Wolff, 2019). Sardines are an important source of food for various predators, including sharks and rays (Alms and Wolff, 2019) functioning as a link in the food web (Wolff et al., 1998), in this respect, the adequate ecosystem-based management of sardines should be a topic of further discussion and clarification with local fishers. Catches of shrimps (same trophic level as sardines) (Baum and Worm, 2009), have decreased significantly over the past two decades, causing a severe reduction in the total value of the catches, but also had effects on the Gulfs' ecosystem (Alms and Wolff, 2019).

Since the different life stages of shrimps are key food items for a great variety of species, their progressive decline in abundance over time shall definitely be of great system impact and require further research and management. It is important to emphasize that the reduction of the inshore groups mentioned by the fishers and described in Alms and Wolff, (2019), has resulted in a decrease in the revenues of small-scale fishers, who are unable to compete with the semi-industrial fishing fleet for offshore resources, because of vessel size, travel distance and storage capacity. The same holds for those species that migrate to cooler and deeper waters (BIOMARCC et al., 2013).

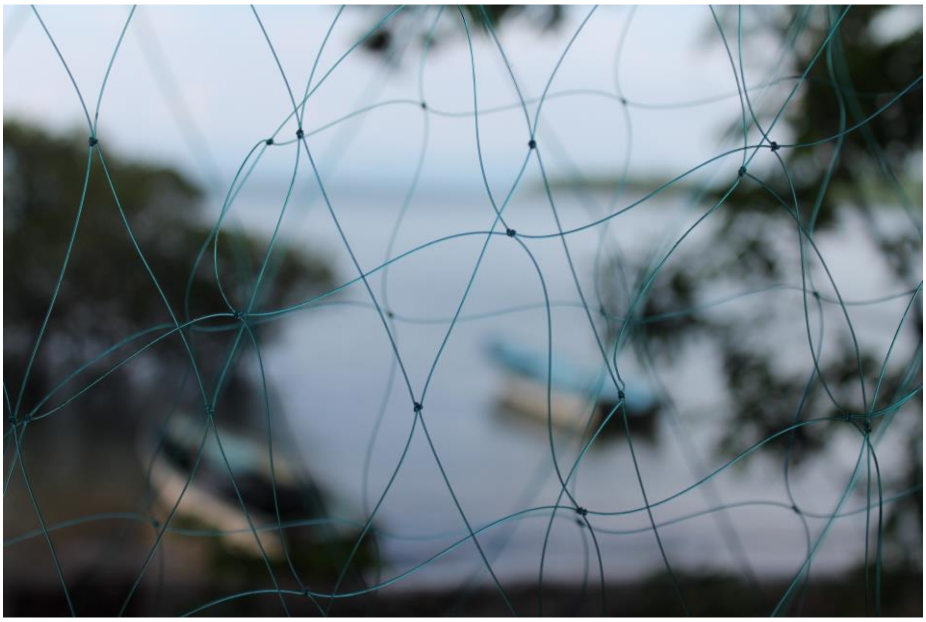
Most of the interviewed fishers are only engaged in fisheries, lacking alternative income sources (Fernández-Carvajal, 2013). The use of prohibited nets and the increase in the size and number of nets, is a common feature of this fishery (Marín-Alpízar, B. and Vásquez, 2014). The development of economic alternatives to fishing in the GoN seems imperative (BIOMARCC et al., 2013). However, fishing is a deeply rooted activity among fishers, and a transition to other jobs is often difficult, especially for older fishers (Fernández-Carvajal, 2013). One challenge is to choose alternatives that deliver the best trade-offs to the gillnet fishing sector while allow keeping the ecosystem health (BIOMARCC et al., 2013). Trophic models such as EwE as a management instrument could guide such potential processes in the GoN.

We are confident that this exercise contributed to fill gaps in the knowledge about the fisheries system of the GoN and we hope that this study shall also stimulate future collaborations of fishers as part of a cumulative and iterative learning process (Tengö et al., 2014). Workshop-mediated integration of LEK and scientific data potentially can reduce conflicts between stakeholders and help to foster the compliance of fishers (Leite and Gasalla, 2013; Msomphora, 2015). Management proposals that local resource users do not agree or comply with will be hard-pressed to meet management goals (Fujitani et al., 2012). We aspire that the outcomes of this study can contribute to new narratives of decision making in the SSF based on stakeholder participation (including the LEK), and the best scientific evidence available.

ACKNOWLEDGMENTS

We deeply thank all fishing communities for their participation. We are grateful with E. Ledezma, E. Alvarez, D. Ledezma, S. Cruz, L. Marín, G. Pérez, D. Pérez, O. Quesada, A. Pérez, and A. Montiel, for their help with the logistics for workshops and interviews. As well with K. Quirós for her valued assistance with data collection and entry. Support was also provided by the ECMAR, Universidad Nacional (Costa Rica), through G. Ulate and O. Pacheco, who offered guidance during the research. We thank L. Artavia for his collaboration with the SIG/maps component of this study and to the reviewers for their valuable feedback.

CHAPTER 3. Marine Education to Reconnect Human Behavior with Ecosystem Resilience
(*Reconnecting with Nature*)



Photos taken in fishing communities of Paquera-Tambor after the workshops developed in this dissertation

CHAPTER 3

The Importance of Values in Predicting and Encouraging Environmental Behavior: Reflections from a Costa Rican Small-scale Fishery

Astrid Sánchez-Jiménez, Douglas MacMillan, Matthias Wolff, Achim Schlüter & Marie Fujitani[1]

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

Sánchez-Jiménez A., MacMillan D., Wolff M. Schlüter A. and Fujitani M. (2021). The importance of values in predicting and encouraging environmental behavior: Reflections from a Costa Rican small-scale fishery. Front. Mar. Sci. 8, 137. https://doi.org/10.3389/fmars.2021.543075

ABSTRACT

Encouraging people's pro-environmental behaviors is an objective of Education for Sustainable Development. In the context of small-scale fisheries, unsustainable fishing practices are compromising the integrity of coastal communities and ecosystems. Ecopath with Ecosim (EwE) is an ecosystem modelling software that presents interactions/changes in the food web as a result of fishing. Despite the multiple applications of EwE in fisheries management, it is unknown from a quantitative perspective whether the application of EwE trophic modeling in environmental education processes and management produces effects on norms and ecological beliefs, and if it alters behavioral intentions of the participants receiving ecosystem modeling information. We conducted a behavior change intervention with gillnet fishers, to compare antecedents of pro-environmental behavior between participants who received an ecosystem-based intervention (lectures containing EwE models; treatment) and those who received lectures that did not involve EwE (control). Based on theories of environmental psychology, we used a pre-post survey control design, to evaluate changes between control/treatment, and to assess the influence of psychometric constructs and fishing characteristics on the behavioral intentions to support sustainable fishing measures and owning a fishing license (revealed behavior). *Personal norms* and *values* were significant at explaining management measures' support, along with some fishing characteristics (e.g. fishing site). Deliberating about possible future scenarios (via EwE-modeling) helped reduce uncertainties, increasing legitimacy and a *perceived behavioral control* (PBC) to support measures. Currently licenses in the Gulf are not granted under defined ecological criteria, and although altruistic-biospheric values scored highly before the intervention began, due to mistrust and high illegal-unlicensed fishing, fishers may be underestimating how much others care about the environment. Value-oriented and ecosystem-based educational interventions may assist in an effective redesign of the licensing system and encourage fishers' intentions to support sustainable measures. Our research indicates the importance of behavior interventions that teach about the impacts of fishing in the ecosystem while helping participants to perceive themselves as capable of implementing actions (PBC) and expressing biospheric-altruistic values to restore trust. Redirecting human behaviors to reconnect with ecosystem resilience can be a leverage point for sustainability and for the compliance of small-scale fisheries management measures.

Keywords: behavior change interventions, social psychology, environmentally relevant behavior, Value-belief-norm (VBN) theory, Theory of Planned Behavior (TPB), Costa Rican Pacific, Ecopath with Ecosim (EwE) modeling, tropical small-scale fisheries (SSF)**.**

3.1. INTRODUCTION

Encouraging people's commitment to protect marine biodiversity and adopt behavior towards sustainability are important objectives of Education for Sustainable Development (ESD) and the Sustainable Development Goals (SDGs) (United Nations, 2016). ESD is particularly relevant today when a rapid response and a behavioral change is needed to address major global environmental problems, such as the climate emergency or biodiversity and ecosystem loss (McKeown, 2002). Overexploitation, ecosystem imbalances, gender inequality and poverty, are some of the environmental and social issues faced by people in coastal areas worldwide, particularly affecting the tropics and small-scale fisheries (SSF) (Kittinger et al., 2013; Pauly et al., 1998; Purcell and Pomeroy, 2015; Salas et al., 2007).

Responding to global challenges requires a shift in our lifestyles and a transformation in the way we think and act (United Nations, 2016). To implement realistic sustainable conservation measures in SSF – given irreducible complexity and uncertainty - solutions at the level of whole ecosystem are required (Walters, 1986). Ideally this would be accompanied by experiential education (Stern et al., 2008), active learning, deliberation and participatory processes (Dietz, 2013), as well as an understanding of the human-nature relationships behind behavior of those individuals and communities that are involved in conservation plans (Kollmuss and Agyeman, 2002).

Education for Sustainable Development is clearly recognized as part of the target 4.7 of the Sustainable Development Goals on Education which "aims to ensure by 2030 all learners acquire knowledge and skills needed to promote sustainable development, through education and sustainable lifestyles" (United Nations, 2016). ESD is also essential to all efforts to achieve the SDGs by promoting societal, economic and political change as well as by transforming people's behavior (McKeown, 2002).

One important step in the direction of ESD is to understand how humans make decisions about environmentally relevant behavior (Kollmuss and Agyeman, 2002). For example, in the case of climate change, the question arises: what makes some people use public transportation, a bicycle or a car, or what makes some individuals eat meat while others become vegan or vegetarian? Attributes such as perceptions and social-ecological characteristics are key drivers of fishers' behavior (Naranjo-Madrigal et al., 2015; Torres-Guevara et al., 2016), in turn, these attributes are based on mental models, particularly values, beliefs, norms and worldviews (Song et al., 2013).

Environmental and social psychology has contributed by proposing and testing theories and models of human-nature relationships that aim to predict environmentally significant behavior (Klöckner, 2013) and identify possible interventions that would motivate transformations in peoples' behavior towards sustainable lifestyles and actions (Abrahamse et al., 2005; Bolderdijk et al., 2013). Values are important components of many models of environmentally significant behavior (Ajzen, 1991; Schwartz and Howard, 1981; Stern, 2000; Stern et al., 1999), and serve as standards to assess whether certain actions are desirable or not in a society (de Groot and Steg, 2008). Within the value orientations (de Groot and Steg, 2008), *biospheric* orientations refer to concern for environment, *altruistic* denote concern for other human beings and *egoistic* orientations represent concern for personal resources and one's own life.

Government policy, environmental education and deliberation have been proposed as vehicles to create changes in people's values; however, as values are molded at an early age and tend to remain stable throughout the years, they can be difficult to change (Schwartz and Bardi, 2001). In this sense, a fruitful area of research for environmentally significant behavior, complementary to the investigation of change in values, has been describing values to predict conservation behavior, which is relevant because values contribute to the specific environmental beliefs, norms and actions that people adopt in the course of their lives (Stern and Dietz, 1994).

The theory of value-belief-norm (VBN) (Stern, 2000) and the theory of planned behavior (TPB) (Ajzen, 2005) have been widely used and remain broadly prevalent in the field of social psychology to explain human pro-environmental behaviors (Bolderdijk et al., 2013; Clayton and Myers, 2015; de Groot and Steg, 2009; Klöckner, 2013; Steg et al., 2005) including marine conservation and fisheries context (e.g., (Fujitani et al., 2017; Olya and Akhshik, 2019; Riepe et al., 2017; Wynveen and Sutton, 2017). Both theories the VBN and the TPB consist of a causal and hierarchical chain of psychological constructs that inform pro-environmental behavior (**Figure 3.1**).

According to the VBN theory (Stern, 2000) individual's *biospheric*, *altruistic* and *egoistic values* (de Groot and Steg, 2008) give rise to a series of *beliefs*. Beliefs are defined as expectations arising from information and experience (Fujitani et al., 2017). Based on these environmental beliefs, the ecological worldview of an individual is shaped (*new ecological paradigm*, NEP) and people may feel responsible for reaching specific pro-environmental goals. A*scription of Responsibility* (AR) is in turn influenced by the individuals' *awareness of consequences* (AC) if not acting pro-environmentally (Stern, 2000). The responsibility once recognized, translates into *personal norms* (PN), defined as a perception of what should to be done in a given context.

Theoretically, all components of the VBN-theory serve as a predictor of environmental behavior, although there are some variations in the prediction power between the variables (Steg et al., 2005; Stern, 2000). For example, norms and beliefs have been identified as strong determinants of environmental decisions (Fujitani et al., 2017; Riepe et al., 2017). It has also been observed that biospheric and altruistic values tend to dominate in prediction (van Riper and Kyle, 2014) and in the stability of pro-environmental behavior, above egoistic values (de Groot and Steg, 2009).

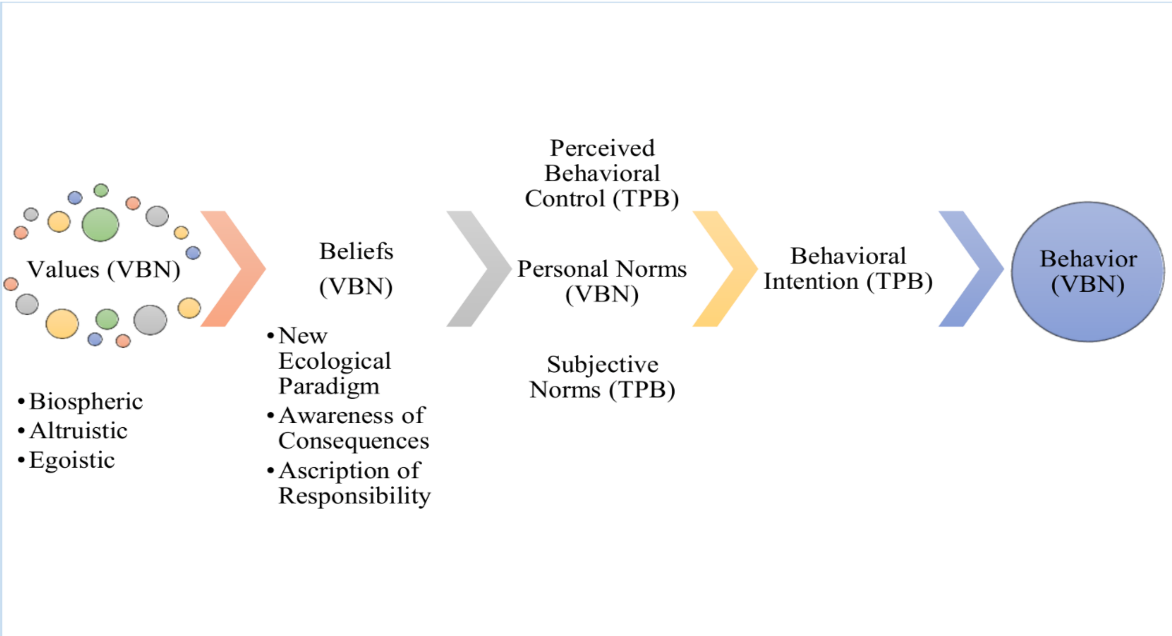


Figure 3.1. Value-belief-norm theory (VBN-theory) together with subjective norms, perceived behavioral control and behavioral intentions from theory of planned Behavior (TPB). Adapted from (Klöckner, 2013).

The TPB establishes that the performance of a certain behavior is directly associated with the *intention* of an individual to perform that behavior (Ajzen, 1991, 2005). This intention increases with an increase in *subjective* or social *norms* (SN) and with an increase in *perceived* *behavioral control* (PBC) (Ajzen, 2005) (Figure 1). Specifically, individuals tend to perform pro-environmental behavior if there is a perception that other relevant people expect them to act in this way and support them in doing so (SN) (Nyborg et al., 2016), and if they perceive themselves as capable of implementing or changing this behavior (PBC) (Clement et al., 2014) also known as perceived self-efficacy (Wynveen and Sutton, 2017).

Scholars have expanded or combined relevant psychological theories of behavior change (Olya and Akhshik, 2019), and for instance have pointed out the importance of habit strength alongside intention in predicting behavior (Klöckner, 2013). (Ajzen, 2005) indicates that intention also increases with an increase in an individual's attitude towards behavior (Attitudes, i.e., a positive evaluation of behavior). For the present study, we used a comprehensive approach of determinants of individual environmentally relevant behavior based on a meta-analysis (Klöckner, 2013) and a combination of two of the most important theories in social psychology, the TPB and VBN. Thus, in addition to revealed *behavior* and the VBN factors, we measured subjective norms, perceived behavioral control and behavioral intentions from the TPB.

To promote environmental sustainability in public policies and management, the existence of citizens with environmental awareness and scientific knowledge is crucial (Kinzig et al., 2013). Educational programs are among the most popular means to foster pro-environmental behavior and actions towards sustainability (Arbuthnott, 2009; Smyth, 2006). Education for Sustainable Development aims to equip individuals with knowledge but also fostering skills and engagement to bring about transformations that lead to more sustainable societies (McKeown, 2002). Nevertheless, it has been shown that the provision of information alone is usually insufficient to affect long-lasting changes in behavior (Fujitani et al., 2016; Sterman, 2008).

If the goal of an educational program is to encourage positive behavior, following models of environmentally significant behavior these programs should target beliefs (Bolderdijk et al., 2013) and foster awareness of consequences and ascription of responsibility (Menzel and Bögeholz, 2009). In order to alter mental models and fundamental beliefs, it has been proposed to create spaces within educational programs for people to reflect, express and negotiate their views, and learn socially and actively (Fujitani et al., 2017). A deliberative processes - in which through discussion respondents are given the opportunity to exchange opinions and arguments (Völker and Lienhoop, 2016) - can deepen consideration of issues, facilitate social learning and help to form preferences in social contexts, for situations that people usually do not have to make decisions about (Macmillan et al., 2002).

A large body of literature indicates that deliberative process anchored on scientific information and management can both provide useful knowledge for decision making as well as foster environmentally significant behavior (Kenter et al., 2011; MacMillan et al., 2006; Spash, 2008; Wilson and Howarth, 2002). One hypothesized way to affect behavioral antecedents, such as beliefs and norms in favor of the environment, is to provide individuals with scientific knowledge, in turn promoting positive connections between people and nature. We suggest that deliberating on an ecological model in environmental education, can help bridge science and society while showing the relationships between people and ecosystems in an accessible way.

A food-web model can provide a basic visual experience of the structure of the marine ecosystem, the interconnection between marine species in addition to showing the role that people play in that ecosystem. A representative example of ecological modeling is the Ecopath with Ecosim (EwE) approach, a software that presents interactions and changes in the food web as a result of fishing (Christensen and Pauly, 2004; Christensen and Walters, 2004b). EwE modeling also allows managers to project past and future states of the system, exploring optimal fishing policies and environmental changes (Christensen and Walters, 2004a; Pauly et al., 2000; Pitcher, 2001).

As EwE trophic models are targeted to answer specific scientific and management questions, the use of a trophic model in a workshops as a scientific educational tool, can create a space for reflection, deliberation and the two-way exchange of information on the management of shared natural resources e.g. Sánchez-Jiménez et al., (2021b). Despite the multiple applications of EwE in fisheries management (Christensen and Walters, 2005), it is unknown from a quantitative perspective whether the application of the EwE food web model in environmental education processes produces effects on norms and ecological beliefs, and if it alters the behavioral intentions of the people who receive information from ecological modeling.

In our case study in the Gulf of Nicoya (GoN), Costa Rica (Pacific Coast), behavior change interventions were developed combining an Ecopath model with Ecosim (EwE) with deliberation, to stimulate an active learning process. Based on (Alms and Wolff, 2019), a description and modeling of the ecosystem of the GoN and its fisheries was presented to discuss the changes in biomass over the last two decades (Alms and Wolff, 2019; Wolff et al., 1998) and a management scenario that involves the reduction of fishing effort for the restoration of species at high trophic levels, as a proxy for ecosystem health.

Within the context of an environmental education experiment, we conducted a behavior change intervention with gillnet fishers, to compare antecedents of pro-environmental behavior between participants who received an ecosystem-based intervention (a lecture with workshop materials containing EwE models) (treatment) and those who received lectures that did not involve EwE models (non-EwE) (control).

Based on the Value-Belief-Norm theory and the Theory of Planned Behavior, we used a pre-post survey control design, to evaluate changes in psychological factors between control and treatment, as well as to assess the influence of psychometric constructs and fishing characteristics on measures of pro-environmental behavior, specifically on the intentions to support fisheries sustainability and a reduction in fishing effort of 25% (measures A and B), along with owning a fishing license (revealed behavior, measure C).

Two hypotheses have been raised: (1) after the intervention we would observe an increase in the scores of psychometrics related with pro-environmental behavior in the treatment compared to the control; (2) of psychometric factors, *values*, *personal norms* and *perceived behavioral control* would have a significant influence on behavioral intentions and behavior (Klöckner, 2013). Our interest has been to explore the role that EwE trophic modeling can play in a behavior change intervention both in a context of Education for Sustainable Development and in small-scale fisheries management. It is expected that in practical applications, participatory management processes of this nature should be reflected in a greater willingness to support policies or projects aimed at sustainability.

3.2. MATERIALS AND METHODS

3.2.1. The Gulf of Nicoya Ecosystem

The GoN (**Figure 3.2**), located on the Pacific coast of Costa Rica, is an important estuary(Wolff et al., 1998) due to high productivity and marine biodiversity (Vargas, 1995, 2016). Thousands of small-scale fishers depend on seafood in the GoN (FAO, 2014). Small-scale fishers rely on fishing nets, longlines, hand lines, as well as practice shellfish harvesting (Marín-Alpízar and Vásquez, 2014). Sardine purse-seiners and shrimp trawlers are other semi-industrial fleets operating in the GoN (Ross-Salazar, 2014), although currently new shrimp trawling permits cannot be granted.The landings of the GoN represented most of the total Costa Rican production, with a peak that occurred in 2000 and a downward trend since then (Chacón et al., 2007); the majority of commercially species are exploited beyond sustainable levels (Wehrtmann and Nielsen Munoz, 2009).

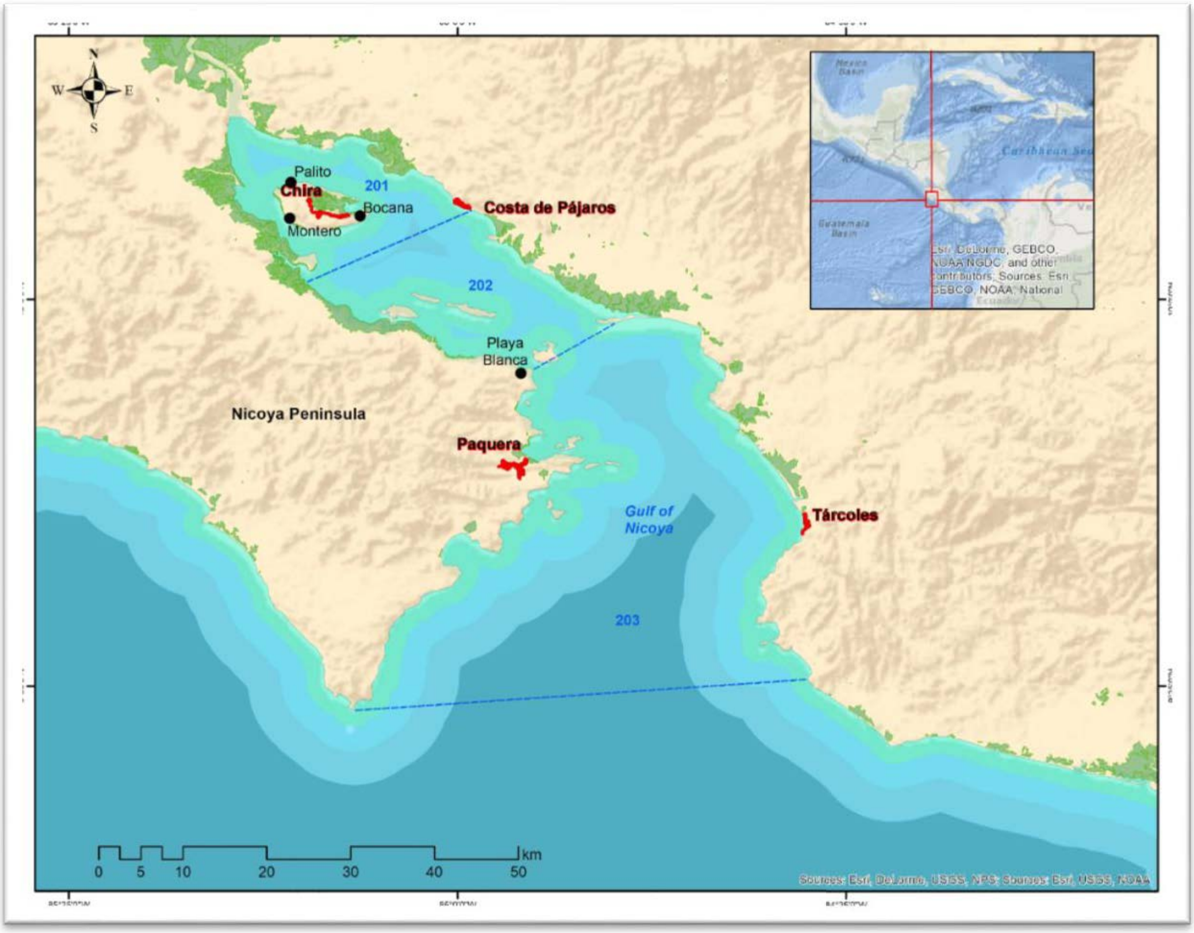


Figure 3.2. The Gulf of Nicoya located on the Pacific coast of Costa Rica. The Gulf is sectored by INCOPESCA into areas 201, 202 and 203 based on species composition and fishing gears used (Marín-Alpízar and Alfaro-Rodríguez, 2019). The four focal points selected for this study are highlighted in the figure.

For management purposes, the Costa Rican institute of fisheries, INCOPESCA, have sectored GoN into three different areas, the inner (zone 201), middle (202) and outer Gulf (203) (Marín-Alpízar and Alfaro-Rodríguez, 2019). For this study we followed the criteria of INCOPESCA and selected four focal points that geographically represent the diversity of artisanal gillnet fisher communities along the GoN. (1) Isla Chira (North internal region), (2) Costa de Pájaros (North intermediate region), (3) Paquera-Tambor (South-West external region) and (4) Tárcoles (South-East external region). Across the sectors is a common presence of species such small pelagics (*Anchoa* sp., *Centengraulis mysticetus*, *Ophistonema* spp.), shrimps (*Litopenaeus* spp.), snapper (*Lutjanus* spp.), and corvinas and snook (*Cynoscion* spp., *Micropogonias altipinnis*, *Centropomus nigrescens*) (Vargas-Zamora et al., 2019).

The basic input parameters collected to create the updated EwE food web model of the GoN, come from INCOPESCA's monthly landings statistics for the main target groups of the fisheries (Alms and Wolff, 2019). Within the EwE modeling software, Ecopath enabled the analysis of the trophic mass balance (biomass and flow) and functioning of the ecosystem (Christensen and Walters, 2004a). Estimation of biomass with Ecopath required making explicit assumption about the ecotrophic efficiency; i.e., the proportion of the total mortality rate of a group accounted by the predation, migration, biomass accumulation and fishing rates (Christensen and Walters, 2004a).

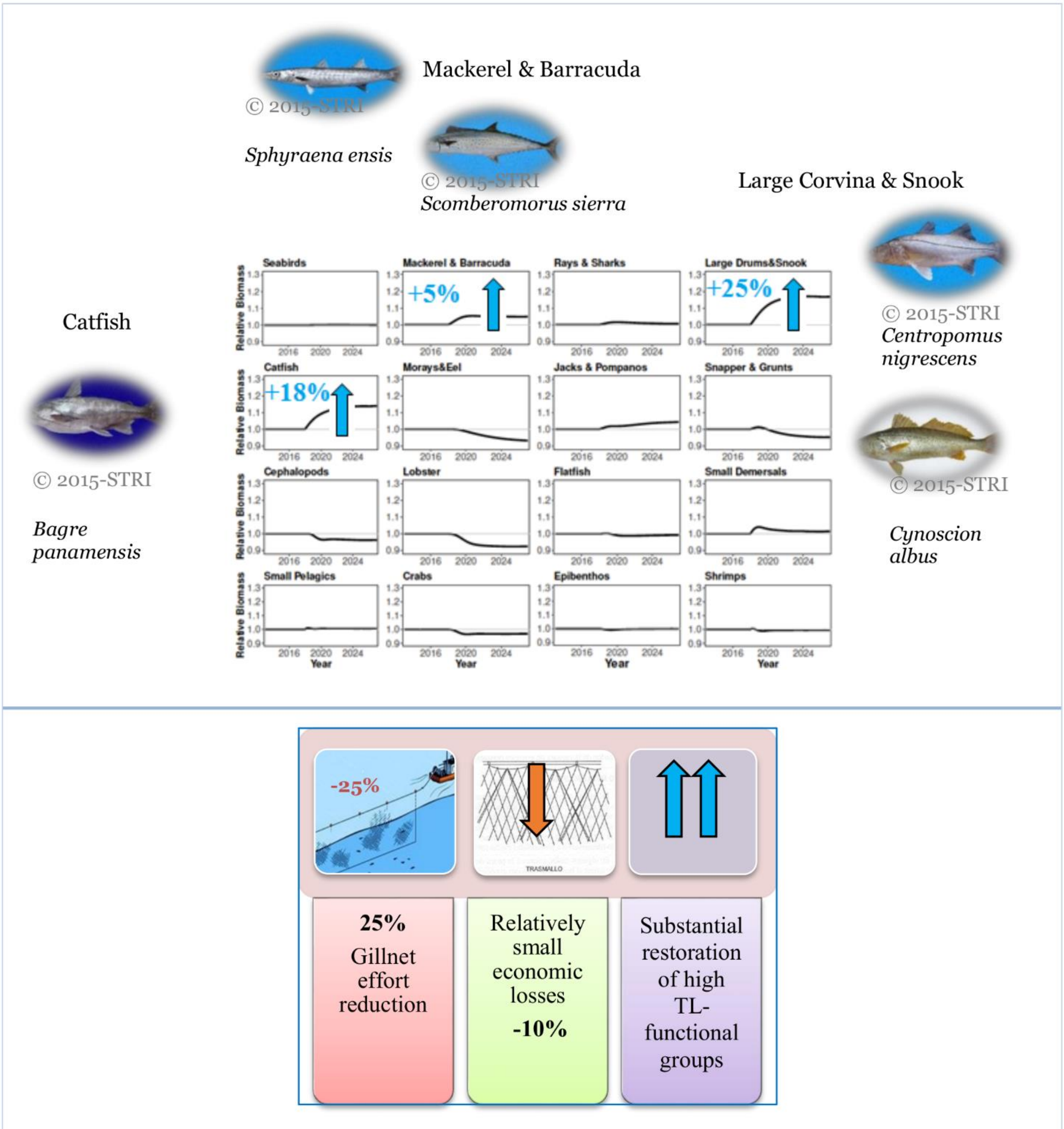
EwE is characterized by its simplicity and management applications, since it is flexible to accommodate future input updates and requires relatively few key data, making it useful in some data-limited fisheries contexts (Bacalso and Wolff, 2014) One potential limitation in applying the EwE approach lies in the quality of available data, so this and other possible situation were addressed based on (Christensen and Walters, 2004a). The time dynamic modeling capability (Ecosim) of EwE (Pauly et al., 2000), facilitated estimating future results of fisheries management alternatives in the Gulf, at combining fishing data with ecological data (biomass and consumption estimates, eco-trophic efficiencies and diet composition).

Based on (Alms and Wolff, 2019), a fishing effort reduction by 25% was modeled, within which relatively small economic losses and the potential for substantial restoration of high trophic level functional groups (large corvina, snook, catfish, mackerel and barracuda) were identified (**Figure 3.3**).

3.2.2. Experimental design

We conducted an experiment of environmental education with small scale gillnet fishers in the GoN to assess outcomes of providing and deliberating upon scientific information. The topic concerned complex ecological issues in the GoN, discussed in relationship with fishing activities, especially the impact of gillnet fisheries on the ecosystem. We compared antecedents of pro-environmental behavior (Fujitani et al., 2017; van Riper and Kyle, 2014) in fishers who were members of an ecosystem-based intervention (a lecture with workshop materials containing EwE) (**Figure 3.3**), with those who received lectures that did not involve EwE.

Using a pre-survey (recruitment) and post-survey (applied to the fishers that participated in the three phases of the study) control design, changes in environmental values, beliefs, norms, and behavioral intentions were evaluated.



© Copyright 2015 – STRI. Images Credit: *B. panamensis, C. nigrescens* and *C. albus,* by Ross Robertson. *S. sierra* by Robertson & Van Tassell. *S. ensi* by Gerald R. Allen.

Figure 3.3. Scenario 25% effort reduction was delivered to the members of an ecosystem-based intervention (lecture containing EwE models), based on (Alms and Wolff, 2019).

The experimental design consisted of three main phases (**Figure 3.4**): (1) a pre-survey in which 101 small-scale gillnet fishers participated, carried out along the Gulf of Nicoya: inland zone (Palito, Bocana and Montero in Isla Chira), middle Gulf (Costa de Pájaros) and external (Paquera-Tambor and Tárcoles); (2) an environmental education program that included two workshops one week apart (to discuss different information each week), in which a total of 86 people were part of the 101 pre-survey fisher and participated in the first workshops, then 73 people were part of the 86 fishers participating in the second workshops; and finally (3) a post survey (after the workshops) for the 58 fishers who participated in the three phases of the study. In total, 14 workshops were held in all communities, with a retention rate from before to after the survey of 57.42%.

This study focuses on the 58 fishers who participated in the three stages of the research. The 15 respondents from the Tárcoles community, who only completed the pre-survey and did not show positive availability for the workshops, were not included in the analysis.

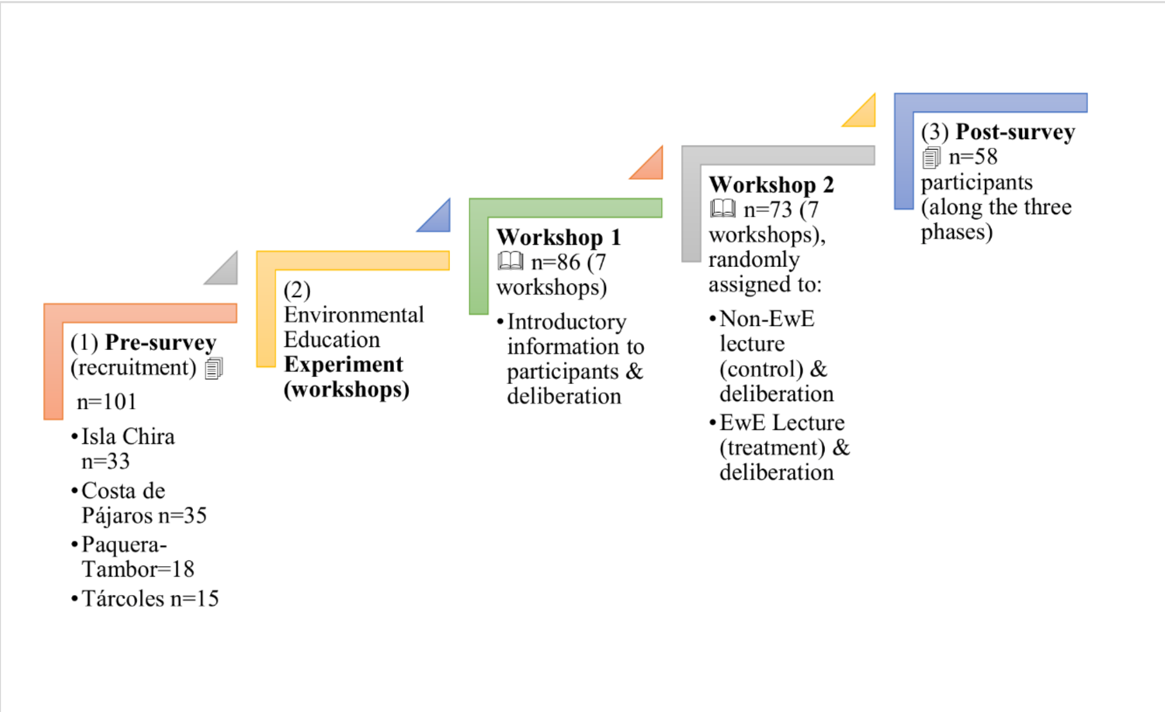


Figure 3.4. Experimental design applied with small-scale gillnet fishers in Gulf of Nicoya; 58 were the number of fishers who participated in the three phases of the study (pre, workshop, and post).

A profile of the participants' socio-economic characteristics are included in Annex II (**Table S2.1, S2.2**). The majority of respondents identified as male (82.8%). The average age of respondents was 41, ranging from 18-70 years old. These characteristics of our sample are similar to the population data for the communities visited (BIOMARCC et al., 2013); 96.6% of respondents were long term residents of GoN (more than 10 years) from which 36.8% reported having fishing experience of 10-20 years and 47.4% of more than 20 years. The majority of fishers (51.7%) completed elementary school and just 12.1% completed high school.

With respect to the surveys, the quality of the responses are determined by the extent to which the respondent understands the question, retrieves and integrates information to form a general judgment and formulate an answer; the type of instrument used (e.g., in person or self-administered surveys/interviews/questionnaires) can have an effect on the responses (Lindhjem and Navrud, 2011). When using in-person surveys, the respondent may feel inclined to provide answers that are socially acceptable or that he/she thinks the interviewer would like to hear, that effect is called social desirability bias (Ressurreição et al., 2012). Taking into account social desirability bias (Nunnally, 1967), the present study was framed within an experimental setting in which also a group control was used for comparison with the members of an Ecopath with Ecosim (ecosystem modeling) groups (treatment).

The level of social desirability also seems to be related to the degree of anonymity and confidence felt by the respondent (Lindhjem and Navrud, 2011), hence in order to improve this anonymity and trust (1) we sought and obtained authorization from community leaders before conducting the surveys, and the wording was pretested and modified accordingly in a pilot survey (and workshop pilot); (2) participants were asked for prior informed consent and provided with a description of the project and the uses of the research data; (3) the interviews were carried out by trained interviewers to clarify the doubts of the respondents, thus minimizing the non-response rates; (4) respondents were encouraged to give honest answers and the confidentiality of the answers was emphasized.

