Quantifying the economic potential of small scale fisheries through better management in the Gulf of Nicoya, Costa Rica

A group project submitted in partial satisfaction of the degree of Master of Environmental Science and Management for the Bren School of Environmental Science & Management

UNIVERSITY OF CALIFORNIA
Santa Barbara

by
Diana Flores
Wagner Quirós
Ignacia Rivera
Alexandra Smith

Faculty advisors:
Andrew Plantinga (Faculty Advisor)
Laura Urbisci (PhD Mentor)

External Advisors:
Gavin MacDonald
Sebastian Tapia

March 24th, 2017

FISHFOREVER Bren School of Environmental Science & Management UNIVERSITY OF CALIFORNIA, SANTA BARBARA rare

Quantifying the economic potential of small-scale fisheries through better management in the Gulf of Nicoya, Costa Rica

As authors of this Group Project report, we archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

Diana Flores

Wagner Quirós

María Ignacia Rivera

Alexandra Smith

The Bren School of Environmental Science & Management produces professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principal of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

Andrew Plantinga, PhD

Laura Urbisci, PhD Candidate

Date

Acknowledgements

We would like to thank many people who supported us and provided advice and mentorship for the duration of our project.

First we would like to thank our Bren Faculty advisor **Andrew Plantinga** for providing us with mentorship and knowledge that allowed us to improve our project. We would also like to thank our PhD mentor **Laura Urbisci,** and our external advisors **Gavin MacDonald** (Sustainable Fisheries Group) and **Sebastian Tapia** (Bren School) for their constant encouragement and commitment to sharing their knowledge.

To our client, **Lindsey Larson** from Rare-Fish Forever, thank you for helping us make this project possible and to the Costa Rican Ambassador for the United States, **Román Macaya Hayes** for his interest in improving the current status of fisheries in the Gulf of Nicoya.

We would also like to thank the following collaborators who helped shape our project by sharing their expertise. **Juliana Herrera** (Fair Trade USA)**, José Francisco Nuñez** (Geoimaginarte), **Cody Szuwalski** (Bren-Sustainable Fisheries Group)**, Renato Molina** (Bren-Sustainable Fisheries Group), and **Christopher Costello** (Bren School).

Finally, we would like to thank the many fishers from the Gulf of Nicoya, the faculty and staff at the Bren School of Environmental Science & Management at the University of California, Santa Barbara and the Latin American Fisheries Fellowship, specially **Jacy Brunkow** for all the support and assistance.

Table of contents

Figures and Tables

Figure 1. Map of the Gulf of Nicoya highlighting subzone 201.

Figure 2. Whitefin weakfish, Corvina reina (*Cynoscion albus,* Günther, 1864).

Figure 3. Net Present Value (NPV) of the different management approaches (long-term closure, seasonal closure, effort control, size selectivity and their combination), under proper compliance (dark blue) and Best Case Scenario (BCS) design (light blue). The *status quo* is represented by the red line at zero NPV as the fishery is assumed to be at open access equilibrium.

Figure 4. Fishers perceptions on the reason why the seasonal closure was not being respected in 2016.

Figure 5. Short-term economic (real profits) path of the Best Case Scenario outcomes of different management approaches over time.

Figure 6. Long-term economic (real profits) path of the Best Case Scenario outcomes of different management approaches over time.

Figure 7. Long-term biomass projections of the Best Case Scenario outcomes of different management approaches over time.

Table 1. Weight classification and prices of the main commercial categories of finfish in Costa Rica (INCOPESCA, 2011).

Table 2. Life-history parameters for Corvina Reina (*Cynoscion albus*).

Table 3. Management approaches, current regulations and the values to model perfect compliance scenarios (PCS) for each one.

Table 4. Fishing mortality ratio (F/F_{msy}), Froese indicators and Spawning Potential Ratio (SPR) estimated for the corvina reina fishery in the upper part of the Gulf of Nicoya based on length data published by INCOPESCA for 2012 and 2014. Red numbers indicate values that deviate from the target point in an undesirable direction.

Acronyms and Abbreviations

	English	*Spanish*
INCOPESCA	Costa Rican Institute of Fisheries and Aquaculture	Instituto Costarricense de Pesca y Acuicultura
SINAC	National System of Conservation Areas	Sistema Nacional de Áreas de Conservación
BIOMARCC	Coastal and Marine Biodiversity of Costa Rica	Biodiversidad Marino-Costera de Costa Rica
MAG	Ministry of Agriculture and Livestock	Ministerio de Agricultura y Ganadería
MARFs	Marine Areas of Responsible Fishing	Áreas Marinas de Pesca Responsable
NGO	Non-Governmental Organization	Organización no Gubernamental
DLA	Data Limited Assessment	Evaluación con datos limitados
SPR	Spawning Potential Ratio	Potential de Desove
NPV	Net Present Value	Valor Actual Neto
BCS	Best Case Scenario	Mejor Escenario Posible

Abstract

The Gulf of Nicoya in Costa Rica is home to dozens of communities that are highly dependent on fishing. Recent research revealed fisheries in the Gulf show signs of overexploitation. To explore the economic potential of improved fisheries management, we focused on the main finfish fishery of the upper Gulf: Corvina Reina (*Cynoscion albus*). Our approach aimed to (i) determine the biological status of this fishery using a replicable data-limited assessment and to (ii) quantify the economic potential of the corvina reina fishery under perfect compliance and improved design of current management. We evaluated four management approaches, effort control, gear restrictions, seasonal closures, long-term recovery closure with model scenarios. We also identified an optimized combined management approach.

Our biological assessment showed the corvina reina fishery is overexploited and underperforming relative to multiple reference points set for sustainable fisheries. Effort reduction showed the greatest potential for economic returns, under perfect compliance. While adjustments to size selectivity had the largest potential for additional returns under optimal policy design with a length at first capture of 67 cm generating the highest economic improvement. In the long-term, reducing effort was the only management approach with positive profits every year, while size selectivity generated the highest net benefits. All scenarios have inherent tradeoffs to account for including biological response time lags, investment in gear change, and effects on employment. We estimated the corvina reina fishery will reach 2.5 million USD in losses due to noncompliance and an additional 1.1 million USD due to sub-optimal economic design over the next 20 years. We hope our results help to improve fisheries management in the upper Gulf by guiding the allocation of efforts to increase compliance and inform the improvement of policy design.

Executive Summary

The Gulf of Nicoya is one of the largest gulfs in Central America and is home to over 80 communities that are highly dependent on fishing as their main economic activity, with few alternative livelihoods in the area. Over the last decade, multiple fisheries have shown signs of overfishing (BIOMARCC-SINAC-GIZ, 2013). Further decline of fisheries resources would result in risk of increased poverty for Gulf of Nicoya (Palacios 2013).

This situation has concerned local authorities and the national government. Consequently, the Ambassador of Costa Rica to the United States has approached our client, Rare and its Fish Forever Program, for assistance in improving fisheries management in the Gulf of Nicoya. To contribute in this process, our project aims to guide the allocation of efforts to increase compliance with fisheries regulations and inform the improvement of policy design by quantifying the economic potential of Nicoya's small-scale fisheries.

Declining catch rates and a persistent low district social development status in the Gulf (Proyecto Golfos, 2014) suggest current management is not generating optimal benefits for resource users. There is compelling evidence that the current management approaches - effort control, closed fishing season, and gear restrictions - have not been working as expected over the last three decades. Low levels of compliance have been observed for all three approaches suggesting that the fishery is in a *de facto* open access state (Marín & Vásquez, 2010; Marín *et al.*, 2013). Furthermore, the lack of ecologic or economic rationale to support the design of regulations has led to ineffective management (Contraloría General de la República de Costa Rica, 2014). Quantifying the benefits that compliance and improved design may generate, is the first step in planning interventions to improve the fishery. By isolating the economic potential of each approach or by combining different approaches over time, managers can strategically focus their limited resources for enforcement and develop more effective policies to avoid overexploitation.

We focused our analysis in the upper Gulf which has historically been a priority target for management interventions. This area serves as the main fishing ground for over 20 fishers associations (Jorge Lopez, personal communication, July 06, 2016)[1] and as a nursery area for several commercially important species in the Gulf (Wolff *et al.* 1998).

1 While conducting fieldwork on July 6th, 2016, the group interviewed Jorge Lopez, the head of Incopesca in the department of Extension and Training. He provided us a list with the 43 fishers associations and their legal representatives, from which 20 of these associations are located in the upper Gulf.

To pilot our analysis, we selected a culturally and economically important fishery as a case study for the area of interest, the corvina reina (*Cynoscion albus*).In 2014 this fishery represented 51 percent of the catch in the area(Marín *et al.*, 2013; Marín & Vásquez, 2014) making it the most important single-species finfish fishery in the upper Gulf by catch. There is high demand for corvina reina in the domestic market due to the excellent quality of its flesh (Fundación MarViva, 2012).

The corvina reina fishery exhibits preferential pricing for larger fish whereby the price per kilogram depends on the size and weight of the fish (INCOPESCA, 2014). There are 3 commercial size classes: *Primera grande*, *Primera pequeña* and *Clase* (Marín & Vásquez, 2010). *Primera Grande* is the premier class, demanding the highest price, while *Clase* is the lowest price class. An individual in *Primera Grande* can command a per kilogram price 6 times higher than a fish in *Clase*.

To first characterize the status of the fishery, we implemented static data poor length-based analyses. Due to inconsistencies in data collection and other severe data limitations, we were unable to perform traditional data-limited time-series stock assessment analyses. Using length-frequency data, we examined the estimated fishing mortality ratio, Froese sustainability indicators, and Spawning Potential Ratio (SPR) to evaluate the size composition of the catch and the fishing pressure on the stock. We obtained a fishing mortality ratio of 1.23, indicating the fishery is overexploited relative to the maximum sustainable yield (MSY). Complementing this estimate, all three Froese sustainability indicators[2] are below the reference level for a healthy stock, showing a decline in performance from 2012 to 2014. Finally, the calculated spawning potential ratio also pointed to an underperforming fishery. This is the first robust effort to evaluate the status of a single species in the Gulf of Nicoya, and it has great potential of replicability for other finfish species across the country

In order to measure the economic potential of the corvina reina fishery for current management approaches under perfect compliance and improved design, we constructed an age-structured model. This approach is applied to determine the theoretical economic optimum of the fishery, taking into consideration age-specific vulnerability of fish to gear type and individual reproductive potential. It also allowed us to incorporate the premium price for larger Corvina, which is relevant for management aimed at maximizing economic outcomes. We analyzed the economic potential of the three primary management approaches currently operating in the Gulf independently, assuming continued noncompliance with all other regulations. We also included a long-term recovery closure scenario and combined management strategies to explore additional outcomes. We then explored the economic and social tradeoffs of the designs that maximized profits

[2] The percent of mature individuals, the optimal size of catch and mega-spawners.

for each approach over a time horizon of interest equal to 20 years.

When we estimated the potential gains under perfect compliance, effort reduction showed the greatest potential for economic returns. Adjustments to size selectivity had the largest potential for additional economic returns under optimal policy design with a length at first capture of 67 cm generating the highest economic improvement. In the long-term, effort was the only management approach with positive profits in every year, while selectivity generated the highest net benefits. The positive response to increased size selectivity is largely driven by the recovery of larger individuals in the population, allowing fishers to take advantage of the preferential market pricing.

All scenarios have inherent tradeoffs to account for including biological response time lags, investment in gear change, and restrictions to fishing. We estimated the corvina reina fishery in the Gulf of Nicoya will reach 2.5 million USD in losses due to noncompliance and an additional 1.1 million USD due to sub-optimal economic design of the combined management policies over the next 20 years. These results are only applicable for a single fishery in the gulf, yet we have identified 13 other species which share similar biological and commercial characteristics that would benefit from a similar analysis. However, the tradeoffs of interventions and their impact on various stakeholders requires significant discussion. Our estimates only considered the direct costs to fishers and do not account for external costs of enforcement, implementation, or potential interference with other fisheries. In this context, changes to regulation can be a long and costly process, often involving consultations and negotiations with local associations.

