The Blue Swimming Crab (*Portunus pelagicus*) Fisheries in the Visayan Sea, Philippines: A Review of Assessment Information and Analysis Options

—Scientific Report No. 2

(October 2019)

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ACKNOWLEDGMENTS

This report was completed during the course of a short-term consultancy (totaling 38.5 working days) during the period between 27 May and 31 October 2019, commissioned by the **Sustainable Fisheries Partnership Foundation (SFP)** and implemented in collaboration with the NSAP of the National Fisheries Research and Development Institute (Philippines). Thanks are due Mr. Enrique Alonso and Mr. Bernal Vilela of SFP for their oversight and assistance during the study, and the officers and staff of NSAP in Regions 5, 6, and 7 for their guidance and collaboration during the course of the study. Mr. Albert Vargas, and the officers of NFRDI Central Office (led by Mr. Francisco Torres Jr.) assisted with NSAP and database updates, software runs and requirements, the conduct of targeted trainings, and the preparation of key figures incorporated in the report. Ms. Drusila Bayate provided valuable technical inputs and insights during the conducting of the study. An anonymous expert from the Science Division of SFP reviewed the report and provided valuable technical edits and revision suggestions to improve the document. The results and recommendations contained in this report, however, remain those of the author, and do not necessarily reflect the views of SFP, NSAP-NFRDI of BFAR, or the persons acknowledged herein.

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To cite this document:

Silvestre, G., S. V. Mesa, E. Cinco, G. A. Tingley (2020). The Blue Swimming Crab (*Portunus pelagicus*) Fisheries in the Visayan Sea, Philippines: A Review of Assessment Information and Analysis Options – Scientific Report No. 2. Honolulu: **Sustainable Fisheries Partnership Foundation** and Bureau of Fisheries and Aquatic Resources, Philippines. 60 pp.

CONTENTS

ACRONYMS AND ABBREVIATIONS

A_{ratio} - Abundance index ratio (= $(Y/f)_{now}/(Y/f)_{MSY}$)

AMSY - Abundance Maximum Sustainable Yield

B - Biomass

B_t - Biomass at year t

B_{t+1} - Biomass at subsequent year t+1

BAS - Bureau of Agricultural Statistics

B/B_o - Biomass-to-virgin-stock biomass ratio

B/B_{MSY} - Biomass-to-biomass producing MSY ratio

BFAR - Bureau of Fisheries and Aquatic Resources

B_{MSY} - Biomass producing MSY

B_R - Biomass below which recruitment may be compromised

B/R - Biomass-per-recruit

(B/R)' - Relative biomass-per-recruit

BSC - Blue swimming crab

B_w - Body wet weight

CBD - Convention on Biological Diversity

CMSY - Catch method for estimating maximum sustainable yield

CPUE - Catch-per-unit-effort or catch rate

CSV - Comma-separated variables

C_t - Catch during year t

CW - Carapace width

DB - Database

DBMS - Database management servers

DC - Diet composition

E - Exploitation ratio, (=F/Z)

EE - Ecotrophic efficiency

ELEFAN - Electronic length frequency analysis

$E_{0.1}$ - Exploitation ratio where change in Y/R is 10% of that at near zero E

$E_{0.5}$ - Exploitation ratio where B/R is 50% of original level

E_{max} - Exploitation ratio where Y/R is maximized for a given c or l_c

EP - Egg production

EwE - Ecopath with Ecosim

exp - Base e of Napierian logarithm

f - Fishing effort

$f_{0.1}$ - Fishing effort where change in yield is 10% of that at near zero level

f_{MSY} - Fishing effort that generates maximum sustainable yield

f_{now} - Fishing effort currently or for period being evaluated

$f_{(\%)}$ - Percentage increase/decrease in fishing effort against current level

F - Fishing mortality rate, expressed in annual terms ($year^{-1}$)

$F_{0.1}$ - Fishing mortality where change in **Y** is 10% of that at near zero **F**

$F_{0.5}$ - Fishing mortality where biomass is 50% of virgin biomass level

F/K - Fishing mortality-rate-to-growth coefficient ratio

F_{max} - Fishing mortality where yield (or index of it) is maximized

F_{MSY} - Fishing mortality rate at or producing **MSY**

FAO - Food and Agriculture Organization of the United Nations

FiSAT - **FAO-ICLARM** stock assessment tools

FMA - Fisheries management area

GSI - Gonado-somatic index

G_w - Gonad wet weight

ICLARM - International Center for Living Aquatic Resources Management

IT - Information technology

k - Unexploited stock size

K - von Bertalanffy growth coefficient/constant

L - Landings

L_{BAR} - Mean length, L_{BAR} method

LBB - Length-based Bayesian method

l_c - Length-at-first-capture, **(Y/R)'** method

L_c - Length-at-first-capture, **LBB** method

L_{c_opt} - Length-at-first capture that maximizes catch and biomass for given **f**

L_m - Length-at-first-maturity

L_{mean} - Mean length of exploited stock, **LBB** method

L_{opt} - Length at maximum biomass in the unfished stock

ln - Napierian or natural logarithm

LF - Length frequency

L_{inf} - Length at infinity of the von Bertalanffy growth equation

M - Natural mortality rate, expressed in annual terms ($year^{-1}$)

M_t - Natural mortality rate at age **t**

MAO - Municipal Agriculture Office

M/K - Natural mortality-rate-to-growth coefficient ratio

MSY - Maximum sustainable yield

MULTIFAN-CL - Multispecies fisheries analysis – catch-at-length method

NFRDI - National Fisheries Research and Development Institute

NSAP - National Stock Assessment Program

P/B - Production-to-biomass ratio

PMO - Program Monitoring Office

P_L - Proportion at a given length

q - Catchability coefficient

Q/B - Consumption-to-biomass ratio

r - Maximum intrinsic rate of stock increase

RP - Reference point

SEAFDEC - Southeast Asian Fisheries Development and Educational Center

SFP - Sustainable Fisheries Partnership Foundation

SPR - Spawning potential ratio

t_0 - Theoretical age at zero length of the von Bertalanffy equation

t_c - Age at capture

t_r - Age at recruitment

UBC - University of British Columbia

US - United States of America

WCPFC - Western and Central Pacific Fisheries Commission

W_{inf} - Weight at infinity of the von Bertalanffy growth equation

Y - Yield or catch

Y/f - Yield or catch-per-unit-effort

$(Y/f)_{now}$ - Yield or catch-per-unit-effort currently or for period being evaluated

$(Y/f)_{MSY}$ - Yield or catch-per-unit-effort at **MSY**

Y/R - Yield-per-recruit

(Y/R)' - Relative yield-per-recruit

Z - Total mortality rate, expressed in annual terms ($year^{-1}$)

EXECUTIVE SUMMARY

This report is the key output of a short-term consultancy commissioned by the Sustainable Fisheries Partnership Foundation (SFP) and implemented by the authors, in collaboration with the NSAP teams of Regions 5, 6, and 7 of the NFRDI-BFAR (Philippines).

The introductory portion of the report provides the context/background, objectives, and scope of the consultancy, including the terms-of-reference, provides information on blue swimming crabs and the fisheries for them, and describes the NSAP, which provides scientific inputs to the management of fisheries in the Philippines (including the BSC fisheries in the Visayan Sea).

The consultancy was implemented in three phases: Phase 1 – data review and evaluation of BSC data collected by NSAP Regions 5, 6, and 7; Phase 2 – methodological analysis options and corresponding methodological use guidelines for analyzing the available BSC data from NSAP Regions 5, 6, and 7; and Phase 3 – training and joint analyses using viable methods and available data from NSAP Regions 5, 6, and 7.

The Phase 1 section of the report provides a summary of work undertaken in pursuit of Phase 1 objectives on the BSC data collection process in Regions 5, 6, and 7, and the corresponding data submission, encoding, and management process employed by NSAP in the three regions. A synopsis of the main results and recommendations of the data review and evaluation are given at the end of the section – setting the stage for Phases 2 and 3 of the consultancy. Forty-eight BSC landing sites are being monitored in the Visayan Sea area for BSC stock assessment purposes.

For each landing site, a designated enumerator collects data for 20-21 days per month. The sampling involves two consecutive days of monitoring the landing site, followed by a non-sampling day for other activities, including data transcription into standard (paper) forms, consolidation of data gathered, and collection of price information beyond the landing site (*e.g.*, in the market/Talipapa, picking and processing stations). The cycle is repeated until 20-21 sampling days in the month are completed. The BSC data collection program of Regions 5, 6, and 7 involves sampling of landings at the selected landing sites (with corresponding landings, effort, and species composition data), stratified by type of fishing gear. Proportional sampling of BSC and other species comprising landings is done to get carapace width (CW) or length composition data. Maturity and price information (together with gonado-somatic index (GSI), maturity, and length-weight data for earlier years) are also collected. The sampling frequency for BSC is twice that which is being conducted by the NSAP regular fish landing monitoring program. The NSAP Project Leaders in Regions 5, 6, and 7 have increased the sampling frequency to improve sample sizes generated (and hence the representativeness of the BSC samples). The BSC landings monitoring has been ongoing for Regions 5, 6, and 7 from 2015 to the present, resulting in a four-and-a-half-year time series data of landings, effort, species, and size composition by gear type (together with prices and maturity data). Region 6 has additional data from late 2010 to the end of 2012. The monitoring and sampling protocols applied are consistent with current best practices in generating representative samples for stock assessment purposes.

The BSC data collection program appears sufficiently robust and broadly aligned with best practices for stock assessment purposes. While recognizing the considerable efforts expended and the quality of the existing data (and the consistency of the data collection process with best practices), a number of recommendations to further improve the data collection program and subsequent use of the data for stock assessment purposes are made, including with respect to the generation of reference points for fisheries management. Fifteen key recommendations are outlined for consideration by NSAP management and regional NSAP teams, in order to: (1) improve and enrich data collection (in terms of additional information that may be collected cost-effectively given ongoing monitoring activities); (2) improve data submission, encoding, and management; and (3) improve and accelerate data analysis and provision of advice from available NSAP BSC data from Regions 5, 6, and 7.

The Phase 2 section of the report provides an overview of the analysis options viable for Regions 5, 6, and 7. Traditional or conventional stock assessment approaches (Surplus Production of Schaefer, 1957 and Fox, 1970, Relative Yield-per-Recruit, Maturity Data and Length-at-first-Maturity, and Recruitment Pattern Analysis) applicable to the available BSC data for elaboration of reference points are discussed. The report then does the same for relatively new and potentially useful analytic approaches (mean length (L_{BAR}) method; spawning potential ratio (SPR) method; length-based Bayesian method (LBB); catch MSY (or MSY estimation method using catch data, CMSY), and abundance maximum sustainable yield (or MSY estimation method using abundance maximum sustainable yield, AMSY), and supplemental/ecosystem approaches). The conceptual background and data requirements inherent in these methods are briefly discussed, and their utility in providing RPs given available BSC data are examined. Treatment of the methods considered viable is further expanded with the provision of technical analysis guidelines.

The analytical methods and relevant guidelines were designed to be utilized under Phase 3 (during the training and joint analyses work with the NSAP teams), covering the various methods.

The Phase 3 section of the report provides a synopsis of the training and joint analyses phase of the consultancy. A summary of the main outcomes (reference points and assessments) from the training and joint analyses workshop conducted in Iloilo City (Philippines) during 25-27 September 2019 is presented. Key follow-up matters and recommendations to improve the reference points after the workshop and consultancy, are outlined. Twenty-four technical staff from Regions 5, 6, and 7 participated in the workshop, together with four observers from Region 4A, one observer from the NSAP Program Monitoring Office (PMO), and one observer from the Philippine Association of Crab Processors, Inc. (PACPI). The workshop simulated the work of “scientific working groups” intended to provide inputs to the Management Boards of Fisheries Management Areas (FMAs), specifically for FMA 11 or the Visayan Sea.

The workshop covered each methodological approach and derived reference points using the appropriate BSC data from Regions 5, 6, and 7. For each method, the workshop covered: (1) an overview of the theory underlying the method; (2) how the reference points were derived for the Visayan Sea BSC stock using NSAP data (for Regions 5, 6, and 7) with their associated technical analysis guidelines; (3) discussions on the utility of the reference point(s) derived; and (4) discussions of assessment process guidelines outlining “next steps” in the refinement and/or improvement of the reference points.

At first, stock structure of BSC in the Visayan Sea was considered, and it was concluded that the BSC in the Visayan Sea is most probably a single stock. This has substantial implications for the subsequent analyses, which excluded the need for separate analysis of BSC data from Regions 5, 6, and 7 (which are administrative, rather than biological demarcations). Combining data using appropriate raising factors across the three regions was feasible. Moreover, such an outcome allows for analyses of Region 6 data (the most extensive and complete) as representative of the Visayan Sea.

Assessments conducted indicated that the BSC stock in the Visayan Sea is highly overfished. Surplus production modeling (using Y/f versus f data for 1991 – 2012) shows that effort reduction of 28-33% from the 2012 effort level would be needed to return to catch rates at MSY. The (Y/R)' assessment indicates the need for reduction of fishing effort by about half (49%) from the 2018 level and an increase in length-at-first-capture to 11.5 cm (=L_m) from the current 9.75 cm to optimize (Y/R)' at viable (B/R). Analysis of maturity using 2011-12 data from NSAP Region 6 and recruitment patterns (from Mesa *et al.* 2018) point to April as a potential closure month (offering about an 8.3% reduction in effort). The length-at-first maturity (L_m) was estimated at 11.5 cm, which may be a viable minimum size limit to enable BSC to spawn before being fully exploited.

The use of new analytical approaches was considerably impacted by the lack of appropriate data for deriving reference points and credible assessments. For those that were used, the results derived were largely consistent with those obtained via conventional analysis approaches. The LBB method gave preliminary results that also indicated high exploitation rates (F/M = 3.1) and low length at first capture (L_{mean}/L_{opt} = 0.79; L_c/L_{c_opt} = 0.72), with very low biomass levels compared to those at MSY (B/B_{MSY} = 0.30) and virgin stock levels (B/B_0 = 0.11). This leads to low (Y/R)' level in 2018 (only 44% of that which can be obtained at MSY). Overfishing was also evident from the AMSY method results, with fishing mortality in 2001 in excess of 68% of that necessary to harvest at MSY. Moreover, BSC stock biomass in 2002 was only 41% of the biomass needed to generate MSY. The AMSY results are also preliminary. Note, however, that the preliminary results are consistent with the overfishing diagnosis from other methods, requiring substantive fishing mortality reduction (of 68%) to get to the F_{MSY} level by about 2002.

