IMPROVING THE ASSESSMENT OF THE LANE SNAPPER (*Lutjanus synagris*) IN A SMALL-SCALE FISHERY IN HONDURAS

A Thesis

by

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ABSTRACT

Small-scale fisheries are difficult to assess and manage adequately due to uncertainties surrounding collected data. For example, data are often limited to fishery-dependent data, and fishing gear, such as a gillnet, is very size-selective. This makes the estimation of important parameters such as total mortality and natural mortality difficult, and thus fishery assessment is challenging. Despite these difficulties, management decisions must be made with the available information. The objectives of this thesis were to estimate the total and natural mortality of Lane Snapper (*Lutjanus synagris*) in the coastal waters of Honduras and determine if the length metric method can be utilized for assessment of this fishery.

The total mortality was estimated using a regression catch-curve analysis applied to fishery-dependent catch per unit effort (CPUE) data. The method accounted for gear selectivity by fitting multiple gear-selectivity curves and determining the best curve using a statistical model selection method. The estimated mortality was compared with other estimates obtained without using a regression catch-curve analysis. The natural mortality was estimated using four different methods; these methods included the Peterson and Wroblewski, Lorenzen, and Sekharan estimators as well as using the “Fish Life” R package. Then, fishing mortality was estimated by subtracting natural mortality from the total mortality. Our results showed that the skewed normal selectivity curve fit the data best. The total mortality estimates were higher compared with other estimates when the CPUE was not corrected for gear selectivity. The natural mortality was consistent among three of the different methods employed, with the exception being the Peterson & Wroblewski estimator. When estimating the fishing mortality, more variation came from total mortality compared to natural mortality. This study also demonstrates the importance of using multiple estimators for total and natural mortality to assess uncertainties associated with models and the underlying data.

The three indicators proposed by Froese were estimated with and without accounting for size-selectivity of the gill nets, and then the resulting indicators were compared. The estimation of the different indicators suggest that the fishery is experiencing recruitment overfishing and growth overfishing is also occurring. My results suggest that the indicators proposed by Froese can be over- or under-estimated when gear selectivity is not taken into account.

DEDICATION

To my family.

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1. INTRODUCTION

Small-scale fisheries are difficult to assess because they are usually data poor and target many species. Fish are also landed at many sites, making it difficult for the collection of fish landing data, which in turn influences the ability to estimate catch per unit effort (CPUE). These conditions limit the application of commonly used statistics and mathematical models to understand the populations, making the assessment and management of these fisheries difficult (Freitas, Rocha, Chaves, & De Moura, 2014; R. Hilborn & Walters, 1992; Martell & Froese, 2013; Pilling et al., 2008; Richards & Maguire, 1998; Sparre & Venema, 1998).

However, studying small-scale fisheries is important. If we include all the activities related to small-scale fisheries, more than 200 million people, including children and elderly, depend on them (Andrew et al., 2007; Delgado, Wada, Rosgrant, Meijer, & Ahmed, 2003; Pauly, 1997). As Mahon (1997) stated, most of the fisheries in developing countries are considered small-scale and data-poor fisheries. The assessment methods that are applied to large-scale fisheries or industrial fisheries are not adequate in assessing the status of small-scale fisheries, and in most cases, the results are often unsatisfactory because the conclusion predictably calls for more and better data (Aschenbrenner et al., 2017; Carruthers et al., 2014; Froese, 2000; Froese, Zeller, Kleisner, & Pauly, 2012; Levin, Holmes, Piner, & Harvey, 2006).

Small-scale fisheries in the tropics are considered among the most difficult to assess because they possess a high diversity of species and because of the sociological and economic aspects that characterize them (Pauly, 1997). New approaches for the assessment of small-scale fisheries in the tropics have been proposed. One of these approaches is using length catch data to set up reference points to obtain sustainability (Babcock, Coleman, Karnauskas, & Gibson, 2013; Babcock, Tewfik, & Burns-Perez, 2018; Cope & Punt, 2009; Froese, 2004; Froese et al., 2012).

Because of the importance of small-scale fisheries, organizations such as the World Wildlife Fund (WWF) and the Coral Reef Alliance (CORAL) have worked in many countries to find the best management approaches for small-scale fisheries. In Tela, Honduras, for the past two years, together with the National University of Honduras (UNAH), these agencies have collected fisheries dependent data, which included recorded length, weight, and species of fish caught by fishermen along with information on fishing gear type and fishing areas. The following chapters of this thesis are aimed at developing tools for the assessment of the fisheries and produce adequate management strategies for small-scale, data-poor fisheries using the coastal fishery data from Honduras as an example. In these chapters, I present the analysis of this data to estimate the parameters that are important for the assessment.

Firstly, I used a statistical model to correct for the selectivity gill nets have on the catch data. Then, I estimated total mortality (Z), natural mortality (M), and fishing mortality (F). Then traditional quantitative methods such as a catch-curve analysis and variations of this method such as the Heincke method and the Chapman and Robson method for the estimation of total mortality (Z) were employed. The Lorenzen estimator, Peterson and Wroblewski estimator, Sehkaran's estimator and the FishLife R package for estimating natural mortality were used and the results were compared. Then, I determined the best approach for the estimation of these parameters for the type of data collected in the fisheries of the area. Finally, a length metric approach proposed by Froese (2004) was applied to the data. To evaluate if the assumption behind this method was appropriate for my data, I evaluated the impact of the selectivity of gill nets on the indicators. Based on the estimated mortality and indicators, management recommendations were developed for this fishery in Honduras.

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2. ESTIMATING MORTALITY FOR THE ASSESSMENT OF A SMALL-SCALE FISHERY: LANE SNAPPER (*Lutjanus synagris*) IN HONDURAS

2.1. Introduction

The management of small-scale fisheries is critically important, affecting millions of people around the world (Andrew et al., 2007; Canales, Hurtado, & Techeira, 2018; Delgado et al., 2003). However, small-scale fisheries are often characterized as being data-poor and possessing a large amount of uncertainty in collected data (Freitas et al., 2014; R. Hilborn & Walters, 1992; Pilling et al., 2008). For example, the landings in small-scale fisheries are often done at any feasible locations along a coast or a river, making the collection of fishery-dependent data very difficult (Pilling et al., 2008). This complicates the estimation of catch per unit effort (CPUE), which is often used as input in fisheries assessment models (Martell & Froese, 2013; Pilling et al., 2008; Richards & Maguire, 1998; Sparre & Venema, 1998). In data-poor fisheries in general, the best information available is often inadequate for the assessment of fish stocks using the statistics and mathematical models that have been developed for large-scale fisheries (Carruthers et al., 2014; Pilling et al., 2008). Therefore, we often need to utilize a limited amount of available information for the assessment of small-scale fisheries.

In small-scale fisheries in the Tropics, gill nets are used widely because they are relatively inexpensive, and less effort is required to catch fish (Acosta & Appeldoorn, 1995; FAO, 2001; Reis & Pawson, 1992). For example, small-scale fisheries in Honduras are characterized as being very traditional, and the most common fishing gear used amongst fishers are gill nets (Carbajal et al., 2017; Lopez et al., 2018). Therefore, the use of landing data of fish collected with gill net is often important for the assessment of stocks in small-scale fisheries.

However, gill nets are one of the most size-selective fishing gears (Doll, Thomas, & Lauer, 2014; Gulland, 1987). Depending on the mesh size of the gill net, size-specific catchability will change because of gear selectivity (Acosta, 1994; Hamley, 1975; Lobyrev & Hoffman, 2018; McClanahan & Mangi, 2004; Reis & Pawson, 1992; Shoup & Ryswyk, 2016).

As a result, the data collected with gill nets always have a bias Pauly (1984), which needs to be corrected before estimating parameters for the assessment of fisheries (Acosta, 1994; Doll et al., 2014; Hamley, 1975; Márquez-Farias, 2005; Minns & Hurley, 1988; Reis & Pawson, 1992).

Once CPUE is corrected for gear selectivity, one of the most common methods to estimate mortality is the catch-curve analysis**.** In this method, catch is divided into age bins, and the natural logarithm of CPUE is regressed against the corresponding age. The slope of the fitted regression line is the estimated instantaneous mortality Z (Chapman & Robson, 1960; Pauly, 1984). When trying to estimate mortality with a regression catch-curve analysis, unbiased age- or size-structured CPUE is critically important, thus correcting for gear selectivity is needed (Hamley, 1975; Hovgård, 1996; Pet, Soed-Pet, & van Densen, 1995; Regier & Robson, 1966; Ricker, 1975).

A regression catch-curve analysis requires additional considerations. For example, there are many thresholds or criterions that can be chosen when deciding points to be included for fitting a regression line. The age of the peak abundance, which is the highest point of the catch-curve (i.e., curve for natural log of CPUE against age), is commonly used as the threshold in age below which data are disregarded. This truncation is necessary because fish below a certain size are not caught effectively with some fishing gear. However, there are some cases in which a greater age may be selected as the threshold to give better results (Pauly, 1984; Smith et al., 2012). The different thresholds need to be chosen carefully depending on the life history of species and population dynamics. For example, when there is high fishing mortality, individuals in older age groups may be scarce, and this will affect the estimation of the slope if only older ages are included in the catch-curve analysis (Smith et al., 2012).

Although catch-curve analysis is a practical method, estimating total mortality with a catch-curve analysis may not be adequate when working with limited data from small-scale fisheries (Branch, 2009; Jensen, 1996). This results especially when the data include many zeros (i.e. zero CPUE at many age classes). For this reason, alternative methods that are not based on regression catch-curve analyses are also being proposed for the estimation of total mortality Z in data-poor fisheries. These alternative methods are based on the relationship between the age at recruitment, mean age and the sample size (Murphy, 1997; Smith et al., 2012).

