SEDAR

Southeast Data, Assessment, and Review

SEDAR 30

U.S. Caribbean Blue Tang

SECTION II: Assessment Process Report

January 2013

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

This information is distributed solely for the purpose of peer review. It does not represent and should not be construed to represent any agency determination or policy.

NOT PEER REVIEWED

Table of Contents

1. WORKSHOP PROCEEDINGS 4
1.1. INTRODUCTION 4
1.1.1 Workshop time and Place 4
1.1.2 Terms of Reference 4
1.1.3. List of Participants 6
1.1.4. List of Assessment Process Working and Reference Papers 6
1.2. PANEL RECOMMENDATIONS AND COMMENT 7
1.2.1. Term of Reference 1 7
1.2.2. Term of Reference 2 7
1.2.3. Term of Reference 3 8
1.2.4. Term of Reference 4 8
1.2.5. Term of Reference 5 8
1.2.6. Term of Reference 6 8
1.2.7. Term of Reference 7 9
1.2.8. Term of Reference 8 9
1.2.9. Term of Reference 9 9
1.2.10. Term of Reference 10 9
2. DATA REVIEW 10
2.1. Commercial landings 10
2.2. Recreational data 11
2.3. Life history 12
2.4. Length-frequency data 12
3. Length-Based Mortality Estimator Methods 13
3.1. Overview 13
3.2. Data sources 13
3.3. Model configuration and equations 13
3.4. Estimated parameters 15
3.5. Uncertainty and measures of precision 15
4. Model Results 15
4.1. Puerto Rico 15

NOT PEER REVIEWED

4.2. St. Thomas and St. John 16
4.3. St. Croix 18
5. Discussion 19
5.1. St. Thomas/St. John 20
5.2. St. Croix 20
6. General conclusions 21
7. References 22
8. Tables 23
9. Figures 45

NOT PEER REVIEWED

1. WORKSHOP PROCEEDINGS

1.1. INTRODUCTION

1.1.1 Workshop time and Place

The SEDAR 30 Assessment Workshop was held October 16-18, 2012 in Miami, Florida.

1.1.2 Terms of Reference

1. Review any changes in data following the data scoping and any analyses suggested by the data scoping. Summarize data as used in each assessment model.
2. Develop population assessment models that are compatible with available data and document input data, model assumptions and configuration, and equations for each model considered.
3. Provide estimates of stock population parameters, if feasible
   - When available, include fishing mortality, abundance, biomass, selectivity, stock-recruitment relationship, and other parameters as necessary to describe the population
   - Include appropriate and representative measures of precision for parameter estimates.
4. Characterize uncertainty in the assessment and estimated values.
   - Consider uncertainty in input data, modeling approach, and model configuration.
   - Consider other sources as appropriate for this assessment
   - Provide appropriate measures of model performance, reliability, and 'goodness of fit'
   - Provide measures of uncertainty for estimated parameters
5. Provide evaluations of yield and productivity
   - Include yield-per-recruit, spawner-per-recruit, and stock-recruitment models
6. Provide estimates of population benchmarks or management criteria consistent with the available data, applicable FMPs, proposed FMPs and Amendments, other ongoing or proposed management programs, and National Standards.
   - Evaluating existing or proposed management criteria as specified in the management summary
   - Recommend proxy values when necessary
7. Provide declarations of stock status relative to benchmarks or alternative data-poor approaches if necessary.
8. Perform a probabilistic analysis of proposed reference points, stock status, and yield.
   - Provide the probability of overfishing at various harvest or exploitation levels
   - Provide a probability density function for biological reference point estimates.
   - If the stock is overfished, provide the probability of rebuilding within mandated time periods as described in the management summary or applicable federal regulations.

NOT PEER REVIEWED

9. Project future stock conditions (biomass, abundance, and exploitation) and develop rebuilding schedules if warranted; include estimated generation time. Stock projections shall be developed in accordance with the following:

   A) If stock is overfished:
   F=0, F=current, F=Fmsy, Ftarget (OY),
   F=Frebuild (max that rebuild in allowed time)

   B) If stock is overfishing
   F=Fcurrent, F=Fmsy, F= Ftarget (OY)

   C) If stock is neither overfished nor overfishing
   F=Fcurrent, F=Fmsy, F=Ftarget (OY)

   D) If data-limitations preclude classic projections (i.e. A, B, C above), explore alternate models to provide management advice.

10. Provide recommendations for future research and data collection.
    - Be as specific as practicable in describing sampling design and sampling intensity
    - Emphasize items which will improve future assessment capabilities and reliability
    - Consider data, monitoring, and assessment needs
11. Complete the Assessment Workshop Report for Review (Section III of the SEDAR Stock Assessment Report).

NOT PEER REVIEWED

1.1.3. List of Participants

Assessment Workshop Panel

Adyan Rios.....NMFS SEFSC Miami
Daniel Matos..... PR DNER
Francisco Pagãn ..... Caribbean Coral Reef Institute
Kevin McCarthy.....NMFS/SEFSC/Miami
Meaghan Bryan..... NMFS/SEFSC
Nancie Cummings.....NMFS/SEFSC/Miami
Richard Appeldoorn..... SSC Representative/University of Puerto Rico

Council Representation

Carlos Farchette .....CFMC

Appointed Observers

Carlos Velazquez ..... Industry Representative/Puerto Rico
Daryl Bryan.....Industry Representative/St. Thomas
Gerson Martinez.....Industry Representative/St. Croix
Gregory Ledee .....Industry Representative/St. Thomas

Attendees

Shannon Cass-Calay .....NMFS/SEFSC/Miami
Clay Porch.....NMFS/SEFSC/Miami

Staff

Andrea Grabman.....SEDAR
Bill Arnold .....SERO
Graciela García-Moliner ..... CFMC Staff
Julia Byrd.....SEDAR
Julie A. Neer .....SEDAR
Michael Larkin.....SERO

1.1.4. List of Assessment Process Working and Reference Papers

Document #	Title	Authors
Documents Prepared for the Assessment Workshop		
SEDAR30-AW-01	Summary of recreational catch and effort for blue tang and queen triggerfish caught in Puerto Rico since 2000	Meaghan Bryan
SEDAR30-AW-02	Evaluation of the available length-frequency information in the US Caribbean Trip	Meaghan Bryan

NOT PEER REVIEWED

	Interview Program (TIP) data	
SEDAR30-AW-03	A review of the life history characteristics of blue tang and queen triggerfish	Adyan B. Rios
SEDAR30-AW-04	Commercial fishery landings of queen triggerfish and blue tang in the United States Caribbean, 1983-2011	Kevin J. McCarthy
Reference Documents		
SEDAR30-RD01	A pilot program to assess methods of collecting bycatch, discard, and biological data in the commercial fisheries of St. Thomas, U.S. Caribbean	MRAG Americas
SEDAR30-RD02	A pilot program to assess methods of collecting bycatch, discard, and biological data in the commercial fisheries of U.S. Caribbean (Saint Croix)	MRAG Americas

NOT PEER REVIEWED

1.2. PANEL RECOMMENDATIONS AND COMMENT

1.2.1. Term of Reference 1

Review any changes in data following the data scoping and any analyses suggested by the data scoping. Summarize data as used in each assessment model.

Commercial landings were presented for Puerto Rico, St. Thomas/St. John, and St. Croix. The recreational intercept data and the length-frequency data from the Trip Interview Program (TIP) were also reviewed. Basic data inputs for this assessment, such as length-frequency data by island and gear, and life history information from published literature, were reviewed in detail.

1.2.2. Term of Reference 2

Develop population assessment models that are compatible with available data and document input data, model assumptions and configuration, and equations for each model considered.

The AW panel recognized that the length-frequency data from TIP were the most consistent species-specific data available for blue tang. As such, the length based total mortality estimator (Gedamke and Hoenig 2006) was applied to the available length data. This approach was only applied to the St. Thomas/ St. John and St. Croix pot and trap fisheries data. The approach was not applied to the data from Puerto Rico due to very limited sample size.

1.2.3. Term of Reference 3

Provide estimates of stock population parameters, if feasible

- *When available, include fishing mortality, abundance, biomass, selectivity, stock-recruitment relationship, and other parameters as necessary to describe the population*
- *Include appropriate and representative measures of precision for parameter estimates.*

Fishing mortality estimates were derived from total mortality estimates from the Gedamke-Hoenig length-based mortality estimator and natural mortality estimates from several published equations. The AW panel expressed concerns regarding the life history parameters, their influence on the model results, and whether the estimates were meaningful. Sensitivity analyses were conducted to illustrate the influence of the input parameters on the estimates of fishing mortality and the potential uncertainty in the fishing mortality estimates.

1.2.4. Term of Reference 4

Characterize uncertainty in the assessment and estimated values.

- *Consider uncertainty in input data, modeling approach, and model configuration.*
- *Consider other sources as appropriate for this assessment*
- *Provide appropriate measures of model performance, reliability, and 'goodness of fit'*
- *Provide measures of uncertainty for estimated parameters*

Since considerable uncertainty exists in the absolute estimates of total mortality from the mean length analysis, a comprehensive sensitivity analysis was conducted.

1.2.5. Term of Reference 5

Provide evaluations of yield and productivity

- *Include yield-per-recruit, spawner-per-recruit, and stock-recruitment models*

Due to limited data and concerns regarding life history parameters, the AW panel did not recommend calculations of yield-per-recruit, spawner-per-recruit, and stock-recruitment estimations. The data limitations are discussed throughout the model results and discussion sections.

1.2.6. Term of Reference 6

Provide estimates of population benchmarks or management criteria consistent with the available data, applicable FMPs, proposed FMPs and Amendments, other ongoing or proposed management programs, and National Standards.

- *Evaluating existing or proposed management criteria as specified in the management summary*
- *Recommend proxy values when necessary*

NOT PEER REVIEWED

Derived fishing mortality estimates are discussed with regard to natural mortality, which can be used as a proxy for F_{MSY}. However, due to data limitations, concerns regarding the life history parameters and the resulting uncertainty in the model results, the AW panel concluded that useful population benchmarks could not be developed during this assessment.

1.2.7. Term of Reference 7

Provide declarations of stock status relative to benchmarks or alternative data-poor approaches if necessary.

The AW Panel concluded that this was not applicable to this assessment given the data limitations.

1.2.8. Term of Reference 8

Perform a probabilistic analysis of proposed reference points, stock status, and yield.

- *Provide the probability of overfishing at various harvest or exploitation levels*
- *Provide a probability density function for biological reference point estimates.*
- *If the stock is overfished, provide the probability of rebuilding within mandated time periods as described in the management summary or applicable federal regulations.*

The AW Panel concluded that a probabilistic analysis of proposed reference points was not possible given data limitations.

1.2.9. Term of Reference 9

Project future stock conditions (biomass, abundance, and exploitation) and develop rebuilding schedules if warranted; include estimated generation time. Stock projections shall be developed in accordance with the following:

A) If stock is overfished:
F=0, F=current, F=Fmsy, Ftarget (OY),
F=Frebuild (max that rebuild in allowed time)

B) If stock is overfishing
F=Fcurrent, F=Fmsy, F= Ftarget (OY)

C) If stock is neither overfished nor overfishing
F=Fcurrent, F=Fmsy, F=Ftarget (OY)

D) If data-limitations preclude classic projections (i.e. A, B, C above), explore alternate models to provide management advice.

Due to the limited data available, a data poor methodology was attempted that does not include projections of stock dynamics. Therefore, projections were not conducted for this analysis. Furthermore, the AW panel acknowledged that projections were not appropriate for the blue tang stocks due to incomplete data and concerns about life history parameters.

1.2.10. Term of Reference 10

NOT PEER REVIEWED

Provide recommendations for future research and data collection.

- *Be as specific as practicable in describing sampling design and sampling intensity*
- *Emphasize items which will improve future assessment capabilities and reliability*
- *Consider data, monitoring, and assessment needs*

The ability to utilize length-frequency data is contingent upon having reliable estimates of life history parameters (von Bertalanffy parameters in particular). Studies on basic life history (e.g. age-growth relationships and estimating natural mortality) in the US Caribbean will greatly enhance the utility of the existing length-frequency data and should provide the greatest benefit to providing management advice in the short term. Studies should be carefully planned to ensure a representative sample of individuals by age/size, region, season etc. This type of research should be placed as a top priority for key species.

Blue tang are a seemingly fast growing fish species with a long life-span. Beyond the age of five, length information is not informative about the age-structure of blue tang populations. A better understanding about how fishing mortality influences population structure will come from collection of catch-at-age data. Sampling efforts should be carefully planned to ensure representative sampling of individuals by fishing gear, mode, region, season etc.

Fishery-independent surveys should be considered as a top research priority for additional data collection. Fishery-independent surveys designed using a rigorous statistical framework will allow for the collection of species-specific catch and effort data that can be used to develop indices of abundance. Indices of abundance are used in stock assessments to inform models about how a population may be changing over time. Fishery-independent surveys can also be used to supplement existing programs by collecting age, length, weight, and reproductive data.

It is essential that continued efforts to improve the data collection of fishery-dependent catch and effort statistics be made. More specifically, continued efforts to collect species-specific catch statistics will be important for future assessments.

NOT PEER REVIEWED

2. DATA REVIEW

2.1. Commercial landings

A detailed description of the methods and results of the commercial landings calculations can be found in working paper SEDAR30-AW-04.

Puerto Rico

Commercial fishery landings data for Puerto Rico were available from self-reported fisher logbooks/sales receipts for the years 1983-2011. Data were reported by species, fishing gear, and fishing center where the catch was landed. Puerto Rico commercial landings have been incompletely reported (Caribbean Fisheries Data Evaluation Final Report, 2009) and required expansion factors to estimate total landings. For the years 2003 to 2011, expansion factors have been coast-specific (north, south, east, and west). Estimation of commercial fishery landings of earlier years used a single, island-wide, expansion factor.

Puerto Rico landings were estimated as: year-specific reported landings * year-specific expansion factor. Estimation of landings for the most recent years (2003-2011) included year and coast-specific expansion factors. Reported landings were assigned to coast based upon the fishing center reported for a trip. Blue tang landings from Puerto Rico had been reported within the species group surgeonfishes; but not by species. The proportion of blue tang within the surgeonfishes species group is unknown. Yearly total expanded surgeonfish landings for Puerto Rico are provided in Table 1 and Figure 1. The numbers of trips with reported surgeonfishes landings are plotted in Figure 2 (by coast) and Figure 3 (by gear).

St. Thomas and St. John

In the US Virgin Islands logbook landings data from the islands of St. Thomas and St. John were compiled separately from St. Croix. Logbook reporting began in 1974; however, landings were initially reported by gear type (e.g., net fish, hook fish, pot fish, and spear fish) and as either snapper/grouper or as other fin fish during the period 1974-1995. Beginning in 1997 in St. Thomas/St. John, some landings data were reported by species group; (e.g., snappers, groupers, parrotfishes, surgeonfishes, etc.) and by gear (hook and line, gill net, SCUBA, trap, etc.). All commercial fishery data reports began including species group in 2000. Species-specific data were reported in the US Virgin Islands during the 2011-2012 fishing year.

The data available for calculating commercial landings of blue tang were the self-reported logbook records from commercial fishers. Landings could only be provided as surgeonfishes (all species combined) due to the lack of species-specific reporting by commercial fishers. Yearly landings data, as reported, were summed by species group and fishing gear and are provided in Table 2 and Figure 4. The numbers of commercial fishing trips with landings of surgeonfishes in St. Thomas and St. John are shown in Figure 5 by gear and year. The landings and number of trips decline in 2011 and are a little more than half those in 2010. This drop in blue tang landings and trips in 2011 may be due to changes in reporting with the commencement of reporting forms. Changes in reporting should be more fully investigated in the future.

St. Croix

The section above (St. Thomas and St. John) contains a brief description of the available landings data which also pertains to St. Croix. Landings could only be provided for surgeonfishes (all species combined) due to the lack of species-specific reporting by commercial fishers. In St. Croix, landings data were available for the years 1998-2011. Yearly landings data, as reported, are provided in Table 3 and Figure 6 (by gear and year). The numbers of commercial fishing trips with landings of surgeonfishes in St. Croix are shown in Figure 7 by gear and year.

2.2. Recreational data

A detailed summary of the available recreational fishery data collected by the Marine Recreational Fisheries Statistics Survey (MRFSS) can be found in working paper SEDAR30-AW-01. During the assessment workshop (AW) the recreational data from MRFSS were evaluated to determine 1) whether the intercept data could be used to develop a relative index of abundance for blue tang and 2) whether the length data was sufficient to use for length-based analyses. In the US Caribbean, MRFSS only collects data in Puerto Rico. Tables 4 and 5 show

NOT PEER REVIEWED

that the number of intercepted trips that caught blue tang was small and the number of length measurements was negligible. The AW panel determined that at the current time, these data are not useful for the assessment of blue tang given the paucity of intercepted recreational fishing trips catching this species.

2.3. Life history

A detailed summary of the life history of blue tang can be found in working paper SEDAR-AW-03. Table 6 summarizes the defined age-length relationships found in the literature. Two studies, Choat and Robertson (2002) and Mutz (2006) provided estimates of the von Bertalanffy growth parameters from various locations in the Caribbean for blue tang. Figure 8 illustrates the von Bertalanffy growth curves derived from the parameters summarized in Table 6. The differences among the von Bertalanffy growth coefficients cause the curves to approach the asymptotic lengths at different rates, but in general the asymptotic length is reached by age five (Figure 8). Beyond the age of five, length is not informative about blue tang age.

Table 9 illustrates the relationship between the von Bertalanffy growth coefficient and the asymptotic length for blue tang. These parameters are generally negatively correlated, which seems true for many of the parameter pairs obtained from the literature (Figure 9). The estimates of the von Bertalanffy growth coefficient and the asymptotic length for Los Roques (Mutz, 2006) are exceptions (Figure 9). The estimated growth coefficients also separated into two groups, K~0.4 and between K~ 0.82 and 1, which describe considerably different growth rates (Figure 9). Given the uncertainty in the growth parameters, a sensitivity analysis was carried out to evaluate the full range of available estimates for these parameters.

2.4. Length-frequency data

Working paper SEDAR30-AW-02 provides a detailed description of the available length-frequency data from the NMFS Trip Interview Program (TIP). A summary of the annual blue tang length measurements can be found in Appendix A in SEDAR30-AW-02.

Table 7 provides a general summary of the total number of blue tang lengths measured, the number of years in which blue tang were measured, and the average number of measured lengths per year. The total number of blue tang length measurements from Puerto Rico was small compared to St. Thomas/St. John or St. Croix. The greatest number of blue tang length measurements were associated with the pot and trap fisheries in St. Thomas/St. John and St. Croix (Table 7). The AW panel agreed that the data available from the pot and trap fisheries in St. Thomas/St. John and St. Croix had sufficient annual sample sizes for length-based analyses. Concerns were raised about the relationship between the observed lengths and the published age-length information. This will be discussed in more detail during the discussion of the model results. In this section, the length frequency data for the pot and trap fisheries in St. Thomas/St. John and St. Croix will be summarized.

