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BIOLOGICAL BASIS FOR THE STOCK ASSESSMENT IN GUYANA USING AN ADAPTIVE EVALUATION AND MANAGEMENT APPROACH FOR DATA-LIMITED FISHERIES

Tesis presentada a la Facultad de Ciencias Naturales y Oceanográficas de la Universidad de Concepción para optar al grado de Magíster en Ciencias con Mención en Pesquerías

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AUTORIZACIÓN

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ABSTRACT

Many data-limited fisheries remain without formal stock assessment and management worldwide, and it is the case of Guyana's fisheries. Before assessing the status of data-limited fisheries, it is essential to start with a biological framework that can provide life-history parameters and biological reference points. We utilized estimates of life history parameters for six species sustaining the small-scale and semi-industrial fisheries from the four administrative regions of Guyana. The life history parameters were estimated using the FishLife R package, a multivariate evolutionary model, which allows determining biological reference points. Catch data covered only from 2015 to 2018, and the time series were not enough to apply a formal data-limited stock assessment model. We utilized yield and biomass per recruit models to estimate the age and length at first capture. Target reference points for fishing mortality based on spawning per recruit and a reduction in absolute spawning biomass (B/B0) were close to 50%. The target fishing mortality was F55% for the target species of the small-scale and semi-industrial fisheries in Guyana. Further study is essential to implement, monitor, and conduct stock assessment of the fisheries, and the framework utilized here is a starting point.

RESUMEN

Muchas pesquerías con datos limitados siguen sin una evaluación y ordenación formales de stock en todo el mundo, y es el caso de las pesquerías de Guyana. Antes de estimar el estado de las pesquerías con datos limitados, es esencial comenzar con un marco biológico que pueda proporcionar parámetros del ciclo de vida y puntos de referencia biológicos. Utilizamos estimaciones de los parámetros del ciclo de vida de seis especies que sustentan las pesquerías en pequeña escala y semi-industriales de las cuatro regiones administrativas de Guyana. Los parámetros de la historia de vida fueron estimados por un modelo evolutivo multivariado (paquete FishLife para R), lo que permitió determinar los puntos de referencia biológicos. Los datos de captura cubrieron solo de 2015 a 2018, y las series de tiempo no fueron suficientes para aplicar un modelo formal de evaluación de poblaciones con datos limitados. Utilizamos modelos de rendimiento y biomasa por recluta para estimar la edad y la talla en la primera captura. Los puntos de referencia objetivo para la mortalidad por pesca basados en la biomasa desovante por recluta y la reducción de la biomasa reproductora absoluta (B/B0) fue cercana al 50%. La mortalidad por pesca objetivo fue F55% para las especies objetivo de la pesca en pequeña escala y semi-industrial en Guyana. Es esencial desarrollar más estudios para implementar, monitorear y

realizar evaluaciones de stock de estas pesquerías, y el marco utilizado en este trabajo es un punto de partida para ello.

GENERAL INTRODUCTION AND OVERVIEW

Among all the different Fishery Science areas, managers' particular interest is stock assessment (Musick & Bonfil, 2005). Stock assessment is the process of collecting, analyzing, and reporting demographic information to determine changes in the abundance of fishery stocks in response to fishing and, to the extent possible, predict future trends of stock abundance under alternative management options. Managers use stock assessments as a basis to evaluate and specify the present and probable future condition of a fishery (NOAA Fisheries). Inherently, stock assessment is instrumental in the development, sustainability, and success of the fishing sector. A stock assessment process, typically coupled with a less detailed model when fewer or limited data, provides limited guidance (Dowling et al., 2019).

Data-poor or limited data, as presumed, weakens the inference throughout the stock assessment process. Data-poor stock assessment and inconclusive analysis results in misinterpreted findings. This narrative has reaching impacts synonymous with ambiguous forecasting, which can mislead managers and the fisheries sector at large (Arnold & Heppell, 2014). In Guyana, managers, data collectors, and stock assessment teams make every effort to ensure data sets and analysis are of standards to make informed decisions to serve the sector better. Even in so doing, challenges arise.

Data collectors often encounter difficulties gathering data from fishers, which causes one to question the credibility of information received, mostly when the task is under burning fishers' concerns. Nevertheless, collectors strategically execute their daily tasks to obtain data at best. The challenges reduce the likelihood of visualizing the fishery's status and would blind to managers and the decision-making process. The data collected are not useless since there are cooperative fishers with collectors, which still leaves gaps in some cases. There being alternatives or suggestions to improve the whole process better would support and guide managers' pronouncement.

In cases where the type and quality of available data, limits a quantitative stock assessment, and the available information is inadequate to determine reference points, the status of a data-limited fishery is uncertain. However, it should not be a reason for not implementing fisheries management (Dowling et al., 2015). Besides, a growing number of approaches are based either on only-catch data or only-length data or combining catch and either abundance index or size-structure to estimate the stock status (Dichmont et al., 2021). One of the challenges faced when conducting a stock assessment is associated with the uncertainty in life-history parameters and catch records of many species (Froese et al., 2012; Arnold & Heppell, 2014). The technical advice for management uses population dynamics models based on fundamental biological processes that include the natural mortality rate, body growth, maturity, and production of juveniles that recruit the exploitable fraction. These processes are essential and adequately modeled, and there are various methods to estimate the life-history parameters by considering invariants in life-history parameters, combined with evolutionary theory, to estimate fundamental parameters for little-studied species (Thorson et al., 2017; Thorson, 2020).

Indeed, juveniles' production is a function of reproductive potential through the stock-recruit relationship (SRR). The parameters of the SRR utilizes the steepness and the unexploited average recruitment level. In turn, the variance and serial correlation of the recruitment process defines the recruitment variability (Rudd & Thorson, 2018). In this way, it is possible to estimate the SRR through the comparative method and the meta-analysis to assess the degree of resilience and biological reference points (Mace, 1994; Goodwin et al., 2006, Zhou et al., 2012; Thorson et al. 2014, Wiff et al., 2016). Therefore, one of the objectives is to analyze Guyana's fish's life history parameters and uncertainty considering the evolutionary life-history model developed by Thorson et al. (2017).

This study promises to steer managers to make more informed decisions while filling gaps to bring to reality the possibility of providing better and improved fisheries services, ensuring the smooth, effective and efficient functioning and development of the sector and the sustainable management of the resources. The emphasis will be on some of the country's most valuable species; *Macrodon ancyclodon* (bangamary), *Nebris microps* (butterfish), *Sciades parkeri* (gillbacker), *Cynoscion acoupa* (grey snapper). Widely documented life-history for similar species from other geographic regions (e.g., FishBase), would help estimate target and limit biological reference points for Guyana's previously mentioned species.

For this reason, this research considered undertaking a "Biological Basis for the Stock Assessment in Guyana using an Adaptive Evaluation and Management Approach for Data-Limited Fisheries". It aims to assist in the identification and filling of gaps in the stock assessment process. Further, it proposes to set the basis for further work in this area. It is a preliminary study oriented to estimate biological reference points, given that it is relatively new to Guyana. For the first time, this approach will be applied to its Fishery. In this context, the thesis included one chapter and a general discussion. The first chapter presents a data-limited framework to estimate biological reference points for six fish species caught by the small-scale and semi-industrial fisheries in Guyana. The general discussion provided a perspective to improve management advice by considering data-limited stock assessment models.