In addition to the estimation of total mortality Z, the estimation of natural mortality M is also important for fisheries management. However, the estimation of natural mortality is difficult even for data-intensive fisheries (Gaertner, 2015; Windsland, 2014). Therefore, methods that use the relation between natural mortality M and life history parameters (such as growth) are suggested when estimating natural mortality M in data-poor fisheries (Gaertner, 2015; Windsland, 2014). In such cases, the use of several estimators for natural mortality is recommended to accommodate model uncertainties (Gaertner, 2015; Kenchington, 2014; Lee, Maunder, Piner, & Methot, 2011; Lorenzen, 1996).

Despite the difficulties associated with the analysis of landing data in small-scale fisheries, fishery dependent data is often the only data that can be feasibly obtained, due to the high costs associated with collecting fishery independent data. Therefore, determining the methods that are the most effective for assessing a stock using the available data in small-scale fisheries is critically important. The objectives of this study were to evaluate different methods for estimating the total mortality, natural mortality, and fishing mortality using available information from a small-scale fishery in Honduras. First, I determined the types of gear-selectivity curves that best represented the data for Lane Snapper (*Lutjanus synagris*), which is the most commonly targeted species in the area. I used data collected with gill nets and analyzed the effects of the selectivity curve on the estimation of the total mortality Z using a regression catch curve analysis. Next, alternative methods, which are not based on regression analysis, were employed for the estimation of total mortality Z for comparison. Then, four different methods for the estimation of natural mortality M were used and the results compared to values found in the literature. Finally, fishing mortality F was estimated based on different combinations of total mortality Z and natural mortality M estimates. Based on these results, I make recommendations for methods to estimate mortality rate of fish in small-scale fisheries.

2.2. Methods

This study was based on data collected in Tela, Honduras (Figure 1) by the Coral Reef Alliance, the World Wildlife Fund (WWF) and the National University of Honduras (UNAH). Tela is a coastal town located in the northern coast of Honduras, and it is a part of the Caribbean Sea. The collection of data was done by surveying fishers from the small-scale fisheries villages of Tornabe, Triunfo de la Cruz, Tela Town and Miami from 2015-2017. These towns were selected because there were greater numbers of fishers compared to other towns and because they were more easily accessible.

For each survey, fishers were chosen by their order of arrival to the coast or port in each village. The surveys in each village were done until there were no more fishers available to survey. In some cases, multiple fishers arrived very close together in time, leading to some fishers departing prior to being surveyed. In this case, the fishers who had arrived later were not included in the surveys. The total number of surveys conducted depended on the number of fishers available, and thus was not consistent among days and between towns. There was also seasonal variability in fishing effort among the different towns. In each survey, information about species, fork length (centimeters), and weight (grams) of every fish caught as well as the duration of the fishing trip (minutes) and fishing gear characteristics (gear type and size, in the case of gill nets the specific mesh size) were recorded. Based on the information, catch (number of fish) per unit effort (minutes) for each gear category (gill nets of mesh size of 2” and 3”) was calculated. For this study, the data belonging to Lane Snapper (*Lujtanus synagris*) caught with gill nets (mesh size 2” and mesh size 3”) were taken into consideration because of the importance of the species for local economies of the area (Carbajal et al., 2017; Lopez et al., 2018).

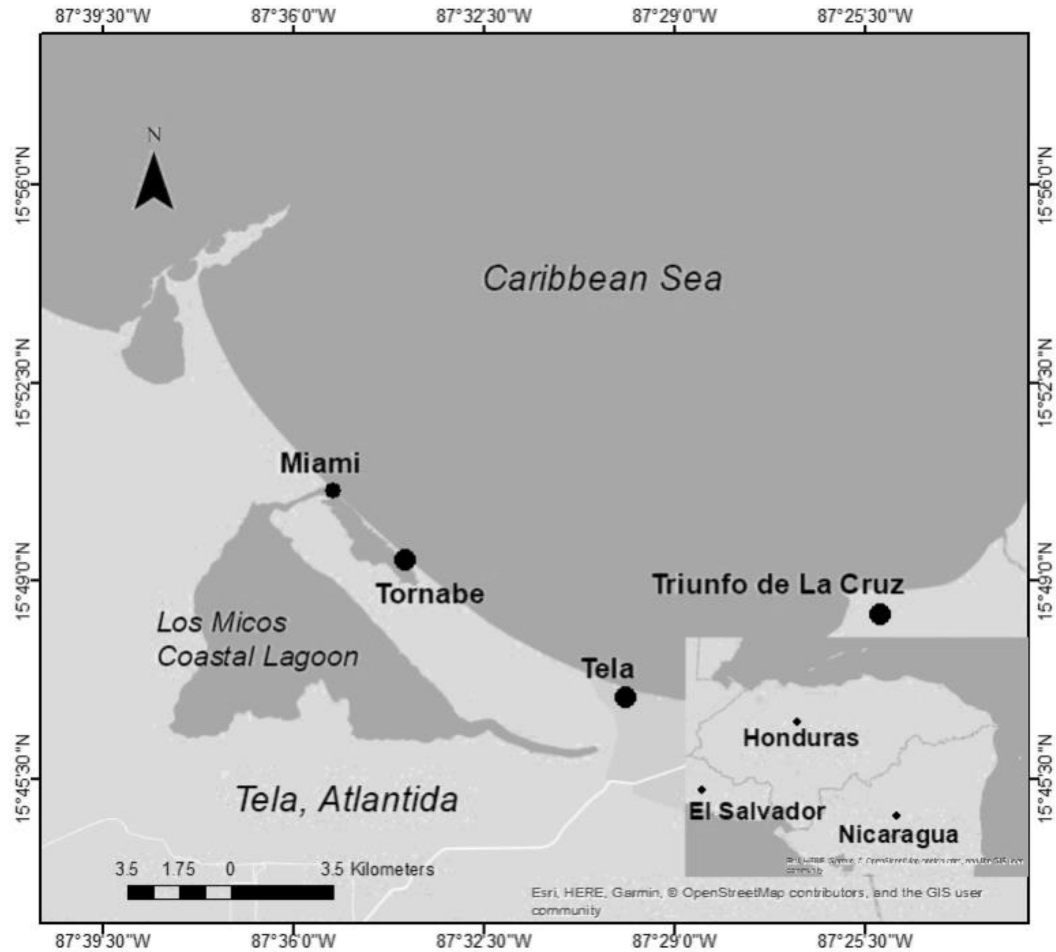

Figure 1. Map of Tela in the northern coast of Honduras and the different villages surveyed: Miami, Tornabe, Tela Town and Triunfo de La Cruz.

2.2.1. Selectivity of gill nets

To determine gear-selectivity, distribution curves (selectivity curves) were fitted to length-specific CPUE as a function of length. In this study, different shapes of the distributions were compared. Previously, it was often assumed that selectivity curves for gill nets were normally distributed (Hamley, 1975; Millar, 2000). However, many authors tested other curves such as lognormal and skewed distributions and found that the shape of the selectivity curve depends on the size and shape of targeted fish (Doll et al., 2014; Fujimori & Tokai, 2001; Hamley, 1975; Holt, 1963; Kawamura, 1972; Lobyrev & Hoffman, 2018).

For this study, three different distribution functions were used as selectivity curves. These functions were:

normal,

$$S_N(R_{ij}) = \exp\left(-\frac{\left(R_{ij}-R_0\right)^2}{2\sigma^2}\right),$$

log-normal,

$$S_L\left(R_{ij}\right) = \exp\left(-\frac{((\ln\left(R_{ij}\right)-\ln(R_0))^2}{2\sigma^2}\right),$$

and skewed normal,

$$S_k\left(R_{ij}\right) = \frac{\exp\frac{-X^2}{2}}{\sigma} * \left[1 + \operatorname{erf}\frac{(K*X)}{\sqrt{2}}\right],$$

where R_0 in each function is the relative length with maximum value of each selectivity curve, σ is the parameter that decides each curve width, j is the mesh size, i is the length of each fish ,l_j is the number of fish with specific lengths caught, R_{ij} is the proportion of fish with specific lengths (l_j) captured with a specific mesh size (m_i), X=$R_{ij} - R_0$, K is the skewness factor for the skewed normal selectivity curve, and *erf* is the error function. Then, the curves were fitted to length-specific CPUE using a maximum likelihood method (Fujimori & Tokai, 2001). The likelihood (lik) is given as

$$lik = \prod_{j=1}^{n}\left[\frac{C_j!}{\prod_{i=1}^{k} C_{ij!}} \prod_{\mathrm{i=1}}^{\mathrm{k}}\left(p_i S(R_{ij})/\sum_{i=1}^{k} p_i\, S(R_{ij})\right)^{Cij}\right].$$

The likelihood was maximized using an optimization routine “fminunc.m” in (MATLAB, 2017). Then, Akaike Information Criteria (AIC) was used to determine the best model.

2.2.2. Estimation of total mortality (Z)

Regression catch-curve analysis

For the estimation of Z, the fork length was converted to age using the following function:

$$Age = -\frac{1}{k} * \log(\frac{L}{L_\infty}) ,$$

where L is the length of the fish caught, L_∞ is the length that the fish of a population would reach if they were to grow indefinitely and *k* is the growth parameter. This function was derived by solving the von Bertalanffy equation for age. For this study, L_∞ of 516 mm and *k*= 0.23 were used, as determined by Appeldoorn and Acosta (1992) for Lane Snapper (*Lutjanus synagris*) in Puerto Rico.

The catch-curve analyses were done by regressing the natural log of the frequency of the catch per unit effort of fish against age. The slope of the fitted line gave the estimated total mortality Z (Pauly, 1984; Robson & Chapman, 1961). Catch-curve analyses were repeated using only the data from gill net of 2" mesh size, 3" mesh size only, and both mesh sizes combined. For each of the gill net type scenarios, the total mortality Z was estimated using each of the different gear selectivity curves and without selectivity correction to determine the effect of selectivity correction on mortality estimates.