Figure 10 shows the annual length-frequency data for blue tang from the St. Thomas/St. John pot and trap fishery available in the TIP database. Annual sample size varied throughout the time-series with an overall size range between 5cm and 40cm. Early in the time-series, especially in 1986, the right tail of the distribution was a prominent feature with many lengths greater than 25cm (Figure 10). The range of the length-frequency distributions varied over time,

NOT PEER REVIEWED

as did the mode of the respective distributions (Figure 10, Table 8). Although blue tang lengths greater than or equal to 25cm were observed later in the time-series, they were not consistent observations (Figure 10). The mode of each annual length-frequency distribution was identified to determine the length at which blue tang were fully vulnerable to fishing. The range of the annual mode estimates varied considerably and between 15cm and 21cm (Table 8).

Figure 11 shows the annual length-frequency data from the St. Croix pot and trap fishery available in the TIP database. Annual sample size varied throughout the time-series with an overall size range between 10cm and 40cm. The length-frequency distributions were stable over time and the annual modes were also stable (Figure 11, Table 9). The range of the annual mode estimates was between 17cm and 19cm (Table 9).

3. Length-Based Mortality Estimator Methods

3.1. Overview

A review of the length frequency data available from the NMFS TIP database indicated that sample sizes were sufficient to conduct a time-series length analysis for a limited number of island and gear combinations (Table 7). Total mortality (Z) estimates and the ability to detect changes in mortality were explored using a variant of the Beverton-Holt length-based mortality estimator (Beverton and Holt 1956, 1957).

3.2. Data sources

The AW panel reviewed the only available source of information regarding length composition, the TIP database, and recommended that these data be used for the analysis. The input values for other parameters populating the model were gathered from the available literature. Preliminary analyses were performed using the values summarized in Table 10. The input values for the von Bertalanffy growth parameters were gathered from Mutz (2006) and represent the age-length relationships for three areas found in the Caribbean. The SEDAR 30 AW panel noted considerable uncertainty about the existing values of von Bertalanffy growth parameters in relation to available lengths data from TIP. This will be discussed along with the model results in a later section of this report.

3.3. Model configuration and equations

The Beverton-Holt mortality estimator has received widespread use, especially in data-limited situations, owing mainly to the minimal parameter inputs, namely the von Bertalanffy growth parameters K and L_∞, the length of first capture (smallest size at which animals are fully vulnerable to the fishery and to the sampling gear), L_c, and the mean length of the animals ($\bar{L}$) above the length L_c:

$$Z = \frac{K(L_\infty - \bar{L})}{\bar{L} - L_c}$$

There are six assumptions behind this method:

1. Asymptotic growth with known parameters K and L_∞ which are constant over time.

NOT PEER REVIEWED

2. No individual variability in growth.

3. Constant and continuous recruitment over time.

4. Mortality rate is constant with age for all ages $t > t_c$, where t_c is the age at first capture.

5. Mortality rate is constant over time.

6. Population is in equilibrium (i.e., enough time has passed following any change in mortality that mean length now reflects the new mortality level).

A criticism of this method is that the assumption of equilibrium (6) is very difficult to meet in the real world situations where any change in fishing pressure disrupts the equilibrium age distribution. For example, with increased fishing pressure, there is a delay before larger/older animals are removed from the population and before the mean length decreases in accordance with the current mortality rate. Likewise, when fishing pressure is decreased, equilibrium can only be reestablished once the smaller/younger animals have grown, and the mean length increases in accordance with the reduced mortality rate.

Gedamke and Hoenig (2006) developed an extension of the Beverton-Holt length-based mortality estimator for use in non-equilibrium situations. This method is quantitatively attractive because it requires minimal and commonly available data, and it does not require the assumption that catch rate is proportional to abundance. The method also allows for a broader application of the mean length approach as it does not require an assumption of equilibrium, which is not often met in real world situations. In addition, the transitional form of the model allows mortality estimates to be made within a few years of a change, rather than having to wait for the mean lengths to stabilize at their new equilibrium level. In other words, as soon as a decline in mean lengths is detected, this model can be applied and the trajectory of decline can be used to estimate the new Z and how mean lengths will change over time.

The method is described in detail in Gedamke and Hoenig (2006) and is summarized below. Like the Beverton and Holt estimator, this extension only requires a series of mean length above a user defined minimum size and von Bertalanffy growth parameters. Therefore, it can be applied in many data poor situations. Gedamke and Hoenig (2006) demonstrated the utility of this approach using both simulated data and an application to data for goosefish caught in the NEFSC fall groundfish survey.

The mean length in a population can be calculated d years after a single permanent change in total mortality from Z_1 to Z_2 yr^{-1} by the following equation:

$$\bar{L} = L_\infty - \frac{Z_1 Z_2 (L_\infty - L_c)\{Z_1 + K + (Z_2 - Z_1)\exp(-(Z_2 + K)d)\}}{(Z_1 + K)(Z_2 + K)(Z_1 + (Z_2 - Z_1)\exp(-Z_2 d))}$$

This equation has been generalized to allow for multiple changes in mortality rate over time (e.g. one change, two changes, three changes etc.). The algorithm was programmed in AD Model Builder in a maximum likelihood framework and used to estimate mortality rates from the

NOT PEER REVIEWED

observed mean lengths. A shell program was written in R to conduct a grid search of potential year(s) of change and also to conduct a sensitivity analysis to input parameters.

Models were run starting with the simplest (i.e. no change in mortality) and then with increasing complexity by sequentially adding the number of change years (Note: each year of change adds two parameters). The Akaike Information Criterion with a correction for small sample size (AIC_c) was calculated for each scenario and will be referred to simply as AIC throughout the remainder of this document. To compare models, the change in AIC (ΔAIC, the difference between AIC and the minimum AIC) was also calculated. When comparing models, a ΔAIC value less that 2 indicated strong support for the model and a ΔAIC value between 3 and 5 indicated moderate support for the model (Burnham and Anderson, 2002).

The first step in the application of this mean-length approach is to determine the length at which animals become fully vulnerable to the gear, L_c. Annual length-frequency plots were constructed for island gear combinations for which sufficient sample sizes were available. L_c was selected visually (Thorson and Prager, 2011) and estimates of central tendency were also calculated to inform the selection. The highest L_c value over the time series was chosen as the input for preliminary runs and the central value from which to develop a sensitivity range. Using the highest L_c value avoids violating model assumptions and the confounding of selectivity and mortality in the calculation of annual mean lengths. The three values of L_c that were identified from the St. Thomas/St. John pot and trap fishery were 19cm, 20cm, and 21cm for use in the preliminary analyses (Table 10, Figure 10). The three values of L_c that were identified from the St. Croix pot and trap fishery for use in the preliminary analyses were 18cm, 19cm, and 20cm (Table 10, Figure 11). The lower value was chosen to avoid confounding between changes in selectivity and total mortality.

3.4. Estimated parameters

The parameters estimated by the non-equilibrium length method, as described above, are the total mortality rates (Z) and the year(s) of change. The total mortality in the most recent time periods is referred to $Z_{current}$ for the remainder of the document.

3.5. Uncertainty and measures of precision

Considerable uncertainty in the von Bertalanffy growth parameters was acknowledged by the SEDAR 26 AW panel. As such, a comprehensive sensitivity analysis was conducted to determine the impact this uncertainty on estimates of total mortality.

The range of the von Bertalanffy growth parameter (K) explored was 0.39-1.03 in increments of 0.1. The range of the asymptotic growth parameter (L_∞) explored was 18.8cm – 24 cm. These ranges were developed from the estimates available in the published literature from the Caribbean (Table 6).

4. Model Results

4.1. Puerto Rico

Mean-length analyses were not conducted for the fisheries of Puerto Rico because the available length samples were considered insufficient by the AW panel. Therefore, the available length data from Puerto Rico were not analyzed.

NOT PEER REVIEWED

4.2. St. Thomas and St. John

Preliminary model runs

The AIC results for the preliminary analyses are summarized in Table 11 and Table 12. For illustrative purposes, Table 11 includes parameter combinations that were not biologically plausible. For example, there were some parameter combinations where the L_c was greater than the L_∞, which is the theoretical maximum length of the population. This is a biologically unreasonable assumption and the results from these model runs are not meaningful. In all model runs where L_c was greater than L_∞, the total mortality estimate reached the upper bound that was placed on this parameter. The lower bound imposed on the total mortality parameter was reached when L_c and L_∞ were within one centimeter of one another. Similar L_c and L_∞ values led to mean lengths that were similar to the L_∞ over time. In these situations, the mean length data indicated that the population had experienced minimal mortality over time and the model estimates of total mortality were constrained at zero (Table 11, Table 12).

The model converged for two input parameter combinations that used 0.49 and 23.1cm as the values for K and L_∞, and L_c values equal to 19cm and 20cm (Table 11). The model with the lowest AIC value and also the strongest support from AIC criteria predicted one change in total mortality in either 1983 or 2000 (Table 11, see the results highlighted in gray). The model run using 19cm as the input value for L_c predicted that total mortality increased from 0.09 to 0.4 after 1983, a 300% increase. The year 1983 is the first year for which data were available and there was a subtle decline in the annual mean length after 1983 (Figure 12). There was not sufficient evidence that any other model was strongly supported by AIC criteria (i.e., ΔAIC was not less than 2). The model run using 20cm as the input value for L_c predicted that total mortality increased from 0.05 to 0.42 after 2000, a 740% increase. Figure 13 shows the model fit to the mean length data. After 2000, mean length declines. Prior to 2000, the mean lengths are quite variable as compared to the mean lengths after 2000.

Sensitivity analysis

Models predicting no change or one change in blue tang total mortality were strongly supported by AIC criteria for the majority of sensitivity runs, irrespective of the input parameter values (Table 13, gray highlighted cells). The runs were almost evenly split between the model predicting no change in total mortality and the model predicting one change. The sensitivity runs predicting no change resulted in very low estimates of total mortality, which was due to similar L_c and L_∞ values. An L_c value similar to the asymptotic lengths resulted in mean lengths that were also similar to the L_∞, informing the model that the blue tang population experienced very little mortality. For those sensitivity runs that strongly supported a single year of change in total mortality, the predicted year of change was ambiguous (Table 14). Almost all years were selected for a number of sensitivity runs; however, the highest number of sensitivity runs (14) predicted 2001 as the year of change in blue tang total mortality (Table 14).

Figure 14 shows the absolute estimates of current total mortality and also shows the obvious sensitivity to the input values. The current total mortality estimates for blue tang ranged between ~0 and 1.25 (Figure 14). In general, higher values of the von Bertalanffy growth coefficient and higher values of the asymptotic length led to higher values of total mortality. The only exceptions were for those parameter combinations where the L_c was less than, but within,

NOT PEER REVIEWED

2cm of the L_∞. In these cases, total mortality was estimated to be close to zero, and was associated with those sensitivity runs that did not support a change in total mortality. In this situation the resulting mean length was similar to the asymptotic length, informing the model that mean size remained close the theoretical maximum and the blue tang population has experienced very little mortality.

Table 15 summarizes the percent change in total mortality for the sensitivity runs that resulted in strong support for the model predicting a single change in total mortality. In all cases a decrease in mean length was observed, which caused the model to predict that total mortality had increased. The magnitude of change was greater than 100% in all cases (Table 15). There were several sensitivity runs that resulted in a percent increases that was questionable (e.g., an increase in total mortality that was 10,000 times greater than the previous time period). In all of these cases, the total mortality estimated for the first time period was close to zero.

The highest value of the range examined for the length-at-full vulnerability ($L_{c)}$ is probably unrealistic. It was included because in two years, 2008 and 2009, the mode of the length-frequency histogram was approximately 21cm (Table 8, Figure 10). The sample sizes were fairly low in both years, more realistic length-at-full vulnerability values for the St. Thomas/St. John pot and trap fishery were between 19cm and 20cm. For these values, the corresponding current total mortality estimates ranged between 0.25 and 1.25 over the range of the von Bertalanffy growth parameters.

Fishing mortality was derived from the minimum and maximum total mortality estimates from the sensitivity analysis and compared to estimates of natural mortality. A rule of thumb that is sometimes adopted in data poor situations is that the fishing mortality to achieve maximum sustainable yield (F_{MSY}) is approximately equal to natural mortality. Fishing mortality estimates greater than natural mortality indicate a fishery is experiencing overfishing while fishing mortality estimates less than natural mortality indicate that a fishery is not experiencing overfishing. Our ability to derive appropriate estimates of fishing mortality is also dependent on having a reliable estimate of natural mortality.

Natural mortality estimates derived from several published equations are presented in Table 16. The natural mortality estimates varied greatly among the natural mortality equations with a range of 0.01 to 2.03. The AW panel suggested that the Pauly equation (Pauly 1980) be used since the von Bertalanffy growth coefficient and the asymptotic length are both included in the equation, and may be robust to their negative correlation. The natural mortality estimates from the Pauly equation ranged between 1.01 and 2.03 (Table 16). The corresponding fishing mortality rates were quite small, and in many cases negative, indicating that the current fishing mortality for blue tang in St. Thomas/St. John is low. These fishing mortality estimates were also less than the Pauly natural mortality estimate. Similar estimates of fishing mortality were obtained when using estimators reliant on the von Bertalanffy growth parameter alone or with the asymptotic length (Table 16, see values not highlighted in gray). Age based natural mortality estimators resulted in much lower estimates of natural mortality (Table 16, highlighted in gray). The fishing mortality estimates for blue tang derived from the age-based natural mortality estimates and the lowest total mortality estimate from the sensitivity analysis were generally less than the estimate of natural mortality. The fishing mortality estimates derived from the age-based natural mortality estimates and the highest total mortality estimate from the sensitivity

NOT PEER REVIEWED

analysis were all greater than the corresponding estimates of natural mortality (Table 16, values highlighted in gray).

4.3. St. Croix

Preliminary model runs

The AIC results from the preliminary analyses are summarized in Table 17 and Table 18. Only four parameter combinations resulted in a model that met convergence criteria, these are highlighted in gray in Table 17. AIC criteria strongly supported (i.e., ΔAIC = 1.484 and 1.54) a model that did not predict a change in total mortality for two of the parameter combinations (input values: L_c=18cm, L_∞=19.9cm, and K = 0.39 y^{-1}; L_c=20cm, L_∞=23.1, and K = 0.49 y^{-1}). The corresponding estimates of total mortality were 0.14 and 0.6. Alternatively, AIC criteria also strongly supported the model that predicted one change in total mortality for the two other sets of parameter combinations (input values: L_c=18cm, L_∞=23.1cm, and K = 0.49 y^{-1}; L_c=19cm, L_∞=23.1cm, and K = 0.49 y^{-1}). The corresponding total mortality estimates were 0.69 and 1.42, and 0.5 and 1.15. The predicted year of change for both model runs was 1983.

Figure 15, Figure 16, Figure 17, and Figure 18 illustrate the model fit to the mean length data for the four model runs. In each, the mean length in 1983 is approximately one to two centimeters larger than other mean lengths throughout the time series, however, only two model runs strongly support a single change in total mortality in 1983, where mean length declines and total mortality was predicted to increase after 1983 (Figure 16, Figure 17). The other two model runs indicate that mean length and total mortality did not change over time (Figure 15, 18).

Sensitivity analysis

Overall, a similar number of sensitivity runs strongly supported either the model predicting constant total mortality, the model predicting a single change in total mortality, or the model predicting two changes in total mortality (Table 19). For those sensitivity runs that resulted in strong support for a model that predicted a change in total mortality, the year of change or the first year of change was in 1983 (Table 20). For those sensitivity runs that resulted in strong support for a model predicting more than one change in total mortality, the second year of change was either 1985 or 1999 (Table 21).

Figure 19 illustrates the estimates of current total mortality and shows the sensitivity of the mortality estimates to the input parameters. In general, higher values of the von Bertalanffy growth coefficient and higher values of the asymptotic length led to higher values of total mortality. The only exceptions were for those parameter combinations where the length-at-full vulnerability was less than, but within, 1cm of the asymptotic length. In these cases, total mortality was estimated to be close to zero and was associated with those sensitivity runs that did not support a change in total mortality. In this situation the resulting mean length was similar to the asymptotic length, informing the model that mean size remained close the theoretical maximum and the blue tang population has experienced very little mortality.

The range of the current total mortality estimates from the sensitivity analysis, not including the estimates approximately equal to zero, was between 0.016 and 3.6 (Figure 19). A narrowed range of total mortality estimates between 0.25 and 2 was also developed, considering

NOT PEER REVIEWED

only the published age-length parameters and length-full-vulnerability (i.e. 19 cm) deemed most reliable by the AW panel (Table 9, Figure 11).

Percent change in total mortality was calculated for those sensitivity runs that strongly supported a single change in total mortality (Table 22, Table 23). All sensitivity runs predicted an increase in total mortality when a single change in total mortality was strongly supported (Table 22). The corresponding percent change in total mortality ranged between 100% and 345%. Focusing on the estimates corresponding to the published von Bertalanffy growth parameters, the range of percent change narrows to between 100% and 250% (Table 22). The increase in total mortality was predicted to occur after 1983 for the majority of sensitivity runs (Table 20). The sensitivity runs equally provided strong support for the model predicting two changes in total mortality. Total mortality was predicted to increase after the first change and percent change ranged between 70% and 1000% (Table 23). The majority of sensitivity runs predicted the first change occurred in 1983, similar to the model predicting one change in total mortality (Table 20). Considering only the published von Bertalanffy values, the range of percent change narrowed to an increase of total mortality between 70% and 600% (Table 23). The second change in total mortality was predicted to occur in either 1985 or 1999 and total mortality was predicted to decline (Table 20, Table 23). The percent decline was estimated to be between 31% and 100% (Table 23).

Fishing mortality was derived from the minimum and maximum total mortality estimates from the sensitivity analyses and compared to estimates of natural mortality. A rule of thumb that is sometimes adopted in data poor situations is that the fishing mortality to achieve maximum sustainable yield (F_{MSY}) is approximately equal to natural mortality. Fishing mortality estimates greater than natural mortality suggest a fishery is experiencing overfishing while fishing mortality estimates less than natural mortality indicate that a fishery is not experiencing overfishing. Our ability to derive appropriate estimates of fishing mortality is also dependent on having a reliable estimate of natural mortality.

Natural mortality estimates were derived to calculate fishing mortality estimates from total mortality (Table 24). The natural mortality estimates are the same as those derived for St. Thomas/St. John and will not be described here. The fishing mortality rates were then compared to the natural mortality rates, which were considered proxies for F_{MSY}. The fishing mortality estimates derived from the lowest total mortality estimates of the various sensitivity runs were less than natural mortality for most of the natural mortality estimators, except Alverson and Carney when the von Bertalanffy growth coefficient was approximately greater than or equal to 0.8 (Table 24). The fishing mortality estimates derived from the highest total mortality estimate were greater than natural mortality for all natural mortality estimators, except Pauly, when the von Bertalanffy growth coefficient was approximately equal to 0.4 (Table 24). All fishing mortality estimates derived from the Pauly natural mortality estimator were less than natural mortality (Table 24). These results confirm that our interpretation of fishing mortality status is highly dependent on the life history parameters and the natural mortality estimators.