In some cases, where a method was deemed inapplicable because appropriate BSC data were unavailable (*e.g.*, CMSY), exercises using simulated or sample data were still conducted to develop participants' familiarity and confidence in the use of the method. Conceptual coverage of inapplicable methods was also done (*e.g.* L_{BAR}, SPR, MULTIFAN-CL, EwE) for participants to understand the methods and limitations in the available BSC data relative to the method, and to help NSAP staff explain why certain methods are not currently being used.

Overall, the results from conventional and new analysis approaches indicate that the fishing effort for BSC (from 1991 to 2018) in the Visayan Sea increased considerably, and overfishing has worsened during this period, requiring effort reduction by about a third (28-33%) by 2012 to about half (49%) by 2018. Moreover, increasing length-at-first-capture closer to L_m (11.5 cm) is desirable, as the L_{c_opt} may be too high for many stakeholders to accept.

This study produced reference points and assessments for the Visayan Sea BSC stock. These results may still be refined given other available BSC data in NSAP Regions 5, 6, and 7. Limitations in material, time, and immediate availability of appropriate data precluded the study from implementing such refinements. To address this, assessment process guidelines were discussed with workshop participants to guide future "next steps" beyond the current study. These "next steps" are outlined for each analysis approach, together with a summary of key reference points and assessment results generated by the study. Assessments and reference points are not static guides and should be refined and improved as new data become available. This is consistent with the "adaptive approach" and the principle of "using the best available scientific evidence" in fisheries management. Overall, the BSC reference points and assessments given in this study are considered sufficiently conclusive to be able to proceed with recommendations to correct fishing effort levels, increase BSC capture sizes, and introduce closed seasons and or closed areas.

1) Introduction

This report was completed during the course of a short-term consultancy between 27 May and 31 October 2019. It was commissioned by the Sustainable Fisheries Partnership Foundation (SFP) and implemented by the authors, in collaboration with the NSAP teams of Regions 5, 6, and 7 of the NFRDI-BFAR (Philippines). This section provides the context/background, objectives, and scope of the consultancy by detailing the consultancy terms of reference, providing information on blue swimming crabs and the fisheries for them, and describing the NSAP, which provides scientific inputs to the management of fisheries in the Philippines (including the BSC fisheries).

1.A) CONSULTANCY TERMS-OF-REFERENCE

This consultancy was intended principally to review historical blue swimming crab (BSC) data gathered under the National Stock Assessment Program (NSAP) for Regions 5, 6, and 7 and to design new approaches to data analysis to develop options for the most appropriate reference points for these fisheries. Moreover, it was also intended to train NSAP and National Fisheries Research and Development Institute (NFRDI) staff on new approaches to stock assessment analysis, elaborating guidelines for their reference. Specifically, the consultancy work required the following:

1. Review NSAP historical data/information collected in Regions 5, 6, and 7 as a basis for recommending/designing new approaches to data analysis to come up with reference points or propose new reference points.

2. Review and analyze the proposed real-time data catch landing submissions from the field enumerators that could be transmitted or tied up with the existing NSAP database system.

3. Consider NSAP's existing sampling scheme and protocol, review the data collection process to ensure it is aligned with the best stock assessment methodology and, if necessary, propose additional actions to improve/advance details of data to be collected.

4. Elaborate guidelines on new approaches to stock assessment analysis such as, but not limited to, the refinement of data inputs for the determination of spawning potential ratio (SPR); length-based Bayesian (LBB) model, CMSY and AMSY, ecosystem-based analysis; and other approaches that are within the bounds of data collected.

5. Ensure that the results indicators used for stock assessment could also be used by the BSC export industry stakeholders in meeting the requirements of international sustainable fishery standards/certifications.

6. Train NSAP and NFRDI personnel on new approaches to stock assessment analysis (point 4).

7. Give guidance to trained personnel in applying the new techniques introduced for stock assessment analysis.

1.B) THE BLUE SWIMMING CRAB (BSC), *PORTUNUS PELAGICUS* (LINNAEUS 1758)

The **BSC** is a true crab (*Infraorder Brachyura*) belonging to the family of swimming crabs (*Portunidae*). Its complete taxonomic classification is as follows (*www.marinespecies.org*):

Kingdom: *Animalia*

Phylum: *Arthropoda*

Subphylum: *Crustacea*

Superclass: *Multicrustacea*

Class: *Malacostraca*

Subclass: *Eumalacostraca*

Superorder: *Eucarida*

Order: *Decapoda*

Suborder: *Pleocyemata*

Infraorder: *Brachyura*

Section: *Eubrachyura*

Subsection: *Heterotremata*

Superfamily: *Portunoidea*

Family: *Portunidae*

Subfamily: *Portuninae*

Genus: *Portunus*

Subgenus: *Portunus (Portunus)*

Species: *Portunus (Portunus) pelagicus*

The species is widely distributed globally – from the Mediterranean in the west all through the Fijian islands in the east, from Japan in the north through southern Australia in the south. **BSC** occurs in shelf areas, particularly in sandy and sandy-muddy substrates commonly in 10-50 m depths, including areas near reefs, mangroves and seagrass, and algal beds (Carpenter and Niem, 1998, *www.Sealifebase.org*, *www.marinespecies.org*). The carapace of **BSC** is rough to granulose; males have a bluish color, and females are a dull green color. The appearance of the species is similar to *Portunus trituberculatus*. The distinction is that there are three frontal teeth and four spines in the merus of the chelipeds of *P. trituberculatus*, while there are four frontal teeth and three spines in the merus of the chelipeds in *P. pelagicus*. Juveniles of the species most commonly occur in intertidal, shallower areas, with movement and dispersal to deeper waters as the individuals grow larger. Maturity is usually attained within one year from birth, and feeding is on various sessile and slow-moving benthic invertebrates. **BSC** are almost exclusively carnivorous, rarely consuming plant material (Carpenter and Niem, 1998).

There are many more studies of **BSC** that cover various aspects of its systematics, biology, and fisheries. More recent studies outside the Philippines (cited here mainly for their coverage of key aspects of **BSC** population biology and compilation of population parameters) include, among others, Hewitt (2008) on BSC natural mortality and stock-recruit relationship; Ikhwanuddin *et al.* (2016) on embryonic development of BSC; Kamrani *et al.* (2010) on BSC stock assessment parameters and reproductive biology of BSC in the Persian Gulf; Sawusdee and Songrak (2009) on stock assessment parameters in Thailand; Sumpton *et al.* (1994) on BSC reproduction and growth in Moreton Bay, Australia; Svane and Cheshire (2005) on various aspects of the biology and spatial modelling in Australia; and Zainab *et al.* (2016) on stock assessment parameters in Pakistani waters and compilation of available growth and mortality parameters. In the Philippines, more recent studies include those of de la Cruz *et al.* (2015) on stock assessment in the eastern Visayas; Mesa *et al.* (2018) on stock assessment in the western Visayas; Nieves *et al.* (2013) on stock assessment in Sorsogon and San Miguel Bay; Romero (2009) on BSC population structure in the Visayan Sea and the Philippines; Safaie *et al.* (2013) on BSC growth and mortality; and Sienes *et al.* (2014) on genetic diversity across the Philippine archipelago (reporting that a putative BSC species distinct from *Portunus pelagicus* occurs in Philippine waters, impacting assessment and management of BSC in the country).

The studies cited above imply that there are at least two stocks of BSC in the Philippines, in the Visayan Sea and Tawi-Tawi waters. *Portunus pelagicus* have relatively fast growth rates, with K usually between 1.0 and 2.0 per year and L_{inf} between 15cm and 22cm carapace width (CW). Maturity is often reached during the first year of the lifespan, with spawning and recruitment occurring year-round, with 1-2 peaks in recruitment pattern. Being invertebrates, the BSC should have high annual recruitment variability. The length-at-first-maturity is usually reached around 10-12 cm CW. Stock death rates are also high, with natural mortality or M estimates (usually based on empirical equations derived from metadata analysis) typically at 1.0-2.0 per year. Exploitation rates of stocks reported are usually high, with fishing mortality (F) often exceeding M, particularly for BSC fisheries in the central Philippines (de la Cruz *et al.*, 2015; Mesa *et al.*, 2018; Nieves *et al.*, 2013).

The global catch of BSC in 2016 was at an all-time high of about 265,000 t, while aquaculture production during the same year was 29 t – down from a high of 41 t in 2014 (*www.fao.org*). The BSC fisheries in the Philippines have been reviewed by, among others, Ingles (2004), Chu *et al.* (2012), and Mesa *et al.* (2018). These reviews point to two eras in the development of the global BSC fisheries: (1) from the late 1940s to the early 1990s, when catches were mostly for domestic consumption and went up to a "first plateau," usually not exceeding 17,000 t/year; and (2) from the mid-1990s to the present when catches (due to combined domestic consumption and exports) increased to a "second plateau" of around 34,000 t/year. The second plateau is associated with the collapse of the *Callinectes sapidus* fishery in the Chesapeake Bay area of the US and the resulting increased demand for pasteurized frozen BSC imports into the US market. The major BSC fishing grounds in the Philippines (which account for about 90 percent of Philippine BSC production) are the inland seas of the Central Philippines, mostly connected with the Visayan Sea, including San Miguel Bay, Malampaya Sound, and waters off the Tawi-Tawi group of islands. Minor BSC crabbing areas include Lingayen Gulf, Manila Bay, and Honda Bay. The BSC fisheries are largely artisanal, and the main fishing gears used are gillnets, crab pots, and crab traps. BSC also appear in catches of trawls, seines, and push nets – but are incidental bycatch and not the targeted species of these gears.

Fisheries management issues in the Philippine BSC fisheries mainly include: excessive fishing effort (*i.e.*, overcapacity), growth overfishing, and high bycatch rates (Chu *et al.*, 2012; Ingles, 1996, 2003, 2004; Ingles and Flores, 2000; Mesa *et al.*, 2018). An updated BSC Management Plan is currently being developed by BFAR in response to these issues and includes measures to set a minimum size limit, limit fishing effort (number and size of fishing gears), set closed seasons/areas, and protect nursery areas of juvenile BSC. The plan is still largely in the process of deliberation and operationalization, and stakeholder consultations are still currently in progress in areas and fisheries to be affected.

1.C) THE NATIONAL STOCK ASSESSMENT PROGRAM (NSAP)

The NSAP was conceived with the following objectives (Santos *et al.*, 2017):

"**General:**

- To generate reliable data as basis in the formulation of policies for the management and conservation of the country's capture fisheries resources in order to attain sustainable utilization and conservation,

- To develop and institutionalize the capacity of BFAR Regional Offices in resource assessment and management.

Specific:

- To determine trends on seasonal distribution, relative abundance, size and species composition of the major capture fisheries resources in each fishing ground,

- To provide estimates of population parameters of the major capture fisheries resources in each fishing ground,

- To complement Bureau of Agricultural Statistics (now under the Philippine Statistics Authority) in the generation of species-specific fisheries statistics."

The activities and initial accomplishments of the program have principally focused on these general and specific objectives. For example, in 2009, based on NSAP parameters at that date, the Philippine country report to the Convention on Biological Diversity (CBD) contained assessments showing that 10 of the country's top 13 fishing grounds were already overfished. NSAP also contributed to numerous area-specific assessments covering Philippine fishing grounds via the BFAR technical paper series and other technical publications – providing assessment inputs for improved fisheries management in these areas. Large-scale closed seasons in the northern Palawan round scad fisheries, Davao Gulf pelagic fisheries, and Zamboanga Peninsula sardine fisheries were also enacted using NSAP assessment inputs.

The NSAP is currently overseen and coordinated by the Program Monitoring Office (PMO) based at the NFRDI, Quezon City. The PMO is led by a National Project Coordinator and Assistant National Project Coordinator, supported by technical and administrative staff. An NSAP team is designated for each of the country's 16 administrative regions, with operations managed by a Project Leader and Assistant Project Leader, who are supported by technical and administrative staff and field enumerators. Data on landings, effort, and size composition of catches are collected by the enumerators in selected major and minor landing sites, following guidelines adopted from FAO and guided mainly by protocols from the Western and Central Pacific Fisheries Commission (WCPFC). Major landing sites were defined as those where the landings are typically "large" and come from both commercial and municipal (artisanal) fishing boats. Minor landing sites were those where landings are typically "low" and come principally from municipal boats.

In 2015, NSAP monitored a total of 840 landing sites in 15 administrative regions of the country (with activities in the Cordillera Administrative Region or CAR, being inland, still to be initiated). For **Regions 5, 6, and 7**, the number of fish landing sites monitored is as follows:

Region 5 – 87 fish landing sites

Region 6 – 105 fish landing sites

Region 7 – 63 fish landing sites.

It is noted, however, that these fish landing sites are not the same as the BSC landing sites being monitored for BSC stock assessment (see below). An enumerator is usually assigned to monitor landings in two fish landing sites (one major and one minor landing site). Another enumerator is usually assigned when the major landing site is to be monitored – so that two enumerators work in tandem to monitor a major landing site. The sampling frequency consists of a three-day cycle. The first day is usually devoted to monitoring the major landing site, and the second day devoted to monitoring the minor landing site. The third day is typically "a rest day from sampling" to focus on data validation, processing, and transcription into standard (paper) forms. The three-day cycle is repeated for the rest of the month until each major and minor fish landing site is monitored 10-11 times during the month. The data are transmitted at the end of every month to the respective regional offices, and after validation/audit are normally transmitted to the **NSAP PMO** for entry into the **NSAP** central (national) database. A total of seven (7) standard (paper) forms are populated and submitted by the field enumerators to the regional office, and transmitted to the **PMO** (after validation and audit procedures). The standard (paper) forms contain mainly landings and species composition, effort (including boat and gear details), and species size composition data for the landing site during specific dates.

The **NSAP** central database (**DB**) was first developed in 1997 (with assistance from the Secretariat of the South Pacific Community's Oceanic Fisheries Program). It was conceived as the national platform and repository of data generated by **NSAP**. The **NSAP** central **DB** consists of the national database and the regional databases. The national database is currently being managed by the **NSAP** Database/ **IT** Administrator (supported by **IT**, technical, and administrative staff) under the oversight of the **NSAP** National Program and Assistant Program Coordinator. The regional databases are under the supervision of the **NSAP** regional Project and Assistant Project Leaders. The **NSAP** central **DB** server is located within the **NFRDI**–Database Management Servers (**DBMS**), which is the main repository of **NFRDI**, containing all databases of the institution. The **NSAP** central **DB** contains, among others, routines for user login (with corresponding access protocols), data entry, editing, analysis, reports generation, queries, and administration.