The survey used in this investigation contained some reversed statements interspersed so people needed to put the necessary effort and take some time to think to optimally answer (Lindhjem and Navrud, 2011), in addition we counted with follow up questions (post survey) to test for consistency of the responses (see more details in the Data Analysis section). The study was conducted primarily from May to July, 2017, as this was a 3-month period of fishing closure in the inner and intermediate zones of the Gulf, created for the protection of the reproductive peak events of target resources (small pelagic fish species, shrimps, snapper, and corvinas) (Sánchez-Jiménez et al., 2019).

Usually fishers from internal zones are not involved in any fishing activity during the closure, which facilitated their recruitment to this study. To maximize respondent attention when answering questions, the interviews were preferentially performed when respondents were apparently relaxed and unoccupied (Ressurreição et al., 2012). A minimum of 10 people were interviewed per community in the expectation of having 5-12 attendees in each workshops, facilitating thus fluency in the conversations within small groups (Macmillan et al., 2002).

3.2.2.1. Pre-survey

In the pre-survey (**Text S3.1** in Annex III) the items were designed to elicit: (1) Socio-economic, demographic characteristics and fishing practices of the respondents; (2) antecedents of pro-environmental behavior through psychological factors associated with pro-environmental behavior; (3) behavioral intentions to support fisheries sustainability and a reduction in fishing effort of 25% (measures A and B), along with owning a fishing license (revealed behavior, measure C); (4) the last part of the survey elicited the availability of fishers to participate in workshops. Each survey session lasted an average of 45 minutes.

Values, beliefs and norms were measured in the survey using 22 items adapted from previous surveys (Kenter et al., 2016; Steg et al., 2005). The values were measure through a Likert response format −1 to 7 where −1 indicated "opposition' to this value", and 7 indicated "of supreme importance". Beliefs and norms where measured in a format 1 to 5 where 1 indicated "strongly disagree", and 5 indicated "strongly agree".

3.2.2.2. Environmental Education Experiments (Workshops)

Two workshops (**Figure 3.4**), one week apart, took place and lasted approximately 4 h. Both workshops included deliberation to provide participants with a space to discuss complex ecological issues in the GoN associated with fishing practices. In the first workshop, everyone received the same introductory information about the state of the ecosystem in the GoN to familiarizing them with the topic. In the second workshop the differences lay in the way the information was presented, since they were randomly assigned to a lecture that either had EwE or did not.

Within workshop 1 (introductory information and deliberation): (1) all participants received the same introductory information about the state and changes over 20 years in catches of shrimps, corvinas and large predatory species, taken from (Alms and Wolff, 2019). (2)

Fishers were asked to deliberate in groups around the information received (See details in (Sánchez-Jiménez et al., 2019). Within workshop 2, people were randomly assigned either to a treatment (containing EwE) or to a control lecture (non-EwE), this served as the control for comparison (Fujitani et al., 2017). Control and treatment both involved deliberation on the info presented, the differences lie in the way the information was offered.

The control lecture: (1) Taught general issues regarding the concepts of marine tropical food webs (Christensen and Pauly, 2004) without discussing the trophic modeling, serving as the control for comparison with the EwE lecture groups to account for social desirability bias and the observer effect in respondents' answers (Fujitani et al., 2017; Nunnally, 1967); (2) participants were told about a hypothetical management option in which a reduction of 25% in the fishing effort would take place but without the modeling context (**Figure S3.1** in Annex III); and (3) they were encouraged to deliberate about this possibility.

In the treatment lecture the facilitator provided via a flip chart presentation: (1) a description of the EwE food web model of the Gulf of Nicoya (Alms and Wolff, 2019) **(Figure S3.2** in Annex III); (2) an explanation about the execution of an EwE model that implied a 25% reduction in fishing effort, with evidence of the recovery of large predatory species implicit in this scenario (**Figure 3.3)**; (3) participants were encouraged to deliberate about the information provided.

3.2.2.3. Post-survey

A follow up survey was administrated after the end of the second workshop based on the pre-survey to measure changes in the psychometric factors after the deliberation (**Text 3.2 i**n Annex III).

3.2.3. Data Analysis

Data were analyzed using R studio version 3.5.3 and JASP version 0.10.2, item and construct relationships were tested with Confirmatory Factor Analysis, as well as reliability analysis (Cronbach's alpha) for internal consistency in respondent's answers (Cronbach, 1951; Ward et al., 2017). Since we hypothesized that the means of the psychometric constructs would obtain a higher score after treatment (EwE lecture) as an increase in the fishers' environmental awareness, in order to address this hypothesis, we compared via an independent group t-Test, the changes in psychometric indicators between samples from pre and post surveys, within control and treatment groups (Fujitani et al., 2017).

Weighted Least Square (WLS) regression analyses were run to test the level of influence of constructs and socio-demographic characteristics on the Gulf of Nicoya residents' behavioral intention and revealed behavior to support three measures of pro-environmental behavior (measures A, B and C). Each management action served as the dependent variable in a regression with antecedents of pro-environmental behavior and socio-demographic characteristics as independent variables.

Variable selection for models used the backwards elimination which is a stepwise approach that begins with a full (saturated) model and at each step gradually eliminates variables, in order to find a reduced model that best explains the data. It reduces the number of predictors, reducing the multicollinearity issues (Hocking, 1976). The dependent variables behavioral intentions measures A and B were continuous variables, and we performed a linear regression. For measure C, the response was categorical (binary, owning a license or not), and so a logistic regression was applied.

3.3. RESULTS

3.3.1. Psychometric Constructs

Psychometric indicators were measured in the questionnaire using 22 items. Factor analysis extracted eight expected constructs from these questions: AR (2 items), PBC (2 items), Universal Values (biospheric and altruistic values) (4 items), AC (2 items), Egoistic values (3 items), PN (2 items), SN (2 items), NEP (5 items) (**Tables 3.1, 3.2**).

TABLE 3.1 | Factor Analysis on values, beliefs and norms regarding rebuilding of high-trophic level species and sustainable fisheries in the Gulf of Nicoya and reliability estimates for each extracted factor (pre-survey sample)

Constructs	Theory	Factor										
		1	2	3	4	5	6	7	8	Mean	SD	Cronbach's' Alpha
Ascription of Responsibility	VBN											0.917
I feel responsible…		0.88								4.12	1.14	
*I don't feel…responsible		0.93								4.21	1.17	
Perceived Behavioral Control	TPB											0.952
It is easy to take action			0.99							3.61	1.53	
*It is difficult…			0.89							3.53	1.46	
Biospheric & altruistic values	VBN											0.772
Respecting the earth...				0.41						5.91	1.31	
Unity with nature…				0.65						5.71	1.37	
Equality…				0.81						5.61	1.64	
A world at peace…				0.43						6.14	1.42	
Awareness of consequences	VBN											0.777
…seas are under a real threat…					0.72					4.68	0.66	
*If the diversity diminished... wouldn't impact. economy					0.89					4.82	0.51	
Egoistic values	VBN											0.596
Wealth…						0.64				3.84	2.20	
Influence						0.49				4.82	2.04	
Authority						0.62				4.02	2,02	
Personal Norms	VBN											0.643
We should protect…							0.41			4.77	0.47	
*We should think about economic…and then about environment							0.97			4.48	0.76	
Subjective norms	TPB											0.549
Most people... think I should support…								0.57		4.75	0.55	
Most people…take action								0.76		4.66	0.59	
New Ecological Paradigm	VBN											0.512
*..the ecological crisis" has been exaggerated									0.67	4.64	0.48	
Plants and animals have… right…		0.29								4.89	0.31	

*Reversed into a positive statement for analysis. VBN (value, belief, norm theory) (Schwartz and Howard, 1981). TBP (the theory of planned behavior) (Ajzen, 1991).

TABLE 3.2 | Factor Analysis on values, beliefs and norms about rebuilding high-trophic level species and sustainable fisheries in the Gulf of Nicoya. Reliability estimates for each extracted factor (post-survey sample).

Construct	Theory	Factor										
		1	2	3	4	5	6	7	8	Mean	SD	Cronbach's' Alpha
Biospheric & altruistic values	VBN											0.774
Respecting the earth…		0.89								5.58	1.18	
Unity with nature…		0.61								5,60	1,63	
Equality…		0.50								5.75	1.54	
A world at peace…		0.73								5.91	1,31	
Perceived Behavioral Control	TPB											0.935
It is easy to take action…			0.96							3.36	1.53	
*It is difficult…			0.84							3.42	1.49	
Egoistic values	VBN											0.726
Wealth…				0.57						4.17	2.00	
Influence…				0.57						3.96	1.99	
Authority…				0.94						3.87	2.02	
Ascription of Responsibility	VBN											0.918
I feel responsible…					0.93					4.07	1.25	
*I don't feel…responsible					0.89					4.09	1.19	
Awareness of consequences	VBN											0.825
…seas are under a real threat…						0.65				4.65	0.78	
*If the diversity…diminished wouldn't impact economy…						0.96				4,63	0,68	
Subjective norms	TPB											0.835
Most people… think I should support…							0.88			4.69	0.85	
Most people…take action…							0.73			4.48	0.72	
New Ecological Paradigm	VBN											0.621
*The "ecological crisis" has been exaggerated								0.96		4.57	0.75	
Plants and animals have right…								0.43		4.84	0.50	
Personal Norms	VBN											0.685
We should protect…									0.67	4.84	0.50	
*We should think about the economic… and then about environment									0.82	4.25	0.65	

*Reversed into a positive statement for analysis. VBN (value, belief, norm theory) (Schwartz and Howard, 1981). TBP (the theory of planned behavior) (Ajzen, 1991).

Reliability estimates for the eight constructs ranged from 0.512 to 0.917 for the pre-survey sample (**Table 3.1**) and from 0.621 to 0.935 for the post-survey sample (**Table 3.2**). Overall Cronbach's alpha was improved by deleting 3 items of the New Ecological Paradigm construct. The recommended corrected item total correlations of 0.4 was exceeded in all cases (Ward et al., 2017). For these reasons, all items were grouped together with their respective indicator theme constructs.

3.3.2. Pre and Post Survey Control Comparisons

The results of the independent group t-Test for the pre and post surveys samples, are reported in **Figure 3.5**. Two values differed between the pre and post surveys samples: Egoistic Values decreased significantly ($p < 0.05$) in the post survey sample within the EwE lecture (treatment). Likewise, an increase ($p < 0.1$) was found in the Perceived Behavioral Control (PBC) values in the post survey sample within the treatment (EwE lecture). No significant differences were found between pre and post survey samples for SN, AC, NEP, PN, AR or for biospheric and altruistic values.

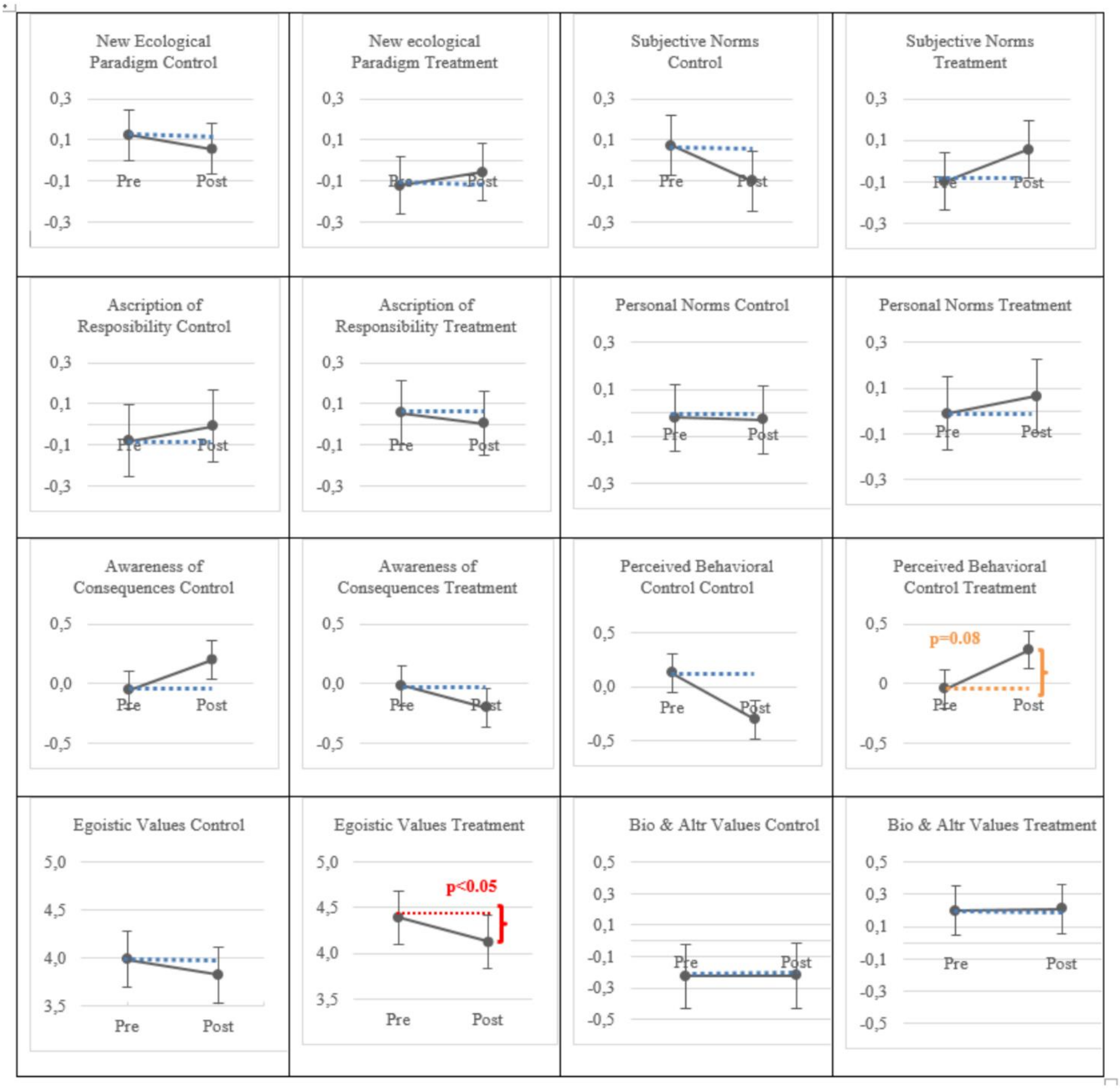


FIGURE 3.5 | Comparison between means of the pre and post survey sample within the control (non-EwE lecture) and treatment (EwE lecture). Blue dotted lines represent the difference between pre and post survey. A red dotted line indicates a significant difference at the $p < 0.05$ level; an orange dotted line shows a difference at the $p < 0.1$ level

3.3.3. Behavioral Intentions and Revealed Behavior to Support Sustainability (Regression Analysis)

Regression analysis assessed the influence of psychometric constructs and fishing characteristics on measures of pro-environmental behavior, specifically on the intentions to support fisheries sustainability and a reduction in fishing effort of 25% (measures A and B), together with owning a fishing license (revealed behavior, measure C) (**Table 3.3**). The estimated correlation between the error terms (Adjusted R^2 or Nagelkerke R^2) for all three models fall within the ranges usually reported in regression models (0.3-0.7), suggesting a reasonable explanatory power (Bacalso et al., 2013). Coefficients for SN, NEP, PBC, fishing profits, fisheries organization and gender fell short of significance. The significant (positive or negative) coefficients under management actions A, B and C are shown as follows:

TABLE 3.3 | Results of regression analysis for the pre and post surveys samples. All figures (except R^2 and Adj.R^2) are standardized ß-coefficients.

	Behavioral Intentions A and B, and revealed behavior C					
Predictor	(A) Support Sustainable Fisheries [Linear regression]		(B) Support a 25% Fishing Effort Reduction [Linear regression]		(C) Owning a Fishing license [Binomial regression; yes, no]	
	Pre (n=51)	Post (n=46)	Pre (n=50)	Post (n=45)	Pre (n=54)	Post (n=49)
Personal Norms	0.3605**	n.s	n.s	0.3312*	n.s	n.s
Subjective norms	n.s	n.s	n.s	n.s	n.s	n.s
Perceived Behavioral Control	n.s	n.s	n.s	n.s	n.s	n.s
Ascription of Responsibility	n.s	n.s	n.s	n.s	n.s	n.s
New ecological Paradigm	n.s	n.s	n.s	ns	n.s	n.s
Egoistic Values	n.s	n.s	-0.1758*	n.s	n.s	n.s
Biospheric & altruistic Values	n.s	n.s	n.s	0.4094**	n.s.	n.s
Fishing profits	n.s	n.s	n.s	n.s	n.s	n.s
Fishing-site (Outer Gulf, PT)	n.s	n.s	-1.6595***	-1.0057***	n.s	n.s
Fisheries organization (member)	n.s	n.s	n.s.	n.s.	n.s	n.s
Fishing gear (finfish gillnet ≥3 inches)	0.7796***	n.s	n.s	1.2856***	n.s	n.s
Fishing-site (middle gulf, CP)	n.s	n.s	0.6039*	0.4778*	n.s	n.s
Gender (male)	n.s	n.s	n.s	n.s	n.s	n.s
Own fishing vessel (yes)	n.s	n.s	n.s	n.s	2.89484**	2.86521***
R^2	0.5182	0.3610	0.6217	0.7188	0.5125 (Nagelkerke R^2)	0.4424 (Nagelkerke R^2)
Adj. R^2	0.4525	0.2986	0.5787	0.6656	0.3690 (Cox & Snell R^2)	0.3237 (Cox & Snell R^2)

*=p<0.05, **=p<0.01, ***=p<0.001, n.s (no significant), PT= Paquera-Tambor, CP= Costa de Pájaros

3.3.3.1. Behavioral Intention to Support Sustainable Fisheries (measure A)

The pre survey sample reflected that personal norms (ß= 0.36, $p<0.01$) regarding marine conservation issues, was the most significant factors in the model. Catching finfish predominantly with large-size mesh gillnet (≥3 inches) was also a significant factor (0.78, $p<0.001$). The regression explained 52% of the total variance (R^2=0.5182) suggesting reasonable explanatory power. On the other hand, the post survey sample showed no significant factors with a 36% of the total variance explained by the regression (R^2= 0.3610).

3.3.3.2. Behavioral Intention to Support 25% Fishing Effort Reduction (measure B)

Regarding the support to reduce 25% the fishing effort, the pre survey sample showed that fishing in the middle Gulf (Costa de Pájaros) (ß= 0.60 $p<0.01$) was the most significant factor in explaining support. Similarly, fishing in the outer GoN (Paquera-Tambor) (ß= -1.66, $p<0.001$) and egoistic values (ß= -0.18, $p<0.05$) were important factors, but the relationship was negative, that is, the more the participants fish in the GoN's outer area and the more the egoistic values, the less support for sustainability. In the post survey sample, fishing in the outer GoN also indicated an important significant factor of opposition (ß= -1.01, $p<0.01$); whereas personal norms (ß= 0.33, $p<0.05$), biospheric and altruistic values (ß= 0.41, $p<0.01$) together with fishing with large-size mesh gillnet (ß= 1.29, $p<0.01$) and being a resident of Costa de Pájaros (ß= 0.48, $p<0.05$) were the most significant positive factors influencing support. The regression explained 72% of the total variance (R^2= 0.72).

3.3.3.3. Revealed Behavior: Owning a Fishing License (measure C)

At the third level of support sustainability by means of owning a fishing license, for the pre survey sample, owning fishing vessel (ß= 2.89, $p<0.01$) was the most significant factor behind owning a fishing license. The regression explained 51% of the total variance (R^2= 0.51). While own a vessel alone (ß= 2.86, $p<0.001$) was the most significant factor influencing support for the post survey sample. The regression explained 44% of the total variance (R^2= 0.4424).

3.4. DISCUSSION

Our interest has been to explore the role that value-oriented, ecosystem-based interventions can play in environmental education and fisheries management. This study showed that EwE treatments altered *perceived behavioral control* of fishers, and that *values*, *personal norm*s and fishing attributes were factors that influenced pro-environmental behavior in the GoN. Details on these findings are discussed below.

3.4.1. *Influence of Cognitive and Fishing Characteristics on Pro-environmental Behavior*

Regression analysis supported the first hypothesis of this study, in terms of the potential that *personal norms* have to explain the intention to support sustainable fishing, both in the pre-survey (support sustainable fisheries measure A) and post-survey (support a 25% fishing reduction, measure B). By definition, personal norms are defined as one's own expectations of specific actions in particular situations that are constructed by the individual and this is relevant since such expectation has proven to be a direct prerequisite for expressing pro-environmental behavior (Klöckner, 2013; Stern et al., 1999) and be related to compliance with management measures in small-scale fisheries (Battista et al., 2018).

Universal values (Schwartz and Bilsky, 1987), both *biospheric* and *altruistic,* as well as *egoistic*, showed potential to explain the support (or lack of it) to reduce the fishing effort by 25%, as has been found in other studies of environmental behavior (Steg et al., 2005; van Riper and Kyle, 2014). Since *egoistic* values focus on the individual's own life over taking care of other people or the environment, they tend to have a negative influence on the prediction of support (de Groot and Steg, 2010), which is the case for measure B in the pre-survey before the workshops.

It is noteworthy that after the workshops and the deliberation process, a change is identified and the *biospheric* and *altruistic* values showed a significant positive influence in supporting the reduction of fishing effort, which makes a call for educational programs that promote an orientation in values (de Groot and Steg, 2009); for instance, informational interventions can make those who care deeply about the environment more inclined to act in accordance with its values (Bolderdijk et al., 2013).

Values are developed at an early age and can remain relatively stable during an individual's life (Manfredo et al., 2017), therefore, complementary options include educational programs aimed at children and young people (tentatively future fishers) to call the attention to the importance of nature and promoting early care relationships with their environment (Menzel and Bögeholz, 2009). In addition to cognitive indicators, fishing characteristics, such as *fishing gear* and *fishing sites* played a role in explaining support for sustainable fishing in the GoN. *Owning fishing vessel* also proved to be one of the factors that influence the ownership of a fishing license. The coefficients for *fishing profits*, *fisheries organization*, and *gender* were not significant in this case.

The *fishing gear* variable showed a significant positive coefficient in the regressions, indicating that fishers using large mesh sizes (gillnets for finfish ≥ 3 inches) tend to support general notions of sustainability of fishing (measured A) and a 25% reduction in fishing effort (measure B). In other words, fishers using gillnets ≥ 3 inches to catch finfish tended to choose management measures that favored rebuilding the biomass of predatory fish over earnings. This is understandable, since in practice they are already utilizing sizes considered legal for the protection of juvenile fish. Illegal fishing is a serious threat to sustainability in the GoN, and although mesh sizes <3 inches are prohibited, the use of 2.5 and 2.75 inches is widespread. A reflection of this is that 80% of corvina catches in the 2010s have not reached the size of spawning maturity (Alms and Wolff, 2019).

The *fishing site* variable showed statistically significant coefficients to support a 25% reduction in fishing effort (measure B). Participants fishing mainly in the middle of the GoN (Costa de Pájaros) support rebuilding the biomass of predatory fish over earnings. In contrast, fishers whose fishing site is the outer Gulf (Paquera-Tambor) show opposition to the measure. The combination of fishing with other economic activities such as tourism in the Paquera-Tambor sector (Chavez Carrillo et al., 2019) and less dependence on fishing activity, may explain the lower interest in supporting the fisheries management measure B.

When considering the discussions in the workshops, the positive coefficients of measure B for the middle gulf seem to respond to a genuine interest in the reconstruction of the biomass of high trophic level species, motivated by the concern of the participants about the high fishing effort in the area and the associated problems of poverty in Costa de Pájaros (Fernández-Carvajal, 2013).

The variable *owning a fishing vessel* alone was found to be a statistically significant coefficient for measure C (ownership of a fishing license). The granting of fishing licenses in the GoN is a management measure to ensure control of fishing effort and that fishers have access to fishing resources. The absence of a clear pattern of what may be influencing people to acquire a license (other than owning a fishing vessel), uncovers a great underlying problem: licenses are not granted under defined technical or ecological criteria, and this is contributing to increase both mistrust among fishers and illegal fishing.

Some of the fishers in this study expressed that unlicensed people would have less to lose if caught fishing illegally during a closure season: "The worst consequence in this case is that their gear would be confiscated." There is a widespread perception among licensed fishers that others will continue to violate restrictions due to unlicensed fishing and a lack of concern for the environment. This has led some people to reconsider their own legal fishing practices, anticipating that others will fish illegally anyway; a social-ecological trap that needs to be addressed (Kittinger et al., 2013). EwE modeling can be useful to provide ecological feedback in redesigning a licensing scheme for effective control of fishing effort. In turn, behavioral interventions can also assist the process by addressing issues of mistrust, compliance and legitimacy among fishers. We refer to this last aspect below.

3.4.2. Changes Before-After the Ecopath Intervention

Average PBC scores, increased in the post-survey for those people who received the EwE lecture, probably attributable to treatment when differences between control and treatment groups are considered. This is promising, as *perceived behavioral control* is clearly associated with pro-environmental behavior in other studies (Clement et al., 2014; Kinzig et al., 2013; Klöckner, 2013). If people perceive that they are capable of changing behavior and implementing an action (PBC) - and they are guided with plausible routes to follow-, they are more likely to act accordingly (Klöckner, 2013).

Given the changes in PBC scores, EwE interventions may be bringing fishers closer to concrete and possible pathways to sustainability, by presenting how a particular reduction in fishing effort has the potential to restore higher trophic level groups (a proxy of ecosystem health). Deliberation about management initiatives can influence not only the perceived ability of people to act (Kenter et al., 2016), but also the perception of the legitimacy of these initiatives (Dietz and Stern, 2008; Fujitani et al., 2017). Such validity is important for a measure to be implemented and is often behind the success of alternative forms of fisheries governance, such as co-management and collective action (Battista et al., 2018).

Educational interventions are recommended that allow people to perceive themselves as capable of implementing actions or changing their behavior, which, for example, strengthen co-management schemes (García-Lozano and Heinen, 2016; Herrón et al., 2020) that already exist in the Gulf of Nicoya and combine them with deliberation strategies (Partelow et al., 2017). Integrating theEwE food web modeling approach into participatory processes can help people envision possible scenarios for the future and thus reduce some of the uncertainties associated with complex environmental problems (Steenbeek et al., 2020) characteristic of small-scale fisheries. This last aspect may be related to the greater *perceived behavioral control* by the fishers after deliberating with EwE.

After the workshops, several of the participants' comments indicated the need for more educational processes such as the current one, finding it as an attractive way to learn, we suggest that these types of interventions can act as an active learning process (Kenter et al., 2016) that also contribute to more legitimate and empowered ways of creating conservation plans. Egoistic values decreased significantly in the post survey within the lecture presenting an EwE model (treatment) and a similar decrease also occurred within the control lecture (non-EwE). Though one cannot know for sure, this change observed in both the control and treatment could be due to social acceptability bias (Steenkamp et al., 2010) in response. This simultaneous change in the two groups is not attributable to the treatment, and illustrates the utility of a pre-test post-test control experimental design.

On the other hand, altruistic and biospheric values did not vary significantly after the EwE lecture, however is notable that their scores were already high from the beginning (Figure 4). Our study indicates that the baseline values held by fishers consulted in the GoN tend towards altruistic and biospheric. This aspect coincides with (Bouman and Steg, 2019), who have indicated that the lack of action in favor of the environment is usually caused by people who structurally underestimate how much others care, rather than being caused by people who undervalue the natural environment. Consequently, highlighting that many value the environment and that they participate in concrete sustainability actions is key to inspiring pro-environmental actions at a broader level (Bouman and Steg, 2019; de Groot and Steg, 2009).

3.4.3. General Conclusions and Future Directions

People's commitments to sustainability are influenced by a complex suite of factors (Nyborg et al., 2016), we found for the study sites in the Gulf of Nicoya that the support of three management measures was influenced by a combination of psychological and fishing characteristics, particularly universal values (biospheric, altruistic and egoistic), PBC, norms (PN) and fishing attributes (fishing gear, fishing site and fishing vessel). Understanding cognitive indicators and human-nature relationships is key step in determining support levels for potential management measures.

The use of the EwE model combined with deliberation performed as an active learning approach that provided people with useful skills and encouraged their PBC to increase resilience to environmental change, which is a psychological construct greatly related to pro-environmental behavior in other studies (Clement et al., 2014; Kinzig et al., 2013; Klöckner, 2013). We propose that visualize and deliberating about possible future scenarios (via Ewe modeling) helped reduce uncertainties associated with complex environmental problems and thus contributed to more legitimate and empowered ways of discussing such intricate issues and potentially of creating conservation plans. An important area for future research would be to follow the fishers longitudinally, conducting a post survey at a later date to detect the impact of the EwE intervention over time (for example, after one year as in Fujitani et al., 2017)).

The baseline values for the fishers in this study tend towards altruistic and biospheric but due to high incidence of illegal fishing, people may be underestimating that many others do care about neighbors and the Gulf's environment. The lack of a clear pattern of what may be influencing people to acquire a license exposes a large underlying problem: licenses are not granted under clear technical or ecological criteria, and this is contributing to increase both mistrust among fishers and illegal fishing.

A scheme that grants licenses according to an ecosystem-based management for the effective control of fishing effort, is a necessary step for the sustainability of the GoN; ecosystem models can be very useful to assist in these processes. However, the absence of psychological characteristics that promote cooperation can negatively impact the effectiveness of a fisheries management system (Battista et al., 2018). Therefore, value-oriented and ecosystem-based educational interventions can also assist in an effective redesign of the licensing system and encourage participants' already existing intentions to support sustainable fisheries measures.

Our research indicates the importance of behavior interventions that teach about the impacts of fishing in the ecosystem while helping participants to perceive themselves as capable of implementing actions (PBC) and stimulating the expression of biospheric-altruistic values towards a trust restoration process. The lack government resources for adequate surveillance in addition to the generalized problems of distrust among fishers, have been previously identified as two of the main factors that hinder compliance and collective action in the Gulf (Chavez Carrillo et al., 2019).

Alternative types of governance systems, such as co-management, are emerging forces (García-Lozano and Heinen, 2016) that already complement existing government policy in the region, but these alternatives depend on mechanisms such as norms and trust (Battista et al., 2018). Hence, investing in the development of capacities for self-organization and deliberation processes is vital for the sustainability of the SSF in the GoN (Chavez Carrillo et al., 2019). Complementarily, behavior change interventions can be developed to address misinformed beliefs (Ward et al., 2017), such as the generalized conception that people care little about the environment and others.

For future studies in the GoN, we suggest the explicit incorporation of a relational (Chan et al., 2016; Klain et al., 2017) and systemic approach to values (Manfredo et al., 2017; Raymond and Kenter, 2016), to better understand the relationships between main agents of the fishing system (e.g. fishers, scientists, decision makers, a healthy ecosystem) (Skubel et al., 2019) and potentially to address some of the mistrust problems identified. Relational values link people and ecosystems through relationships with nature, including the notions of a good life, such as trust in neighbors or a sense of purpose (Chan et al., 2016). By connecting with other people, the places that people care, the family and human well-being, nature can become part of what an individual cares for; therefore, as (Klain et al., 2017) suggest, appealing to those relational values has the capacity to improve connections with the natural world.

Further exploration of the role of EwE interventions in terms of reconnecting actors with each other and with the ecosystems' resilience and ability to support life is recommended. The expression of biospheric, altruistic and tentatively relational values, carries the possibility of making more evident the prevalence of personal choices that already have a positive effect on ecosystems and other people (Bouman and Steg, 2019), which could potentially inspire trust among fishers, as well as new norms that would lead from individual to collective action (Nyborg et al., 2016). Since values are formed in childhood, value-oriented programs could also target young people (future fishers) to engage from an early age in new ways of relating to others and to ecosystems (Menzel and Bögeholz, 2009)

In order to complement government policy, non-governmental organizations (NGOs) can channel educational campaigns that strengthen trust among participants and other expected social reactions (Lucas et al., 2008; Mackay et al., 2018), for example, make visible certain behaviors within communities (Nyborg et al., 2016), such as the notion that neighbors are actually involved in sustainable fishing practices or specific social movements. Government agencies can make use of interventions that have already been tested in experimental contexts such as the current one, to implement at scale in the GoN, and create participatory spaces that allow a better understanding of the personal norms and values of the actors involved in specific behaviors (Raymond and Kenter, 2016).

Our research indicates the importance of behavior change interventions (Battista et al., 2018) and recognizes that redirecting human behaviors to reconnect with ecosystem resilience (Folke et al., 2016) can be a leverage point for sustainability (Abson et al., 2017) in the Gulf of Nicoya, and for the compliance of small-scale fisheries management measures.

ACKNOWLEDGMENTS

We sincerely thank local communities and fishers from the coastal areas of the Gulf of Nicoya, in the Central Pacific Coast of Costa Rica for allowing, actively participating and supporting data collection of this study in 2017. Support was also provided by Grettel Ulate (ECMAR, Universidad Nacional) who offered guidance during the research. We thank Luis Artavia for his collaboration with the Gulf of Nicoya SIG of this paper. We are grateful for the time and input from the two reviewers of this paper, which have greatly improved the manuscript.

CHAPTER 4. Plural-Values-and-Ecosystem-based Fisheries Management (Restructure Fishing Institutions)

Group deliberation and decision-making among fishers that occurred during the workshops held in the Gulf of Nicoya.

CHAPTER 4

Plural-values-and-ecosystem-based-Approach to Examine Policy Feasibility: a Leverage Point for Sustainability in Tropical Small-scale Fisheries

Astrid Sánchez-Jiménez, Marie Fujitani, Matthias Wolff, and Douglas MacMillan

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

Sánchez-Jiménez A., Fujitani M., Wolff M. and MacMillan D. (2021). (Manuscript submitted). Plural-values-and-ecosystem-based-Approach to Examine Policy Feasibility: a Leverage Point for Sustainability in Tropical Small-scale Fisheries

Submitted on November 2021 to *Ecology and Society.* The Manuscript was under review at the moment of presenting the dissertation.

ABSTRACT

The Sustainable Development Goals (SDGs) call for fisheries management and research approaches that are ecological and locally appropriate, thus the identification of fisher's values, and worldviews involved in the consideration of policies is essential. However, conventional fisheries management does not take into account ecosystem interactions and underestimates the importance of stakeholder's behavior and intrinsic motivations. Since ecosystems matter in multiple ways for different individuals (i.e., pluralism of values), through a case study in a tropical small-scale fishery (SSF), the Gulf of Nicoya (GoN) Costa Rica, a field experiment approach was adopted to incorporate fishers' environmental motivations and values into ecosystem-based fisheries management. Motivations were examined using a contingent valuation exercise and a deliberative phase that focused on fishery-ecosystem-policy interactions underpinned by an Ecopath-with-Ecosim ecological model. The willingness to accept (WTA) fishing effort reductions via the implementation of a closed season, was estimated for 58 fishers. The WTA to reduce fishing effort was influenced by the ecosystem-based deliberation, with fishers focusing on a fair compensation amid persistent poverty issues. WTA was also influenced by intrinsic, relational, and instrumental values held by fishers. It is concluded that a plural-values-and-ecosystem-approach for designing fishery policies can be a leverage point for sustainability and science should engage in collaborative research that integrate multiple ecosystem values expressed by societal institutions, especially groups typically marginalized in decision-making. We argue that achieving SDGs 1 (no-poverty) and 5 (gender equality) can enable transitions to achieve the SDG 14 (life underwater) in the GoN and other tropical SSF.

Keywords: leverage points for sustainability, plural-values-and-ecosystems approach, Willingness to Accept (WTA), tropical small-scale Fisheries (SSF), sustainable developmental goals (SDGs), SDGs: 1 ("no-poverty")-5 ("gender equality")-14 ("life below water").

4.1 INTRODUCTION

Despite the fact that most of the world's fisheries are small-scale fisheries (SSF) and their great contribution to employment, food security and poverty alleviation for millions of people, the sustainability of this sector faces significant challenges (Chuenpagdee and Jentoft, 2018). One of the most pressing issues for SSF, is overfishing which in turn is associated to significant losses of marine biodiversity and degradation of ecosystems (Kittinger et al., 2013). As a consequence, there are downward trends in the total catch and a decrease in the well-being of society and particularly of people who depend directly on fishing, as is the case in numerous coastal communities in tropical areas (Cinner, 2009). Enabling transitions to achieve Sustainable Development (SDGs) 14 (life underwater) in tropical SSF calls for transformative research approaches (Diz et al., 2019) and initiatives of fisheries management that are locally relevant, ecologically feasible and culturally appropriate (Zheng et al., 2021).

In the Anthropocene i.e., the age of humans, people have become the main driver of change on planet Earth (Crutzen, 2006; Rockström et al., 2009). However, traditional single-species fisheries management and policy-making in SSF have scarcely incorporated the incentives and constraints that influence fishing behavior (Fisher, 2012). Deeper holistic approaches have also been lacking that take account of changes in structure of ecosystems as a result of fishing (Link, 2002). Within Ecosystem-based Fisheries Management (EBFM) (Pikitch et al., 2004), trophic ecosystem modeling tools as Ecopath with Ecosim (EwE) (Christensen and Pauly, 1992), have enabled managers to comprehensively understand the direct and indirect impacts of fishing on the structure and function of ecosystems (Christensen and Pauly, 2004) and management dynamics (Christensen et al., 2011; Christensen and Walters, 2004b).

Integrated management approaches have taken steps towards recognizing the nature of SSF as complex social-ecological systems (Basurto et al., 2013) and have also provided initial knowledge about the fishing effects on ecosystem services (Christensen et al., 2015; Steffen et al., 2015). EwE modeling for example describes ecosystems as food webs with interactions between their component species and a good representation of high trophic level species in fish landings is often considered as a proxy of ecosystem health and sustainability (Link, 2002; Pauly et al., 2002). Yet, despite the progress regarding holistic management methods, integrating ecological modeling and human dimensions into EBFM requires more and improved collaborative processes between scientists, institutional actors and fishery workers (Bentley et al., 2019; Power et al., 2004; Steenbeek et al., 2020).

The preferences of the stakeholders for designing fishery policies need to be taken into account to ensure successful results both ecologically and socially (Lam et al., 2019; Martín-López et al., 2007). Nevertheless, their inclusion is not straightforward as fisher communities are often very heterogeneous. In the case of the SSF sector, people's interests are influenced by the local context in terms of fishing technology used and the wider economic situation (Quesada-Alpízar, 2006), and behavior is strongly influenced by plural motivations, personal and cultural worldviews and values (Deb, 2018). Pluralism of values results from the fact that nature matters in multiple ways for different individuals (Maca Millán et al., 2020; Zafra-Calvo et al., 2020), groups or collectives (Álvarez-Farizo et al., 2007; Kenter et al., 2016) and cultures (Ressurreição et al., 2012).