HYPOTHESIS

The quality and quantity of data collected over the years in Guyana have been used successfully by managers. However, to manage, regulate, and promote the sustainable development of fisheries and to obtain the benefit for the participants in the sector and the national economy, additional analysis will further solidify actions taken by managers.

Introduction and involvement of programs supporting stock assessment, specifically data-limited fisheries undergoing fisheries assessment and management, managers will be better guided. They will be able to make informed decisions based on scientific evidence. In this way, it is essential to estimate life-history parameters for Guyana's fish that allow us to determine the target and limit biological reference points supporting Guyana's fisheries' sustainability.

Working hypothesis

1. The life-history parameters for the species sustaining the small-scale and semi-industrial fishery allow determining precautionary biological reference points for target fishing mortality and biomass reduction to 50%.

2. Target reference fishing mortality for the species is lower than natural mortality.

OBJECTIVES

General objective

To determine a data-limited framework to estimate life-history parameters, analyze catch data, and determine biological reference points for the small-scale and semi-industrial fisheries in Guyana.

Specific objectives

1) To estimate life-history parameters for data-limited and valuable species of Guyana fisheries.
2) To determine target and limit reference points for data-limited and valuable species of Guyana fisheries.

Outcome

- To set the foundation for further investigation and development as more information becomes available.

CHAPTER 1

A framework for data-limited fisheries stock assessment in Guyana: life-history parameters and biological reference points*

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Abstract

Many data-limited fisheries remain without formal stock assessment and management worldwide, and it is the case of Guyana's fisheries. Before estimating the status of data-limited fisheries, it is essential to start with a biological framework that can provide life-history parameters and biological reference points. We utilized estimates of life history parameters for six species sustaining the small-scale and semi-industrial fisheries from the four administrative regions of Guyana. The life history parameters were estimated by the multivariate evolutionary model FishLife for R, which allows determining biological reference points. Catch data covered only from 2015 to 2018, and the time series were not enough to apply a formal data-limited stock assessment model. We utilized yield and biomass per recruit models to estimate the age and length at first capture. Target reference points for fishing mortality based on spawning per recruit and a reduction in spawning biomass (B/B_0) close to 50%. The target fishing mortality was F55% for the target species of the small-scale and semi-industrial fisheries in Guyana. Further study is essential to implement, monitor, and conduct stock assessment of the fisheries, and the framework utilized here is a starting point.

1 Introduction

Assessment and management of data-limited fish stocks are a challenge worldwide because they have insufficient data and (or) capacity to estimate biomass and fishing mortality regarding safe biological references (Dowling et al. 2019). In cases where the type and quality of available data limit a quantitative stock assessment, and the available information is inadequate to determine reference points, the status of a data-limited fishery is uncertain. However, it should not be a reason for not implementing fisheries management (Dowling et al., 2015). Besides, a growing number of approaches are based either on only-catch data or only-length data or combining catch and either abundance index or size-structure to estimate the stock status (Dichmont et al., 2021).

One goal is to maintain sufficient spawning stock biomass to avoid recruitment overfishing as a desirable outcome of biologically sustainable fisheries (Sissenwine & Shepherd, 1987; Mace, 1994). The most common models that underlie biological reference points are stock-recruitment relationships, per-recruit models or dynamic pool, and surplus production models (Sissenwine & Shepherd, 1987; Gabriel & Mace, 1999). Often, in data-limited cases where either only catch or fishery-dependent catch rates (i.e., catch per unit effort) are available, the logistic surplus production is the most utilized model (Martell &

Froese, 2013; Zhou et al., 2017a; Froese et al., 2017). The length-based spawning potential ratio (LBSPR) model is one of the data-limited stock assessment models applied to length-frequency data and utilized to estimate the status of a given stock (Hordyk et al., 2014a; Hordyk et al., 2014b; Hordyk et al., 2016, Prince et al., 2015; Chong et al., 2019). The status is compared with a reduction in spawning biomass per recruit relative to the unexploited level and expressed as a percentage, usually 40% (Clark, 1991; Mace, 1994). LBSPR model requires life-history parameters, such as the ratio of natural mortality to growth coefficient M/K and the asymptotic length L_∞ (Hordyk et al., 2016).

Before applying any data-limited stock assessment model is desirable to count with efficient methods to provide prior life-history parameters to determine limit reference point (LRP) and target reference points (TRP) for spawning biomass and fishing mortality. Under the precautionary approach, operational targets may require reference points lower than MSY to reduce the risks of declining recruitment (FAO 1995; Caddy & Mahon 1995; Caddy & McGarvey, 1996).

In Guyana, despite the large-scale industrial seabob (*Xiphopeneaus kroyeri*) and various finfish species, small-scale fisheries operate nearshore and supply both the local and the export market for finfish (MacDonald et al., 2015). Some valuable finfish species for small-scale artisanal fisheries are demersal fishes such as bangamary (*Macrodon ancyclodon*), butterfish (*Nebris microps*), gillbacker (*Sciades parkeri*), grey snapper (*Cynoscion acoupa*), seatrout (*Cynoscion *virecens*), and semi-industrial fisheries fishing for red snapper (*Lutjanus purpureus*).

In Guyana, most of the life-history parameters have been estimated outside, particularly in Brazil and Venezuela, and documented in FishBase (Froese & Pauly, 2020). One of the challenges faced when conducting a stock assessment is the uncertainty in catch records and life-history parameters. The technical advice for management uses population dynamics models based on fundamental biological processes that include mortality, growth, maturity, and production of juveniles recruiting to the exploitable stock. These processes are essential, and there is an efficient method to estimate life-history parameters for little-studied species (Thorson et al., 2017; Thorson, 2020). The multivariate model and tools to develop life-history parameters for any fish taxon without local and reliable life history are available in the FishLife R package (https://github.com/James-Thorson-NOAA/FishLife). Considering that the evolutionary life-history model only provides a starting point for filling the gaps, this paper aims to provide a framework for data-limited fisheries in Guyana, emphasizing estimates of biological reference points for small-scale and semi-industrial fisheries.

2 MATERIALS AND METHODS

2.1 Study area, Fisheries, and Catch data

Guyana has 10 Administrative Regions, and the catch and effort data was sourced from the Ministry of Agriculture, Fisheries Department, Guyana, from four main fishing areas: Region 2 - Pomeroon-Supenaam, Region 4 - Demerara-Mahaica, Region 5 - Mahaica-Berbice, and Region 6 - East Berbice-Corentyne. (Figure 1)

The main commercial species *Macrodon ancyclodon* (bangamary), *Nebris microps* (butterfish), *Sciades parkeri* (gillbacker), *Cynoscion acoupa* (grey snapper), *Cynoscion virecens* (sea trout), and *Lutjanus purpureus* (red snapper) contribute to the small-scale and semi-industry fishery. Region 4 has the most landing sites and secures the most revenue. All the study species can be found in all four (4) regions but in different quantities and during different seasons. All species fall under marine fishery. Time series of catch data for the finfish is available from 2015 and were obtained from the Ministry of Agriculture, Fisheries Department, Guyana.