It has been noted that uploading, documentation, and archiving of data to the **NSAP** central **DB** remains a continuing challenge (see Santos *et al.*, 2017). Changes in **BFAR** management and staff turnover often further complicate the challenges. The database is currently at version 6.0, and efforts to improve the database are continuing. For example, plans are underway to migrate the **NSAP** central **DB** from a stand-alone application to a web application, in an effort to improve accessibility to various (authorised) users. Expansion of the **DB** to include environmental, socioeconomic, and other information has also been proposed. These improvements need immediate attention, together with measures to address the challenges noted (as well as those given in the next section below).

2) Phase 1: Data Review and Evaluation

This section provides a summary of work undertaken during **Phase 1** of the consultancy engagement, the **BSC** data collection process in **Regions 5, 6, and 7**, and the corresponding data submission, encoding, and management process employed by **NSAP** in the three regions. A synopsis of the main results and recommendations of the data review and evaluation are given at the end of the section – setting the stage for **Phases 2** and **3** of the consultancy.

2.A) WORK/ACTIVITIES UNDERTAKEN

A number of work/activities were undertaken by the main author pursuant to Phase 1 objectives. These covered work implemented during the period 27 May to 08 June 2019, and are detailed chronologically in **Annex 1**.

2.B) DATA COLLECTION

The **NSAP** teams of **Regions 5, 6, and 7** deploy one field enumerator per **BSC** landing site to monitor landings (by boat or gear type) and related effort, species composition, and size frequency (specifically carapace width (**CW**) in the case of **BSC**) data. Each enumerator employs sampling stratified by gear type (to get landings, effort, and species composition). Proportional sampling of landings by species is employed to get size frequency data. The proportional samples for size composition are also used for reproductive biology studies on **BSC** (noting **CW** and maturity stage in a five-point scale, see Mesa *et al.*, 2018). Moreover, prices of **BSC** in the landing place are noted by the enumerator (as well as selling prices by brokers, in the market or Talipapa, and in the picking and processing stations). Collection of data for analysis of the **CW**-weight relationship, maturity, and gonado-somatic index (**GSI**) were done during the earlier years of the monitoring program

(2011-2012 and 2015 for Region 6; and 2015 for Regions 5 and 7), but has been largely discontinued with completion of analysis for relevant parameters.

The number of BSC landing sites being monitored in the Visayan Sea area for BSC stock assessment purposes total 48 landing sites. These are broken down by region, as follows:

Region 5 – nine landing sites (seven major and two minor landing sites);

Region 6 – 22 landing sites (14 major and eight minor landing sites); and

Region 7 – 17 landing sites (seven major and 10 minor landing sites).

Figures 1, *2*, and *3 (pages 42 and 43)* illustrate the geographical distribution of the BSC landing sites for Region 5, 6, and 7, respectively. It is worth noting that the 48 BSC landing sites currently being monitored in Regions 5, 6, and 7 are largely different from the fish landing sites being covered by the regular NSAP fish monitoring (see NSAP description above and Santos *et al.*, 2017 for a description of the NSAP fish landing sites and definition of major and minor landing places). The NSAP Project Leaders for Regions 5, 6, and 7 have periodically assessed the BSC data being collected, and have commendably added more landing sites to improve the coverage and frequency of the BSC samples (subject to budget availability).

For each landing site, the designated enumerator collects data for 20-21 days per month (depending on the total number of days in the month). The sampling involves two consecutive days of monitoring the landing site, followed by a non-sampling day for other activities, including data transcription into standard (paper) forms, consolidation of data gathered, and collection of price information beyond the landing site (*e.g.*, in the market/Talipapa, picking and processing stations). The cycle is repeated until 20-21 sampling days in the month are completed. The sampling frequency for BSC is twice that of the NSAP regular fish landing monitoring. The NSAP Project Leaders in Regions 5, 6, and 7 have increased the sampling frequency to improve sample sizes generated (and hence the representativeness of the BSC samples). The BSC landings monitoring has been ongoing for Regions 5, 6, and 7 from 2015 to the present (2019), resulting in time series data of landings, effort, species, and size composition by gear type (together with prices and maturity data) for four-and-a-half years. Moreover, Region 6 also has these data from late 2010 to the end of 2012.

2.C) DATA SUBMISSION, ENCODING, AND MANAGEMENT

Each of the field enumerators consolidate the data collected into standard (paper) forms and submit these with primary/field notes to the appropriate regional NSAP office on a monthly basis. Monthly salaries/payments to field enumerators are usually conditional on submission of monitoring data collected for the month. The data submitted are subjected to two "audit" levels prior to incorporation into the BSC database in each region. The first "audit" is conducted by the team of encoders based at the regional office (checking for data validity, outliers, species identification, etc.). Validation of questionable entries is done by the team of encoders with the field enumerator concerned before encoding is accomplished. The second "audit" of data submissions is done by the regional BSC Project Leader on encoded data (for outliers and potentially questionable entries). Only data that has passed through these two "audit" and validation levels are included in the regional MS Excel BSC database for each region.

Management of the BSC data and (Excel) database is currently done by the individual BSC Project Leader for each region, in collaboration with their respective team of encoders at the respective regional office. Incorporation or uploading of the BSC data into the central NSAP database has not been accomplished thus far for Region 6 (although this has largely been done for Regions 5 and 7). Failure to add the Region 6 data to the central NSAP database is due to two main reasons: (1) the extended time needed for processing primary data submissions from field enumerators at the regional BSC NSAP office – leading to the regional BSC NSAP team failing to submit data within deadlines prescribed by central NSAP database personnel, and (2) dissatisfaction with the query/output routines of the central NSAP database – leading to outputs that are difficult to use by the regional BSC NSAP teams (*e.g.*, length composition data submitted are reclassified by output routines into length classes with mid-points that are difficult to use for analysis and interpretation purposes). Improved coordination (and periodic dialogues) between the central NSAP database team and regional NSAP teams is necessary to address these issues. It is noted that the larger number of BSC landing sites in Region 6 contributes to the timing issues of uploading data into the central NSAP database. Moreover, limitations in dedicated staff (viz., with no "other" functions/responsibilities) comprising the central NSAP database team have also contributed to issues in uploading, updating, and use of the central NSAP database.

Treatment and analysis of data for various purposes is currently done by each of the BSC Project Leaders in Regions 5, 6, and 7 (in collaboration with their respective encoding and IT team). The use of Excel spreadsheets in this regard can be cumbersome and laborious at times, and will increasingly prove to be so as the data collection and data time series expands. Moreover, back-up and access issues will increasingly be contentious as the data collection program proceeds, partially due to demands for transparency being voiced by various sectors. The use of Microsoft Access (as a replacement for Microsoft Excel) for the regional DBs should be considered (as is already being done for the national NSAP DB). Sustainability and integrity of the data time series will also need attention with, among others, the natural turnover of personnel and its effect on the necessary institutional memory of the context of the data time series. Much effort and resources have obviously been dedicated by government in generating the BSC data time series. To build on this, data transmission and consolidation at the regional and national/central NSAP offices deserve attention in the near future.

2.D) DATA REVIEW RESULTS AND RECOMMENDATIONS

The BSC data collection program of Regions 5, 6, and 7 involves sampling of landings at selected landing sites (with corresponding landings, effort, and species composition data), stratified by type of fishing gear. Proportional sampling of BSC and other species comprising landings is done to get CW or length composition data. Maturity and price information (together with GSI, maturity, and length-weight data for earlier years) are also collected. The monitoring and sampling protocols applied are consistent with current best practices in generating representative samples for stock assessment purposes (see, for example, Cadima, 2003; Cadima *et al.*, 2005; de Graaf *et al.*, 2014; FAO, 1999, 2000, 2003; SEAFDEC, 2004; Sparre and Venema, 1998a and b; Stamatopoulus 2002). The NSAP teams of Regions 5, 6, and 7 have done a commendable "adaptive" approach to improve sampling frequency, coverage, and size of their sampling program. The periodic review process they have instituted has proven to be productive, and has had positive impacts on improving their data collection program. Data collection programs are usually judged on the basis of the following criteria: (1) timeliness, (2) accuracy and precision, (3) cost-effectiveness, and (4) utility ("useability") (see Cadima *et al.*, 2005; de Graaf *et al.*, 2014; FAO, 1999, 2000, 2003; Sparre and Venema, 1998a). The NSAP data collection program is best judged considering the full cycle from data collection to management, analyses, and provision of management advice. NSAP management should bear these criteria in mind in the case of the BSC work and the larger NSAP monitoring program. The BSC data collection program, at this juncture, appears sufficiently robust and broadly aligned with best practices for stock assessment purposes, although some improvements are advisable.

While recognizing the considerable efforts expended and the quality of the existing data (and the equivalence of the data collection process with best practices), a number of recommendations are still worth considering. This is to further improve the data collection program and subsequent use of the data for stock assessment purposes (particularly with respect to the generation of reference points for fisheries management).

A number of challenges and corresponding recommendations have been mentioned above relevant to the NSAP data collection and management process. Additional recommendations are outlined below for consideration by NSAP management and regional NSAP teams:

1. Clarify and emphasize the conceptual difference between monitored landings (**L**) and estimates of total catch. This has repeatedly been done in various NSAP trainings and meetings throughout the years, but still remains a conceptual challenge among members of the NSAP teams nationally and regionally. It is typically total catch (and corresponding effort and length composition) that is used in stock assessments, and not landings information (which is only a part of total catch). For example, plotting total landings (**L**) versus effort (**f**) in monitored landing places in Schaefer modeling is incorrect, as total landings are only a part of total catch or extraction from the stock. Moreover, effort in the monitored landing places is only a part of the total effort exerted on the stock by the entire fisheries. It is important in this regard to be able to conduct effort or gear inventories (*i.e.*, number of fishing units and number of days of operation per year by gear type) to be able to "raise" or estimate the total catch from the monitored landings data. Effort inventories (at least once a year, or quarterly if feasible) should be programmatically included in the NSAP work to complement the landings data collected by the field enumerators. Failure to do so delimits the analytical approach and/or models that can be utilized to provide reference points for fisheries management purposes. For upcoming landings monitoring, effort/gear inventories should thus be done to complement the ongoing data collection program. The Region 6 NSAP team has done this for 2011 and 2012, and budgetary limitations should be addressed to enable this work to continue, as well as for Regions 5 and 7. For past data time series where gear/effort inventories were not conducted, "mining" the records of the Municipal Agriculture Officers (MAOs) and/or brokers may allow historical reconstruction of the effort/gears operating in the fishery in the past years. In addition, BFAR regional offices should have records of commercial boats that can be used to complement the municipal effort/gear information from the MAOs and/or brokers.

2. Inclusion of a system of grid squares so that landings data may be linked spatially to the area of operation of the fishing unit/gear being monitored can enrich the utility of the data being generated. For example, this would allow future use of the data in spatially explicit models (see, for example, the various contributions in Svane and Cheshire, 2005 and the work of Fournier *et al.*, 1998; Christensen and Walters, 2004; and Pauly *et al.*, 2000). Inclusion of spatial information in current data collection efforts can also potentially benefit the design and implementation of area closures or other spatial management measures in the future.

3. The current BSC data should be uploaded to the NSAP central database to ensure, for example, improved data management, access, security, back-up, analysis, tractability, and sustainable use. Product price and reproductive biology data currently collected by enumerators (particularly from Region 6) should also be included in the NSAP central database, and the other regions should also be encouraged to collect the same types of data. For example, analysis of costs and earnings by gear type can be informed by the price information, coupled with fixed, variable, and opportunity costs, which can be "mined" from records of operators and/or brokers (who frequently capitalize fishing operations). Analysis of value-added through the supply chain can later arise from the price information collected at the landings and from the brokers, markets, picking stations, processing stations, and exporters. Such economic information will likely prove useful in designing and implementing future management approaches and/or interventions.

4. Appropriate and more useful query/output routines of the NSAP central database should be developed, mindful of reporting and analysis requirements of (and in consultation with) both national and regional NSAP teams. Upload requirements and deadlines should be reviewed and reset, cognizant of field work conditions and regional office realities. NSAP central database personnel need to be better motivated in this regard and helped to deliver the necessary service-orientation and support role they should play for the NSAP central database, to serve its important purpose Periodic dialogues and team-building exercises among various national and regional teams should be considered to help address this issue.

5. Gear selectivity studies, principally on trawl, bottom-set gillnets, and crab pots/traps for BSC, are needed. Aggregation of data from the various gears (*e.g.*, length composition) typically requires raising in proportion to the contribution to total catch and correction for gear selectivity (*e.g.*, selection and deselection by length). More information on gear selectivity, including by region and season, should help improve the "representativeness" of the data, help standardize data treatment, and help improve assessment results.

6. Transitioning from purely paper-based data collection to paper-cum-electronic data collection at the level of the field enumerators should improve accuracy, timeliness, and cost efficiency of data collection. There no longer appears to be any stumbling block in this direction in terms of IT and communications technology requirements. Budgetary limitations (*i.e.*, for acquisition of tablets and data transmission), however, should be given attention, mindful of the benefits and costs associated with transitioning to electronic recording (see, for example, Hatfield Indonesia, 2019 and the Oceans Project website hosted at *www.seafdec.org*). Electronic recording should avoid the "flood" of data that comes in at the end of every month (particularly from Region 6), making submission, encoding, "audits," acceptance, and transmission of data collected a continuous process throughout the month. If electronic transcription proves difficult to do at the actual landing sites, field enumerators can use every third day for transcribing data electronically (instead of paper-based consolidation of data collected over the previous two days). This makes submission of data every three days feasible, and being in electronic format would save the NSAP team at the regional office from the requirements of encoding, freeing up more time for data "audit" and validation.

7. Periodic refresher courses on species identification (taxonomy) and fisheries stock assessment are necessary for the regional NSAP teams, including for the field enumerators. This should provide the NSAP teams with better skills, understanding, appreciation, and motivation for the work they are doing. Such periodic courses are also necessary to keep the team's skills base up-to-date, given the turnover in personnel comprising the NSAP teams in the various regions, and may also help with some motivational issues.