Valuing ecosystems can be understood as reasons of importance that people attribute to nature (Arias-Arévalo et al., 2018). The Intergovernmental Platform on Biodiversity and Ecosystem Services IPBES (IPBES, 2019a; Pascual et al., 2017) has classified environmental values as intrinsic, relational and instrumental (Arias-Arévalo et al., 2017; Christie et al., 2019). Instrumental values represents means to an end (utility) and are often measured in monetary terms (Arias-Arévalo et al., 2017), intrinsic values allude to the value of ecosystems independent of people or their utility to humans (moral obligations) (Chan et al., 2016). Relational values refer to the importance of specific relationships and responsibilities individuals hold when interacting with other people and with non-human nature (Chan et al., 2016; Himes and Muraca, 2018).

Identifying plural values entails the integration of diverse valuation approaches (Jacobs et al., 2016; Martín-López et al., 2014). Monetary and non-monetary valuation are possible paths for an integrated valuation of ecosystems (Christie et al., 2012; Gómez-Baggethun et al., 2014). They include quantitative methods (e.g., surveys), qualitative (e.g., interviews (Loureiro and Lotade, 2005), mixed methods (Kenter et al., 2016; Lienhoop and MacMillan, 2007b), deliberative approaches (MacMillan et al., 2005) and psychometric approaches (Spash et al., 2009). Deliberative valuation combines the presentation of scientific (or technical) information with in-depth dialogue with groups or in workshops (Macmillan et al., 2002), and psychometric approaches (Spash et al., 2009) derive from social and environmental psychology and can help understand how universal values (Dietz, 2013) relate to different types of beliefs, norms, and behaviors (Stern et al., 1999).

Via deliberation, psychometric approaches and the examination of fishery-ecosystem-policy interactions underpinned by an Ecopath-with-Ecosim trophic model, the main objective of the present study is to investigate means to improve the way in which the plurality and heterogeneity in the values and worldviews of fishers can be incorporated into management and policy formulation in the SSF. The general assumption is that a plural values and ecosystems approach to examining policy feasibility can be useful to this end and represents a leverage point for sustainability in the management of tropical SSFs. This is because recognizing the impacts of fishing on ecosystems and connecting with the plural and intrinsic motivations that lead people to act in a sustainable way, contains the seed to restructure the behavior (Sánchez-Jiménez et al., 2021a) and the representation of societal institutions (civil society, government and private sector) in policy design.

With the Costa Rican Pacific coast, particularly small-scale fishers in Gulf of Nicoya (GoN) as a case study of tropical SSF, the hypothesis is tested that ecosystems matter in multiple ways for different gillnet fishers (i.e., pluralism of values) and that interdisciplinary-and-transdisciplinary research can help incorporate heterogeneity in ecosystem-based fisheries management. Mainly it is hypothesized that examining policy viability represents a complex process influenced by plural values and multiple motivations, including socioeconomic factors, personal norms, altruistic and biospheric motivations, as well as an understanding the ecological processes involved. In the GoN, one of the main policy interventions include a 3-month seasonal closure along with an economic subsidy to fishers in need. However the subsidy scheme is not yet well harmonized with the SDGs nor is it optimally arresting the deterioration of social and economic conditions of the fisher in the GoN (Coyle et al., 2015; Proyecto Golfos, 2012).

Here a field experiment approach was adopted in the GoN to estimate the willingness to accept (WTA) a reduction in fishing effort (through the implementation of a closed season), in order to rebuild biomass of high trophic-level functional groups within the ecosystem (Sánchez-Jiménez et al., 2021a) and to incorporate small-scale fishers' environmental motivations-and-values into ecosystem-based fisheries management. The process included a contingent valuation exercise and a deliberative phase that focused on fishery-ecosystem-policy interactions underpinned by an Ecopath-with-Ecosim trophic ecological model (Alms and Wolff, 2019) along with examining: (1) motivations (egoistic, biospheric, altruistic, norms and beliefs) toward sustainability; (2) investigating how these motivations and other factors (ecosystem information, socioeconomic factors) influence the fisher´s willingness to accept

(WTA); (3) using qualitative data from a deliberation process to classify overall intrinsic, relational, and instrumental values by which fishers support or reject conservation measures.

This research aimed to shed light on deep leverage points that are often under-investigated and in many cases overlooked (Abson et al., 2017) by conventional fisheries management to examine the ecological and socio-economic feasibility of policy interventions. The scheme of economic subsidy currently applied during the fishing closed season in the GoN is thus explored to better understand the heterogeneity and multiple motivations of fishers behind supporting the reduction of fishing effort and biomass rebuilding, along with the potential this has to restructure societal institutions and to align system patterns of behavior with SDG 14 in tropical SSFs.

4.2. MATERIALS AND METHODS

4.2.1. Study site: the Gulf of Nicoya, Costa Rica

The Gulf of Nicoya (Central Pacific of Costa Rica) (**Figure 4.1**) is a tropical estuary of great importance in terms of primary productivity and biodiversity and with a large fishing tradition (Pacheco-Urpí, 2013). In the 1990s, an Ecopath model of the GoN analyzed the interactions of multiple species and the impact of fishing on the ecosystem (Wolff et al., 1998). The model showed that shrimp overexploitation was seriously affecting the food web of the entire system, and it was suggested that sustainable catch levels can be achieved by significantly reducing fishing effort (Wolff et al., 1998). Twenty years later an updated version (Alms and Wolff, 2019) showed that the general structure and functionality of the ecosystem was maintained over the years, due to the existence of mutually redundant shrimp and sardine species. Instead, high economic value shrimp and higher trophic level predatory species had suffered a considerable decline over the course of the years, indicative of a significant overfishing of the system.

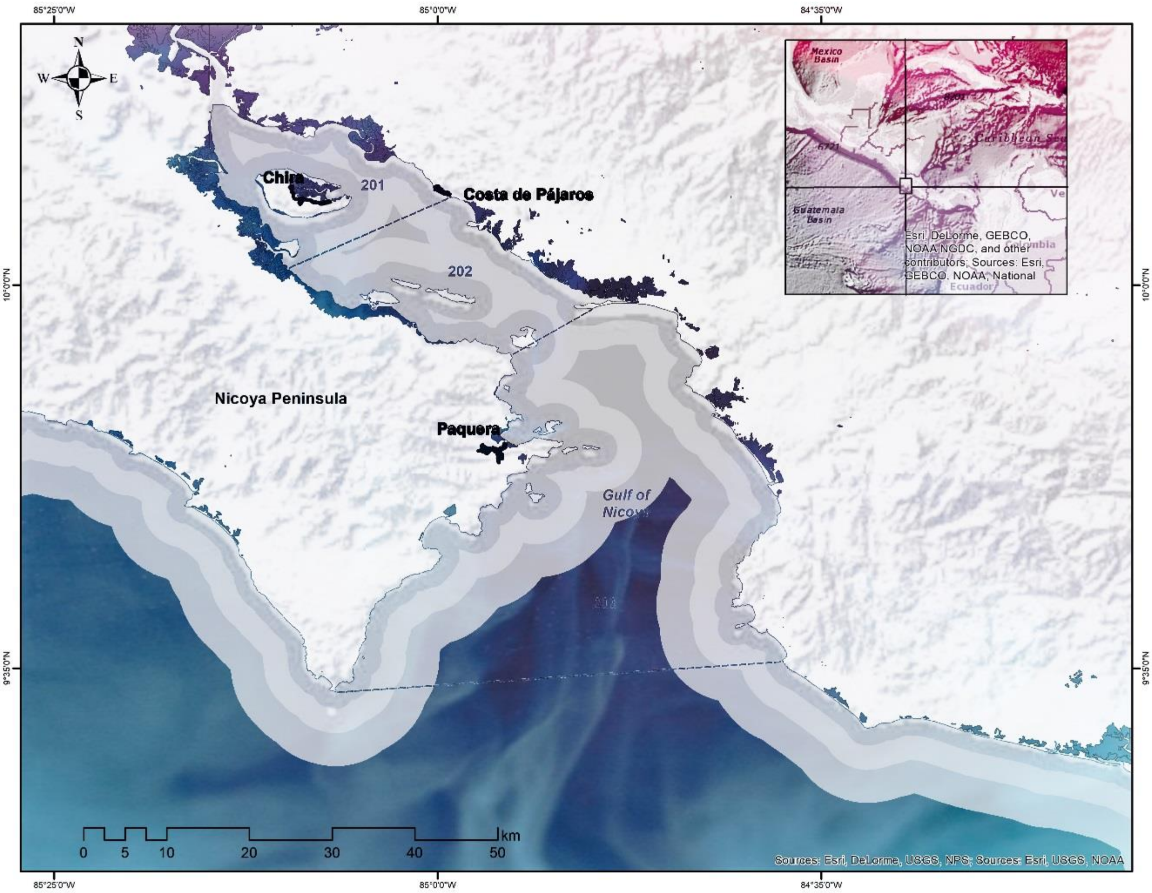


Figure 4.1. Gulf of Nicoya located on the Pacific coast of Costa Rica, areas 201, 202 and 203 (Marín-Alpízar and Alfaro-Rodríguez, 2019). The focal points selected for this study are highlighted in the figure.

A closed season in the inner GoN has been implemented along with a compensatory subsidy in an attempt to reduce fishing effort and protect reproductive peak of some target species. To compensate the fishers for the closure period, the Mixed Social Aid Institute (IMAS for its Spanish acronym) (Marín-Cabrera, 2012) in coordination with INCOPESCA (Costa Rican fisheries institution), allocate economic subsidies to small-scale fishers in need, approximately 40% of a minimum wage. Problems arise as there are only few alternative livelihoods to fishing (e.g. agriculture, livestock and small tourism businesses) (Pachecho-Urpí et al., 2013), and many communities are disadvantaged with low income levels, large families and with little access to the national health system, education and even adequate nutrition (Fernández-Carvajal, 2013).

To better understand the motivations of fishers to support the closed season and its effectiveness for align fishers' behaviors with the SDG 14, three small-scale fishing communities three small-scale fishing communities have been chosen in the GoN (**Figure 4.1**) with common characteristics such as catching corvina, using fishing gillnets as main fishing gear, and representing the geographic diversity of the GoN: (1) Isla de Chira (northern, interior region); (2) Costa de Pájaros (northern, intermediate region) and (3) Paquera-Tambor (southwest region).

4.2.2. Deliberation and Plural Valuation of the Gulf of Nicoya Ecosystem

A deliberative valuation was carried out within an experimental setting from May-July 2017, during a three-month closed season in the GoN, and consisted of three main phases (**Figure 4.2**): (1) A pre-survey; (2) two deliberative workshops (one week apart) with valuation scenarios and a split sample design for those people deliberating on ecosystem modeling information (EwE modeling); finally (3) a post- survey (after the workshops) for the fishers who participated in the three phases of the study. The 58 people who participated in all three phases of the study and took part in the post-survey are the focus of this paper.

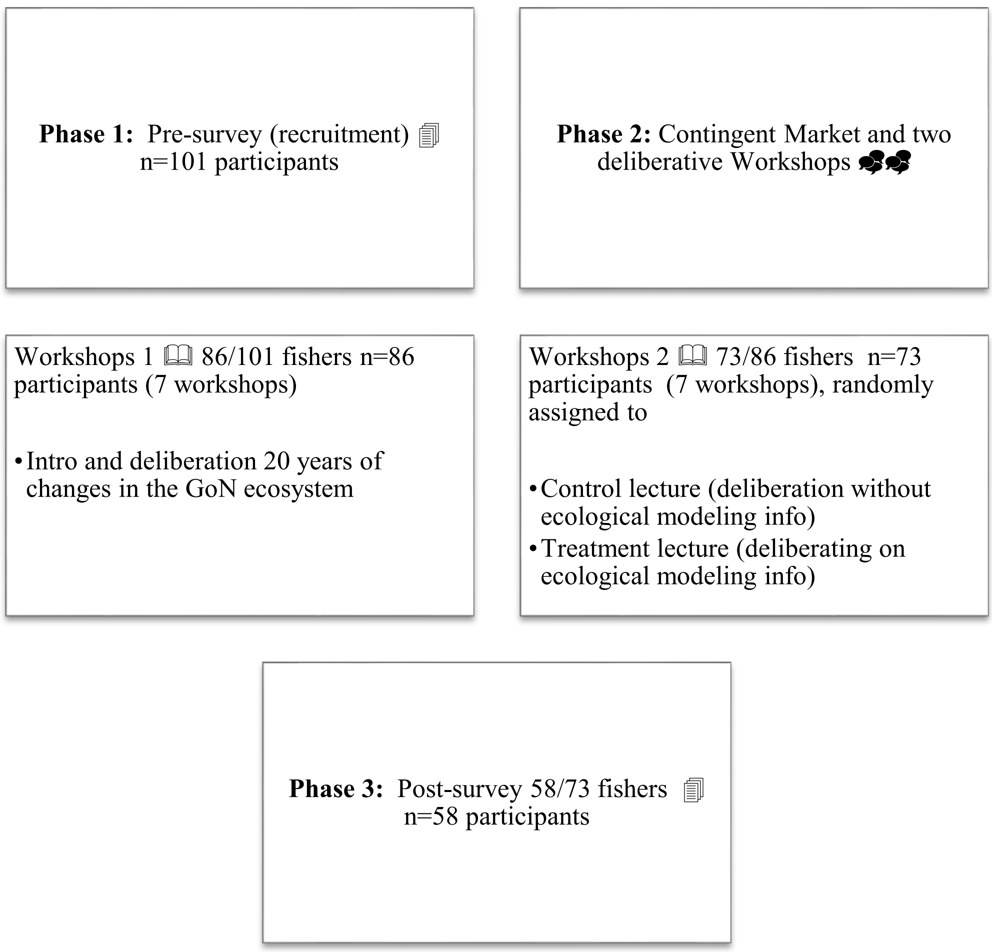


Figure 4.2. Phases of the Deliberative Plural Valuation developed in the Gulf of Nicoya.

4.2.2.1. Phase 1 Pre-survey

The survey was designed to elicit: (1) local fishing context (technology used, fishing sites, demographics and economic situation) of the respondents; (2) motivations (psychometrics) were measured by means of 22 items through a Likert response format (**Text S3.1** in Annex III), in which the "values" ranged from −1 to 7 where −1 indicated "opposition' to this value", and 7 indicated "of supreme importance". "Beliefs" and "norms" where measured in a format 1 to 5 where 1 indicated "strongly disagree", and 5 indicated "strongly agree" (Kenter et al., 2016; Steg et al., 2005); (3) availability of fishers to participate in the workshops. We contacted community leaders to authorize the study and recruited participants based on the INCOPESCA fishers' records. Prior informed consent was obtained from all respondents before research was begun, and they were provided with a description of the project and the uses of the research data. The wording and bid offers for the valuation exercise were pre-tested in a pilot survey and workshop. Each survey session lasted 45 minutes on average.

4.2.2.2. Contingent Market

The hypothetical market was designed in a way that allowed participants to engage in a monetary transaction that is credible to the individuals and that reflects their own perspectives (Lienhoop and MacMillan, 2007a). A pilot workshop with small-scale fishers indicated that fishers would agree with a subsidy payment scheme, based on their willingness to accept (WTA) financial assistance from the government during the closed season ('veda') to protect reproductive peaks of small pelagic fish species. Fishers currently received and have received such payments in the past years, hence a modified payment card (in the same format as a 'government cheque') was adopted to contribute to realism in terms of the fishing closure (**Figure S4.1** in Annex IV).

In 2017 (year of the workshops), the 'veda' subsidy included a monthly financial support of 145,000.00 Costa Rican Colones (CRC) (~ 250 US dollar). We evaluated the WTA expressed by small-scale fishers (gillnet users) to reduce fishing effort in order to support a program on sustainable fisheries, which comprises hypothetical reductions of fishing effort (less fishing hours) by 25% and 45%. Ultimately these reductions would contribute to the biomass rebuilding of functional groups that occupy high trophic levels (TL), including large corvina, snook, catfish, mackerel and barracuda.

Food web approaches include species diversity, but also material, energy flows and interactions between species (Montoya et al., 2015). The valuation scenarios used in this study considered marine biodiversity in terms of functional groups and their biomass, defined by different types of interactions and ecological roles of species within the food web (Alms and Wolff, 2019). The Alms & Wolff models (2019) comprised 22 functional groups (3 groups of primary producers and 10 different groups of fish) (**Table S1.2** in Annex I). The participants understood the presence of high trophic level species as indicative of ecosystem health, concepts with which they had shown to be familiar in the pilot study.

Sustainability was recognized as the ability of societies to maintain the integrity of the natural system over time, which can consequently contribute to present and future human well-being. The payment cards were presented as different checks in an envelope, where people signed all those who would be willing to accept (WTA), with the understanding that it would be the minimum WTA for a month of fishing closure. The payment card included four checks with one offer each expressed in local currency: 26,000.00, 36,000.00, 46,000.00 and 56,000.00 CRC (38, 53, 67 and 82 USD respectively), representing subsidy claims for closure (**Figure S4.1** in Annex IV). The elicitation exercise was carried out within a deliberation and a workshop context (described below), to provide people with sufficient information and time to reflect and discuss about it in their groups and at home. Checks in envelopes intended to offer privacy in decision making.

Group deliberation around scientific ecosystem-based information (food web modelling) in the treatment group, sought to internalize and dissect some of the complex trade-offs and changes usually involved in decision making in the small-scale fishing context. The WTA question was framed as follows (**Figure 4.3**): "*Let's reflect on [functional groups]. What would be the minimum amount you would be willing to accept, in a once only payment issued by IMAS, in order to reduce fishing effort in fishing hours by [25% or 45%] and contribute to the rebuilding of [high trophic functional groups] by [ ]%?*"

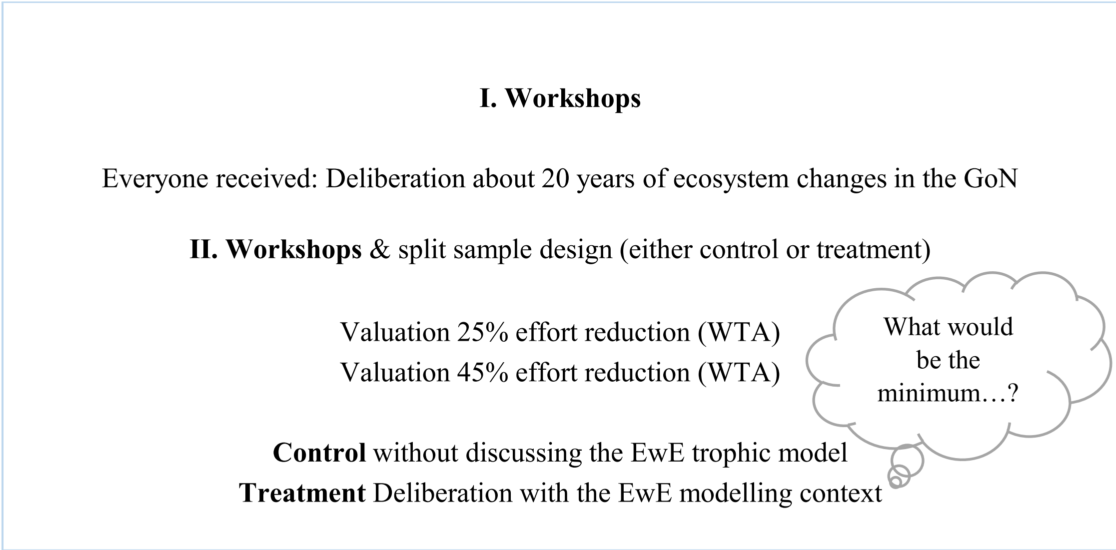


Figure 4.3. Contingent market overview and experimental design. The control groups did not involve detailed information on fishing gear or ecosystem interactions. The treatment groups provided evidence for stock recovery of large predatory species under scenarios of fishing effort reduction.

To mitigate hypothetical bias (latent difference between the real and hypothetical payments), the valuation exercise included caveats about the institute of social aid (IMAS) budget constraints (Arrow et al., 1993), which is the Costa Rican institution in charge to grant such subsidies. Also claims were designed in proportion to the actual amount of the subsidy. The bid values presented were based on the results of the pilot workshop to avoid influencing the responses with the amounts presented on the card (anchor and range effects) (Veisten et al., 2004).

The use of a payment card facilitated the task of assigning a monetary value (Veisten et al., 2004). In turn the values in the cards were offered randomly (Cameron and Huppert, 1989) and within an interactive “cheque” dynamic, to alleviate the strategic bias, the cognitive burden of the respondent, as well as to reduce the no responses (Ressurreição et al., 2011). To address the social desirability bias, in which participants may respond accordingly to what they perceive as expected, the contingent valuation in this study incorporated an experimental setting in workshops (Arrow et al., 1993).

4.2.2.3. Experimental setting in workshops

The participants were presented with two fishing (gillnet) effort reduction scenarios 25% and 45% reduction over two workshops (**Figure 4.3**). These were done one week apart and lasted for four hours each, to assess the WTA to support a hypothetical program on sustainable fisheries that would rebuild populations of large croakers, corvina, snook, catfish, mackerel and barracuda, being these groups high trophic level species and indicators of health and sustainability of the ecosystem under study. Group deliberations on the reasons to support (or lack of support) effort reductions (WTA) were recorded and notes were taken of relevant aspects of the discussions.

Within workshops 1 (Sánchez-Jiménez et al., 2019), all participants received and deliberated on the same introductory information about the status and changes over 20 years in the catches of shrimp, large corvina and large predatory species, extracted from Alms and Wolff (2019). Within workshops 2 people deliberated on the scenario 25% effort reduction and some of them also on the scenario 45% effort reduction, depending on their random assignment to either the control or the treatment group.

In the *control group,* the participants were invited to deliberate on a hypothetical management option in which a 25% reduction in fishing effort would occur, but without discussing the scenario simulation results of the EwE trophic model of the GoN (**Figure S4.2** in Annex IV). In the *treatment group lecture,* the facilitator presented two scenario simulation results of the EwE trophic model that included a 25% and 45% reduction in fishing effort, together with a description and explanation of the EwE food web model of the GoN (Alms and Wolff, 2019) (**Figures S4.3, S4.4** in Annex IV). Participants were encouraged to deliberate on each scenario provided. This design allowed for comparison and to account for the social desirability bias and the observer effect in the responses of the respondents (Arrow et al., 1993; Fujitani et al., 2017).

4.2.2.4. Phase 3 Post-survey

A follow up survey was administrated after the end of the second workshop based on the pre-survey. It also included some debriefing questions, including reasons to accept fishing effort reduction (**Text S3.2** in Annex III).

4.2.3. Data Analysis

Data were analyzed using R studio version 3.5.3. Via an independent group t-Test, we compared WTA across scenarios, WTA between control and treatment groups and the changes in psychometric indicators between samples from pre and post surveys, within control and treatment groups (Fujitani et al., 2017). A logistic regression was run for each WTA level, to model the choice to accept each individual compensation check in the envelope. Motivations (psychometrics), socio-economic, and fishing characteristics were used as independent variables, while the WTA as a dependent variable.

The WTA results were subsequently examined in light of the qualitative information of the deliberation. To assess the values attributed by local fishers to the marine ecosystem of the GoN, group deliberations on the reasons by which fishers support or reject fishing effort reductions (WTA) were recorded, transcribed the text and subsequently coded into three value domains (i.e., instrumental, intrinsic and relational) according to the IPBES environmental values classification (IPBES, 2019a) and following the articulated values used by (Arias-Arévalo et al., 2018) and (Klain et al., 2017). From the coding, relevant statements that highlighted the themes and value domains were extracted.

4.3. RESULTS

4.3.1. Characteristics of Participants

Most of the respondents were males (82.8%). The average age of respondents was 41 (from 18-70 years old), 47.4% of respondents held over 20 years of fishing experience, 51.7% completed elementary school but just 12.1% completed high school. A majority of the respondents reported owning a boat (69%) and having a monthly income from fishing in the range of 200000CRC to 300000 CRC (**Table S2.1** in Annex II). Fisher's baseline motivations about sustainability tended to be biospheric/altruistic, while perceived behavioral control accounted for the lowest scores (**Figure 4.4**). Internal consistency in respondents' answers, a confirmatory factor analysis, along with the differences between control and treatment in the fisher's motivations can be found in (Sánchez-Jiménez et al. 2021).

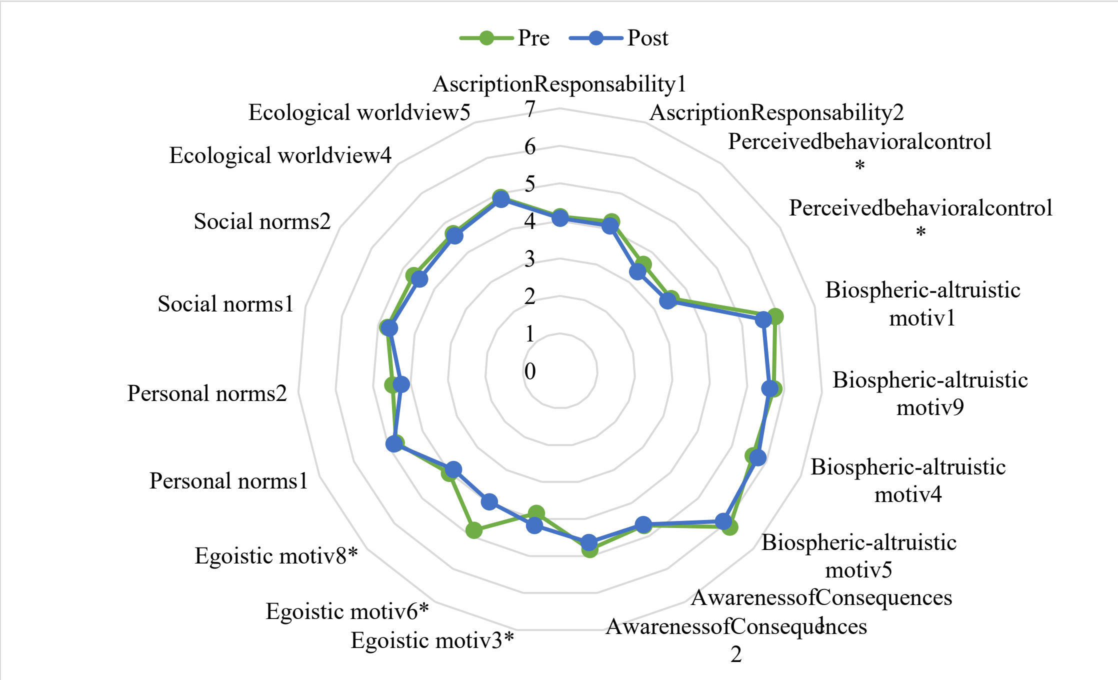


Figure 4.4. Baseline motivations (n=58) about sustainability for the pre and post survey samples. Tendencies toward biospheric and altruistic motivations, while perceived behavioral control accounted for the lowest scores. *Significant differences from pre to post survey.

4.3.2. Willingness to Accept for Fishing Effort Reductions

4.3.2.1. WTA scenarios comparisons

Mean WTA was significantly higher ($p<0.001$) for the scenario with 45% effort reduction compared to the scenario 25% effort reduction, which is in line with a priori expectations as scenario 45% effort reduction implies the greatest decrease in fishing time (**Figure 4.5.A**). The treatment (groups receiving a lecture with EwE modeling resulted in a significant higher WTA for the reduction of 25% fishing effort at the $p < 0.1$ level in comparison with the control group (**Figure 4.5.B**).

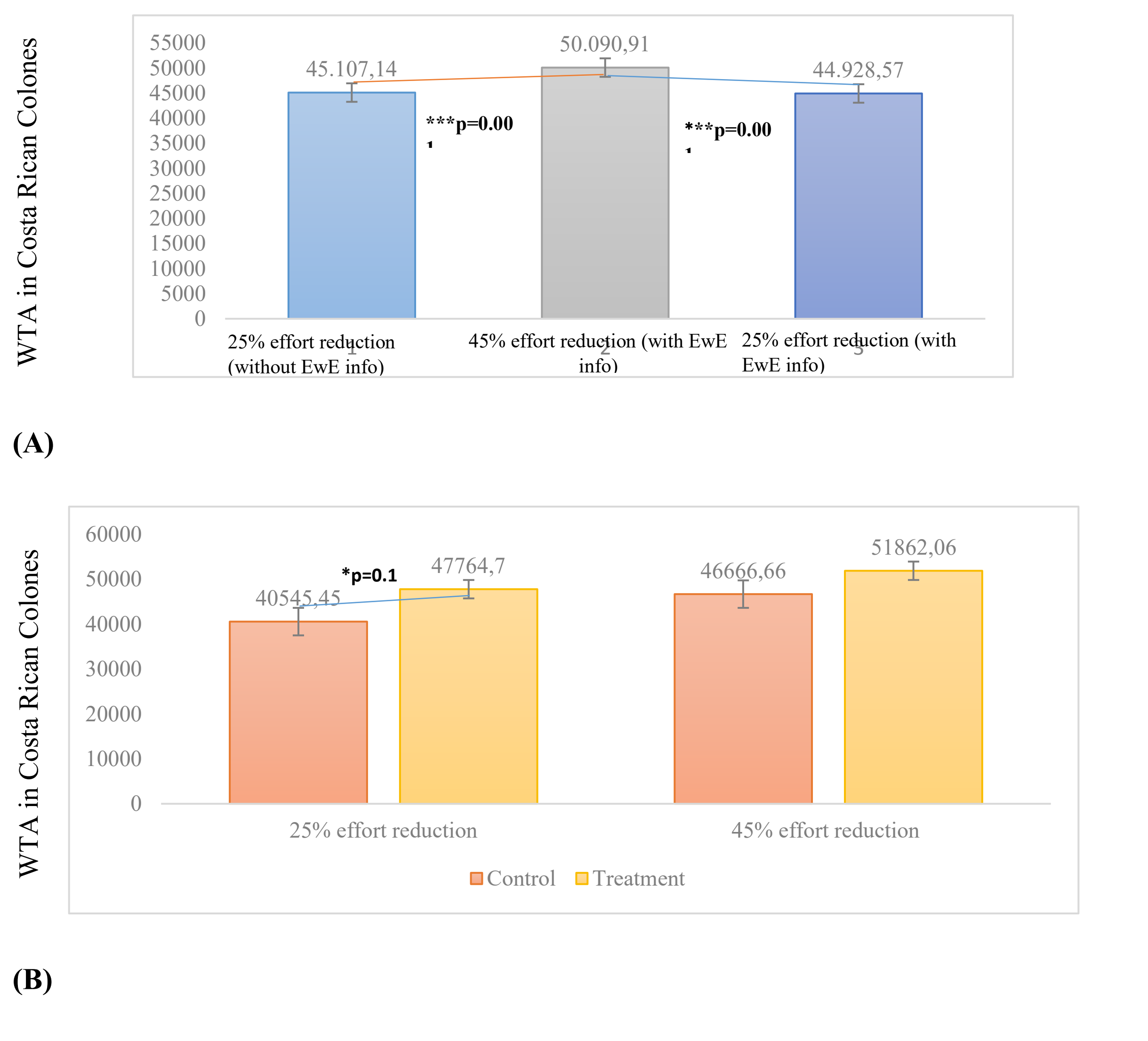


Figure 4.5. Comparison between WTA means. **(A)** WTA comparison between scenario 45% effort reduction and scenario 25% effort reduction. **(B)** WTA comparison between control group (lecture not using EwE modeling) versus treatment group (lecture using EwE modeling) in the post-survey (after workshops). Asterisks=significant differences

4.3.2.2. Motivations and Factors Underlying Fisher´s Willingness to Reduce Fishing Effort

Regression analysis showed the influence of psychometric constructs from theories of environmentally significant behavior (for details see Sánchez-Jiménez et al., (2021b) and the local fishing context (technology used, fishing sites and economic situation) on fisher´s WTA to reduce fishing effort (**Table 4.1**). The estimated correlation between the error terms (Adjusted R^2) for all three models fall within the ranges usually reported in regression models (0.36-0.83). The hypothesis that personal norms (PN) would influence significantly the WTA was confirmed for both the 25% and the 45% effort reduction. Pro-environmental PNs were associated with lower subsidy amounts.

Biospheric-altruistic motivations and fisheries profits were significant coefficients for scenario 25% (lectures with EwE information and without it). In general terms, lower altruism/biospheric values were related with higher amounts of subsidy while higher fishing profits with lower subsidy amounts. Other factors were identified: egoistic motivations (negative relationship), ascription of responsibility, and awareness of consequences, also ecological worldviews and fishing in the outer gulf. A selection of high subsidies in the 45% effort reduction scenario, displayed a relationship with the intervention that involved EwE modeling. The significant (positive or negative) coefficients under scenarios 25% and 45 effort reduction are summarized in **Table 4.1.**

Table 4.1. Results of regression analysis on the explanatory power of motivations and the local fishing context on fisher´s WTA to reduce fishing effort, pre and post surveys samples.

	Lower subsidy amounts												Higher subsidy amounts											
	WTALevel1 ₡26000						**WTALevel2 ₡36000**						**WTALevel3 ₡46000**						**WTALevel4 ₡56000**					
Environmental Motivations	Pre			Post			Pre			Post			Pre			Post			Pre			Post		
Ecological Worldviews -NEP	2.10*	ns	ns	ns	ns	ns	ns	Ns	1.52*	2.77*	ns	ns	ns	ns	ns	-2.03*	ns	ns	ns	ns	-1.11*	ns	ns	ns
Social Norms	ns	ns	ns	ns	ns	ns	ns	Ns	ns	ns	ns	ns	ns	ns	ns	ns	4.49*	ns	ns	ns	ns	ns	ns	ns
Ascription of Responsibility	1.97*	ns	ns	ns	ns	ns	ns	Ns	ns	ns	1.46*	ns	ns	ns	ns	-1.99*	-4.94*	ns	ns	ns	ns	ns	ns	ns
Personal Norms	ns	3.07*	ns	ns	ns	ns	1.58*	Ns	2.41*	ns	1.80*	ns	ns	ns	ns	ns	ns	ns	-1.33*	ns	ns	ns	ns	ns
Awareness of Consequences	ns	ns	ns	ns	ns	ns	ns	Ns	ns	ns	ns	ns	ns	ns	ns	ns	-3.81*	ns	-1.20*	-1.20*	ns	ns	ns	ns
Perceived Behavioral Control	ns	ns	ns	ns	ns	ns	1.62*	Ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Egoistic Motivations	ns	ns	ns	-1.54*	ns	ns	ns	Ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.55*	ns	ns	0.87*
Biospheric/Altruistic motiv	ns	ns	ns	ns	ns	ns	ns	Ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-1.05*	ns	ns	-1.05*	ns	ns
Fishing profits	ns	ns	ns	ns	ns	ns	ns	Ns	ns	0.01*	ns	ns	ns	ns	ns	ns	ns	ns	ns	-0.01*	ns	ns	-0.01*	ns
Fishing-site (Outer Gulf, PT)	ns	ns	ns	ns	ns	ns	ns	Ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	5.72*	ns	4.46*	5.62*	
Own fishing vessel (yes)	ns	ns	ns	ns	ns	ns	ns	Ns	ns	ns	ns	ns	-3.49*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
EwE intervention	ns	ns	ns	ns	ns	ns	ns	Ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	2.90*
R^2 (Nagelkerke R^2)	0.60	0.64	0.46	0.83	0.79	0.71	0.52	0.48	0.52	0.54	0.54	0.71	0.53	0.32	0.50	0.36	0.63	0.32	0.39	0.60	0.39	0.46	0.65	0.47
Adj. R^2 (Cox & Snell R^2)	0.38	0.39	0.19	0.54	0.50	0.43	0.33	0.31	0.33	0.36	0.36	0.43	0.31	0.17	0.21	0.20	0.35	0.17	0.25	0.40	0.27	0.30	0.44	0.32

*=p<0.1, **=p<0.05, ns (no significant), PT= Paquera-Tambor, WTA=Willingness to Accept. Relationships: positive (*green asterisk) and negative (*red asterisk) relationships □= 25% lecture without EwE info □=25% lecture with EwE info □45% lecture with EwE info

4.3.3. Overall Classification of Plural Values and Motivations

Within the qualitative data generated from the workshops, motivations (biospheric/altruistic, personal norms) stood out, as well as the attribution of plural values to the GoN ecosystem (i.e., intrinsic, relational and instrumental) (**Table 4.2**). Most deliberative statements were in the domain of relational value. We classified "livelihood" as instrumental and relational statements, since it implies an ecosystem service but is not strictly self-oriented, it includes concern for the family well-being.

Table 4.2. Deliberation statements about the reasons on why to accept or reject the economic subsidy during the closed season. Classified according the IPBES themes and value domains (IPBES, 2019a).

Value domain	Articulated theme	Deliberation Statements (reasons on why to accept/reject) subsidy
Intrinsic (In)	Moral duties to organisms	"It's important to protect species for the health of the ecosystem" "Immediate measures are needed right now to protect species" "We are all somehow responsible"
Relational (Re)	Kinship and care	-"What is important is the life of the species" -"The Gulf cries out for our help" "A few years ago a dolphin used to visit us to play and we enjoyed their presence"
	Identity	"There were sharks, hawksbill and green turtles, but today we hardly see them"…these are the changes in our Gulf"
	Altruism	"The problem is not considering the future generations" "We must empower women" "More education is needed"
	Ecological Resilience	-"We must reflect, if we continue as we are now, in 15 years there will be nothing" -"Shrimp reproduce a lot after the closed season" -"But why act, if there will never be a change" -"You must bear in mind that the Gulf is everyone's farm"
	Social influence	-"I would engage, but people do not respect "the veda", even warn each other when the patrol is on the way"
Instrumental (Ins)	Monetary benefits	"The mackerel would recover, yes, but people do not buy it "
Ins/Re	Livelihood	"I think about the economy of my home first"
Ins/Re	Livelihood	-"I am both a mother and father, so I need the money to sustain my family"

Some of the articulated themes an value domains used by (Klain et al., 2017) and (Arias-Arévalo et al., 2018).

4.4. DISCUSSION

Fishers' decisions went beyond merely rational concerns about the flow of goods and services of traditional bio-economic approaches. Instead, notions of justice, care, sense of identity, altruism, and relationships within community or family members, along with ecological information and the local fishing context (fishing sites, profits) mediated their choices. Most statements expressed in the deliberation process belong to the domain of relational values.

4.4.1. *Motivations to Reduce Fishing Effort: Entering a Plural and Relational Domain*

Within social psychology theories (Klöckner, 2013), it is indicated how egoistic, altruistic and biospheric motivations influence environmentally significant behavior (Stern, 2000; Stern et al., 1999). Altruistic motivations transcend personal concern to other human beings, and biospheric motivations extend these concerns to non-human species and the environment (de Groot and Steg, 2008; Steg et al., 2005). Here the basic motivations for reducing fishing effort in the survey tended to be biospheric (**Figure 4.4**), and this trend may be influenced by the close relationship that small-scale fishers maintain with the natural environment for their livelihoods. A similar trend was shown towards altruistic motivations, these being concerns for non-human species and the environment (de Groot and Steg, 2008; Steg et al., 2005). Inversely, lower biospheric-altruistic motivations were generally associated with higher subsidy claims (WTA).