2.2 Framework Proposal for Reference Points

The framework for data-limited fisheries stock assessment and biological reference points estimation is summarized in Figure 2. We identified two sources of uncertainty for Guyana small-scale fisheries, which allow us to propose two tiers. One relies on the availability of life-history parameters data, which are essential to advance in looking for reference points. In the absence of all required life-history parameters, we propose to utilize FishLife (see below) as a starting step to compute biological reference points by analyzing per recruit models (Figure 2). Per-recruit models could be combined with a proxy for Maximum Sustainable Yield *(MSY)* from catch data (Froese et al., 2012; Anderson et al., 2012). Hence, to obtain estimates for average recruitment and biomass, either for unexploited (B_0) or at the maximum sustainable yield (B_{MSY}) (Figure 2). Nevertheless, the catch time series is short for the fisheries here studied, and tier 2 should be applied in future research.

2.3 Life-history Parameters

We applied the evolutionary life-history model of Thorson et al. (2014), Thorson et al. (2017), and Thorson (2020) as implemented in the FishLife package for R (https://github.com/James-Thorson-NOAA/FishLife). The FishLife package utilizes a comprehensive evolutionary model of life-history parameters and fitted to longevity, growth, natural mortality, and maturity data available from FishBase (https://www.fishbase.in/home.htm) (Froese & Binohlan, 2000; Froese & Binohlan, 2003), as well as stock-recruitment parameters and population parameters from the RAM Legacy Database (https://www.ramlegacy.org) (Ricard et al., 2012). The model predicts a vector of life-history parameters along phylogenetic lineages using a multivariate random walk model. Model predictions follow a multivariate normal distribution, with lower taxonomic levels having more precise parameters than higher levels. A Major Axis Regression *(MAR)* allows interpreting the association of one trait and another trait (for example, natural mortality and asymptotic weight), which implies eigen-decomposition (eigenvalues and eigenvectors) of evolutionary covariance. The advantage of FishLife is to predict all life-history parameters simultaneously and useful to consider the uncertainty for both well-studied species and poorly studied species (Thorson, 2020).

Also, we obtained the length-weight parameter (*a*) from $a = W_\infty / L^b$ and considering b=3, which is a good approach (Froese, 2006). Following Pauly (1983), the growth parameter t_0 was computed by

$$t_0 = -10^{(-0.392 - 0.275 log_{10}(L_\infty) - 1.038 log_{10}(K))} \quad \text{...1)}$$

where L_∞ and K are von Bertalanffy growth parameters.

2.4 Biological Reference Points

Once the life-history parameters were obtained, a yield-per-recruit *(YPR)* analysis was carried out to get the age at first capture, i.e.,

$$YPR = FW_{\infty}\exp\left(-M(t_c - t_r)\right)\left(\frac{1}{Z} - \frac{3\exp\left(-\mathrm{K}(t_c - t_0)\right)}{\mathrm{Z}+\mathrm{K}} + \frac{3\exp\left(-2\mathrm{K}(t_c - t_0)\right)}{Z+2K} - \frac{\exp(-3\mathrm{K}(t_c - t_0))}{\mathrm{Z}+3\mathrm{K}}\right) \quad \ldots 2)$$

where F is the fishing mortality rate, W_{∞}, K and t_0 are von Bertalanffy growth parameters, M is the natural mortality rate, Z is the total mortality rate (Z=F+M), t_r is the age at recruitment (set equal to 1 for all the species), and t_c is the age at first capture. This parameter (t_c) is an input to determine either a logistic selectivity curve, i.e.,

$$S_t = \frac{1}{1+\exp(-(t-t_c)/\delta)} \quad \ldots 3)$$

Where S_t is selectivity at age t, and δ is a shape parameter for the slope of the curve, which was set between 0.25 and 0.5 for a steeper selectivity curve. With the aim of comparing length-based reference points, we compute the ratio between the length at first capture (L_c) and L_{∞}, which can be used as a reference for data-limited length-based stock assessment (Froese et al., 2018).

Once obtained the selectivity (S_t) and L_c/L_{∞} ratio, the spawning biomass per-recruit analysis consists of a dynamic pool approach (i.e., Cubillos et al., 2002). The spawning biomass per recruit was computed by

$$BPR = \sum_{t}^{A} p_t w_t n_t e^{-T_s(M+S_tF)} \quad \ldots 4)$$

where p_t is maturity ogive, w_t is the body weight at age t, n_t is the relative survival, and M is the natural mortality rate, T_s is the spawning time (set equal to 0). We utilized the negative exponential survival equation for numbers, i.e.,

$$n_t = \begin{cases} 1 & \text{if} \quad t = 1 \\ n_{t-1}e^{-(M+S_tF)} & \text{if} \quad t = 2, \ldots, A-1 \\ n_{t-1}e^{-(M+S_{t-1}F)}/(1-e^{-(M+S_tF)}) & \text{if} \quad t = A \end{cases} \quad \ldots 5)$$

We computed the spawning potential ratio ($SPR=BPR/BPR_{F=0}$) and got a proxy for the fishing mortality rate at the maximum sustainable yield, i.e., F_{MSY} = x%$BPR_{F=0}$ (Mace, 1994; Brooks et al., 2009). We analyzed the following alternative target 60%, 55%, 50%, and 45% for target fishing mortality. After, based on the steepness (h) for the stock-recruitment provided by FishLife, we resolve for the spawning biomass depletion (B/B_0) by utilizing the following expression

$$h = \left(1 - \frac{B}{B_0}\right) / \left(1 - 5\frac{B}{B_0} + 4SPR_{target}\right) \quad \ldots 6)$$

Equation (5) assumes an underlying Beverton and Holt stock-recruitment relationship (Thorson et al., 2019). Considering the precautionary approach and the uncertainty in the status of the different species, we selected the target fishing mortality for B/B_0 values close to 50% of B_0. The Limit Reference Point for biomass was half of the target B/B_0, and therefore close to 25% of B_0.

3 RESULTS

3.1 Catch

National total catch and the total for the species analyzed show fluctuations over the years (Figure 3A), with an important contribution of the total for the species here considered. Bangamary shows an average catch close to 1,500 metric tons and the highest catch in 2017, and butterfish, gillbacker, and seatrout exhibit a declining trend from 2015 to 2018. The large demersal grey snapper shows a slightly declining trend over the year, and the red snapper shows lower catch, increasing over the years, from 2015 to 2018 (Figure 3B).

3.2 Life-history Parameters

The life-history parameters and derived parameters for the six species for Guyana are shown in *Table 1*. Grey snapper and red snapper are significantly large and long-lived, as compared to the rest. In turn, sea trout and butterfish are larger than bangamary and gillbacker, but similar in longevity (Table 1), growth, and maturity (Figure 4). Nevertheless, red snapper reaches an enormous asymptotic weight and latest age at maturity (Figure 4). The steepness (*h*) is similar, ranged between 0.653 (bangamary) and 0.71 (red snapper and gillbacker) (Table 1).