In addition to testing if different selectivity curves and mesh sizes made differences in the estimation of total mortality Z, two different thresholds (Threshold A and B) were used in the catch-curve analysis. Threshold A was defined as the age immediately to the right of the highest point on the catch-curve Appeldoorn and Acosta (1992), and Threshold B was defined simply as an age of 3 years (Aschenbrenner et al., 2017). The points after both thresholds were used for the estimation of the slope and thus of the total mortality Z for each catch-curve analysis.

2.2.3. Alternative methods for estimating total mortality

Because of limited data in small-scale fisheries, using a regression catch-curve analysis will require additional care. In many cases with data from small-scale fisheries, there is little to no information from older age classes, often containing only a single individual or none. This is because fish populations are often heavily exploited (Hoenig, 1983; Ricker, 1975; Smith et al., 2012), which in turn will affect the estimation of the slope and thus of the total mortality Z. For this reason, alternative methods were proposed. In this study, I apply these methods and compare the results.

One of the alternative methods was proposed by Chapman & Robson (1960):

$$CR(\widehat{Z}) = log_e \left(\frac{1+\bar{T}-T_C-1/N}{\bar{T}-T_C}\right),$$

where $\bar{T}$ is the mean age of the fish in the sample that are greater or equal to age T_C , where T_C is the minimum age of fish in the sample that is considered to be fully recruited, and N is the number of fish that are greater or equal to age T_C . This method assumes that the survivorship after recruitment follows a geometric distribution. For this study T_C was obtained by plotting the frequency of catches at different ages for each gill net, and the age with the highest frequency was considered to be the age of full recruitment T_C . Similarly, $\bar{T}$ and N were estimated from the frequency of catches at different ages. The associated variance estimator was:

$$VAR\left[CR(\hat{Z})\right] = \frac{\left[1 - e^{-CR(\hat{Z})}\right]^2}{Ne^{-CR(\hat{Z})}}$$

In a similar manner, the equation proposed by Heincke in 1913 (Smith et al., 2012) was used to estimate the survival rate s as $\hat{s} = \frac{N-N_0}{N}$, where N is the number of fully recruited fish and N_0 is the number of fish that are available in the fully recruited age (Froese, 2004). The total mortality Z was then estimated using the equation: $-\,log_e(\hat{s})$. The variance was estimated as:

$$VAR(\hat{Z}) = \frac{1-\hat{S}}{N\hat{S}}$$

The different values of total mortality estimated with these methods were compared with my estimates from the catch curve analyses and with the values estimated in different studies for the same species.

2.2.4. Estimation of natural mortality (M)

Natural mortality is one of the most important and most difficult parameters to estimate for stock assessment of fisheries, and, for data-poor fisheries the options to estimate these parameters are limited (Andrews & Mangel, 2012; Hewitt et al., 2011; Then, 2014). When used for management of data-poor fisheries, it is recommended to use several different estimators to assess model uncertainty (Kenchington, 2014; Pascual & Iribarne, 1993). For this study, four different estimators for natural mortality were used: Peterson and Wroblewski estimator (1984), Lorenzen estimator (1996), Sekharan estimator (1975) and the method using the R package “Fish Life” written by Thorson in 2017.

Peterson and Wroblewski estimator:

Peterson and Wroblewski (1984) used an allometric relationship to model natural mortality based on wet weight (Kenchington, 2014; Peterson & Wroblewski, 1984). The method was developed based on the idea that there is a close connection between the natural mortality and growth parameters across a wide variety of pelagic organisms (Gulland, 1987; Kenchington, 2014; Post & Evans, 1989; Siegfried & Sansó, 2009). For estimating natural mortality, the following equation was used:

$$M_W = 1.28w^{-0.25}$$

where M_W is the estimation of natural mortality and w is the weight in grams.

Depending on the type of available data, the estimation of w might require different approaches. Lorenzen (1996) recommended taking the average weight among multiple individuals to estimate w. However, in many cases, the data might include outliers. For these cases, it is more accurate to use the median of the multiple weights or using the midpoint of a weight-age relationship for a species to estimate w. For this study, the von Bertalanffy growth curve (VBGC) fitted to weight-at-age reported by Aschenbrenner et al. (2017) was used.

Lorenzen estimator:

Lorenzen (1996) used a regression approach to model natural mortality with weight. Similar to Peterson and Wroblewski (1984), the Lorenzen estimator is also based on the idea that natural mortality is highly correlated with growth parameters. However, while the Peterson and Wroblewski estimator uses all pelagic taxa combined to develop the allometric relations between weight and natural mortality, the Lorenzen estimator is based solely on juvenile and adult freshwater and marine fishes (Andrews & Mangel, 2012; Kenchington, 2014; Lorenzen, 1996, 2000). Lorenzen (1996) proposed the following relationship between natural mortality and weight:

$$M_L = 3.00w^{-0.288}$$

where M_L is the estimated natural mortality, and w is the weight in grams. In a similar manner, w was estimated using the approaches as described for the Peterson and Wroblewski estimator.

Sekharan estimator:

Sekharan (1975) argued that for many fisheries in the tropics, the methods for estimating natural mortality based on allometric growth relationships were not adequate because many of them were composed of fish that have short and sometimes determinate lifespans. For this reason, he proposed that the natural mortality was closely related to the maximum observed age of a species as:

$$M_S = \frac{4.6}{T_{max}}$$

where M is the estimation of natural mortality, and T_{max} is the maximum age in years. To estimate T_{max} two different approaches were used: 1) the maximum age observed in my data and 2) the maximum age observed in the length-age curve for Lane Snapper according to Aschenbrenner et al. (2017). These two approaches were chosen because the maximum age in my data differs from the one reported in other studies. Because of the simplicity of this method, it has been widely used in assessing data-poor fisheries around the world (Kenchington, 2014).

Estimation of natural mortality using "Fish Life" R package

In a study by Thorson, Munch, Cope, and Gao (2017), a multivariate model for trait evolution along a taxonomic tree was used to estimate life history variables of approximately 32,000 species of fish, assuming that taxonomically related species share life history characteristics. Using trait evolution information, they developed the R package "Fish Life" to estimate natural mortality of fish (Thorson, 2017). In this study, natural mortality for the Lane Snapper (*Lutjanus synagris*) was estimated using this R package.

2.2.5. Estimation of fishing mortality (F)

Fishing mortality F is estimated by subtracting natural mortality M from the total mortality Z (F=Z-M). For this study, these estimations were done for all the combinations of the natural mortality and total mortality estimates. Fishing mortality estimates were rounded to two decimal points and were ranked for further analysis and interpretation.

2.3. Results

2.3.1. Total mortality Z with catch curve-analysis

Total mortality Z with different Thresholds without correction for selectivity

Using Threshold A (Figure 2) for the data from mesh size 2", the estimate of Z was 1.93 (n=714, SE= 0.11, R^2=0.994), the estimate of Z with Threshold B was 2.05 (n=714, SE= 0.20, R^2=0.99). Similarly, for the data from mesh size 3", using Threshold A, the Z estimate was 2.09 (n=547, SE=0.33, R^2=0.95), and using Threshold B, the Z estimate was 1.69 (n=547, SE=0.33, R^2=0.95). When combining both mesh sizes, the Z estimate was 1.79 (n=1261, SE=0.19, R^2 =0.97) with Threshold A and 2.07 (n=1261, SE=0.19, $R^{2=}$0.98) with Threshold B. The values of Z ranged from 1.63-2.07.

Total mortality Z with different Thresholds with selectivity correction

Based on the AIC (Table 1), skewed normal curve had the best fit for selectivity correction. The parameters (R_0, σ^2 and k) estimated using the maximum likelihood method are shown in Table 1.

Table 1. Estimation of parameters for selectivity functions using combined data from mesh size 2" and 3" with the maximum likelihood function.

Selectivity function	Parameter	Estimation of parameters with likelihood function	Standard Error (SE) for R_0	AIC values
Normal	R_0	4.19	0.001623	1455
	σ^2	0.71		
Lognormal	R_0	4.05	0.001596	1420
	σ^2	0.05		
Skewed normal	R_0	3.27	0.001434	1418
	σ^2	1.49		
	k	2.65		

With the skewed normal selection curve (Figure 2), the estimation of total mortality Z when using the data from mesh size 2” with Threshold A was 0.94 (SE= 0.19, R^2=0.93). When using Threshold B, the estimate of total mortality Z was 0.79 (SE=0.38, R^2=0.82). When I compared these results with the estimated Z without correction of selectivity (Z=1.93 and 2.05), I observed that the estimated Z’s with the correction of selectivity were lower (regardless of the threshold used). When using data from mesh size 3”, the estimated total mortality Z with Threshold A was 1.82 (SE=0.25, R^2=0.95) and with Threshold B was 1.93 (SE=0.42, R^2=0.92). When data from both mesh sizes were combined, the estimated total mortality Z with Threshold A was 0.86 (SE=0.36, R^2=0.55) and with Threshold B was 0.77 (SE=0.50, R^2=0.37). In general, correcting for selectivity resulted in lower values of Z compared to those estimated without selectivity correction (Figure 2). Using the skewed normal curve for the correction of selectivity, the total mortality Z ranged between 0.77 and 1.93.