8. Serious attention should be given by the BFAR and NFRDI management to improving job security and exploring a "career track" for NSAP field enumerators and personnel. The current (rolling) three-to-six-month job orders for most NSAP field and regional personnel leads to job insecurity and relatively high staff turnover, which may lead to future instability and questions on sustainability of the "NSAP system." High levels of staff turnover will also tend to lead to poorer data quality.

9. Onboard monitoring and sampling of catches during fishing operations by gear type (in addition to monitoring at landing sites) should be considered by NSAP management and NSAP regional teams. An annual (or quarterly, if feasible) sampling should provide estimates of the quantitative difference between catches (*i.e.*, what is extracted from the sea/stock) and landings (*i.e.*, what is brought/landed in the landing sites). This can enable estimation of discards, field consumption, field sales, egg removal rates (viz., removal of mature gonads), and proportion of the catch set aside for home consumption. This can lead to raising factors that can be used to correct landings data to actual catch data (or true catch or actual extraction from the fishing ground, which is

what is typically used for stock assessment purposes). Noting of environmental information (*e.g.*, bottom water temperature, pH, salinity, dissolved oxygen, substrate) and grid square location during onboard monitoring should open the possibility for studies relating fisheries abundance and environmental conditions, especially if GPS systems can be used in the future (see, for example, the contributions in Svane and Cheshire, 2005).

10. Sampling the size (**CW**) composition of the **BSC** in picking and processing stations should be considered, as validation checks on the size distribution being recorded in the landing sites (and being used for size-based assessments). This may be informative where minimum size limits exist or are being considered, and could be done in conjunction with the collection of price information from these locations by the field enumerators.

11. Field enumerators should be encouraged to collect consistent data (*e.g.*, species and size compositions of crabs and other species comprising landings by gear type), with periodic monitoring to ensure consistency. While the primary focus of the monitoring is the **BSC**, information on the bycatch of various gears is important in assessing gear or "technological" interactions at a subsequent stage. Such assessments are useful in management efforts to address fishing gear competition and conflicts, as well as wider ecosystem impacts of fishing. This is especially of interest in areas where the fisheries interact with endangered, threatened, or protected species.

12. The "mining" of the literature for feasible parameters for use in Ecopath modeling in the Visayan Sea (*e.g.*, number of trophic groups and biomass estimates, production-to-biomass ratios or total mortality **Z**, ecotrophic efficiency, diet composition, and consumption-to-biomass ratio for each of the trophic groups) (see Ecopath treatment given in Christensen and Walters, 2004; Pauly *et al.*, 2000; Steenbeck *et al.*, 2016). The existing **NSAP** data are still quite a distance from ecosystem approaches (given their data input requirements), but constructing preliminary trophic models (using largely existing Ecopath models and parameters for very similar tropical ecosystems such as the Visayan Sea) should be considered in the medium-term future (three-to-five years). This is because current assessments (and reference points) are specific to the current ecosystem situation or "steady state." It is useful in the future to explore if these will be robust with changes in abundance of other species or trophic groups (that constitute the prey and predator of the BSC).

13. Assignment of full-time or dedicated staff (free from other tasks/responsibilities) should be considered by NSAP management for the NSAP national database team and the NSAP national technical team. The current complement or number of staff may seem sufficient, but may be problematic if staff are assigned various other tasks apart from their NSAP work. The proportion of time actually spent on NSAP may at times be very limited. Addressing this issue should allow accelerated and timely uploading of data from the regions, as well as their accelerated and timely consolidation and analyses. Note that the recent resignation of the principal IT person in charge of the NSAP national database is impacting the update and use of the database.

14. Assignment of full-time, dedicated technical analysts (free from other tasks or responsibilities) to accelerate the analyses and publication of NSAP results should be considered by NSAP management. These analysts may be given specific regional or fisheries management area (FMA) responsibilities in producing analyses and advice to NSAP management. The technical analysts may be supported by the establishment of technical working groups composed of internal (NFRDI) and external experts (academics or consultants) to accelerate timely assessments and provision of advice using NSAP data.

15. The NSAP system was initiated in 1997, now more than 22 years ago. An independent and systematic (external) evaluation of NSAP is needed to assess its utility (considering usability, timeliness, accuracy/precision, and cost-effectiveness), productivity and impact, and directions/measures for system improvement, among others. NSAP in 1995 was conceived with the widespread popularity (and influence among Philippine fisheries scientists) of the ICLARM (now WorldFish) stock assessment framework, influencing its model-based sampling and data generation design. It is opportune to objectively revisit the system at this stage, and chart its future development and directions.

3) Phase 2: Analysis Options and Guidelines

This section provides an overview of the analysis approaches that were deemed viable given the nature of the available NSAP BSC data for Regions 5, 6, and 7. It first covers the activities undertaken during Phase 2 of the consultancy engagement. It then proceeds to cover appropriate traditional or conventional stock assessment approaches (surplus production, relative yield-per-recruit, maturity data and length-at-first-maturity, and recruitment patterns) applicable to the available BSC data for the development of candidate reference points. It then proceeds to do the same for the relatively new and potentially useful analytical approaches (L_{BAR}, SPR, LBB, CMSY, AMSY, and supplemental or ecosystem approaches) that have been suggested to be viable for analyses of the BSC data. Technical guidelines in conducting the analyses and development of candidate reference points from approaches that were deemed viable are also given. Overviews of the analytical approaches and relevant guidelines were designed to be used during Phase 3 (during training and joint analyses work with the NSAP teams), covering applicable methods.

3.A)WORK/ACTIVITIES UNDERTAKEN

The main work and activities undertaken in pursuit of Phase 2 objectives are given chronologically in Annex 1. This includes the work conducted from 14 June to 17 September 2019.

3.B) CONVENTIONAL ANALYSES AND RELATED GUIDELINES

In the following sections dealing with assessment methods and approaches to developing candidate reference points, there are many methods that use "length," which is the most common measurement of size in fish. However, for BSC, size is more usually measured as carapace width (CW), and CW should be substituted into all methods that describe using length.

This sub-section covers conventional analysis approaches for elaborating reference points (and related technical guidelines) that are applicable to the existing BSC data in Regions 5, 6, and 7. It covers the following modelling approaches: surplus production analysis (Schaefer, 1957 and Fox, 1970), relative yield-per-recruit analysis, analysis of maturity data, and analysis of recruitment patterns. These methods/approaches have previously been the subject of trainings conducted for the NSAP staff and officials, such that only brief overviews of the theory behind the methods are covered, with emphasis given to the technical guidelines for estimating relevant parameters and RPs, together with their interpretation and use for fisheries management. These guidelines were used and discussed with NSAP Regions 5, 6, and 7 staff during the training and joint analyses phase of the consultancy (Phase 3, see below), using available BSC data. In cases where the relevant regional BSC data were not available (or deemed inappropriate), data from Mesa *et al.* (2018) were used for exercises to give trainees/participants the needed familiarity and confidence in the use of the methods.

3.B.1) Surplus Production Models

The theory behind surplus production models has been covered at length by a number of authors (see, for example, Caddy, 1980; Cadima, 2003; Gulland, 1983; Pauly, 1984; Ricker, 1975; Sparre and Venema 1998a and b). The basic model was first introduced by Graham (1935) and more widely popularized by its use by Schaefer (1954, 1957) in the assessment of yellowfin tuna in the eastern tropical Pacific Ocean. The Schaefer (1957) model is premised on, among others, the assumption that the growth of a fish population (in terms of biomass) through time can aptly be described by the logistic equation. A fish population newly introduced into a finite ecosystem will grow in biomass until it reaches the maximum carrying capacity of the ecosystem due to limited food availability. The biomass growth through time is described by a logistic curve.

Ricker (1975) gives a very good and concise explanation for the logistic curve in fish population growth (worth quoting here directly rather than restating), as follows:

"**1.** Near maximum stock density, efficiency of reproduction, and often the actual number of recruits, is less than at smaller densities. In the latter event, reducing the stock will increase recruitment.

2. When food supply is limited, food is less efficiently converted to fish flesh by a large stock than by a smaller one. Each fish of the larger stock gets less food individually; hence a larger fraction is used merely to maintain life, and a smaller fraction for growth.

3. An unfished stock tends to contain more older individuals, relatively, than a fished stock. This makes for decreased production, in at least two ways:

(a) Larger fish tend to eat larger foods, so an extra step may be inserted in the food pyramid, with consequent loss of efficiency of utilization of the basic food production.

(b) Older fish convert a smaller fraction of the food they eat into new flesh – partly, at least because mature fish annually divert much substance to maturing eggs and milt."

The first derivative of the logistic function is parabolic in shape, implying that the highest "surplus production" or yield from the stock may be derived at an intermediate level of stock abundance (*e.g.*, at 50 percent of virgin stock abundance), fishing mortality (**F**), or fishing effort (**f**). Fox (1970) introduced a modification to the Schaefer (1957) model illustrating that empirically the plot of yield (**Y**) against effort (**f**) is better described by an exponential function. The Fox (1970) model is more appropriate for population growth in biomass terms (given that the logistic equation was adopted from models of human population growth in numbers). Moreover, he showed that the decline in catch-per-unit-effort (**Y/f**) with increasing effort (**f**) is empirically better described by a negative exponential (rather than a linear) function. The model of Fox (1970) usually gives more conservative estimates of **MSY** and (higher) fishing effort generating **MSY** (f_{MSY}) for the same yield (**Y**) and fishing effort (**f**) time series. Pella and Tomlinson (1969) introduced a generalized surplus production model to handle varying empirical trends in the plots of **Y** versus **f** (although this and other modifications of the model to correct assumptions of the basic surplus production models will not be covered further in the current treatment).

The equations for the Schaefer (1957) and Fox (1970) models are (in the notation of Sparre and Venema, 1998a), as follows:

$Y_i/f_i = a + b*f_i$, for f_i less than or equal to $-a/b$	*(Schaefer, 1957)*	*[Eq. 1]*
$ln(Y_i/f_i) = c + d*f_i$	*(Fox, 1970)*	*[Eq. 2]*

where: **f**(**i**) is fishing effort in year **i** (for **i** = 1, 2, … n); **Y**(**i**) is yield (catch in weight) for year **i**; **a** and **c** are the intercepts of the linear regression; **b** and d are the slopes of the linear regression; and **ln** is the natural logarithm sign. From these formulations, the following may be computed:

$MSY = -0.25*(a^2/b)$	*(Schaefer, 1957)*	*[Eq. 3]*
$MSY = -(1/d)*exp(c-1)$	*(Fox, 1970)*	*[Eq. 4]*
$f_{MSY} = -0.5*(a/b)$	*(Schaefer, 1957)*	*[Eq. 5]*
$f_{MSY} = -1/d$	*(Fox, 1970)*	*[Eq. 6]*

where **exp** is the base of Napierian logarithms. The **MSY** and f_{MSY} derived from these models are used as limit reference points (rather than target **RP**s due to inherent data and natural uncertainties) for many fisheries. The $f_{0.1}$ (fishing effort where the slope of the surplus production curve is 10 percent of that at near zero **f** levels) is now taken as a target reference point for the fisheries modeled.

Technical guidelines for the computation of reference points using the Schaefer (1957) model include the following:

Step 1: Prepare the Y_i time series. Check and confirm that the **Y** estimates for each year **i** are unbiased estimates of total catch or extraction from the fish stock under investigation. Check and confirm that correct raising factors were used in aggregating the catch from all gears and landing places. Confirm that catch from both monitored and non-monitored fishing effort and landing places are included.

Step 2: Prepare the f_i time series. Check and confirm that the **f** estimates for each year **i** are unbiased estimates of total fishing effort used to exploit the fish stock under investigation. Confirm that correct raising factors were used in aggregating the fishing effort from various gears and landing places. Confirm that fishing effort from both monitored and non-monitored landing places are included in the effort estimate for each year **i**.

Step 3. Compute for the Y_i/f_i time series. Review plots of Y_i versus f_i and Y_i/f_i versus f_i. Confirm that there are sufficient Yi and Yi/f_i observations through the range of f_i. (Note: A frequent challenge in **NSAP** data is the lack of data points in the ascending part of the surplus production curve; check that this is not an issue. If it is an issue, consider using other viable approaches/ methods. See, for example, **CMSY** and **AMSY** below.)

Step 4: Run the Yi/f_i versus f_i time series through the linear regression software/app. Note the slope and intercept from the linear regression and compute for the **MSY** and f_{MSY} values. Examine these values and their utility as limit **RP**s for **BSC** in the region.

Step 5: Note the standard deviation and confidence limits of the intercept and slope estimates. Check that these are within acceptable limits (*e.g.*, standard deviation and 95-percent confidence limits about the mean are not too wide, resulting in **MSY** and f_{MSY} estimates that have wide ranges).

Step 6: Estimate the $f_{0.1}$ value from the model using the slope and intercept estimates obtained. Examine the utility of the $f_{0.1}$ value as target reference point (**RP**) for the **BSC** fisheries in the region.

The guidelines for computing the **RP**s for the Fox (1970) model consist of the same six steps enumerated above for the Schaefer (1957) model, except that Steps 3 and 4 are modified, as follows:

Step 3. Compute for the **ln** Y_i/f_i time series. Review plots of Y_i versus f_i and **ln** Y_i/f versus fi. Confirm that there are sufficient Yi and **ln** Yi/fi observations through the range of f_i. (Note: A frequent challenge to **NSAP** data is the lack of data points in the ascending part of the surplus production curve; check that this is not an issue. If it is, consider using other methods. See, for example, **CMSY** and **AMSY** below.)

Step 4: Run the **ln** Yi/f_i versus f_i time series through the linear regression software/app. Note the slope and intercept from the linear regression and compute for the **MSY** and f_{MSY} values. Examine these values and their utility as limit **RP**s for **BSC** in the region.

There are many criticisms regarding the assumptions and limitations of the (basic) Schaefer (1957) and Fox (1970) models that are found in the literature. These include, among others, the following: **(1)** failure to explicitly incorporate the actual population processes that generate growth and death in fish populations; **(2)** the steady state or equilibrium assumption (that the stock has stabilized to current fishing or environment); **(3)** the deterministic nature of the models; **(4)** the assumption of constant catchability over extended time periods (ignores "learning" and improved fishing efficiency through time); **(5)** environmental factors are ignored; **(6)** trophic interactions are ignored; **(7)** requires a large range of fishing effort (both high and low); **(8)** ignores migration (evidently a sampling problem); **(9)** abundance index (catch-per-unit-of-effort) is proportional to true abundance (biomass) of the stock; and **(10)** fishing is density-independent. Modifications to the basic models are many and varied, in attempts to address the assumptions and limitations inherent in the model (see, for example, Froese *et al.*, 2016; Pauly, 1979; Sparre and Venema, 1998a). The basic surplus production models, however, have remained widely used (with varying success), due to their simplicity (needs only catch and effort data), cost-efficiency (requiring relatively few and more available (catch and effort) input parameters), the fact that they do not need age structure of the stock, and empirical consistency with catch and effort trends in many fisheries, particularly in data-sparse, tropical fisheries.