The economic benefits of increased compliance demonstrated in our analysis reinforce the need to fully implement the National Marine Strategy of Control and Surveillance. We recommend this be coupled with community engagement to increase efficacy. Although we have demonstrated significant room for design improvements, there are still gains to be made from compliance with current regulations. Attention should also be given to priority areas such as the upper part of the Gulf of Nicoya. One area of focus may be the implementation of the Interinstitutional Surveillance Station, inaugurated in July 2016, but still inactive due to delay generated by differences in administrative procedures among INCOPESCA, the Coast Guards and the National System of Conservation Areas (SINAC).

We hope that our results will motivate the Costa Rican government and the local communities to improve compliance and regulation design in the upper part of the Gulf of Nicoya, which could generate substantial fisheries and economic improvements.

Significance and project objectives

The Gulf of Nicoya is a tectonic estuary of about 1,830 Km^2 located on the Pacific coast of Costa Rica (Gocke *et al.*, 2001). The Gulf is one of the largest in Central America and is home to over 80 communities that are highly dependent on fishing as their main economic activity, with few alternative livelihoods in the area. It is considered to be one of the most important ecological and geographical systems in Costa Rica.

Over the last decade multiple fisheries in the region have shown signs of overfishing. A 2013 report from the BIOMARCC Project (Coastal and Marine Biodiversity of Costa Rica) showed that the combination of excessive fishing effort, illegal fishing gear, and lack of legislation for minimum size limits has led to an overexploitation of the main fishing resources of the Gulf of Nicoya (BIOMARCC-SINAC-GIZ, 2013).

Further decline of fisheries resources would result in increased risks of poverty for Gulf of Nicoya's coastal inhabitants whose livelihood mainly depend on this activity. The national government, NGOs and local communities, have implemented several efforts to reverse these trends, unfortunately to no avail, as over-exploitation of fish stocks continues (Palacios, 2013; Marín *et al.*, 2013).

This situation has concerned local authorities and the national government. The ambassador of Costa Rica to the United States has approached Rare and its Fish Forever Program, our client, for assistance in improving fisheries management in the Gulf of Nicoya. Based on that we set our objective, which is to:

"Quantify the economic potential of Nicoya's small-scale fisheries to guide the allocation of efforts to increase compliance and inform the improvement of policy design"

Based on our goal we selected a culturally and economically important fishery from the upper part of the Gulf of Nicoya, the corvina reina (*Cynoscion albus*), as a case study. Our analysis addresses three research questions:

Question 1: What is the status of the corvina reina fishery in the region?

Question 2: What is the economic potential of the corvina reina fishery for current management approaches, under perfect compliance and improved design?

Question 3: What are the economic and social tradeoffs involved with optimal outcomes of different management approaches over time?

Background

The upper part of the Gulf, also known as Zone 201, is an ecologically and economically important area (Figure 1). This area is irrigated by the Tempisque River and holds important mangrove ecosystems, which serve as nurseries and spawning areas for many commercially important marine and estuary fish species (Wolff *et al.*, 1998).

Figure 1. Map of the Gulf of Nicoya highlighting subzone 201 in darker blue.

This 160 Km^2 area is home to multispecies (shrimp and finfish) and multi-gear (handline, gillnets and longlines) artisanal fisheries. It is estimated that over one dozen local fisher's associations use this area as an important fishing ground, with the most valuable finfish species being the corvina reina (*Cynoscion albus*) (Figure 2).

Figure 2. Whitefin weakfish, Corvina reina (*Cynoscion albus,* Günther, 1864).

Corvina reina (*Cynoscion albus*), is a benthopelagic finfish that feeds on shrimp, small fish and cephalopods. According to Marin & Vasquez (2012), one stock has been identified in the upper gulf while a second stock is associated at the mouth of the Tárcoles River (Zone 3).

Corvina reina has a high commercial value in the upper part of the Gulf. It represented up to 44% and 51% of the catch in 2012 and 2014 respectively (Marín *et al.*, 2013; Marín & Vásquez, 2014). It is sold domestically through intermediaries that then sell it to restaurants, fish markets and supermarkets either as fresh or frozen whole fish (CIMS, 2011).

The corvina reina fishery exhibits preferential pricing at market whereby the price per kilogram depends on the size and weight of the fish (INCOPESCA, 2014). There are 3 commercial size classes: *Primera grande*, *Primera pequeña* and *Clase* (Marín & Vásquez, 2010). *Primera Grande* is the premier class, demanding the highest price, while *Clase* is the lowest price class (Table 1).

Table 1. Weight classification and prices of the main commercial categories of finfish in Costa Rica (INCOPESCA, 2011)

Commercial size categories	**Fish weight** (kg)	**Price 2012** (USD per kg)
Primera grande	More than 2.5 kg	4.31
Primera pequeña	Less than 2.5 kg	3.25
Clase	Less than 0.4 kg	0.71

Gillnets are the most common gear type in the corvina reina fishery with 47 percent of fishers reporting use(Appendix III). This is a mesh or nylon net, with a height of 1.5 meters and lengths varying between 400 and 500 meters. Currently, variable mesh sizes are allowed: 3 inches for shrimp and 3.5 to 8 inches for finfish, although increasingly smaller meshes have been used illegally, including 2 inch mesh size (Fernández Carvajal, 2016).

The communities that border the upper Gulf of Nicoya are considered underdeveloped relative to other parts of the country. A Marine Spatial Planning study (Proyecto Golfos, 2014) carried out in the Gulf identified that the upper part holds three districts categorized as very low social development (Isla Chira, Colorado and Porozal) and low social development (Quebrada Honda, Mansión, and San Pablo)[3].

Local fishing associations in this part of the Gulf are interested in improving fisheries management. In 2015 eight local fishers associations proposed to

3 The specific indicators used for estimating this index used by the Ministry of Development and Planning of Costa Rica considers several dimensions such as: participation in economic activities, civic processes and access to the national health system, security, appropriate nutrition, education, and training (Proyecto Golfos, 2014).

INCOPESCA the creation of a Marine Area of Responsible Fishing[4] for the whole upper part of the Gulf of Nicoya as a measure to improve the perceived decline in fisheries resources. The importance of the Corvina Reina fishery in the upper part of the Gulf of Nicoya, combined with the interest for better management from local group leaders and the low social development status observed in these communities, make this a strong case for exploring management improvement outcomes.

1. Fisheries management in the Gulf of Nicoya

Declining catch rates and a persistent low social development index status of communities in the upper Gulf suggest current management is not generating optimal benefits for resource users. There is compelling evidence that the current management approaches - effort control, closed fishing season, and gear restrictions- have not been working as intended over the last three decades.

1.a Effort control

Effort control is implemented through the allocation of fishing licenses. There is strong evidence of very low compliance for this approach. Local managers estimated that 50% of the boats currently fishing in the area are unlicensed. There has been a moratorium in place for new licenses since 2002 (Jorge Lopez, personal communication, July 06, 2016)[5]. The fixed number of fishing licenses has not been based on scientific criteria or an economic reference point. There is currently no quantitative biological or economic outcome target for effort management.

1.b Closed fishing season

Since 1985, there has been a 3-month complete closure of all fishing in major areas of the Gulf, typically during the months of May to July (Executive Decree N° 16804-MAG) (Carvajal, 2013).[6] This period was selected based on the estimated shrimp reproductive peak (Poder Ejecutivo, 1985). After 30 years of seasonal closures, reports from INCOPESCA Technical and Development Department have shown that the closures did not achieve their goals (MarViva, 2015). A

[4] MARFs are legally designated territories proposed by local communities in which fishing activity is regulated by a management plan mainly design around gear zoning although some of them include intermittent or permanent closures. None of the areas impose catch or size limits nor do they restrict access (Lozano & Heinen, 2015).

[5] During the fieldwork, on July 6th of 2016, the group had an interview with Jorge Lopez, the person in charge of Incopesca in the Department of Extension and Training. He informed us about the background of the closure as well as the process of Incopesca for giving licenses to fishers.

[6] In 2016, the closure was extended to 4 months.

survey conducted by the research department of INCOPESCA showed that 94% of fishers report noncompliance with the closure (Marin *et al*., 2013).

1.c Size selectivity

The detrimental effects of noncompliance with effort controls and closures are further exacerbated by the prevalent use of illegal gear. There is currently no minimum size regulation in place for any of Costa Rica's finfish fisheries. Instead, size selection is managed through gear restrictions.

Studies from Marín *et al*. (2013) show that during field biological monitoring, INCOPESCA encountered up to 95% of fishing boats with illegal mesh sizes. The use of nets smaller than 3 inches increases the catch of juvenile individuals that have not yet reproduced, negatively affecting recruitment and population growth. The increased mortality rate for juvenile fish reduces the number of larger individuals which are both more valuable and more fecund. The lower market value for small individuals requires fishers to extract more individuals to cover their costs. This creates a positive feedback loop between overexploitation and the expanding use of illegal mesh sizes (Chacón *et al*., 2007).

In addition to the problems generated by noncompliance, there are design flaws in the gear regulations that further reduce their efficacy. Legal minimum mesh sizes differ for different fisheries that spatially overlaps. As an example, gillnets for shrimp have a legal minimum mesh size of 3 inches while finfish have a minimum allowable size of 3.5 inches. But Corvina Reina feed on shrimp thus are found in the same grounds as shrimp making them vulnerable to gillnets targeting shrimp

In spite of these management interventions, fisheries revenues continue to decline and overall community vulnerability remains high. Low levels of compliance have been observed for all three approaches suggesting that the fishery is in a *de facto* open access state (Marín & Vásquez, 2010; Marín *et al*., 2013). Furthermore, the lack of ecologic or economic rationale to support the design of regulations has led to ineffective management (Contraloría General de la República de Costa Rica, 2014). Quantifying the benefits that compliance and improved design may generate is the first step in planning interventions to improve the fishery. By isolating the economic potential of each approach managers can strategically focus their limited resources for enforcement and develop more effective policies to avoid overexploitation.

Methods

1. Data information

Fishery dependent length composition data for corvina reina (*Cynoscion albus*) from 2012 (n=2,360) and 2014 (n=1,013), were obtained from INCOPESCA reports (Marin *et al.*, 2013; Marín, 2015). INCOPESCA also published landings and prices per commercial categories in the Gulf of Nicoya (INCOPESCA, 2012) (Table 1). Finally, life history parameters were collected for the species (Mug-Villanueva *et al*. 1994) and are included below in Table 2.

Table 2. Life-history parameters for Corvina Reina (*Cynoscion albus*).

Parameter	Value	Description	Reference
L_∞	122.1 cm	Asymptotic length	Mug-Villanueva *et al.* 1994
k	0.172	Von Bertalanffy Growth rate	Mug-Villanueva *et al.* 1994
t_0	0.919	Theoretical length at age zero	Mug-Villanueva *et al.* 1994
W_a	0.024	*a* for weight at length equation	Fishbase.com
W_b	2.824	*b* for weight at length equation	Fishbase.com
m_{50}	55 cm	Length at which 50% of individuals are mature	Marín & Vásquez 2012
m_{95}	62.7 cm	Length at which 95% of the individuals are mature	Empirical estimate
S_{50}	29 cm	Length at which 50% of individuals are vulnerable to the fishery	Empirical estimate
S_{50}	32 cm	Length at which 95% of individuals are vulnerable to the fishery	Empirical estimate
h	0.7	Steepness parameter	Myers *et al. 1999*
females	0.6	Proportion of the stock that is female	Marín & Vásquez, 2012
eggs/gram	41	Number of eggs per gram	Proyecto FIP, 1999

2. Data Limited Assessment of Corvina reina (*Cynoscion albus*)

2.a. Length-base estimations of fishing mortality ratio

Due to inconsistencies in data collection and other severe data limitations, we were unable to perform traditional data-limited time-series stock assessment analyses. To characterize the status of the fishery, we applied static data poor length-based analyses. The first approach was to investigate the fishing mortality ratio.