5. Discussion

Although it is possible to identify overfishing if natural mortality can be considered a proxy for F_{MSY}, and natural mortality is well known, it is not possible to determine stock status relative to biomass based metrics using length-based analytic methods alone. Given the inherent

NOT PEER REVIEWED

data limitations, the AW panel concluded that the length-based approach should be applied to the blue tang length data from the TIP database to ascertain whether mortality has changed over time, to identify the direction of change and the relative magnitude of change, and to derive fishing mortality estimates from total mortality and estimates of natural mortality. The implications of these analyses are discussed below.

5.1. St. Thomas/St. John

The results from the sensitivity analysis using the length data from the St. Thomas/St. John pot and trap fishery indicates a change in total mortality may have occurred. Total mortality was predicted to increase for those sensitivity runs strongly supporting a change in total mortality. The year of change, however, was ambiguous. The magnitude of this proportional increase in total mortality was highly variable and strongly related to the von Bertalanffy growth coefficient, larger growth coefficient led to a greater predicted proportional increase in total mortality.

Natural mortality was used as a proxy for F_{MSY}. In data poor situations, this proxy is used to evaluate whether a fishery is experiencing overfishing. Natural mortality was estimated using a number of published equations that were reliant on either the von Bertalanffy growth parameters or maximum age. The comparisons of fishing mortality and natural mortality indicated that fishing mortality may or may not be greater than natural mortality. The fishing mortality estimates derived from the low estimate of total mortality that was associated with a von Bertalanffy growth coefficient equal to 0.4 was generally less than the natural mortality estimates, irrespective of the natural mortality estimator. The fishing mortality estimates derived from the high estimate of total mortality that was associated with a von Bertalanffy growth coefficient approximately equal to 0.8 were greater than natural mortality when natural mortality was derived from age-based estimators and less than natural mortality when natural mortality was derived from growth parameter-based estimators.

The length-frequency data indicate that since 1983, the length distributions have remained relatively stable. However, in the 1980s and from 2006 to the present, there were more frequent length measurements of blue tang from the St. Thomas/ St. John pot and trap fishery. The number of length measurements between these two time periods was quite small, making it difficult to determine whether the lack of larger blue tang is due to a sampling issue or fishing effects. This points to the need for more comprehensive and consistent sampling by the Trip Interview Program in St. Thomas.

The relative stability of the blue tang length-frequency data indicates that current fishing mortality experienced by blue tang in St. Thomas/St. John may be sustainable. It is difficult to definitively make this conclusion given that length data are not available prior to 1983. It is therefore unknown whether the annual length-frequency data from the St. Thomas/St. John pot and trap fishery observed between 1983 and 2011 reflect a shift in size from relatively unexploited times.

5.2. St. Croix

The results from the analysis of the blue tang length data from the St. Croix pot and trap fishery indicate that an increase in total mortality may have occurred in 1983. This increase in

NOT PEER REVIEWED

total mortality is due to a decrease in mean length after 1983, which remains fairly stable through the rest of the time series.

Fishing mortality was derived from the lower and upper total mortality estimates from the sensitivity analysis and natural mortality, which was estimated using various published equations. Comparisons of fishing mortality relative to natural mortality indicated that fishing mortality may or may not be greater than natural mortality. The fishing mortality estimates derived from the low estimate of total mortality that was associated with a von Bertalanffy growth coefficient equal to 0.4 was generally less than natural mortality, irrespective of the natural mortality estimator.

Examination of the annual length-frequency data for the time period when data were available (1983-2011), the annual length-frequency distributions for St. Croix have remained relatively stable over time. This indicates that the exploitation rates over this time period may be sustainable. It is difficult to definitely conclude that the exploitation rates have been sustainable since length data from years prior to 1983 are not available. It is, therefore, unknown whether this stable size distribution represents a new stable reduction in size or if this size distribution has been stable since fishing for blue tang began in St. Croix.

6. General conclusions

The absolute total mortality estimates, as well as the fishing and natural mortality estimates, from this analysis should be considered with caution. The techniques used are sound; however, the information contained in the available data makes it difficult to interpret the predicted mortality rates. Several published studies that described the von Bertalanffy growth relationship for blue tang and provided estimates of the von Bertalanffy growth parameters were available for this analysis. During the AW, the panel evaluated the published parameter sets and determined that there were two possible explanations for the growth of blue tang. The first was described by slower growth, K ~0.4, and the second was described by faster growth, K~0.8-1. The von Bertalanffy growth coefficient is an important input parameter that influences the estimate of total mortality, as was shown in the sensitivity analyses. It also served as the underpinning of the natural mortality estimates that were used to derive fishing mortality and evaluate the status of the fishery. The disparate estimates of growth led to considerable uncertainty in the mortality estimates. They also made it difficult to meaningfully interpret stock status in terms of fishing mortality, in the absence of a weighting system giving credence to one life-history strategy over another. The AW panel discussed the limitations of the available studies. Both suffered from small sample sizes and the size range from which they sampled was quite small. These concerns point to the need for well-designed growth studies for this species (and many other species in the US Caribbean).

Another cause for concern that weakens confidence in the absolute estimates of mortality, as was discussed by the AW panel, is that the blue tang age-length relationship erodes at a very early age relative to its lifespan. The foundation of length-based analytical tools is that changes in the size structure of the population reflect changes in the age structure of the population. Given that blue tang appear to reach their asymptotic length rather quickly, and larger fish may represent several age groups, the AW panel suggested that a length-based approach may not be appropriate for this species. It is strongly recommended that future data collection efforts focus

NOT PEER REVIEWED

on collecting catch-at-age data that will more adequately describe changes in the population structure of blue tang over time.

7. References

Alverson, D.L., and M.J. Carney. 1975. A graphic review of the growth and decay of population cohorts. *Journal du Conseil international pour l'Exploration de la Mer* 36(2):133–143.

Beverton, R.J.H. and S.J. Holt. 1956. A review of methods for estimating mortality rates in fish populations, with special reference to sources of bias in catch sampling. Rapports et Proces-verbaux des Reunions, Conseil International Pour L'Exploration de la Mer 140:67-83.

Beverton, R.J.H. and S.J. Holt. 1957. On the dynamics of exploited fish populations. U.K. Ministry of Agriculture, Fisheries, Food, and Fishery Investigations Series II, Vol. XIX.

Burnham, K. P., and Anderson, D.R. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach, 2nd ed. Springer-Verlag.

Choat, J.H. and D.R. Robertson. 2002. Age-based studies on coral reef fishes. In: Sale P.F. (ed) Coral reef fishes. Dynamics and diversity in a complex ecosystem. Academic Press, New York.

Gedamke, T. and J.M. Hoenig. 2006. Estimating mortality from mean length data in nonequilibrium situations, with application to the assessment of goosefish. Transactions of the American Fisheries Society 135: 476-487.

Hewitt, D.A., and J.M. Hoenig. 2005. Comparison of two approaches for estimating natural mortality based on longevity. Fishery Bulletin 81(4):898–903.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 81(4):898–903.

Jensen, A.L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Canadian Journal of Fisheries and Aquatic Sciences 53(4):820–822.

Mutz, S.J. 2006. Comparative growth dynamics of Acanthurid fishes. School of Marine Biology and Aquaculture, James Cook University.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *Journal du Conseil international pour l'Exploration de la Mer* 39(2):175–192.

Ralston, S. 1987. Mortality rates of snappers and groupers. Pages 375–404 *In*: J.J. Polovina and S. Ralston (eds.), Tropical Snappers and Groupers: Biology and Fisheries Management. Westview Press, Boulder Colorado. 659 p.

Thorson, J. T., and M. H. Prager. 2011. Better catch curves: Incorporating age-specific natural mortality and logistic selectivity. Transactions of the American Fisheries Society 140: 356–366.

NOT PEER REVIEWED

8. Tables

Table 1. Puerto Rico expanded commercial landings of surgeonfishes, 1983-2011. Note, blue tang have not been reported by species; the species group surgeonfishes includes blue tang and other species. Surgeonfishes landings for certain years may not be presented due to confidentiality constraints. * indicates years in which data are available

Year	Surgeonfishes
1983	
1984	
1985	
1986	
1987	39
1988	
1989	
1990	
1991	471
1992	173
1993	
1994	
1995*	
1996	317
1997	
1998*	
1999*	
2000	
2001	28
2002*	
2003*	
2004	
2005	
2006	
2007	
2008	
2009	
2010	
2011	
Total	**1,106**

NOT PEER REVIEWED

Table 2. St. Thomas and St. John reported commercial landings of surgeonfishes (no expansion factors applied), 2000-2011.

Year	Surgeonfishes
2000	31,215
2001	36,550
2002	41,305
2003	42,121
2004	45,806
2005	40,076
2006	39,040
2007	37,633
2008	37,385
2009	31,718
2010	31,927
2011	16,640
Total	**431,415**

Table 3. St. Croix reported commercial landings of surgeonfishes (no expansion factors applied), 1998-2011.

Year	Surgeonfishes
1998	41,040
1999	34,596
2000	36,992
2001	44,249
2002	54,632
2003	42,039
2004	47,570
2005	48,853
2006	51,062
2007	48,625
2008	38,127
2009	37,274
2010	29,035
2011	31,556
Total	**585,649**

NOT PEER REVIEWED

Table 4. Summary of the MRFSS intercept data for blue tang by year. The summary includes the number of AB1 catch, which refers to the number of observed landed blue tang and blue tang reported as dead, number of B2 catch, which refers to the number of blue tang released alive, the number of trips catching blue tang; total number of intercepted trips catching any recreationally caught species in Puerto Rico, the proportion of trips catching blue tang, and the number of angler hours.

Year	AB1	B2	# of positive trips	Total # of trips	Proportion positive	Angler Hours
2000	0	0	0	737	0	3658
2001	1	1	2	768	0.003	4349
2002	0	0	0	517	0	3098.5
2003	1	0	1	812	0.001	5022
2004	0	0	0	621	0	3643.5
2005	0	0	0	426	0	2329
2006	0	0	0	366	0	2118.5
2007	0	1	1	572	0.002	2953.5
2008	0	0	0	623	0	3393.5
2009	0	1	1	581	0.002	3148.5
2010	0	0	0	588	0	3054.5
2011	0	0	0	774	0	3530.5
Total	2	3	5	7385	0.0006	40299

NOT PEER REVIEWED

Table 5. The number of length measurements in the MRFSS database for blue tang.

Platform	Mode	Gear	Year	Number of observations
PR	Shore	Hook and line	2001	1
			2003	1

Table 6. Life history parameters for blue tang in the western Atlantic including: maximum age and length (FL: fork length; SL: Standard length; TL: total length), and the age-length relationship.

			Length -age $L_t = L_\infty(1-e^{K(t-\ to)})$				
Location	t_{max} (years)	L_{max} (mm)	L_∞	K	t_o	n	Source
San Blas	16	-	183 SL	0.477	-0.310	110	Choat and Robertson (2002)
Belize	15	242 FL	188 FL	1.030	-0.150	92	Mutz (2006)
Los Roques	20	285 FL	199 FL	0.390	-0.112	81	Mutz (2006)
Margarita	20	335 FL	-	-	-	74	Mutz (2006)
San Blas	16	261 FL	231 FL	0.490	-0.251	110	Mutz (2006)
Asencion	37	-	193 FL	0.403	-	-	Choat and Robertson (2002)
Lee Stocking	27	-	174 FL	0.817	-	-	Choat and Robertson (2002)
Asencion	37	304 FL	244 FL	0.420	-0.092	112	Mutz (2006)
Bermuda	43	250 FL	203 FL	1.010	-0.412	105	Mutz (2006)
Lee Stocking	27	256 FL	219 FL	0.880	-0.419	77	Mutz (2006)

NOT PEER REVIEWED

Table 7. Summary of Trip Interview Program (TIP) data for blue tang including: the number of length measurements, the number of years samples, the average number of lengths per year, and the analysis type by island and gear type. TS indicates a length-based time-series analysis was done and ID indicates insufficient data for analysis.

Island	Gear type	Number of lengths	Number of years sampled	Average number of lengths year^{-1}	Analysis
-	Pots & traps	62	1	-	-
Puerto Rico	Hook & line	1	1	1	ID
Puerto Rico	Nets	121	6	20.2	ID
Puerto Rico	Pots & traps	19	6	3.2	ID
St. Thomas/ St John	Hook & line	21	2	10.5	ID
St. Thomas/ St John	Nets	22	3	7.33	ID
St. Thomas/ St John	Pots & traps	2996	21	142.6	TS
St. Croix	Hook & line	90	3	30	ID
St. Croix	Nets	1462	15	97.5	ID
St. Croix	Pots & traps	32220	29	1111	TS

NOT PEER REVIEWED

Table 8. Measures of central tendency and skewness for the blue tang length frequency data from the St. Thomas and St. John pot and trap fishery. Estimates correspond to the annual length frequency plots shown in Figure 10.

Species	Gear	Island	Year	Mean	Median	Mode	Skewness
Blue tang	Pots and traps	St. Thomas and St. John	1983	19.80	16.50	15.75	0.77
			1984	19.40	19.50	17.25	0.69
			1985	21.60	21.00	17.25	0.78
			1986	21.10	21.00	20.25	-0.68
			1987	19.70	19.50	17.25	0.43
			1988	17.23	18.00	18.75	-0.74
			1991	20.45	19.50	18.75	0.75
			1992	18.58	18.00	17.25	1.20
			1993	20.03	19.50	17.25	1.10
			1994	20.02	19.50	18.75	0.79
			1995	19.60	19.50	18.75	0.40
			1996	22.26	21.00	20.25	0.90
			2002	21.84	21.00	18.75	0.96
			2003	22.50	22.50	20.25	0.36
			2004	21.58	21.00	20.25	1.32
			2005	19.47	19.50	18.75	1.56
			2006	18.32	18.00	17.25	0.36
			2008	21.00	21.00	21.75	0.00
			2009	21.55	21.00	21.75	0.53
			2010	21.01	21.00	20.25	1.16

NOT PEER REVIEWED

Table 9. Measures of central tendency and skewness for the blue tang length frequency data from the St. Croix pot and trap fishery. Estimates correspond to the annual length frequency plots shown in Figure 11.

Species	Gear	Island	Year	Mean	Median	Mode	Skewness
Blue tang	Pots and traps	St. Croix	1985	19.13	19.50	17.25	0.94
			1986	19.31	18.00	17.25	1.36
			1987	18.88	18.00	17.25	1.31
			1988	18.84	18.00	17.25	1.42
			1989	18.34	18.00	17.25	0.86
			1990	17.76	18.00	17.25	1.44
			1991	18.38	18.00	17.25	7.37
			1992	18.57	18.00	17.25	1.26
			1993	18.40	18.00	17.25	1.09
			1994	18.44	18.00	17.25	1.36
			1995	18.45	18.00	17.25	1.15
			1996	18.52	18.00	17.25	0.94
			1997	18.31	18.00	17.25	0.60
			1998	18.70	18.00	17.25	1.33
			1999	18.60	18.00	17.25	0.69
			2000	18.63	18.00	17.25	1.59
			2001	19.04	18.00	17.25	0.57
			2002	19.16	19.50	17.25	0.92
			2003	19.50	18.75	17.25	0.63
			2004	20.00	19.50	18.75	0.46
			2005	20.08	19.50	18.75	0.39
			2006	17.40	18.00	17.25	-0.59
			2007	18.88	18.00	17.25	1.04
			2008	19.32	19.50	18.75	1.31
			2009	19.09	19.50	18.75	0.21
			2010	18.94	18.00	17.25	0.76
			2011	19.55	19.50	18.75	1.09

NOT PEER REVIEWED

Table 10. Input parameters used for the analysis of the blue tang length data, L_c: length at full vulnerability, K: von Bertalanffy growth coefficient, and L_∞: asymptotic length used for the preliminary model run. The von Bertalanffy growth parameters were obtained from Mutz (2006).

Species name	Island	Gear type	L_c (cm)	K	L_∞ (cm)
Blue tang	St. Thomas/St. John	Pots and traps	19, 20, 21	1.03	18.8
			19, 20, 21	0.39	19.9
			19, 20, 21	0.49	23.1
Blue tang	St. Croix	Pots and traps	18, 19, 20	1.03	18.8
			18, 19, 20	0.39	19.9
			18, 19, 20	0.49	23.1

Table 11. The results from preliminary length-based analyses that used the blue tang length data from the St. Thomas/St. John pot and trap fishery. The summarized results represent the models with the lowest AIC value for a given set of input parameters. Results highlighted in gray met convergence criteria.

Gear	Island	L_c (FL mm)	Estimates	L_∞ = 18.8 K = 1.03	19.9 0.39	23.1 0.49
Pots and traps	St. Thomas & St. John	19	Nchanges	0	1	1
			Change year	-	1983	1983
			Z	4.99	0.001, 0.00101	0.09, 0.4
		20	Nchanges	0	0	1
			Change year	-	-	2000
			Z	5	4.99	0.05, 0.42
		21	Nchanges	0	0	0
			Change year	-	-	-
			Z	5	5	0.001

NOT PEER REVIEWED

Table 12. The full AIC results from the preliminary analyses using the blue tang length data from the St. Thomas/St. John pot and trap fishery. The rows highlighted in gray have the lowest AIC values. Parameter combinations where L_c was greater than L_∞ were excluded from this summary. Total mortality values that are equal to 0.001 or are greater than or equal to 4.99 indicate the model did not converge and parameter bounds were reached.

L_c	K	L_∞	Npar	Nobs	Nchange	AIC	ΔAIC	LLIKE	*Z*	*Z1*	Change Year1	*Z2*	Change Year2	*Z3*	Change Year3	*Z4*
19	0.39	19.9	2	21	0	118.252	10.371	56.79	4.99	-	-	-	-	-	-	-
			4	21	1	107.881	0	48.69	-	0.001	1983	0.001	-	-	-	-
			6	21	2	115.381	7.5	48.69	-	0.001	1983	0.001	1985	0.001	-	-
			8	21	3	125.381	17.5	48.69	-	0.001	1983	0.001	1985	0.001	1987	0.001
19	0.49	23.1	2	21	0	64.84	4.01	30.08	0.28	-	-	-	-	-	-	-
			4	21	1	60.82	0	25.16	-	0.09	1983	0.40	-	-	-	-
			6	21	2	63.31	2.48	22.65	-	0.09	1986	4.20	1988	0.38	-	-
			8	21	3	67.88	7.05	19.94	-	0.09	1986	4.24	1988	0.14	2001	0.49
20	0.49	23.1	2	20	0	58.00	6.71	26.65	0.14	-	-	-	-	-	-	-
			4	20	1	51.30	0	20.31	-	0.05	2000	0.43	-	-	-	-
			6	20	2	58.58	7.28	20.06	-	0.03	1983	0.12	2001	0.41	-	-
			8	20	3	64.38	13.09	17.65	-	0.00	1985	3.47	1987	0.00	2001	0.43
21	0.49	23.1	2	20	0	59.87	0	27.58	0.001	-	-	-	-	-	-	-
			4	20	1	64.40	4.53	26.87	-	0.001	1996	0.38	-	-	-	-
			6	20	2	71.88	12.01	26.71	-	0.001	2003	2.61	2005	0.001	-	-
			8	20	3	82.51	22.64	26.71	-	0.001	1983	0.001	2003	2.61	2005	0.001

NOT PEER REVIEWED

Table 13. The frequency of sensitivity runs predicting zero, one, or two changes in blue tang total mortality (*Z*). Four length-at-full vulnerability (L_c) values and the length data from the St. Thomas/St. John pot and trap fishery were used as inputs. Results highlighted in gray represent the majority of sensitivity runs.