3.B.2) Relative Yield-Per-Recruit

The Beverton and Holt (1957) model explicitly incorporates the population processes responsible for biomass addition to the stock (growth and recruitment) and biomass removal from the stock (natural and fishing mortality). Yield is computed on a per-recruit basis, removing the uncertainties associated with estimating recruitment, and focusing the computation of yield on the relative dynamics between growth and mortality processes of the population. The basic model incorporates growth using the von Bertalanffy growth equation (expressed in terms of weight), the exponential decay equation to describe population decline in numbers through time/age, constancy of natural mortality (**M**) through time/age, and sums yield-per recruit through the non-exploited and exploited phase of the population. The Beverton and Holt (1957) model, in the notation of Sparre and Venema, 1998a), is as follows:

$$Y/R = F*\exp[-M*(t_c - t_r)] * W_{inf} * \{(1/Z) - (3s/Z+K) + (3s^2/Z+2K) - (s^3/Z+3K)\} \quad [Eq.\ 7]$$

where:

$s = \exp[-K*(t_c-t_0)]$

K = von Bertalanffy growth constant

t_0 = von Bertalanffy parameter (theoretical age at zero length)

t_c = age at first capture

t_r = age at recruitment

W_{inf} = asymptotic body weight of the von Bertalanffy growth equation

F = fishing mortality

M = natural mortality

Z = **F**+**M**, total mortality.

The model is used to assess the fishing mortality (**F**) and age-at-first-capture (t_c) that maximizes (or optimizes) **Y/R** from the fish stock. Although the equation looks complicated, the theory behind the model is simple, and the equation is relatively easy to compute (using simple apps or Microsoft Excel). The biomass-per-recruit (**B/R**) is also computed in **Y/R** assessments to show the trend in **B/R** with variation in **F** and t_c. The **B/R** for a given **F** and t_c is computed by dividing the **Y/R** estimate by **F** (*i.e.*, **B/R** = (**Y/R**)/**F**).

Beverton and Holt (1966) simplified the basic Beverton and Holt (1957) model, requiring fewer parameters and moving to the use of lengths rather than ages in the assessment. The relative yield-per-recruit model introduced by Beverton and Holt (1966), in the notation of Sparre and Venema, 1998a, is as follows:

$$(Y/R)' = E*U\ M/K * [1 - (3U/1+m) + (3U2/1+2m) - (U3/1+3m)] \quad [Eq.\ 8]$$

where:

(Y/R)' = relative yield-per-recruit

m = (1-**E**)/(**M/K**) = **K/Z**

U = 1/ (l_c/L_{inf}), or fraction of growth remaining after entry into exploited phase

E = **F/Z**, exploitation rate or fraction of mortality caused by fishing

L_{inf} = asymptotic length of the von Bertalanffy growth equation

l_c = length-at-first-capture

and the rest as previously defined. The **(Y/R)'** is assessed as a function of **E** and **U**, **c** (=l_c/L_{inf}) or l_c. Typically, it is **(Y/R)'** as a function of **E** and **c** which are computed. The parameters E_{max} (exploitation rate producing maximum **(Y/R)'**), $E_{0.1}$ (exploitation rate where marginal increase in **(Y/R)'** is 10 percent of that at near zero **E** levels), and $E_{0.5}$ (exploitation rate where the stock is reduced to 50 percent of unexploited or virgin stock biomass) are usually computed and used as reference points. Specifically, E_{max} is usually used as the limit reference point, and $E_{0.1}$ is used as the target reference point. Relative biomass-per-recruit **(B/R)'** may also be computed by dividing **(B/R)'** with **F**. The **(B/R)'** corresponding to E_{max} and $E_{0.5}$ is examined and assessed relative to their acceptability in relative biomass (or abundance and catch-per-unit-effort) terms for the exploited stock.

Guidelines for the computation of reference points using the Beverton and Holt (1966) relative yield-per-recruit model include the following:

Step 1: Prepare the **BSC** length frequency (**LF**) (**CW** frequency for **BSC**) distribution time series. Convert the **CW** time series Excel files into relevant **ELEFAN** 0 files in **FiSAT** (Gayanilo *et al.* 2005). Print out the **ELEFAN** 0 files using the **ELEFAN I** routine in **FiSAT**. Check and confirm that the **LF** distribution samples are unbiased estimates of **CW** distribution of the **BSC** stock being assessed. Confirm that proper raising factors and data treatment were used in generating the **CW** distribution.

Step 2: Using the plot of the **CW** distribution time series in **ELEFAN I**, check that the data shows a "credible" semblance of modal progression through the **CW** classes. Compute for the parameters of the von Bertalanffy growth equation (L_{inf}, **K** and t_0) using **ELEFAN I** in **FiSAT**. Validate that the estimates are reasonable (using literature data). (Note: Other methods for estimating the growth parameters of the von Bertalanffy equation may be used. See, for example, Gayanilo *et al.*, 2005 and Sparre and Venema, 1998a for other options).

Step 3: Compute the parameter **Z** for the stock using the catch curve method in the **ELEFAN II** routine in **FiSAT**. Check and confirm that the estimates are reasonable (examining the points used in estimating **Z** using the descending part of the catch curve, as well as literature values for **BSC**). Estimate the parameter **M** using the empirical equation of Pauly (1980) in **ELEFAN II** of **FiSAT**. (**Steps 1-3** above may be largely skipped if previous estimates of growth and mortality parameters have been derived in previous analyses conducted by the **NSAP** team from **Regions 5, 6, and 7**. Checking and confirming that the input **LF** data are unbiased for the chosen method, however, should be retained.) (*Note:* Other methods for estimating the mortality parameters of the exponential decay model may be used. See, for example, Gayanilo *et al.*, 2005 and Sparre and Venema, 1998a for a sample of other viable options.)

Step 4: Generate the yield isopleth diagram using the relative yield-per-recruit (Beverton and Holt, 1966) routine in **FiSAT** and the growth and mortality parameters obtained in **steps 2** and **3** above. Estimate E_{max}, $E_{0.1}$ and $E_{0.5}$, and corresponding l_c for the **BSC** stock and examine the viability of using these as **RP**s for management of **BSC** in the region. Compute for the relative biomass-per-recruit corresponding to these **E** values and examine their acceptability in terms of catch rate and potential recruitment reduction.

Criticisms of the Beverton and Holt (1957, 1966) models are many and varied. These include questions about the assumption of constancy of parameters used throughout the exploited phase of the population, to the host of criticisms enumerated above for surplus production models. The popularity of the method to this day stems from, among others, its relative conceptual simplicity, relative cost effectiveness, conceptual tractability, length-based nature, and wide availability of computational routines (software/apps). Advice derived from the relative yield-per-recruit model, however, should be considered mindful of its various inherent limitations and assumptions.

3.B.3) Maturity Data and Minimum Size Limits

The **NSAP** team of **Regions 5, 6, and 7** collects data on maturity (or reproductive biology) of **BSC**. A five-point scale of female gonadal maturity (see Sumpton *et al.*, 1994; Mesa *et al.*, 2018) is used, as follows:

Stage I (Immature/Virgin): Non-ovigerous.

Stage II (Developing/Maturing): Ovigerous with pale-to-dark-yellow egg mass. No eyespots visible in eggs.

Stage III (Mature/Ripening): Ovigerous with yellow-grey egg mass. Eye spots present.

Stage IV (Spawning/Gravid): Ovigerous with grey egg mass. Eye spots and chromatophores discernible.

Stage V (Spent/Resting): Presence of egg remnants.

These data (proportion of mature females by length class) may be used to derive estimates of size-at-first-maturity (**$CW_m = L_m$**) for the **BSC** stock and used as input for setting minimum size limits (which can be used as a precautionary reference point). The theory behind the use of minimum size limits is based on the concept that stock reproductive capacity is protected (and thus the stock sustained) when fish are allowed to spawn at least once before they enter the exploited phase (or die).

Estimation of **CWm** starts with the assumption that the logistic curve describes the increase in proportion of mature fish (from zero to 1) as the fish grows in time (or through length classes). The logistic equation may be stated, with slight modification of the notation used by Sparre and Venema, 1998a, as follows:

$$P_L = 1/ [1 + (\exp^{a + b*L})] \qquad [Eq. 9]$$

where **P_L** = the proportion of mature fish in **CW** class **L**

exp = the base of Napierian logarithm

L = the mid-point of the **CW** class interval

a and **b** = constants.

For estimation purposes, the logistic equation is often linearized, as follows:

$$\ln [(1/P_L) – 1] = a + b*L \qquad [Eq. 10]$$

where **l_n** stands for Napierian logarithm, and the rest as previously defined. Note that the two equations above are undefined when **P_L** equals 0 or 1. It is thus important to bear in mind in the computations to exclude data for length intervals where zero or full maturity is obtained. The **CW** at which 25 percent (**$CW_{25\%}$**), 50 percent (**$CW_{50\%}$**), and 75 percent (**$CW_{75\%}$**) of fish are mature may be computed using the linear regression parameters derived as follows:

$$CW_{25\%} = (a – \ln 3)/ b \qquad [Eq. 11]$$

$$CW_{50\%} = a / b \qquad [Eq. 12]$$

$$CW_{75\%} = (a + \ln 3)/ b. \qquad [Eq. 13]$$

The value of **$CW_{50\%}$** is often taken as the size-at-first-maturity, **CW_m**.

Technical guidelines for the estimation of **CW_m** are as follows:

Step 1: Generate the proportion of mature **BSC** (by **CW** class) table using regional **BSC** data. It is best to aggregate these (through the months) for each year for which data are available. Check and confirm that the data are unbiased samples.

Step 2: Choose the data to include in the linear regression analysis (ensuring no 0 and 1 values of **P_L** are included).

Step 3: Run the data through available linear regression analysis app/software and derive the estimates of **a** and **b**. Confirm that the estimates of **a** and **b** are acceptable, examining the standard deviations and confidence intervals associated with the parameters.

Step 4: Compute for **$CW_{25\%}$**, **$CW_{50\%}$**, and **$CW_{75\%}$**. Choose the CWm to use.

Step 5: Examine the viability of using CWm as minimum size limit for the **BSC** fishery in your region. Check which gears catching **BSC** are landing crabs below the minimum size limit.

Data for the analysis of gonado-somatic index (GSI) is also collected by the NSAP team of Regions 5, 6, and 7. GSI (%) is computed (Ismen, 2002) by the teams, as follows:

$$GSI\ (\%) = (G_w/B_w) * 100 \qquad [Eq.\ 14]$$

where G_w = (total) gonadal wet weight

B_w = (total) body wet weight.

It is possible to examine the mean GSI (%) per month (within a given year) and potentially use the period around the peak or highest GSI (%) month as a precautionary reference point. The concept is premised on protecting the stock during peak reproductive months to maximize spawning success and recruitment to the stock. The use of peaks in % mature crabs plotted by month involves the same concept/principle. Complementary use of plots of GSI (%) by month and % mature individuals by month can be explored in examining viable closed season/period measures. The closed season/period may cover the entire fishing ground or only selected areas. Further supported by analysis of recruitment patterns (see below), these can prove useful for BSC fisheries management.

The technical guidelines for using maturity data in examining viable temporal measures or closed seasons/periods for the BSC fisheries include the following:

Step 1: Generate the table showing mean GSI (%) by month (for a given year). Check and confirm that the data are from unbiased samples and that correct raising factors were used in generating the table. Repeat the process for years where data are available.

Step 2: Plot the monthly mean GSI (%) table for each year. Note the peaks and the months they occur. Note if there is consistency across years when the highest mean GSI (%) occurs.

Step 3: Generate the table showing the % mature by month (for a given year). This involves, for each month, aggregating crabs in Stages II, III, and IV, divided by the total number of individuals (Stages I to V, inclusive). Check and confirm that the data are from unbiased samples and that correct raising factors were used in generating the table. Repeat the process for years where data is available.

Step 4: Plot the monthly % mature table for each year. Note the peaks and the month/s they occur. Note if there is consistency across years in the months when peaks in % mature females occur.

Step 5: Examine the consistency in the months/periods when GSI (%) and % mature individuals are at a peak. Check if these months/periods can be viably used as closed seasons/periods for the BSC in your region. Note that the temporal closure may cover the entire fishing ground or only selected areas of the fishing ground.

Step 6: Check consistency with results of analysis of recruitment patterns (see below) generated via ELEFAN II of FiSAT.

3.B.4) Recruitment Patterns

Recruitment in many tropical fisheries has been noted to occur year-round, with one or two peaks in recruitment observed for most stocks/species (Pauly 1979, 1984). Simply put, this is taken to mean that evolution has adapted (or "selected" individuals in) the stock/population in a manner as to maximize reproduction during periods when the convergence of factors leads to maximum survival of offspring and reproductive success. This leads to the elaboration of cohorts in the population, which is used in population dynamics studies (for example, in the estimation of growth parameters by tracing the modal progression through time of the cohort). A routine in ELEFAN II of FiSAT allows for the estimation of "recruitment patterns", via back-projection of length frequency distributions onto the time axis (Pauly, 1984; Gayanilo *et al.*, 2005). This leads to estimation of relative time period (*e.g.*, week or month) when recruitment pulses occur or are at a maximum in the span of a year. NSAP investigators have used these outputs to assess the number of recruitment pulses that are evident for given stocks (see, for example, Mesa *et al.*, 2018 and references therein). Extension of such analyses may be feasible, such that the time periods when peak recruitment pulses occur are noted, and examined for use as candidate reference points for temporal closures. Note that the "recruitment pattern" output from **FiSAT** is expressed in "relative time periods," and examination of the **CW** distribution is often done to "fix" or estimate the time periods when the recruitment pulse/s occur. The use of monthly data on **GSI** (%) and proportion of mature individuals (see above) may be used with length (**CW**) distributions (to examine early growth) and fix on the time period axis when the recruitment pulses occurred.