In the deliberation, altruistic statements (**Table 4.1**), especially regarding concerns for the future of youth and the education of women, were mentioned as important reasons to support the proposed management measures. In the post survey higher scores of *ascription of responsibility* were related to lower amounts of subsidy (WTA) and in light of theories of environmentally significant behavior (Stern et al., 1999) a greater *awareness* of environmental *consequences* leads to a greater sense of responsibility to act in favor of the environment. Responsibility towards other living organisms (human and non-human), once recognized, is translated into personal norms, and defined as a perception of what should be done in a given context and this is what directly precedes environmental decision-making.

Personal norms showed significance at explaining the WTA for all the scenarios, higher PNs in relation to the environment displayed associations with lower subsidy claims (**Table 4.1**). This was expected, since personal norms are directly related with pro-environmental behaviors (Klöckner, 2013). While peer pressure and social norms are important predictors of pro-environmental behaviors (Kinzig et al., 2013), social norms showed a significant positive coefficient for higher subsidy amounts (**Table 4.2**). A possible explanation for what led some people to increase their subsidy claims (WTA) can be found in the relational value statements articulated during deliberation, which indicated that their ability to act pro-environmentally is affected due to the perception of that others care little about the health of the ecosystem.

With regard to ecological worldviews (*new ecological paradigm*, NEP) (Dunlap, 2008), the post survey shows that after the interventions (including ecological modeling), people were better able to recognize ecological limitations for human growth and the importance of maintaining the balance with nature. Lower awareness of the ecological impacts (NEP) of fishing coincides with higher amounts of subsidy (**Table 4.1**). in contrast, there is a generalized notion in the GoN that nature exists mainly for human use, so in addition to a relationship with ecological worldviews, the influence of egoistic motivations on choices can be explaining to some extend this response, as egoistic motivations prioritize concerns for one's own life (Steg et al., 2005). In the 45% reduction scenario, the selection of higher subsidy amounts are related with an underlying concern for own resources and those of the family.

Overall, the effect of social influence and relationships within the community and family members is reflected in the fishers' values assigned to the ecosystem. While a genuine interest for others and the care of the natural environment was expressed through marked biospheric-altruistic motivations, the lack of social cohesion and the perception that others care less about the environment, showed to negatively affect the willingness to reduce fishing effort. In the case of livelihoods, which we have classified as a theme in the instrumental and relational domains (**Table 4.2**), concern for the well-being of the family is also implicit. Hence, some enhancing social influences can be considered to encourage pro-environmental behaviors (Klain et al., 2017).

Finally, people tend to act in favor of the environment if they perceive themselves capable of doing so effectively, and despite the fact that deliberation using information from the EwE model has been shown to influence the perceived behavioral control (PBC) of the participants (Sánchez-Jiménez et al., 2021b), in the current contingent valuation exercise, the PBC accounted for the lowest scores throughout the overall process (Figure 4.5) and was not reflected in the WTA options. These results reveal the influence that other fishing and socioeconomic factors may have on the behavior of fishers, including the latent economic limitations of the participants. Low income from fishing and the great dependence on fishing as the single means of earning a living stand out. These further factors are discussed below.

4.4.2. Achieving SDGs No-poverty and Gender equality can help to Achieve SDG14

The combination of fishing with other economic activities such as tourism among the participants of Paquera-Tambor (Chavez Carrillo et al., 2019), may be explaining the higher average WTA compared to other communities, either due to a lower interest to support the proposed fisheries measures or for greater freedom to express their refusal to policies that do not seem economically beneficial to them. At present, there are few alternative livelihoods to fishing in the GoN, such as agriculture, livestock and small tourism businesses. The subsidy incentive is designed to offer approximately 40% of the minimum wage in that occupation category (fishing) during the 3-4 months no-fishing period. The measure encourages people to save money upfront and does require community work during the closed season.

The deliberation process showed that meeting the basic economic needs for sustenance during the closed season is a matter of concern. Here we articulate the main apprehensions mentioned: (1) accessing the subsidy implies receiving significantly less than usual income (at least 60% less); (2) by accepting it is not possible to get involved in other productive activities; (3) large families imply higher expenses (a mean of 3.3 members); (4) small-scale fishers may have a limited ability to save money due to the fact that much of their income is unstable generated on a day-to-day basis and depending on environmental conditions that lead to a cessation of fishing for some periods of the year. Moreover there is no enough knowledge about financial aspects.

As anticipated, the lower the economic benefits from fishing, the higher the WTA chosen for the 25% effort reduction scenario (**Table 4.1**). In the case of the 45% reduction scenario, the discussion on ecological modeling (treatment) deepened the conversation not only about the ecosystem interactions but also around minimizing economic losses and what seemed to be a fair price to accept, considering the poverty experienced by many fishers. A salient, in turn a disquieting quote, was: "three months of closure is a torment for many." Even in cases where the benefit to the ecosystem was clear and palpable, the term sacrifice was used repeatedly to describe the trade-offs: "I accepted the subsidy despite the great sacrifice, because we need to recover the Gulf".

Poverty and inequality threaten human well-being (Ravera et al., 2016) and ecological functioning. Several families in the GoN live in poverty and even below the poverty line (Pacheco-Urpí, 2013). During the closed season, the situation worsens for many fishers, some of them must buy on informal credit in local stores and sometimes even need to decide between paying for basic bills or food. Hence, despite understanding the importance of recovering species, non-compliance during the closed season is not unusual (A.S-J., personal observation). A seasonal fishing closure immersed in a subsidy scheme that ignores the contributions of SSF to poverty eradication (Fernández-Carvajal, 2013) and food security (Beltrán-Turriago, 2014) is a vicious circle that must be addressed.

Thousands of fishers work as helpers without fishing license, thus their activity does not appear in the INCOPESCA lists and the access to the subsidy will depend on the licensed fishers who hire them, this is the reality for several women (Fernández-Carvajal, 2013). For the current research we relied on community leaders for recruitment of interviewees/workshop participants, who in turn relied on the fishers' records of INCOPESCA. The result was that 82.8% of the respondents were males, and although it is true that traditionally men are engaged in fishing, we corroborated in the field what Fernández-Carvajal (2013) states, that many women carry out fishing and fish cleaning functions but are only recognized as assistants, so their work becomes "invisible". The same applies for care aimed at the children and elderly people that tend to fall on unpaid work of women and girls.

Interestingly, despite the vulnerable condition experienced by many, in recent years it has been precisely marginalized collectives, especially that of women, who have launched relevant aquaculture and rural tourism projects as alternatives to fishing (e.g., Costa de Pájaros and Isla de Chira), in partnership with universities and NGOs. The GoN needs fishing incentives to strengthen policies for gender equality, education, capacity building and empowerment of creditworthy people. Also, an economy of care that makes visible the role of care, the economic value of it and generate market demand for these services (López Montaño et al., 2015). The role of women and other marginalized groups as active SSF agents to transform, adapt to change and diversify the economy, from the margins (Ravera et al., 2016) deserves further attention and research. Achieving SDGs 1 ("no-poverty") and 5 ("gender equality") in light of SDG 14 ("life below water") can create cascading benefits that help achieve other SDGs.

4.4.3. Research Approaches are needed to foster Collaboratively Designed Policies

Despite there is extensive scientific information developed in the GoN in past decades (Vargas-Zamora et al., 2019; Vargas, 1995) it is also necessary to address environmental problems from an explicit social-ecological system approach in a way that bring science closer to society through research that links cross-sectoral collaboration (Smith and Basurto, 2019; UNESCO, 2019). In this paper, the role of science as a catalyst for these processes is explored, both through the development of new information and through the design of applied and transdisciplinary research that facilitate the co-production of new knowledge.

Diverse studies have shown the importance of deliberation in terms of allowing participants with time to reflect on the information provided, to share their knowledge and perceptions regarding the values at stake, and to understand how this can lead to a more informed decision-making process (Álvarez-Farizo et al., 2009; Bunse et al., 2015; Kenter, 2020; Kenter et al., 2011; Lienhoop and MacMillan, 2007a; Lo and Spash, 2013; Macmillan et al., 2002; Philip and MacMillan, 2005; Spash, 2008). The deliberative research approach applied here provided different points of view on how to improve the health of the GoN ecosystem and sustain fishing activity over time. Since perceptions of the value of ecosystems can overlap or may raise conflict between different social actors and institutions (Skubel et al., 2019), we suggest that collaboration and trust-building are essential pieces for an inclusive governance.

In the near future, it is necessary to expand the circles of deliberation, valuation and trust-building to more institutions of civil society, government and the private sector (Bennett et al., 2019). In line with the ideas of creating an AMPR network (Ulate-Garita, 2020), acting from the local to the cantonal and regional with a global perspective (biosphere boundaries) (Folke et al., 2016; Steffen et al., 2015). The circles would include marginalized groups, NGOs, scientists, media, industry, and small businesses, among others. Collaborative research in the GoN may aspire to design applied and transdisciplinary research, identify actors' networks and prioritize the inclusion of marginalized groups (especially of women), in order to strengthen social resilience and restructure the stakeholders' institutions, of so that the policy design is representative of the multiplicity of values.

4.4.4. Ecological and Socioeconomic Feasibility of Effort-reduction Policies

As expected, the highest mean WTA corresponded to the scenario with the greatest reduction in fishing hours (minus 45%). The significant difference between the mean WTA of the 25% and 45% scenarios (**Figure 4.5**), may be outlining real life preferences and actual feasibility for the 25% effort reduction, an alternative that in turn has the potential to achieve substantial biomass rebuilding of high trophic level functional groups, including large corvina, mackerel and barracuda. Managers can further explore at a scale the preferences of different stakeholders for this measure and consider it as a plausible way to allocate resources in the GoN. However, such a reduction would require addressing key compliance issues and incorporating appropriate fishing incentives that recognize local voices.

Ecosystem-based fisheries management (EBFM) has advanced in the last decade and begins to include the fishers' choices and fishing practices (Bacalso et al., 2013). EBFM is comprehensively addressing socio-ecological and economic factors (e.g. (Fulton et al., 2014; Rehren et al., 2018), also equity considerations (Voss et al., 2014) even universal values and behavioral change interventions (Sánchez-Jiménez et al., 2021b). Nevertheless as (Lam et al., 2019) indicate, an ecosystem-based management framework that includes values and ethics becomes necessary. The current study builds on these advances and represents a novel contribution in tropical SSF towards a framework that integrates ecosystem-based management and multiple values social actors assign to the ecosystem.

We argue that a plural values and ecosystem approach to examining policy feasibility represents a leverage point for sustainability (Abson et al., 2017) in SSF as it takes fisheries management one step further by recognizing the importance of ecosystems in terms of the relationships, services and intrinsic characteristics that people attribute to nature. Therefore, the ocean can not only support fisheries and human societies, but people have the capacity and responsibility to care for and maintain healthy ecosystems in return (Kimmerer, 2013), a potentially transformative notion of reciprocity for the design of conventional policies.. Sustainable behaviors can be enhanced e.g., via relational values by connecting people with what they already care about and identify with (e.g., family, communities) (Chan et al., 2016), encouraging universal values (Raymond and Kenter, 2016; Sánchez-Jiménez et al., 2021b) or embodying qualities such as compassion or kindness (Hochschild, 2016).

4.4.5. Enabling transitions to achieve SDG-14 in tropical Small-scale Fisheries

After better understanding the fishers' motivations to support the reduction of fishing effort, it is suggested to reconsider the current subsidy scheme, towards a more efficient allocation of resources and thus improve compliance with this policy intervention. The financial subsidy is essential to meet the basic needs of fishers in need during closure, however the current system is not serving its purpose as it still overlooks the essential contributions of SSF and the fishing female sector to poverty eradication (Frangoudes et al., 2019). It will be helpful to identify strategic alliances between the community, the public and private sectors to resume the licensing process along with a fair increase in the economic subsidy.

Complementary long term incentives can be incorporated to the subsidy closure in the GoN and in the tropical SSF to reinforce the intrinsic motivations of fishers and local ownership, in the direction of a fair and blue economy (Bennett et al., 2019) including: (1) adequate monitoring of the number of boats/gear used (to manage fishing effort); (2) strengthen policies for gender equality; (3) support capacity development and quality education; (4) simplification of the procedures to be subject to bank credit; (5) productive alternatives and care economy; (6) traceability and certifications of fishery products; (7) nature-based solutions for adaptation to climate change, (8) an equitable distribution of benefits, and (9) inclusive and ecosystem-based decision-making processes.

Based on this case study in the tropical Pacific, the GoN, we argue that science should embark on new models of collaborative research to design SSF policies, founded on healthy ecosystems and social equity that incorporate the needs and plurality of values among the different agents of the fishing system, especially the marginalized groups. An adequate inclusion of the voices of the female fisheries sector as active agents of change represents an opportunity for equity, diversification of the local economy and sustainable development that deserves further research and support. This way of designing fishery policies can support the health of the ecosystem and in turn contribute to examine the best trade-offs for the (gillnet) fishing sector (Sánchez-Jiménez et al., 2019) which, consequently, can enable transitions in tropical SSF to align societal institutions' behaviors with the SDG 14.

ACKNOWLEDGEMENTS
Our gratitude to the fishing communities of the Gulf of Nicoya for sharing so much wisdom with us. Without funding from Leibniz Center for Tropical Marine Research (ZMT), Germany, through the project 3601, Leibniz Chair of Environment, this study would not have been possible, so we thank ZMT for this and their logistic support.

CHAPTER 5. General Discussion: Leverage Points for Sustainability Transformation

We can't meaningfully proceed with healing, with restoration, without "re-story-ation."
— Robin Wall Kimmerer

Photo above: participants from the female fishing sector deliberating on changes in the Gulf of Nicoya ecosystem. Bottom photo taken within an ecotourism project run by a group of fisher women in the gulf.

CHAPTER 5

Interplay between Leverage Points for Sustainability Transformation: Evidence from a Tropical Small-Scale Fishing System

Astrid Sánchez-Jiménez, Marie Fujitani, Douglas MacMillan & Matthias Wolff

This is the thesis's version of the work. Please cite the final version as:

Sánchez-Jiménez A., Fujitani M., MacMillan D. and Wolff M. (2021). (Manuscript submitted). Interplay between Leverage Points for Transforming Sustainability: Evidence from a Tropical Small-Scale Fishing System

Submitted on November 2021 to *People & Nature.* The Manuscript was under review at the moment of presenting the dissertation.

ABSTRACT

Small-scale fisheries (SSF) contribute significantly as a source of nutrition, income and employment in tropical coastal areas. However, given the scale and magnitude with which SSF catches continue to decline, rather than incremental steps, it is vital to choose management interventions that foster a transformative change at the systems level. This synthesis aimed to identify and classify the range of interventions to address overfishing and ecosystem degradation in a tropical small-scale fishing system. Three different studies recently developed by the authors in the Gulf of Nicoya (GoN, Pacific coast of Costa Rica) were analyzed to shed light on deep leverage points towards sustainability. To classify interventions, based on systems theory we applied a perspective of leverage points focused on places to intervene in complex systems and create systemic change. We found that although more powerful interventions exist for igniting transformation, conventional fisheries management overlooks them (e.g., ecosystem-based management interventions that preserve biodiversity, intrinsically motivated women participating in sustainability processes, and other voices that remain underrepresented in decision-making). The management of the SSF in the GoN is carried out primarily from a single-species approach, and although this has its place, altering the course of the fishing system requires a socio-ecological system approach focused on under-researched areas underlying overfishing. Included are: (a) the behavioral (and economic) causes of compliance; (b) values and mindsets that shape emerging goals and institutions; (c) as well as two-way learning processes to promote environmental stewardship and awareness of the ecological impacts of fishing.

Keywords: leverage points for sustainability, ecosystem-based approach, value plurality, tropical small-scale Fisheries (SSF), sustainable developmental goals (SDGs)

5.1 INTRODUCTION

Small-scale Fisheries provide almost half of global fish landings (FAO, 2015) and are an essential source of nutrition, income and employment for many people in coastal and rural communities (Crona et al., 2020) with particular importance in tropical areas. The SSF typify the interdependence between people and nature, characteristic of complex social-ecological systems (Basurto et al., 2013; Leslie et al., 2009, 2015; Ostrom, 2009). This system is driven by the behavior of the stakeholders, greatly depending on external pressures such as climate change and market demands (Salas et al., 2007) but also on the state of the exploited resources. Multiple influences together can lead to sustainable fisheries or inversely to overfishing depending on the management direction taken. Numerous management interventions currently applied in SSF have limited the potential for a transformational change (Chuenpagdee and Jentoft, 2018) since they have focused on incentives that contribute to overcapacity leading to overfishing (Grafton et al., 2006; Lubchenco et al., 2016), and in practice only occasionally, fisheries management is approached as a systemic social-ecological issue (Fujitani et al., 2018).

Interventions in traditional fisheries management such as the control of catch volumes and the minimum mesh sizes, are useful to manage specific target stocks, but they lack a holistic approach that also takes into account the human-nature relations and the health and changes in the structure of the ecosystem (Link, 2002). With the adoption of Sustainable Development Goal 14 (SDG 14, "life underwater") of the 2030 Agenda for Sustainable Development (United Nations, 2015), the member countries of the United Nations agreed on the priorities to generate science-based policies, support small-scale fishers, end subsidies that contribute to overfishing, and protect and restore marine-coastal ecosystems. This is complemented by the approval of the voluntary guidelines to improve fisheries sustainability (FAO, 2015) in which the FAO member States encourage the necessary changes to warrant the viability of SSF as a means of food security and poverty eradication.

Considering the large contributions of SSF to tropical coastal areas and the scale and magnitude of catch declines, loss of biodiversity, damage and loss of ecosystems, it is of utmost importance to choose governance transformations and management tools that foster social, environmental, and economic sustainability (Chuenpagdee and Jentoft, 2018). For transforming social-ecological systems towards sustainability, understanding where and how to intervene is indispensable (Abson et al., 2017; Meadows, 1999).

Within systems theory, leverage points are places in a complex system, such as fisheries, where a small change in one thing can produce changes in everything (Meadows, 1999). Twelve leverage points have been identified as influencing the behavior of a system, ranging from shallow to deep (Meadows, 1999). These places have been subsequently grouped into four characteristics of the system, shallow: 1) *parameters* (mechanistic, materials) and 2) *feedbacks* (processes); deep: 3) *design* (information flows, system norms, self-organizing system structure) and 4) *intent* (underlying values and mindsets that shape the system goals) (Abson et al., 2017).

There is a need to focus on deeper and possibly more effective points of intervention (Riechers et al., 2021a) while acknowledging the interactions and synergies between leverage points (Chan et al., 2020) (Fischer and Riechers, 2019). In this review and synthesis, the Gulf of Nicoya (GoN) on the Pacific coast of Costa Rica has been used as a case study to illustrate a tropical small-scale fishing system, in which a leverage points perspective is applied as a framework and as an analysis tool (Abson et al., 2017; Fischer and Riechers, 2019; Meadows, 1999). The overall goal is to identify current sustainability interventions and interactions between shallow and deep leverage points to provide a basis for prioritizing research and management efforts for transforming tropical SSF towards sustainability. One hypothesis is that fisheries management interventions in the SSF of the GoN have as yet mainly focused on shallow leverage points (parameters and feedbacks) that are relatively easy to implement but produce little change in the overall functioning of the system (Meadows, 1999).

If achieving the Sustainable Developmental Goals (SDGs) is desired, interventions in the GoN need to follow a social-ecological system approach with transformative responses at the design and intention level of that system and that transcend conventional fisheries management. To address this hypothesis, three different studies recently developed by the authors (Sánchez-Jiménez et al., 2019; Sánchez-Jiménez et al., 2021b and Sánchez-Jiménez et al., 2021a), are analyzed to shed light on deep leverage points and potentially more powerful but under-researched areas of intervention.

From there we (1) extract information regarding current interventions for the sustainable management of SSF in the GoN; (2) characterize interventions according to the leverage points perspective, which identifies the interaction between deep and shallow interventions; and finally (3) identify specific deep leverage points with the potential to transform the sustainability of the SSF.

5.2. MATERIALS AND METHODS

5.2.1. Small-Scale Fisheries in the Gulf of Nicoya

The GoN SSF is a large tropical estuary located in the Pacific coast of Costa Rica that embodies the characteristics of a social-ecological system (Glaeser et al., 2009; Glaser et al., 2012). Environmental conditions in the GoN favor the development of wide biodiversity of fish and benthic invertebrates (Vargas, 1995; Wolff et al., 1998). Mangrove ecosystems also play an important role as a habitat for the reproduction and larval development of many marine species (Vargas, 2016), in addition to contributing to primary productivity by providing organic matter (Stern-Pirlot and Wolff, 2006; Wolff, 2006). Shrimps reproduction and development take place in mangroves and this group is a key food for a variety of species as well as being of direct economic importance (Alms and Wolff, 2019; Wolff et al., 1998). In addition to fish, other species are also present, including seabirds, cetaceans and critically endangered sea turtles (e.g., the hawksbill turtle) (CREMA, 2014).

Coastal and marine ecosystems in the GoN allow the development of an extended fishing activity. The SSF, along with being traditionally vital to the region's culture (Fernández-Carvajal, 2013) is fundamental for food security (Beltrán-Turriago, 2014; FAO, 2003) and the livelihood of thousands of small-scale fishers. SSF in the GoN are multi-gear and multispecies (Herrera-Ulloa et al., 2011), including gillnets, lines (bottom longlines and drifting longlines), handlines and manual gear (traps and mollusk extraction) (BIOMARCC et al., 2013). The whiteleg shrimp (*Litopenaeus vannamei*) and the corvina reina (*Cynoscion albus*) are key resources for the local economy, and gillnet is the most commonly used gear for both corvina and shrimp. The reduction in catches at the highest trophic level across the 1993-2013 period (Alms and Wolff, 2020), is a sign of the unsustainable path the fishery has taken (Pauly et al., 1998).

The GoN ecosystem and the economy have been affected by a drastic catch reduction of shrimp over the last decades, as different life stages of shrimp are key foods for a variety of species, including groups of commercial importance (Alms and Wolff, 2019; Wolff et al., 1998). Some of the management interventions applied in the GoN are: (1) restriction of the fishing effort through the allocation of licenses; (2) the control of the mesh size of the fishing gear; (3) a seasonal closure together with an economic subsidy (BIOMARCC-SINAC-GIZ, 2013); and (4) the delimitation of Marine Areas for Responsible Fishing (AMPR) (Lozano and Heinen, 2016a) through the initiative of the fishing communities. Single-species management such as mesh size control does not necessarily address ecological impact in tropical SSFs with multiple gears and numerous species (Herrón et al., 2020). Alternative strategies to standard fisheries management are needed to move towards a holistic social-ecological systems management and to a sustainability transformation in the SSF of the GoN.

5.2.2. Leverage Points for Sustainability Transformation

Leverage points are places within a complex system where a small shift can influence the behavior of the entire system (Meadows, 1999). Sustainability interventions can be classified by the system characteristics they target into four categories leverage for systemic change (Abson et al., 2017): changes in (1) intent (deep leverage); (2) design (relatively deep leverage); (3) feedbacks (relatively shallow leverage) and (4) parameters (shallow leverage) (**Table 5.1**). Within shallower leverage, *parameters* correspond to the measurable system features (e.g., subsidies and taxes) while *feedbacks* to the interaction within the system (e.g., models to predict responses). Inside deeper leverage, *design* relate to the social structures that manage feedbacks and parameters (Abson et al., 2017) including information flows and rules of the system (e.g., sanctions, controls or incentives). *Intent* includes the underlying values, goals, and worldviews that shape the emerging direction and the conditions for a self-organized system structure (Meadows, 1999).

Table 5.1. Twelve leverage points (Meadows, 1999) classified into four system characteristics according to the leverage for systemic change (Abson et al., 2017; Riechers et al., 2021a).

Leverage points	System characteristics
12. Constants, parameters, numbers 11. The size of buffers and other stabilizing stocks, relative to their flows 10. Structure of material stocks and flows	4 Parameters: measurable system features
9. Length of delays, relative to the rate of system changes 8. Strength of negative feedback loops, relative to the effect they are trying to correct against 7. Gain around driving positive feedback loops	3 Feedbacks: interaction within the system
6. Structure of information flow, access to information; type and diversity of information (e.g., cultural or biological); biodiversity to improve genetic information diversity 5. Rules of the system 4. Power to add, change, evolve, or self-organize system structure	2 Design: systemic structures; institutional arrangements; sanctions, controls, incentives; co-management schemes
3. Goals of the system 2. Mindset out of which the system arises (goals, structure, rules) 1. Power to transcend paradigms	1 Intent: long-term trajectory of system behavior Values, worldviews, beliefs

Some interventions have great potential for systemic change (Abson et al., 2017) but are usually under-investigated (Fischer and Riechers, 2019), including: (1) *rethink* how different information and participatory approaches can help guide management to solve societal issues (Kittinger et al., 2013); (2) *reconnect* and reorient human behavior with nature, resilience and with the capacity of ecosystems to support life (Folke et al., 2016); and (3) *restructure* institutions by improving the way in which heterogeneity in (behavior, values) can be incorporated into research and management (Abson et al., 2017; Jacobs et al., 2016; Lindkvist et al., 2020). Three studies recently developed by the authors explore the SSF case of the GoN, (Sánchez-Jiménez et al., 2019), (Sánchez-Jiménez et al., 2021b) and (Sánchez-Jiménez et al., 2021a), and were analyzed to shed light on deep leverage points and potentially more powerful areas for transforming sustainability, albeit under-researched in tropical SSF.

5.3. RESULTS

5.3.1. Current Interventions in the Gulf of Nicoya Small-scale Fisheries

By consolidating the information on deep areas of intervention for the SSF in the GoN, presented in Chapters 2 (Sánchez-Jiménez et al., 2019), 3 (Sánchez-Jiménez et al., 2021b) and 4 (Sánchez-Jiménez et al., 2021a) of this dissertation, it is possible to analyze them in the context of a leverage points perspective, starting with a synthesis of current management interventions. Based on these results, the main policy interventions within the GoN small-scale fisheries are described below.

5.3.1.1. Control of Fishing Effort (via Fishing Licenses Allocation)

The legal right to fish is limited to fishers who have a license, currently a large number of fishers do not have licenses. To decrease the overall fishing effort in the 2000s, the distribution of fishing licenses was suspended (Flores et al., 2017). Moreover the permits granted have not been assigned under technical or scientific criteria that take into account the health of the ecosystem or social equity. Compliance with "owning a license" is low and is not associated with particular psychometric characteristics of the fishers, but rather with the mere possibilities of accessing a permit (Sánchez-Jiménez et al., 2021b). In consequence, mistrust, inequality and social vulnerability have been detected as effects associated with the absence of fishing rights (Sánchez-Jiménez et al., 2021b).

Given the problems associated with the assignment of licenses, a shared perception among fishers was that most of the small-scale fishers worked illegally in the GoN. Furthermore, only licensed fishers (and helpers registered) are eligible for the compensation subsidy during the closed season; many working women are particularly vulnerable by this situation (Fernández-Carvajal, 2013). Formalization of fishing rights for small-scale fishers could be resumed on the basis of fishing effort enforcement, for example by regulating a maximum number of vessels through a census of the current number of vessels and fishers (Flores et al., 2017) and with underlying ecological reasoning (e.g., using ecological modeling). Future participatory monitoring programs may obtain biological information (catches, sizes, species) as a basis for a rational, stock assessment-based granting of licenses (OECD, 2021).

5.3.1.2. Closed Fishing Season and Economic Subsidy

The three-month seasonal closure is intended to maintain healthy populations of marine species of commercial interest (e.g., shrimp, sardines, croaker and snook) by protecting the spawning stock during the peak spawning period in particular areas of the GoN. Studies suggest that the measure has contributed to a reduction in fishing effort (Alms and Wolff, 2019), and workshop participants mentioned a notable recovery in shrimp biomass after closure. However, there are some aspects that affect the effectiveness of this management measure, including the great increase in fishing pressure once the closed season is over and significant problems of compliance with the regulation (Sánchez-Jiménez et al., 2021b).

While a temporal closure has the potential to trigger systemic change by allowing the recovery of several species, it currently does not generate optimal benefits by ignoring vulnerability and poverty issues in fishing communities subject to closure. The objective of the economic subsidy is to cover the basic needs of approximately 1,400 permit holders and registered assistants (CRC 145,000 per month per person) (JDIP / 090-2021) (INCOPESCA, 2021). However, the number of family members of the workshop participants is 3.3 on average and the perception is that the subsidy is not enough to cover basic needs. It is necessary to reconsider the current scheme in terms of the quantity offered, the need to reactivate licensing and parallel incentives that strengthen the fishers' intrinsic motivations (Sánchez-Jiménez et al., 2021a), e.g., traceability processes or certifications that ensure where, how and when the fishing was carried out to improve the value chain for the benefit of fishing communities, fish quality and environmental sustainability.

5.3.1.2. Size Selectivity (through Gear Restrictions and Minimum Landing Size of Individual Species)

The mesh size enforced for adult corvina (> 55 cm) is 3.5 inches, while for shrimp gillnets it is 3.0 inches. Shrimp gillnets typically by-catch a variety of small individuals, including juvenile corvina that are sold cheaply. Added to this is the problematic situation of illegal fishing (mesh size <3 inches). As a result of the intense use of gillnets with too small mesh sizes, over time shrimp gillnets have become less profitable (Alms and Wolff, 2019). Studies have found in Isla Chira that currently the use of hand lines is more efficient than the use of finfish gillnets (3.5 inches), which in turn generate higher income than shrimp gillnets (3 inches) (Ulate-Garita, 2020).

Gear restrictions and efforts to apply a minimum size limit (for individual species) take into account sizes at first maturity for commercially important coastal fish species (Bystrom, 2017). Both types of interventions can be effective not only in protecting the spawning stock but also in optimizing the market value of the fishery, as larger individuals also tend to have higher prices (Flores et al., 2017; Ulate-Garita, 2020). This measure, However, does not necessarily consider ecosystem interactions of species nor are differences among juvenile and adult habitats, nor the interaction between fishing gears taken into account (Herrón et al., 2019). Fishers also expressed a lack of clarity about the minimum size of target species, when multiple species are caught simultaneously (Sánchez-Jiménez et al., 2019). Since the health of the ecosystem greatly depends on the abundance of middle and high trophic level groups (Wolff et al., 1998), it is essential is to rethink current shrimp net restrictions.

5.3.1.3. Marine Areas for Responsible Fishing (AMPRs)

The sites selected for this research coincide with the AMPRs Palito-Montero in Isla Chira, Costa de Pájaros and Paquera-Tambor, although the focus was not on these protected areas as such, but on the fishing activity (especially gillnet fishing) carried out by inhabitants of these communities, which take place inside and outside the AMPR. There are currently seven AMPRs and they constitute a pillar on which to build for aligning the country's conservation and participatory management policies with the FAO Voluntary Guidelines for SSF (Sabau, 2017). However, for this alignment to occur, significant challenges still need to be addressed.

While the AMPRs represent a significant step towards fishers' inclusion, there is still a lack of strategies that promote active participation and mechanisms that adequately include the voices of local community members in the management process (Chavez Carrillo et al., 2019). Fishers do not have official authority to patrol their areas, and in general there is insufficient representation from the SSF sector within the INCOPESCA board of directors (1/9 members) (Bystrom, 2017). There is also a deficiency of adequate training to face financial and administrative problems with zoning, responsibilities and roles (Partelow et al., 2021).

Moreover, there are issues of a lack of social cohesion and trust among stakeholders that affect collective action and compliance with this mechanism (García-Lozano and Heinen, 2016).

5.3.1.4. Other Sustainability Interventions

In the 1980s, when the first signs of overexploitation were visible, government export incentives helped boat owners improve their technology (Herrera-Ulloa et al., 2011). By the early 2000s, 70% of fishing subsidies in Costa Rica included policies to maintain high catch rates even when fishing was not profitable, including fuel subsidies, tax exceptions and support for fisheries development (García-Lozano and Heinen, 2016). While fishing effort in the GoN declined after its peak in the 2000s, the catch per unit effort (CPUE) of SSF and the semi-industrial fleet increased, which may suggest that (at least some) populations began to recover. However, a high CPUE can also mask true species abundance and overexploitation trends (Alms and Wolff, 2019).

Fuel subsidies allowed semi-industrial trawl fleets to remain profitable. When shrimp biomass reduction became obvious, these fleets added inshore fish to its target species and expanded the activity to deeper waters (Herrera-Ulloa et al., 2011). Shrimp trawl fleets ceased to operate when the Costa Rican Supreme Court in 2013 stated that no more licenses would be granted by recognizing the environmental damage of the activity, e.g., the quantity and diversity of by-catch species (Arana et al., 2013), and by recognizing the lack of scientific elements that support the sustainability of the technique, prevailing the precautionary principle. The remaining licenses continued until they expired in 2019 and the trawl fishing prohibition was ratified in 2020 when decree number 9909 for shrimp fishing was vetoed (Casa Presidencial, 2020).

In 2018 Costa Rica spent about 1,654.15 EUR per fisher to reduce the cost of fishing inputs, by giving fuel support, payments to reduce the cost of ice or bait, and by the construction and modernization of vessels and the purchase of new fishing gear (OECD, 2021). By the end of 2020, the National Institute for Rural Development (INDER) (Inder, 2020) had invested around 2 billion CRC (~2,651,899.27 EUR) in infrastructure projects, including a large bivalve mollusk plant, and also the sponsoring of research projects within the Marine Park. As part of the technological change strategy, 35,000,000.5 million CRC (~53,272.97 EUR) were spent for equipment and supplies for the investment in 7 motor boats with the potential to reduce water pollution by not using a mixture of gasoline and oil.

Other interventions included a vast legal framework for ocean governance in Costa Rica (Rodríguez-Chávez et al., 2019) and some initiatives of mangrove reforestation. In addition, the AMPRs demarcation project was launched with a system of buoys to mark the boundaries of the areas and prevent illegal fishing (Bystrom, 2017); as well as the process of installing and regulating beacons with the support of NGOs to track vessels of medium commercial fleet and contribute to surveillance, considering that the large-scale commercial fleet already should comply with the regulation (OECD, 2021).

5.3.2 Interplay between Shallow and Deep Leverage Points

Based on a leverage point perspective (Fischer and Riechers, 2019; Meadows, 1999), the current sustainability interventions are classified into four system characteristics according to the leverage gradient for systemic change (Abson et al., 2017): changes in (1) intent (deep leverage); (2) design (relatively deep leverage); (3) feedbacks (relatively shallow leverage) and (4) parameters (shallow leverage) (**Figure 5.1**).

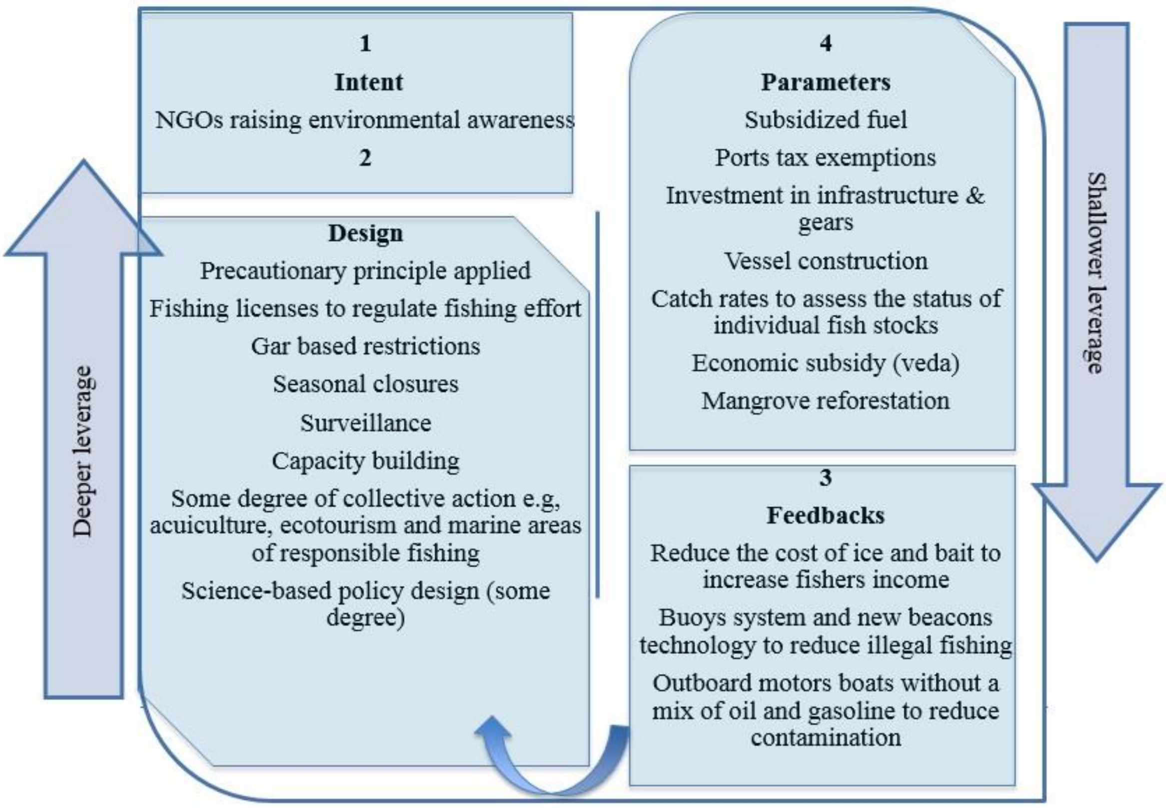


Figure 5.1. Main sustainability interventions identified and current status of fisheries management in the Gulf of Nicoya. Interventions are classified according to the gradient of leverage for systemic change (Abson et al., 2017), into four system characteristics (intent, design, feedbacks and parameters) from deep to shallow leverage points.

5.3.2.1. Identifying the Potential for Sustainability Transformations

The fisheries report of the Organization for Economic Cooperation and Development (OECD) (**Figure 5.2**) suggests that port tax exemptions (shallow leverage) represent 24.5% of the financing disbursed for the Costa Rican fishing sector in 2018 (OECD, 2021). Management regulations, compliance and surveillance (relatively deep leverage) accounted for 59.2%. The smallest fraction (16.3%) was used for capacity building to improve the skills of fishers to operate their businesses more efficiently and sustainably (OECD, 2021) (relatively deep leverage). There is no data available in the OECD report on money earmarked to understand and integrate the role of mindsets in sustainability transformations, to address differences in management values and goals, or to promote environmental awareness (deep leverage).