Total instantaneous mortality (*Z*) is the sum of natural mortality (*M*) and fishing mortality (*F*). Therefore, *F* can be represented as follows:

$$F = Z - M$$

To estimate of *Z* with reduced uncertainty, we applied two methods to our length-frequency data, (i) the catch curve and (ii) the Lbar. Both methods assume that the length distribution of catch in a given year (beyond a designated length at first capture) is representative of the total population.

The catch curve analysis assumes the fishery is currently in equilibrium (constant recruitment and mortality), mortality is constant across all age classes, and that there have been no significant perturbations to the population in recent years. Because we assume the population is in equilibrium, total mortality can be estimated by regressing the logarithm of catch-at-age in numbers on age (Simpfendorfer *et al*., 2005). That is, the catch curve obtains an estimate of Z from the slope of the linear relation between the natural logarithm of frequency-at-age in a sample against age as given by the following equation (Pauly, 1983):

$$log_e N = a + bt$$

Where:
$log_e N$ = Natural logarithm of the number of fish in the sample for a given age (*N*)
t = Age
b = Estimate of *Z*, with inverse sign

We applied the von Bertalanffy growth equation to convert the length distribution to age frequency with one-year bins.

The Lbar method uses the minimum and maximum length of the fish as well as the mean length within the fished sizes and growth parameters (Ehrhardt & Ault, 1992; Ault, 2008). This method estimates Z by applying the following equation[7]:

$$Z = k \frac{L_\infty - LBAR}{LBAR - L_c}$$

Where:
Z = Total mortality
M = Natural mortality
F = Fishing mortality,
K = Von Bertalanffy growth rate
L_∞ = Asymptotic length of the species
L_c = first length at full selectivity[8]
$LBAR$ = Mean length between L_c and L_∞

To estimate M, we applied the following Beverton and Holt life history invariant relationship (Prince 2015):

$$M = K\ x\ 1.5$$

Where M is natural mortality and K is the von Bertalanffy growth rate.

Finally, we assume that a level of F equal to M would generate Maximum Sustainable Yield (MSY) (Zhou, 2012)[9]. This gives us a point of reference to compare the estimate of fishing mortality exhibited by the fishery (F) and the value of fishing mortality that would yield MSY (F_{MSY}). If the fishery is operating at MSY, the ratio between F and F_{MSY} will equal 1. When the ratio between fishing and natural mortality is greater than 1, the fishery can be considered overexploited.

2.b. Length-base estimates of Spawning Potential Ratio (SPR)

SPR is an indicator of the current egg production in relation to the maximum production at unfished levels (Wallace *et al.*, 2001)[10]. SPR can be calculated

---

7 The assumptions for this method includes: (i) Closed population, (ii) equilibrium conditions, (iii) species exhibits indeterminate growth, (iv) mortality rate is constant for animals above L_c and over time, (v) selectivity is constant for fishes of length L_c and larger and (vi) constant and continuous recruitment over time.

8 Full selectivity (L_c) is defined as the mode of the length frequency data.

9 There have been conflict assertions concerning this assumption where some analysis suggests $F_{MSY} = 0.8M$. We chose the more conservative value for our analysis.

10 For developing this method, it is necessary to count with life history parameters and an estimate of fishing mortality. In addition, it assumes: (i) fecundity is proportional to weight, (ii)

using the biomass of the entire adult stock or the number of the eggs they produce. This measure is called Spawning Stock Biomass (SSB) and when converted to a per-recruit basis, the Spawning Stock Biomass per Recruit (SSBR). This indicator reflects the impact of fishing on the ability of each recruit to contribute to spawning (Goodyear, 1993).

The SPR is the estimated ratio between the number of eggs produced by the fished stock (SP_{fished}) and the number of eggs that would be produced by a pristine population ($SP_{unfished}$) in equilibrium as shown below:

$$SPR = \frac{SP_{fished}}{SP_{unfished}}$$

To estimate SP_i, for i = {fished, unfished}, we defined the egg production and the estimated age production as follows:

$$Eggs_{\mathrm{i}} = \sum_{i=a}^{A} N_{a,i} \, * \, f_a \, * \, M_a$$

Where:
N_a = Abundance of fish at age *a*,
f_a = Fecundity at age *a*
M_a = Probability of being mature at age *a*

To translate length to weight and to then obtain fecundity, we assumed allometric growth. Hence, fecundity at a given age (f_a) is given by:

$$f_a = w_a \, * \, eggs/grams$$

Where:
w_a = Weight at age *a*
$eggs/grams$ = Number of eggs produced per gram for Corvina Reina.

To determine the probability of being mature, we assumed a logistic relationship with age. Thus, M_a is given by:

$$M_a = \frac{1}{1 + e^{-log(19)\frac{(l_a - m_{50})}{(m_{95} - m_{50})}}}$$

---

species shows indeterminate growth, (iii) recruitment is continuous and constant over time and (iv) mortality rate is constant.

Where:
l_a = Length at age a
m_{50} = Length at which 50% of individuals are mature
m_{95} = Length at which 95% of individuals are mature

The abundance-at-age at equilibrium is given by (N_a) :

$$N_{a,i} = \begin{cases} R_0, & if\ a = 1 \\ N_{a-1}e^{Z_{a-1,i}}, & if\ \ a < 1 \end{cases}$$

Where:
R_0 = Number of initial recruits
N_{a-1} = Abundance at the previous age
$Z_{a-1,i}$ = Instantaneous mortality rate of the previous age for the scenario *i*

The value of instantaneous total mortality for the unfished stock $(Z_{a,unfished})$is equal to M as the only source of mortality are natural factors, estimated as described in the previous section. While the instantaneous total mortality for the fished stock $(Z_{a,fished})$ is given by:

$$Z_{a,fished} = M + s_aF$$

Where:
M = Natural mortality,
s_a = Vulnerability to the fishery at age *a*
F = Value of fishing mortality for a given year, estimated as described in the previous section.

Vulnerability to the fishery presents the following behavior:

$$S_a = \frac{1}{1+ e^{-log(19)\frac{(l_a - S\ \ _{50})}{(S_{95}\ - S_{50})}}}$$

Where:
l_a = Length at age a,
S_{50} = Length at which 50% of individuals are vulnerable to the fishery
S_{95} = Length at which 95% of individuals are vulnerable to the fishery

2.c. Froese sustainability indicators

To evaluate the composition of the catch and the population, we applied the following Froese sustainability indicators: percentage of mature fish in catch, percent of specimens with optimum length in catch, and percentage of mega-spawners in catch (Froese, 2004).

The first indicator measures the proportion of mature fish in catch with a target of 100 percent mature individuals.

The second indicator specifies the percentage of fish caught at optimum length (L_{opt}). This is the maximum length obtained by multiplying the number of fish - in a given unfished year class - by its mean individual weight. Then, this optimal length allows us to reach the maximum yield and revenue from the specific fishery[11] (Froese, 2004). The target for this indicator would be the 100 percent of fish captured at optimal length within a range of ±10%. This optimal length is larger than the length at first maturity and it can be estimated from natural mortality and growth parameters (Froese, 2004; Froese & Binohlan, 2000), following the equation:

$$L_{opt} = L_{\infty} \frac{3}{3 + \frac{M}{K}}$$

Where:
L_{∞} = Asymptotic length
M = Instantaneous rate of natural mortality
K = rate of curvature of the von Bertalanffy growth curve

The last indicator is the percentage of mega-spawners in the catch, with a target within 30–40% if no upper size limit exists in the fishery (Froese, 2004). A mega-spawner fish is a fish of a size larger than the optimum length with a high reproductive capacity, because the number of eggs increases exponentially with length in most species and these eggs have a higher probability of survival (Solemdal, 1997; Trippel, 1998; Froese, 2004).

3. Age-structure model to estimate relative biomass and relative profit production of corvina reina.

The age-structure model is applied to determine the theoretical economic optimum of the fishery, taking into consideration size-specific vulnerability of fish to the gear and price. This approach divides the fish population into age classes, each one with associated length and weight values. Population dynamics are

[11] In the case of fisheries with preferential pricing for larger fish, the optimal length that maximizes revenues may differ from the optimal length that maximizes catch.

driven by recruitment, individual growth, natural mortality, and fishing mortality (Hordyk *et al.*, 2014). A major advantage of age-structured fishery models is that they do not require a long time series of data on the fishery (Tahvonen, 2009).

3.a. Model assumptions

Individual fish grow following the von Bertalanffy growth function. This growth function assumes that the rate of growth declines with size, so that the rate of change in length, *l*, may be described by:

$$l = l_{\infty}(1 - e^{-K\,(A_t - A_{to})})$$

Where:
K = Growth coefficient
l_{∞} = Asymptotic length at which growth is zero (named also *L-infinity*)
A_{t0} = Initial size of the organism and is defined as the theoretical age at which the organisms would have had zero size.

- There is no length or weight variability between individuals of the same age class.
- There is no immigration or emigration from the population
- Fishing gear exhibits knife-edge selectivity
- Catchability coefficient (q) is equal to 1. (Appendix I)
- Spawning occurs after total annual mortality.
- Marginal cost is constant across all selectivity (Appendix I).
- Fixed costs are included as depreciation in the marginal cost estimate[12].
- Real prices are constant over time.
- The corvina fishery is currently in a zero-profit stat of open access equilibrium.

3.b. Model description

We consider a population with 18 age classes. For each of these classes we modeled the annual abundance based on an age-specific total instantaneous mortality, which is a function of 3 control variables that allow us to model the different management approaches. Based on the abundance estimations we were able to calculate absolute biomass and catch that can be translated into profits by estimating revenues and subtracting costs of effort.

[12] Fixed costs have been included in the marginal cost function (Appendix I). We allocate fixed cost over time. For example, instead of having a fixed cost of 100 USD for and item that lasts 4 years, we state here the cost in 25 USD a year in depreciation for 4 years.

Total mortality

In the age-structure model, the total fishing mortality is a function of natural mortality, fishing mortality, the proportion of the year open to fishing and an age-specific vulnerability to the fishery. The function is given by:

$$Z_a = M + \mu s_a F$$

Where:
Z_a = Total mortality at age a,
M = Natural mortality
μ = Proportion of year open to fishing
F = Fishing mortality
s_a = Vulnerability to the fishery at age a

Vulnerability to the fishing gear is defined as:

$$s_a = \{1, \quad if \quad l_a \geq L_c \; 0, \quad if \quad l_a < L_c$$

Where:
l_a = Length at age a
$L_{c:}$ = Length at first capture

Abundance at age a

The abundance, N, at age a at time t is given by:

$$N_{a,i} = \begin{cases} R_t, & if \; a = 1 \\ N_{a-1,t-1} e^{Z_{a-1}}, & if \;\; 1 < a < a_{max} \\ N_{a-1,t-1} e^{Z_{a-1}} \;\; + N_{a,t-1} e^{Z_{a,i}}, & if \;\; a = \; a_{max} \end{cases}$$

Where:
R_t = Number of recruits at time t
$N_{a-1,t}$ = Abundance at previous age at previous time
e^{Za-1} = Proportion of individuals who survive to be one year older in the next year
a_{max} = Maximum age

The number of recruits at time t, (R_t) is estimated using the Beverton-Holt equation with density-dependence and steepness. This formula is a reparameterization of the Beverton-Holt equation that uses more meaningful biological parameters in the stock recruitment relationship. As a result, the recruits in time t are a function of the spawning biomass (*SB*) in the previous year, *t*-1.

$$R_t = \frac{0.8\, R_0\, h\, Eggs_{t-1}}{0.2\, \Theta\, R_0 (1-h) + (h-0.2)\, Eggs_{t-1}}$$

Where:
H = Steepness parameter[13]
R_0 = Initial recruitment
Θ = Stock recruitment parameter that indicates the ratio of virgin biomass to the virgin recruitment
$Eggs_{t-1}$ = Number of eggs produced the previous year

Eggs production in year t ($Eggs_t$) is given by the following formula:

$$Eggs_t = \sum_{i=a}^{A} N_{a,t} \; * \; f_a \; * \; M_a \; * \; females$$

Where:
$N_{t,\,a}$ = Abundance of fish that are at age *a* at time *t*
f_a = Fecundity at age *a*
M_a = Probability of being mature at age *a*
females: = Proportion of the stock that is female

The parameter Θ is explained by the three following equations:

$$\Theta = \sum_{i=a}^{A} Unfished_a * \; f_a \; * \; M_a \; * \; female$$

$$Unfished_a = \; R_0 + \sum_{i=2}^{A} Unfished_{i-1} * e^{-M}$$

13 This parameter is between 0.2 and 1 for the Beverton-Holt equation. Then, outside this range, population does not reach a stable equilibrium in the absence of fishing.