Given the high exploitation rates of fish stocks in the country, reduction of overall fishing capacity (fishing effort or fishing mortality) on the whole stock is evidently needed. Consideration, however, of temporal closures is gaining wide popularity among fisheries management authorities in the country. This may provide partial relief from the high exploitation rates – particularly in areas where fishing effort reduction is difficult due to enforcement, economic, social, and political factors. The relative costs and benefits (to various sectors and stakeholders) and sufficient consultations, however, should be considered, mindful of the long-term relative inefficiency (capital and labor) that is inherent in temporal/area closures.

Technical guidelines for estimation of reference points for potential time periods (*e.g.*, weeks or months) to use in temporal or seasonal closures are as follows:

Step 1: Prepare the **BSC CW** frequency (=**LF**) distribution time series. Convert the **CW** time series Excel files into **ELEFAN** 0 files in **FiSAT** (Gayanilo *et al.*, 2005). Print out the **ELEFAN** 0 files using the **ELEFAN I** routine in **FiSAT**. Check and confirm that the **CW** distribution samples are unbiased estimates of **CW** distribution of the **BSC** stock. Confirm that proper raising factors and data treatment were used in generating the **CW** distribution.

Step 2: Using the plot of the **CW** distribution time series in **ELEFAN I**, check that the data shows a "credible" semblance of modal progression through the length classes. Compute for the parameters of the von Bertalanffy growth equation (L_{inf}, **K** and t_0) using **ELEFAN I** in **FiSAT**. Validate that the estimates are reasonable (using literature data). (Note: **ELEFAN I** will provide estimates of growth parameters even minus any semblance of modal progression – which

is highly undesirable given its methodological foundation. In this situation, other methods for estimating the growth parameters of the von Bertalanffy equation should be considered. See, for example, Gayanilo *et al.*, 2005 and Sparre and Venema, 1998a for examples of other options).

Step 3: Generate the recruitment pattern for the **BSC** stock using the "recruitment pattern" routine in **ELEFAN II** of **FiSAT**. Approximate the time period when recruitment pulses occur using the plots of the **CW** distribution data, the **GSI** (%) data by time period, and the proportion of mature females by time period (mindful of early rapid growth in the species).

Step 4: Examine the utility and viability of using the time period when peaks in recruitment pulses occur as candidate reference points for temporal or seasonal closures. Among others, principal questions and discussions should include: enforcement viability; relative benefits and advantages to various fisheries, sectors, and stakeholders; and relative costs and disadvantages to various fisheries, sectors, and stakeholders. A temporal closure may cover an entire fishing ground or only selected areas, based on biological, economic, social, and or political considerations.

3.C) NEW ANALYTICAL APPROACHES AND RELATED GUIDELINES

This subsection covers relatively new analytical approaches for defining candidate reference points (and related technical guidelines) that were suggested to be applicable to the existing BSC data in Regions 5, 6, and 7. It covers the following analytical approaches: mean length (L_{BAR}) of the stock or population; spawning potential ratio (SPR); length-based Bayesian method (LBB); catch MSY (or MSY estimation method using catch data, CMSY), and abundance maximum sustainable yield (or MSY estimation method using abundance maximum sustainable yield, AMSY), and supplemental/ ecosystem approaches (Froese, 2004; Froese *et al.*, 2016a). The conceptual background and data requirements inherent in these methods are briefly discussed, and their utility in providing candidate RPs given the available BSC data are examined. Consideration of the methods deemed viable for the BSC data are further expanded with the provision of technical analysis guidelines. This was not done for analytical approaches that were deemed unsuitable given the available data.

The methods covered here have previously been the subject of a number of training events conducted with the NSAP staff and officials, such that only a brief overview of the theory behind each method is covered, with emphasis given to examination of their utility given the available BSC data. Technical guidelines for estimating relevant parameters and candidate RPs, together with their interpretation and use for fisheries management, were prepared for each of the applicable methods. These guidelines were used and discussed with the regional NSAP teams during the training events and joint analyses phase of the consultancy (Phase 3, see below). In cases where the regional BSC data were not available (or deemed inappropriate), data from Mesa *et al.* (2018) or sample data were used for exercises to develop familiarity and confidence in the use of the methods.

3.C.1) Mean Length (L_{BAR}) Method

The L_{BAR} method is used in stock assessment to provide estimates of total mortality rate (Z) given prevailing exploitation rates and conditions. The method is based principally on the concept that, given the exponential decay model describing the stock death process, the mean length of fish comprising the stock (L_{BAR}) decreases as Z increases. Clearly for BSC, the "length" measurement described here is carapace width (CW). The method is by no means new, but deemed by many as having potential utility given that it is length-based and requires few data inputs. The method in fact was first introduced by Beverton and Holt (1956), and is known in the stock assessment community as the "Beverton and Holt Z equation" method (Sparre and Venema, 1998a). The method was further refined by Powell (1979) and Wetherall *et al.* (1987) and extended to what is now known as the "Powell-Wetherall plot" for estimating Z. The method has gained popularity in tropical situations (see, for example, Ault *et al.*, 2005; Mesa *et al.*, 2018; Pauly, 1984; and Sparre and Venema, 1998a), and is used to estimate prevailing Z and fishing mortality rate, F (given a credible estimate of natural mortality M in the exploited stock, as F is equal to Z minus M). The estimated F is compared to RPs given optimum F (*e.g.*, F_{max}, $F_{0.5}$ or $F_{0.1}$), to examine exploitation status.

Beverton and Holt (1956) showed that the functional relationship between Z and L_{BAR} is (using the notation of Sparre and Venema, 1998a), as follows:

$$Z = K * [(L_{inf} - L_{BAR}) / (L_{BAR} - L')] \qquad [Eq. 15]$$

where L_{BAR} = the mean length of fish of length L' and longer

L' = the length for which all fish of that length and longer are under full exploitation (note: L' is the lower length class limit of the lowest length class where full exploitation begins)

K = the growth coefficient of the von Bertalanffy growth equation

L_{inf} = the asymptotic length of the von Bertalanffy growth equation.

L_{BAR} is typically computed from a (representative) length frequency distribution/sample of the stock, usually aggregated over a period of one year. As is evident, the L_{BAR} method provides estimates of the prevailing Z and F in an exploited stock, and does not itself (independently) provide any estimate of relevant RPs for the stock. For this reason, the method is not treated further in this report. (Interested readers, however, are referred to section 4.5.1, page 148 of Sparre and Venema, 1998a for a more detailed conceptual treatment and a worked example illustrating how parameters of the method are estimated).

3.C.2) Spawning Potential Ratio (SPR) Method

The SPR method is a widely-accepted approach in fisheries management for addressing recruitment overfishing in exploited fish stocks. It is based on the concept that a sufficient number of fish should be left in the sea (under prevailing exploitation rates) to reproduce, perpetuate, and sustain the stock. SPR is a measure of current egg production of the fished stock relative to the maximum possible egg production at the unfished stock level. The SPR is defined (Hordyk *et al.*, 2015a and b) as:

$$SPR = EP_{fished} / EP_{unfished} \qquad [Eq. 16]$$

where EP_{fished} is the egg production of the fished stock under prevailing exploitation conditions, and $EP_{unfished}$ is the egg production of the unfished stock.

Put simply, EP of the fished (and unfished) stock is computed as a function of population decline in numbers described by the exponential decay model, population growth in size described by the von Bertalanffy growth equation, the fecundity (number of eggs) at length function, proportion of mature fish at length function, and the vulnerability (selectivity) proportion at length function. SPR is computed for a given fishing mortality rate (F) from size composition data, and the F obtained is evaluated against alternative F scenarios and corresponding impact (increase or decrease) on SPR. Moreover, the prevailing F obtained is usually compared with an F reference point that optimizes SPR, generally SPR equal to 0.2 – 0.4 (from metadata and sensitivity analyses), that is most risk-averse to recruitment overfishing for many species with various life history strategies and/or population processes (Hordyk *et al.*, 2015a).

The SPR method assumes, among others, the following: (1) the stock is in equilibrium; (2) the size composition data are representative of the stock; (3) selectivity is asymptotic (dome-shaped selectivity underestimates SPR); (4) the population functions enumerated for the method above (exponential decay model, von Bertalanffy growth model, etc.) adequately describe the relevant population processes; and (5) both sexes have the same growth and the sex ratio is at parity (nearly 1:1), or that the length composition data and biological parameters pertain to females only.

It is noted with respect to the SPR method that:

- The data for BSC available in NSAP Regions 5, 6, and 7 do not allow for (direct) estimation of the fecundity and selectivity (vulnerability) at size functions. These were revisited, confirmed, and evaluated with the NSAP teams in the three regions. (Note that without the fecundity at size function, the method may be reduced to a spawning biomass-per-recruit or relative biomass-per-recruit approach. See relative biomass-per-recruit, above and Goodyear, 1993).

- The method does not provide any reference point independently. The SPR and F provided, as noted above, are compared with generally accepted RPs (optimum SPR and corresponding F) to assess exploitation status and recruitment overfishing.

- "With high variability in annual recruitment, the estimates of SPR became increasingly unreliable" (Hordyk, 2015a). Annual recruitment in BSC is highly variable, which is typical for invertebrate stocks that are r-selected in terms of life history strategy.

For these reasons, and principally because of the first bullet, the SPR method is not considered further in this report. The method, however, should be revisited in the near future (1-3 years) as the required fecundity and selectivity functions become available, keeping in mind the recruitment variability issue for **BSC**. (Interested readers are referred to Hordyk *et al.*, 2015a and b for more detailed explanations of the method. The **SPR** routines given, for example, in the FISHE (*www.fishe.edf.org*) or Murdoch University (*www.whatsthecatch.murdoch.edu.au*) websites provide Excel-based tools for estimating the required parameters of the method. Use of the method in assessing actual fisheries is given, for example, in Slipke *et al.* (2002) and Hordyk *et al.* (2015a). The **F** values leading to **SPR** of 0.2, 0.3, and 0.4 may be computed when appropriate selectivity- and fecundity-at-size functions become available for **BSC** in **NSAP Regions 5, 6, and 7**. The **SPR**s of 0.2, 0.3, or 0.4 may be considered as candidate reference points in the future, mindful of the limitations of the method for species with high recruitment variability.)

*3.C.3) Length-Based Bayesian (**LBB**) Method*

The **LBB** method was first introduced by Froese *et al.* (2016b) for assessment of fisheries in data-poor situations. It is deemed of high potential utility in typical data-limited tropical fisheries, as it only requires representative length frequency (**LF**) data as an input. It requires no information on age, maturity, selectivity, recruitment, growth, effort, or mortality, just representative **LF** data from the fishery.

The **LBB** method derives priors for asymptotic length of the von Bertalanffy growth equation (L_{inf}) and selectivity from aggregated annual **LF** samples, and assumes a prior relative natural mortality (**M/K**) ratio of around 1.5. Given these priors, **LBB** then performs Bayesian analyses of the annual **LF** data to simultaneously estimate L_{inf} , prevailing length at first capture (L_c), **M/K**, and relative fishing mortality (**F/K**) of the exploited phase of the stock. Put simply, the method (and implementing software) estimates the stock size structure (with the associated L_{inf}, L_c, **M/K**, and **F/K**) that best explains the **LF** sample from the stock. With these parameters estimated, **LBB** then provides an estimate of current biomass relative to virgin stock biomass (B/B_0) and current biomass relative to biomass producing **MSY** (B/B_{MSY}). This is done using a combination of standard fisheries equations (yield-per-recruit and related equations, Beverton and Holt, 1957, 1966). In addition, the method provides an estimate of length-at-first capture that would maximize catch and biomass for a given fishing effort (L_{c_opt}). The **LBB** method, moreover, proposes a reference point to evaluate whether the current stock size structure is indicative of a healthy stock. It proposes the mean length in an exploited stock relative to the length at maximum biomass in the unfished stock (L_{mean}/L_{opt}) as indicative of a healthy stock. The stock is healthy the closer the ratio is to unity. (Note that the L_{mean} from **LBB** is the same as L_{BAR} presented earlier. Different symbols and notations are used in this report to distinguish estimates obtained using the two different methods).

The parameter estimates provided by the **LBB** method may be used to guide management directions to optimize stock exploitation. For example:

- when L_c is lower than L_{c_opt}, consider fishing at larger sizes closer to L_{c_opt}
- when B/B_{MSY} is low, consider increasing capture sizes and reducing fishing effort/capacity
- when L_{mean}/L_{opt} is low, consider reducing fishing effort and increasing capture sizes to bring the ratio closer to unity.

The **LBB** method assumes, among others, that: (**1**) the **LF** data inputs are representative; (**2**) fish growth follows the von Bertalanffy equation, (**3**) stock death process follows the exponential decay model, and (**4**) inter-annual recruitment variability is not high (*i.e.*, strong recruitment pulses do not mask the real stock size structure that is caused by fishing). Users should be mindful of these assumptions in using the method. **LBB** is attractive, however, given its limited input (and therefore cost) requirements.

A recent (March 2019) training has been provided by Quantitative Aquatics to **NFRDI** scientists on the method (*www.q-quatics.org*), and the materials (*e.g.*, lectures, exercises and software) provided during this training may be consulted for more detailed consideration. In this regard, caution in the use of mortality estimates from **LBB** is emphasized. It should be remembered that the (relative) mortality estimates "are not recent," but pertain to a period equal to the mean generation time of the stock (under equilibrium).

Technical guidelines for use of the method include the following:

Step 1: Prepare the annual **LF** data input. Confirm that the **LF** data are representative samples, checking that proper data treatment and raising factors were used in their generation. Note the context and caveats regarding the **LF** data, if any.

Step 2: Format the **LF** data according to the **CSV** file templates: ComDat.CSV and Stock_ID.CSV.

Step 3: Source viable (growth) parameters which may be used as input priors.

Step 4: Install a recent version of **R** on your computer. **LBB** was tested under **R** version 3.4.4 and 3.5.0, available at *www.r-project.org/*, although newer versions should also work.

Step 5: Use RStudio as **R** development environment. RStudio is a free software available for use in several Operating Systems (*e.g.*, Windows, Linux, OS) and can be downloaded at *www.rstudio.com/products/rstudio/download/*.

Step 6: Install the Gibbs sampler JAGS for your Operating System from the web site *http://sourceforge.net/projects/mcmc-jags/files/JAGS/4.x/*.

Step 7: To run the code, several **R** packages are required. In the **R** Console, execute the following commands (*i.e.*, cut and paste into the Console window, then hit Enter and wait):

- install.packages ("R2jags")
- install.packages ("Hmisc")
- install.packages ("lattice")
- install.packages ("survival")
- install.packages ("Formula")
- install.packages ("ggplot2").