The yield per recruit analysis (Figure 4) shows ages at first capture between 1.5 (bangamary) and 6 (red snapper), and the length at first capture ranged between 22.9 cm (bangamary) and 59.1 cm (red snapper) (Table 2). The resulting logistic selectivity curves for the species show a steeper shape, with almost 95% of fully exploited ages after the age at first capture (Figure 5).

3.3 Biological Reference Points

Unexploited spawning biomass per recruit ($SPR_{F=0}$) and alternative targets for fishing mortality based on reductions of $SPR_{F=0}$ are in Table 2 for F60% to F45%. The equivalent reduction in absolute spawning biomass (B/B_0), regarding the steepness estimates, fluctuated between 36.6% at F45% (bangamary) and 55.5% at F60% (gillbacker and red snapper) (Table 2). According to the criterium of selecting a depletion close to 50%, the target fishing mortality is F55% for the target species of the small scale and semi-industrial fisheries in Guyana.

4 DISCUSSION

In Guyana, the small-scale and semi-industrial fisheries contributes significantly to the country's GDP, after the seabob fishery, and comprises of the economic species and provides food security and employment. The semi-industrial fishery comprises vessels measuring up to 18 m long and operates in a depth between 120 m and the shelf break. Small-scale fishing, on the other hand, contains vessels measuring from 6 to 18 m propelled by sail, outboard or inboard engines using gears such as Chinese seine (fyke net), pin seine (beach seine), cadell lines and handlines, drift seine, gillnets and circle seine, with gillnet being the most widely or popularly used gear while Chinese seine was banned due to the damage it causes. In addition to gear use, these vessels' trip lasts as long as 18 days with iceboxes' help to preserve the production.

Although marine fisheries landings area for Guyana is available from FAO's FishStat database since 1950, the quality and accuracy depend on the statistical collection (MacDonald et al., 2015). The FAO database has been the foundation of many global fisheries studies (Kleisner et al., 2013; Froese et al., 2012; Anderson et al., 2012). However, the catch statistics are often incomplete and have been reconstructed (Pauly & Zeller, 2016; Pauly & Zeller, 2019). However, the catch data collection of the small-scale fishing is a complex task in Guyana, and the Ministry of Agriculture, Fisheries Department, has been working continuously to improve it. Time series of catch are essential to apply data-limited stock assessment models (Martell & Froese, 2013; Zhou et al., 2017a,b; Froese et al., 2017). Besides, the catch-only methods are poor classifiers of stock status and can produce imprecise and biased estimates of B/B_{MSY}, particularly for lightly exploited stocks (Free et al., 2020).

The stock assessment for the species studied here present an additional level of complexity since most of them are transboundary stocks. The bangamary, butterfish, gillbacker, and seatrout are marine, brackish, and demersal species in the Western Atlantic, from Nicaragua to northern Argentina (Cervigón et al., 1992; Cervigón, 1993; Keith et al., 2000). Most of the species are distributed in coastal areas, estuaries, and lower parts of rivers, from Guyana to northern Brazil (Keith et al., 2000). The grey snapper is a marine, freshwater, brackish, demersal species located from Panama to Argentina (Riede, 2004). The red snapper is a marine, demersal species distributed widely throughout the Caribbean Sea, from Cuba to northeastern Brazil (Rivas, 1966). Management of shared stocks is a challenge, and probably the local fishing effects are due to partial fishing mortality. The countries must take the necessary precautions to ensure the sustainability of transboundary resources. In this context, the framework outlined here is an important initial step for determining the basis for managing the fisheries.

The framework implemented for life-history parameters has advantages and disadvantages. At present, life-history parameters for the species analyzed have been determined outside of Guyana and often dispersed in the literature and consolidated in the FishBase database. When life-history parameters are consistent and estimated simultaneously within a given model such as FishLife, the statistical uncertainty contained in the covariance can be utilized to improve the estimates when new and better data become available. Besides, the life-history parameters (mean and variance-covariance) could be sampled at random to construct operating models and evaluate data-limited stock assessment models (Carruthers & Agnew, 2016). Disadvantages rely on the uncertainty of the local biological and ecology of the species, and that gap is one of the most important in Guyana. However, stock assessment and management usually perform under the best information available at present. Thus, the life-history parameters predicted by FishLife for economically important species contributing to the small-scale and semi-industrial fisheries in Guyana seem to be consistent and reliable.

The reference points for the target fishing mortality rate usually are based on spawning biomass per recruit models and are often considered a proxy for the maximum sustainable yield (Clark, 1991; Mace, 1994; Brooks et al., 2009). If the fishing mortality effectively produces the maximum sustainable yield, it implies a steepness value consistent with the spawning biomass producing the MSY; i.e., B_{MSY}. The range of alternative reference for the target fishing mortality, and the ratio B/B_0 they produced, given the steepness, assume an underlying stock-recruitment relationship of Beverton and Holt (Thorson et al., 2019). In cases where the original status of the stock is unknown, and the recruitment has not declined, for many species with productive life histories, fishing mortality is likely to be an appropriate proxy (Carruthers & Agnew, 2016).

The target fishing mortality based on F55% is a proxy of F_{MSY}, based on per recruit analysis, and usually smaller than M and F_{MSY} (Zhou et al., 2012). Although MSY has been criticized (Finley & Oreskes, 2013), a target depletion of the spawning biomass close to 50% would be a precautionary constraint for fisheries (Pauly & Froese, 2020). The biological reference points will be accurate by regularly updating the life-history parameters and implementing a monitoring plan for biological measurements oriented to account for changes in size composition and population structure (Tsai et al., 2011). Besides, the social context in which biological reference points are implemented is essential (MacNeil, M. A., 2013). The stock status is uncertain in Guyana, and further research is required to properly implement, monitor and conduct stock assessment of the fisheries, and the framework utilized here is a starting step.