Where:
f_a = Fecundity at age *a*
M_a = Probability of being mature at age *a*
females = Proportion of the stock that is female
R_0 = Pristine recruitment
M = Natural mortality

Harvest at time t

The catch-at-age *a* at time *t* ($C_{a,t}$) was calculated using the Baranov equation. It assumes that the fish population is in equilibrium over time and that fishing and natural mortality are constant over time and age (Xiao, 2005) and occur simultaneously (Baranov, 1918):

$$C_{a,t} = \frac{F_a}{Z_a} N_{a,t}(1 - e^{-Z_a})$$

The first term, $\frac{F_a}{Z_a}$ expresses the proportion of individuals in each age class that were harvested and the second expression $N_{a,t}$ $(1 - e^{-Za-1})$ represents the total number of deaths.

3.c. Revenues and profits

Our revenue estimate captures the preferential size pricing by grouping age classes from the model into their corresponding commercial class based on average weight at each age. Using average price per kilogram data from 2012 (MarViva Responsible Markets Department), we constructed a revenue function where P_3 is the highest price paid for larger sizes, P_2 is the price for the intermediate class, and P_1 the lowest price the smallest fish.

$$Revenue = \sum_{a=1}^{a=3} C_a w_a P_1 + \sum_{a=4}^{a=6} C_a w_a P_2 + \sum_{a=6}^{a=A} C_a w_a P_3$$

Where C_a is the number of individuals caught at age *a,* w_a the weight (g) of individuals at age *a, and* P_1, P_2, P_3 is the fish price per gram for different size categories.

To estimate profits, we calculated the difference between total revenues for the corvina fishery and total costs. Total cost are estimated as the product of marginal cost (*MC*) and fishing mortality (*F*)[14] (Appendix I).

$$Profit = Revenue - MC * F$$

4. Estimation of absolute biomass

To generate an absolute biomass estimate for Corvina Reina in the upper Gulf, we first estimated catch. The total catch of Corvina Reina in the upper Gulf was estimated using data from INCOPESCA on reported landings by commercial categories in the entire Gulf in 2012 (Appendix II). We corrected for the portion of landings contributed by the upper part as well as for illegal unreported and unregulated catch (Trujillo *et al.* 2015). Because there is no data available for the species composition within each commercial class, we assumed that all species contributed equally, by weight, to the landings of each category. We then, looked for the number of initial recruits that would lead us to the estimated catch for 2012 assuming that the fishery has been operating since 1970 under the conditions of selectivity and fishing mortality estimated for 2012. With this estimated number of initial recruits, we set our initial condition in terms of absolute abundance and biomass while maintaining the proportional age distribution observed in 2012.

5. Management approaches and modeled scenarios

All the modeled scenarios started with the initial condition described above. For each scenario the model was run for 20 years with a discount rate of 0.09, reflecting the high opportunity costs faced in the context of small-scale fisheries. We selected this time horizon as it was considered to be a reasonable period of interest from a manager's perspective while still being long enough to capture the effects of management changes. Natural mortality was held constant scross iterations and was the same for all scenarios. To model each single management approach, we varied a single control variable and held all other values constant at the level observed for 2012. The control variables used to evaluate the different management approaches are fishing mortality (*F*), length at first capture (L_c), and the proportion of the year open to fishing (μ). Therefore, unless the management scenario represented effort reduction, the level of fishing mortality was set equal to the value estimated by the catch curve method for 2012[15]. Similarly, unless the management scenario represented changes in size selectivity, the length at first capture was set at the mode of the length-frequency data for 2012. Unless the management scenario included seasonal closures, the portion of the year open to fishing was set equal to 1 based on the complete noncompliance with the 4-

[14] Fishing mortality is here interchangeable with effort under principles established in the Gordon Schaefer model by assuming a catchability coefficient equal to 1.

[15] We used the value of fishing mortality obtained from the catch curve. This method was considered to be more robust than Lbar method because it incorporated more data points.

month seasonal closure reported in 2012.

Table 3. Management approaches, current regulations and the values to model the perfect compliance scenario (PCS) for each one.

Management Approach	Current Regulation	Value of control variables to model PCS
Long-term closure	Not in place	-
Seasonal Closure	4 months	$\mu = 0.33$
Effort Control	50% of the current boats[16]	$F = 0.5 * F_{2012}$
Size selectivity	Length at first capture of 45 cm[17]	$L_c = 45$ cm
Combined	4-month closure, 50% of the current effort and a length at first capture of 45 cm	$\mu = 0.33$, $F= 0.5*F_{2012}$ and $L_c = 45$ cm

We modeled 5 different management approaches (i) long-term recovery closure, (ii) seasonal closure, (iii) effort control, (iv) size selectivity and (v) all the previous combined excluding long-term closure. Although there are no long-term closures being implemented in the area, we included this approach as it has been suggested by researchers and managers as a recovery strategy for the Gulf[18]. For each management approach we looked at two scenarios, the perfect compliance scenario (PCS) and the best case scenario (BCS). The PCS corresponds to the scenario representing the current management approach established "on paper" and the net present value (NPV) generated in this scenario is the value that would be generated over 20 years if the regulation in

---

16 We consider licenses as the current effort control regulation. Since there is no information regarding the number of licenses in the upper Gulf or the number of boats, we applied the estimates provided by representatives from INCOPESCA reporting that approximately 50 percent of the boats currently fishing in the Gulf are unlicensed.

17 We considered minimum mesh-size as the current size selectivity regulation. Legal minimum mesh size for Corvina Reina is 3.5" which has been associated to a length at first capture equal to 45 cm (Lai *et al.*, 1992) .

18 During the fieldwork conducted on July of 2016, different stakeholders (e.g. government agencies, scholars and NGOs) were interviewed to identify management intervention being currently considered for managing the Gulf. Consequently, these suggested approaches were considered in the model.

place would be completely complied with (Table 32). The BCS corresponds to the scenario at which the NPV over 20 years is maximized, thus it corresponds to an optimal regulation design under perfect compliance.

6. Fisher's perceptions about compliance with the 2016 closure

In order to supplement our quantitative analysis, two fieldtrips were performed between July and September of 2016. Fishers representatives of most associations along the Gulf were contacted by phone and asked to participate in a survey, as well as to invite other members of the association to participate[19]. The list of official contacts was obtained from INCOPESCA. The survey was applied individually in different locations such as landing points, beaches, restaurant or fishers houses depending on fisher's availability. Independent fishers encountered in the field were also asked to participate. Surveys were performed in Spanish by 5 different interviewers. The questionnaire included a free elicitation (open ended question) regarding compliance with the closure and the reasons behind noncompliance if reported. This methodology enables personal, spontaneous, and relatively unfiltered responses (Gelcich *et al.* 2016). Other questions about demographics and fishing activity were also included at the beginning of the questionnaire. In total, 88 fishers were surveyed. Only 49 were asked about reasons for noncompliance as this question was introduced during the second sampling period[20]. Reasons for noncompliance provided as open ended questions were categorized by topic.

---

[19] All fishing associations were tried to be contacted but in some cases, contact information was wrong or they did not answer.

[20] We performed two visits to the region, the first one between 2nd and the 15th of July and the second one between 22th August and 8th September. Between these periods we considered of important value to add this question after asking for closure compliance. As this was added at the end of the section we do not expected it to influence other answers presented in this report. Samples in both periods were representative of the entire Gulf.

Results

1. Corvina reina fishery status

All but one of the estimated data-poor indicators suggest that the fishery of corvina reina in the upper part of the Gulf of Nicoya is in an overexploited state (Table 4). Only the fishing mortality ratio (F/F_{msy}), estimated for 2012 using the Lbar method, corresponds with an underexploited status.

Table 4. Fishing mortality ratio (F/F_{msy}), Froese indicators and Spawning Potential Ratio (SPR) estimated for the corvina reina fishery in the upper part of the Gulf of Nicoya based on length data published by INCOPESCA for 2012 and 2014. Red numbers indicate values that deviate from the target point in an undesirable direction.

Indicator	Target	Value for Corvina fishery 2012	Value for Corvina fishery 2014
Percentage of mature individuals in the catch	> 90	**40.9**	**29.2**
Percentage of individuals within ±10% of the optimal length in the catch	100	**15.7**	**15.7**
Percentage of mega-spawners in the catch	30-40	**28.6**	**16.9**
SPR	40	**22.7**	**23.9**
F/F_{msy} estimated with the catch curve method	1	**1.29**	**1.21**
F/F_{msy} estimated with the Lbar method	1	**0.79**	**1.21**

All three Froese sustainability indicators are below the target for a healthy fish stock population, and show a decline in performance from 2012 to 2014. Finally, the spawning potential ratio also shows suboptimal status (Table 4).

2. The economic potential of the corvina reina fishery for current management approaches under perfect compliance and improved design

Based on interviews with fishermen and managers, we assumed the corvina fishery is currently in a zero-profit state of open access equilibrium. Operating under this assumption, we assert that with no intervention the fishery will continue at the current equilibrium. This established our *status quo* reference point as zero net present value over 20 years. Using 2012 length frequency data, we estimated a fishing mortality of 0.33, while length at first capture was found to be 32 cm. These values were used as controls to model the scenarios for different single management approach interventions.

Profits under both, perfect compliance scenario (PCS) and best case scenario (BCS) for all management approaches translate into significant improvements relative to the *status quo* as shown in Figure 3. PCS of existing management approaches project increases ranging from 1.6 to 2.4 million USD in NPV. If compliance alone where improved, effort control would be the management alternative generating the highest benefits. While increasing size selectivity showed the highest positive effect (all else constant) under BCS, reaching almost 3.5 million dollars (Figure 3)[21].

2.a. Long-term closure

Our analysis of closing the corvina reina fishery anywhere from 1 to 20 consecutive years showed that the BCS corresponds to 7-year closure. We estimated this would result in 2.5 million additional NPV over 20 years (Figure 3). Here the scenario assumes no additional management interventions once the fishery reopens.

2.b. Seasonal closure

This scenario generated the smallest benefits out of all the different management interventions. Current annual closure in the upper Gulf lasts 4 months. We estimated that while there are minimal gains to be made by extending the seasonal closure, other policies such as effort control and selectivity had more potential (Figure 3). All else constant, NPV was maximized with a seasonal closure of 7 months.

2.c. Effort control

The improved design for this scenario does not generate many additional benefits as compared to other policies such as selectivity for example. Out of the different single management approaches, decreasing effort generates the highest returns from compliance with current regulations (Figure 3).

---

[21] Here optimal is defined as the value for a given management approach which maximized the net present value of the fishery over a 20-year period.

2.d. Size selectivity

Under compliance, the fishery would generate nearly 2 million dollars over 20 years (Figure 3). By adjusting the minimum size to 67 centimeters, this fishery would reach a value of about 3.5 million dollars, showing how gear selectivity has the biggest impacts on improving its value (Figure 3)[22].

2.e. Combined scenarios

We examined the net benefit of compliance across the three current policies simultaneously. Here we found the combined cost of noncompliance is an estimated 2.5 million USD in NPV over the next 20 years. Finally, we modeled the combination of policies that would maximize the value of the fishery. We estimate that an 8 percent reduction in effort, coupled with a minimum size of 75 cm and no seasonal closures would generate an additional 3.5 million dollars in NPV (Figure 3).