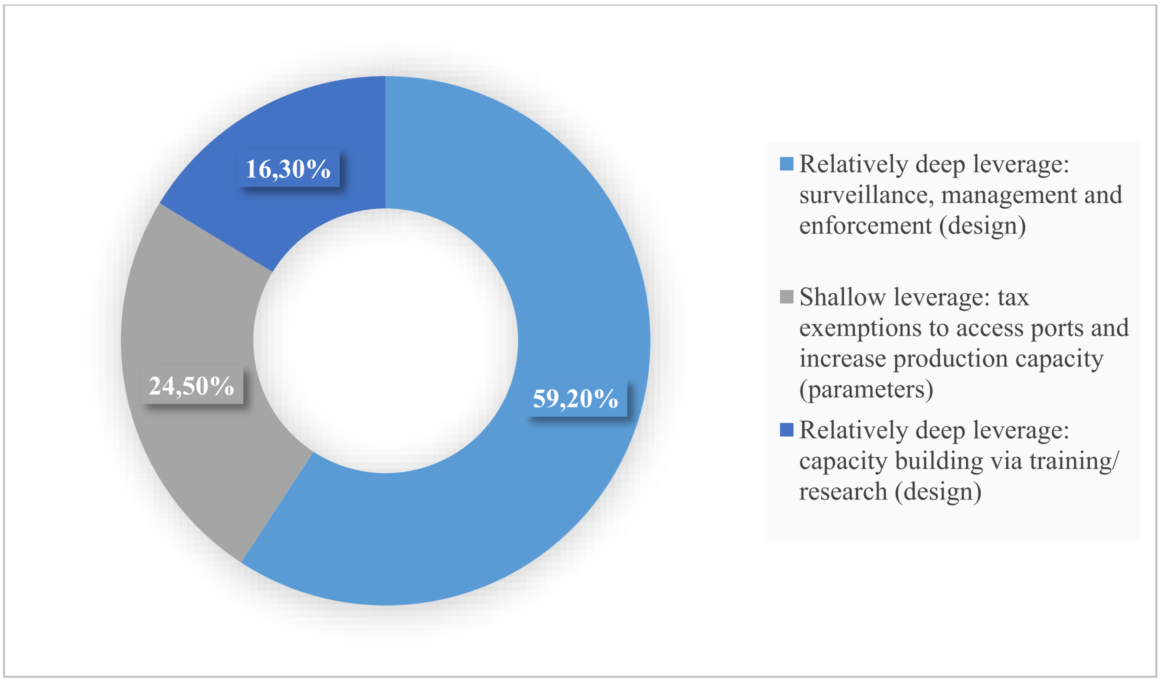


Figure 5.2. Support disbursed for Costa Rican fisheries in 2018 according to the OECD, (2020) and potential for sustainability transformations in the Gulf of Nicoya.

Interventions aimed at directly benefiting fishers and businesses include fuel subsidies, support for vessel building, and gear modernization or purchase (OECD, 2021) (shallow leverage points). As already stated above, in 2018, Costa Rica spent USD 1916 per fisher on policies to reduce the cost of inputs, within which the fuel subsidy represented the highest proportion, despite the fact that it has been demonstrated worldwide that the measure has unintended consequences such as overfishing, undeclared and illegal fishing (OECD, 2021).

Another aspect that has been neglected is the incompatibility of this measure with the overarching threat of climate change and the necessary reduction objectives in use of fossil fuels of decarbonizing in the economy.

In the GoN, a large number of policy interventions are directed at shallow and relatively shallow leverage points, being effective for specific purposes but with limited capacity to transform the trajectory of the entire SES. Currently there is also support for various design interventions (relatively deep leverage) including an overhaul of the legal framework (Rodríguez-Chávez et al., 2019). However, as noted in previous sections, there are other key aspects at the design and intent level that have been ignored, such as the underlying behavioral causes of compliance issues and the absence of an ecosystem-based approach. Multiple voices of the SSF are still excluded and underrepresented in decision-making, including women, ultimately reducing collaborations among stakeholders.

Interventions that address shallow leverage points, such as investment and technology, can clearly generate beneficial results, but attention needs to be paid to the interaction between shallow and deep interventions (Riechers et al., 2021b). For example, making adjustments and increasing the current economic closure subsidy will be of great importance in ensuring that small-scale fishers can meet their basic needs during the seasonal closure. In turn it is vital to address, the connections between poverty, vulnerability and overfishing (Beltrán-Turriago, 2014; Béné et al., 2010; Cinner, 2009). Thus, long-term goals such as well-being and social equity (Bennett et al., 2019) should be folded in to system intent (deep leverage), as well as processes of environmental awareness (deep leverage) and access to education (relatively deep and deep leverage).

5.4. DISCUSSION

5.4.1. Uncovering Deep Leverage Points for Sustainability Transformation

To initiate transformational changes aimed at sustainability, the goals and rules of the system (i.e. deep leverage points) need to be addressed more directly. This section focuses on identifying the possibility for deep leverage points, priority areas for intervention, and strategic actions with the potential to achieve systemic change in tropical SSF and the GoN.

5.4.1.1. Integrating knowledge Systems to Understand Ecosystem Impacts of Fishing

The main impacts of fishing on the GoN ecosystem (1993-2013) were identified in (Sánchez-Jiménez et al., 2019) after analyzing the similarities, complementarities and differences between two ecological knowledge systems: a system trophic model (TM) (Alms and Wolff, 2019) and local ecological knowledge (LEK). Both systems similarly revealed a severe decrease in the catch of shrimp and corvina along with an increasing impact of gillnet fishing and semi-industrial trawling, as well as an increase in fishing effort towards larger-sizes corvinas. The information from both systems, when complemented (**Figure S5.1** in the Annex), identified significant reductions in the catch of high trophic level species (mackerel, barracudas, sharks and rays), economic losses due to the capture of small individuals and changes in the catch now dominated by sardines (instead of the economically valuable shrimp), also increase in the use of illegal gillnets. Finally, in contrast to the perception of the workshop participants, fisheries data used for the EwE model identified a reduction in sardine catches (Sánchez-Jiménez et al., 2019).

The EwE model shows a notable decrease in abundance of intermediate trophic level species such as shrimp and sardines, with great ecological and socioeconomic consequences, since these species exert a key wasp-waist control over their prey and predators (Alms and Wolff, 2020). It is noteworthy that the regulation of sardine and shrimp catches (AJDIP 270/2009) and their ecological status was not clear to several fishers (Sánchez-Jiménez et al., 2019), who expressed their desire to deepen their understanding of the ecological reasoning behind the interventions. In this context it is interesting to note that the structure of the GoN ecosystem and its functionality has been maintained over the years, mainly due to the redundancy between species of medium trophic level that predominate in the catches (shrimp, small pelagic and small demersal fish). The larger ecological impacts are caused by gillnet fishing, semi-industrial shrimp trawling and sardine purse seiners (Alms and Wolff, 2020).

Fishers perceived illegal fishing as key factors in generating conflicts (Sánchez-Jiménez et al., 2019). Within the SSF, the use of gillnets (legal and illegal combined) has the most negative impact on several functional groups and influence the distribution and abundance of large predators (e.g. corvinas, snook and catfish) (Alms and Wolff, 2019). A reduction of these predators can potentially create cascading effects, for example, an increase in benthic macroinvertebrates (Baum and Worm, 2009). The information provided by the fishing community points to impacts particularly from illegal gillnet fishing (e.g., mesh size less than 3 inches). Fishers also perceived that illegal artisanal dragnets and illegal gillnets turned into purse seines are causing serious reductions in catches and drops in prices of the SSF, as the techniques capture entire schools of large and small fish.

EwE-type balanced mass trophic models offer advantages by requiring relatively little information (Bacalso and Wolff, 2014) and, combined with LEK, improve the understanding of the state of the ecosystem (Ainsworth and Pitcher, 2005b). Management interventions in the GoN may be aimed at preserving biodiversity and redundancy of low-medium trophic level groups in the ecosystem, as well as the biomass rebuilding of high trophic level species. The EwE model provided information on the impact of the different fishing fleets, on the biomass pools of the different model groups, but does not describe possible reductions in the size class of the species within biomass compartments (Sánchez-Jiménez et al., 2019). Hence, the information provided by fishers on the size reductions of corvinas and shrimps due to illegal gillnet fishing is a relevant paired information. The complementarity between LEK and the EwE model provided the most detailed chronology (1993-2013) of the development and impacts of fishing on the GoN (**Figure S5.2** in the Supporting Information).

5.4.1.2. Marine Education that Reconnects Human Behavior with Ecosystem Resilience

Our results support the hypothesis that interventions in marine education, using an EwE trophic model as a holistic tool for the description of the ecosystem and the fishery impact may positively influence pro-environmental behavior (Sánchez-Jiménez et al., 2021b), beliefs and norms (Arbuthnott, 2009; Fujitani et al., 2016; Menzel and Bögeholz, 2009; Smyth, 2006). Communicating ecological scientific evidence (EwE model) combined with deliberation and negotiation of people's points of view, facilitated an active social learning process (Fujitani et al., 2017), which has shown potential to promote environmental awareness and responsibility within GoN participating fishers to subtly reconnect them with existing (intrinsic) motivations to act sustainably (Sánchez-Jiménez et al., 2021b). Ascription of responsibility influences personal norms (PN) (Klöckner, 2013), and in this study case PN showed significance to explain the support for possible management measures.

Personal norms and universal values were important in explaining support for management measures (Sánchez-Jiménez et al., 2021b). Providing fishing communities with spaces to build shared norms (Partelow et al., 2021) will be necessary to overcoming problems of non-compliance with regulations. Previous studies have found that non-compliance significantly affects collective action and is detrimental to sustainability in the GoN (Chavez Carrillo et al., 2019; García-Lozano and Heinen, 2016). Deliberating on possible future scenarios using an EwE model helped reduce uncertainties, increasing legitimacy and a perceived behavioral control (PBC) of fishers to support the measures. Particularly relevant to SSF are ecosystem-based educational programs that target norms, universal values, perceived behavioral control (PBC) as well as governance structures that empower people, due to their potential effect on reconnecting with ecosystem resilience, and their power to influence the situation and act accordingly (Sánchez-Jiménez et al., 2021b).

5.4.1.3. Incorporating Plurality of Values into an Ecosystem Approach to Fisheries: towards Relational Definitions of SSF

Given the various underlying factors that mediated fishers' choices and the plurality of values (intrinsic, instrumental, and relational) attributed to the GoN ecosystem (Sánchez-Jiménez et al., 2021a), inclusive deliberative mechanisms are needed to develop commitments that go beyond obtaining consensus. The application of relational values can reconnect actors with each other and with marine ecosystems through what is already important for them (e.g. family, friends) (Klain et al., 2017). Altruistic and biospheric motivations predominate among the participating GoN fishers (Sánchez-Jiménez et al., 2021b), so if properly channeled, there are already indispensable conditions to redesign the fishing institutions so that the rules, regulations and norms allow the expansion of these values (Chan et al., 2020). However, low compliance must be addressed, due to underlying problems, e.g., lack of trust between peers (Chavez Carrillo et al., 2019) and lack of ecological reasoning in policy design (Sánchez-Jiménez et al., 2021a).

Problems of poverty, inequalities and unresolved disagreements on illegal fishing persist in the GoN, so biomass rebuilding (with the help of ecological models) goes hand in hand with the restoration of trust between the different actors. An integration of an ecosystem approach to fisheries with a value-relational orientation can facilitate the expansion of commitments by leading to conceptions of reciprocity (Kimmerer, 2013), in which marine ecosystems can sustain fishing and people. In turn, people have intrinsic motivations and can develop a sense of responsibility and their own capacities to maintain and care deeply for ecosystems, so that nature is understood as a single living and interdependent social-ecological system. More relational definitions of SSF (Smith and Basurto, 2019) are needed for ecosystem-based management, since society well-being depends on the ecosystem and its services and the conservation of biodiversity depends on human behavior and governance (Martín-López and Montes, 2015).

Progress is needed to develop mechanisms that facilitate the discussion of differences in preferences between actors (Chuenpagdee and Jentoft, 2018). Small-scale fisheries harbor a diversity of values, perceptions and heterogeneous preferences. Even within gillnet fisheries there are differences that are not well represented in decision-making in the GoN. The integration of an ecosystem-based approach (e.g., ecological modeling) with a plural valuation perspective (i.e., multiple values that stakeholders assign to the ecosystem) builds on previous work connecting values, ethics, and an ecosystem approach for fisheries management (Lam et al., 2019). In this way, an applied perspective is offered for the management of tropical SSF, for examining the ecological and socioeconomic viability of policy interventions, as well as the pluralistic motivations that underlie the willingness to change and support management alternatives for sustainability (Sánchez-Jiménez et al., 2021a)

5.4.1.4. Inter-and-transdisciplinary Research to Foster Collaboratively Designed Policies

A strategic action that supports the objectives of the United Nations Decade of Ocean Sciences for Sustainability, 2020-2030, is to ensure that there is evidence-based management (UNESCO, 2019), sensitive to the local, regional and global context (Lindkvist et al., 2020). For fisheries in the GoN, research methodologies are needed that contribute to reconciling local needs with sustainable development goals (SDGs) (United Nations, 2016) as well as aligning management and governance interventions with the FAO voluntary guidelines for SSF (FAO, 2015). Considering the importance of inter-and-trans-disciplinary assessments (Martín-López and Montes, 2015), EwE trophic models can be used as an interactive and two-way learning communication tool to collaboratively assess the impacts of fishing on the ecosystem and the viability of a complex fishery policies (Sánchez-Jiménez et al., 2021b, 2021a).

To integrate deliberation and knowledge co-creation in decision making in the GoN, it is needed to invest in data collection and analysis, in community monitoring for fisheries management, and participatory research approaches. Concrete steps already taken here include integrating multiple methodologies to interpret and analyze interdisciplinary, quantitative, and qualitative data, as well as promoting collaboration between scientists from different disciplines and non-academic sectors (Sánchez-Jiménez et al., 2021b, 2021a). Thus, it is sought that scientific practice can be framed beyond a political advisor (Riechers et al., 2021a) and more as an active agent within the fishing system (Skubel et al., 2019) which participates and fosters cross-sectoral collaboration for the development of fisheries policies aimed at transforming sustainability.

5.4.1.5. Integrating Women's Contributions to Fisheries for Achieving Sustainable Developmental Goals

Many women carry out fishing and fish cleaning functions but are often only recognized as assistants, so they are not part of the official government records of INCOPESCA fishers (Fernández-Carvajal, 2013) and if they are not formally registered by their employers as helpers, they will not be able to access the economic subsidy during the closed fishing season (Sánchez-Jiménez et al., 2021a). Poverty and job instability is a common feature in the GoN keeping fishing workers in a state of social vulnerability. In addition, the care of children and the elderly tends to fall into the unpaid work of women and girls. The contribution of women in the GoN fisheries in general is overlooked and there are multiple voices not represented in decision-making. There is a need to make the intentional effort to integrate the voices and contributions of women to fisheries, in decision making, research and sustainability processes (Frangoudes et al., 2019).

Social transformations have been taking place in the GoN, for example organized women in Isla Chira and Costa de Pájaros have developed alternatives to fishing through tourism and aquaculture (Sánchez-Jiménez et al., 2021a). This raises the importance of investigating the role of women and other groups within the SSF in poverty eradication (Sánchez-Jiménez et al., 2021a) and as agents to actively transform the economy from the margins (Ravera et al., 2016). Addressing poverty (SDG 1) and gender inequalities (SDG 5), in light of what a healthy marine ecosystem represents (SDG 14) can be a leverage to achieve other SDGs in tropical SSF, and certainly for the GoN (Sánchez-Jiménez et al., 2021a).

5.4.2. Trophic Models and Deliberation to Envisioning a Collective Desired Future

A look at the current state of the ecosystem and possible future scenarios helped reduce some of the uncertainties associated with decision-making in a complex socio-ecological system, as well as collectively envision what kind of future (or futures) is desired (Sánchez-Jiménez et al., 2021b). Backcasting-management tools enable to establish a common vision of the future (at the design and intent level of the system) and facilitate the development of interventions that consequently fulfill the intended purpose (Fischer and Riechers, 2019; Riechers et al., 2021a).

A key condition for transforming the governance of SSF is moving towards shared goals (Chuenpagdee and Jentoft, 2018) that align with the principles promoted in the voluntary guidelines of the SSF and the SDGS. EwE simulations on effort reduction proved useful due to the possibility of biomass rebuilding, with economic losses that varied to a greater or lesser extent. Deliberating on EwE models as a planning tool offers the possibility to include scientists from different disciplines, government organizations and small-scale fishers to be part of a common vision of the future (Bacalso et al., 2013; Nash et al., 2021).

5.4.3. From Traditional Fisheries Management to Systems Management

Current GoN administration relies on several interventions useful to manage and alleviate symptoms of overfishing in specific target species, but which ignore the depth of the impacts of fishing on ecosystem health (McClanahan et al., 2009) and on the society well-being. Existing interventions also reduce collaborations, overlook intrinsic motivations and diverse voices in decision-making. By applying a leverage point perspective (Abson et al., 2017; Meadows, 1999), it was possible to identify priority areas to achieve systemic changes towards sustainability and despite the challenges ahead, the results here presented show that the solutions are already within the GoN social-ecological system. Nonetheless, new lenses are required to look at the essentials and reallocate resources consequently (Chan et al., 2020; Conlon, 2021).

One of the priorities is to ensure ecosystem-based management that preserve the redundancy of low-medium trophic level groups and that allows biomass rebuilding of high trophic level species, for which it is advisable to invest in processes of data collection, analysis and knowledge co-production. Scientific practice can help to build bridges between scientific information and fishing actors (Nash et al., 2021). The application of EwE-type balanced mass trophic models proved useful in data-limited tropical SSF contexts, as these models require relatively little data compared to complex single-species population models, and they allow a solid validation (Link, 2002). It should be noted that illegal fishing and unreported fishing are not included in the EwE models applied, since they are not quantified by INCOPESCA (Alms and Wolff, 2020), but there is great potential in integrating ecological models with LEK to further improve the quality of the model data input (Ainsworth and Pitcher, 2005b, 2005a).

Of great importance is supporting intrinsically motivated women's collectives (and other groups) who have developed alternatives to fishing, reorienting existing participatory mechanisms such as AMPRs, and continuing the path of political decisions sustained so far with a degree of scientific information and the use of the precautionary principle. Rather than subsidizing fishing effort and capacity, it is more influential to disburse resources to fishers in need (OECD, 2021) (e.g., via a quality closure subsidy), support them to develop sustainable and efficient businesses, improve the scheme of seasonal closure as it allows the recovery of several species and provide viable alternative livelihoods to ultimately reduce overcapacity in fisheries. The socioeconomic impacts of COVID-19 pandemic (Bennett et al., 2020), were not considered here but together with the climate emergency must be addressed as a cross-cutting challenge for the management of SSF, given the increased vulnerability of ecosystems and fishing communities (Alms and Wolff, 2020; Wabnitz et al., 2018).

The results suggest that although there are interventions with greater leverage for transformative change, they are often disregarded by conventional coastal (Riechers et al., 2021a) and fisheries management. For example, interventions of marine education (using ecological models) can help incorporate existing, albeit latent, values of responsibility to empower people to act pro-environmentally on the basis of these ethics. Thus, current values and beliefs (system intent) can restructure institutions to integrate new social norms and respective legal changes (Chan et al., 2020) (system design) that address the resilience of the social-ecological system; altering consequently the feedbacks and parameters of the system (Abson et al., 2017) (e.g., technology, investment) to favor emerging sustainable properties (Lindkvist et al., 2020) (**Figure 5.3**).

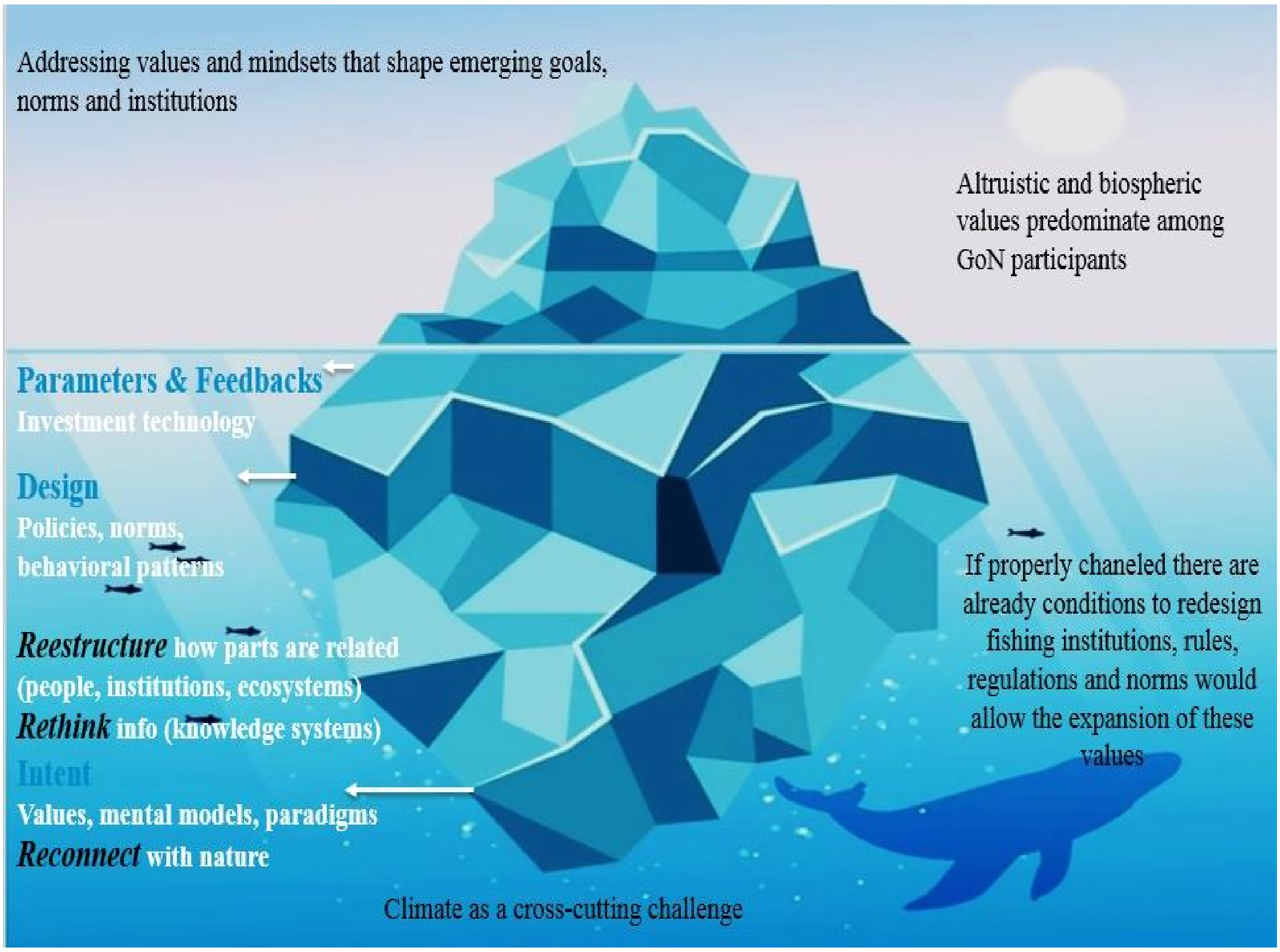


Figure 5.3. Shifting from conventional fisheries management to social-ecological resilience and systems management. The underlying values and mindsets of the system shape the emerging goals, policies, investment and technology used.

Some priorities are highlighted to transition from traditional SSF management to social-ecological systems management in the GoN (**Figure 5.4**), and they are classified into five broad areas: (1) explore the flows of LEK and scientific information to address environmental issues; (2) raise awareness about the ecological impacts of fishing, by educating and reconnecting human behavior with ecosystem resilience and with people' intrinsic abilities (care) to act pro-environmentally; (3) foster value plurality and cross-sectoral commitments and collaborations, through inter-and-transdisciplinary research that prioritizes women's voices, and other collectives emerging from the margins; (4) deliberating on ecosystem-based planning tools to join scientists, government and fishers to a common vision of the future; then (5) recognize ecological roles within the food web and opt for ecosystem-based management interventions that preserve biodiversity (e.g., redundancy of low-medium trophic level groups and biomass rebuilding of high trophic level species).

Deeper + Increading leverage – Shallower

Parameters
- Improved economic subsidy to help fishers in need during the closed season
- Mangrove reforestation
- Investment

Feedbacks
- Models to predict responses
- Technology

Design
- New and better incentives: e.g., sustainable fishing certification
- Reactivating licenses allocation to regulate fishing effort
- Targeting behavior and norms, responsibilities and accountability
- Better informed decisions: science-based, laws and precautionary principle
- Support the ability of fishers to self-organize and build share norms, including the existing network of AMPRs
- Improved seasonal closure as it allows the recovery of several species
- Inter-and transdisciplinary research approaches to foster cross-sectoral collaboration
- Acknowledge the SSF contributions to poverty eradication
- Integrate the voices and contributions of women to fisheries in policy design
- Inter-and-transdisciplinary research fostering deliberation and cross-sector collaboration
- Exploring structure of information flows: LEK and scientific info (e.g., trophic models)
- Rethinking shrimp-and-sardine fishing regulations and opt to preserve ecosystem biodiversity (e.g., redundancy of low-medium trophic level groups and biomass rebuilding of high trophic level species).
- Systems management
- Addressing and recognizing ecological roles within the food web

Intent
- A Plural-values and ecosystem-based perspective for tropical SSF: wellbeing, social equity and healthy ecosystems
- Underpinning SDG 14 and other goals of the system to achieve sustainability transformations: gender equality, poverty eradication
- Relational definitions of SSF and social-ecological systems: nature (both social and ecological phenomena) understood as a single living and interdependent system, human-nature reciprocity
- Compromises and common visions of the future
- Targeting awareness of ecological and social impacts of fisheries and perceived ability to change
- Raise awareness about the ecological impacts of fishing, by educating and reconnecting with nature and ecosystem resilience
- Addressing mindsets, norms, values, beliefs

Figure 5.4. Priority interventions for the Gulf of Nicoya are classified according to the gradient of leverage for systemic change (Abson et al., 2017) from shallow to deep leverage points.

Developing trust is required within the approaches of fishing management, since under the misbelief that the marine ecosystem health is unimportant to others, many neighbors within the GoN have become "the unreal others" (Brach, 2012; Sánchez-Jiménez et al., 2021b), and this has deepened the feeling of separation and failed environmental commitments. Research can also help facilitate people's reconnection with themselves (Ives et al., 2020), with each other, and with the resilience (Hedlund-de Witt et al., 2014; Ives et al., 2018) of marine ecosystems. As fishers, scientific researchers, policy makers, and NGOs emotionally feel the impacts of fishing and the rapid environmental change on biodiversity loss, future research may also explore subtle areas such as the emotional terrain of environmental issues (Neckel and Hasenfratz, 2021) by examining the role of embodying fear, anger, hope or compassion (Hochschild, 2016; Macy and Brown, 2014) in making sense of the ecological crisis and in envisioning alternative futures.

In this review and synthesis, a leverage point perspective (Abson et al., 2017; Fischer and Riechers, 2019; Meadows, 1999) was used as a lens to understand the dynamics of the GoN social-ecological fishing system. Its application can lead to a new paradigm for SSF management, in which both ecological and social phenomena, are understood as a unified whole, a single living system in which the parts only work in relation to each other (Wulf, 2015). If light is shed on the essentials, there are deep leverage points that can transform the trajectory of the entire system towards more sustainable states. Based on that understanding, the results presented here are expected to aide prioritizing research and management efforts, as well as suggesting possible pathways to kindle sustainability transformations in tropical SSF.

ACKNOWLEDGEMENTS

A special thanks to the women from the Gulf of Nicoya who inspired and contributed to this work, particularly Sandra Cruz, Ester Ledezma, Damaris Pérez, and Albanis Montiel, for their help with the logistics of the workshops and interviews. Similarly to Karen Quirós for supporting data collection and presenting us the natural jewels of Isla Chira. A sincere thanks to Bárbara Escobar, Talía Chamorro and Gleice Alves for the application of the surveys, the photographic documentation and driving to the study area.

LITERATURE CITED

Abrahamse, W., Steg, L., Vlek, C., and Rothengatter, T. (2005). A review of intervention studies aimed at household energy conservation. *J. Environ. Psychol.* 25, 273–291. doi:10.1016/j.jenvp.2005.08.002.

Abson, D. J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., et al. (2017). Leverage points for sustainability transformation. *Ambio* 46, 30–39. doi:10.1007/s13280-016-0800-y.

Ainsworth, C. H., and Pitcher, T. J. (2005a). Estimating illegal, unreported and unregulated catch in British Columbia's marine fisheries. *Fish. Res.* 75, 40–55. doi:10.1016/j.fishres.2005.05.003.

Ainsworth, C. H., and Pitcher, T. J. (2005b). Using Local Ecological Knowledge in Ecosystem Models. *nsgl.gso.uri.edu* Rep 05–02, 89–304. Available at: https://nsgl.gso.uri.edu/aku/akuw03002/ak-sg-05-02p289-322.pdf [Accessed July 5, 2021].

Ajzen, I. (1991). The theory of planned behavior. *Organ. Behav. Hum. Decis. Process.* 50, 179–211. doi:10.1016/0749-5978(91)90020-T.

Ajzen, I. (2005). *Attitudes, Personality and Behaviour*. 2nd Editio. , ed. I. Ajzen Maidenhead, United Kingdom: Open University Press Available at: https://www.mheducation.co.uk/attitudes-personality-and-behaviour-9780335217038-emea-group [Accessed July 13, 2020].

Alms, V., and Wolff, M. (2019). The Gulf of Nicoya (Costa Rica) Fisheries System: Two Decades of Change. *Mar. Coast. Fish.* 11, 139–161. doi:10.1002/mcf2.10050.

Alms, V., and Wolff, M. (2020). Identification of Drivers of Change of the Gulf of Nicoya Ecosystem (Costa Rica). *Front. Mar. Sci.* 7, 707. doi:10.3389/fmars.2020.00707.

Álvarez-Farizo, B., Gil, J. M., and Howard, B. J. (2009). Impacts from restoration strategies: Assessment through valuation workshops. *Ecol. Econ.* 68, 787–797. doi:10.1016/j.ecolecon.2008.06.012.

Álvarez-Farizo, B., Hanley, N., Barberán, R., and Lázaro, A. (2007). Choice modeling at the "market stall": Individual versus collective interest in environmental valuation. *Ecol. Econ.* 60, 743–751. doi:10.1016/j.ecolecon.2006.01.009.

Arana, P. M., Orellana, J. C., Villalobos-Rojas, F., Wehrtmann, I. S., and Nielsen-Muñoz, V. (2013). By-catch associated with fisheries of Heterocarpus vicarius (Costa Rica) and Heterocarpus reedi (Chile) (Decapoda: Pandalidae): a six-year study (2004-2009). *J. Crustac. Biol.* 33, 198–209. doi:10.1163/1937240X-00002123.

Arbuthnott, K. D. (2009). Education for sustainable development beyond attitude change. *Int. J. Sustain. High. Educ.* 10, 152–163. doi:10.1108/14676370910945954.

Arias-Arévalo, P., Gómez-Baggethun, E., Martín-López, B., and Pérez-Rincón, M. (2018). Widening the Evaluative Space for Ecosystem Services: A Taxonomy of Plural Values and Valuation Methods. *Environ. Values* 27, 29–53. doi:10.3197/096327118X15144698637513.

Arias-Arévalo, P., Martín-López, B., and Gómez-Baggethun, E. (2017). Exploring intrinsic, instrumental, and relational values for sustainable management of social-ecological systems. *Ecol. Soc.* 22, art43. doi:10.5751/ES-09812-220443.

Armada, N. B., Bacalso, R. T. M., Rosales, R. M. P., and Lazarte, A. T. (2018). Right-sizing as a strategy for allocating fishing effort in a defined marine ecosystem: A Philippines case study. *Ocean Coast. Manag.* 165, 167–184. doi:10.1016/j.ocecoaman.2018.08.018.

Arrow, K., Solow, R., Portney, P. R., Leamer, E. E., Radner, R., and Schuman, H. (1993). Report of the NOAA Panel on Contingent Valuation. *Fed. Regist.* 58, 4601–4614. Available at: https://edisciplinas.usp.br/pluginfile.php/4473366/mod_folder/intro/Arow_WTP.pdf [Accessed February 3, 2021].

Bacalso, R. T. M., Juario, J. V., and Armada, N. B. (2013). Fishers' choice of alternative management scenarios: A case study in the Danajon Bank, Central Philippines. *Ocean Coast. Manag.* 84, 40–53. doi:10.1016/j.ocecoaman.2013.07.008.

Bacalso, R. T. M., and Wolff, M. (2014). Trophic flow structure of the Danajon ecosystem (Central Philippines) and impacts of illegal and destructive fishing practices. *J. Mar. Syst.* 139, 103–118. doi:10.1016/j.jmarsys.2014.05.014.

Basurto, X., Gelcich, S., and Ostrom, E. (2013). The social–ecological system framework as a knowledge classificatory system for benthic small-scale fisheries. *Glob. Environ. Chang.* 23, 1366–1380. doi:10.1016/j.gloenvcha.2013.08.001.

Battista, W., Romero-Canyas, R., Smith, S. L., Fraire, J., Effron, M., Larson-Konar, D., et al. (2018). Behavior change interventions to reduce illegal fishing. *Front. Mar. Sci.* 5, 403. doi:10.3389/fmars.2018.00403.

Baum, J. K., and Worm, B. (2009). Cascading top-down effects of changing oceanic predator abundances. *J. Anim. Ecol.* 78, 699–714. doi:10.1111/j.1365-2656.2009.01531.x.

Beaudreau, A. H., and Levin, P. S. (2014). Advancing the use of local ecological knowledge for assessing data-poor species in coastal ecosystems. *Ecol. Appl.* 24, 244–256. doi:10.1890/13-0817.1.

Beddington, J. R., Agnew, D. J., and Clark, C. W. (2007). Current Problems in the Management of Marine Fisheries. *Science (80-.).* 316, 1713–1716. doi:10.1126/science.1137362.

Begossi, A. (2015). Local ecological knowledge (LEK): understanding and managing fisheries. *Fish. Knowl. Ecosyst. approach to Fish.*, 7.

Beltrán-Turriago, C. (2014). *Contribución de la pesca y la acuicultura a la seguridad alimentaria y el ingreso familiar en Centroamérica*. Primera ed. Panamá: FAO Available at: www.fao.org/publications [Accessed June 28, 2021].

Béné, C., Hersoug, B., and Allison, E. H. (2010). Not by Rent Alone: Analysing the Pro-Poor Functions of Small-Scale Fisheries in Developing Countries. *Dev. Policy Rev.* 28, 325–358. doi:10.1111/j.1467-7679.2010.00486.x.

Bennett, N. J., Cisneros-Montemayor, A. M., Blythe, J., Silver, J. J., Singh, G., Andrews, N., et al. (2019). Towards a sustainable and equitable blue economy. *Nat. Sustain.* 2, 991–993. doi:10.1038/s41893-019-0404-1.

Bennett, N. J., Finkbeiner, E. M., Ban, N. C., Belhabib, D., Jupiter, S. D., Kittinger, J. N., et al. (2020). The COVID-19 Pandemic, Small-Scale Fisheries and Coastal Fishing Communities. *Coast. Manag.* 48, 336–347. doi:10.1080/08920753.2020.1766937.

Bentley, J. W., Hines, D. E., Borrett, S. R., Serpetti, N., Hernandez-Milian, G., Fox, C., et al. (2019). Combining scientific and fishers' knowledge to co-create indicators of food web structure and function. *ICES J. Mar. Sci.* 76, 2218–2234. doi:10.1093/icesjms/fsz121.

BIOMARCC, SINAC, and GIZ (2013). Evaluación de las pesquerías en la zona media y externa del Golfo de Nicoya, Costa Rica. San José, Costa Rica.

Bolderdijk, J. W., Gorsira, M., Keizer, K., and Steg, L. (2013). Values Determine the (In)Effectiveness of Informational Interventions in Promoting Pro-Environmental Behavior. *PLoS One* 8, e83911. doi:10.1371/journal.pone.0083911.

Bouman, T., and Steg, L. (2019). One Earth Commentary Motivating Society-wide Pro-environmental Change. *One Earth* 1, 27–30. doi:10.1016/j.oneear.2019.08.002.

Brach, T. (2012). Trance of the "Unreal Other" - Tara Brach. Available at: https://www.tarabrach.com/trance-of-the-unreal-other-audio/ [Accessed November 25, 2021].

Brenes, C. L., Coen, J. E., Chelton, D. B., Enfield, D. B., León, S., and Ballestero, D. (2003). Wind driven upwelling in the Gulf of Nicoya, Costa Rica. *Int. J. Remote Sens.* 24, 1127–1133. doi:10.1080/0143116021000028632.

Bunse, L., Rendon, O., and Luque, S. (2015). What can deliberative approaches bring to the monetary valuation of ecosystem services? A literature review. *Ecosyst. Serv.* 14, 88–97. doi:10.1016/j.ecoser.2015.05.004.

Bystrom, A. (2017). Analysis of small scale fishery development within Costa Rica´s MPA system. Available at: http://www.fao.org/3/i6742e/i6742e.pdf#page=33 [Accessed September 28, 2021].

Cameron, T. A., and Huppert, D. D. (1989). OLS versus ML estimation of non-market resource values with payment card interval data. *J. Environ. Econ. Manage.* 17, 230–246. doi:10.1016/0095-0696(89)90018-1.

Casa Presidencial, C. (2020). Presidente veta Ley para pesca de camarón – Presidencia de la República de Costa Rica. Available at: https://www.presidencia.go.cr/comunicados/2020/10/presidente-veta-ley-para-pesca-de-camaron/ [Accessed October 1, 2021].

Chacón, C., Araya, U., Vásquez, A., Brenes, M., and Marín, A. (2007). Estadísticas pesqueras del Golfo de Nicoya, Costa Rica 1994-2005: Proyecto Manejo Sostenible de la Pesquería para el Golfo de Nicoya. Available at: http://www.sidalc.net/cgi-bin/wxis.exe/?IsisScript=CIAGRO.xis&method=post&formato=2&cantidad=1&expresion=mfn=005742 [Accessed March 13, 2020].

Chan, K. M. A., Balvanera, P., Benessaiah, K., Chapman, M., Díaz, S., Gómez-Baggethun, E., et al. (2016). Opinion: Why protect nature? Rethinking values and the environment. *Proc. Natl. Acad. Sci.* 113, 1462–1465. doi:10.1073/pnas.1525002113.