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ANNEX I

LIST OF FIGURES

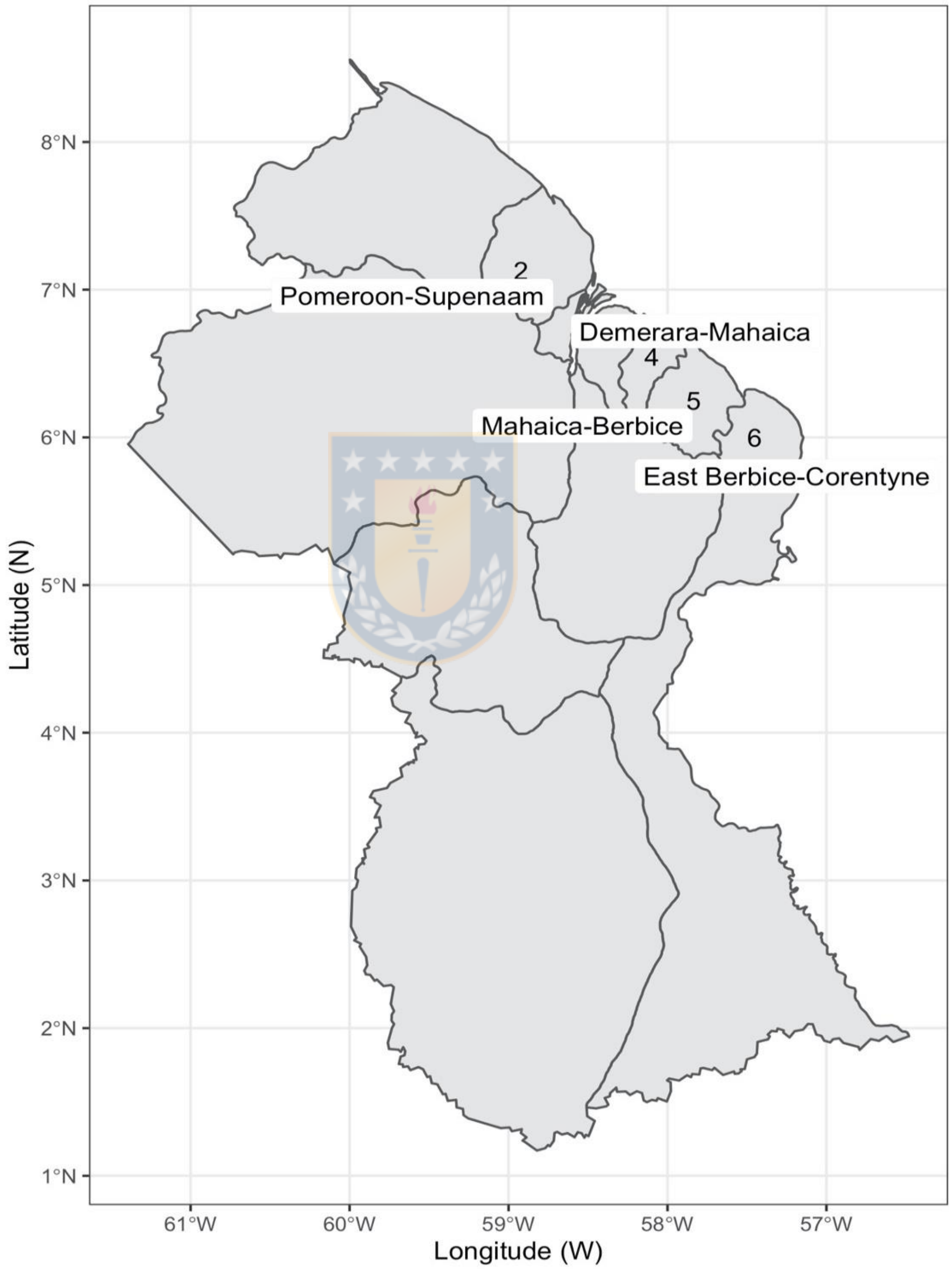

Figure 1. Guyana map showing the four main Administrative Regions where the Small-scale and Semi-industrial Fisheries operate

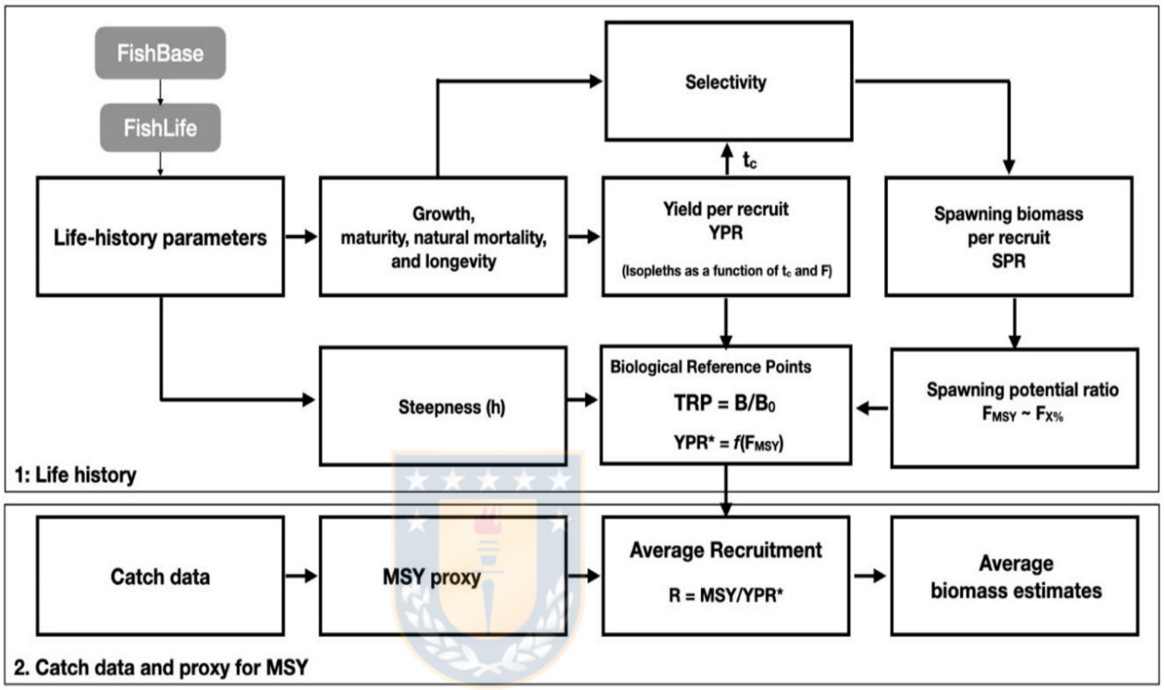

Figure 2. Flow diagram for the estimation of life-history parameter and biological reference points for data-limited fisheries in Guyana, with the emphasis on species sustaining the small scale and semi-industrial fisheries.