	Number of changes in total mortality (*Z*)		
L_c	0 change	1 change	2 changes
19	24	13	11
20	8	24	0
20.5	16	16	0
21	16	8	0
Total	64	61	11

NOT PEER REVIEWED

Table 14. The frequency of sensitivity runs predicting one or two changes in blue tang total mortality (*Z*) and the associated predicted first year of change. These results represent all parameter combinations used for the sensitivity analysis. The length data from the St. Thomas/St. John pot and trap fishery were used for this analysis.

	Number of changes in total mortality (*Z*)	
Year of first change	1 change	2 changes
1983	4	0
1984	2	0
1985	7	6
1986	0	5
1992	2	0
1993	3	0
1994	8	0
1995	3	0
1999	2	0
2000	5	0
2001	14	0
2002	8	0
2003	3	0
Total	61	11

NOT PEER REVIEWED

Table 15. The percent change in total mortality for the sensitivity runs strongly supporting the model predicting a single year of change. The data used for these sensitivity runs were the blue tang length data from the St. Thomas/St. John pot and trap fishery.

		K							
L_c	L_∞	0.39	0.49	0.59	0.69	0.79	0.89	0.99	1.03
19	22.5	563.88	650.88						
	23.1	299.24	341.63						268.15
	24	162.34	179.01	150.26	157.81	164.77	170.79	175.76	177.46
20	22.5	36017.10	40008.90	41743.88	43457.56	45175.15	46912.23	51333.27	52073.36
	23.1	861.93	771.24	750.67	688.10	690.10	698.67	709.69	714.20
	24	213.76	206.84	199.99	195.20	191.52	194.19	191.98	191.15
20.5	23.1	36358.30	38413.70	42586.27	44706.05	49340.70	51636.88	53916.90	52492.11
	24	402.45	378.83	366.04	358.23	349.86	346.35	343.28	342.15
21	24	707.04	645.14	627.74	587.63	587.01	589.51	592.69	593.89

NOT PEER REVIEWED

Table 16. Natural and fishing mortality estimates for blue tang caught by the St. Thomas/St. John pot and trap fishery. Input parameters include: asymptotic length (L_∞, FL mm), the von Bertalanffy growth coefficient (*K*), maximum age (*tmax*), the proportion of population at the maximum age (*P*), and temperature (the average for Puerto Rico: www.nodc.noaa.gov/dsdt/cwtg/oatl.html. Footnotes indicate the equation associated with each publication. Fishing mortality estimates (*F= Z-M*) result from two estimates of total mortality from the sensitivity analysis and the natural mortality estimates. Cells highlighted in gray indicate *F* is greater than *M*.

Input parameters					Source of natural mortality equation							
L_∞	*K*	*tmax*	*P*	Temp	Alverson and Carney 1975[1]	Pauly 1980[2]	Hoenig 1983[3] (regression)	Hoenig 1983[4]	Ralston 1987[5]	Jensen 1996[6] (theoretical)	Jensen 1996[7] (derived from Pauly 1980)	Hewitt and Hoenig 2005[8]
244	0.42	14	0.05	26.6	0.15	1.05	0.22	0.15	0.88	0.63	0.67	0.21
231	0.49	14			0.12	1.18			1.03	0.74	0.78	
219	0.88	14			0.02	1.75			1.83	1.32	1.41	
203	1.01	14			0.01	1.96			2.10	1.52	1.62	
199	0.39	14			0.17	1.06			0.82	0.59	0.62	
188	1.03	14			0.01	2.03			2.14	1.55	1.65	
					Total mortality assumed equal to 0.25 (lower estimate from sensitivity analysis)							
L_∞	*K*	*tmax*	*P*	Temp	Fishing mortality estimates							
244	0.42	14	0.05	26.6	0.10	-0.80	0.03	0.10	-0.63	-0.38	-0.42	0.04
231	0.49	14			0.13	-0.93			-0.78	-0.49	-0.53	
219	0.88	14			0.23	-1.50			-1.58	-1.07	-1.16	
203	1.01	14			0.24	-1.71			-1.85	-1.27	-1.37	
199	0.39	14			0.08	-0.81			-0.57	-0.34	-0.37	
188	1.03	14			0.24	-1.78			-1.89	-1.30	-1.40	

NOT PEER REVIEWED

Figure 16. continued.

					Source of natural mortality equation							
					Alverson and Carney 1975[1]	Pauly 1980[2]	Hoenig 1983[3] (regression)	Hoenig 1983[4]	Ralston 1987[5]	Jensen 1996[6] (theoretical)	Jensen 1996[7] (derived from Pauly 1980)	Hewitt and Hoenig 2005[8]
					Total mortality assumed equal to 2 (upper estimate from sensitivity analysis)							
L_∞	K	$tmax$	P	Temp	Fishing mortality estimates							
244	0.42	14	0.05	26.6	1.10	0.20	1.03	1.10	0.37	0.62	0.58	1.04
231	0.49	14			1.13	0.07			0.22	0.52	0.47	
219	0.88	14			1.23	-0.50			-0.58	-0.07	-0.16	
203	1.01	14			1.24	-0.71			-0.85	-0.27	-0.37	
199	0.39	14			1.08	0.19			0.43	0.67	0.63	
188	1.03	14			1.24	-0.78			-0.89	-0.30	-0.40	

[1] $M = 3K/(\exp[0.38*K*tmax) - 1]$

[2] $M = \exp[-0.0152 + 0.6543*\ln(K) - 0.279*\ln(L\infty/10) + 0.4634*\ln(\text{Temp})]$

[3] $M = \exp[1.44 - 0.982*\ln(tmax)]$

[4] $M = -\ln(P) / tmax$

[5] $M = 0.0189 + 2.06K$

[6] $M=1.5K$

[7] $M=1.6K$

[8] $M=4.22/tmax$

NOT PEER REVIEWED

Table 17. The results from the preliminary length-based analyses that used the blue tang length data from the St. Croix pot and trap fishery. The summarized results represent the models with the lowest AIC value for a given set of input parameters or is strongly supported by AIC criteria (i.e., ΔAIC≤2). Results highlighted in gray met convergence criteria.

				L_∞ = 18.8	19.9	23.1
Gear	Island	Lc (FL mm)	Estimates	K = 1.03	0.39	0.49
Pots and traps	St. Croix	18	Nchanges	0	0	1
			Change year	-	-	1983
			Z	0.001	0.14	0.69, 1.42
		19	Nchanges	0	0	1
			Change year	-	-	1983
			Z	5	0.001	0.5, 1.15
		20	Nchanges	0	0	0
			Change year	-	-	-
			Z	5	4.99	0.6

NOT PEER REVIEW

Table 18. The full AIC results from the preliminary analyses using the blue tang length data from the St. Croix pot and trap fishery. The rows highlighted in gray have the lowest AIC values. In most cases, no other model is supported by AIC criteria. Total mortality values that are equal to 0.001 or are greater than or equal to 4.99 indicate the model did not converge and parameter bounds were reached.

L_c	K	L_∞	Npar	Nobs	Nchange	AIC	ΔAIC	LLIKE	*Z*	*Z1*	Change Year1	*Z2*	Change Year2	*Z3*	Change Year3	*Z4*
18	1.03	18.8	2	29	0	92.96	0	44.25	0.001	-	-	-	-	-	-	-
			4	29	1	98.16	5.21	44.25	-	0.001	1983	0.001	-	-	-	-
			6	29	2	104.31	11.36	44.25	-	0.001	1983	0.001	1985	0.001	-	-
			8	29	3	111.69	18.74	44.25	-	0.001	1983	0.001	1985	0.001	1987	0.001
18	0.39	19.9	2	29	0	55.46	1.484	25.52	0.144	-	-	-	-	-	-	-
			4	29	1	59.05	5.042	24.69	-	0.157	1995	0.001	-	-	-	-
			6	29	2	54.01	0	19.09	-	0.054	1985	1.006	1988	0.021	-	-
			8	29	3	60.46	6.447	18.63	-	0.054	1985	1.016	1988	0.001	2007	0.714
18	0.49	23.1	2	29	0	55.49	2.41	25.52	1.31	-	-	-	-	-	-	-
			4	29	1	53.09	0	21.71	-	0.69	1983	1.42	-	-	-	-
			6	29	2	54.35	1.26	19.26	-	0.67	1983	1.49	1999	0.99	-	-
			8	29	3	59.02	5.94	17.91	-	0.67	1983	1.48	2001	0.43	2005	1.25
19	0.39	19.9	2	29	0	84.53	0	40.04	0.001	-	-	-	-	-	-	-
			4	29	1	89.74	5.21	40.04	-	0.001	1983	0.001	-	-	-	-
			6	29	2	95.89	11.36	40.04	-	0.001	1983	0.001	1985	0.001	-	-
			8	29	3	103.26	18.73	40.03	-	0.001	1983	0.001	1988	0.001	2009	3.46
19	0.49	23.1	2	29	0	62.69	2.81	29.12	1.01	-	-	-	-	-	-	-
			4	29	1	59.89	0	25.11	-	0.50	1983	1.15	-	-	-	-
			6	29	2	64.46	4.57	24.32	-	0.47	1983	1.25	1989	1.00	-	-
			8	29	3	68.08	8.19	22.44	-	0.49	1983	1.20	2001	0.19	2005	1.30
20	0.49	23.1	2	28	0	59.50	1.54	27.51	0.60	-	-	-	-	-	-	-
			4	28	1	59.46	1.51	24.86	-	0.34	1983	0.74	-	-	-	-
			6	28	2	57.96	0	20.98	-	0.18	1983	1.65	1985	0.59	-	-
			8	28	3	63.64	5.68	20.03	-	0.17	1983	1.79	1985	0.44	0.70	1991

NOT PEER REVIEWED

Table 19. The frequency of sensitivity runs predicting no change, one change, or multiple changes in blue tang total mortality (*Z*). Four length-at-full vulnerability (L_c) values and the length data from the St. Croix pot and trap fishery were used as inputs.

	Number of changes in total mortality (*Z*)			
L_c	No change	1 change	2 changes	3changes
18	14	8	26	0
19	7	25	0	0
19.5	14	8	10	0
20.5	15	1	8	0
21	9	0	1	6
Total	59	42	45	6

Table 20. The frequency of sensitivity runs predicting one, two, or three changes in blue tang total mortality (Z) and the associated predicted first year of change. These results represent all parameter combinations used for the sensitivity analysis. The length data from the St. Croix pot and trap fishery were used for this analysis. Results highlighted in gray show the year with support from the majority of sensitivity runs.

	Number of changes in total mortality (Z)		
First year of change	1	2	3
1983	42	33	6
1985	0	3	0
1986	0	9	0
Total	42	45	6

NOT PEER REVIEWED

Table 21. The frequency of sensitivity runs predicting two or three changes in blue tang total mortality (*Z*) and the associated predicted second year of change. These results represent all parameter combinations used for the sensitivity analysis. The lengths from the St. Croix pot and trap fishery were used as the input data. Results highlighted in gray show the year with support from the majority of sensitivity runs.

	Number of changes in total mortality (*Z*)	
Year of second change	2	3
1985	19	6
1988	3	0
1989	3	0
1996	6	0
1999	14	0
Total	45	6

NOT PEER REVIEWED

Table 22. The percent change in total mortality for the sensitivity runs strongly supporting the model predicting a single change in total mortality. The data used for these sensitivity runs were the blue tang length data from the St. Croix pot and trap fishery

		K							
L_c	L_∞	0.39	0.49	0.59	0.69	0.79	0.89	0.99	1.03
18	21		107.96	119.92					
	23.1							245.52	259.57
	24					212.74	247.09	278.16	289.16
19	21					205.60	234.96	263.18	274.14
	22.5			143.91	164.46	187.52	213.26	241.84	254.12
	23.1		128.76	151.68	178.20	208.50	242.76	281.13	297.64
	24	115.57	142.25	174.14	211.16	252.83	298.10	345.45	364.59
19.5	22.5		106.06	125.75			183.75	205.02	213.91
	23.1	91.92			153.21	176.59			
20.5	24			106.00					

NOT PEER REVIEWED

Table 23. The percent change in total mortality for the sensitivity runs strongly supporting the model predicting two years of change. The data used for these sensitivity runs were the blue tang length data from the St. Croix pot and trap fishery. ‡ indicates that the total mortality estimate prior to the first change was approximately equal to 0.001 causing an impressive percent increase in total mortality.

		K															
		0.39		0.49		0.59		0.69		0.79		0.89		0.99		1.03	
L_c	L_∞	1st Δ	2nd Δ	1st Δ	2nd Δ	1st Δ	2nd Δ	1st Δ	2nd Δ	1st Δ	2nd Δ	1st Δ	2nd Δ	1st Δ	2nd Δ	1st Δ	2nd Δ
18	19.5											144744‡	-99.9	209299‡	-99.9	238502‡	-99.9
	21							177.8	-51.0	165.0	-47.2	115.8	-51.5	114.9	-49.8	114.4	-49.1
	22.5	125.8	-44.6	82.1	-43.6	137.2	-34.9	159.2	-34.5	185.6	-34.4	216.2	-34.3	250.6	-34.1	265.3	-34.1
	23.1	77.4	-43.0	123.7	-33.4	147.1	-33.1	175.7	-32.9	209.0	-32.8	245.8	-32.6				
	24	70.3	-38.5	136.6	-31.5	168.9	-31.4	205.9	-31.2								
19.5	23.1											656.3	-42.3	747.0	-41.5	784.9	-41.1
	24			415.9	-44.4	480.9	-42.5	558.9	-40.9	625.7	-38.8	673.5	-35.9	707.4	-32.9	718.2	-31.7
20.5	23.1									1229.6	-70.6	1284.5	-69.0				
	24	525.7	-64.4					665.9	-58.2	710.5	-56.1	762.3	-54.2	820.3	-52.6	844.6	-51.9
21	24									1285.1	-66.9						

NOT PEER REVIEWED

Table 24. Natural and fishing mortality estimates for blue tang caught by the St. Croix pot and trap fishery. Input parameters include: asymptotic length (L_∞, FL mm), the von Bertalanffy growth coefficient (*K*), maximum age (*tmax*), the proportion of population at the maximum age (*P*), and temperature (the average for Puerto Rico: www.nodc.noaa.gov/dsdt/cwtg/oatl.html. Footnotes indicate the equation associated with each publication. Fishing mortality estimates (*F*= *Z-M*) result from two estimates of total mortality from the sensitivity analysis and the natural mortality estimates. Cells highlighted in gray indicate *F* is greater than *M*.

Input parameters					Source of natural mortality equation							
L_∞	*K*	*tmax*	*P*	Temp	Alverson and Carney 1975[1]	Pauly 1980[2]	Hoenig 1983[3] (regression)	Hoenig 1983[4]	Ralston 1987[5]	Jensen 1996[6] (theoretical)	Jensen 1996[7] (derived from Pauly 1980)	Hewitt and Hoenig 2005[8]
244	0.42	14	0.05	26.6	0.15	1.05	0.22	0.15	0.88	0.63	0.67	0.21
231	0.49	14			0.12	1.18			1.03	0.74	0.78	
219	0.88	14			0.02	1.75			1.83	1.32	1.41	
203	1.01	14			0.01	1.96			2.10	1.52	1.62	
199	0.39	14			0.17	1.06			0.82	0.59	0.62	
188	1.03	14			0.01	2.03			2.14	1.55	1.65	
					Total mortality assumed equal to 0.25 (lower estimate from sensitivity analysis)							
L_∞	*K*	*tmax*	*P*	Temp	Fishing mortality estimates							
244	0.42	14	0.05	26.6	0.10	-0.80	0.03	0.10	-0.63	-0.38	-0.42	0.04
231	0.49	14			0.13	-0.93			-0.78	-0.49	-0.53	
219	0.88	14			0.23	-1.50			-1.58	-1.07	-1.16	
203	1.01	14			0.24	-1.71			-1.85	-1.27	-1.37	
199	0.39	14			0.08	-0.81			-0.57	-0.34	-0.37	
188	1.03	14			0.24	-1.78			-1.89	-1.30	-1.40	

NOT PEER REVIEWED

Table 24. continued.

					Source of natural mortality equation							
					Alverson and Carney 1975[1]	Pauly 1980[2]	Hoenig 1983[3] (regression)	Hoenig 1983[4]	Ralston 1987[5]	Jensen 1996[6] (theoretical)	Jensen 1996[7] (derived from Pauly 1980)	Hewitt and Hoenig 2005[8]
					Total mortality assumed equal to 2 (upper estimate from sensitivity analysis)							
L_∞	K	*tmax*	P	Temp	Fishing mortality estimates							
244	0.42	14	0.05	26.6	1.85	0.95	1.78	1.85	1.12	1.37	1.33	1.79
231	0.49	14			1.88	0.82			0.97	1.27	1.22	
219	0.88	14			1.98	0.25			0.17	0.68	0.59	
203	1.01	14			1.99	0.04			-0.10	0.49	0.38	
199	0.39	14			1.83	0.94			1.18	1.42	1.38	
188	1.03	14			1.99	-0.03			-0.14	0.46	0.35	

[1] $M = 3K/(\exp[0.38*K*tmax) - 1]$

[2] $M = \exp[-0.0152 + 0.6543*\ln(K) - 0.279*\ln(L_\infty/10) + 0.4634*\ln(\text{Temp})]$

[3] $M = \exp[1.44 - 0.982*\ln(tmax)]$

[4] $M = -\ln(P) / tmax$

[5] $M = 0.0189 + 2.06K$

[6] $M=1.5K$

[7] $M=1.6K$

[8] $M=4.22/tmax$

NOT PEER REVIEWED

9. Figures

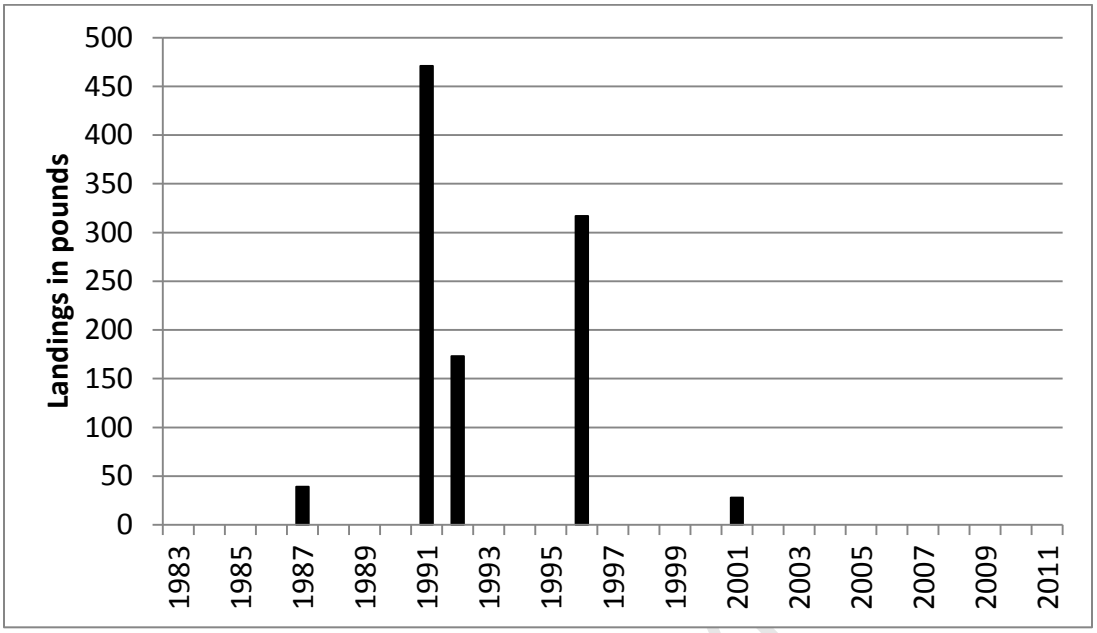

Figure 1. Puerto Rico yearly commercial fishery expanded landings of surgeonfishes reported for all gears, 1983-2011. Note: data from all gears were combined due to small sample sizes and confidentiality constraints.