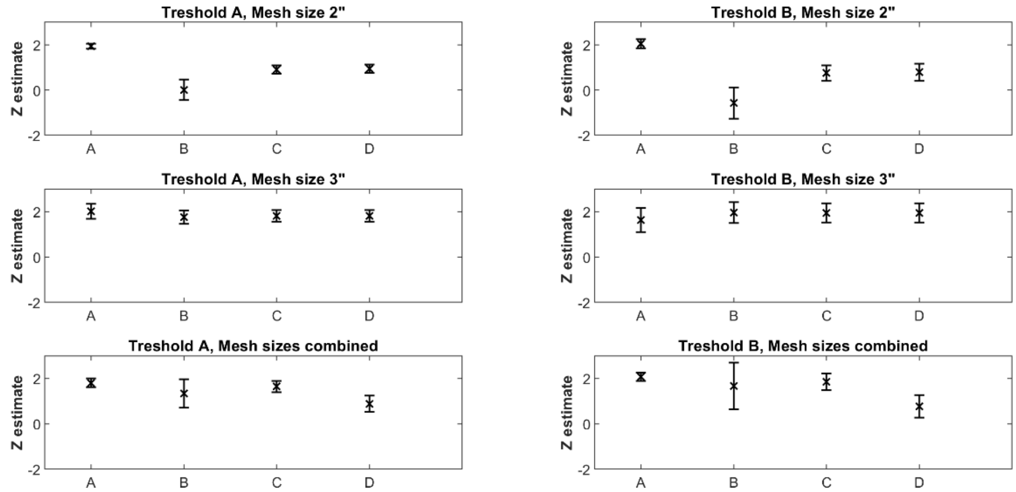

Figure 2. Estimated Z for different mesh sizes, different thresholds and different selectivity curves: A=No selectivity correction, B=Normal selectivity curve, C=Lognormal selectivity curve and D=Skewed normal selectivity curve.

2.3.2. Total mortality Z using alternative methods

The total mortality Z estimates obtained using the Chapman & Robson (1960) method were 0.84 and 0.91 for mesh size 2” and 3”, respectively (with standard errors of 0.0019 and 0.003 respectively). The estimated total mortality Z with the Heincke (1913) method were 0.003 for mesh size 2” and 0.0078 for mesh size 3” with the standard errors of 0.0017 and 0.002 respectively. Both estimators gave Z lower than that estimated with no selectivity correction (using the regression catch-curve), and the estimated Z obtained using the Chapman & Robson estimator were similar to the values obtained when correcting for selectivity using the skewed normal function.

2.3.3. Natural mortality M

Figure 3 shows the different estimates for natural mortality M estimated using the four previously described methods. The estimates ranged from 0.2276 to 0.6102. The use of the average and median weight (average=267.1094 grams and median= 252 grams) with the

Lorenzen estimator gave the highest values of natural mortality M (M=0.60, M=0.6102 and M=0.4376 with average weights, median weights and the midpoint). The Peterson & Wroblewski method resulted in much lower values of estimated natural mortality using the average weight (M= 0.3166), the median weight (M=0.3213), and the midpoint (M=0.2407).

The Sekahran estimator gave values like the Lorenzen estimator (M=0.575 and M=0.46). When using the R-package "FishLife", the estimated natural mortality M was 0.4131.

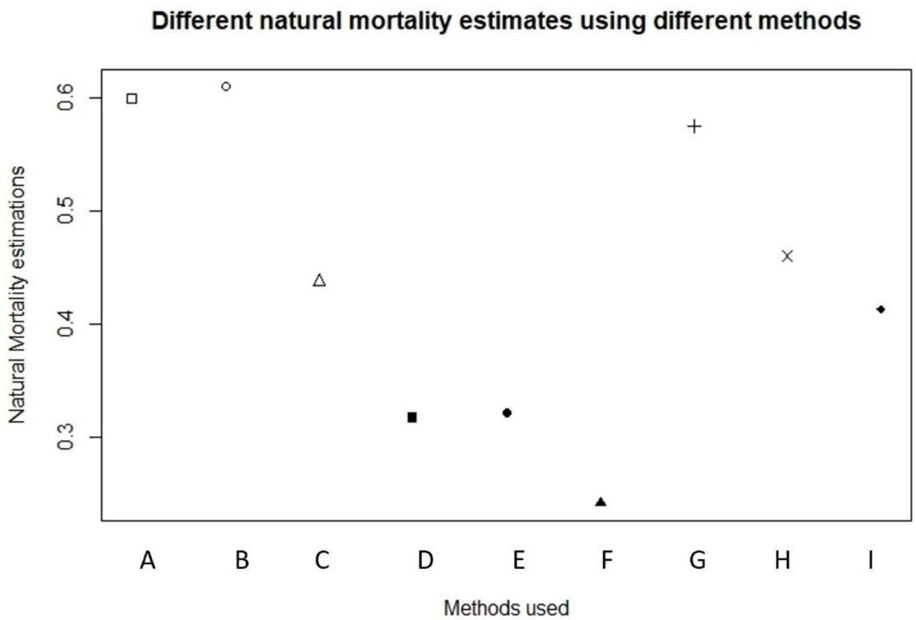

Figure 3. Estimated natural mortality M using different methods; A=Lorenzen estimator using average of weights, B=Lorenzen estimator using median of weights, C=Lorenzen midpoint 8 years, D=Peterson & Wroblewski estimator using average of weights, E= Peterson & Wroblewski estimator using median of weights, F= Peterson & Wroblewski estimator using midpoint 8 years, G= Sekahran estimator with T=8 years, H= Sekahran with T= 10 years and I= FishLife Package.

2.3.4. Fishing mortality F

All the combinations of total mortality Z and natural mortality M were used for calculating fishing mortality F (**Appendix A**). The different fishing mortality estimates were ranked (Table 2) from lowest to highest and different shade is used for emphasizing the ranks. The ranks were more consistent (observing the shade variation from left to right) among the methods for the estimation of natural mortality M (Average Variance=337.2, this was calculated by taking the average of the variance for each method), except when using the Peterson & Wroblewski estimator using the midpoint of weight-age curve. On the other hand, there was more variation (observing the shade variation from top to bottom) among the different methods used for the estimation of total mortality Z (Average Variance= 1549.1). The variation is greater between correcting for selectivity and not correcting for it, and among different mesh sizes.

Table 2. Ranks of the different fishing mortality values according to what total mortality Z method and natural mortality M method were used.

Natural mortality methods	Lorenzen average weight	Lorenzen median weight	Lorenzen midpoint weight age 8 years	Peterson & Wroblewski average weight	Peterson & Wroblewski median weight	Peterson & Wroblewski midpoint weight age 8 years	Sekharan T=8	Sekharan T=10	FishLife	Variance for M methods
Total mortality methods										
Without selectivity Threshold A mesh size 2	133	94	122	122	122	9	114	111	126	1442.4
Selectivity Normal distribution Threshold A mesh size 2	10	11	3	4	4	36	5	6	1	113.6
Selectivity Lognormal distribution Threshold A mesh size 2	34	33	56	55	55	39	47	45	61	104.7
Selectivity Skewed normal distribution Threshold A mesh size 2	37	36	59	58	58	109	51	49	63	460.2
Without selectivity Threshold B mesh size 2	106	105	127	127	127	19	123	121	131	1239.8
Selectivity Normal distribution Threshold B mesh size 2	20	21	14	15	15	26	16	17	13	17.3
Selectivity Lognormal distribution Threshold B mesh size 2	23	22	42	42	42	28	37	35	49	88.3
With selectivity Skewed normal distribution Threshold B mesh size 2	27	26	46	45	45	105	40	38	52	546.1
Without selectivity Threshold A mesh size 3	103	102	126	126	126	82	121	119	130	255.3
Selectivity Normal distribution Threshold A mesh size 3	79	78	106	105	105	87	96	94	113	156.1
Selectivity Lognormal distribution Threshold A mesh size 3	85	84	111	111	111	87	101	99	119	171.1
Selectivity Skewed normal distribution Threshold A mesh size 3	84	83	111	110	110	73	101	99	118	238.4
Without selectivity Threshold B mesh size 3	71	70	92	92	92	100	85	82	100	123.4
Selectivity Normal distribution Threshold B mesh size 3	98	97	124	124	124	97	116	114	127	163.0
Selectivity Lognormal distribution Threshold B mesh size 3	95	94	122	122	122	97	113	111	126	166.5
With selectivity Skewed normal distribution Threshold B mesh size 3	95	94	122	122	122	85	114	111	126	226.4
Without selectivity Threshold A mesh sizes combined	83	82	109	109	109	66	100	97	117	277.9
Selectivity Normal distribution Threshold A mesh sizes combined	65	64	70	70	70	75	69	68	77	17.4

Selectivity Lognormal distribution Threshold A mesh sizes combined	**72**	**71**	**94**	**93**	**93**	**35**	**86**	**83**	**101**	**397.9**
Selectivity Skewed normal distribution Threshold A mesh sizes combined	**33**	**32**	**54**	**53**	**53**	**111**	**45**	**44**	**60**	**549.1**
Without selectivity Threshold B mesh sizes combined	**108**	**107**	**129**	**128**	**128**	**76**	**125**	**23**	**132**	**1290.9**
Selectivity Normal distribution Threshold B mesh sizes combined	**75**	**74**	**96**	**96**	**96**	**90**	**89**	**86**	**104**	**100.0**
Selectivity Lognormal distribution Threshold B mesh sizes combined	**88**	**87**	**115**	**114**	**114**	**27**	**105**	**103**	**121**	**832.4**
Selectivity Skewed normal distribution Threshold B mesh sizes combined	**25**	**24**	**44**	**44**	**44**	**9**	**38**	**36**	**51**	**175.8**
Heincke method mesh size 2	**11**	**12**	**3**	**4**	**4**	**9**	**5**	**6**	**2**	**12.9**
Heincke method mesh size 3	**10**	**11**	**3**	**3**	**3**	**31**	**5**	**6**	**1**	**84.9**
Chapman and Robson mesh size 2	**30**	**29**	**50**	**50**	**50**	**37**	**42**	**41**	**57**	**93.6**
Chapman and Robson mesh size 3	**35**	**34**	**56**	**56**	**56**	**44**	**48**	**45**	**62**	**97.0**
Variance for Z methods	**1293.2**	**1117.0**	**1795.6**	**1775.4**	**1775.4**	**1168.0**	**1593.1**	**1495.1**	**1928.8**	

2.4. Discussion

Small-scale fisheries are important for millions of people around the world as a source of both food and income (Andrew et al., 2007; Delgado et al., 2003). However, a lack of adequate data is preventing the assessment and management of small-scale fisheries (Worm et al., 2009). Furthermore, common statistical models for the assessment and management of fisheries are typically developed for large-scale fisheries and require a large amount of data, often making it difficult to employ these methods in small-scale fisheries (Mahon, 1997; Pilling et al., 2008). The identification of the best approaches for the estimation of key parameters in the fishery models such as total mortality and natural mortality with data available from small-scale fisheries is an important step toward improving small-scale fishery management. In this study, I used data from a small-scale fishery in Honduras and applied different methods and criteria to estimate total mortality, natural mortality, and fishing mortality of a commercially important species lane snapper (*Lutjanus synagris*).