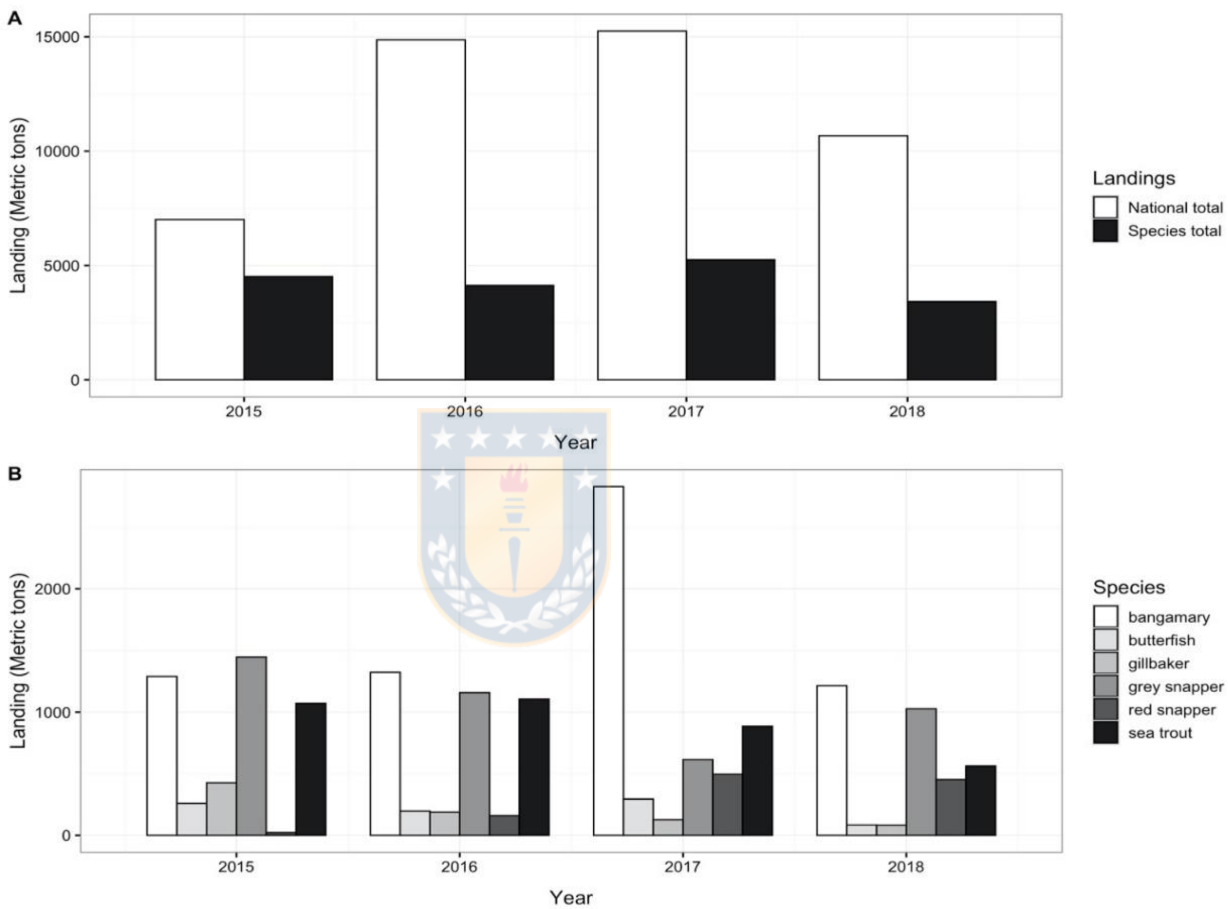

Figure 3. Landing estimates of total national and the species sustaining the small-scale and semi-industrial fisheries in Guyana

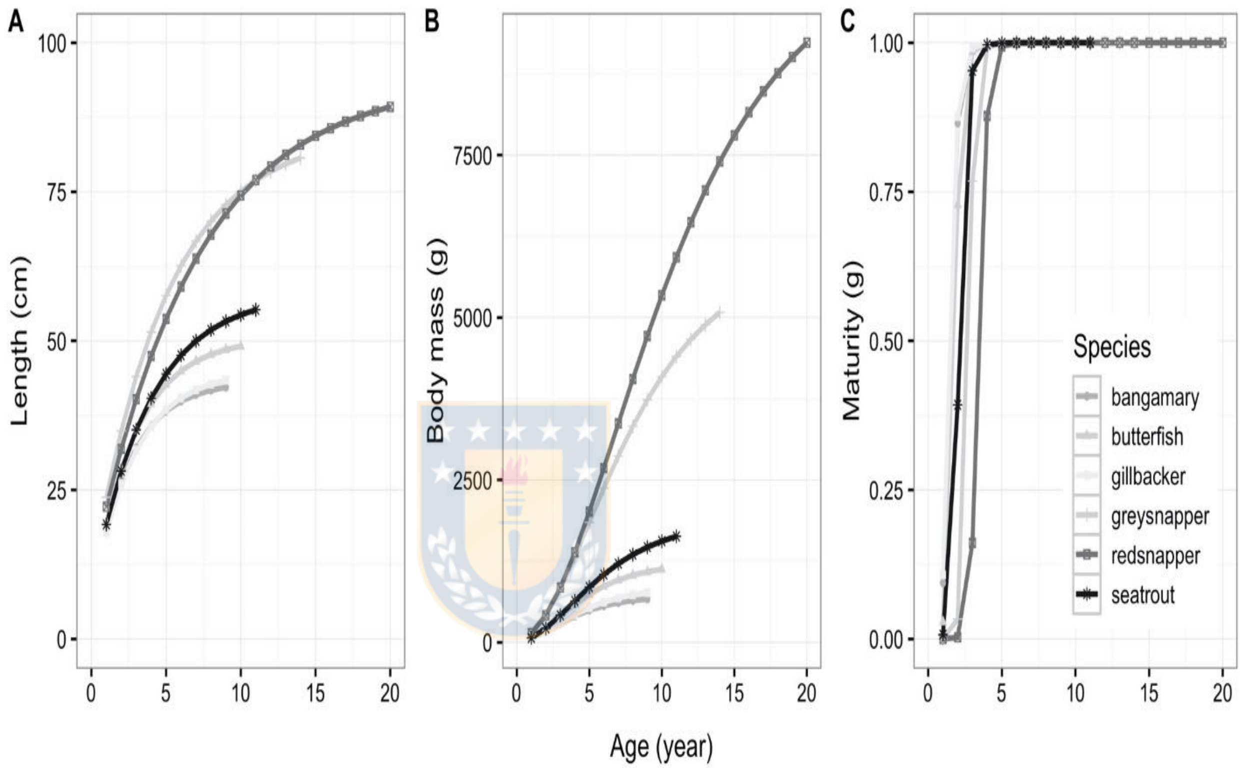

Figure 4. Growth by length (A) and body mass (B), and maturity for main species sustaining the small scale and semi-industrial fisheries in Guyana.