Chan, K. M. A., Boyd, D. R., Gould, R. K., Jetzkowitz, J., Liu, J., Muraca, B., et al. (2020). Levers and leverage points for pathways to sustainability. *People Nat.* 2, 693–717. doi:10.1002/pan3.10124.

Chavez Carrillo, I. I., Partelow, S., Madrigal-Ballestero, R., Schlüter, A., and Gutierrez-Montes, I. (2019). Do responsible fishing areas work? Comparing collective action challenges in three small-scale fisheries in Costa Rica. *Int. J. Commons* 13, 705–746. doi:10.18352/ijc.923.

Christensen, V., Coll, M., Buszowski, J., Cheung, W. W. L., Frölicher, T., Steenbeek, J., et al. (2015). The global ocean is an ecosystem: simulating marine life and fisheries. *Glob. Ecol. Biogeogr.* 24, 507–517. doi:10.1111/geb.12281.

Christensen, V., and Pauly, D. (1992). ECOPATH II — a software for balancing steady-state ecosystem models and calculating network characteristics. *Ecol. Modell.* 61, 169–185. doi:10.1016/0304-3800(92)90016-8.

Christensen, V., and Pauly, D. (2004). Placing fisheries in their ecosystem context, an introduction. *Ecol. Modell.* 172, 103–107. doi:10.1016/j.ecolmodel.2003.09.002.

Christensen, V., Steenbeek, J., and Failler, P. (2011). A combined ecosystem and value chain modeling approach for evaluating societal cost and benefit of fishing. *Ecol. Modell.* 222, 857–864. doi:10.1016/j.ecolmodel.2010.09.030.

Christensen, V., and Walters, C. J. (2004a). Ecopath with Ecosim: methods, capabilities and limitations. *Ecol. Modell.* 172, 109–139.

Christensen, V., and Walters, C. J. (2004b). Trade-offs in ecosystem-scale optimization of fisheries management policies. *Bull. Mar. Sci.* 74, 549–562.

Christensen, V., and Walters, C. J. (2005). Using ecosystem modeling for fisheries management: Where are we. in *ICES CM*.

Christie, M., Fazey, I., Cooper, R., Hyde, T., and Kenter, J. O. (2012). An evaluation of monetary and non-monetary techniques for assessing the importance of biodiversity and ecosystem services to people in countries with developing economies. *Ecol. Econ.* 83, 67–78. doi:10.1016/j.ecolecon.2012.08.012.

Christie, M., Martín-López, B., Church, A., Siwicka, E., Szymonczyk, P., and Mena Sauterel, J. (2019). Understanding the diversity of values of "Nature's contributions to people": insights from the IPBES Assessment of Europe and Central Asia. *Sustain. Sci.* 14, 1267–1282. doi:10.1007/s11625-019-00716-6.

Christie, P., Pollnac, R. B., Fluharty, D. L., Hixon, M. A., Lowry, G. K., Mahon, R., et al. (2009). Tropical Marine EBM Feasibility: A Synthesis of Case Studies and Comparative Analyses. *Coast. Manag.* 37, 374–385. doi:10.1080/08920750902937994.

Chuenpagdee, R., and Jentoft, S. (2018). Transforming the governance of small-scale fisheries. *Marit. Stud.* 17, 101–115. doi:10.1007/s40152-018-0087-7.

Cinner, J. E. (2009). Poverty and the use of destructive fishing gear near east African marine protected areas. *Environ. Conserv.* 36, 321–326. doi:10.1017/S0376892910000123.

Clayton, S., and Myers, G. (2015). *Conservation Psychology: Understanding and Promoting Human Care for Nature, 2nd Edition | Wiley*. Wiley-Blackwell.

Clement, C. A., Henning, J. B., and Osbaldiston, R. (2014). Integrating Factors that Predict Energy Conservation: The Theory of Planned Behavior and Beliefs about Climate Change. *J. Sustain. Dev.* 7, 46–69. doi:10.5539/jsd.v7n6p46.

Conlon, K. (2021). A social systems approach to sustainable waste management: leverage points for plastic reduction in Colombo, Sri Lanka. *Int. J. Sustain. Dev. World Ecol.*, 1–19. doi:10.1080/13504509.2020.1867252.

Costanza, R. (1991). Ecological Economics: A Research Agenda. 2. Available at: https://www.sciencedirect.com/science/article/pii/S0954349X05800074 [Accessed June

21, 2021].

Costanza, R., D'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., et al. (1997). The value of the world's ecosystem services and natural capital. *Nature* 387, 253–260. doi:10.1038/387253a0.

Coyle, V., Duca, R., Jones, C., and Roopcharan, K. (2015). Analyzing and Improving the Fishing Supply Chain in Costa Rica. San Jose, Costa Rica Project Center - IQP Available at: http://www.wpi.edu/academics/ugradstudies/project-learning.html [Accessed January 21, 2021].

CREMA (2014). Pacific hawksbill turtle connectivity confirmed between Nicaragua and Costa Rica. Available at: https://www.cremacr.org/en/pacific-hawksbill-turtle-connectivity-confirmed-between-nicaragua-and-costa-rica/.

Crona, B. I., Pomeroy, R. S., and Purcell, S. W. (2020). Editorial: Small-Scale and Artisanal Fisheries: Insights and Approaches for Improved Governance and Management in a Globalized Context. *Front. Mar. Sci.* 7. doi:10.3389/fmars.2020.00455.

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika* 16, 297–334. doi:10.1007/BF02310555.

Crutzen, P. J. (2006). "The 'Anthropocene,'" in *Earth System Science in the Anthropocene* (Berlin/Heidelberg: Springer-Verlag), 13–18. doi:10.1007/3-540-26590-2_3.

Danielsen, F., Jensen, P. M., Burgess, N. D., Coronado, I., Holt, S., Poulsen, M. K., et al. (2014). Testing Focus Groups as a Tool for Connecting Indigenous and Local Knowledge on Abundance of Natural resources with Science-Based Land Management Systems. *Conserv. Lett.* 7, 380–389. doi:10.1111/conl.12100.

de Groot, J. I. M., and Steg, L. (2008). Value Orientations to Explain Beliefs Related to Environmental Significant Behavior. *Environ. Behav.* 40, 330–354. doi:10.1177/0013916506297831.

de Groot, J. I. M., and Steg, L. (2009). Mean or green: which values can promote stable pro-environmental behavior? *Conserv. Lett.* 2, 61–66. doi:10.1111/j.1755-263X.2009.00048.x.

de Groot, J. I. M., and Steg, L. (2010). Relationships between value orientations, self-determined motivational types and pro-environmental behavioural intentions. *J. Environ. Psychol.* 30, 368–378. doi:10.1016/j.jenvp.2010.04.002.

Deb, A. K. (2018). 'surrender to nature': Worldviews and rituals of the small-scale coastal fishers of Bangladesh. *Mar. Policy* 92, 1–12. doi:10.1016/j.marpol.2018.01.010.

Dietz, T. (2013). Bringing values and deliberation to science communication. *PNAS* 110, 14081–14087. doi:10.1073/pnas.1212740110.

Dietz, T., and Stern, P. C. (2008). *Public Participation in Environmental Assessment and Decision Making*. Washington, D.C.: National Academies Press doi:10.17226/12434.

Diz, D., Morgera, E., and Wilson, M. (2019). Marine policy special issue: SDG synergies for sustainable fisheries and poverty alleviation. *Mar. Policy* 110, 102860. doi:10.1016/j.marpol.2017.08.020.

Dorninger, C., Abson, D. J., Apetrei, C. I., Derwort, P., Ives, C. D., Klaniecki, K., et al. (2020). Leverage points for sustainability transformation: a review on interventions in food and energy systems. *Ecol. Econ.* 171, 106570. doi:10.1016/j.ecolecon.2019.106570.

Dunlap, R. E. (2008). The New Environmental Paradigm Scale: From Marginality to Worldwide Use. *J. Environ. Educ.* 40, 3–18. doi:10.3200/JOEE.40.1.3-18.

FAO (2003). FAO Fisheries & Aquaculture - Perfiles sobre la pesca y la acuicultura por países - La República de Colombia. Available at: http://www.fao.org/fishery/facp/CRI/es#CountrySector-Statistics [Accessed June 24, 2021].

FAO (2014). *Contribución de la pesca y la acuicultura a la seguridad alimentaria y el ingreso familiar en Centroamérica. Panamá.* Available at: www.fao.org/publications%0Ahttp://www.fao.org/3/a-i3757s.pdf [Accessed March 13, 2020].

FAO (2015). Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication. Rome, Italy.

Fernández-Carvajal, D. (2013). Pesca Artesanal y pobreza en comunidades aledanas al Golfo de Nicoya. *Rev. Ciencias Soc.* 140, 137–152. doi:10.15517/rcs.v0i140.12319.

Fischer, J., Jorgensen, J., Josupeit, H., Kalikoski, D., and Lucas, C. M. eds. (2015). *Fishers' knowledge and the ecosystem approach to fisheries Applications, experiences and lessons in Latin America*. Rome, Italy: FAO, Roma. IT. 2015. 278 p.

Fischer, J., and Riechers, M. (2019). A leverage points perspective on sustainability. *People Nat.* 1, 115–120. doi:10.1002/pan3.13.

Fisher, J. (2012). No pay, no care? A case study exploring motivations for participation in payments for ecosystem services in Uganda. *Oryx* 46, 45–54. doi:10.1017/S0030605311001384.

Flores, D., Quirós, W., Rivera, I., and Smith, A. (2017). Quantifying the Economic Potential of Small-Scale Fisheries through Better Management in the Gulf of Nicoya, Costa Rica. Available at: https://bren.ucsb.edu/projects/quantifying-economic-potential-small-scale-fisheries-through-better-management-gulf-nicoya [Accessed September 28, 2021].

Folke, C., Biggs, R., Norström, A. V., Reyers, B., and Rockström, J. (2016). Social-ecological resilience and biosphere-based sustainability science. *Ecol. Soc.* 21, art41. doi:10.5751/ES-08748-210341.

Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., and Rockström, J. (2010). Resilience Thinking: Integrating Resilience, Adaptability and Transformability. *Ecol. Soc.* 15, art20. doi:10.5751/ES-03610-150420.

Frangoudes, K., Gerrard, S., and Kleiber, D. (2019). Situated transformations of women and gender relations in small-scale fisheries and communities in a globalized world. *Marit. Stud.* 18, 241–248. doi:10.1007/s40152-019-00159-w.

Fujitani, M. L., Fenichel, E. P., Torre, J., and Gerber, L. R. (2012). Implementation of a marine reserve has a rapid but short-lived effect on recreational angler use. *Ecol. Appl.* 22, 597–605. doi:10.1890/11-0603.1.

Fujitani, M. L., Fenichel, E. P., Torre, J., and Gerber, L. R. (2018). Synthesizing ecological and human use information to understand and manage coastal change. *Ocean Coast. Manag.* 162, 100–109. doi:10.1016/J.OCECOAMAN.2017.10.001.

Fujitani, M. L., McFall, A., Randler, C., and Arlinghaus, R. (2016). Efficacy of lecture-based environmental education for biodiversity conservation: a robust controlled field experiment with recreational anglers engaged in self-organized fish stocking. *J. Appl. Ecol.* 53, 25–33. doi:10.1111/1365-2664.12560.

Fujitani, M., McFall, A., Randler, C., and Arlinghaus, R. (2017). Participatory adaptive management leads to environmental learning outcomes extending beyond the sphere of science. *Sci. Adv.* 3, e1602516. doi:10.1126/sciadv.1602516.

Fulton, E. A., Smith, A. D. M., Smith, D. C., and Johnson, P. (2014). An Integrated Approach Is Needed for Ecosystem Based Fisheries Management: Insights from Ecosystem-Level Management Strategy Evaluation. *PLoS One* 9, e84242. doi:10.1371/journal.pone.0084242.

García-Lozano, A. J., and Heinen, J. T. (2016). Identifying Drivers of Collective Action for the Co-management of Coastal Marine Fisheries in the Gulf of Nicoya, Costa Rica. *Environ. Manage.* 57, 759–769. doi:10.1007/s00267-015-0646-2.

Gilchrist, G., Mallory, M., and Merkel, F. (2005). Can local ecological knowledge contribute to wildlife management? Case studies of migratory birds. *Ecol. Soc.* 10.

Glaeser, B., Bruckmeier, K., Glaser, M., and Krause, G. (2009). "Social-Ecological Systems Analysis in Coastal and Marine Areas: A Path toward Integration of Interdisciplinary Knowledge," in *Current Trends in Human Ecology* (Cambridge Scholars Publishing), 183–203. doi:10.5848/CSP.0441.00008.

Glaser, M., Christie, P., Diele, K., Dsikowitzky, L., Ferse, S., Nordhaus, I., et al. (2012). Measuring and understanding sustainability-enhancing processes in tropical coastal and marine social–ecological systems. *Curr. Opin. Environ. Sustain.* 4, 300–308. doi:10.1016/j.cosust.2012.05.004.

Gocke, K., Cortés, J., and Murillo, M. M. (2001). The annual cycle of primary productivity in a tropical estuary: The inner regions of the Golfo de Nicoya, Costa Rica. *Rev. Biol. Trop.* 49, 289–306. Available at: www.rbt.ac.cr,www.ucr.ac.cr [Accessed June 27, 2021].

Gómez-Baggethun, E., Martín-López, B., Barton, D., Braat, L., Saarikoski, H., E., K., et al. (2014). State-of-the-art report on integrated valuation of ecosystem services State-of-the-art report on integrated valuation of ecosystem services Special Issue of Sustainability Journal: Agroecology for the Transition towards Social-Ecological Sustainability Vi. Available at: http://www.openness-project.eu [Accessed January 16, 2021].

Grafton, R. Q., Arnason, R., Bjørndal, T., Campbell, D., Campbell, H. F., Clark, C. W., et al. (2006). Incentive-based approaches to sustainable fisheries. *Can. J. Fish. Aquat. Sci.* 63, 699–710. doi:10.1139/f05-247.

Hedlund-de Witt, A., de Boer, J., and Boersema, J. J. (2014). Exploring inner and outer worlds: A quantitative study of worldviews, environmental attitudes, and sustainable lifestyles. *J. Environ. Psychol.* 37, 40–54. doi:10.1016/j.jenvp.2013.11.005.

Hernández-Blanco, M., Costanza, R., and Cifuentes-Jara, M. (2021). Economic valuation of the ecosystem services provided by the mangroves of the Gulf of Nicoya using a hybrid methodology. *Ecosyst. Serv.* 49, 101258. doi:10.1016/j.ecoser.2021.101258.

Herrera-Ulloa, A., Villalobos-Chacón, L., Palacios-Villegas, J., Viquez-Portuguéz, R., and Oro-Marcos, G. (2011). "Coastal fisheries of Costa Rica," in *Coastal fisheries of Latin America and the Caribbean. FAO Fisheries and Aquaculture Technical Paper.*, eds. S. Salas, R. Chuenpagdee, A. Charles, and J. . Seijo (Rome, Italy: FAO), 137-153. Available at: https://www.academia.edu/download/49671707/Coastal_fisheries_of_Costa_Rica.pdf [Accessed June 23, 2021].

Herrón, P., Castellanos-Galindo, G. A., Stäbler, M., Díaz, J. M., and Wolff, M. (2019). Toward Ecosystem-Based Assessment and Management of Small-Scale and Multi-Gear Fisheries: Insights From the Tropical Eastern Pacific. *Front. Mar. Sci.* 6. doi:10.3389/fmars.2019.00127.

Herrón, P., Kluger, L. C., Castellanos-Galindo, G. A., Wolff, M., and Glaser, M. (2020). Understanding gear choices and identifying leverage points for sustainable tropical small-scale marine fisheries. *Ocean Coast. Manag.*, 105074. doi:10.1016/j.ocecoaman.2019.105074.

Himes, A., and Muraca, B. (2018). Relational values: the key to pluralistic valuation of ecosystem services. *Curr. Opin. Environ. Sustain.* 35, 1–7. doi:10.1016/j.cosust.2018.09.005.

Hochschild, A. R. (2016). *Strangers in their own land: Anger and mourning on the American right*. Paperback. New York: The New Press.

Hocking, R. R. (1976). A Biometrics Invited Paper. The Analysis and Selection of Variables in Linear Regression. *Biometrics* 32, 1. doi:10.2307/2529336.

INCOPESCA (2021). Inicia veda en el golfo de Nicoya | Prensa INCOPESCA. Available at: https://prensaincopesca.blogspot.com/2021/06/inicia-veda-en-el-golfo-de-nicoya.html [Accessed November 25, 2021].

Inder, C. (2020). Pesca responsable en el Golfo de Nicoya se fortalecerá con nuevos equipos. Available at: https://www.inder.go.cr/noticias/comunicados/2020/N179-pesca-golfo-nicoya.aspx [Accessed October 1, 2021].

IPBES (2019a). "Global Assessment Report on Biodiversity and Ecosystem Service," in *Debating Nature's Value*, eds. E. Brondizio, J. Settele, D. S, and H. Ngo (Bonn, Germany), 1–12. Available at: https://scholar.google.com/scholar?hl=es&as_sdt=0%2C5&q=Global+assessment+report+on+biodiversity+and+ecosystem+services+of+the+Intergovernmental+Science-Policy+Platform+on+Biodiversity+and+Ecosystem+Services&btnG= [Accessed January 16, 2021].

IPBES (2019b). Summary for policymakers of the global assessment report on biodiversity and ecosystem services. Bonn, Germany doi:10.5281/ZENODO.3553579.

Ives, C. D., Abson, D. J., von Wehrden, H., Dorninger, C., Klaniecki, K., and Fischer, J. (2018). Reconnecting with nature for sustainability. *Sustain. Sci.* 13, 1389–1397. doi:10.1007/s11625-018-0542-9.

Ives, C. D., Freeth, R., and Fischer, J. (2020). Inside-out sustainability: The neglect of inner worlds. *Ambio* 49, 208–217. doi:10.1007/s13280-019-01187-w.

Jacobs, S., Dendoncker, N., Martín-López, B., Barton, D. N., Gomez-Baggethun, E., Boeraeve, F., et al. (2016). A new valuation school: Integrating diverse values of nature in resource and land use decisions. *Ecosyst. Serv.* 22, 213–220. doi:10.1016/j.ecoser.2016.11.007.

Jiren, T. S., Riechers, M., Bergsten, A., and Fischer, J. (2021). A leverage points perspective on institutions for food security in a smallholder-dominated landscape in southwestern Ethiopia. *Sustain. Sci.* 16, 767–779. doi:10.1007/s11625-021-00936-9.

Jouffray, J.-B., Crona, B., Wassénius, E., Bebbington, J., and Scholtens, B. (2019). Leverage points in the financial sector for seafood sustainability. *Sci. Adv.* 5, eaax3324. doi:10.1126/sciadv.aax3324.

Kenter, J. (2020). "Deliberative and Non Monetary Valuation of Ecosystem Services. ," in *Les services écosystémiques dans les espaces agricoles.*, ed. Paroles de chercheur(e)s, 127–138. doi:10.15454/nwq9.

Kenter, J. O. (2016). Editorial: Shared, plural and cultural values. *Ecosyst. Serv.* 21, 175–183. doi:10.1016/j.ecoser.2016.10.010.

Kenter, J. O. (2018). IPBES: Don't throw out the baby whilst keeping the bathwater; Put people's values central, not nature's contributions. *Ecosyst. Serv.* 33, 40–43. doi:10.1016/j.ecoser.2018.08.002.

Kenter, J. O., Hyde, T., Christie, M., and Fazey, I. (2011). The importance of deliberation in valuing ecosystem services in developing countries—Evidence from the Solomon Islands. *Glob. Environ. Chang.* 21, 505–521. doi:10.1016/j.gloenvcha.2011.01.001.

Kenter, J. O., Jobstvogt, N., Watson, V., Irvine, K. N., Christie, M., and Bryce, R. (2016). The impact of information, value-deliberation and group-based decision-making on values for ecosystem services: Integrating deliberative monetary valuation and storytelling. *Ecosyst. Serv.* 21, 270–290. doi:10.1016/j.ecoser.2016.06.006.

Kimmerer, R. W. (2013). *Braiding sweetgrass: indigenous wisdom, scientific knowledge, and the teachings of plants*. 1st Ed. Minnesota: Milkweed Editions.

Kinzig, A. P., Ehrlich, P. R., Alston, L. J., Arrow, K., Barrett, S., Buchman, T. G., et al. (2013). Social Norms and Global Environmental Challenges: The Complex Interaction of Behaviors, Values, and Policy. *Bioscience* 63, 164–175. doi:10.1525/bio.2013.63.3.5.

Kittinger, J. N., Finkbeiner, E. M., Ban, N. C., Broad, K., Carr, M. H., Cinner, J. E., et al. (2013). Emerging frontiers in social-ecological systems research for sustainability of small-scale fisheries. *Curr. Opin. Environ. Sustain.* 5, 352–357. doi:10.1016/j.cosust.2013.06.008.

Klain, S. C., Olmsted, P., Chan, K. M. A., and Satterfield, T. (2017). Relational values resonate broadly and differently than intrinsic or instrumental values, or the New Ecological Paradigm. *PLoS One* 12, e0183962. doi:10.1371/journal.pone.0183962.

Klöckner, C. A. (2013). A comprehensive model of the psychology of environmental behaviour—A meta-analysis. *Glob. Environ. Chang.* 23, 1028–1038. doi:10.1016/j.gloenvcha.2013.05.014.

Kollmuss, A., and Agyeman, J. (2002). Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environ. Educ. Res.* 8, 239–260. doi:10.1080/13504620220145401.

Lam, D. P. M., Martín-López, B., Horcea-Milcu, A. I., and Lang, D. J. (2021). A leverage points perspective on social networks to understand sustainability transformations: evidence from Southern Transylvania. *Sustain. Sci.* 16, 809–826. doi:10.1007/s11625-020-00881-z.

Lam, M., Pitcher, T., Surma, S., Scott, J., Kaiser, M., White, A., et al. (2019). Value- and ecosystem-based management approach: the Pacific herring fishery conflict. *Mar. Ecol. Prog. Ser.* 617–618, 341–364. doi:10.3354/meps12972.

Leite, L., and Pita, C. (2016). Review of participatory fisheries management arrangements in the European Union. *Mar. Policy* 74, 268–278. doi:10.1016/J.MARPOL.2016.08.003.

Leite, M. C. F., and Gasalla, M. A. (2013). A method for assessing fishers' ecological knowledge as a practical tool for ecosystem-based fisheries management: Seeking consensus in Southeastern Brazil. *Fish. Res.* 145, 43–53. doi:10.1016/j.fishres.2013.02.013.

Leslie, H. M., Basurto, X., Nenadovic, M., Sievanen, L., Cavanaugh, K. C., Cota-Nieto, J. J., et al. (2015). Operationalizing the social-ecological systems framework to assess sustainability. *Proc. Natl. Acad. Sci.* 112, 5979–5984. doi:10.1073/pnas.1414640112.

Leslie, H. M., Schlüter, M., Cudney-Bueno, R., and Levin, S. A. (2009). Modeling responses of coupled social–ecological systems of the Gulf of California to anthropogenic and natural perturbations. *Ecol. Res.* 24, 505–519. doi:10.1007/s11284-009-0603-8.

Lienhoop, N., and MacMillan, D. (2007a). Valuing wilderness in Iceland: Estimation of WTA and WTP using the market stall approach to contingent valuation. *Land use policy* 24, 289–295. doi:10.1016/j.landusepol.2005.07.001.

Lienhoop, N., and MacMillan, D. C. (2007b). Contingent Valuation: Comparing Participant Performance in Group-Based Approaches and Personal Interviews. *Environ. Values* 16, 209–232. doi:10.3197/096327107780474500.

Lindhjem, H., and Navrud, S. (2011). Are Internet surveys an alternative to face-to-face interviews in contingent valuation? *Ecol. Econ.* 70, 1628–1637. doi:10.1016/j.ecolecon.2011.04.002.

Lindkvist, E., Wijermans, N., Daw, T. M., Gonzalez-Mon, B., Giron-Nava, A., Johnson, A. F., et al. (2020). Navigating Complexities: Agent-Based Modeling to Support Research, Governance, and Management in Small-Scale Fisheries. *Front. Mar. Sci.* 6, 733. doi:10.3389/fmars.2019.00733.

Link, J. S. (2002). What does ecosystem-based fisheries management mean? *Fisheries* 27, 18–21. Available at: www.fisheries.org [Accessed January 20, 2021].

Lo, A. Y., and Spash, C. L. (2013). Deliberative monetary valuation: In search of a democratic and value plural approach to environmental policy. *J. Econ. Surv.* 27, 768–789. doi:10.1111/j.1467-6419.2011.00718.x.

Lobo-Calderón, A. M., Gutiérrez-Delgado, V., and Ross-Salazar, E. eds. (2012). *Guía de identificación de filetes de pescado y mariscos*. San José, Costa Rica: Fundación MarViva. 61.

López Montaño, C., Rodrígeuz Enríquez, C., Rey de Marulanda, N., and Ocampo, J. A. (2015). *Bases para un nuevo Modelo de Desarrollo con igualdad de género*. , ed. M. Claudia Holstine Colombia Available at: https://repositorio.unal.edu.co/handle/unal/57679 [Accessed March 25, 2021].

Loureiro, M. L., and Lotade, J. (2005). Interviewer Effects on the Valuation of Goods with Ethical and Environmental Attributes. *Environ. Resour. Econ.* 30, 49–72. doi:10.1007/s10640-004-1149-4.

Lozano, A. J. G., and Heinen, J. T. (2016a). Identifying drivers of collective action for the co-management of coastal marine fisheries in the Gulf of Nicoya, Costa Rica. *Environ.*

Manage. 57, 759–769.

Lozano, A. J. G., and Heinen, J. T. (2016b). Property relations and the co-management of small-scale fisheries in Costa Rica: Lessons from Marine Areas for Responsible Fishing in the Gulf of Nicoya. *Mar. Policy* 73, 196–203.

Lubchenco, J., Cerny-Chipman, E. B., Reimer, J. N., and Levin, S. A. (2016). The right incentives enable ocean sustainability successes and provide hope for the future. *Proc. Natl. Acad. Sci.* 113, 14507–14514. doi:10.1073/pnas.1604982113.

Lucas, K., Brooks, M., Darnton, A., and Jones, J. E. (2008). Promoting pro-environmental behaviour: existing evidence and policy implications. *Environ. Sci. Policy* 11, 456–466. doi:10.1016/j.envsci.2008.03.001.

Maca Millán, S., Arias-Arévalo, P., and Restrepo-Plaza, L. (2020). An experimental approach to the design of payment for ecosystem services: the role of plural motivations and values. *Exp. Econ.* Available at: https://www.researchgate.net/profile/Paola_Arias-Arevalo/publication/345252942_An_experimental_approach_to_the_design_of_payment_for_ecosystem_services_the_role_of_plural_motivations_and_values/links/5fa1817992851c14bcff77d2/An-experimental-approach-to-th [Accessed December 11, 2020].

Mackay, M., Jennings, S., van Putten, E. I., Sibly, H., and Yamazaki, S. (2018). When push comes to shove in recreational fishing compliance, think 'nudge.' *Mar. Policy* 95, 256–266. doi:10.1016/j.marpol.2018.05.026.

Mackinson, S. (2001). Integrating local and scientific knowledge: an example in fisheries science. *Environ. Manage.* 27, 533–545. doi:10.1007/s0026702366.

Mackinson, S., Wilson, D. C., Galiay, P., and Deas, B. (2011). Engaging stakeholders in fisheries and marine research. *Mar. Policy* 35, 18–24. doi:10.1016/j.marpol.2010.07.003.

Macmillan, D. C., Philip, L., Hanley, N., and Alvarez-Farizo, B. (2002). Valuing the non-market benefits of wild goose conservation: a comparison of interview and group based approaches. *Ecol. Econ.* 43, 49–59. doi:10.1016/S0921-8009(02)00182-9.

MacMillan, D., Hanley, N., and Lienhoop, N. (2006). Contingent valuation: Environmental polling or preference engine? *Ecol. Econ.* 60, 299–307. doi:10.1016/j.ecolecon.2005.11.031.

MacMillan, D., Lienhoop, N., and Potts, J. (2005). "New approaches to valuing environmental benefits using contingent valuation," in *Environment, Information and Consumer Behaviour (New Horizons in Environmental Economics Series)*, eds. Karup, Signe, Russell, and C. S (Edward Elgar, Cheltenham), 249–262. Available at: https://books.google.com/books?hl=es&lr=&id=bx1-OMyfOdgC&oi=fnd&pg=PA249&ots=db00DwDlmc&sig=SaRfF6SAhKQyJJGjw7b9e5SpQ6E [Accessed January 13, 2021].

Macy, J., and Brown, M. (2014). *Coming Back to Life: The Updated Guide to The Work that Reconnects*. , ed. M. Fox Gabriola Island, BC V0R 1X0, Canada: New Society.

Manfredo, M. J., Bruskotter, J. T., Teel, T. L., Fulton, D., Schwartz, S. H., Arlinghaus, R., et al. (2017). Why social values cannot be changed for the sake of conservation. *Conserv. Biol.* 31, 772–780. doi:10.1111/cobi.12855.

Marín-Alpízar, B. and Vásquez, A. R. (2014). Informe especial acerca del resultado de los muestreos biológicos realizados en 7 comunidades del interior del Golfo de Nicoya durante los meses de octubre 2013 a marzo 2014. Puntarenas, Costa Rica.

Marín-Alpízar, B., and Alfaro-Rodríguez, J. (2019). Época Reproductiva De La Corvina Reina Cynoscion Albus, Aguada C. Squamipinnis Y Picuda C. Phoxocephalus, Especies De Alto Interés Comercial En La Zona Interior Del Golfo De Nicoya, Vertiente Del Pacífico, Costa Rica. Puntarenas Available at: https://www.academia.edu/download/60634075/24_Inf._Final_epoca_reprod._Corvinas_Vr._FINAL20190918-37771-hs8bck.pdf [Accessed November 25, 2020].

Marín-Alpízar, B., and Vásquez, A. R. (2014). Informe especial acerca del resultado de los muestreos biológicos realizados en 7 comunidades del interior del Golfo de Nicoya durante los meses de octubre 2013 a marzo 2014. Puntarenas, Costa Rica.

Marín-Cabrera, M. (2012). Identificación y caracterización de actores institucionales y de la sociedad civil claves en la gestión de las AMUM Golfo de Nicoya y Pacífico Sur. Proyecto SINAC-BID – MarViva. 103.

Martín-López, B., Gómez-Baggethun, E., García-Llorente, M., and Montes, C. (2014). Trade-offs across value-domains in ecosystem services assessment. *Ecol. Indic.* 37, 220–228. doi:10.1016/j.ecolind.2013.03.003.

Martín-López, B., and Montes, C. (2015). Restoring the human capacity for conserving biodiversity: a social–ecological approach. *Sustain. Sci.* 10, 699–706. doi:10.1007/s11625-014-0283-3.

Martín-López, B., Montes, C., and Benayas, J. (2007). The non-economic motives behind the willingness to pay for biodiversity conservation. *Biol. Conserv.* 139, 67–82. doi:10.1016/j.biocon.2007.06.005.

McClanahan, T. R., Castilla, J. C., White, A. T., and Defeo, O. (2009). Healing small-scale fisheries by facilitating complex socio-ecological systems. *Rev. Fish Biol. Fish.* 19, 33–47. doi:10.1007/s11160-008-9088-8.

McKeown, R. (2002). Education for Sustainable Development Toolkit. Energy, Environment and Resources Center. Available at: https://www.calltutors.com/data/assignments/requirements/13570/ESD-toolkit-_-University-of-Tennessee.pdf [Accessed March 13, 2020].

Meadows, D. (1999). Leverage Points Places to Intervene in a System. 3 Linden Road Hartland, Vermont, United States.

Menzel, S., and Bögeholz, S. (2009). The Loss of Biodiversity as a Challenge for Sustainable Development: How Do Pupils in Chile and Germany Perceive Resource Dilemmas? *Res. Sci. Educ.* 39, 429–447. doi:10.1007/s11165-008-9087-8.

Millenium Ecosystem Assesment, M. (2005). *Ecosystems and Human Well-being: Synthesis*. Washington, DC: Island Press Available at: https://millenniumassessment.org/documents/document.356.aspx.pdf [Accessed June 21, 2021].

Montoya, D., Yallop, M. L., and Memmott, J. (2015). Functional group diversity increases with modularity in complex food webs. *Nat. Commun.* 6. doi:10.1038/ncomms8379.

Msomphora, M. R. (2015). Stakeholder participation and satisfaction in the process of developing management plans: The case of Scottish Inshore Fisheries Groups. *Ocean Coast. Manag.* 116, 491–503. doi:10.1016/j.ocecoaman.2015.09.015.

Naranjo-Madrigal, H., and Bystrom, A. (2019). "Analyzing Fishing Effort Dynamics in a Multispecies Artisanal Fishery in Costa Rica: Social and Ecological System Linkages," in *Viability and Sustainability of Small-Scale Fisheries in Latin America and The Caribbean*, eds. Salas S., M. Barragán-Paladines, and R. Chuenpagdee (Springer, Cham). doi:10.1007/978-3-319-76078-0_16.

Naranjo-Madrigal, H., van Putten, I., and Norman-López, A. (2015). Understanding socio-ecological drivers of spatial allocation choice in a multi-species artisanal fishery: A Bayesian network modeling approach. *Mar. Policy* 62, 102–115. doi:10.1016/j.marpol.2015.09.003.

Nash, K. L., Alexander, K., Melbourne-Thomas, J., Novioaglio, C., Sbrocchi, C., Villanueva, C., et al. (2021). Developing achievable alternate futures for key challenges during the UN Decade of Ocean Science for Sustainable Development. *Rev. Fish Biol. Fish.* doi:10.1007/s11160-020-09629-5.

Neckel, S., and Hasenfratz, M. (2021). Climate emotions and emotional climates: The emotional map of ecological crises and the blind spots on our sociological landscapes. *Soc. Sci. Inf.* 60, 253–271. doi:10.1177/0539018421996264.

Nunnally, J. (1967). *Psychometric Theory*. NY, US: McGraw-Hill, US.

Nyborg, K., Anderies, J. M., Dannenberg, A., Lindahl, T., Schill, C., Schluter, M., et al. (2016). Social norms as solutions. *Science (80-.).* 354, 42–43. doi:10.1126/science.aaf8317.

OECD (2021). OECD Review of Fisheries Country Notes, January 2021 . OECD doi:10.1787/7946BC8A-EN.

Olya, H. G. T., and Akhshik, A. (2019). Tackling the Complexity of the Pro-environmental Behavior Intentions of Visitors to Turtle Sites. *J. Travel Res.* 58, 313–332. doi:10.1177/0047287517751676.

Ostrom, E. (2009). A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science (80-.).* 325, 419–422. doi:10.1126/science.1172133.

Pachecho-Urpí, O. P., Salas, S., and Sierra, L. (2013). Modelo de gestión para la sostenibilidad de los recursos pesqueros del Golfo de Nicoya, Costa Rica. *Rev. Geográfica América Cent.* 1, 165–193.

Pacheco-Urpí, O. (2000). Proceso para la Instauración de un Plan de Desarrollo y Conservación del Golfo de Nicoya y Estrategias de Mediación. Available at: https://scholar.google.com/scholar?hl=es&as_sdt=0%2C5&q=Pacheco-Urpí%2C+O.+2000.+Proceso+para+la+instauración+de+un+plan+de+desarrollo+y+conservación+del+Golfo+de+Nicoya+y+estrategias+de+mediación.+Instituto+Costarricense+de+Pesca+y+Acuicultura+%28Incopes [Accessed September 23, 2018].

Pacheco-Urpí, O. (2013). Gestión de los recursos marinos costeros de las comunidades de Costa de Pájaros y Manzanillo en el interior del Golfo de Nicoya, Costa Rica. Available at: http://repositorio.conicit.go.cr:8080/xmlui/handle/123456789/81 [Accessed January 30, 2021].

Paramor, O. A. L., Hatchard, J. L., Mikalsen, K. H., Gray, T. S., Scott, C. L., and Frid, C. L. J. (2005). Involving fishers in the development of a fisheries ecosystem plan. *ICES C.* 32.

Partelow, S., Jäger, A., and Schlüter, A. (2021). Linking Fisher Perceptions to Social-Ecological Context: Mixed Method Application of the SES Framework in Costa Rica. *Hum. Ecol.* 49, 187–203. doi:10.1007/s10745-021-00228-x.

Partelow, S., Schlüter, A., von Wehrden, H., Jänig, M., and Senff, P. (2017). A Sustainability Agenda for Tropical Marine Science. *Conserv. Lett.* 11, e12351. doi:10.1111/conl.12351.

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., et al. (2017). Valuing nature's contributions to people: the IPBES approach. *Curr. Opin. Environ. Sustain.* 26–27, 7–16. doi:10.1016/j.cosust.2016.12.006.

Patterson, J., Schulz, K., Vervoort, J., van der Hel, S., Widerberg, O., Adler, C., et al. (2017). Exploring the governance and politics of transformations towards sustainability. *Environ. Innov. Soc. Transitions* 24, 1–16. doi:10.1016/j.eist.2016.09.001.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., and Torres, F. (1998). Fishing Down Marine Food Webs. *Science (80-.).* 279, 860–863. doi:10.1126/science.279.5352.860.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T. J., Sumaila, U. R., Walters, C. J., et al. (2002). Towards sustainability in world fisheries. *Nature* 418, 689–695. doi:10.1038/nature01017.

Pauly, D., Christensen, V., and Walters, C. (2000). Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. in *ICES Journal of Marine Science*, 697–706. doi:10.1006/jmsc.2000.0726.

Philip, L. J., and MacMillan, D. C. (2005). Exploring Values, Context and Perceptions in Contingent Valuation Studies: The CV Market Stall Technique and Willingness to Pay for Wildlife Conservation. *J. Environ. Plan. Manag.* 48, 257–274. doi:10.1080/0964056042000338172.

Pikitch, E. K., Santora, C., Babcock, E. A., Bakun, A., Bonfil, R., Conover, D. O., et al. (2004). Ecosystem-based fishery management. *Science (80-.).* 305, 346–347. doi:10.1126/science.1098222.

Pita, C., Pierce, G. J., and Theodossiou, I. (2010). Stakeholders' participation in the fisheries management decision-making process: Fishers' perceptions of participation. *Mar. Policy* 34, 1093–1102. doi:10.1016/j.marpol.2010.03.009.

Pitcher, T. J. (2001). Fisheries managed to rebuild ecosystems? Reconstructing the past to salvage the future. *Ecol. Appl.* 11, 601–617. doi:10.1890/1051-0761(2001)011[0601:FMTRER]2.0.CO;2.