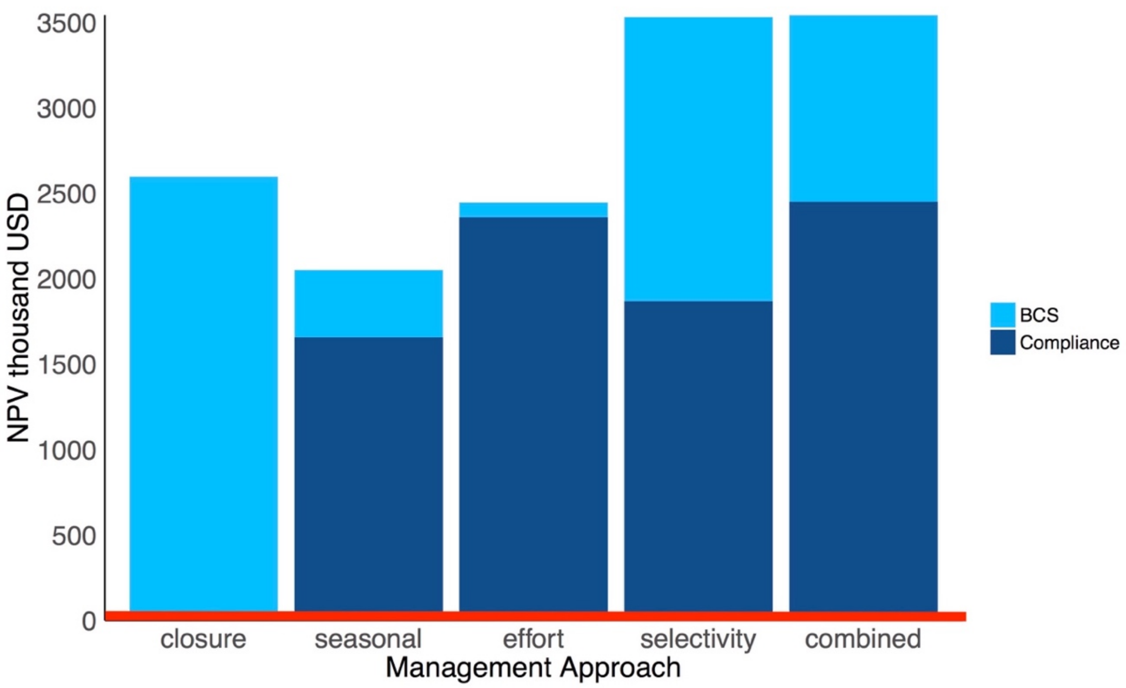

Figure 3. Net Present Value (NPV) of the different management approaches (long-term closure, seasonal closure, effort, selectivity and their combination), under perfect Compliance (dark blue) and Best Case Scenario (BCS) design (light blue). The *status quo* is represented by the red line at zero NPV as the fishery is in open access equilibrium.

[22] It is important to note here that while this scenario does not initially implement any form of effort reduction, there is an implicit assumption that additional entry to the fishery is somehow prohibited as profits grow over time.

2.f Fisher's perceptions about the reasons for noncompliance with current fisheries legislation in the Gulf of Nicoya

We use compliance with seasonal closures as a reference point for compliance in the Gulf of Nicoya. We found 93% (n=82) of fishers believed the closure was violated in 2016 (Appendix III). The two main reasons related to economic need of fishers (31%), and to the lack of surveillance by authorities (26%), (Figure 4)[23]. Other responses include fishers' disregard for regulations (16%) and excessive administrative requirements to obtain economic help during the closure (12%). Lack of law enforcement and inefficient authorities corresponded to 6% and 7% of the responses respectively. Finally, ineffective planning by authorities and opportunities to cheat both represented 1% of responses.

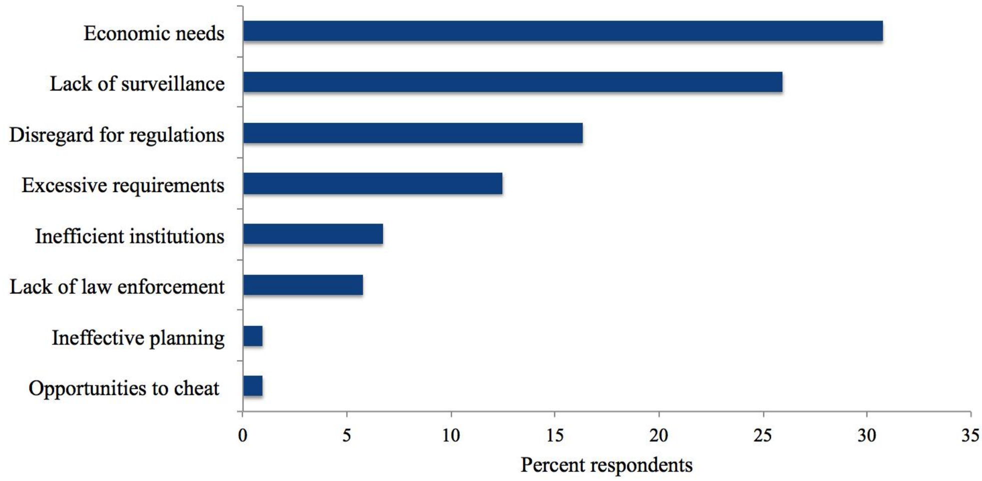

Figure 4. Fishers perceptions on the reason why the seasonal closure was not being respected in 2016 in the Gulf of Nicoya (n=49).

3. Economic and social tradeoffs of the Best Case Scenario outcomes of different management approaches over time based on real profits

In this context, the selection of management requires consideration of both economic and social tradeoffs. For small-scale fisheries in developing countries, delays in returns can prove critical to the success or failure of a policy. This is due to the difference of short term economic needs against the medium-long term management response. To close this gap, incentives play an important role for fishers. We analyzed the trends over time of real profits generated by the best case management scenarios. This allows us to see the range between the current and most economically desirable status, each coupled with tradeoffs

[23] Although the total number of fishers surveyed was 88, the answers about the reasons for noncompliance to the closure in 2016, came from 49 interviewed. This is due an additional question introduced in the second sampling period.

(Appendix V) that are important to consider when making decisions. When tradeoffs exist in fisheries management decisions, there is no simple answer to the “best” management strategy. In our analysis we identified efficient strategies that maximizes economic benefits over time. Nevertheless, stakeholders must make a value-based judgment considering different dimensions of management outcomes in ecological, social and economic terms (Appendix V).

3.a. Management Scenario 1, Long term closure

The optimal policy for this scenario includes 7 of years of no fishing which would have negative short-term impacts for the communities where many livelihoods depend on fishing and few alternatives are readily available (Figures 5 and 6). Once the fishery is reopened, we see a rapid decline in profits. Ultimately we would expect this would return to an open access equilibrium of zero profits (Figure 6). This result is motivated by a race to fish behavior that quickly decreases accumulated benefits from the recovery closure.

3.b. Management Scenario 2, Seasonal closure

In this case profits are negative for the first 2 years (Figure 5). Without some form of assistance, this would likely be a period of hardship for local fishers. Seasonal closures, both short term and long term also restrict access to other fisheries in areas inhabited by corvina reina.

3.c. Management Scenario 3, Effort

Of all the different scenarios, effort reduction is the only one with consistently positive profits. There is a rapid increase of profit and this intervention outperforms others over the first three years (Figures 5 and 6). However, the optimal effort level would require a 60 percent reduction in fishing. While there are varied strategies available to limit effort, this will likely mean loss of per capita income or jobs. This potential increases in poverty has associated equity concerns that would need to be taken into account.

3.d. Management Scenario 4, Selectivity

Gear selectivity is the most effective single management approach in terms of maximizing the net present value of the fishery (with a minimum size of 67 cm capture). We find a reduced profit for the first 2 years (Figure 5) and that estimate has not taken gear replacement costs into account. Profits increase rapidly after year 4, not by increasing the number of fish caught, but by increasing the size of individuals caught, which command a higher price per kg at market (Figure 6). The implementation of a minimum size for corvina reina would require a full ban on mesh sizes smaller than 6 inches in areas where corvina reina are present.

This would interfere with other fisheries in the Gulf of Nicoya such as shrimp, and therefore additional tradeoffs would need to be taken into account.

3.e. Management Scenario 5, Combined scenarios

The combined approach also reports losses over the first two years and trajectory overlaps with gear selectivity (Figure 5). The combination requires an 8% reduction in effort and a higher minimum size limit of 75 cm. The small difference in returns of net present value better motivates other single management approaches such as selectivity as they both follow almost the same path with a very small economic difference (Figure 6). The positive response of selectivity is largely driven by the recovery of larger individuals in the population, allowing fishers to take advantage of the preferential market pricing.

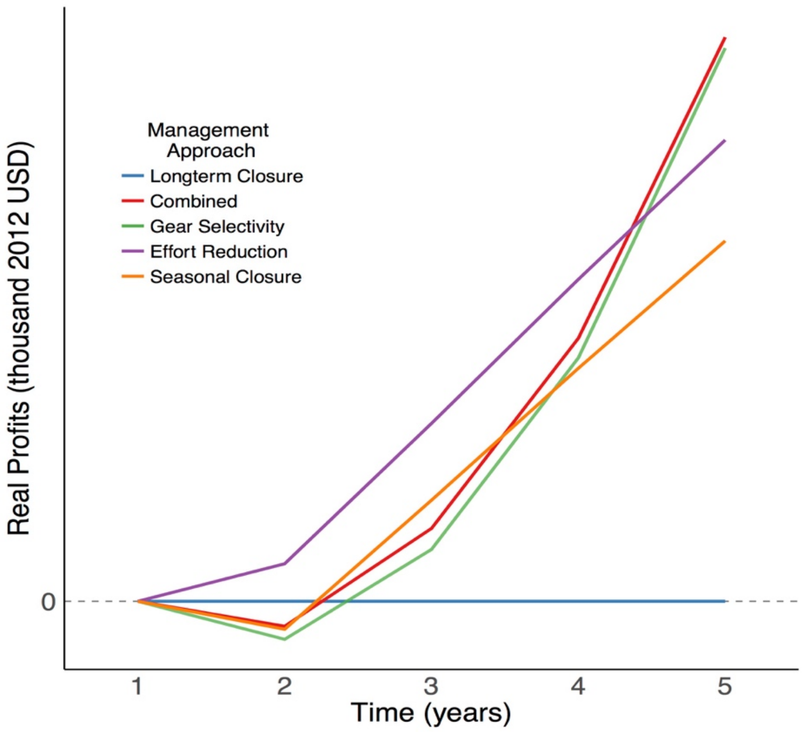

Figure 5. Short-term economic (real profits) path of the Best Case Scenario outcomes of different management approaches over time.