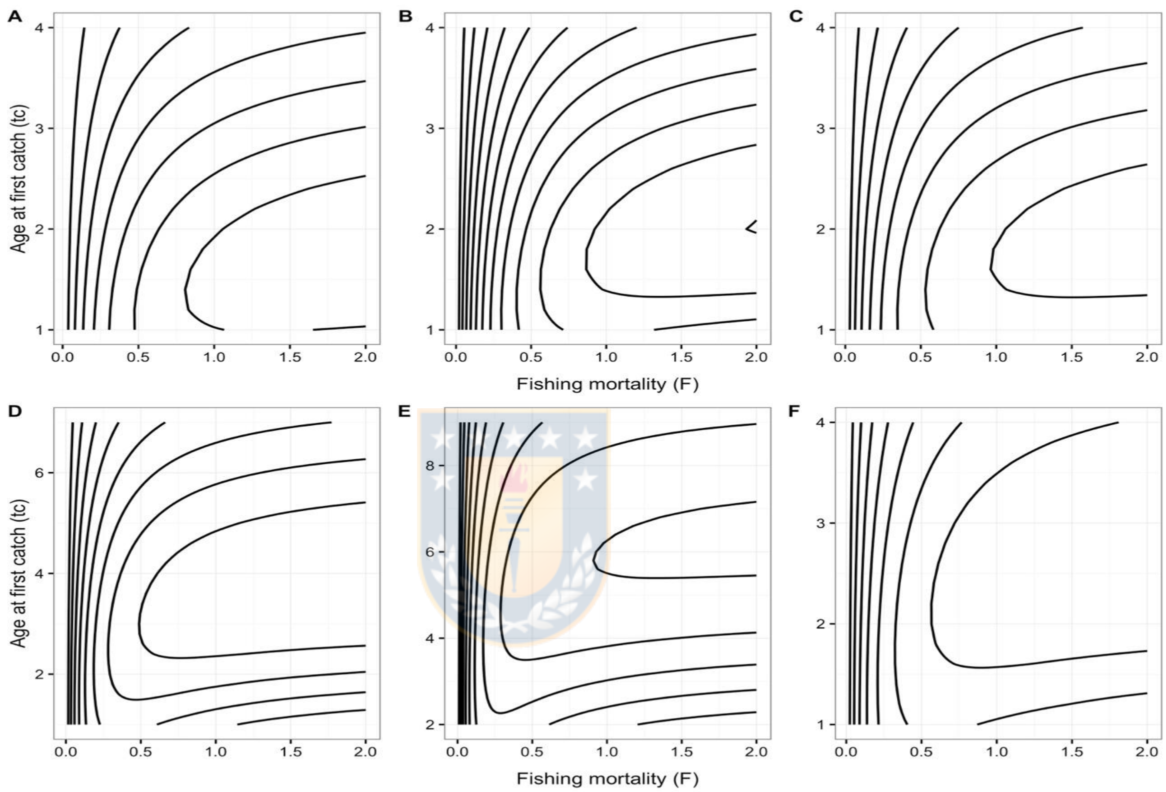

Figure 5. Isopleth diagrams for a combination of age at first capture (tc) and fishing mortality (F) according to life-history parameters for bangamary (A), butterfish (B), gillbacker (C), grey snapper (D), red snapper (E), and sea trout (F).

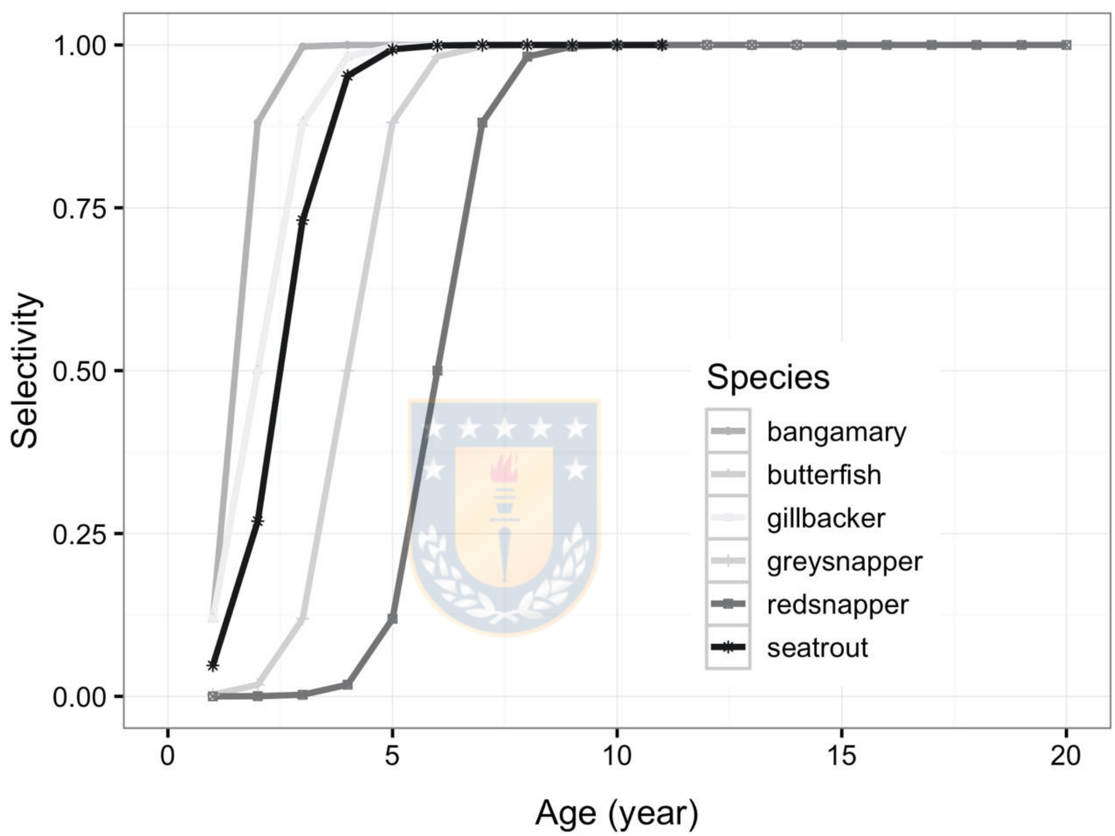

Figure 6. Selectivity curves based on the age at first capture (tc) and the selectivity-shape parameters (see Table 1).

TARGET SPECIES

Macrodon ancyclodon – Bangamary

Nebris microps – Butterfish

Sciades parkeri – Gillbacker

Cynoscion acoupa - Grey snapper

Lutjanus purpureus - Red snapper

Cynoscion virecens – Seatrout

LIST OF TABLES

Table 1. Life-history parameters estimated for the target species of small-scale and semi-industrial fisheries in Guyana.

Parameter	Symbol	Units	Bangamary	Butterfsh	Gillbacker	Grey snapper	Red snapper	Seatrout
Asymptotic length	L_∞	cm	43.2	50.5	44.9	85.3	93.8	58
Asymptotic weight	W_∞	g	716.5	1225	853.2	5991.2	10716.1	1893.6
Growth coefficient	K	$year^{-1}$	0.403	0.345	0.357	0.2	0.145	0.267
	t_0	year	-0.37	-0.417	-0.414	-0.635	-0.864	-0.532
Natural mortality rate	M	$year^{-1}$	0.7	0.6	0.6	0.36	0.22	0.47
Maximum Age	t_{max}	year	9	10	9	14	20	11
	t_m	year	1.9	2.2	2.3	3.5	4.1	2.7
Length at Maturity	L_m	cm	22.8	26.6	22.1	41.6	43.5	29.1
Length-Weight	a		0.0089	0.0095	0.0094	0.0096	0.0129	0.0096
	b		3	3	3	3	3	3
Steepness	h		0.65	0.67	0.71	0.66	0.71	0.7
Age at first capture	t_c	year	1.5	2	2	4	6	2.5
	δ		0.25	0.25	0.25	0.25	0.25	0.25
Length at first capture	L_c		22.9	28.6	25.9	51.5	59.1	32.2
Reference ratio	L_c/L_∞		0.529	0.566	0.578	0.604	0.630	0.555

Table 2. Biological reference points for fishing mortality and spawning biomass for the target species of the small-scale and semi-industrial fisheries in Guyana. Selected values are in bold.