Power, M. D., Haggan, N., and Pitcher, T. J. (2004). The community workshop: how we did it, and what we learned from the results. *Fish. Cent. Res. Reports* 12, 126.

Proyecto Golfos (2012). Estado del Área Marina de Uso Múltiple Golfo de Nicoya. Costa Rica. 83.

Purcell, S. W., and Pomeroy, R. S. (2015). Driving small-scale fisheries in developing countries. *Front. Mar. Sci.* 2, 44. doi:10.3389/fmars.2015.00044.

Quesada-Alpízar, M. A. (2006). Participation and fisheries management in Costa Rica: From theory to practice. *Mar. Policy* 30, 641–650. doi:10.1016/j.marpol.2005.09.001.

Ravera, F., Iniesta-Arandia, I., Martín-López, B., Pascual, U., and Bose, P. (2016). Gender perspectives in resilience, vulnerability and adaptation to global environmental change. *Ambio* 45, 235–247. doi:10.1007/s13280-016-0842-1.

Raymond, C. M., and Kenter, J. O. (2016). Transcendental values and the valuation and management of ecosystem services. *Ecosyst. Serv.* 21, 241–257. doi:10.1016/j.ecoser.2016.07.018.

Rehren, J., Wolff, M., and Jiddawi, N. (2018). Holistic assessment of Chwaka Bay's multi-gear fishery – Using a trophic modeling approach. *J. Mar. Syst.* 180, 265–278. doi:10.1016/j.jmarsys.2018.01.002.

Ressurreição, A., Gibbons, J., Dentinho, T. P., Kaiser, M., Santos, R. S., and Edwards-Jones, G. (2011). Economic valuation of species loss in the open sea. *Ecol. Econ.* 70, 729–739. doi:10.1016/j.ecolecon.2010.11.009.

Ressurreição, A., Gibbons, J., Kaiser, M., Dentinho, T. P., Zarzycki, T., Bentley, C., et al. (2012). Different cultures, different values: The role of cultural variation in public's WTP for marine species conservation. *Biol. Conserv.* 145, 148–159. doi:10.1016/j.biocon.2011.10.026.

Riechers, M., Brunner, B. P., Dajka, J.-C., Duşe, I. A., Lübker, H. M., Manlosa, A. O., et al. (2021a). Leverage points for addressing marine and coastal pollution: A review. *Mar. Pollut. Bull.* 167, 112263. doi:10.1016/j.marpolbul.2021.112263.

Riechers, M., Loos, J., Balázsi, Á., García-Llorente, M., Bieling, C., Burgos-Ayala, A., et al. (2021b). Key advantages of the leverage points perspective to shape human-nature relations. *Ecosyst. People* 17, 205–214. doi:10.1080/26395916.2021.1912829.

Riepe, C., Fujitani, M., Cucherousset, J., Pagel, T., Buoro, M., Santoul, F., et al. (2017). What determines the behavioral intention of local-level fisheries managers to alter fish stocking practices in freshwater recreational fisheries of two European countries? *Fish. Res.* 194, 173–187. doi:10.1016/j.fishres.2017.06.001.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., et al. (2009). A safe operating space for humanity. *Nature* 461, 472–475. doi:10.1038/461472a.

Rodríguez-Chávez, M., UNCTAD, and DOALOS (2019). An Overview on the Legal and Institutional Framework in Ocean Affairs. Available at: http://creativecommons.org/licenses/by/3.0/igo/. [Accessed October 1, 2021].

Ross-Salazar, E. (2014). Artes, métodos e implementos de pesca. Fundación Marviva. 86.

Saavedra-Díaz, L. M., Rosenberg, A. A., and Pomeroy, R. (2015). "Why Colombian marine fishers' knowledge is a fundamental tool for marine resource management and assessment," in *Fishers' Knowledge and the Ecosystem Approach to Fisheries: Applications, Experiences and Lessons in Latin America'.(Eds J. Fischer, J. Jorgensen, H. Josupeit, D. Kalikoski, and CM Lucas.) pp*, 89–106.

Sabau, G. (2017). "Costa Rica: A Champion of the Small-Scale Fisheries Guidelines," in *Springer*, 355–378. doi:10.1007/978-3-319-55074-9_17.

Salas, S., Chuenpagdee, R., Charles, A., and Seijo, J. (2011). *Coastal fisheries of Latin America and the Caribbean*. Available at: http://www.fao.org/3/a-i1926e.pdf [Accessed September 23, 2018].

Salas, S., Chuenpagdee, R., Seijo, J. C., and Charles, A. (2007). Challenges in the assessment and management of small-scale fisheries in Latin America and the Caribbean. *Fish. Res.* 87, 5–16. doi:10.1016/j.fishres.2007.06.015.

Sánchez-Jiménez, A., Fujitani, M., MacMillan, D., Schlüter, A., and Wolff, M. (2019). Connecting a Trophic Model and Local Ecological Knowledge to Improve Fisheries Management: The Case of Gulf of Nicoya, Costa Rica. *Front. Mar. Sci.* 6, 126. doi:10.3389/fmars.2019.00126.

Sánchez-Jiménez, A., Fujitani, M., Wolff, M., and MacMillan, D. (2021a). Plural-values-and-ecosystem-based-Approach to Examine Policy Feasibility in tropical Small-scale Fisheries: a Leverage Point for Sustainability. *Manuscript Submitted for Publication*

Sánchez-Jiménez, A., MacMillan, D., Wolff, M., Schlüter, A., and Fujitani, M. (2021b). The Importance of Values in Predicting and Encouraging Environmental Behavior: Reflections From a Costa Rican Small-Scale Fishery. *Front. Mar. Sci.* 8, 137. doi:10.3389/fmars.2021.543075.

Sánchez-Jiménez, A., Morales-Ramírez, Á., Samper-Villarreal, J., and Sánchez-Noguera, C. (2014). Percepción comunitaria y procesos de Gestión Integrada de Zonas Costeras en el Pacífico Norte de Costa Rica. *Rev. Biol. Trop.* 62, 139. doi:10.15517/rbt.v62i4.20040.

Schlüter, M., Lindkvist, E., and Basurto, X. (2021). The interplay between top-down interventions and bottom-up self-organization shapes opportunities for transforming selfgovernance in small-scale fisheries. *Mar. Policy* 128, 104485. doi:10.1016/j.marpol.2021.104485.

Schwartz, S. H., and Bardi, A. (2001). Value hierarchies across cultures: Taking a similarities perspective. *J. Cross. Cult. Psychol.* 32, 268–290. doi:10.1177/0022022101032003002.

Schwartz, S. H., and Bilsky, W. (1987). Toward a universal psychological structure of human values. *J. Pers. Soc. Psychol.* 53, 550–562. doi:10.1037/0022-3514.53.3.550.

Schwartz, S. H., and Howard, J. A. (1981). A normative decision-making model of altruism. In J. P. Rushton (Ed.), Altruism and helping behaviour: Social, personality and developmental perspectives (pp. 189–211). Hillsdale, NJ: Erlbaum.

Skubel, R. A., Shriver-Rice, M., and Maranto, G. M. (2019). Introducing Relational Values as a Tool for Shark Conservation, Science, and Management. *Front. Mar. Sci.* 6. doi:10.3389/fmars.2019.00053.

Smith, H., and Basurto, X. (2019). Defining Small-Scale Fisheries and Examining the Role of Science in Shaping Perceptions of Who and What Counts: A Systematic Review. *Front. Mar. Sci.* 6, 236. doi:10.3389/fmars.2019.00236.

Smyth, J. C. (2006). Environment and education: a view of a changing scene: Reprinted from Environmental Education on Research (2005) 1(1), pp. 3–20. *Environ. Educ. Res.* 12, 247–264. doi:10.1080/13504620600942642.

Song, A. M., Chuenpagdee, R., and Jentoft, S. (2013). Values, images, and principles: What they represent and how they may improve fisheries governance. *Mar. Policy* 40, 167–175. doi:10.1016/j.marpol.2013.01.018.

Spash, C. L. (2007). Deliberative monetary valuation (DMV): Issues in combining economic and political processes to value environmental change. *Ecol. Econ.* 63, 690–699. doi:10.1016/j.ecolecon.2007.02.014.

Spash, C. L. (2008). Deliberative Monetary Valuation and the Evidence for a New Value Theory. *Land Econ.* 84, 469–488. doi:10.3368/le.84.3.469.

Spash, C. L., Urama, K., Burton, R., Kenyon, W., Shannon, P., and Hill, G. (2009). Motives behind willingness to pay for improving biodiversity in a water ecosystem: Economics, ethics and social psychology. *Ecol. Econ.* 68, 955–964. doi:10.1016/j.ecolecon.2006.09.013.

Steenbeek, J., Romagnoni, G., Bentley, J. W., Heymans, J. J., Serpetti, N., Gonçalves, M., et al. (2020). Combining ecosystem modeling with serious gaming in support of transboundary maritime spatial planning. *Ecol. Soc.* 25, art21. doi:10.5751/ES-11580-250221.

Steenkamp, J.-B. E. M., De Jong, M. G., and Baumgartner, H. (2010). Socially Desirable Response Tendencies in Survey Research. *J. Mark. Res.* 47, 199–214. doi:10.1509/jmkr.47.2.199.

Steffen, W., Richardson, K., Rockstrom, J., Cornell, S. E., Fetzer, I., Bennett, E. M., et al. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science (80-.).* 347, 1259855–1259855. doi:10.1126/science.1259855.

Steg, L., Dreijerink, L., and Abrahamse, W. (2005). Factors influencing the acceptability of energy policies: A test of VBN theory. *J. Environ. Psychol.* 25, 415–425. doi:10.1016/j.jenvp.2005.08.003.

Sterman, J. D. (2008). ECONOMICS: Risk Communication on Climate: Mental Models and Mass Balance. *Science (80-.).* 322, 532–533. doi:10.1126/science.1162574.

Stern-Pirlot, A., and Wolff, M. (2006). Population dynamics and fisheries potential of Anadara tuberculosa (Bivalvia: Arcidae) along the Pacific coast of Costa Rica. *Rev. Biol. Trop.* 54, 87–100. doi:10.15517/rbt.v54i1.26838.

Stern, M. J., Powell, R. B., and Ardoin, N. M. (2008). What Difference Does It Make? Assessing Outcomes From Participation in a Residential Environmental Education Program. *J. Environ. Educ.* 39, 31–43. doi:10.3200/JOEE.39.4.31-43.

Stern, P. C. (2000). New Environmental Theories: Toward a Coherent Theory of Environmentally Significant Behavior. *J. Soc. Issues* 56, 407–424. doi:10.1111/0022-4537.00175.

Stern, P. C., and Dietz, T. (1994). The Value Basis of Environmental Concern. *J. Soc. Issues* 50, 65–84. doi:10.1111/j.1540-4560.1994.tb02420.x.

Stern, P. C., Dietz, T., Abel, T., Guagnano, G. A., and Kalof, L. (1999). A value-belief-norm theory of support for social movements: The case of environmentalism. *Hum. Ecol. Rev.* 6, 81–97. Available at: https://www.jstor.org/stable/24707060 [Accessed March 10, 2020].

Tengö, M., Brondizio, E. S., Elmqvist, T., Malmer, P., and Spierenburg, M. (2014). Connecting Diverse Knowledge Systems for Enhanced Ecosystem Governance: The Multiple Evidence Base Approach. *Ambio* 43, 579–591. doi:10.1007/s13280-014-0501-3.

Torres-Guevara, L. E., Lopez, M. C., and Schlüter, A. (2016). Understanding artisanal fishers' behaviors: The case of Ciénaga Grande de Santa Marta, Colombia. *Sustain.* 8, 549. doi:10.3390/su8060549.

Trujillo, P., Cisneros-Montemayor, A. M., Harper, S., Zylich, K., and Zeller, D. (2015). Reconstruction Of Costa Rica's Marine Fisheries Catches, 1950-2010. Vancouver Available at: www.fao.org [Accessed June 23, 2021].

Ulate-Garita, G. (2020). Funcionalidad Socioeconómica Y Biológica Del Área Marina De Pesca Responsable Palito – Montero, En Isla De Chira, Golfo De Nicoya, Costa Rica.

UNESCO (2019). United Nations Decade of Ocean Science for Sustainable Development. Available at: https://www.oceandecade.org/ [Accessed April 4, 2021].

United Nations (2015). Transforming our world: the 2030 Agenda for Sustainable Development Transforming our world: the 2030 Agenda for Sustainable Development Preamble. Available at: https://sdgs.un.org/sites/default/files/publications/21252030 Agenda for Sustainable Development web.pdf [Accessed June 21, 2021].

United Nations (2016). Education - United Nations Sustainable Development. *UN Web Serv. Sect. Dep. Public Information, United Nations*. Available at: https://www.un.org/sustainabledevelopment/education/ [Accessed March 10, 2020].

van Riper, C. J., and Kyle, G. T. (2014). Understanding the internal processes of behavioral engagement in a national park: A latent variable path analysis of the value-belief-norm theory. *J. Environ. Psychol.* 38, 288–297. doi:10.1016/j.jenvp.2014.03.002.

Vargas-Zamora, J. A., López-Sánchez, M. I., and Ramírez-Coghi, A. R. (2019). Fishes from the Gulf of Nicoya, Pacific, Costa Rica: An update of the lists of the Skimmer and Victor Hensen research vessels. *Rev. Biol. Trop.* 67, 913–934. doi:10.15517/rbt.v67i4.36609.

Vargas, J. A. (1995). The Gulf of Nicoya Estuary, Costa Rica: Past, present, and future cooperative research. *Helgoländer Meeresuntersuchungen* 49, 821–828. doi:10.1007/BF02368405.

Vargas, J. A. (2016). "The Gulf of Nicoya Estuarine Ecosystem," in *Costa Rican Ecosystems* (University of Chicago Press), 139–161. doi:10.7208/chicago/9780226121642.003.0006.

Veisten, K., Fredrik Hoen, H., Navrud, S., and Strand, J. (2004). Scope insensitivity in contingent valuation of complex environmental amenities. *J. Environ. Manage.* 73, 317–331. doi:10.1016/j.jenvman.2004.07.008.

Völker, M., and Lienhoop, N. (2016). Exploring group dynamics in deliberative choice experiments. *Ecol. Econ.* 123, 57–67. doi:10.1016/j.ecolecon.2016.01.006.

Voorhis, A. D., Epifanio, C. E., Maurer, D., Dittel, A. I., and Vargas, J. A. (1983). The estuarine character of the Gulf of Nicoya, an embayment on the Pacific coast of Central America. *Hydrobiologia* 99, 225–237. doi:10.1007/BF00008774.

Voss, R., Quaas, M. F., Schmidt, J. O., Tahvonen, O., Lindegren, M., and Möllmann, C. (2014). Assessing Social – Ecological Trade-Offs to Advance Ecosystem-Based Fisheries Management. *PLoS One* 9, e107811. doi:10.1371/journal.pone.0107811.

Wabnitz, C. C. C., Lam, V. W. Y., Reygondeau, G., Teh, L. C. L., Al-Abdulrazzak, D., Khalfallah, M., et al. (2018). Climate change impacts on marine biodiversity, fisheries and society in the Arabian Gulf. *PLoS One* 13, e0194537. doi:10.1371/JOURNAL.PONE.0194537.

Walters, C. (1986). *Adaptive Management of Renewable Resources*. Internatio. New York: Collier Macmillan Publishing Company Available at: http://pure.iiasa.ac.at/id/eprint/2775/1/ER-86-012.pdf [Accessed March 13, 2020].

Walters, C., Martell, S. J. D., Christensen, V., and Mahmoudi, B. (2008). An Ecosim model for exploring Gulf of Mexico ecosystem management options: implications of including multistanza life-history models for policy predictions. *Bull. Mar. Sci.* 83, 251–271.

Ward, B. M., Doney, E. D., Vodden, K., and Bath, A. J. (2017). The importance of beliefs in predicting support for a South Coast National Marine Conservation Area in Newfoundland and Labrador, Canada. *Ocean Coast. Manag.* 162, 6–12. doi:10.1016/j.ocecoaman.2017.12.021.

Wehrtmann, I. S., and Cortés, J. eds. (2009). *Marine Biodiversity of Costa Rica, Central America*. Dordrecht: Springer Netherlands doi:10.1007/978-1-4020-8278-8.

Wehrtmann, I. S., and Nielsen Munoz, V. (2009). The deep water fishery along the Pacific coast of Costa Rica, Central America. *Lat. Am. J. Aquat. Res.* 37, 543–554. doi:10.3856/vol37-issue3-fulltext-19.

Wilson, M. A., and Howarth, R. B. (2002). Discourse-based valuation of ecosystem services: establishing fair outcomes through group deliberation. *Ecol. Econ.* 41, 431–443. doi:10.1016/S0921-8009(02)00092-7.

Wolff, M. (2006). Biomass flow structure and resource potential of two mangrove estuaries: insights from comparative modelling in Costa Rica and Brazil. *Rev. Biol. Trop.* 54, 69–86. doi:10.15517/rbt.v54i1.26837.

Wolff, M., Koch, V., Chavarría, J. B., and Vargas, J. A. (1998). A trophic flow model of the Golfo de Nicoya, Costa Rica. *Rev. Biol. Trop.* 46, 63–79. doi:10.15517/rbt.v46i6.29645.

Wulf, A. (2015). *The Invention of Nature: Alexander von Humboldt's New World*. (1st ed.). London: John Murray.

Wynveen, C. J., and Sutton, S. G. (2017). Engaging Great Barrier Reef Stakeholders: Mediation Analyses of Barriers Among the Antecedents of Pro-Environmental Behavior. *Hum. Dimens. Wildl.* 22, 126–141. doi:10.1080/10871209.2016.1265185.

Zafra-Calvo, N., Balvanera, P., Pascual, U., Merçon, J., Martín-López, B., van Noordwijk, M., et al. (2020). Plural valuation of nature for equity and sustainability: Insights from the Global South. *Glob. Environ. Chang.* 63, 102115. doi:10.1016/j.gloenvcha.2020.102115.

Zheng, X., Wang, R., Hoekstra, A. Y., Krol, M. S., Zhang, Y., Guo, K., et al. (2021). Consideration of culture is vital if we are to achieve the Sustainable Development Goals. *One Earth* 4, 307–319. doi:10.1016/j.oneear.2021.01.012.

ANNEX

Fishing communities of the Gulf of Nicoya: Costa de Pájaros (above) and Playa Blanca, Paquera-Tambor (below).

ANNEX I

Supplements for Chapter 1

Table S1.1 Definitions of the concept of value applied along the dissertation chapters

- **Universal values** (Schwartz and Bilsky, 1987)**:** Stable principles that guide human judgments and action (biospheric, altruistic and egoistic values). Also known as transcendental values.

Ecosystem services-related values (Arias-Arévalo et al., 2018; Pascual et al., 2017)

- **Plural values:** Different ways of perceiving the importance of nature, ecosystems and ecosystem services (instrumental, intrinsic and relational) IPBES
- **Intrinsic value:** The value of nature, ecosystems, or life as ends in themselves, irrespective of their utility to humans.
- **Instrumental value**: The value of nature as merely a means to an end.
- **Relational values**: The importance attributed to meaningful relations and responsibilities between humans and between humans and nature.

Contextual values: worth or importance of something that is dependent on the context, and from monetary or non-monetary value indicators such as willingness to pay or accept (WTP or WTA) rankings and ratings (Raymond and Kenter, 2016).

Table S1.2. Functional groups and main taxa of group included in the Ecopath with Ecosim model of the Gulf of Nicoya developed by (Alms and Wolff, 2019)

Functional Groups	Main taxa of group
1. Seabirds	*Anhinga anhinga*, *Fregata magnificens*, *F. minor*, *Oceanodroma melania*, *Pelecanus erythrorhynchos*, *P. occidentalis*, *Phalacrocorax brasilianus*, *Sula* spp., and others
2. Rays & Sharks	*Aetobatus narinari*, *Dasyatis longus*, *Raja velezi*, *Torpedo peruana*, *Urotrygon* spp., *Zapteryx xyster*; *Alopias superciliosus*, *Isurus oxyrinchus*, *Mustelus henlei*, *M. lunulatus*, *Sphyrna lewini*
3. Mackerel & Barracuda	*Scomberomorus sierra*, *Sphyraena ensis*
4. Large Corvina (drum) & Snook	*Cynoscion albus*, *C. stolzmanni*; *Centropomus nigresces*, *C. viridis*
5. Morays & Eels	*Anguila amarilla*, *A. negra*, *Brotula clarkae*, *Cynoponticus coniceps*, *Ophichthus zophochir* and others
6. Catfish	*Aruis* spp., *Bagre panamensis*, *B. pinnimaculatus*, *Cuminate colorado*, *Notarius troschelii*
7. Flatfish	*Cyclopsetta querna*, *Paralichthys woolmani*, *Syacium latifrons*, *S. ovale*, *Symphurus* spp., *Trinectes* sp. and others
8. Small Demersals	Small and juvenile Scianidae and Centropomidae, Mullidae, Sparidae, Blenniidae, Gerreidae, Gobiidae, Scorpaenidae, Serranidae and others
9. Snapper & Grunts	*Lutjanus colorado*, *L. guttatus*, *L. novemfasciatus*, *L.* spp., *Haemulopsis axilaris*, *H. elongatus*, Haemulon scudderii, *H.* spp., *Pomadasys* sp.
10. Carangids	*Caranx caballus*, *C.* spp., *Gnathanodon speciosus*, *Oligoplites* spp., *Selene peruviana*, *Seriola rivoliana*
11. Small Pelagics	*Anchoa* spp., *Cetengraulis mysticenus*, *Opisthonema* spp.
12. Cephalopods	*Euaxoctopus panamensis*, *Lolliguncula* spp., *Octopus vulgaris*
13. Lobster	*Panulirus gracilis*
14. Crabs	*Calappa convexa*, *Callinectes arcuatus*, *C.* spp., *Pleuroncodes* sp., *Squilla* sp., Gecarcinidae, Grapsidae, Xanthidae
15. Epibenthos	*Anadara* spp., Mytilidae, Ostreidae and other bivalvia, Strombidae and other Gastropoda, Diogenidae, Echinodermata, Ispopoda, Paguridae
16. Endobenthos	Polycheata: Capitellida, Orbiniida, Spionida, Branchiostomidae and others
17. Shrimps	Penaeidae: Litopenaeus spp., *Heterocarpus* spp. *Farfantepenaeus* spp. *Xiphopenaeus riverti*, *Protrachypene precipua*, *Rimapenaeus byrd*i, Solenocera: *Solenocera agassizii*
18. Zooplankton	Copepoda: Calanoida & others, Chaetognatha, Crustacea larvae, Ichtyoplankton, Bivalvia and Brachiopoda larvae, Ostracoda, Cladocera, Foraminifera, Appendicularia
19. Mangroves	*Rhizophora* sp., *Pelliciera* sp., *Avicennia* sp.
20. Microphytes	Cyanobacteria, benthic diatoms
21. Phytoplankton	Centric and pennate diatoms, Dinoflagellates and others
22. Detritus	

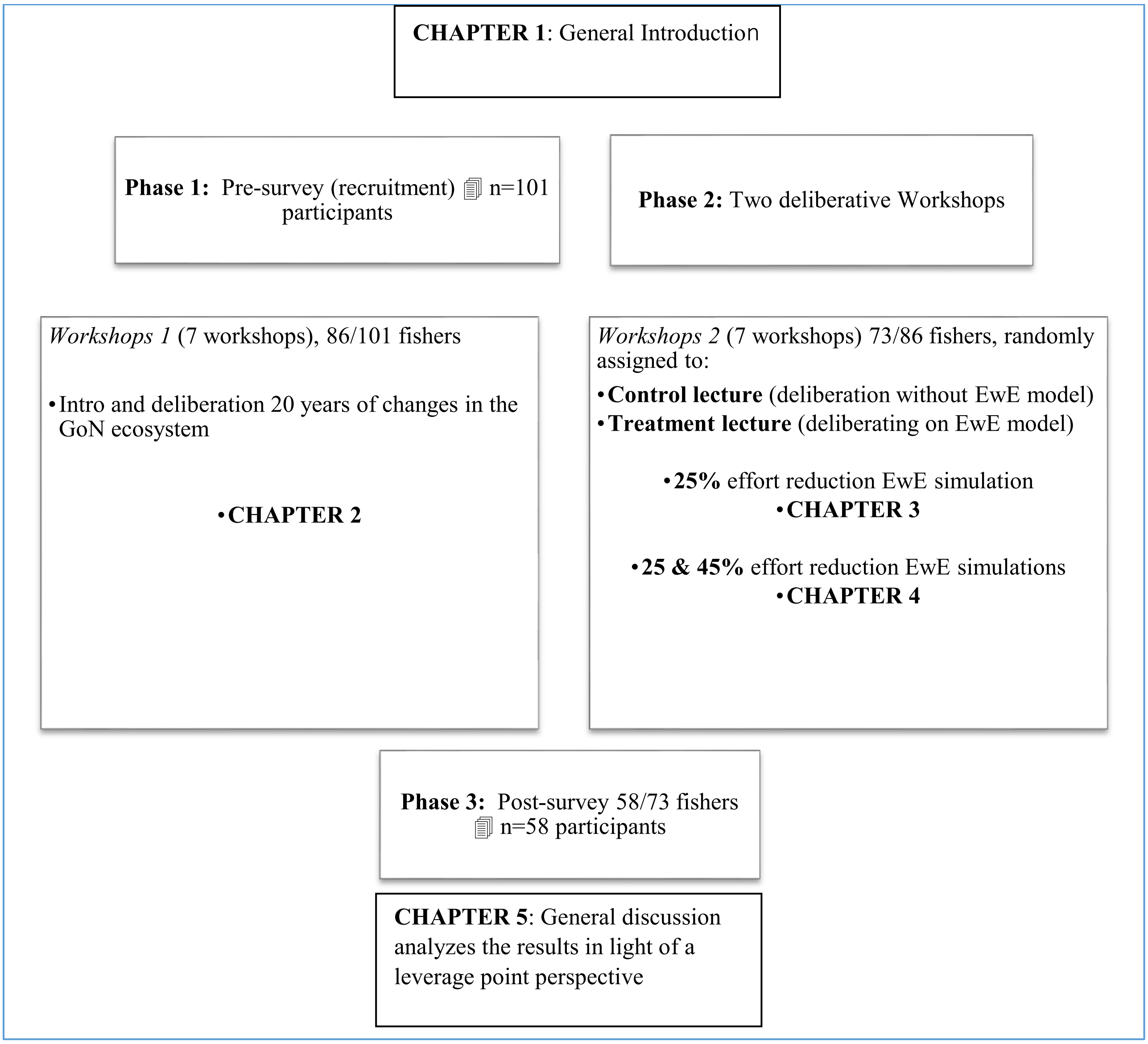


Figure S1.1. Thesis outline and experimental design applied along the chapters of this dissertation.

ANNEX II
Supplements for Chapter 2

Text S2.1. Recruitment questionnaire contents. English version of the recruitment questionnaire applied to fishers in the Gulf of Nicoya.

Centro de Investigación en Ciencias del Mar y Limnología
Universidad de Costa Rica
San Pedro, Costa Rica
+ (506) 2511-2200

Leibniz Centre for Tropical Marine Research (ZMT)
Fahrenheitstr. 6
28359 Bremen, Germany
+49 (421) 23800-70

Number of the survey	Place	Date and time

Code Site: Isla Chira 99 ( ) Costa de Pájaros 98 ( ) Paquera 96 ( )

Good morning!

This interview is part of a doctoral study about adaptation of small scale fishers to more sustainable fishing schemes in the Gulf of Nicoya. The interview is confidential and volunteer, all the information gathered will be used for the purpose of academic research and you can drop the interview at any given moment. Are you interested in being part of it?

(1) Socio-economic, demographic characteristics and fishing practices

General Respondent Information

Do you live here?

☐ Yes ☐ No

For how long have you been living in the community?

☐ 1-5 years ☐ 5-10 years ☐ More than 10 years

Are you currently a fisher?

☐ Yes ☐ No

Which option represent you better? I´ve been a fisherman for…

☐ Less than 5 years ☐ between 5-10 years ☐ between 10-20 years

☐ More than 20 years

Which are the three most important species do you fish?

☐ Croakers ☐ Shrimps ☐ Snappers

☐ Sardines ☐ Others__________________

Which fishing gears do you use for fishing each species?

☐ Hand line __________________ ☐ Gillnet __________________ ☐ Longline __________________

☐ Taiwanese line __________________ ☐ Other__________________

In a typical day of a good fishing season, for how long do you go out and fish with your main fishing gear? Hours per day

☐ Less than 6 hours ☐ 6-9 hours ☐ 9-12 hours

☐ 12-15 hours☐ More than 15 hours

In a typical day of a good fishing season, for how many days in a week do you go out and fish?

☐ Less than 2 days ☐ 2-6 days ☐ Everyday

Do you have a fishing license of INCOPESCA up to date?

☐ Yes ☐ No (go and ask about demographic and household information, and end of the survey)

Demographic information of the respondent

Genera

☐ Male ☐ Female ☐ Other

How old are you?

☐ 8-25 years old ☐ 26-32 years old ☐ 33-39 years old

☐ 40-46 years old ☐ 47-53 years old ☐ 54-60 years old

☐ Senior citizen

Which is your highest level of formal education approved?

☐ None ☐ Incomplete primary school☐ Complete primary

☐ Incomplete high school ☐ Complete high school ☐ incomplete university

☐ Complete University ☐ Technician ☐ Other_____________

Household and socio economic information of the respondent

Which statement represent you better about your household?

☐ I´m the owner of my house☐ my house is rented ☐ I live with relatives

☐ Other

Which economic activities do you practice?

☐ Fishing ☐ Tourism services (hotel, restaurant) ☐ Tour operator

☐ Housework ☐ Student ☐ Office services

What is the main source (job or activity) of income in your household?

☐ Fishing ☐ Tourism ☐ Agriculture Other

From every 100,000 colones of income in your household, approximately how much do you get from the main source of work?

Colones

How many people depend of your income?

Number of dependents

Which option represent you better? For fishing I use…

☐ A simple boat ☐ “Panga con motor fuera de borda” ☐ “Lancha con motor infra borda”

☐ I don’t use boat

If you use a boat, are you the captain of the boat?

☐ Yes ☐ No

Are you the owner of the boat?

☐ Yes ☐ No

How do you acquire the boat?

☐ Own savings ☐ Bank loan ☐ Informal loan

☐ Inherited ☐ Borrowed ☐ Other

(2) Feedback and availability to workshops

Additional Feedback

Do you have something additional to comment?

Thank you very much for taking the time to answer this survey. All the information contained here is really appreciated and will be used for the purpose of this research only. To finish, there is just one more question:

Would you like to provide us some personal information like your name and a telephone number where I can to contact you for invite you to a workshop?

☐ Yes | ☐ No

Personal Information

First Name	Last Name	Gender	Age
Address	**City**	**Email**	**Phone**

Supporting Figures

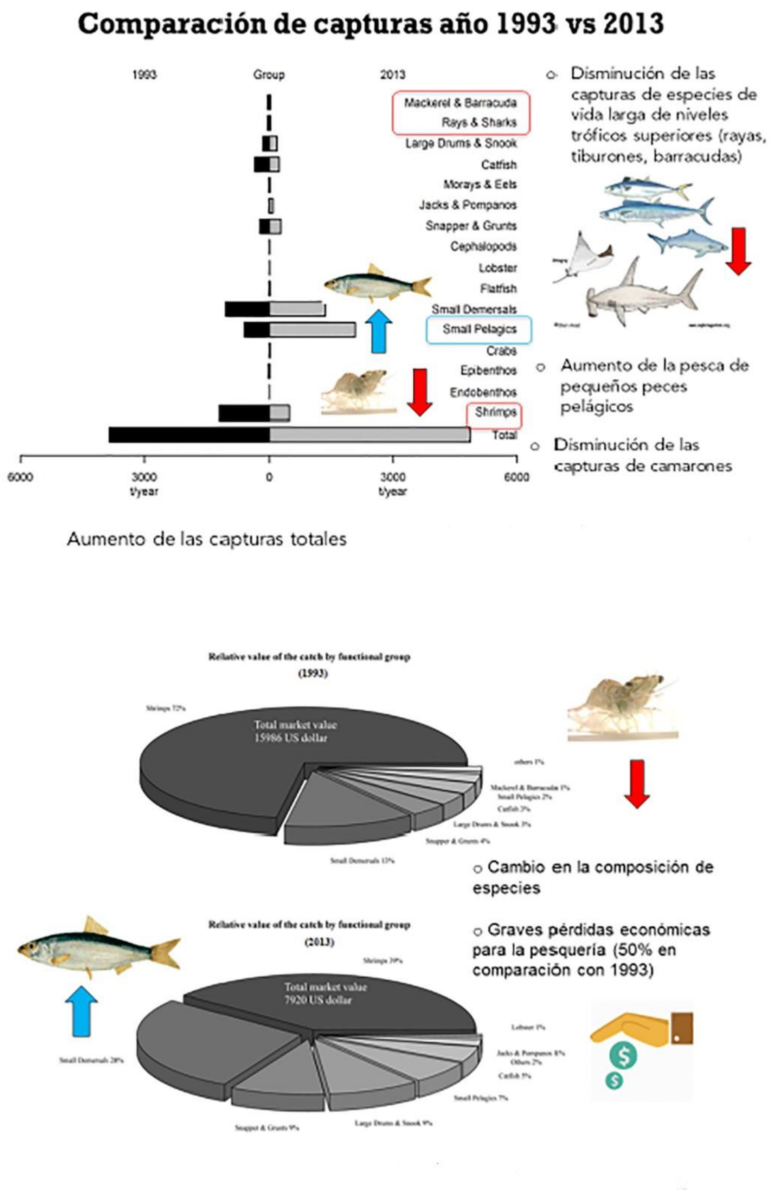


Figure S2.1. Lecture slides of workshops 1 (in the original language Spanish). Changes in the catch and the relative value of the catch by functional groups 1993 vs 2013. Adapted from (Alms and Wolff, 2019).

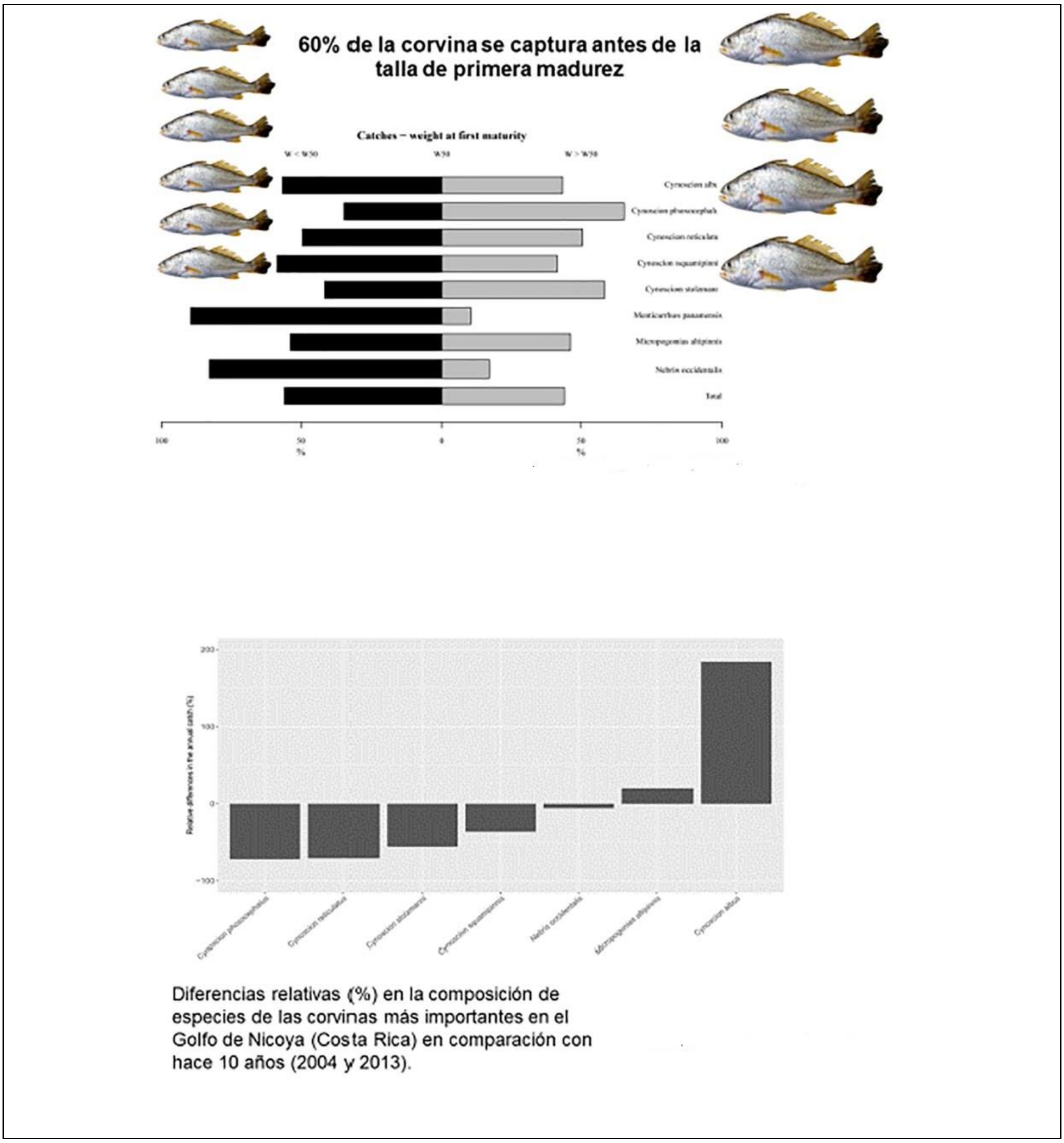


Figure S2.2. Lecture slides of workshop 2 (in the original language Spanish). Changes in the catch of corvinas 1993 vs 2013. Adapted from Alms and Wolff, (2019).

Transcription of the slides:

There is a reduction in catches of corvinas and shrimps that led to additional changes (Alms and Wolff, 2019):
(1) a decline in the commercial value of the catches (almost 50%) compared to that in the 1990s. Although shrimps still represent the largest contribution (39%) of the total value, an important percentage of the economic value (35%) is currently provided by species of lower commercial price, as is the case of small demersal (28%, e.g., small corvinas) and small pelagic species such as sardines and anchovies (7%), other species of higher trophic levels only contribute small percentages, such as snappers (9%), large corvinas (9%) and catfish (5%).
(2) Eighty percent of corvinas caught in the 2010s had not reached the size at first maturity, and were thus small individuals of lower market prices.
(3) There are changes in corvinas and shrimps in terms of the species composition of the catches, while the capture of whitefin weakfish and tallfin croaker have increased, the catches of other corvina species have diminished by 35%; likewise there was a severe decrease in the catches of coastal shrimp species, including the white shrimp and the Pacific sea bob shrimp ~titi.