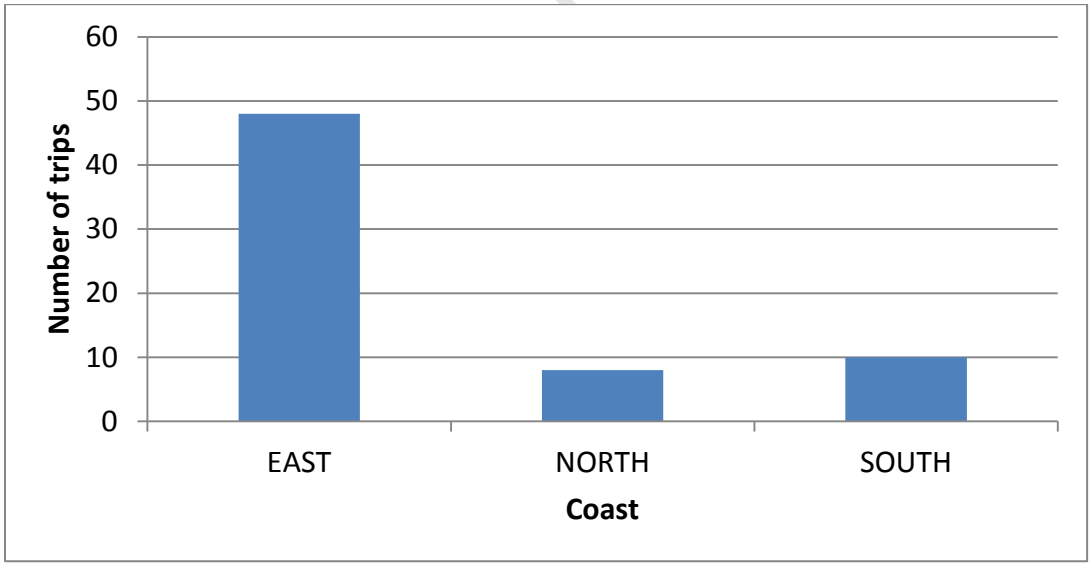

Figure 2. Puerto Rico reported commercial fishing trips with surgeonfish landings, 1983-2011, by coast. Note: trips reporting surgeonfishes from the west coast of Puerto Rico could not be presented due to confidentiality constraints. Data were combined across years due to small sample sizes.

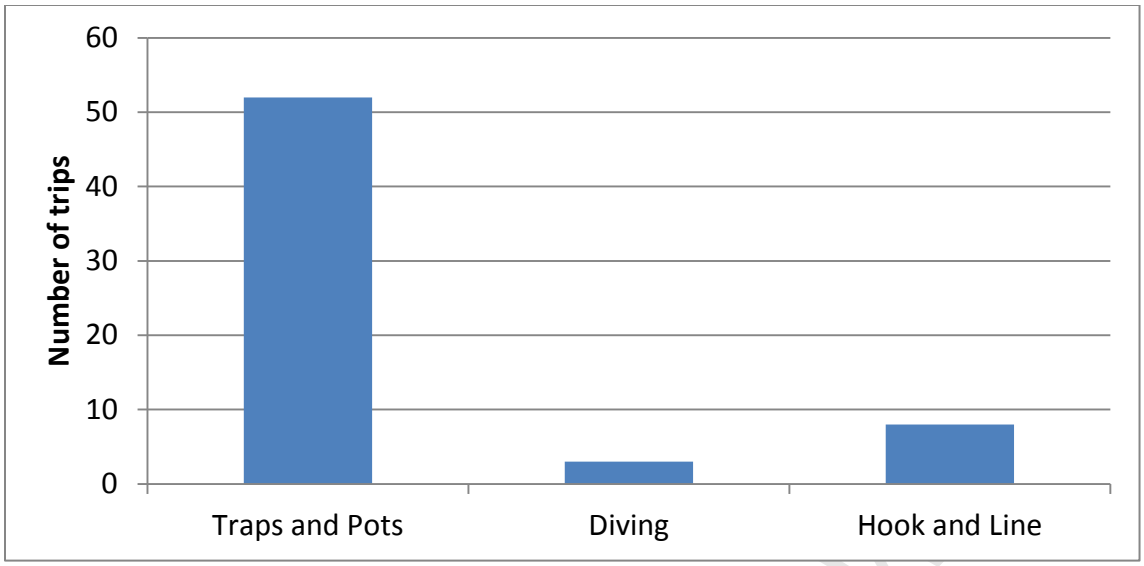

Figure 3. Puerto Rico reported commercial fishing trips with surgeonfish landings, 1983-2011, by gear. Data were combined across years due to small sample sizes.

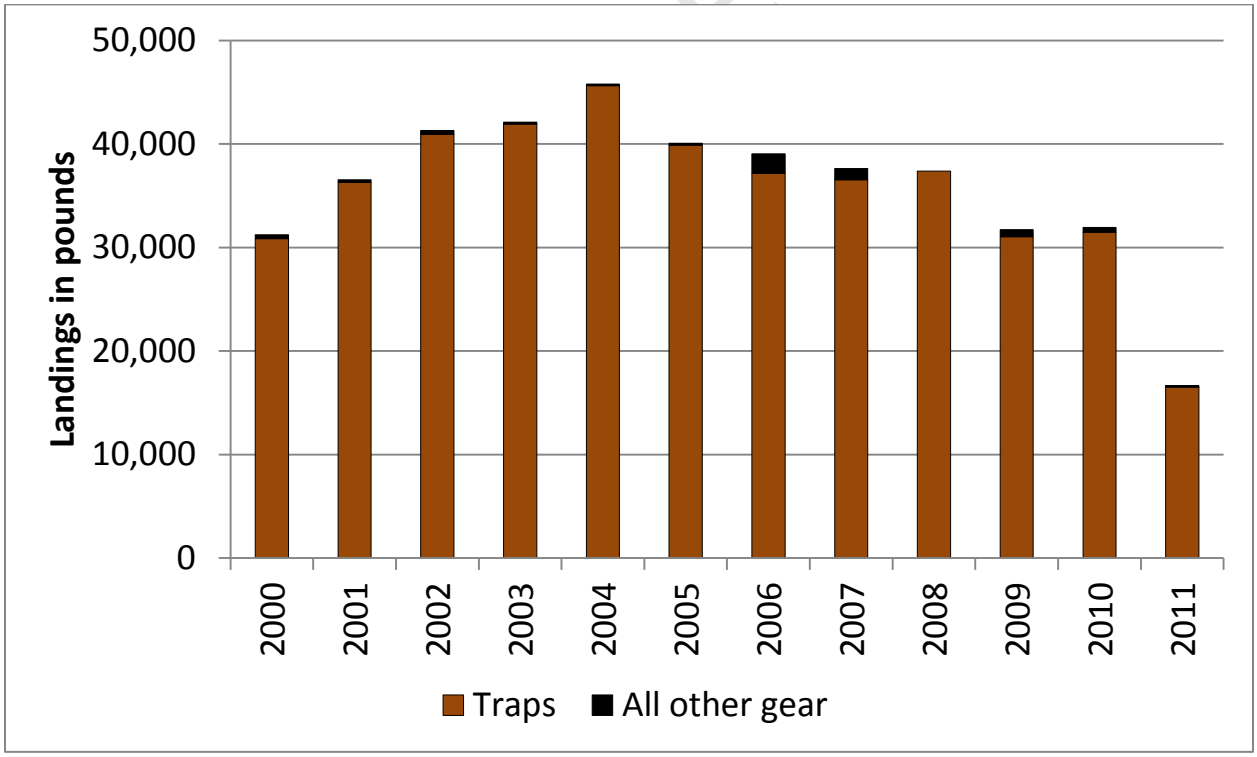

Figure 4. Yearly commercial landings of surgeonfishes as reported (no expansion factors applied) on fisher logbooks from St. Thomas and St. John by gear and year.

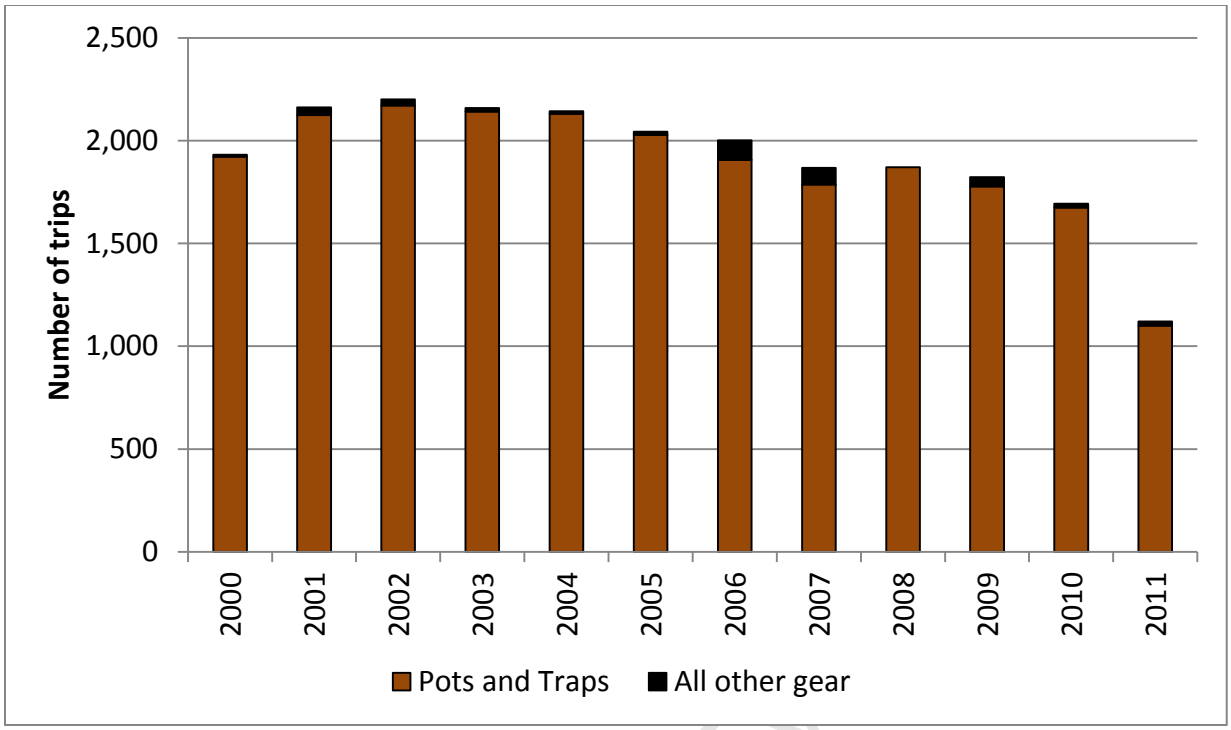

Figure 5. St. Thomas and St. John reported commercial fishing trips with surgeonfish landings by gear and year.

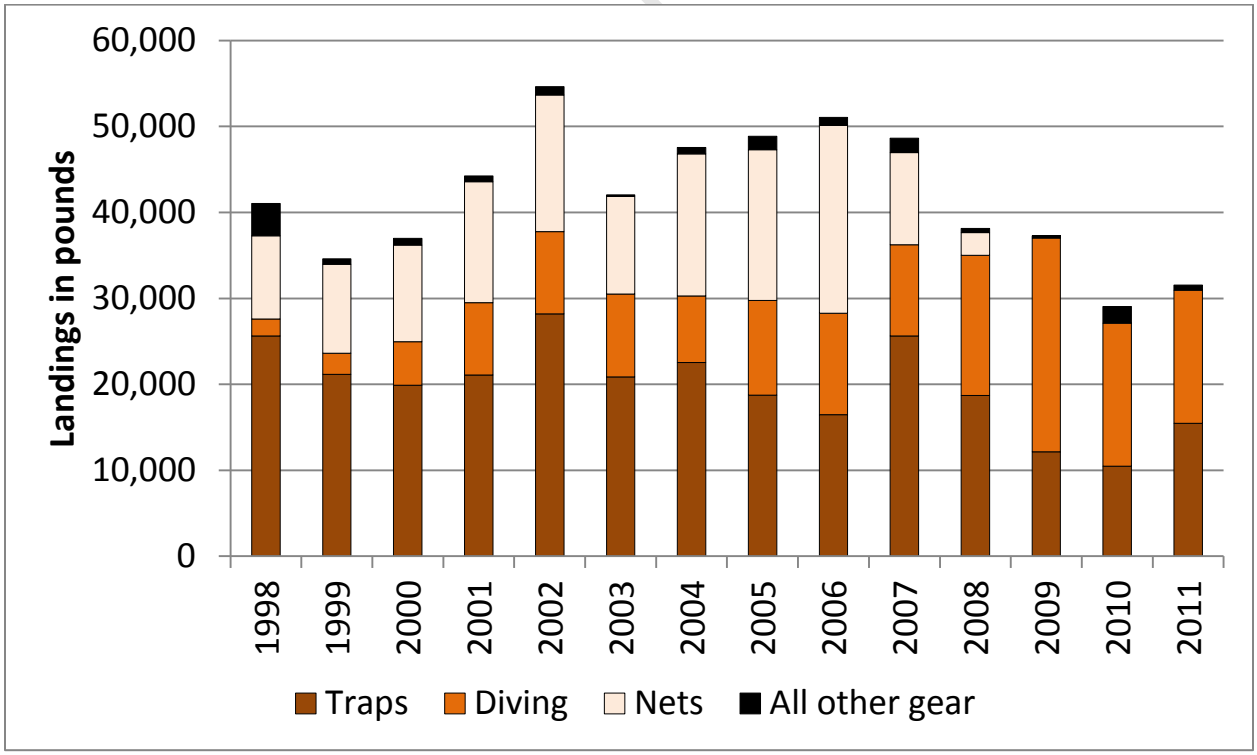

Figure 6. Yearly commercial landings of surgeonfishes as reported (no expansion factors applied) on fisher logbooks from St. Croix by gear and year.

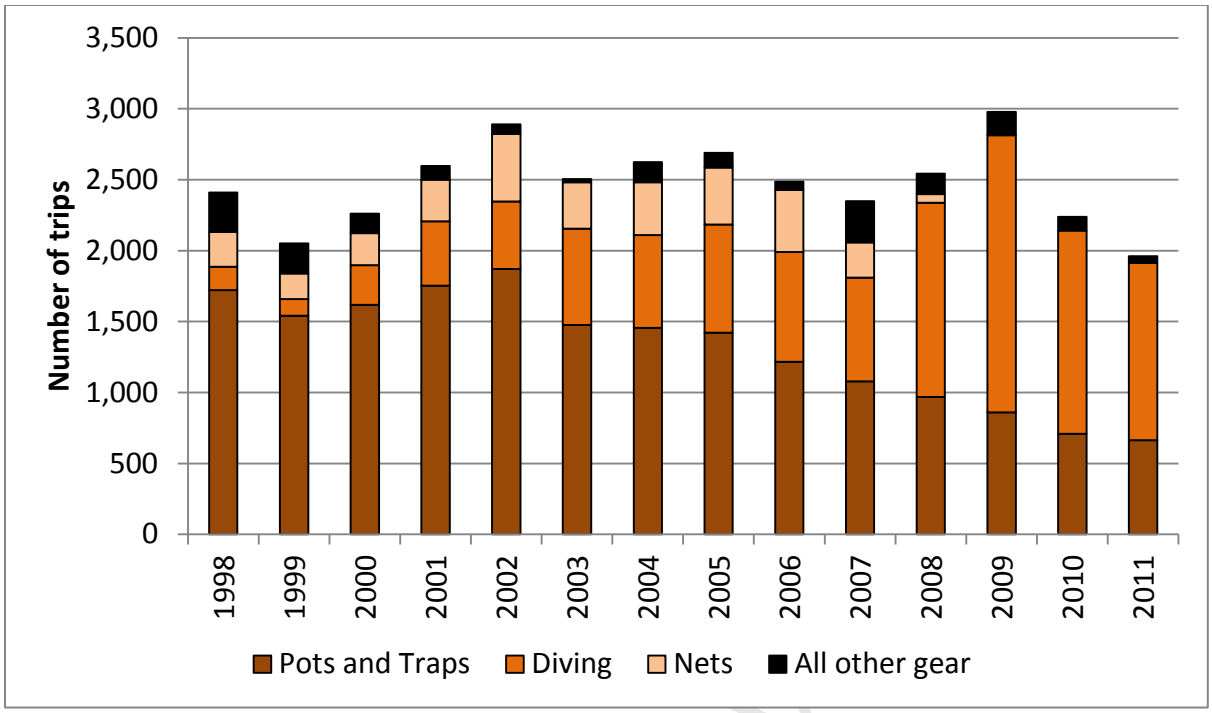

Figure 7. St. Croix reported commercial fishing trips with surgeonfish landings by gear and year.

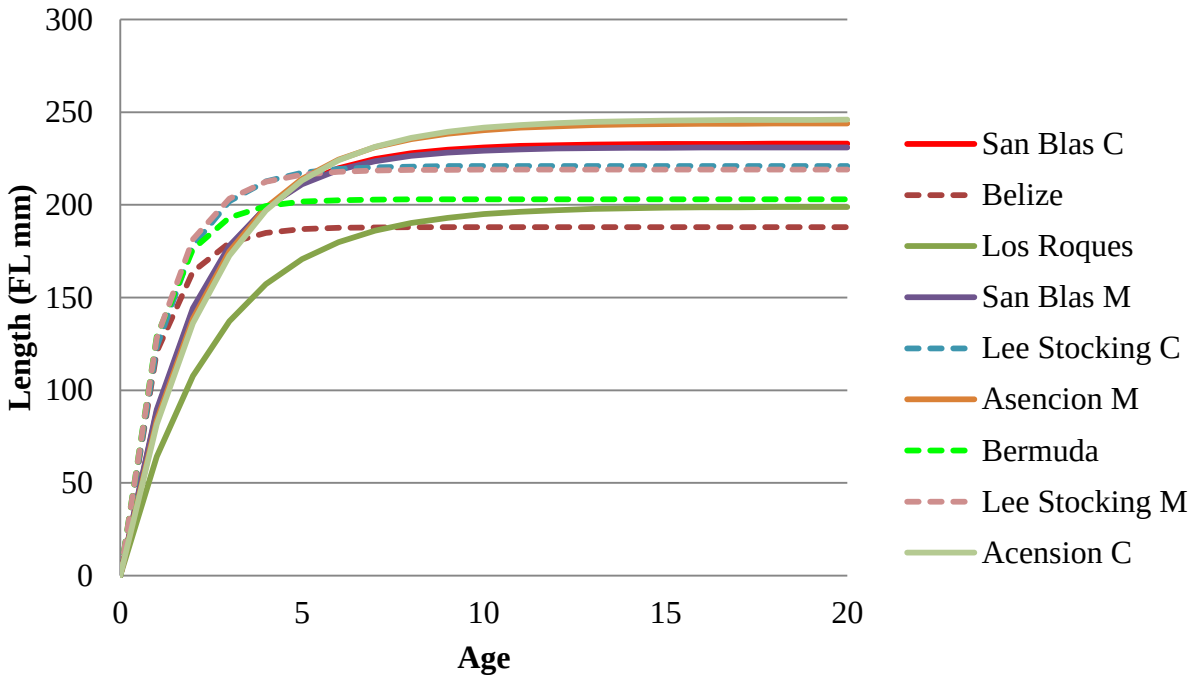

Figure 8. von Bertlanffy growth curves for blue tang. This figure corresponds with Table 6. In the figure legend, the letter C following the location indicates the input values were from Choat and Robertson (2002) and the letter M indicates the input values were from Mutz (2006).