In this study, I dealt with the truncation of data that results from the selectivity of gill nets (Márquez-Farias, 2005). The estimated total mortality Z with selectivity correction were smaller compared with estimated Z without selectivity correction (Figure 2). As Acosta (1994), Hamley (1975) and Reis and Pawson (1992) suggest, the selectivity of gill net has a strong impact on the size distribution of the captured fish. This leads to bias in the catch per unit effort (CPUE) estimates, which, in turn, causes bias in the estimation of total mortality Z. Overall, the total mortality estimates for this study were in the range of values obtained for other studies in different areas (Table 3). Some differences in the values might be a result of differences in ecology (i.e. natural mortality), the level and type of fishing pressure, and potential bias associated with the methods used for estimating the mortality.

Table 3. Estimated total mortality and natural mortality of *Lutjanus synagris* from different areas.

Location	Fishing gear used	Length measurement used	L∞(mm)	k	Z	M	Study
Puerto Rico	Hook & line	Fork length	450	0.23	1.48-1.65	0.527	(Appeldoorn & Acosta, 1992)
Florida	Not specified	Total length	501	0.1337	0.68	0.4	(Manooch & Mason, 1984)
Brasil	Gill nets and Hook & line	Total length	560	0.22	0.58	0.17-0.36	(Aschenbrenner et al., 2017)
Honduras	Hook & line	Fork length	410	0.25	0.72-2.06	N/A	(Berthou et al., 2001)
Honduras	Gill nets	Fork length	450	0.23	0.006-2.07	0.24-0.61	This study

In this study, various methods were used for estimating total mortality Z. When using regression catch-curve analysis, the variation among the different scenarios might be due to the inclusion of many zeros and/or not enough data for older age classes (Hamley, 1975; Jensen, 1996). In addition, the estimated total mortality with the data obtained with gill nets of mesh size 3” were consistently greater than those with gill nets of mesh size 2”. This might indicate that older individuals are experiencing higher fishing pressure. Of the three methods (regression catch-curve analysis, Chapman & Robson estimator and the Heincke estimator) used for the estimation of Z, the Heincke method resulted in the lowest estimated total mortality. The Heincke method assumes catchability is the same among age classes after recruitment. When the catchability of individuals in the age immediately after recruitment is greater than older age classes, it tends to underestimate the survival rate and thus affect the estimate of total mortality

Z. Contrary to Smith et al. (2012), I suggest the Heincke method should be avoided for assessment in data-poor fisheries because I rarely had similar catchability among age classes.

On the other hand, the estimated natural mortality M was more consistent among the different methods employed (Figure 3), except with the Peterson & Wroblewski estimator, which gave substantially lower estimates. According to Gulland (1987) and McGurk (1987), the fact that the estimator is based on the relationship of weight and natural mortality of all pelagic taxa (i.e. not specific for fish) results in biased M using the Peterson & Wroblewski method. Furthermore, Andrews and Mangel (2012) stated that Lorenzen (1996) found a stronger relationship between weight and natural mortality in his estimator compared with the Peterson and Wroblewski (1984) estimator, and this might explain why the estimates with the Peterson & Wrobleweski estimator are different. Apart from the use of the Peterson & Wroblewski estimator, it appears that the variation among the estimated total mortality has a greater effect on the fishing mortality estimations than variation among the estimated natural mortality. It is recommended to use many methods for the estimation of natural mortality to obtain a range of values to incorporate model uncertainty (i.e. the assumptions behind the models) (Hewitt et al., 2011; Vetter, 1988). The Lorenzen estimator, the Sekharan estimator and the FishLife R package are relatively easy to implement. Therefore, I recommend using these three methods.

The fishery of Lane Snapper in Honduras is of great importance for coastal towns (fishing in the Atlantic Ocean and the Caribbean Sea), mainly because of its high economic value when compared to other species (e.g., Jacks) and because they are relatively easy to capture. Traditionally this species has been targeted by different gears (e.g., gill nets, traps, hook and line) with little or no restrictions towards the catches. As a result, fishers currently target the species for its economic value, but they use more fishing effort and more selective fishing gear (i.e gill nets) (Carbajal, Sierra, & Lopez, 2017; Gobert et al., 2005; Lopez, Sierra, San Martin Chicas, Caballero, & Carbajal, 2018). Consequently, for the Lane Snapper in Honduras, the estimated fishing mortality (**Appendix A**) was greater than the estimated natural mortality which suggests that the lack of management may be the cause of a high exploitation rate and this is a serious concern for this particular fishery.

I have demonstrated that selectivity has an impact on the estimation of total mortality, and that total mortality estimates have a greater effect on the variability in the fishing mortality estimates than natural mortality estimates. However, data in small-scale fisheries have additional uncertainty. For example, because the intensity of fishing in Honduras (and in most small-scale fisheries around the world) varies substantially among seasons, scattered surveys over a prolonged period results in inaccurate data by having insufficient sampling during a fishing season. This may be overcome by surveying more intensively during fishing seasons. In addition, sampling also suffers from the fact that fishers sometimes hide a part or all of catches. This may occur when their catch includes some species that are illegal to keep. Many fishers also have their preferred fishing areas so that the sample may not be representative of the entire population. Small-scale fisheries data will likely always suffer from these and other types of uncertainty in addition to different assumptions in statistical models. Although this study does not overcome all of these problems, I accounted for gill net selectivity and incorporated various approaches to estimate total, natural, and fishing mortality. I consider the approach presented in this study to be a step toward developing improved approaches for obtaining useful information in the management of small-scale fisheries.

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2.6. References

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3. ASSESMENT OF A SMALL-SCALE FISHERY: LANE SNAPPER (*Lutjanus synagris*) USING A LENGTH METRIC METHOD

3.1. Introduction

The status of the small-scale fisheries around the world is uncertain because of lack of adequate data (Ault, Smith, Luo, Monaco, & Appeldoorn, 2008; Babcock et al., 2013; Babcock et al., 2018; Worm et al., 2009). These fisheries are often not assessed or are assessed inadequately (Aschenbrenner et al., 2017; Carruthers et al., 2014; Froese, 2000; Froese et al., 2012; Levin et al., 2006). Because the stock-assessment models used for the assessment of fisheries are designed for large-scale fisheries, requiring a large amount of high-quality data (Cope & Punt, 2009), it is often very difficult to assess small-scale fisheries using these models (Babcock et al., 2013; Babcock et al., 2018; Froese et al., 2012). Nevertheless, small-scale fisheries are very important globally and still need to be assessed (Andrew et al., 2007; Ray Hilborn et al., 2003; Pauly, 1997).

In order to assess the status of small-scale fisheries, models used to assess large-scale fisheries (such as yield per recruit) are often applied; however, because of the complexity inherent in the models and the data needed to use them, the results are often not satisfactory (Froese, 2004). Thus, through time, it was suggested that for the assessment of small-scale fisheries, the assessment methods should depend on size/age frequency data, which are relatively easy to obtain, rather than count or biomass data (Freitas et al., 2014; Orensanz et al., 2005; Punt, Campbell, & Smith, 2001; Worm et al., 2009). The analysis of length-frequency data can provide important information about shifts in the population age/size structure, which can be indicative of overexploitation (Babcock et al., 2018).

Among these attempts, one of the most promising methods is the length metric method proposed by (Froese, 2004).The method utilizes length data from catches to estimate three indicators of overfishing: (1) percentage of mature fish present in the length frequency data, (2) percentage of fish caught within an optimal length and (3) percentage of "mega-spawners" present in the length frequency data. These indicators are designed to examine the size distribution of fish in the ocean. The logic behind them is that 1) there should be a high percentage of mature individuals (individuals that are above the length where at least 50% of the population has reproduced at least once) in the ocean to avoid recruitment overfishing, 2) there should be a high percentage of individuals that are considered to be within the range of optimal lengths; which is the length at which the highest yield can occur, and 3) the percentage of "mega-spawners" present in the ocean should be between 20% and 40% to conserve large and mature individuals to avoid growth overfishing (Aschenbrenner et al., 2017; Cope & Punt, 2009; Froese, 2004). Its simplicity makes the method very attractive to fishery managers (Aschenbrenner et al., 2017; Busilacchi, Williams, Russ, & Begg, 2012; Cope & Punt, 2009; Cury & Christensen, 2005; Francis, Hixon, Clarke, Murawski, & Ralston, 2007; Lewin, Arlinghaus, & Mehner, 2006).

These indicators provide important information for fishery assessment (Babcock et al., 2018). As defined by Worm et al. (2009), overfishing occurs when the catches in a given period are at maximum sustainable yield level or exceed the catches that exceed desired levels, such as maximum yield-per-recruit. Overfishing may be categorized into recruitment overfishing, which occurs when recruitment is reduced, or growth overfishing, which happens when too many small fish are caught. Indicators 1 and 3 determine these two types of overfishing that might be occurring in the fishery (Sissenwine & Shepherd, 1986). Indicator 2 helps to achieve the maximum yield of the fishery (Froese, 2004).