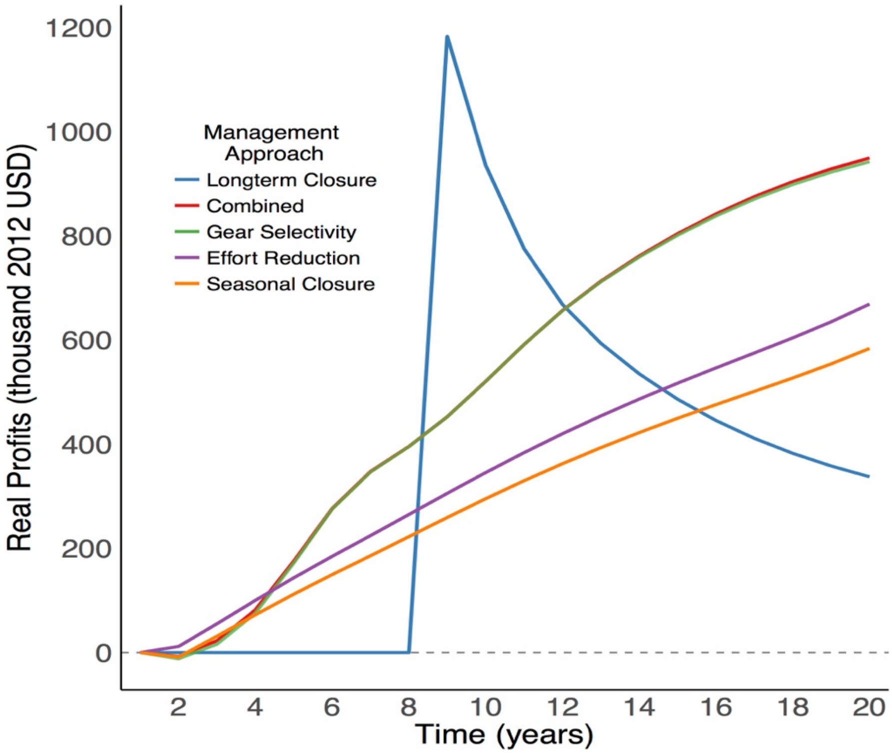

Figure 6. Long-term economic (real profits) path of the Best Case Scenario outcomes of different management approaches over time. Gear selectivity (green) is overlaps the Combined approach (red)

Although we set economic targets to assess management outcomes, there is an implicit concern for the sustainability of the fish stock. An overemphasis on economic gains without consideration of the biological impacts may result in overharvesting in the short run to compensate for the economic penalty put in place by discounting future profits. Within the model, economic results are driven by changes in the corvina reina biomass over time. All five of the optimal management scenarios increased biomass following similar improvement trends with exception of the long-term closure.

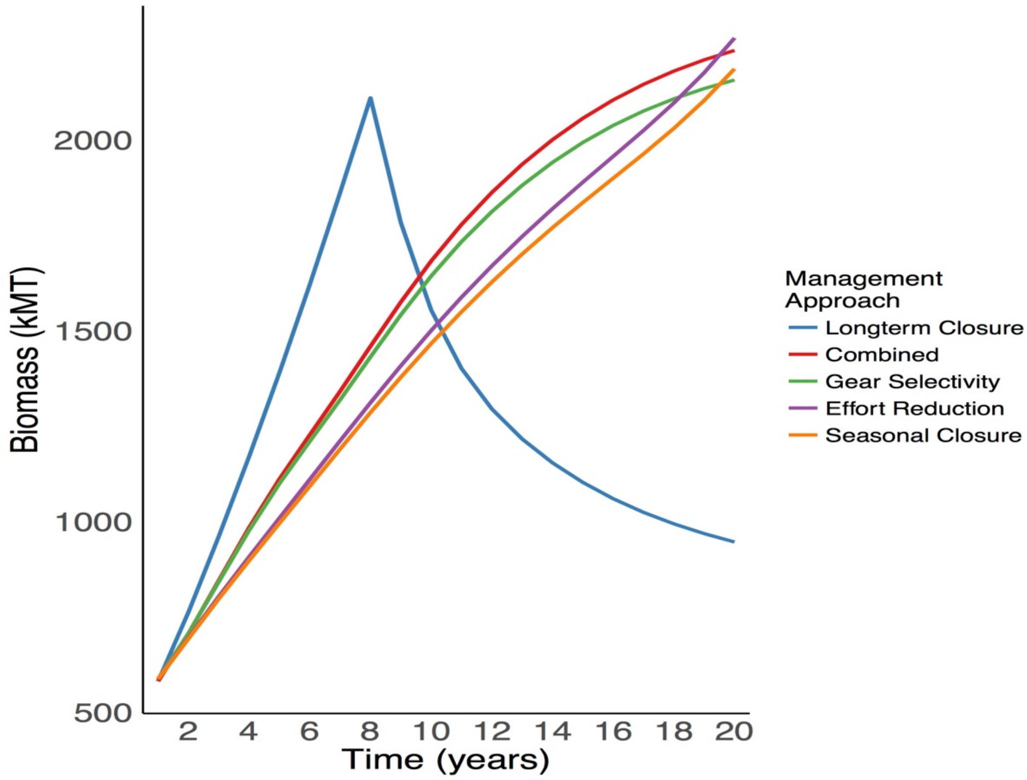

Figure 7. Projected biomass (thousand metric tons) of corvina reina in the upper Gulf of Nicoya modeled under optimal design and perfect compliance with (i) effort control (purple), (ii) seasonal closures (orange), (iii) gear selectivity (green), (iv) long-term closure (blue), and (v) combined management interventions (red).

Discussion

Based on our results it is clear that the Corvina Reina fishery in the upper Gulf is underperforming. To our knowledge the data limited assessment approach used to characterize this fishery is the first effort to evaluate the status of a single species in the Gulf of Nicoya. Although our analysis only focuses on the Corvina Reina fishery, management efforts are the same for the other targeted species in the upper Gulf, therefore it is likely that other finfish species are presenting similar fishing conditions. Given the limited resources available to managers, the only way of establishing the status of these other species is by applying similar data-limited assessments as the ones presented in this report.

Traditional fisheries stock assessments rely on high quality data and quantitatively complex population dynamic models (Hilborn & Walters, 1992). Species specific abundance, biomass, effort and catch data for many fisheries in developing countries are commonly nonexistent, as is the case for Costa Rica. With these conditions, simple indicators of stock performance such as the ones used in our analysis are gaining in popularity (Froese, 2004). Another advantage of these methods is that they are easy to understand, facilitating the communication among stakeholders. Replication of the methods employed here can allow managers in Costa Rica to identify threaten stocks and develop more targeted management to make better use of their limited resources.

As reflected by the status of the corvina reina fishery assessment, in conjunction with reports from external consultants and INCOPESCA, management has not being effective. This lack of effective management can be due to a poor policy design, lack of monitoring, weak enforcement, weak institutions or more likely a combination of all of these. All of these conditions have led the fishery to an open access status. When an open access fishery reaches equilibrium, we expect zero aggregate profit. This is an undesirable point as all benefits dissipate (Gordon, 1954), generating no economic gains. For managers, escaping this equilibrium point requires costly planning and investment. Our analysis provides insight to possible strategies to recover from this zero profit scenario and quantifies the maximum expected return This information will allow managers to make more informed decisions in the allocation of their limited resources. Although we present here results for optimizing the NPV, this methodology can be applied to meet multiple criteria with additional considerations for external costs and tradeoffs.

Controlling fishing effort through the number of boats, the gear used and enforcing a minimum size constraint on catch are basic management strategies utilized worldwide (Selig *et al.*, 2016). Our review and subsequent analysis of compliance in the Gulf of Nicoya suggests that these strategies are effectively absent. This is not a problem unique to the Gulf of Nicoya. Resources for enforcement and monitoring are limited across the country. Even when communities have driven management efforts such as the Marine Areas of Responsible Fishing, they face a challenge due to cost of continued surveillance patrols to protect their area. While some communities have more comprehensive gear restrictions in place, no minimum sizes have been established. The results of our analysis suggest that this may therefore led them to underperform in the long-term.

As our model considers the size component of this fishery it allowed us to incorporate the preferential pricing for larger fish into policy recommendations. By increasing size selectivity, it is possible to allow the current population of fishermen to continue fishing while driving the stock toward a healthier distribution which we expect will generate more revenues in the future. One limiting assumption of this scenario is that there will be no decline in prices with an increased supply of larger fish and that corvina of different sizes are perfect substitutes. Market dynamics where beyond the scope of our analysis, but should also be considered if size selectivity strategies are going to be pursued. Additionally, our analysis holds the exploitation rate constant under the new size restrictions. We know that fishing effort (in hours or number of gear) is likely to be responsive to changes in management. While we can recommend that a maximum number of vessels be established and enforced, other forms of effort can be much harder to monitor and control.

Although we found managing for size selection had the greatest potential returns, we expect this approach would generate some additional external conflicts. Our profit optimizing minimum size would require either a complete exclusion of gillnets or a ban on mesh sizes smaller than 6 inches in the upper gulf. This would interfere with other fisheries in the upper part of the Gulf of Nicoya that rely on smaller gillnets. It would also require fishers to invest in new gear and some would need to adjust to new fishing methods. INCOPESCA would likely need to develop programs to alleviate the cost of this transition.

All of the management interventions considered here have inherent tradeoffs requiring a significant discussion with an array of stakeholders, most importantly users. Our estimates only consider some of the direct costs to fishers and do not account for external costs of enforcement, implementation, or potential interference with other fisheries. In this context, changes to regulation can be a long and a costly process, often involving consultations and negotiations with local associations. We have demonstrated the potential benefits of compliance and policy designs to inform the maximum returns to this process. We are aware that perfect compliance and design are impossible to achieve in practice and that trade-offs needs to be incorporated in this regard. However, by considering the maximum potential we hope to allow managers to make more informed decision in the allocation of their limited resources.

Conclusions

The corvina reina fishery is currently in a state of overexploitation. If the current management remains unchanged, we estimate this fishery will underperform by 2.5 million USD due to noncompliance and an additional 1.1 million USD due to sub-optimal economic design.

If no adjustments to current policies are made, prioritizing compliance with effort restrictions will generate the greatest economic returns. While current legislation is in place for compliance, implementation requires improvements in monitoring and enforcement. The first step may be to conduct a full census of fishing effort in the Gulf to effectively and accurately control effort. There is currently no reliable estimate of the number of fishing boats in the Gulf of Nicoya.

The highest returns for the corvina fishery (all else constant) are generated by the implementation of a minimum size of 67 cm. This estimate does not require a reduction in the current fishing effort in the Gulf. Currently Costa Rica has no size limit legislation for any of its fisheries. The results shown in this report should serve as an incentive to promote this type of legislation. We have identified 13 other fisheries in the upper Gulf that exhibit some form of preferential size pricing and could benefit from our approach. Further exploration of the direct and indirect costs of this management approach is still needed. Under any legislation adjustment, surveillance and enforcement must be a priority.

The economic benefits of fisheries compliance demonstrated in our analysis, reinforces the need to fully implement the National Marine Strategy of Control and Surveillance[24] coupled with community engagement. Attention should be given to priority areas such as the upper part of the Gulf of Nicoya. An important focus should be given to the implementation of the Interinstitutional Surveillance Station in the upper part of the Gulf of Nicoya inaugurated in July 2016, but still inactive given to lack of interinstitutional agreement between INCOPESCA, Coast Guards and the National System of Conservation Areas (SINAC)[25].

Recommendations for further analysis.
With the intention to provide managers with a tool to explore different combinations of gear selectivity, effort levels, seasonal and long-term closures over time, we developed an interactive user interface to model additional

---

[24] MINAE. Costa Rica Verde y Azul. Informe de Labores 2010-2014. [Internet]. [cited 2017, March 8th]. Available from: http://www.minae.go.cr/recursos/2014/INFORME_FINAL_MINAE_2010-2014.pdf

[25] Bureaucracy killing the Gulf of Nicoya. [Internet]. [cited 2017, March 7th]. Available from: http://www.vozdeguanacaste.com/en/articles/2017/02/17/editorial-bureaucracy-killing-gulf-nicoya

scenarios. The application is helpful for exploring policy options that result in different outcomes of profit, catch, revenue and biomass depending on the levels of management proposed (Appendix VI).

References

Arendse, C. J., Govender, A., & Branch, G. M. (2007). Are closed fishing seasons an effective means of increasing reproductive output?: A per-recruit simulation using the limpet *Cymbula granatina* as a case history. *Fisheries research*, *85*(1), 93-100.

Ault, J. S., Smith, S. G., Luo, J., Monaco, M. E., & Appeldoorn, R. S. (2008). Length-based assessment of sustainability benchmarks for coral reef fishes in Puerto Rico. *Environmental Conservation*, *35*(3), 221.

Baranov, F. I. (1918). *On the question of the biological basis of fisheries*.