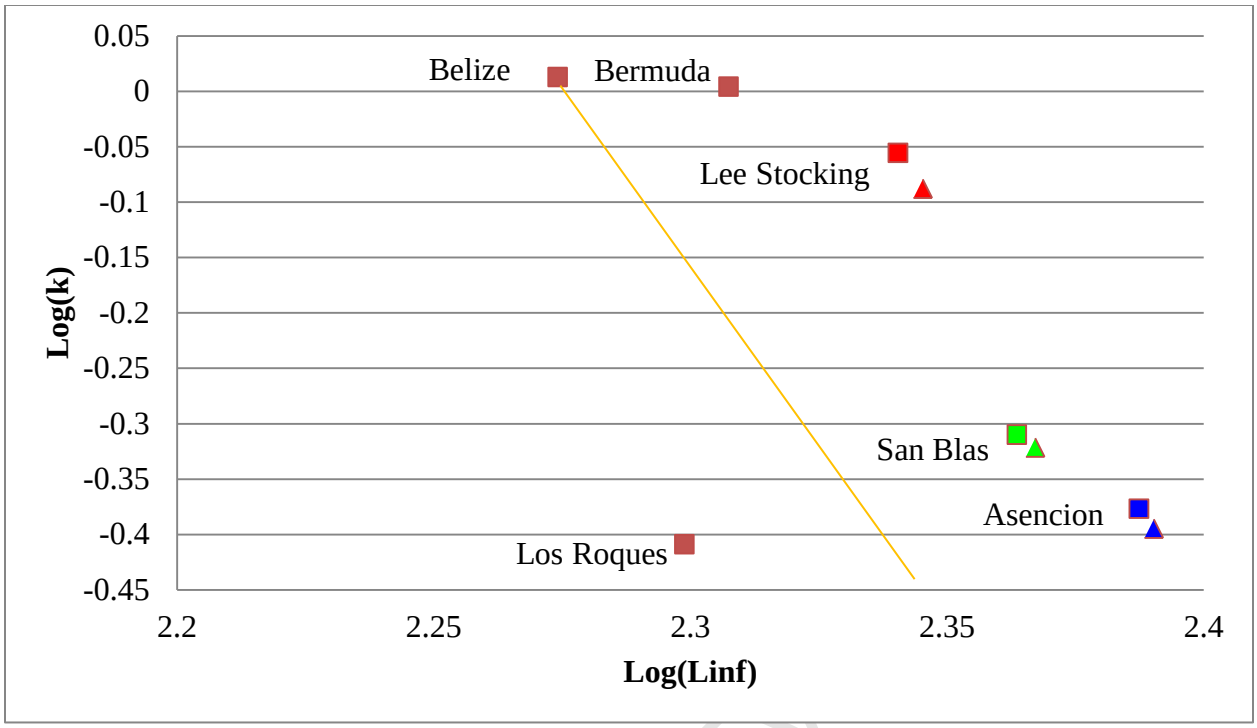

Figure 9. The relationship between the von Bertalanffy growth coefficient (k) and the asymptotic length (Linf) for blue tang. The squares represent values from Choat and Robertson (2002) and the triangles represent values from Mutz (2006). Each point represents a different location in the Caribbean. The yellow line has a slope of -2.

NOT PEER REV

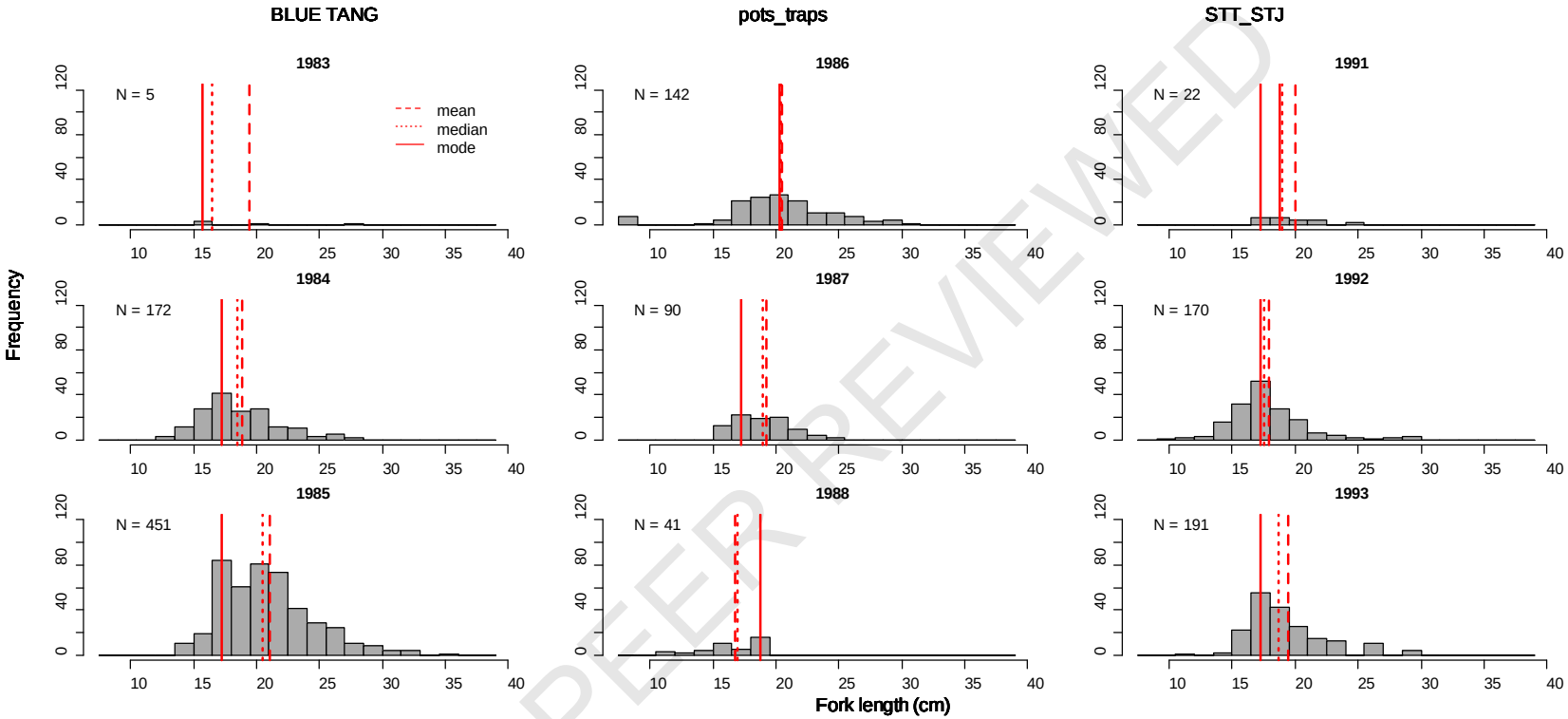

Figure 10. Length frequency plots of blue tang from the St. Thomas/St. John pot and trap fishery. The bin size is 1.5cm. The solid red line is the mode, the dashed red line is the mean, and the dotted line is the median. In some instances there is more than one mode because the frequency of more than one length bin is equal.

NOT PEER REVIEWED

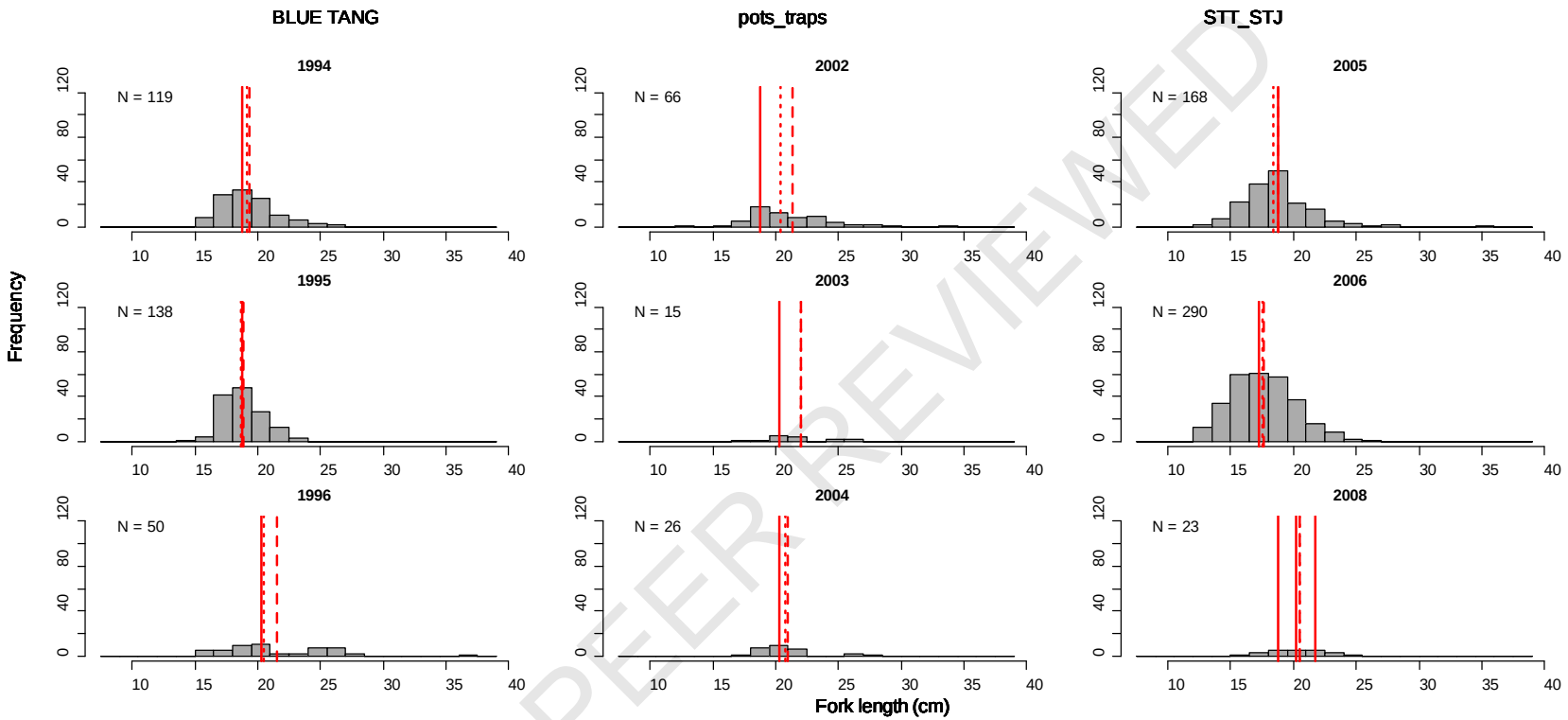

Figure 10. continued

NOT PEER REVIEWED

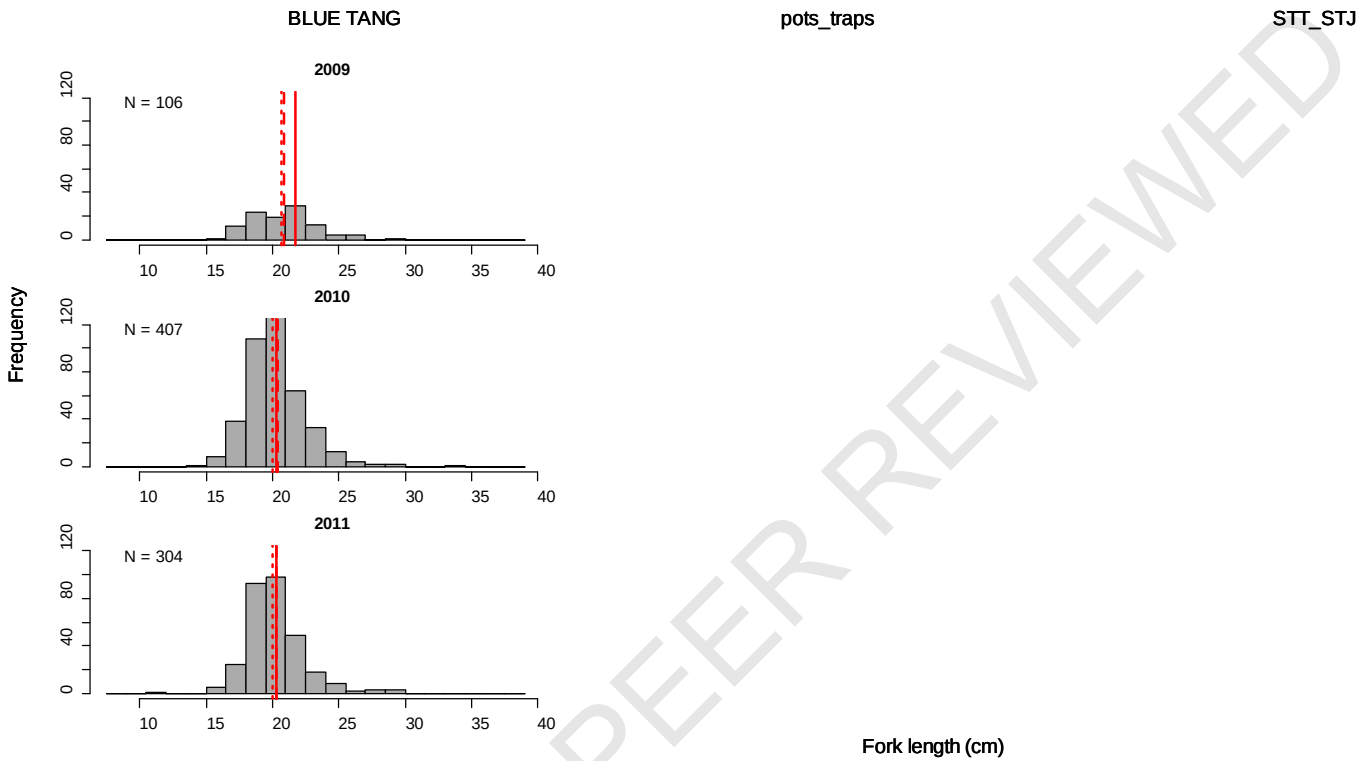

Figure 10. continued

NOT PEER REVIEWED

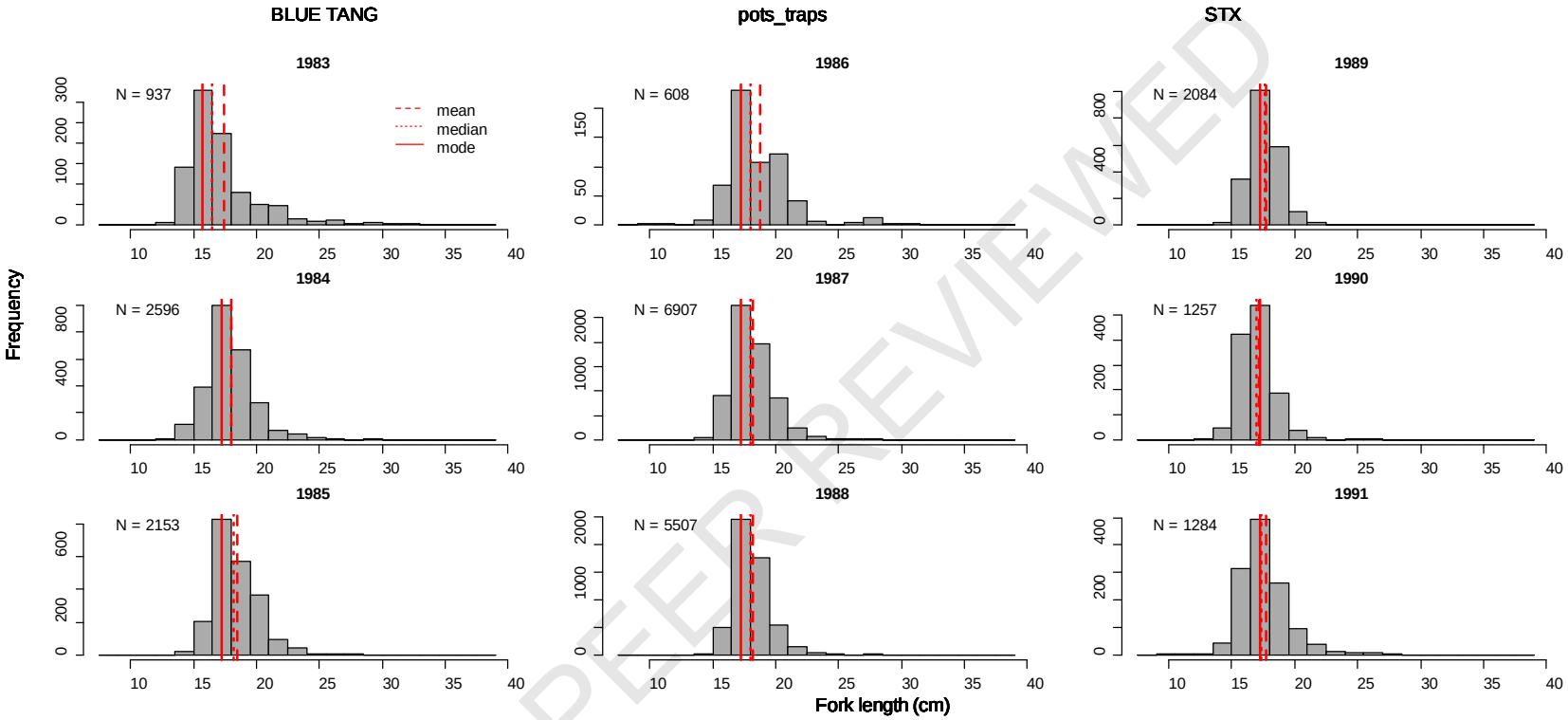

Figure 11. Length frequency plot of blue tang from the St. Croix pot and trap fishery. The bin size is 1.5cm. The solid red line is the mode, the dashed red line is the mean, and the dotted line is the median. In some instances there is more than one mode because the frequency of more than one length bin is equal. Note: The Y-axis scale varies year to year.