Even though using these indicators might be promising for the assessment of small-scale fisheries, one major drawback is the underlying assumption that the catch length composition is representative of the fish in the ocean (Babcock et al., 2013; Cope & Punt, 2009). The data in small-scale fisheries usually are fishery dependent data. This is particularly problematic when the catches do not represent the natural populations because of gear selectivity. Gill nets are one of the most size-selective fishing gear (Doll et al., 2014; Gulland, 1987). Thus, the catches may not represent the actual structure of the population of the stock when gill nets are used, which are very common in small-scale fisheries (Acosta, 1994; Hamley, 1975; Lobyrev & Hoffman, 2018; McClanahan & Mangi, 2004; Reis & Pawson, 1992; Shoup & Ryswyk, 2016).

Developing an approach for assessing and managing small-scale fisheries with simple methods using readily available data is critically important. The objectives of this study were to determine if the assumption behind the method proposed by Froese (2004) is appropriate for the Lane Snapper (*Lutjanus synagris*) from a small-scale fishery in Honduras and to determine the status of the population of the Lane Snapper (*Lutjanus synagris*) under the current management. I will use length data collected in Tela, Honduras, as a case study and discuss the adequacy of the length-based method for the assessment of small-scale fisheries.

3.2. Methods

Sampling was conducted in Tela, Honduras (Figure 4) by the Coral Reef Alliance, the World Wildlife Fund (WWF), and the National University of Honduras (UNAH). Tela is a coastal town located in the northern coast of Honduras, being part of the Caribbean Sea and the Mesoamerican Reef. The data was collected by surveying fishers in the villages of Tornabe, Triunfo de la Cruz, Tela Town, and Miami from 2015 to 2017. The surveys in each village were done until there were no more fishers available to survey. The total number of surveys depended on the number of fishers available and thus was not consistent among days and towns. These towns were selected because there was a greater number of fishers than other towns and because of the accessibility to the towns.

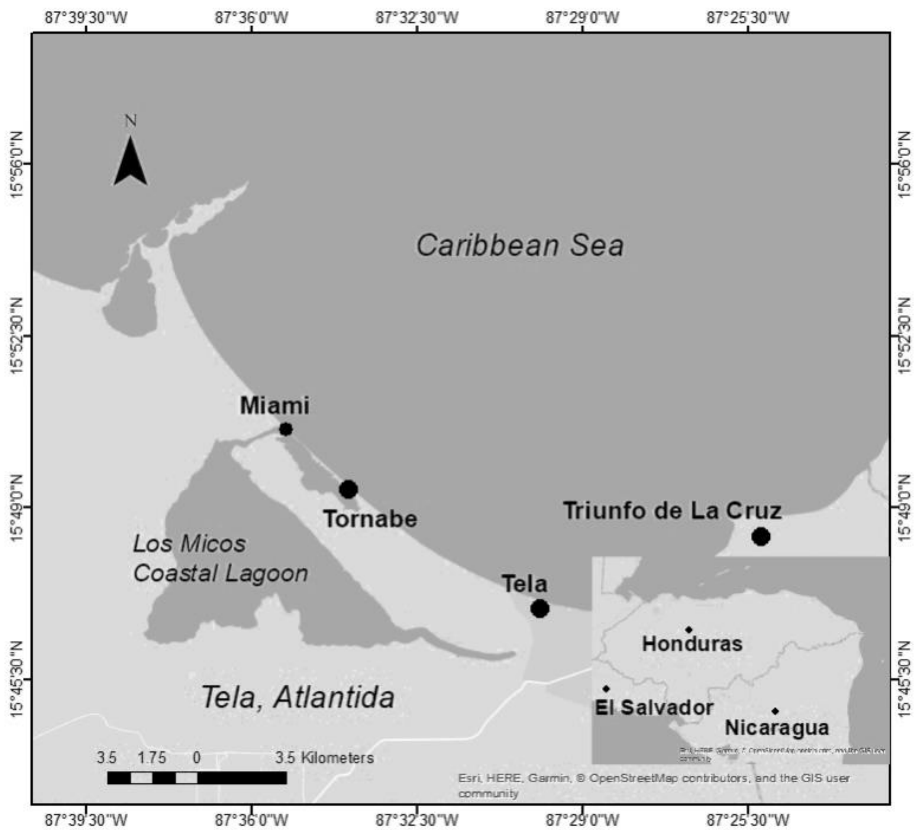

Figure 4. Map of Tela in the northern coast of Honduras and the villages surveyed: Miami, Tornabe, Tela Town and Triunfo de La Cruz.

In each survey, species, fork length (centimeters) and weight (grams) for each fish, duration of the fishing trip (minutes), and fishing gear characteristics (gear type and in the case of gill nets the specific mesh size) were recorded. The data included many species caught with multiple types of fishing gear. For this study, I analyzed data for Lane Snapper (*Lutjanus synagris*) caught with gill nets of two different mesh sizes (2" and 3").

For this study, the length-based method proposed by Froese (2004) was applied to assess the Lane Snapper (*Lutjanus synagris*) fishery in Tela, Honduras. The method consists of the estimations of three indicators that provide the information needed for the assessment of the fishery. The main assumption behind this method is that the length composition of the catch is representative of the length composition of the fish in the ocean.

Each indicator was determined for the data belonging to Lane Snapper (*Lutjanus synagris*) caught with gill nets of mesh sizes 2" and 3". The selectivity curve estimated for the same population by Castillo et al. (2018) was used to correct for the gear selectivity. The different indicators were described as follows:

1. **Percentage of mature fish present in the length frequency data**

The catches of healthy fisheries are expected to include a high percentage of mature individuals (Aschenbrenner et al., 2017; Froese, 2004). For this indicator, I determined the amount and percentage of individuals that were above the L_{50}, which was the length where 50% of the individuals were able to reproduce. For this study, the average of the different values for L_{50} reported in the study in Roatan, Honduras was used (Berthou et al., 2001).

2. **Percentage of fish caught within an optimal length**

The optimal length is the length of individuals caught where the maximum yield is achieved (Froese, 2004), and it was estimated using the expression given by Beverton (1992):

$$L_{opt=} \quad \frac{3L_{\infty}}{(3+\frac{M}{k})}$$

Where L_∞ is the maximum length that fish in the population would reach if they were to grow indefinitely, k is the growth parameter, and M is the natural mortality. For this study, L_∞ of 51.6 cms and k of 0.23 were used taking the values for Lane Snapper (*Lutjanus synagris*) in Puerto Rico (Appeldoorn & Acosta, 1992). Different natural mortalities estimated for Lane Snapper (*Lutjanus synagris*) by Castillo et al. (2018) were used to assess the impact on the optimal length estimation. A range ±10% of the optimal length, as proposed by Babcock et al., (2013), Cope & Punt, (2009), and Froese (2004), was used to determine the percentage of the catch that falls within the optimal length.

3. Percentage of fish caught that are "mega spawners"

The "mega spawners" in the catch are those fish that are old and are larger than the optimal length (estimated in indicator 2). These fish are of major importance to the fishery because the larger fish tends to be more fecund (Froese, 2004; Gwinn et al., 2015). I estimated the percentage of fish that were larger than 1.1 times the optimal length and considered it to be the percentage of "mega spawners" present in the catch. The expected percentages of "mega spawners" should be between 30% - 40 % for a healthy stock without overfishing. The percentage of "mega spawners" lower than 20% indicates potential overfishing (Babcock et al., 2018; Froese, 2004).

3.3. Results

3.3.1. Indicator 1: Percentage of mature fish in the length distribution of the catches

Figures 5 and 6, demonstrate the length-frequency distribution of the different catches with gill nets of mesh size 2" and 3" without selectivity correction. For mesh size 2" (Figure 5), the percentage of mature individuals that are being caught is 13% (when using an L_{50} of 24 centimeters), which results in 87% of immature fish in the catch with this mesh size. On the other hand, for mesh size 3” (Figure 6), there was 70% of mature individuals reported in the catches (30% of immature individuals). For this indicator, the percentage of mature individuals should be high (Froese, 2004). As seen in Figures 5 and 6, gill nets of mesh size 3” catch the percentage of mature individuals close to what is recommended whereas gill nets of mesh size 2” catch a large amount of immature fish and thus should not be allowed to use.

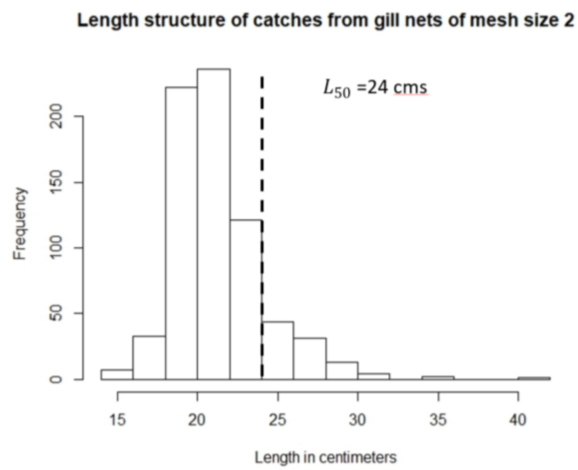

Figure 5. Length distribution of Lane Snapper (*Lutjanus synagris*) caught with gill nets of mesh size 2”, the dashed line demonstrates the L_{50} used and the frequency of fish that are above and below this.