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

Carvajal, D. F. (2013). Pesca artesanal y pobreza en comunidades aledañas al Golfo de Nicoya. *Revista de Ciencias Sociales*, (140). Retrieved from http://revistas.ucr.ac.cr/index.php/sociales/article/view/12319

Chacón A., Araya H., Vásquez A., Brenes R., & Marín B. (2007). Estadísticas pesqueras del Golfo de Nicoya, Costa Rica, 1994-2005. Proyecto Manejo Sostenible de la Pesquería para el Golfo de Nicoya. INCOPESCA-UNA-JICA. Puntarenas, Costa Rica.

Contraloría General de la República de Costa Rica (2014). Auditoría de carácter especial sobre la gestión de INCOPESCA vinculada al cumpliento de sus funciones en materia de aprovechamiento y uso sostenible de los recursos marinos. San José, Costa Rica.

Coope SoliDar R.L. (2013). Fortaleciendo la gobernanza marina desde las comunidades de pesca artesanal: Áreas marinas de pesca responsable y la visión desde sus protagonistas en el mar. San José, Costa Rica.

Ehrhardt, N. M., & Ault, J. S. (1992). Analysis of Two Length-Based Mortality Models Applied to Bounded Catch Length Frequencies. *Transactions of the American Fisheries Society*, *121*(1), 115–122.

Fernández Carvajal, D. (2016). Artisanal fishing and poverty in the communities near the Nicoya´ s Gulf. San José, Costa Rica.

Froese, R. (2004). Keep it simple: three indicators to deal with overfishing. *Fish and fisheries*, 5(1), 86-91.

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

Fundación Marviva. Casi 30 años después: Veda anual en el Golfo de Nicoya no ha dado resultados. Retrieved from: http://marviva.net/index.php/es/consumoresponsable/10-noticias/archivo-de-notas/406-casi-30-anos-despues-veda-anual-en-el-golfo-de-nicoya-no-ha-dado-resultados

Gelcich, S., Cinner, J., Donlan, C. J., Tapia-Lewin, S., Godoy, N., & Castilla, J. C. (2016). Fishers' perceptions on the Chilean coastal TURF system after two decades: problems, benefits, and emerging needs. *Bulletin of Marine Science*.

Gocke, K., Cortés, J., & Murillo, M. M. (2001). The annual cycle of primary productivity in a tropical estuary: the inner regions of the Golfo de Nicoya, Costa Rica. *Revista de biología tropical*, *49*, 289-306.

Goodyear, C. P.(1993). Spawning stock biomass per recruit in fisheries management: foundation and current use. *Canadian Special Publication of Fisheries and Aquatic Sciences*, 67-82.

Gordon, H. S. (1954). The economic theory of a common-property resource: the fishery. *Journal of political economy*, *62*(2), 124-142.

Hilborn, R., & C. J. Walters. (1992). Quantitative fisheries stock assessment: choice, dynamics, and uncertainty. Chapman and Hall, New York.

Hordyk, A., Ono, K., Valencia, S., Loneragan, N., & Prince, J. (2015). A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. *ICES Journal of Marine Science: Journal du Conseil*, 72(1), 217-231.

Instituto Costarricense de Pesca y Acuicultura (INCOPESCA). (n.d). Commercial species of Costa Rican. Retrieved from https://www.incopesca.go.cr/mercado/documentos/catalogo-pesca.pdf

Instituto Costarricense de Pesca y Acuicultura (INCOPESCA). (2014). Comportamiento de las estadísticas comerciales 2014-2015. Retrieved from https://www.incopesca.go.cr/mercado/boletin/boletin_1_2014/boletin%20_semestral_2014-2015.pdf

López, J. (2016, July 06). Personal interview.

Lester, S. E., McDonald, G., Clemence, M., Dougherty, D. T., & Szuwalski, C. S.

(2016). Impacts of TURFs and marine reserves on fisheries and conservation goals: Theory, empirical evidence, and modeling. *Bulletin of Marine Science*.

Lai, H. L., Mug, M., & Gallucci, V. F. (1992). Management strategies for the tropical corvina reina, Cynoscion albus, in a multimesh size gillnet artisanal fishery. In *Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations, Anchorage, Alaska*.

Lozano, A. J. G., & Heinen, J. T. (2016). Identifying drivers of collective action for the co-management of coastal marine fisheries in the Gulf of Nicoya, Costa Rica. *Environmental management*, *57*(4), 759-769.

Marín, B., & A.R. Vásquez. (2010). Evaluación de los recursos pesqueros Post-Veda 2009 en el interior del Golfo de Nicoya. Documento técnico N° 2 del departamento de Investigación Pesquera de INCOPESCA, Puntarenas, Costa Rica.

Marín, B., Araya , H., & Vásquez, A.R. (2013). Informe del resultado de la veda 2012, basado en encuesta aplicada a pescadores artesanales del Golfo de Nicoya. Documento Técnico N° 14 del Departamento de Investigación Pesquera de Incopesca. Puntarenas, Costa Rica.

Marín, B. & Vásquez, A.R. (2012). Estimación de la talla de primera madurez sexual criterio L50% (TPM) de la corvina reina *Cynoscion albus* (Perciforme: Scianidae) bajo condiciones de sobreexplotación de su población en el Golfo de Nicoya, Costa Rica. Documento Técnico N° 11. Departamento de Investigación Pesquera de INCOPESCA. Puntarenas, Costa Rica.

Marín, B., & Vásquez A. (2014). Informe especial acerca de los resultados de los muestreos biológicos realizados en siete comunidades del interior del Golfo de Nicoya durante los meses de octubre 2013 y marzo 2014. Departamento de investigación y desarrollo del INCOPESCA. Puntarenas, Costa Rica.

Marín, B., Araya , H.,Vásquez, A.R. & Chavarría , J. (2013). Informe de resultado de Veda basado en muestreos biológicos realizados en siete comunidades del interior del Golfo de Nicoya. Documento técnico N°. Departamento de Investigación Pesquera de INCOPESCA. Puntarenas, Costa Rica.

Marín, B. (2015). Evaluación de los recursos pesqueros y de la veda 2014 en la zona interior del Golfo de Nicoya. Documento Técnico N° 20. Departamento de Investigación Pesquera de INCOPESCA. Puntarenas, Costa Rica.

Marín, B. (2015). Evaluación de los recursos pesqueros y de la veda 2014 en la zona interior del Golfo de Nicoya. Documento Técnico N° 14 del Departamento de Investigación Pesquera de Incopesca. Puntarenas, Costa Rica.

Fundación MarViva. (2012). Guía de Identificación de Filetes de Pescado y Mariscos. Retrieved from http://www.marviva.net/Publicaciones/Guia_de_identificacion_de_filetes_de_pescado_y_mariscos.pdf

Mug-Villanueva, M., Gallucci, V. F., & Lai, H. L. (1994). Age determination of corvina reina (Cynoscion albus) in the Gulf of Nicoya, Costa Rica, based on examination and analysis of hyaline zones, morphology and microstructure of otoliths. *Journal of fish biology*, *45*(2), 177-191.

Myers, R. A., Keith G. B., & Nicholas J. B. (1999). Maximum Reproductive Rate of Fish at Low Population Sizes. *Canadian Journal of Fisheries and Aquatic Sciences* 56 *(12)*: 2404–19.

Palacios, J. A. (2013). Evaluación de la pesquería en la zona interna del Golfo de Nicoya, Costa Rica. San José, Costa Rica.

Pauly, D. (1983). *Some simple methods for the assessment of tropical fish stocks* (No. 234). Food & Agriculture Org.

Poder Ejecutivo. (1985). Decreto Ejecutivo 16804-MAG. Disposiciones Generales Relativas a la Pesca Artesanal en Pequeña Escala. San José, Costa Rica.

Proyecto FIP. (1999). Estudio biológico pesquero de la corvina en la zona centro-sur. Departamento de Oceanografía. Universidad de Concepción. Chile. Proyecto No 97-19. 152 p.

Centro de Inteligencia de Mercados Sostenibles (CIMS). (2011). Manual de oportunidades de mercado viables y factibles para la MIPYME del sector pesquerías sostenibles. Fascículo 3: Costa Rica. Retrieved from https://es.scribd.com/document/53090449/COSTA-RICA-Manual-de-oportunidades-de-mercado-viables-y-factibles-para-la-MIPYME-del-sector-pesquerias-sostenibles

Proyecto Golfos. (2014). Plan de Ordenamiento Espacial Marino del Área Marina de Uso Múltiple Golfo de Nicoya. San José, Costa Rica.

Simpfendorfer, C., Bonfil, R., & Robert J. L. (2005). "Mortality Estimation." In Management Techniques for Elasmobranch Fisheries, edited by John A Musick and Ramón Bonfil. Rome: Food and Agriculture Organization of the United Nations.

Solemdal, P. (1997). Maternal effects – a link between the past and the future. Journal of Sea Research 37, 213–227.

Tahvonen, O. (2009). Economics of harvesting age-structured fish populations. *Journal of Environmental Economics and Management*, 58(3), 281-299.

Trippel, E.A. (1998) Egg size and viability and seasonal offspring production of young Atlantic Cod. Transactions of the American Fisheries Society 127, 339–359.

Trujillo, P., Cisneros-Montemayor, A., Harpera, S. Zylich, K., & Zellera, D. (2015). Reconstruction of Costa Rica Marine Fisheries Catches , 1950-2010. Working Paper 2015-31. Sea Around Us, Fisheries Centre, University of British Columbia, , Vancouver , BC, Canada.

Wallace, R. K., & Fletcher, K. M. (2000). Understanding fisheries management: a manual for understanding the federal fisheries management process including analysis of the 1996 Sustainable Fisheries Act.

Watson, R. A., Die, D. J., & Restrepo, V. R. (1993). Closed seasons and tropical penaeid fisheries: a simulation including fleet dynamics and uncertainty. *North American Journal of Fisheries Management*, *13*(2), 326-336.

Wolff, M., Koch, V., Chavarria, J. B., & Vargas, J. A. (1998). A trophic flow model of the Golfo de Nicoya, Costa Rica. *Revista de biología tropical*, 46, 63-80.

Xiao, Y. (2005). Catch equations: restoring the missing terms in the nominally generalized Baranov catch equation. *Ecological modelling*, 181(4), 535-556.

Zhou, S., Yin, S., Thorson, J. T., Smith, A. D., & Fuller, M. (2012). Linking fishing mortality reference points to life history traits: an empirical study. *Canadian Journal of Fisheries and Aquatic Sciences, 69(8)*, 1292-1301.

Appendix I. Estimating Marginal Cost

Using open-access principles developed in the Gordon-Schaefer model (Gordon, 1954), we assume that the corvina reina fishery is in a current state of open access equilibrium in which the fishery is generating zero profits. We relate fishing mortality to effort using equation:

$$F = qE$$

where *F* is fishing mortality, *q* is the catchability coefficient, and *E* is effort. For simplicity of analysis we assume a catchability coefficient of 1. This makes effort a unitless index equal to *F*.

To estimate a marginal cost of effort, a range of steady state equilibrium were explored for the fishery and a cost line were fitted so that could generate zero profits at our observed open access equilibrium and when fishing effort is equal to zero (Figure A1). Functionally, the marginal cost estimate then becomes:

$$MC = \frac{Revenue_{OA}}{F_{OA}}$$

where, *MC* is the marginal cost, $Revenue_{OA}$ is the revenue at open access equilibrium, and F_{OA} is effort at open access equilibrium.