NOT PEER REVIEWED

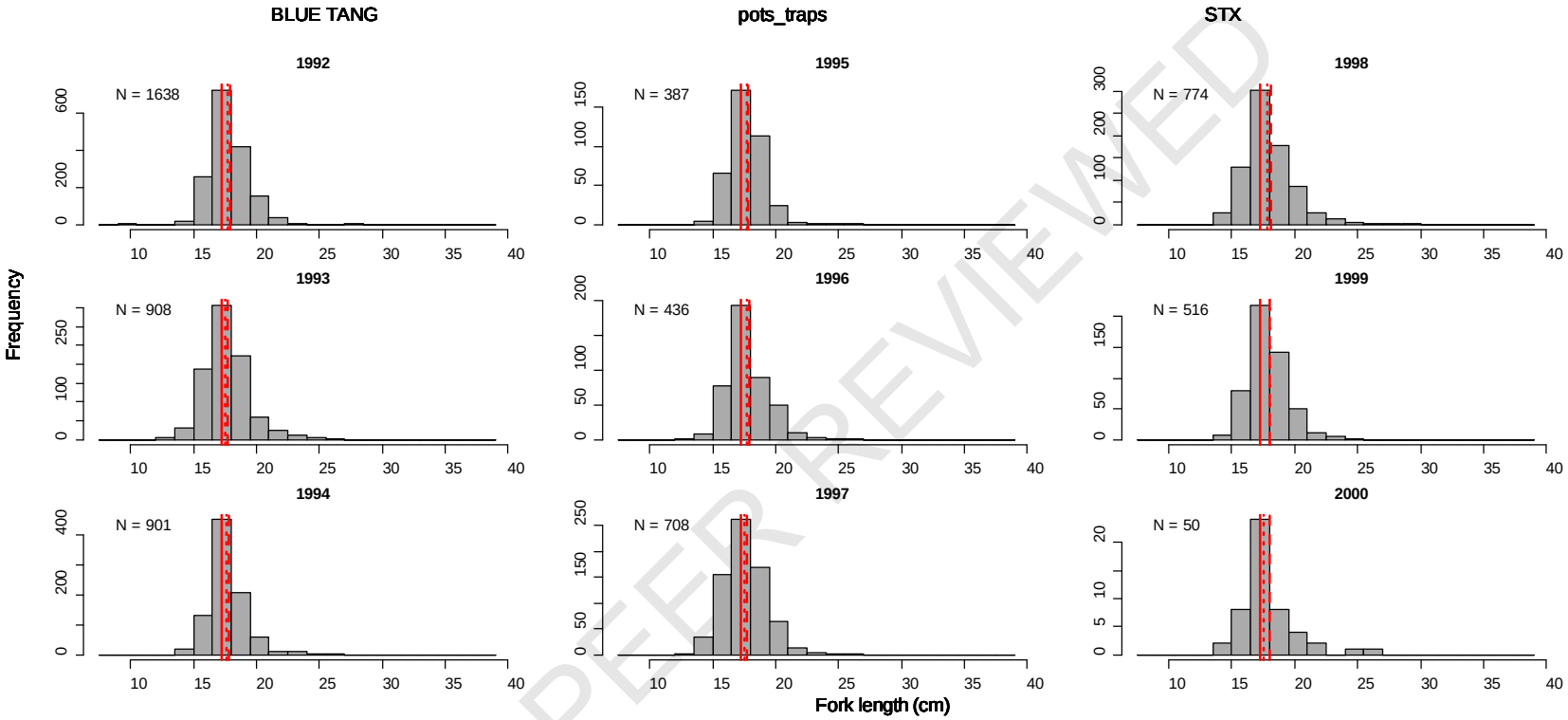

Figure 11. continued

NOT PEER REVIEWED

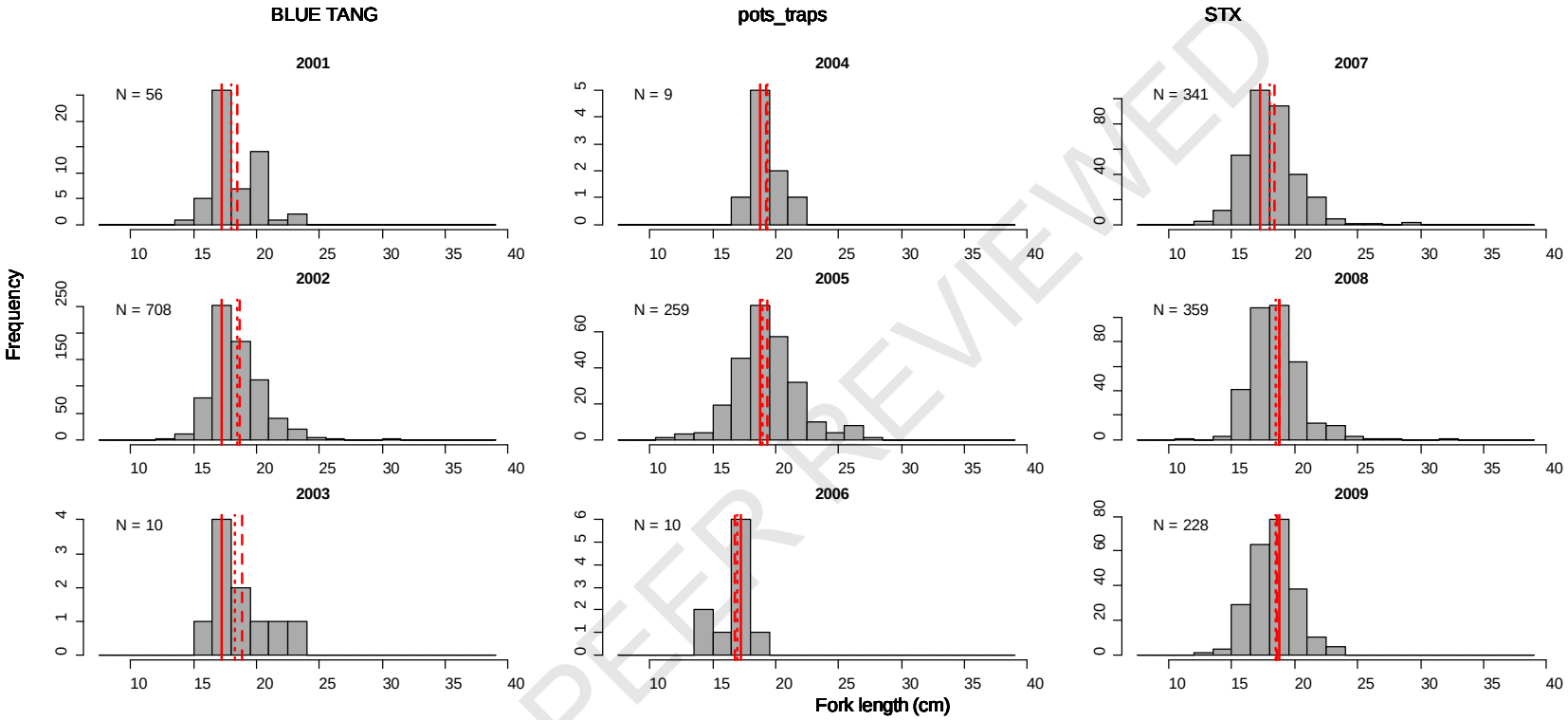

Figure 11. continued

NOT PEER REVIEWED

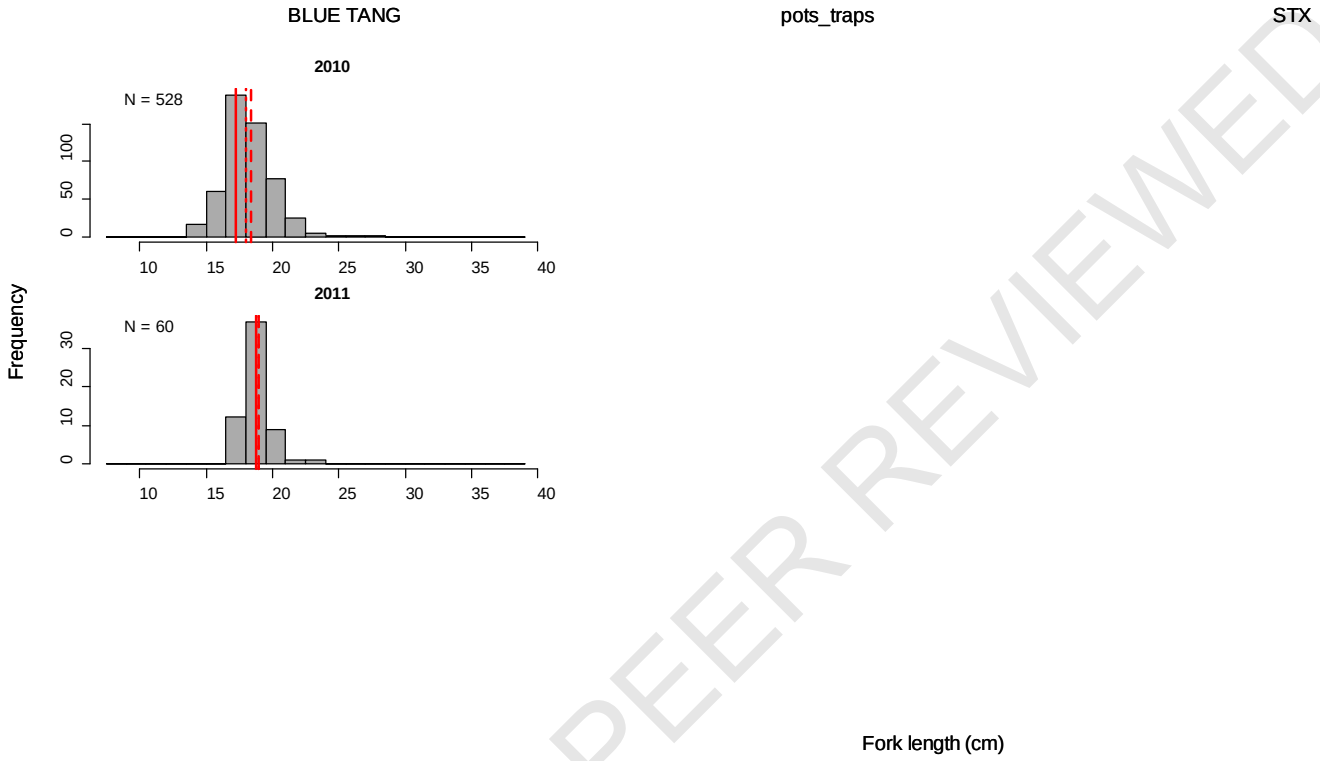

Figure 11. continued

NOT PEER REVIEWED

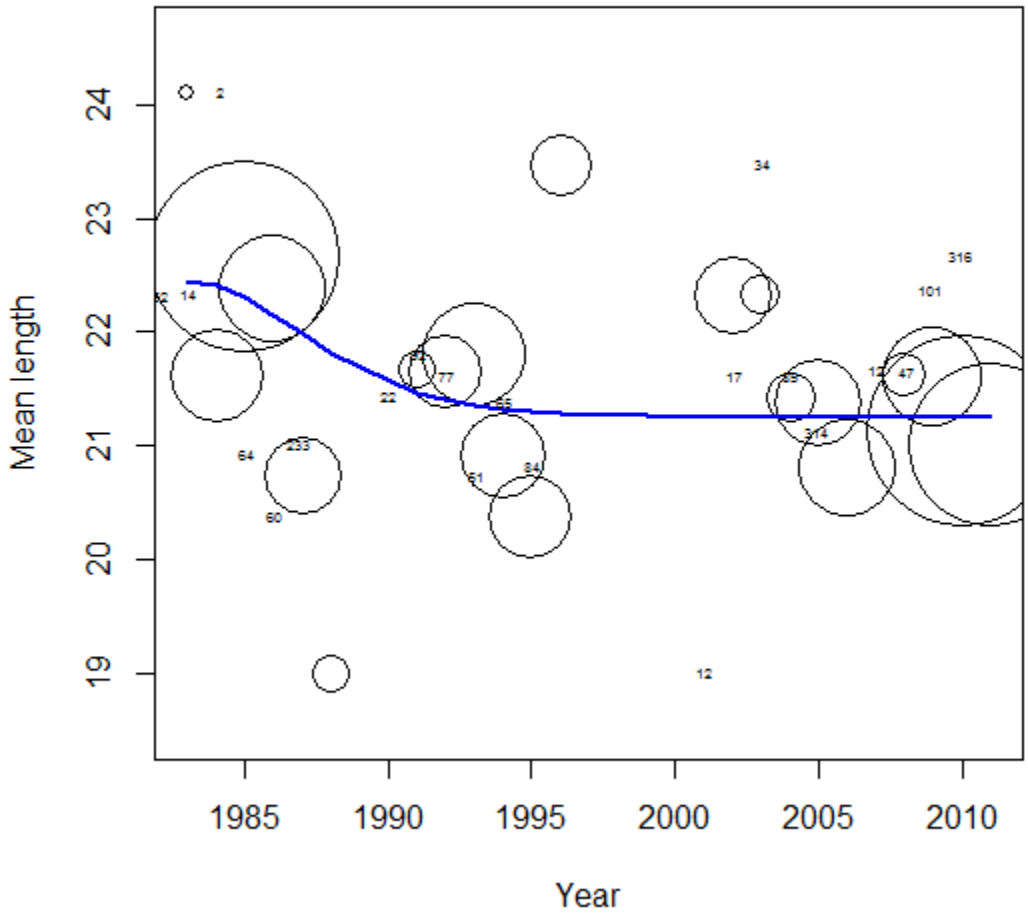

Figure 12. The model fit to the blue tang length data from the St. Thomas/St. John pot and trap fishery. The model fit shown predicts one change in total mortality and had the lowest AIC value. The input parameter values used were L_c = 19cm, L_∞ = 23.1cm, and K = 0.49. Bubble size represents the annual sample size scaled with respect to other years.

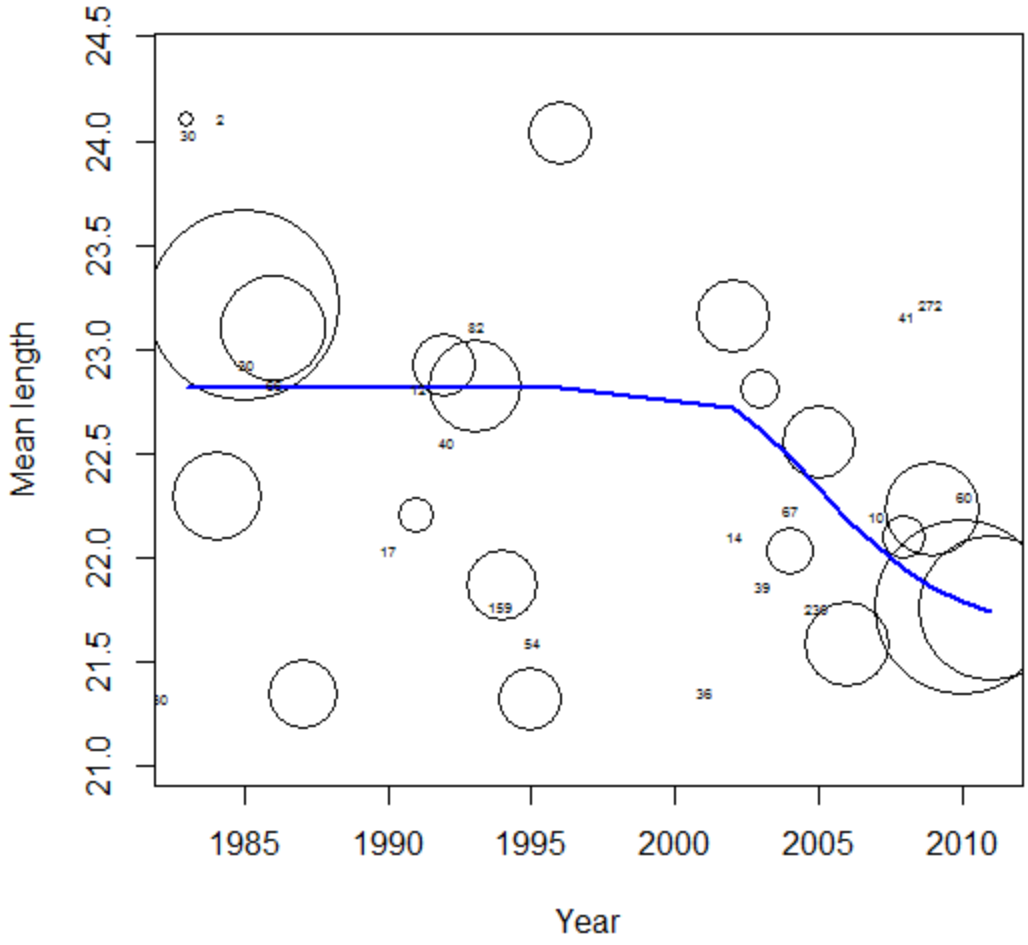

Figure 13. The model fit to the blue tang length data from the St. Thomas/St. John pot and trap fishery. The model fit shown predicts one change in total mortality and had the lowest AIC value. The input parameter values were: L_c = 20 cm, L_∞ = 23.1cm, and K = 0.49. Bubble size represents the annual sample size scaled with respect to other years.