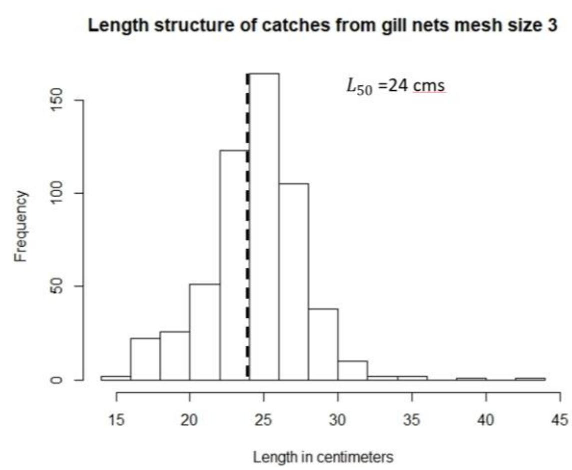

Figure 6. Length distribution of Lane Snapper (*Lutjanus synagris*) caught with gill nets of mesh size 3”, the dashed line demonstrates the L_{50} used and the frequency of fish that are above and below this.

After correcting for the selectivity (for mesh sizes 2" and 3") and obtaining the percentage of individuals that are above L_{50} (24 cm), there are around 21% of mature individuals in the stock in the ocean.

3.3.2. Indicator 2: Percentage of fish caught at an optimum length

Different values of natural mortality as estimated by Castillo et al. (2018), were used to obtain the optimum length of capture and the range of optimum lengths. Figures 7 and 8 show the length-frequency for each mesh size and the range of lengths considered to be optimum for capture. The different natural mortalities had an impact on these ranges and thus on the percentages of individuals that were captured at an optimum length (Table 4). As with indicator 1, gill nets of mesh size 2" have low percentages of capturing fish that are in the optimum length (the captures of individuals in optimum length range from 3%-14%). On the other hand, gill nets of mesh size 3" have higher percentages of individuals that are being captured in the optimum lengths, ranging from 10% to 56%.

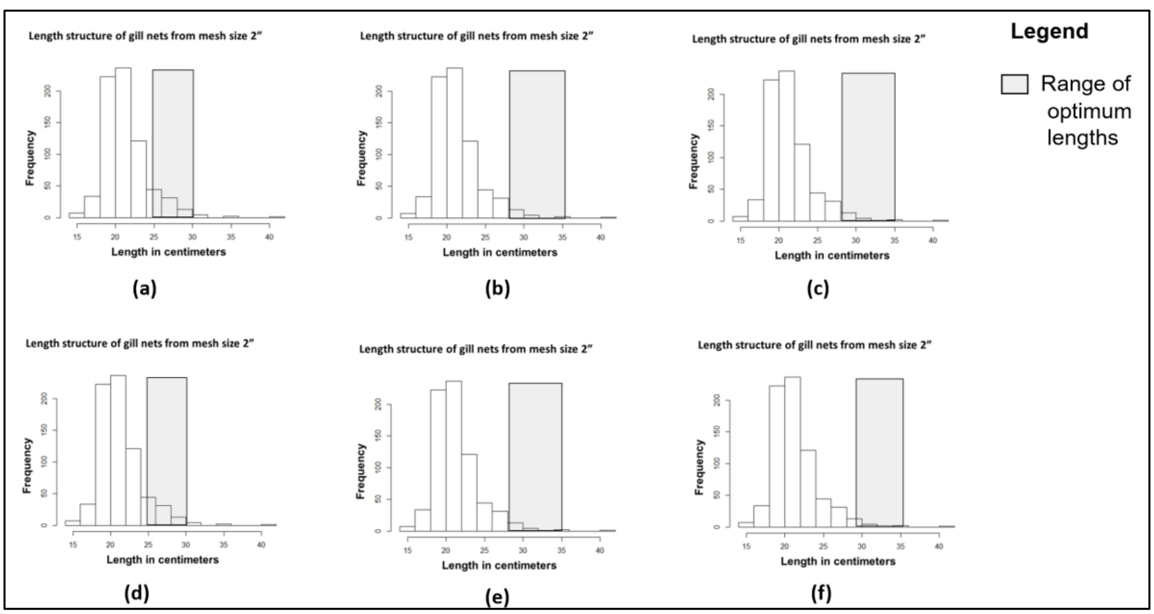

Figure 7. Length frequency distributions of fish caught with mesh size 2" and the optimum range of lengths.

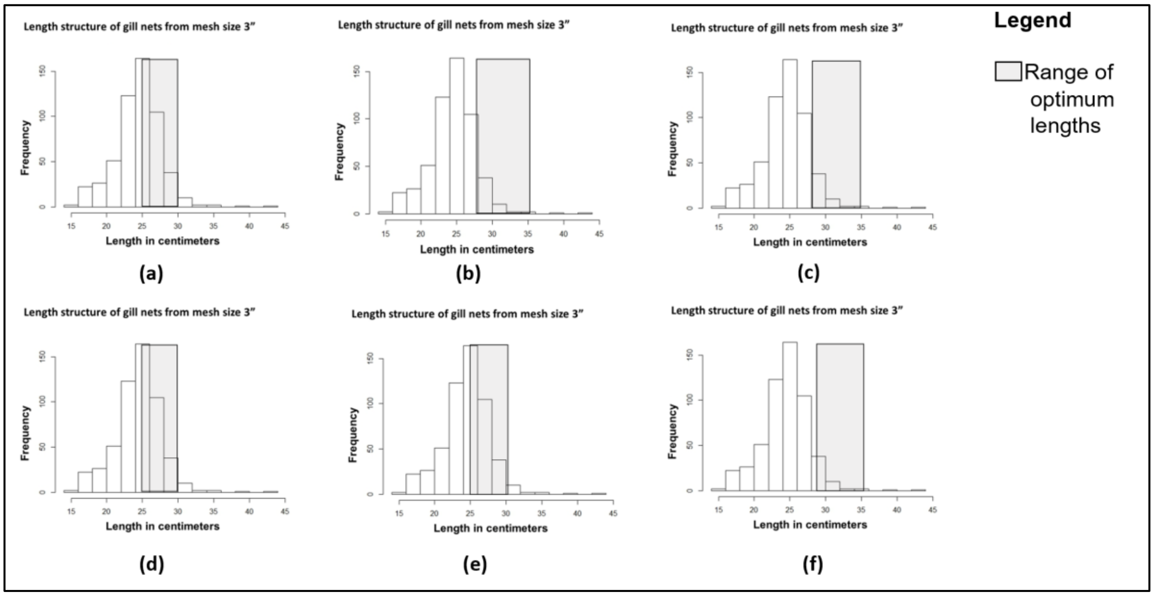

Figure 8. Length frequency distributions for mesh size 3” and the optimum range of lengths.

Table 4. Percentage of individuals caught at optimum length with different mesh sizes under different values of assumed natural mortality, with and without selectivity correction.

Natural mortality value used	Mesh size	Percentage of individuals caught in optimum length with selectivity correction	Percentage of individuals caught in optimum length without selectivity correction
0.6	" 2	20.05%	12.46%
0.61	" 2	20.05%	12.46%
0.438	" 2	11.42%	4.62%
0.575	" 2	21.10%	12.61%
0.46	" 2	11.42%	4.48%
0.4113	" 2	7.34%	2.66%
0.6	" 3	20.41%	56.12%
0.61	" 3	20.41%	56.12%
0.438	" 3	5.25%	17.73%
0.575	" 3	20.80%	57.40%
0.46	" 3	5.20%	17.55%
0.4113	" 3	2.77%	9.51%

When correcting for the selectivity that gill nets have, the results indicate that approximately 20% of fish in the ocean would be in optimum length to be caught (Table 4).

3.3.3. Indicator 3: Percentage of fish caught that are considered to be "mega spawners"

The percentages of mega spawners that are being caught with both mesh sizes (2" and 3") were very low (0 and 0.18 respectively). For this indicator, the percentage of mega spawners in the catch should be greater than 20% for a stock to be considered healthy (Froese, 2004). Similarly, when taking the selectivity into consideration there is about 5% of mega spawners in the population in the ocean.

3.4. Discussion

The method proposed by Froese (2004) to assess a fish stock may not be adequate for the assessment of small-scale fisheries without correction for size-selectivity of fishing gear. The method assesses the size distribution of the stock in the ocean based on size distribution in the catch. Therefore, the assumption behind this method is that there is no gear selectivity affecting the catches of the fishermen and thus the catches are representative of the fish stock (Babcock et al., 2018; Cope & Punt, 2009). However, most small-scale fisheries use size-selective fishing gear, and it was the case with my data from the small-scale fishery in Honduras.

When I used the catches from a fishing gear that targets smaller fish (example: Lane Snapper data collected with mesh size 2" gill nets from Honduras) to estimate the indicators without consideration of the impact of the selectivity, I will obtain lower values for indicators 1 and 2 (Table 5)**.** Using these indicators without selectivity correction to make management decisions can be problematic (Cope & Punt, 2009). For example, indicator 1 without selectivity correction suggests that only 13% of the stock is mature (using the catch as a representation of the stock); however, the same indicator after correcting for gear selectivity suggests 21% of the stock is mature.

Table 5. Estimation of indicators with and without selectivity correction using catches from mesh size "2 gill nets and 3" gill nets.

Size of mesh size gill nets	Indicator	Estimation of indicators not correcting for selectivity	Estimation of indicators correcting for selectivity
2"	Indicator 2	12.46%	20.05%
2"	Indicator 2	4.62%	11.42%
2"	Indicator 2	12.61%	21.10%
2"	Indicator 2	4.48%	11.42%
2"	Indicator 2	2.66%	7.34%
2"	Indicator 3	~0	~5%
3"	Indicator 1	70%	21%
3"	Indicator 2	56.12%	20.05%
3"	Indicator 2	56.12%	20.05%
3"	Indicator 2	17.73%	11.42%
3"	Indicator 2	57.40%	21.10%
3"	Indicator 2	17.55%	11.42%
3"	Indicator 2	9.51%	7.34%
3"	Indicator 3	0.18%	~5%

On the contrary, with fishing gear that target larger sizes of fish (example: Lane Snapper data collected with mesh size 3" gill nets from Honduras), the catch and thus length structure consist of larger age classes. As a result, when selectivity is not taken into consideration, the estimation of the indicators 1 and 2 proposed by Froese (2004) higher values will tend to occur (table 5). Indicator 1 (without selectivity correction) suggests that 70% of the individuals in our catch is mature; this may suggest the stock is healthy. However, the percentage of mature individuals when taking selectivity into account is 21%, and thus recommending using mesh size 3" (or larger) might affect the older age classes of the stock. This will cause problems when interpreting the indicators to make management recommendations (Babcock et al., 2013; Babcock et al., 2018; Cope & Punt, 2009).