Reference points	Symbol	Units	Bangamary	Butterfsh	Gillbacker	Grey snapper	Red snapper	Seatrout
Unexploited spawning biomass per recruit	$BPR_{F=0}$	g	259.0	457.0	328.3	3031.5	10246.2	799.8
Target fishing mortality rate	F60%	$year^{-1}$	0.40	0.398	0.477	0.28	0.17	0.28
	F55%	$year^{-1}$	**0.50**	**0.50**	**0.61**	**0.36**	**0.21**	**0.35**
	F50%	$year^{-1}$	0.62	0.63	0.78	0.47	0.28	0.44
	F45%	$year^{-1}$	0.77	0.79	1.01	0.62	0.37	0.55
Target depletion of the spawning biomass	B/B_0 at F60%		0.54	0.54	0.56	0.54	0.56	0.55
	B/B_0 at F55%		**0.48**	**0.49**	**0.50**	**0.48**	**0.50**	**0.50**
	B/B_0 at F50%		0.42	0.43	0.443	0.426	0.443	0.440
	B/B_0 at F45%		0.37	0.37	0.387	0.369	0.387	0.384
Limit depletion of the spawning biomass	B_{lim}/B_0		**0.24**	**0.24**	**0.25**	**0.24**	**0.25**	**0.25**

GENERAL DISCUSSION

In Guyana, the fisheries of bangamary, butterfish, gillbaker, grey snapper, sea trout, and red snapper contributed 36.2% to the national landings between 2015 and 2018. The red snapper landings increased from 22.84 to 496.12 metric tons during this period, suggesting a developing phase of the semi-industrial fishery. Besides, butterfish, gillbaker, grey snapper, and sea trout exhibited a slightly declining trend. Only the bangamary small-scale fishery showed stable landings. Nevertheless, the landing time series analyzed were short and not long enough to apply catch-only stock assessment models (Froese et al., 2017). Regardless, the catch-only methods are imprecise and biased to estimates of target reference points, i.e., B/BMSY (Free et al., 2020).

Another challenging issue for stock assessment is the boundary of the stock unit for most of the species. The species are widely distributed in the Caribe Sea and Western Atlantic, and probably most of them are transboundary stocks. According to the corrected FAO's FishStat database by SeaAroundUs (MacDonald et al., 2015; http://www.seaaroundus.org/), Brazil accounts for most regional landings. Venezuela has historically reported bangamary and red snapper landings, while Suriname report mainly bangamary, grey snapper, red snapper, and sea trout (Figure A1). In this context, the FAO database could be utilized to explore regional estimates by applying catch-only stock assessment models and determining partial fishing mortality for the species in Guyana. Besides, the FAO database has been the foundation of many global fisheries studies (Kleisner et al., 2013; Froese et al., 2012; Anderson et al., 2012).

Accordingly, it is essential to advance on the biological basis for Guyana's stock assessment and fisheries management, particularly considering an adaptive evaluation and management approach for data-limited fisheries. Therefore, the first step in the proposed framework is to estimate the stocks' life-history parameters, hence biological reference points.

The estimation of life-history parameters is a complex task, which often starts with age and growth studies. Often, estimates of the natural mortality rate are based on several empirical models requiring von Bertalanffy growth parameters, maximum age, and (or) age at maturity. Usually, growth parameters and maturity are dispersed in the literature, and some other essential parameters must be estimated. The advantage of FishLife is precisely to estimate all the necessary parameters for different population dynamics analyzes once samples of length composition and catch started to be compiled. For example, fishery length composition data are input for LBSPR and estimate the status (Hordyk et al., 2016). Thus, the L_c/L_∞ and M/K parameters provided here could be good starting values.

The target fishing mortality estimation based on spawning biomass per recruit is a proxy of FMSY (Mace, 1994; Brooks et al., 2009), depending on the target. Here, a reduction of 50% in the spawning biomass could be satisfactory (Pauly & Froese, 2020) and F55% could be used to compare the performance of fishing operations. In addition, the statistical uncertainty contained in the covariance can be utilized to improve the estimates when new and better data become available. Finally, the mean and variance-covariance could be sampled at random to construct alternative operating models and evaluate data-limited stock assessment models (Carruthers & Agnew, 2016).

The stock status is uncertain for the species supporting the small-scale and semi-industrial fisheries in Guyana. Therefore, further research is required to implement monitoring and stock assessment fisheries properly. However, the framework utilized here is a starting step.

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ANNEX II

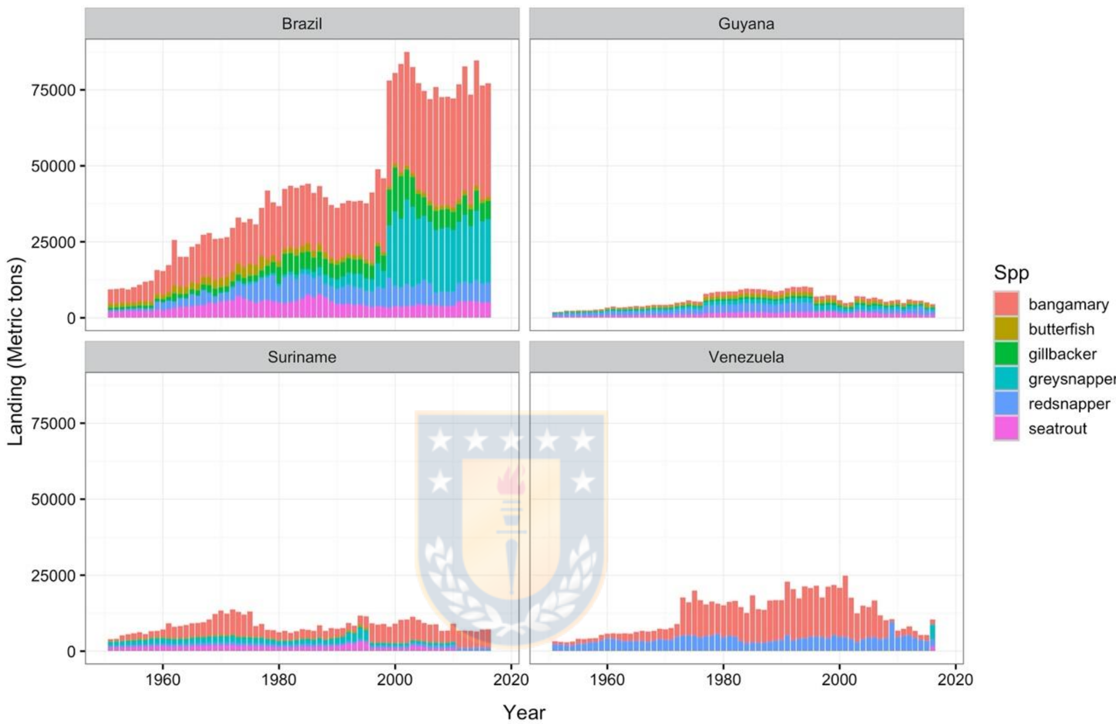

Figure A1. Landing statistics available in the FAO FishStat database for the countries in the Western Atlantic. Source: Sea Around Us project (http://www.seaaroundus.org/)