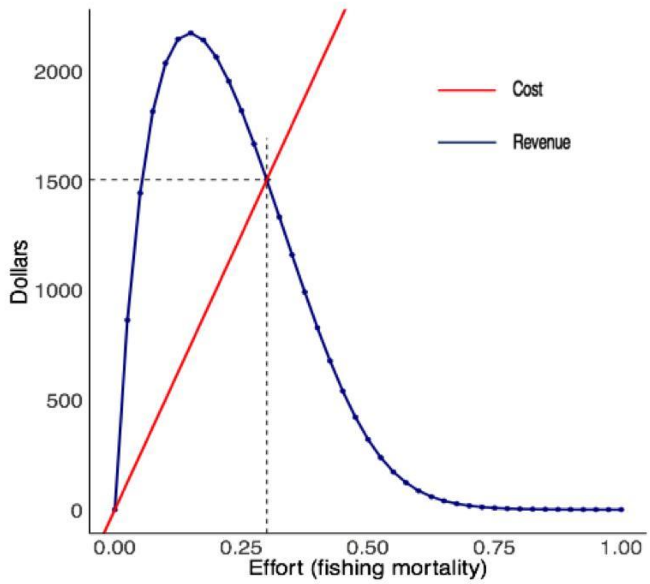

Figure A1. Marginal cost estimation under the open access principles of the Gordon-Schaefer model.

Appendix II. Estimation of catch of Corvina Reina in the upper Gulf

	Commercial Category		
	Primera Grande*	Primera Pequeña**	Clase***
Reported landings (kg) in 2012 for the Gulf of Nicoya[26]	176272	508292	480872
Number of species per commercial category[27]	4	13	25
Portion of the landings that come from Zone 201[28]	0.51	0.51	0.51
Unreported illegal fishing correction factor[29]	2.6	2.6	2.6
Estimation of Corvina Reina landing in Zone 201(kg)	58434	51846	25505

* Large fish size (Premier size)
** Medium fish size
*** Small fish size

[26] INCOPESCA. 2012 Database. [Internet]. [cited 2017, Jan 10]. Available from: www.incopesca.go.cr

[27] MarViva. Department of Sustainable Markets.

[28] Araya, H., Vásquez, A. (2005). Evaluación de los recursos pesqueros en el Golfo de Nicoya , Costa Rica. Años 2001-2004. Departamento de Investigación Pesquera de INCOPESCA. 43p.

[29] Trujillo, P., Cisneros-Montemayor, A., Harpera, S. Zylich, K and Zellera, D. (2015). Reconstruction of Costa Ricas Marine Fisheries Catches , 1950-2010. Working Paper 2015-31. Sea Around Us, Fisheries Centre, University of British Columbia, , Vancouver , BC, Canada.

Appendix III. Survey sample characteristics

Between July and September of 2016, two fieldtrips were developed to collect information and to conduct a survey in the Gulf of Nicoya. 88 fishers were surveyed about compliance of the closure in the Gulf during that year (Table A1). While the first section of the survey included questions about demographics and fishing activity from all respondents, a free elicitation (open ended question) were applied during the second sampling period to 49 respondents to allow them to express their opinion about the main reasons for noncompliance of the closure.

Table A1. Characteristics of the survey sample in the Gulf of Nicoya

Survey sample in the Gulf of Nicoya, 2016.

Characteristic	*n*	Percentage of total
Gender		
Male	78	89
Female	10	11
Age		
18-24	1	1
25-34	6	7
35-44	15	17
45-54	31	35
55-64	29	33
65+	6	7
Location		
Zone 201	36	41
Zone 202	45	51
Zone 203	7	8
Years of fishing		
1-10	3	3
11-21	16	19
22-32	29	34
33-43	24	28
44-54	9	10
55-65	5	6
Activity/Occupation		
Fishing is the primary activity	68	77
Other activity apart from fishing	15	17
Not answered	5	6
Association		
Fisher associated to a fishing community	71	81
Independent fisher or not associated	17	19
Gear type use in fishing activity [1]		
Gillnet	72	47
Handline	37	24
Longline	33	22
Other gears	10	7

[1] The number of fishers interviewed is 88 but a fisher can use more than one fishing gear. For this characteristic, the the total is based in the number of responses (n=152).

Appendix IV. Full NPV Results by Management Approach

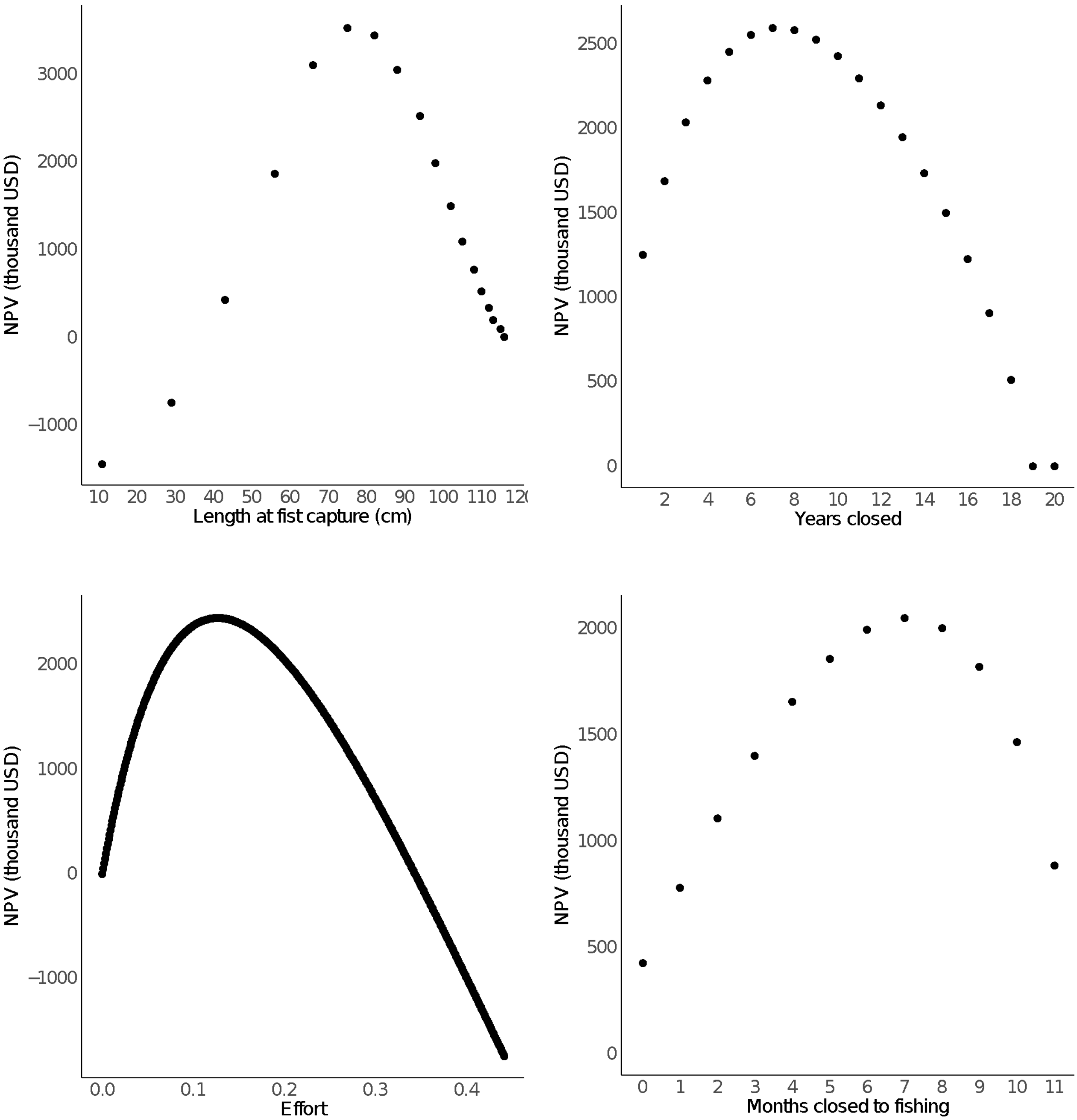

Figure A2. Net present values (NPV) under different management approach designs for gear selectivity, long-term recovery closure, effort, and monthly closure.

Appendix V. Tradeoffs from the different management approaches

Table 2.A. Ecological, social, and economic tradeoffs from different management approaches

Approach	Ecologial	Social	Economic
Effort Control	• **Fishing pressure** in the whole system would **decrease** and generate **ecological improvements**	• Would better organize the fishery for the long term but under the cost of **livelihoods lost**	• There would be a number of people **without economic benefits** while others would have **economic improvements**
Gear Selectivity	• Accounts for the management of **one species** and does not considers ecosystem effects	• Fishing behavior and gear change in multispecies--multigear fisheries generates high **resistance**	• Maximizes economic **benefits for one species** while **limiting** economic benefits from other smaller and **lower trophic species**
Seasonal Closures	• Would allow for **multispecies recovery**, and therefore ecosystem improvement	• Limits fishers livelihoods for months and therefore requires stronger **incentives** for fishers to support and comply with	• Closure time limits economic benefits from fishing but allows for population growth, which increases the value of the fishery. Post-closure behavior generates a **race to fish** that quickly **disseminates benefits**
Long term Closures	• Would allow for **multispecies recovery**, and therefore ecosystem improvement	• The long **time** lapse under limited labor opportunities generates **strong resistance** for fishers to support	• Economic benefits require a **long time lapse** and the **race** to fish **quickly decreases benefits**

Appendix VI. User Interface for exploring different combinations of management approaches and their outcomes.

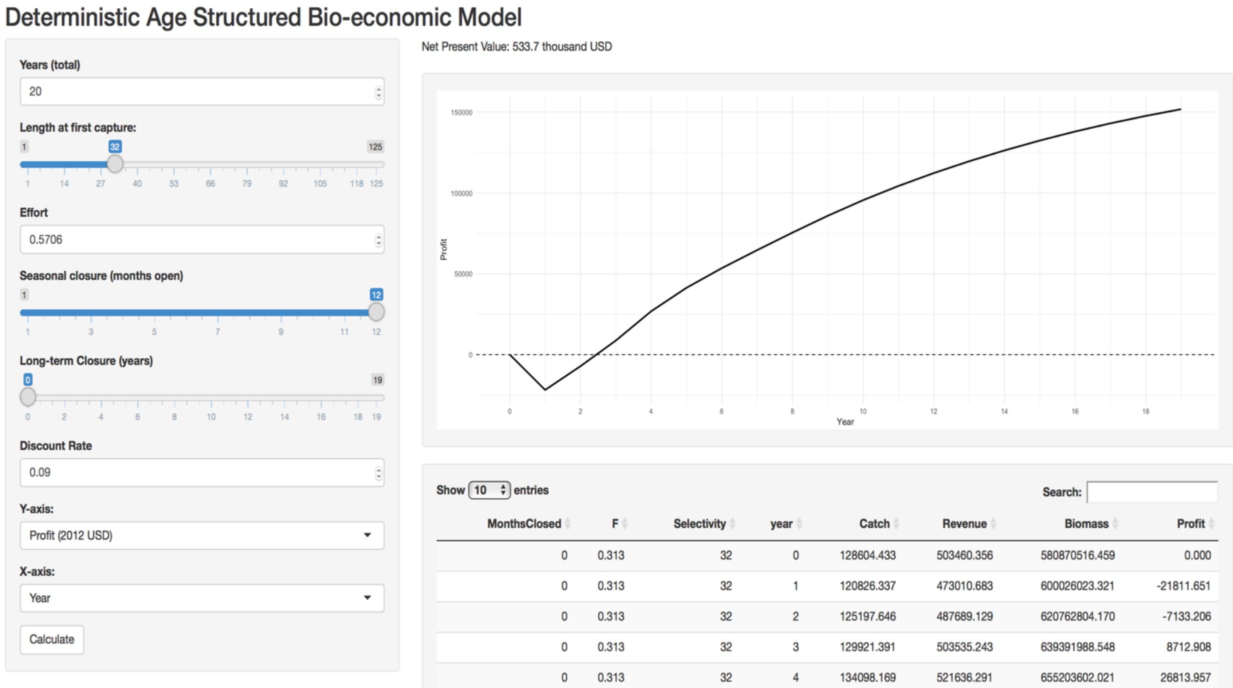

Figure A3. Deterministic Age-Structured Bioeconomic Model interface for exploring different management options (selectivity, effort, seasonal and long term closure) and a variety of targets such as profit, catch, biomass and revenue.