Although indicator 3 values for both mesh sizes (2” and 3”) are lower when compared with the indicator estimated after correction for gear selectivity (Table 5), the estimation can also be higher if gear with much larger mesh size is used. It can potentially suggest the stock may be healthy, but it does not reflect the true condition of the stock (Babcock et al., 2018).

The status of the Lane Snapper in Tela, Honduras based on the three indicators after correcting for the size-selectivity of the gill nets is an overfished stock. With indicator 1, the percentage is of 21%, which suggests a small percentage of fish are mature. Similarly, with indicator 3, the percentage of mega spawners is currently 5%, which should be greater than 30%. Therefore, recruitment overfishing and growth overfishing are occurring with the stock (Froese, 2004; Froese et al., 2018; Froese et al., 2012). Agreeing with Castillo et al. (2018), there seems to be high fishing pressure (resulting in high fishing mortalities) which is currently causing the overfishing. Because of this, I recommend that the managers should eliminate the use of mesh size “2 gill nets entirely. Even though they are illegal to use in Honduras (as stated by the law), there are many fishermen still using them. It may be difficult to enforce the ban mesh size 2” gill nets of in Honduras because of the unique sociological and economical characteristics surrounding the fishery. I recommend working side by side with the fishermen and local organizations to implement this recommendation (Carbajal et al., 2017).

At the same time, the fishing pressure on the older age classes should be reduced. To achieve this goal, I recommend closing the areas where older age classes of Lane Snapper spend most time and protect these areas from gill net fisheries. This can be a part of the marine protected area (MPA). In addition, the overall fishing effort should be decreased by reducing the number of gill nets the fishers can use in each fishing trip.

In general, when the method proposed by Froese (2004) is used, the results should be interpreted with caution. Without consideration of the selectivity of fishing gear, the indicators may be overestimated or underestimated. However, I also understand that the simplicity of the method, which is the major advantage of it, is undermined by including an additional step in calculating the indicators taking selectivity into consideration. Furthermore, there may not be adequate data to correct for gear selectivity. However, as my results suggest, it is very important to correct for this selectivity. When it is necessary to use the indicators estimated without correcting for gear selectivity, it is important to know that indicators are overestimated when fishing gear selects smaller fish and underestimated when gear selects larger fish. Then, the management decision should be adjusted accordingly. It may be necessary to take a precautionary approach when the fishing gear is highly selective to certain sizes to protect a stock. Overall, the length metric method proposed by Froese (2004) might seem promising for small-scale fisheries because the data that is needed can be easily obtained and it provides useful information about the stock.

3.5. Acknowledgements

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4. CONCLUSIONS

The research for this thesis was done to fill knowledge gaps in the assessment and management of small-scale fisheries. I used data from small-scale fisheries in Honduras as a case study. The results presented in chapters 2 and 3 provide information to deal with some of the uncertainty surrounding small-scale fisheries.

In chapter 2, I demonstrated the effects of the size selectivity of gill nets on catch data. Then, I demonstrated how the total mortality estimation is affected by the gear selectivity. Without correcting for the selectivity, the overestimation of total mortality (Z) resulted regardless of the mesh size of the gill nets used or the methods used. This is important to understand because if it is not taken into consideration when making management recommendations or policies, there might be a higher impact on the stock in the future. I also compared the results with other methods to estimate the total mortality. My results suggested the Heincke method should be avoided because it tends to underestimate the total mortality estimations, and this might lead to erroneous management decisions. Finally, I estimated natural mortality (M) using the Lorenzen estimator, the Sekharan estimator, and the FishLife R package. I suggest the Peterson and Wroblewski estimator be avoided because it grossly underestimated the natural mortality. When managing these fisheries, it is important to try a range of natural mortality estimations to account for uncertainties.

The study presented in Chapter 3 assessed the length metric method proposed by Froese (2004) when it is applied to a small-scale fishery using the data from Honduras as a case study. It demonstrated that the selectivity of the fishing gear (in this case gill nets) needs to be taken into consideration. Without correcting for the selectivity, with a fishing gear that targets large fish, the indicators estimations are higher; on the other hand, when using a fishing gear that targets smaller fish, the indicators estimations are lower. Understanding these biases is very important for managers in charge of making management decisions. Thus, if this method is to be used for the assessment of small-scale fisheries it is important to correct for the size-selectivity of fishing gear. If this is not possible the interpretation of these indicators should be done cautiously.

Overall both chapters also provided important information about the status of Lane Snapper (*Lutjanus synagris*) in Honduras. This fishery is experiencing high fishing mortality (F) indicating overfishing. Also, the different indicators suggest the fishery is currently experiencing both recruitment overfishing and growth overfishing.

Small-scale fisheries, such as the one in Honduras, are very important for millions of people around the world, but a large part of them remain unassessed. This thesis provided approaches that could potentially be used to try and solve these issues.

4.1 References

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APPENDIX A

Method used for estimating M	Lorenzen average weight	Lorenzen median weight	Lorenzen midpoint weight age 8 years	Peterson & Wroblewski average weight	Peterson & Wroblewski median weight	Peterson & Wroblewski midpoint weight age 8 years	Sekharan T=8	Sekharan T=10	FishLife
Method used for estimating Z									
Without selectivity Threshold A mesh size 2	1.34	1.33	1.62	1.62	1.36	1.48	1.53	1.50	1.70
With selectivity Normal distribution Threshold A mesh size 2	-0.59	-0.60	-0.31	-0.32	-0.57	-0.45	-0.41	-0.43	-0.23
With selectivity Lognormal distribution Threshold A mesh size 2	0.30	0.29	0.59	0.58	0.33	0.44	0.49	0.47	0.66
With selectivity Skewed normal distribution Threshold A mesh size 2	0.34	0.33	0.63	0.62	0.37	0.48	0.53	0.51	0.70
Without selectivity Threshold B mesh size 2	1.45	1.44	1.73	1.73	1.48	1.59	1.64	1.61	1.81
With selectivity Normal distribution Threshold B mesh size 2	-1.17	-1.18	-0.89	-0.90	-1.15	-1.03	-0.99	-1.01	-0.81
With selectivity Lognormal distribution Threshold B mesh size 2	0.15	0.14	0.43	0.43	0.18	0.29	0.34	0.31	0.51
With selectivity Skewed normal distribution Threshold B mesh size 2	0.19	0.18	0.48	0.47	0.22	0.33	0.38	0.36	0.55
Without selectivity Threshold A mesh size 3	1.42	1.41	1.70	1.70	1.44	1.56	1.61	1.58	1.78
With selectivity Normal distribution Threshold A mesh size 3	1.16	1.15	1.45	1.44	1.19	1.30	1.35	1.33	1.52
With selectivity Lognormal distribution Threshold A mesh size 3	1.22	1.21	1.50	1.50	1.24	1.36	1.40	1.38	1.58
With selectivity Skewed normal distribution Threshold A mesh size 3	1.21	1.20	1.50	1.49	1.24	1.36	1.40	1.38	1.57
Without selectivity Threshold B mesh size 3	1.03	1.02	1.31	1.31	1.05	1.17	1.22	1.19	1.39
With selectivity Normal distribution Threshold B mesh size 3	1.37	1.36	1.65	1.65	1.39	1.51	1.55	1.53	1.73
With selectivity Lognormal distribution Threshold B mesh size 3	1.34	1.33	1.62	1.62	1.36	1.48	1.52	1.50	1.70
With selectivity Skewed normal distribution Threshold B mesh size 3	1.34	1.33	1.62	1.62	1.36	1.48	1.53	1.50	1.70
Without selectivity Threshold A mesh sizes combined	1.20	1.19	1.48	1.48	1.22	1.34	1.39	1.36	1.56
With selectivity Normal distribution Threshold A mesh sizes combined	0.74	0.73	1.02	1.02	0.76	0.88	0.92	0.90	1.10
With selectivity Lognormal distribution Threshold A mesh sizes combined	1.04	1.03	1.33	1.32	1.07	1.18	1.23	1.20	1.40
With selectivity Skewed normal distribution Threshold A mesh sizes combined	0.29	0.28	0.57	0.56	0.31	0.43	0.47	0.45	0.64
Without selectivity Threshold B mesh sizes combined	1.47	1.46	1.76	1.75	1.50	1.61	1.66	1.64	1.83
With selectivity Normal distribution Threshold B mesh sizes combined	1.07	1.06	1.35	1.35	1.09	1.21	1.26	1.23	1.43

With selectivity Lognormal distribution Threshold B mesh sizes combined	1.25	1.24	1.54	1.53	1.28	1.39	1.44	1.42	1.61
With selectivity Skewed normal distribution Threshold B mesh sizes combined	0.17	0.16	0.45	0.45	0.19	0.31	0.36	0.33	0.53
Heincke method mesh size 2	-0.60	-0.61	-0.31	-0.32	-0.57	-0.46	-0.41	-0.43	-0.24
Heincke method mesh size 3	-0.59	-0.60	-0.31	-0.31	-0.57	-0.45	-0.41	-0.43	-0.23
Chapman and Robson mesh size 2	0.24	0.23	0.52	0.52	0.27	0.38	0.43	0.40	0.60
Chapman and Robson mesh size 3	0.31	0.30	0.59	0.59	0.34	0.45	0.50	0.47	0.67