Step 8: Two different data files are required by **LBB**, which should be placed in the same directory as the script. The names of these files are specified in the code (line 20 for Stock ID info) and as first parameter in each line of the Stock ID file. Examples are provided with the code and their structure is specified.

Step 9: Make sure that the source file and the downloaded **R** script are in the same directory.

Step 10: Open the downloaded **LBB** script (**LBB**_11.R) in RStudio. Use the tab "Session" and select "Set Working Directory" to "To Source File Location", so the code will find the data files. Alternatively, in line 17 of the code, you can explicitly state your working directory.

Step 11: If you wish to use your own input files, just change the file name of the ID.File in line 20 and the name in the File column of the ID file for the respective stock. If you create your own input files, make sure you use the same headers (case sensitive) as in the provided example files. Make sure you are using comma-delimited (.csv) files (Note: You can look at the data in a simple text editor such as Notepad to check for consistent use of commas; semi-colons are not accepted.)

Step 12: The R-code can analyze all stocks, or a single stock can be specified in the "Select stock to be analyzed" section of the code, according to the stock identification specified at line 14. To specify the stock to analyze, just enter the unique name or identifier of the stock there (*e.g.*, Stock – "tur.27.4"). To make the code run on all the stocks in the ID-file, just comment out line 14 (put # in front).

Step 13: In RStudio, click on "Source" (or press Ctrl+A followed by Ctrl+R or Ctrl+Shift+S) to execute the code.

Step 14: When the run or analysis is complete, the results can be found in the console window, as well as the **LBB** graphs window (which can be saved manually).

Step 15: Note and examine the parameter estimates provided by **LBB** and evaluate their implications for management of **BSC** in the region. Note data input and method caveats and explore next analysis and/or refinement steps.

3.C.4) Catch MSY (CMSY) and Abundance Maximum Sustainable Yield (AMSY)

The **CMSY** method was first introduced by Froese *et al.* (2016b) for use in data-sparse situations when only catch data are available. While surplus production models (Schaefer 1957, Fox 1970) use time series of catch and effort data, the **CMSY** method uses time series of catch data with the resilience (**r**) of the species or stock. The basic biomass dynamics are governed by (the re-expressed Schaefer 1957 equation in biomass terms) function:

$$B_{t+1} = B_t + r\,[(1- (B_t/k)]\,B_t - C_t \qquad [Eq.\ 17]$$

where B_{t+1} is the exploited biomass in the subsequent year **t+1**, B_t is the current biomass, C_t is the catch in year **t**, **r** is the maximum intrinsic rate of stock increase, and **k** is the unexploited stock size. Put simply, the **CMSY** algorithm uses a prior range of **r** (from life history traits of the stock), a prior range of **k** (derived from maximum catch), and prior ranges of B_t/k (at the beginning and end of the catch time series from **LBB** or expert knowledge). All **r-k** combinations that are compatible with the life history traits (**r**, **M**, **K**), the catch time series (C_t), and expert knowledge (B_t/k) are identified by a Monte-Carlo approach, and an **r-k** combination representative of high **r** values is chosen as the best estimate. The best estimate of **r** and **k** are then used to compute for the following reference points:

$$MSY = r * (k/4) \qquad [Eq.\ 18]$$

$$F_{MSY} = 0.5 * r \qquad [Eq.\ 19]$$

$$B_{MSY} = 0.5 * k \qquad [Eq.\ 20]$$

$$BR = 0.5 * B_{MSY} \qquad [Eq.\ 21]$$

where **MSY** is maximum sustainable yield, F_{MSY} is the fishing mortality corresponding to **MSY**, B_{MSY} is the biomass producing **MSY**, and B_R is the biomass below which recruitment may be compromised. The assumptions and criticisms of the **CMSY** method are the same as those previously outlined for surplus production models above. Evidently, the difficulty of deriving reliable catch data from available **BSC** data covering the entire stock remains a challenge. For this reason, the **CMSY** method is not considered further in this report.

AMSY is a complementary (Bayesian) method to **CMSY** meant for use in data-sparse situations, when only catch-per-unit-effort (**CPUE**) data are available. It is still currently under development, and **AMSY** documentation and publication is still in progress. Its developers encourage preliminary use of the method for available data (see, for example, the training provided by Quantitative Aquatics to **NFRDI** at *www.q-quatics.org*), although at the moment they discourage use of its results for management until the **AMSY** documentation/publication is completed. Given the nature of **NSAP** data, the **AMSY** tool holds very high potential utility in analysis of program data sets.

Put simply, and proceeding from equation 17, a prior range for **r** is derived from life history traits, a prior range for **k** is derived from maximum catch, and a single prior range for B_t/k (anywhere in the time series) is derived from expert knowledge. The catchability coefficient (**q**) is estimated by **AMSY** (given **B** = **CPUE**/**q**). All **r-k** combinations compatible with the life history traits (**r**, **M**, **K**), the catches (C_t), and expert knowledge (B_t/k) are identified by a Monte-Carlo approach. The **r-k** combination representing the highest **r** values is chosen as best estimate. Equations 18-21 are then used to provide estimates of the fisheries reference points. Assumptions and criticisms of the method are the same as those given above for surplus production models.

Technical guidelines for use of the **AMSY** method include the following:

Step 1: Prepare the annual **CPUE** time series data input. Confirm that the **CPUE** data constitute representative samples, checking that proper data treatment and raising factors were used in their generation. Note the context and caveats regarding the **CPUE** data, if any.

Step 2: Format the **CPUE** data according to the **CSV** file templates: ComDat.CSV and Stock_ID.CSV.

Step 3: Source viable priors (**r**, **k** range, B_t/k range) that may be used as input priors.

Step 4: Install a recent version of **R** on your computer. **AMSY** was tested under **R** version 3.4.4 and 3.5.0, available at *www.r-project.org/*, although newer versions should also work.

Step 5: Use RStudio as **R** development environment. RStudio is a free software available for use in several operating systems (*e.g.*, Windows, Linux, OS) and can be downloaded at *www.rstudio.com/products/rstudio/download/*.

Step 6: Install the Gibbs sampler JAGS for your operating system from the web site *http://sourceforge.net/projects/mcmc-jags/files/JAGS/4.x/.*

Step 7: To run the code, several **R** packages are required. In the **R** Console, execute the following commands (*i.e.*, cut and paste into the Console window, then hit Enter and wait):

- install.packages ("R2jags")
- install.packages ("Hmisc")
- install.packages ("lattice")
- install.packages ("survival")
- install.packages ("Formula")
- install.packages ("ggplot2").

Step 8: Two different data files are required by **AMSY**, which should be placed in the same directory as the script. The names of these files are specified in the code (line 20 for Stock ID info) and as first parameter in each line of the Stock ID file. Examples are provided with the code, and their structure is specified.

Step 9: Make sure that the source file and the downloaded R script are in the same directory.

Step 10: Open the downloaded **AMSY** script in RStudio. Use the tab "Session" and select "Set Working Directory" -> "To Source File Location," so the code will find the data files. Alternatively, in line 17 of the code, you can explicitly state your working directory.

Step 11: If you wish to use your own input files, just change the file name of the ID. File in line 20 and the name in the File column of the ID file for the respective stock. If you create your own input files, make sure you use the same headers (case sensitive) as in the provided example files. Make sure you are using comma-delimited (.csv) files. (Note: You can look at the data in a simple text editor such as Notepad to check for consistent use of commas; semi-colons are not accepted.)

Step 12: The **R**-code can either analyze all stocks or a single stock can be specified in the "Select stock to be analyzed" section of the code, according to the stock identification specified at line 14. To specify the stock to analyze, just enter the unique name or identifier of the stock there (*e.g.*, Stock – "tur.27.4"). To make the code run on all the stocks in the ID-file, just comment out line 14 (*i.e.*, put # in front).

Step 13: In RStudio, click on "Source" (or press Ctrl+A followed by Ctrl+R or Ctrl+Shift+S) to execute the code.

Step 14: When the run or analysis is complete, the results can be found in the console window, as well as the **AMSY** graphs window (which can be saved manually).

Step 15: Note and examine the parameter estimates provided by **AMSY** and evaluate their implications for management of **BSC** in the region. Note data input and method caveats and explore next analysis and/or refinement steps.

Note that steps 4-14 pertaining to **R** installation and running the code are very similar to the steps given for **LBB** above. The steps are repeated, however, to ensure that the guidelines can be used independently (of **LBB**) by users during other occasions. These guidelines should be reviewed and refined after access to the **AMSY** User Manual and algorithm when they are finalized, as well as the conduct of the training and joint analyses phase.

3.C.5) Supplemental Approaches and Guidelines

A variety of other methods were suggested to the authors during discussions with NSAP national and regional officials, as well as during consultations with selected experts. These methods were also explored for their utility in providing reference points for the BSC fisheries and their applicability given the nature of available NSAP BSC data from Regions 5, 6, and 7.

The Ecopath with Ecosim (EwE) ecosystem modeling approach involves an integrated method and software for trophic mass balance analysis (Ecopath); dynamic modeling (Ecosim) for exploring impacts of fishing, environmental disturbances, and policy options; and spatial modeling (Ecospace) for exploring policies for marine protected area establishment or area closures (factoring in explicitly spatial dispersal/ advection processes). The Ecopath model was first introduced by Polovina (1984a and b), in his work in a coral reef area called French Frigate Shoals. The method was subsequently refined and further extended by fishery scientists working at ICLARM (now WorldFish Center) and the University of British Columbia, or UBC (Christensen and Walters, 2004; Pauly *et al.*, 2004; Steenbeck *et al.*, 2016; *www.ecopath.org*). The method has been used to produce mass balance box models for many ecosystems over the past 34 years, and has been widely used to derive models of fisheries ecosystems – principally due to the wide availability of the EwE software and analysis/support efforts of ICLARM and UBC scientists and research programs.

The Ecopath master equation, in the notation of Polovina (1984a), requires that for each trophic or functional group i in an ecosystem, mass balance should occur over a given time period, such that:

$$B_i * (P/B)_i * EE_i = Y_i + [Sum_j\, B_j * (Q/B)_j * (DC)_{ij} \ldots] \quad \text{[Eq. 22]}$$

where

B_i and B_j = biomasses, the latter pertaining to trophic group j, the consumers of i

$(P/B)_i$ = production-to-biomass ratio of trophic group i

EE_i = ecotrophic efficiency, the fraction of production consumed within, or caught from the system

Y_i = fisheries catch of trophic group i, remembering Y=FB

Sum_j = summation sign through j

$(Q/B)_j$ = food consumption per unit biomass of j

$(DC)_{ij}$ = contribution of trophic group i to the diet of trophic group j

... = additional terms (optional) to reflect change in biomass over the time of a study or assessment, *e.g.*, net emigration.

The system of linear equations for the various trophic/functional groups is solved to achieve mass balance, and typically a box model is produced showing the quantified network of flows across trophic groups from the biomass, production, and consumption estimates. Various extensions to the basic Ecopath model have been made to account for various system complexities and to extend the method to the Ecosim and Ecospace approaches (Steenbeck *et al.*, 2016).

Evidently, the data input requirements for the EwE approach are far too (many and) demanding viewed against the available data for NSAP Regions 5, 6, and 7. For this reason, the method is not considered further in this report. The main potential utility of the EwE approach lies in evaluating the robustness of RPs and management directions (given the fact that the BSC fisheries operate in multispecies and multi-gear situations). Changes in relative biomass or abundance of the various species or trophic groups comprising the fisheries ecosystem alters the energy/biomass budget of the ecosystem. This may impact the BSC reference system (and thus its applicability) when species/gear balance under the present steady-state is altered, affecting the BSC predator and prey abundances and prevailing mortalities. Armada *et al.* (2018), for example, used the EwE approach in right-sizing fishing efforts in a marine ecosystem in Danajon Bank, Central Philippines. Their work (and see Steenbeck *et al.* 2016) indicates, among others, that ecosystem modeling that accounts for multispecies, multi-gear interactions may lead to scenarios that may be counter-intuitive when only single-species assessments are considered. It may be worth revisiting the **EwE** approach in the medium term (the next three-to-five years) when more relevant inputs/data become available, and as the **NSAP** teams of **Regions 5, 6, and 7** "mine" the literature from fisheries ecosystems with similar characteristics as those of the Visayan Sea.

It should also be noted, however, that Ecopath/Ecosim models are not widely used in developing **RP**s or in providing direct management advice relating to stock status. This is largely because more reliable methods are available and usually preferred.

The **MULTIFAN-CL** was also explored for its utility with respect to the available **BSC** data from **Regions 5, 6, and 7**. The **MULTIFAN-CL** is a statistical, age-structured, length-based model routinely used (by the South Pacific Community in advising the **WCPFC**) for stock assessment of tuna and other pelagic species. As the Philippines is part of the **WCPFC**, use of the method in the country is being encouraged – including analysis of **NSAP** data for tuna and other pelagics and, lately, the **BSC** data sets. The method was first introduced by Fournier *et al.* (1998), and its refinements, extensions, and improvements up to August 2017 are given in Davies *et al.* (2017). Typical inputs to **MULTIFAN-CL** are as follows:

- *Total catch*
- *Catch rate* (**CPUE**)
- *Size frequency*
- *Tagging data*

stratified by fishing/fishery, region, and time period. The typical output parameters estimated by the method include:

- *Initial numbers-at-age in each region*
- *Number in each age class 1 for each time period or quarter in each region (the recruitment)*
- *Growth parameters*
- *Natural mortality-at-age* (**M_t**)
- *Movement*
- *Selectivity-at-age by fishery/gear*
- *Catch*
- *Effort deviations (random variations in the effort-fishing mortality relationship) for each fishery*
- *Initial catchability (qi)*
- *Catchability deviations (cumulative changes in catchability with time) for each fishery.*

"Parameters are estimated by fitting to a composite likelihood comprised of the fits to the various data types, and penalized likelihood distributions for various parameters" (Davies *et al.,* 2017).

The lack of tagging and total catch data (given challenges in aggregating monitored landings data to total catch) limits the use of the method in analyzing the currently available **NSAP BSC** data from **Regions 5, 6, and 7**. The magnitude of data requirements (and associated costs) may also preclude the use of the method for a relatively lower value fishery like **BSC** (compared to the tuna fisheries). Nevertheless, it is recommended that the use of the method be revisited in the medium term (three-to-five years), or be considered during the course of the systematic (external) "**NSAP** system" review recommended above.