Supporting tables

Table S2.1 | Categorical variables that characterize the interviews respondents.

Respondents‘ characteristics	Total response	% Response	Respondents‘ characteristics	Total response	% Response	Respondents‘ characteristics	Total response	% Response
Gender	N=58		**Education**	N=58		**Time of residence**	N=58	
Male	*48*	***82.8***	None	4	6.9	1-5 years	1	1.7
Female	10	17.2	Primary (inc)*	9	15.5	5-10 years	1	1.7
N	58	100.0	*Primary (co)**	*30*	***51.7***	*>10 years*	*56*	***96.6***
			H-school* (inc)	8	13.8	N	58	100.0
			H-school(co)	7	12.1			
Boat owner	N=58		**Basic Expenses ₡***	N=55		**Income from fishing ₡***	N=57	
No	18	31.0	*80-110 ^{000*}*	*13*	***23.6***	100 ^{000*}	11	19.3
Yes	*40*	69.0	110-140 ^{000}	11	20.0	200 ^{000}	22	***38.6***
			140-170 ^{000}	7	12.7	300 ^{000}	22	**38.6**
			170-200 ^{000}	10	18.2	500 ^{000}	2	3.5
			200-230 ^{000}	10	18.2			
Fishing experience	N=57		**Fishing-effort (hours)**	N=57		**Fishing effort (days)**	N=58	
<5 years	4	7.0	<6 hours	11	19.3	< 2 days	2	3.4
5-10 years	5	8.8	*6-9 hours*	*23*	***40.4***	2-6 days	23	39.7
10-20 years	21	36.8	9-12 hours	17	29.8	*every day*	*33*	***56.9***
>20 years	*27*	***47.4***	12-15	6	10.5			
Fishing gear	N=57		**Commercial species caught**	N=58		**Fishing sites**	N=58	
Gillnet	*98*	***66.7***	*Corvina & shrimps*	*20*	***34.5***	Zone 201 (1)	10	17.2
Gillnet & handline	15	26.3	Corvina & snappers	15	25.9	Zone 202 (2)	5	8.6
Gillnet bottomline	4	7.0	Corvina	13	22.4	Zone 203 (3)	13	22.4
			Shrimps	6	10.3	*Zones 1 & 2*	*19*	***32.8***
			All species	4	6.9	Zones 1 & 3	1	1.7
						Zones 3 & 2	5	8.6
						All sites	5	8.6

*The basic expenses and the income from fishing are given in Costa Rican colones (₡), €:1 ₡611.00 (as of survey year/month). Inc= incomplete and co= complete, h-school stands for high school. ^{000} = thousand.

Table S2.2 | Continuous variables that characterize the interviews respondents.

Respondents‘ characteristics	Total response	Ave.	Min.	Max.	s.d
-Age	58	41	18	70	12,52
-Number of dependents	58	3,3	0	7	1,46

ANNEX III

Supplements for Chapter 3

Text S3.1. Pre-survey. English version of the pre-survey applied to fishers in the Gulf of Nicoya.

Centro de Investigación en
Ciencias del Mar y
Limnología
Universidad de Costa Rica
San Pedro, Costa Rica
+ (506) 2511-2200

Leibniz Centre for Tropical Marine Research (ZMT)
Fahrenheitstr. 6
28359 Bremen, Germany
+49 (421) 23800-70

Number of the survey	Place	Date and time

Code Site: Isla Chira 99 ( ) Costa de Pájaros 98 ( ) Paquera 96 ( )

Good morning!

This interview is part of a doctoral study about adaptation of small scale fishers to more sustainable fishing schemes in the Gulf of Nicoya. The interview is confidential and volunteer, all the information gathered will be used for the purpose of academic research and you can drop the interview at any given moment. Are you interested in being part of it?

(1) Socio-economic, demographic characteristics and fishing practices

General Respondent Information

Do you live here?

☐ Yes ☐ No

For how long have you been living in the community?

☐ 1-5 years ☐ 5-10 years ☐ More than 10 years

Are you currently a fisher?

☐ Yes ☐ No

Which option represent you better? I´ve been a fisherman for…

☐ Less than 5 years ☐ between 5-10 years ☐ between 10-20 years

☐ More than 20 years

Which are the three most important species do you fish?

☐ Croakers ☐ Shrimps ☐ Snappers

☐ Sardines ☐ Others___________________

Which fishing gears do you use for fishing each species?

☐ Hand line ___________________ ☐ Gillnet ___________________ ☐ Longline ___________________

☐ Taiwanese line ___________________ ☐ Other___________________

In a typical day of a good fishing season, for how long do you go out and fish with your main fishing gear? Hours per day

☐ Less than 6 hours ☐ 6-9 hours ☐ 9-12 hours

☐ 12-15 hours☐ More than 15 hours

In a typical day of a good fishing season, for how many days in a week do you go out and fish?

☐ Less than 2 days ☐ 2-6 days ☐ Everyday

Do you have a fishing license of INCOPESCA up to date?

☐ Yes ☐ No (go and ask about demographic and household information, and end of the survey)

Demographic information of the respondent

Genera

☐ Male ☐ Female ☐ Other

How old are you?

☐ 8-25 years old ☐ 26-32 years old ☐ 33-39 years old

☐ 40-46 years old ☐ 47-53 years old ☐ 54-60 years old

☐ Senior citizen

Which is your highest level of formal education approved?

☐ None ☐ Incomplete primary school ☐ Complete primary

☐ Incomplete high school ☐ Complete high school ☐ incomplete university

☐ Complete University ☐ Technician ☐ Other_____________

Household and socio economic information of the respondent

Which statement represent you better about your household?

☐ I´m the owner of my house ☐ my house is rented ☐ I live with relatives

☐ Other

Which economic activities do you practice?

☐ Fishing ☐ Tourism services (hotel, restaurant) ☐ Tour operator

☐ Housework ☐ Student ☐ Office services

What is the main source (job or activity) of income in your household?

☐ Fishing ☐ Tourism ☐ Agriculture Other

____

From every 100,000 colones of income in your household, approximately how much do you get from the main source of work?

Colones

____

How many people depend of your income?

Number of dependents

____

Which option represent you better? For fishing I use…

☐ A simple boat ☐ "Panga con motor fuera de borda" ☐ "Lancha con motor infra borda"

☐ I don't use boat

If you use a boat, are you the captain of the boat?

☐ Yes ☐ No

Are you the owner of the boat?

☐ Yes ☐ No

How do you acquire the boat?

☐ Own savings ☐ Bank loan ☐ Informal loan

☐ Inherited ☐ Borrowed ☐ Other

(2) Antecedents of pro-environmental behavior

Questions about your values and beliefs (Kenter et al., 2016)

The next set of questions will give us an indication of what your values and beliefs are in relation to the environment. Don't think the questions for too long, just use your first feeling to answer the questions.

How important are the following values as a guiding principle in your life? For each one please tick one the boxes from opposed to this value to of supreme importance

Values	Egoistic	BV2.3 EGO	-Wealth, material possessions, money	-1, 0, 1, 2, 3, 4, 5, 6, 7 (Opposed to this value -1 Not important 0 Slightly important 1 Slightly important 2 Important 3 Vastly important 4 Vastly important 5 Very important 6 Of supreme importance 7)
		BV2.6 EGO	-Influence, having an impact on people and events	
		BV2.8 EGO	-Authority, the right to lead or command	
	Altruistic	BV2.2 ALT	-Social justice, correcting injustice, care for the weak	

		BV2.4 ALT	-Equality, equal opportunity for all	
		BV2.5 ALT	-A world at peace, free of war and conflict	
	Biospheric	BV2.1 BIO	-Respecting the earth, harmony with other species	
		BV2.7 BIO	-Protecting the environment, preserving nature	
		BV2.9 BIO	-Unity with nature, fitting into nature	

Listed below are statements about the relationships between humans and the environment. For each one please indicate whether you strongly disagree, mildly disagree, are unsure, mildly agree or strongly agree with it.

Beliefs	New Ecological Paradigm	NEP1 World views*	-Humans have the right to modify the natural environment to suit their needs (stated negatively)*	1, 2, 3, 4, 5 (strongly disagree, mildly disagree, unsure, mildly agree, strongly agree)
		NEP2 World views	-Humans are severely abusing the environment	
		NEP3 World views	-The earth is like a spaceship with very limited room and resources	
		NEP4 World views*	-The so-called "ecological crisis" facing humankind has been greatly exaggerated (stated negatively)*	
		NEP5.1 World views	-Plants and animals have as much right as humans to exist	
	Awareness of consequences	AC1 Consequences	-Many forms of life in our seas are under a real threat from human activities	1, 2, 3, 4, 5 (strongly disagree, mildly disagree, unsure, mildly agree, strongly agree)

		AC2 Consequences*	-If the diversity of life in the seas would be diminished, it would not significantly impact on our economy (stated negatively)*	
	Ascription of responsibility	AR1 Responsibility*	-I feel responsible for the plight of rare or endangered species of plants and animals	1, 2, 3, 4, 5 (strongly disagree, mildly disagree, unsure, mildly agree, strongly agree)
		AR2 Responsibility*	-I don't feel personally responsible for environmental issues, as they are the responsibility of government and industry (stated negatively)*	
Norms (TPB)	Social norms	SN1 Social	-Most people important to me think I should support conservation of sea life	1, 2, 3, 4, 5 (strongly disagree, mildly disagree, unsure, mildly agree, strongly agree)
		SN2 Social	-Most people important to me support taking action to protect the marine environment	
Norms	Personal norms	PN1 Personal	-We should protect spaces for other species to live and thrive in our marine environment	1, 2, 3, 4, 5 (strongly disagree, mildly disagree, unsure, mildly agree, strongly agree)
		PN2 Personal*	-We should think about the economic importance of the seas first, and only then about environment and conservation issues (stated negatively)*	

TPB	Perceived behavioral control	PBC1 Behavioral	-It is easy to take action to support protection of the marine environment	1, 2, 3, 4, 5 (strongly disagree, mildly disagree, unsure, mildly agree, strongly agree)
		PBC2 Behavioral*	-It is difficult for me to do anything significant that would help conservation of sea life (stated negatively)*	

(3) Support for management measures

How important are the following measures to support sustainability and the health of the ecosystem in Gulf of Nicoya? For each one please tick one the boxes as an expression of your support, from opposed to this measure to of supreme importance

(A) Intention to support sustainable fisheries management	-1, 0, 1, 2, 3, 4, 5, 6, 7 (Opposed to this measure -1 Not important 0 Slightly important 1 Slightly important 2 Important 3 Vastly important 4 Vastly important 5 Very important 6 Of supreme importance 7)
(B) Intention to support a specific management action (reduction of 25% in the fishing effort) (C) Actual behavior to support sustainable fisheries (fishing license ownership)	

(4) Additional Feedback

Do you have something additional to comment?

Thank you very much for taking the time to answer this survey. All the information contained here is really appreciated and will be used for the purpose of this research only.

Personal Information

First Name	Last Name	Gender	Age
Address	City	Email	Phone

Supporting Figures

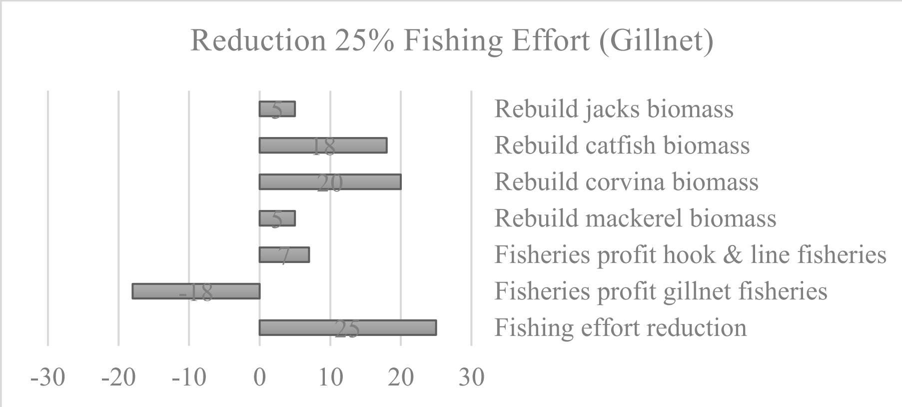


Fig S3.1. Information about scenario 25% effort reduction delivered in the workshops-2 to the control group based on (Alms and Wolff, 2019). No detailed information on species and fishing gears interactions were presented.

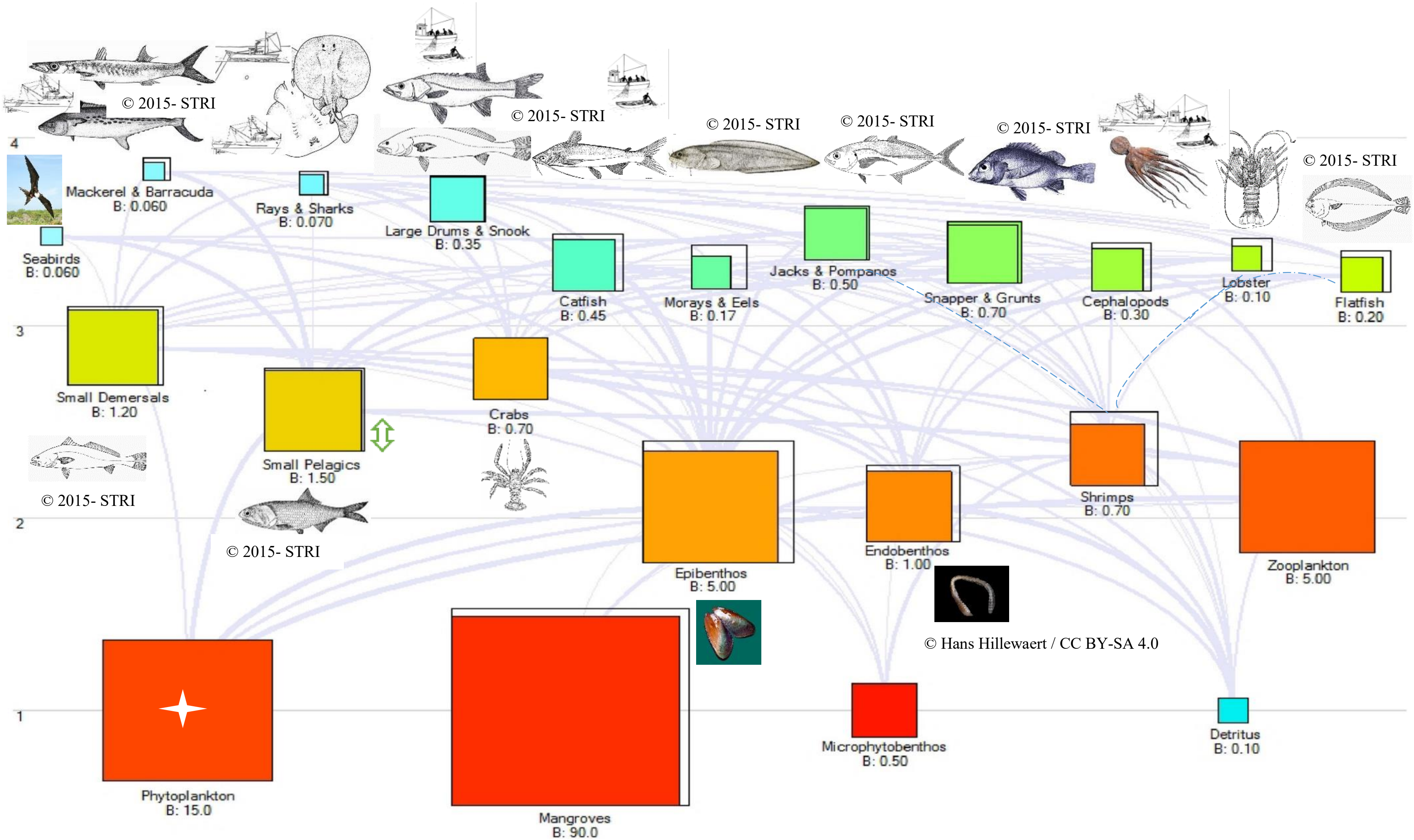


Figure S3.2. Information delivered to the treatment group regarding the Gulf of Nicoya EwE model. Trophic flows (gray lines proportional in size to magnitude) together with the biomass changes of the compartments along two decades in the Gulf of Nicoya ecosystem, filled colored squares (2013) vs open squares (1993); the vertical position of boxes mark their trophic level in the system. Adapted from Alms & Wolff (2019) with permission of the authors.

Text S3.2. Post-survey. English version of the post-survey applied to fishers in the Gulf of Nicoya.

Centro de Investigación en
Ciencias del Mar y
Limnología
Universidad de Costa Rica
San Pedro, Costa Rica
+ (506) 2511-2200

Leibniz Centre for Tropical Marine Research (ZMT)
Fahrenheitstr. 6
28359 Bremen, Germany
+49 (421) 23800-70

Number of the survey	Place	Date and time

Code Site: Isla Chira 99 ( ) Costa de Pájaros 98 ( ) Paquera 96 ( )

Good morning!

This interview is part of a doctoral study about adaptation of small scale fishers to more sustainable fishing schemes in tge Gulf of Nicoya. The interview is confidential and volunteer, all the information gathered will be used for the purpose of academic research and you can drop the interview at any given moment. Are you interested in being part of it?

(1) Antecedents of pro-environmental behavior

Questions about your values and beliefs (Kenter et al., 2016)

The next set of questions will give us an indication of what your values and beliefs are in relation to the environment. Don't think the questions for too long, just use your first feeling to answer the questions.

How important are the following values as a guiding principle in your life? For each one please tick one the boxes from opposed to this value to of supreme importance

Values	Egoistic	BV2.3 EGO	-Wealth, material possessions, money	-1, 0, 1, 2, 3, 4, 5, 6, 7 (Opposed to this value -1 Not important 0

				Slightly important 1 Slightly important 2 Important 3 Vastly important 4 Vastly important 5 Very important 6 Of supreme importance 7)
		BV2.6 EGO	-Influence, having an impact on people and events	
		BV2.8 EGO	-Authority, the right to lead or command	
	Altruistic	BV2.2 ALT	-Social justice, correcting injustice, care for the weak	
		BV2.4 ALT	-Equality, equal opportunity for all	
		BV2.5 ALT	-A world at peace, free of war and conflict	
	Biospheric	BV2.1 BIO	-Respecting the earth, harmony with other species	
		BV2.7 BIO	-Protecting the environment, preserving nature	
		BV2.9 BIO	-Unity with nature, fitting into nature	

Listed below are statements about the relationships between humans and the environment. For each one please indicate whether you strongly disagree, mildly disagree, are unsure, mildly agree or strongly agree with it.

Beliefs	New Ecological Paradigm	NEP1 World views*	-Humans have the right to modify the natural environment to suit their needs (stated negatively)*	1, 2, 3, 4, 5 (strongly disagree, mildly disagree, unsure, mildly agree, strongly agree)
		NEP2 World views	-Humans are severely abusing the environment	
		NEP3 World views	-The earth is like a spaceship with very limited room and resources	
		NEP4 World views*	-The so-called "ecological crisis"	

		NEP5.1 World views	facing humankind has been greatly exaggerated (stated negatively)* -Plants and animals have as much right as humans to exist	
	Awareness of consequences	AC1 Consequences	-Many forms of life in our seas are under a real threat from human activities	1, 2, 3, 4, 5 (strongly disagree, mildly disagree, unsure, mildly agree, strongly agree)
		AC2 Consequences*	-If the diversity of life in the seas would be diminished, it would not significantly impact on our economy (stated negatively)*	
	Ascription of responsibility	AR1 Responsibility*	-I feel responsible for the plight of rare or endangered species of plants and animals	1, 2, 3, 4, 5 (strongly disagree, mildly disagree, unsure, mildly agree, strongly agree)
		AR2 Responsibility*	-I don't feel personally responsible for environmental issues, as they are the responsibility of government and industry (stated negatively)*	
Norms (TPB)	Social norms	SN1 Social	-Most people important to me think I should support conservation of sea life	1, 2, 3, 4, 5 (strongly disagree, mildly disagree, unsure, mildly agree, strongly agree)
		SN2 Social	-Most people important to me support taking action to protect the marine environment	
Norms	Personal norms	PN1 Personal	-We should protect spaces for other species to live and thrive in our marine environment	1, 2, 3, 4, 5 (strongly disagree, mildly disagree, unsure, mildly agree, strongly agree)
		PN2 Personal*	-We should think about the economic	

			importance of the seas first, and only then about environment and conservation issues (stated negatively)*	
TPB	Perceived behavioral control	PBC1 Behavioral	-It is easy to take action to support protection of the marine environment	1, 2, 3, 4, 5 (strongly disagree, mildly disagree, unsure, mildly agree, strongly agree)
		PBC2 Behavioral*	-It is difficult for me to do anything significant that would help conservation of sea life (stated negatively)*	

(2) Support for management measures

How important are the following measures to support sustainability and the health of the ecosystem in Gulf of Nicoya? For each one please tick one the boxes as an expression of your support, from opposed to this measure to of supreme importance

(A) Intention to support sustainable fisheries management	-1, 0, 1, 2, 3, 4, 5, 6, 7 (Opposed to this measure -1 Not important 0 Slightly important 1 Slightly important 2 Important 3 Vastly important 4 Vastly important 5 Very important 6 Of supreme importance 7)
(B) Intention to support a specific management action (reduction of 25% in the fishing effort)	
(C) Actual behavior to support sustainable fisheries (fishing license ownership)	

(3) Additional Feedback

What do you think of the workshops in terms of what you learned and how the information was communicated? Please indicate if you have any suggestions for improvement.

Thank you very much for taking the time to answer this survey. All the information contained here is really appreciated and will be used for the purpose of this research only.

ANNEX IV
Supplements for Chapter 4

Supporting Figures

Figure S4.1. Deliberating on scenarios and payment card ('government cheque'). Four checks (bids) in CRC were put into an envelope and were randomly sequenced and handed to each fisher.

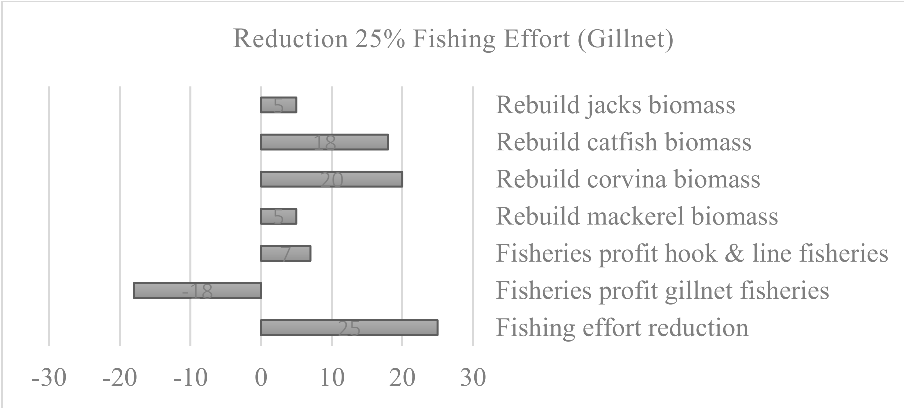
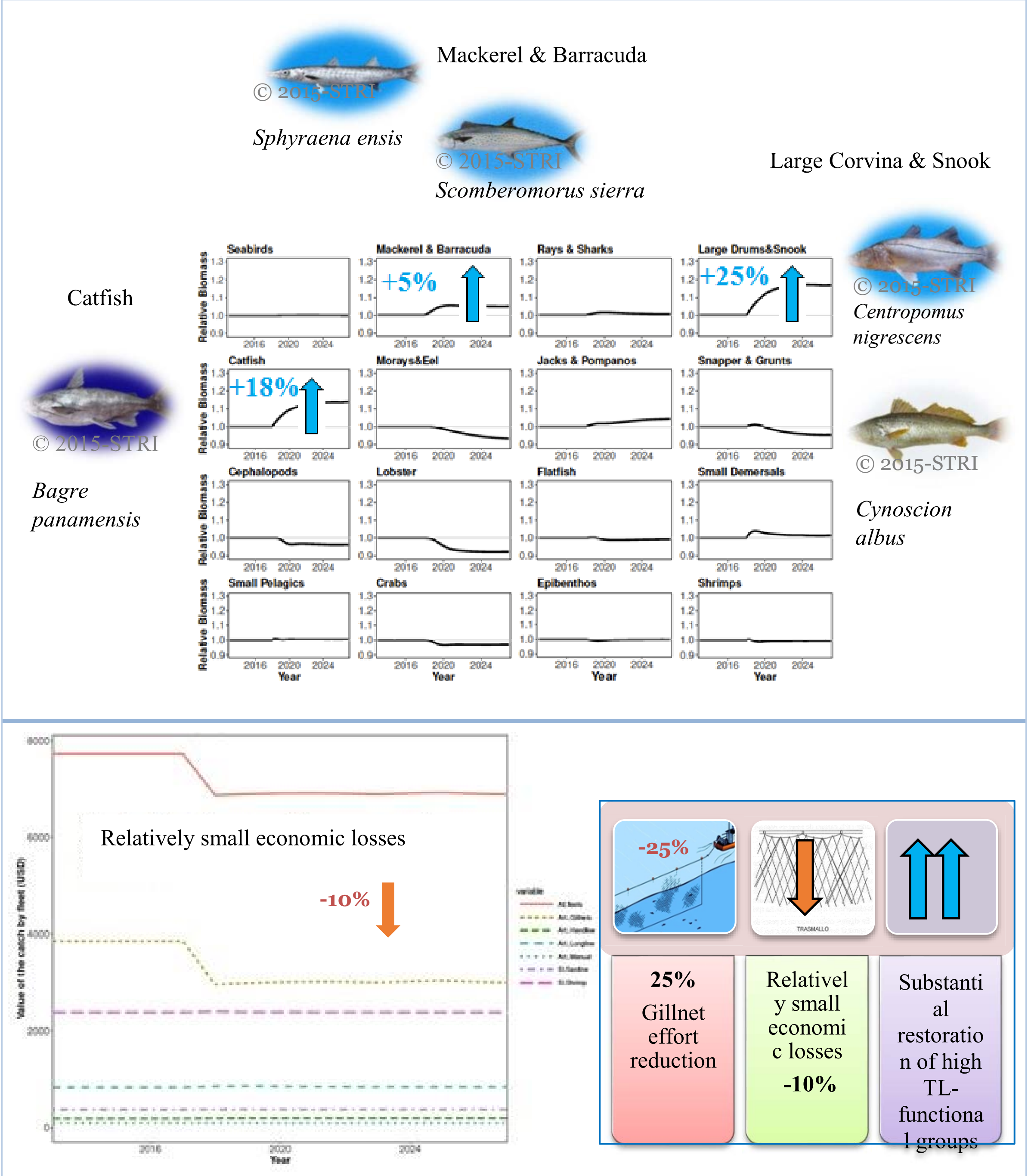


Fig S4.2. Information about scenario 25% effort reduction delivered in the workshops 2 to the control group. Based on (Alms and Wolff, 2019), no detailed information on species and fishing gears interactions were presented.



© **Copyright 2015** – STRI. Images Credit: *B. panamensis, C. nigrescens* and *C. albus,* by Ross Robertson. *S. sierra* by Robertson & Van Tassell. *S. ensi* by Gerald R. Allen.

Fig S4.3. Information about scenario 25% effort reduction delivered to the treatment group (lecture containing EwE models) in the workshops-2, based on (Alms and Wolff, 2019). Interactions with other species and fishing gears were displayed. Gillnet fleet effort reduction by 25% provides relatively small economic losses and may achieve substantial restoration of high TL-functional groups (large corvina & snook, catfish and mackerel & barracuda).

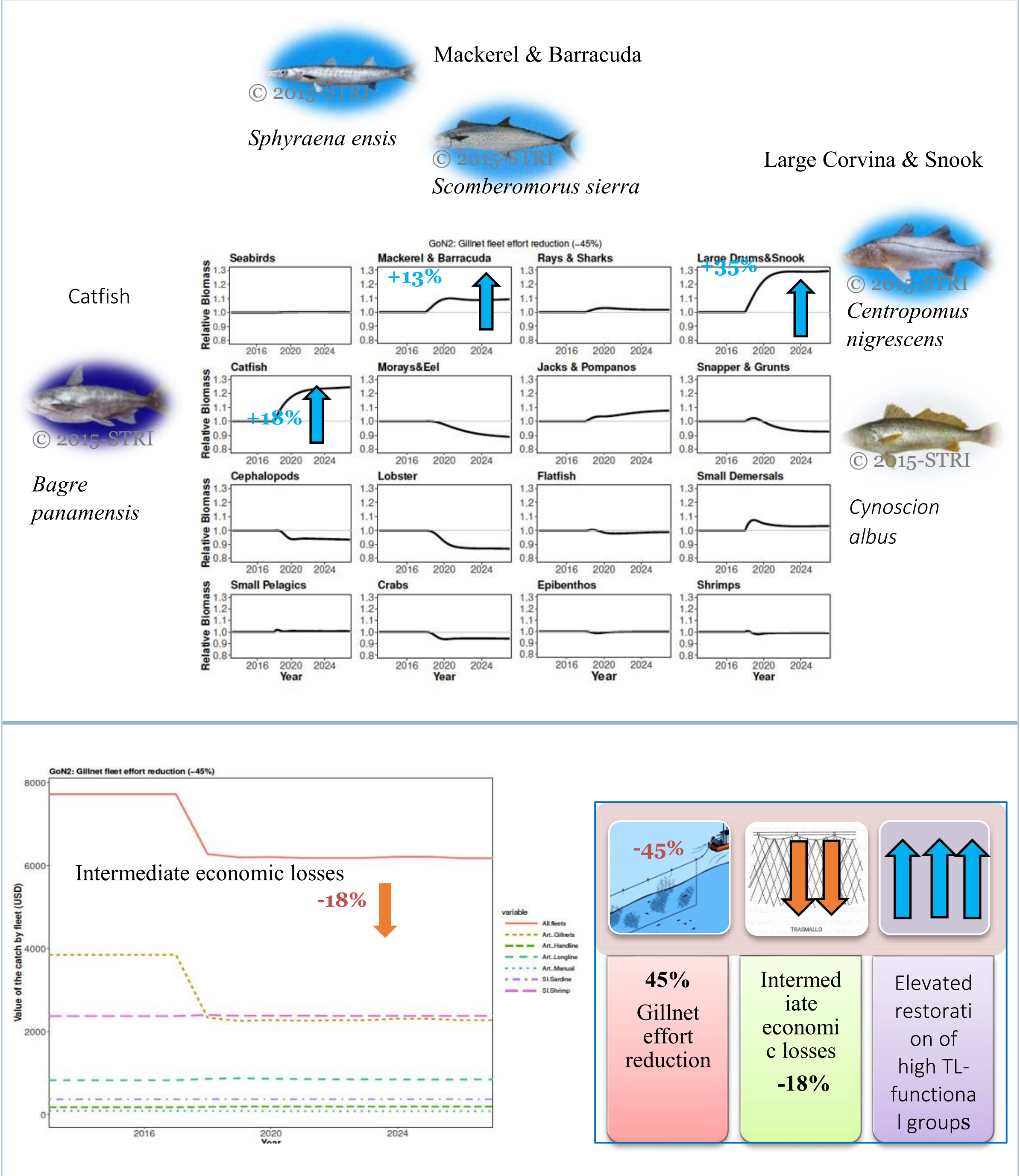


Fig S4.4. Scenario C, 45% effort reduction delivered to the treatment group in the workshops-2. Interactions with other species and fishing gears were displayed. Gillnet fleet effort reduction by 45% provides intermediate economic losses but elevated restoration values of high TL-functional groups (large corvina & snook, catfish and mackerel & barracuda).

ANNEX V
Supplements for chapter 5

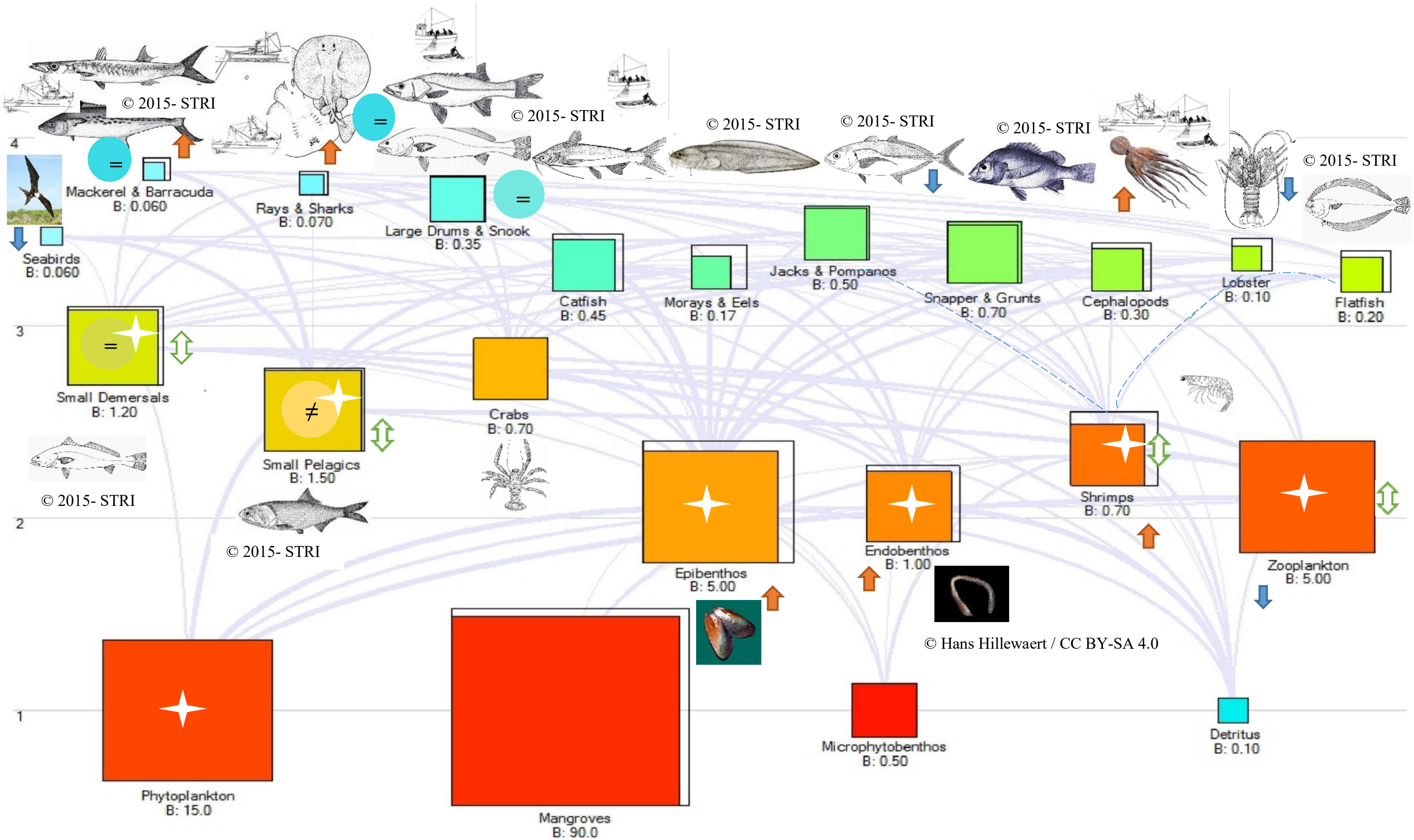


Figure S5.1. EwE model for the Gulf of Nicoya and local ecological knowledge coupled. Trophic flows (gray lines proportional in size to magnitude) together with the biomass changes of the compartments along two decades in the Gulf of Nicoya ecosystem, filled colored squares (2013) vs open squares (1993); the vertical position of boxes mark their trophic level in the system. ⇧Bottom–up: controlled by their prey. ⇩Top–down: control on their prey ⇳Wasp-waist: control on their prey and predators. = fishers' perception coincides; ≠ fishers' perception differs. ✦Keystone functional groups. Adapted from Alms & Wolff (2019) with permission of the authors.

Various sources (1950s-1980s)				LEK + EwE modeling (1993-2013)		
1950s	1960s	1970s	1980s	1990s EwE	2000s EwE	2010s (EwE)
• Start of fish production Growth 42.61 MT per year gradually	• SSF fishery was very small and small boats were launched from the beach • Development and growth of fishing production 151.2 MT per year	• Maximum fish production 303.19 MT anually • Use of trawlnets in the shrimp fishery by the semiindustrial fleet from 1945 to 1975 caused severe damage to the internal area of the gulf • Gillnets were introduced • Peak phase from 1979 to 1986	• Visible abundance of living organisms (comercial and non-commercial groups) • Shrimps and corvinas widely fished • 1986 use of monofilament net increased • Start of fishing overfishing phase • Approx. 101.2 TM annualy • A decrease in fish catches • Catch of croakers at the level of overexploitation • Boat owners, aided by government export incentives, started to built bigger boats and began to sail longer distances.	• Early 1990s: "shrimp fever" • Shrimp dominated cathes • Towards the end of the decade, initial reduction of large drums (e.g., *Cynoscion albus)* and shrimps • Increasing impact of gillnets • In 1993, rays and sharks were negatively affected by the gillnet • Increasing catch trend (SSF) • Most fisheries resources reached the highest catches between the 1980s and 1990s.	• Peak in the catches of SSF in early 2000s • Illegal gillnets 2.5-2.75 inches widely used • Severe decrease of corvinas & white shrimps • Corvinas (changes in species composition and size reduction) • Economic loses • Peak of sardine catches and from here a drastic reduction • Overall effort reduction • approximately 70% of fisheries subsidies in Costa Rica (~$32M USD) were the kinds generally classified as harmful	• Extended use of gillnets (legal and illegal 80%) • Fishing effort decreased (shrimps) • Fishing effort of corvinas increased • From shrimp- to sardine-dominated catches • Declining biomass of shark, ray, functional groups and their overall decreasing catches • Increase in total fishery catches, decerase in overall fishing effort due to a lack of resources and vedas, increase in CPUE

Figure S5.2 Resulting chronology of fisheries development in the Gulf of Nicoya by combining different sources (Herrera-Ulloa et al., 2011; Trujillo et al., 2015; Ulate-Garita, 2020) (1950-1980) and the results of the local ecological knowledge integrated with Ecopath with Ecosim modeling (1993-2013) (Alms and Wolff, 2019; Sánchez-Jiménez et al., 2019)

Ort, Datum: ___________________________

Versicherung an Eides Statt

Ich, Astrid Sánchez Jiménez,

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