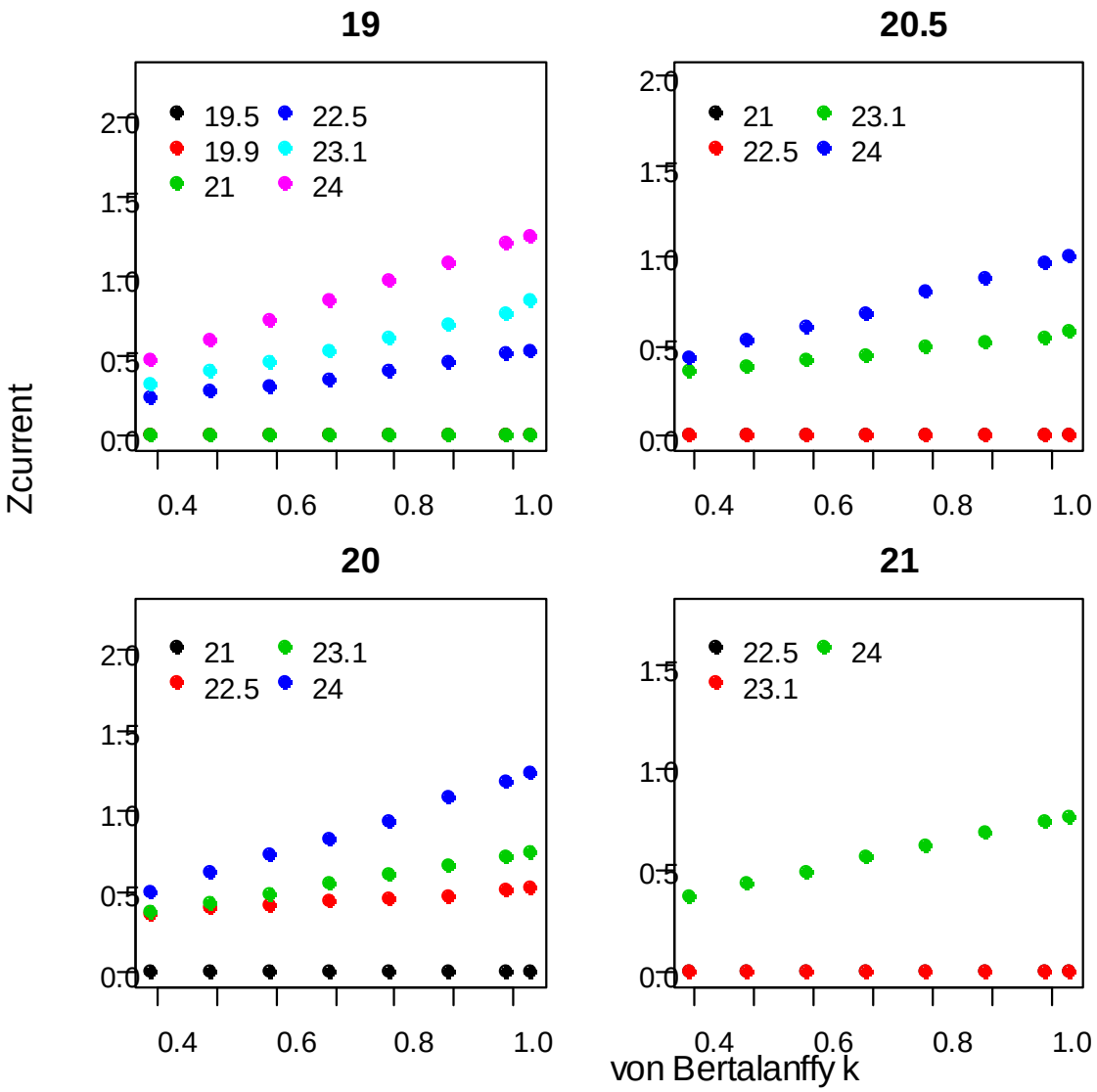

Figure 14. The estimates of the current total mortality, Zcurrent, from the sensitivity analysis carried out on the blue tang length data from the St. Thomas/St. John pot and trap fishery. Each panel represents a different length-at-full vulnerability value, L_c, and is indicated above each panel. The colored points represent different values of L_∞, which are indicated in the figure legend.

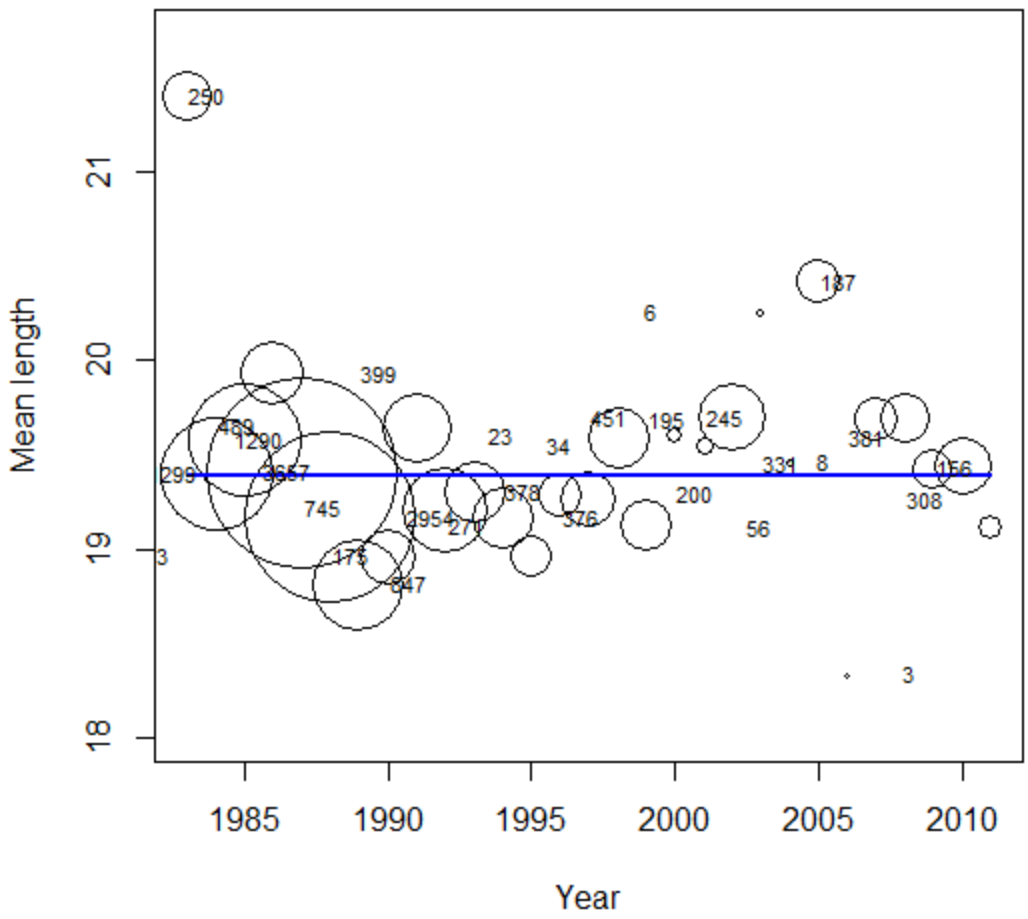

Figure 15. The model fit to the blue tang length data from the St. Croix pot and trap fishery. The model fit shown predicts no change in total mortality and had the lowest AIC value. The input parameter values used were L_c = 18cm, L_∞ = 19.9cm, and K = 0.39, the L_c input value differs from Figures 16-18. Bubble size represents the annual sample size scaled with respect to other years.

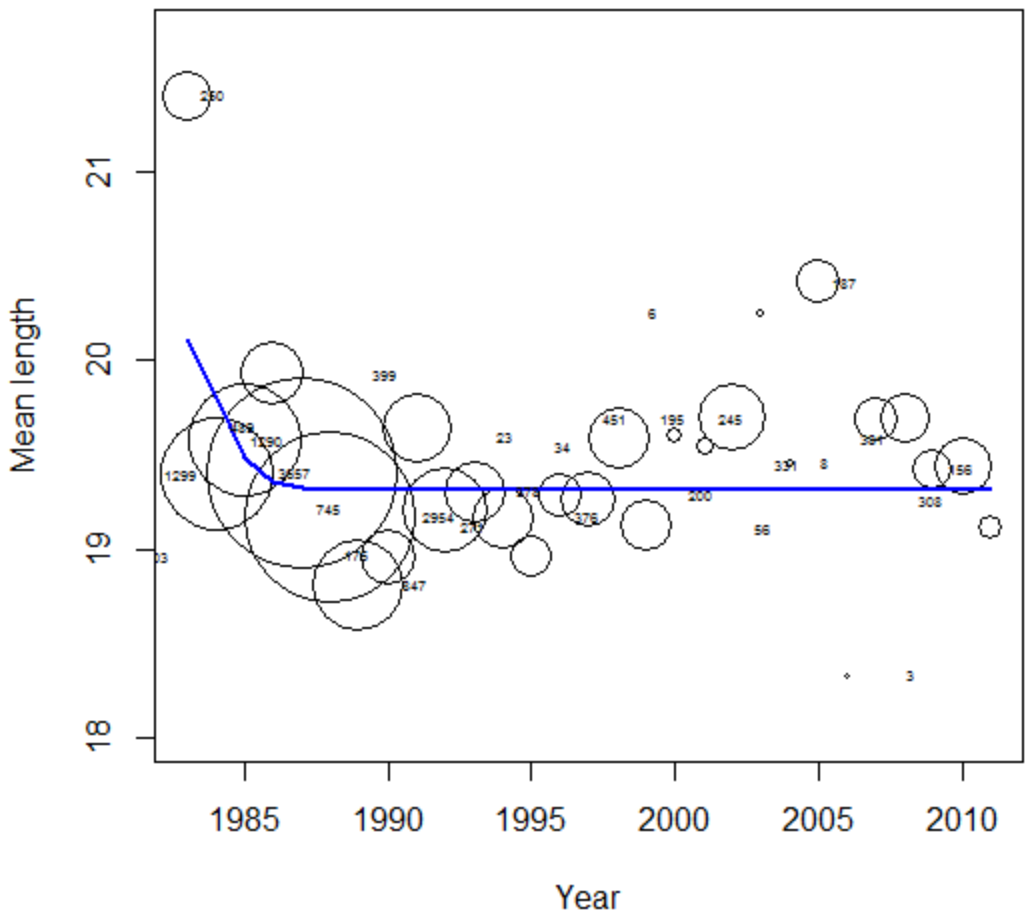

Figure 16. The model fit to the blue tang length data from the St. Croix pot and trap fishery. The model fit shown predicts one change in total mortality and had the lowest AIC value. The input parameter values used were L_c = 18cm, L_∞ = 23.1cm, and K = 0.49, the L_c input value differs from Figures 15, 17, and 18. Bubble size represents the annual sample size scaled with respect to other years.

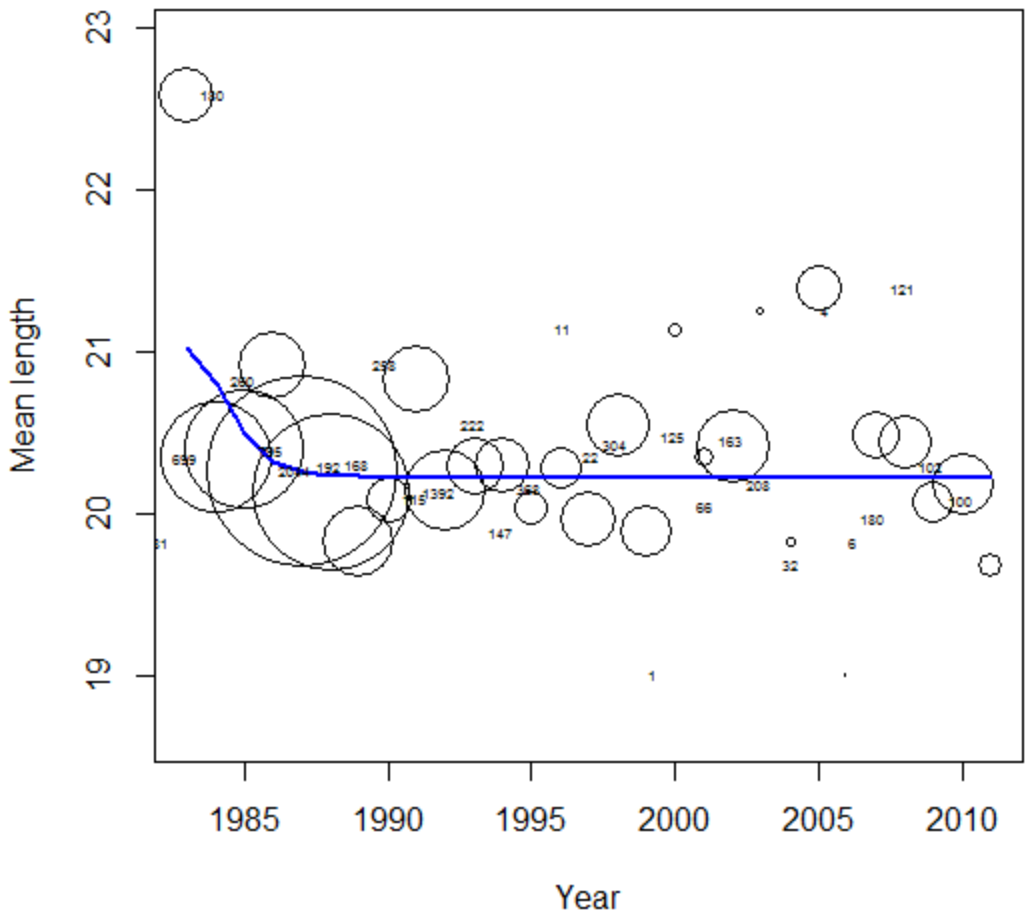

Figure 17. The model fit to the blue tang length data from the St. Croix pot and trap fishery. The model fit shown predicts one change in total mortality and had the lowest AIC value. The input parameter values used were L_c = 19cm, L_∞ = 23.1cm, and K = 0.49, the L_c input value differs from Figures 15, 16, and 18.. Bubble size represents the annual sample size scaled with respect to other years.

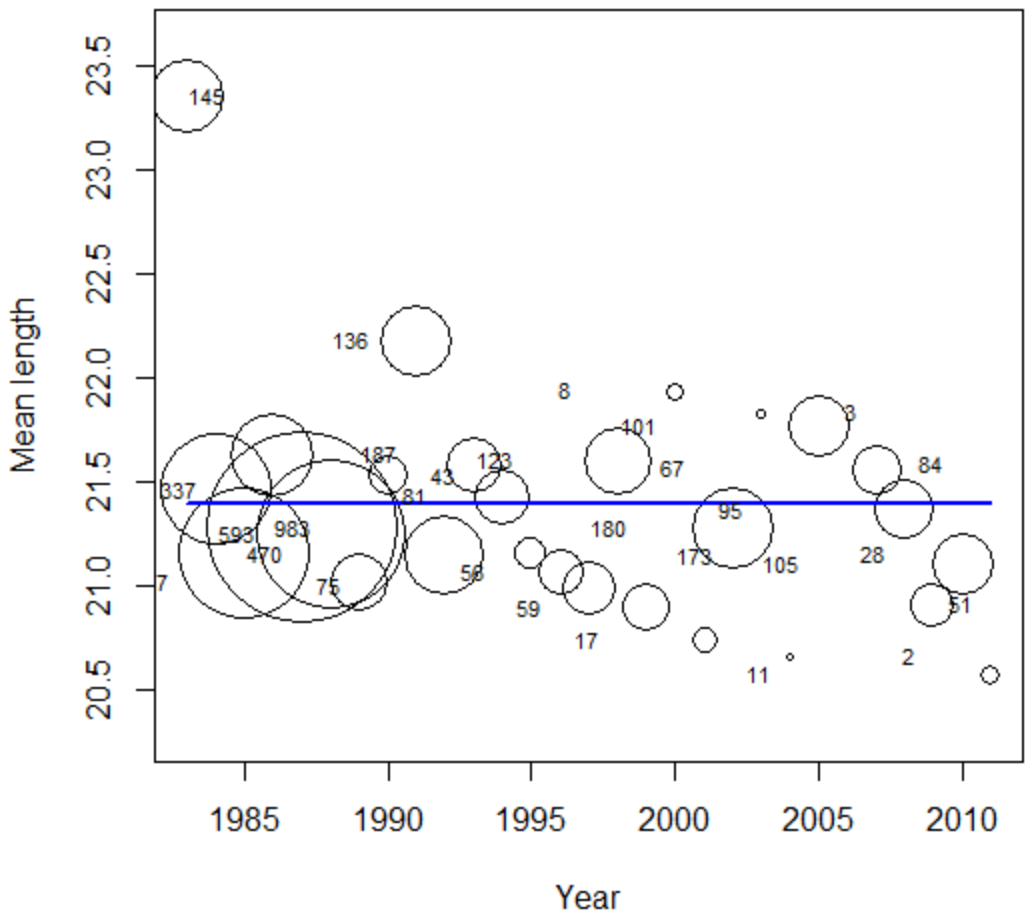

Figure 18. The model fit to the blue tang length data from the St. Croix pot and trap fishery. The model fit shown predicts one change in total mortality and had the lowest AIC value. The input parameter values used were L_c = 20cm, L_∞ = 23.1cm, and K = 0.49, the L_c input value differs from Figures 15 - 17. Bubble size represents the annual sample size scaled with respect to other years.

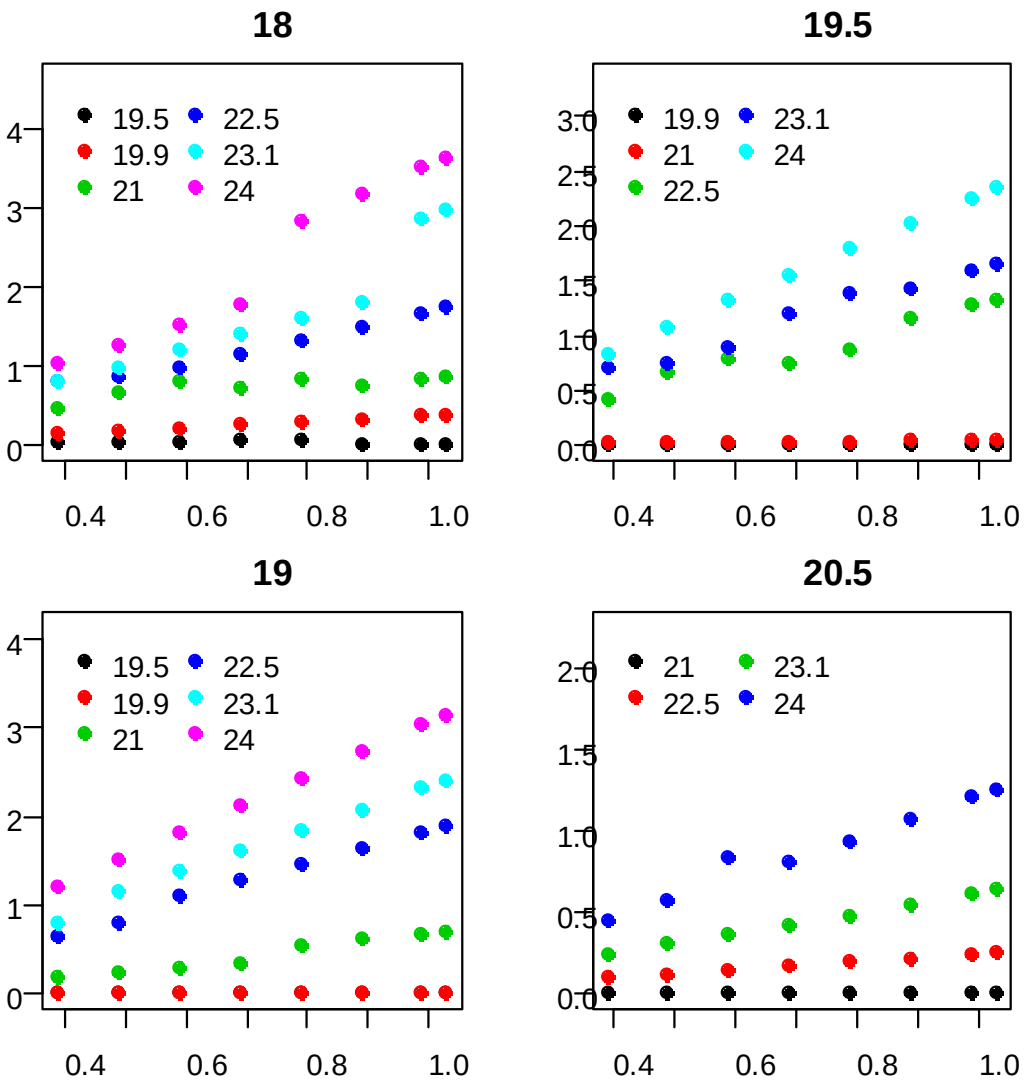

Figure 19. The estimates of the current total mortality, Zcurrent, for blue tang from the sensitivity analysis carried out on the data from the St. Croix pot and trap fishery. Each panel represents a different length-at-full vulnerability value, L_c, and is indicated above the panel. The colored points represent different values of L_∞, the values are indicated in the figure legend.