A number of methods based on simple indicators or "common sense rules of thumb" have also been suggested recently to minimize the impacts of fishing on the ecosystem (see Froese, 2004; Froese and Binohlan, 2000; Froese *et al.*, 2016a). These indicators have been noted to be of high potential in involving stakeholders (*e.g.*, fishers, dealers, processors, exporters, consumers) in the management and conservation of fish stocks and fisheries. These indicators include the following:

1. "Percentage of mature fish in the catch, with 100% as an ideal and 90% as a reasonable target" (Let them spawn, Froese, 2004). (Given the available BSC data, this may be computed as the percentage of mature BSC (total, female, male) comprising landings or CPUE by gear type and for all gear types combined.)

2. “Percentage of fish caught at the optimum length for harvest, with 100% as a target, in the process minimizing any adverse impacts of fishing” (Let them grow, Froese, 2004). (Given available BSC data, this is best computed as the percentage of BSC landings or CPUE caught at or above the optimum length for harvest, by fishing gear type and total for all gear types.)

3. “Percentage of mega-spawners in the catch, with 0% as a target. If the catch reflects the age structure of the stock, 30-40% of mega-spawners in the catch would likely represent a healthy population, with 20% being a lower limit” (Let the mega-spawners live, Froese, 2004). (Given available BSC data, this is best computed as the percentage of BSC landings or CPUE composed of what is defined as mega-spawners, by fishing gear type and total for all gears combined.)

4. “Take less than nature by ensuring that mortality caused by fishing is less than the natural rate of mortality” (Froese *et al.*, 2016a). (Given available BSC data, this is best evaluated by comparing the values of F with M, ensuring F is less than M.)

5. “Maintain population sizes above half of natural abundance, so they fulfill their ecosystem functions as prey and predator” (Froese et. al., 2016a). (Given available BSC data, this may be evaluated by comparing current B/R with the B/R at virgin stock levels. Alternatively, CPUE by gear type may be compared with CPUE at virgin stock level or onset of the fisheries, assuming CPUE is unbiased and proportional to stock abundance.)

6. “Let fish grow and reproduce, by adjusting the size at first capture such that mean length in the catch equals the length where the biomass of the unexploited cohort would be maximum (L_{c_opt})” (Froese *et al.*, 2016a). (Given available BSC data, compare L_{BAR} to L_{c_opt} and adjust length at capture such that L_{BAR} is equal or closest to L_{c_opt}. The Length Frequency Analysis Wizard in Fishbase, available at www.fishbase.org, contains routines for doing this.)

Note that the six simple indicators enumerated immediately above pertain to single-species stocks to prevent overfishing or minimize ecosystem impacts of fishing a stock. This approach recognizes that the stock is a part of the ecosystem and its maintenance preserves its ecosystem functions as prey or predator. Impacts of fishing on other species/groups comprising the ecosystem are ignored (but see the EwE approach above). Further, we may consider the following simple indicators for evaluating some of the wider (other species) ecosystem impacts of fishing (see, for example, Ingles, 2003; Ingles and Flores, 2000):

1. Percentage species composition comprising landings or CPUE by major fishing gear used to catch BSC. (Given the available BSC data, this may be used to evaluate species overlap in catch of fishing gears used to harvest BSC or impact of gears used to catch BSC on other species in the fisheries ecosystem. It is suggested that this be done showing composition of the top 20 species/groups, by fishing gear and total for all gears combined.)

2. Percentage of bycatch of commercially valuable species to total catch, with 0 percent as ideal. (Given the available BSC data, this may be calculated as the percentage of landings or CPUE composed of bycatch or non-targeted species with commercial value, by fishing gear and total for all gears. In multispecies, multi-gear fisheries, non-targeted species may comprise a major part of landings and contribute substantially to food and income of fishers.)

3. Percentage of bycatch of non-commercially valuable species to total catch, with 0 percent as ideal. (Given the available BSC data, this may be calculated as the percentage of landings or CPUE composed of bycatch or non-targeted species with no commercial value, by fishing gear and total for all gears combined. In multispecies, multi-gear fisheries, non-targeted species may comprise a major part of landings. Note that this includes only species of little or no economic or commercial importance.)

4. Percentage of endangered, threatened, and protected (**ETP**) species in total catch, with 0 percent as ideal. (Given available **BSC** data, this may be computed as the percentage of sharks, rays, skates, and other **ETP** species in the landings or **CPUE**, by fishing gear and total for all gears combined.) Catches and catch rates of **ETP** species should normally be recorded in numbers rather than biomass.

5. Percentage of (non-**BSC**) species i to total catch of species i in gear j comprising immature individuals, with 0 percent as ideal. (Given the available **BSC** data, this may be calculated using landings or **CPUE** data by gear type and total for all gear types combined. This may be used to look at the impact of the **BSC** fishery using gear j on maximizing the reproductive potential or recruitment for other major species comprising the catch. It is recommended that this indicator initially be computed for the top five species comprising commercially valuable species in the catch by gear type and total for all gear types combined.) The appropriate spatial extent of such analyses would also need to be defined based on, for example, the stock or species range and the scale of overlap with the **BSC** fisheries.

6. Percentage of (non-**BSC**) species **i** to total catch of species **i** in gear **j** comprising individuals below the optimum length of capture for species **i**, with 0 percent as ideal. (Given the available **BSC** data, this may be calculated using landings or **CPUE** data by gear type and total for all gear types combined. This may be used to look at the impact of the **BSC** fishery using gear **j** on optimal length at first capture for other major species comprising the catch. It is recommended that this indicator initially be computed for the top five species comprising commercially valuable species in the catch by gear type and total for all gear types combined.) The appropriate spatial extent of such analyses would also need to be defined based on, for example, the stock or species range and the scale of overlap with the **BSC** fisheries.

The 12 simple indicators enumerated above do not provide estimates of reference points (sensu stricto). Instead, they provide estimates of prevailing conditions in the fishery, which are then compared to measures of optimality based on simple "common sense indicators." Management measures are then elaborated to bring the prevailing condition in the fishery (the indicator) toward the ideal situation defined by the prescribed measure of optimality (the reference point). The indicators mentioned above involve mostly simple ratio or proportion computations (expressed in percentage terms) and are relatively easy to calculate using Microsoft Excel tools or methods already familiar to **NSAP** staff. For this reason, detailed technical guidelines are not provided. (Interested readers, however, may refer to the Length Frequency Analysis Wizard of Fishbase at ***www.fishbase.org*** for tools particularly relevant to indicators given by Froese, 2004 and Froese *et al.*, 2016a, above.) Calculation of these simple indicators were assigned as "take-home assignments" during the training and joint analyses phase of the consultancy (see Phase 3 below), after coverage and discussion of the theory/concept underlying the individual indicators. The computed indicators were to be subsequently assessed by the **NSAP** teams of **Regions 5, 6, and 7**, and potentially viable management measures examined in consultation with relevant stakeholders. While such indicators, in the absence of other, better, and more tested methods, may be helpful, sole reliance on these relatively untested approaches should be avoided as they may mislead on the status of the fisheries and the stocks being taken. Where these are the only approaches available, more effort to collect appropriate data and conduct more reliable, informative, and accepted methods is indicated.

4) Phase 3: Training and Joint Analyses

This section provides a synopsis of the training and joint analyses phase of the consultancy. The work and activities conducted under **Phase 3** are first described. A summary of the main outcomes (*e.g.*, reference points) from the actual training and joint analyses workshop conducted in Iloilo City (Philippines) during 25-27 September 2019 is then presented. Key follow-up actions and recommendations requiring attention to improve the reference points after the workshop (and period of the consultancy) are subsequently outlined.

4.1) WORK AND ACTIVITIES UNDERTAKEN

Data access, review, and validation activities, as well as training and joint analyses preparations, were already largely cited in the previous section (for chronological purposes). Principal work/activities in pursuit of Phase 3 objectives of the consultancy are given in **Annex 1**.

4.2)JOINT ANALYSES AND REFERENCE POINTS

The agenda for the training and joint analyses workshop with **NSAP** Project Leaders and staff of **Regions 5, 6, and 7** in Iloilo City, Philippines from 25-27 September 2019 is given in **Annex 2**. A total of 24 technical staff from **Regions 5, 6, and 7** participated in the workshop, together with four observers from **Region 4A**, one observer from **NSAP PMO**, and one observer from PACPI (see **Annex 3**). After a brief opening program and round of introductions, the workshop modality was clarified with the participants. The workshop was conducted as a simulation of the work of "scientific working groups," intended to provide inputs to the Management Boards of FMAs (**FMA** 11 or the Visayan Sea in this particular case). Hence, no teacher-student nor trainer-trainee modality was to be fostered. All workshop participants were expected to actively contribute and participate in generating and deliberating the workshop outputs and recommendations, and were encouraged to jointly own and be responsible for workshop results and follow-up actions. The workshop subsequently proceeded to cover each methodological approach and derive reference points via these methods using appropriate **BSC** data from **Regions 5, 6, and 7**. For each method, the workshop generically covered: **(1)** brief overviews and discussions of the theory underlying the method or analysis approach; **(2)** exercises to derive reference points for the Visayan Sea **BSC** stock using **NSAP** data (for **Regions 5, 6, and 7**) and the method under consideration (with their associated technical analysis guidelines); **(3)** discussions on the utility of the reference point/s derived in the management of the **BSC** fisheries in the Visayan Sea; and **(4)** discussions of assessment process guidelines outlining "next steps" in the refinement and/or improvement of the reference points (conceding that available material time and analysis have allowed estimation of reference points up to a certain level, which variously may still be improved using other **BSC** data).

The first deliberation during the workshop considered whether **BSC** in the Visayan Sea could be considered as one unit stock (capable of independent exploitation). Stock delineation studies were considered (Romero, 2009 and Sienes *et al.*, 2014), and questions regarding the existence of any barrier that precludes free genetic exchange across the Visayan Sea were discussed. The workshop consensus reached was to consider **BSC** in the Visayan Sea as one stock, until any evidence to the contrary becomes available. This has substantial implications for the subsequent analyses, which precluded the need for separate analysis of **BSC** data from **Regions 5, 6, and 7** (which, after all, are administrative rather than biological demarcations). Combining data (with appropriate aggregating factors) across the three regions is thus deemed feasible. Moreover, such consensus allows for analyses of **Region 6** data (which is the most extensive and complete) as representative of the Visayan Sea situation, given relative limitations in availability of data from **Regions 5 and 7**.

Derivation of reference points using surplus production models was limited by the lack of total yield and total effort data for **BSC** in the Visayan Sea (as discussed in the previous sections). To be able to proceed, an extension in the use of the Schaefer (1957) and Fox (1970) models was introduced for consideration of workshop participants. The extension involved the use of the **Y/f** versus **f** linear regression plot and using the following ratio as reference point:

$$A_{ratio} = (Y/f)_{now}/(Y/f)_{MSY} \qquad \text{[Eq. 23]}$$

where A_{ratio} is the abundance index ratio, $(Y/f)_{now}$ is the yield per-unit-effort currently (or the period being evaluated), and $(Y/f)_{MSY}$ is the yield per-unit-effort at **MSY**. Note that mathematically:

$$(Y/f)_{MSY} = 0.5 * a \qquad \text{(Schaefer, 1957)} \qquad \text{[Eq. 24]}$$

$$(Y/f)_{MSY} = 0.37(exp^{c}) \qquad \text{(Fox, 1970)} \qquad \text{[Eq. 25]}$$

where a and c are intercepts of the linear regression (as defined in equations 1 and 2). Note that the A_{ratio} value of unity is ideal. A value less than 1 implies that **MSY** has been exceeded (and thus requires effort reduction); and a value greater than 1 implies that the fishery is below **MSY** (and may allow for an increase in fishing effort). The allowable fishing effort increase or decrease to get to an A_{ratio} of unity may be approximated as:

$$f_{(\%)} = [(f_{MSY} - f_{now})/ f_{now}] * 100 \qquad \text{[Eq. 26]}$$

where $f_{(\%)}$ is the percentage increase/decrease from fishing effort currently (or for the period being evaluated), f_{MSY} is the fishing effort at $(Y/f)_{MSY}$, and f_{now} is the fishing effort currently (or for the period being evaluated). Note that the value of $f_{(\%)}$ is negative when effort reduction is required, and positive when effort increase toward **MSY** is feasible.

The extension to the surplus production models (Schaefer, 1957 and Fox, 1970) as expressed in equations 23-26 (inclusive) was applied to **BSC** catch and effort data given in Mesa *et al.* (2018) for the years 1991-1995 (inclusive), 2011, and 2012. The catch and fishing effort time series (tabulated data for which was provided by **NSAP Region 6** staff from those used in Mesa *et al.*, 2018) were as follows:

- 1991 -**Y** = 400,000 kg, **f** = 4,000 panel
- 1992 -**Y** = 750,000 kg, **f** = 5,000 panels
- 1993 -**Y** = 1,075,000 kg, **f** = 7,000 panels
- 1994 -**Y** = 500,000 kg, **f** = 2,500 panels
- 1995 -**Y** = 250,000 kg, **f** = 1,125 panels
- 2011 -**Y** = 1,535,820 kg, **f** = 32,172 panels
- 2012 -**Y** = 1,149,790 kg, **f** = 24,372 panels.

The linear regression results are as follows: **(1) a** = 184.35 kg/panel; (2) **b** = -0.004854; (3) **c** = 1655.64; **(4) d** = -0.048. The method results are as follows: **(1)** A_{ratio} using the Schaefer (1957) model was 0.51, with $(Y/f)_{now}$ = 47.2 kg/panel and $(Y/f)_{MSY}$ = 92.2 kg/panel; **(2)** A_{ratio} using the Fox (1970) model was 0.71, with $(Y/f)_{now}$ = 50.0 kg/panel and $(Y/f)_{MSY}$ = 70.2 kg/panel; (3) $f_{(\%)}$ using the Schaefer (1957) model was -32.8%, with f_{now} = 28,258 panels and f_{MSY} = 18,988 panels; and **(4)** $f_{(\%)}$ using the Fox (1970) model was -28.5%, with f_{now} = 28,837 panels and f_{MSY} = 20,624 panels. Overall, the results indicate substantive overfishing that has led to catch rates much lower than those generated at **MSY**, and requiring substantive fishing effort reduction of 28.5-32.8% of fishing effort levels in 2012.

Note that the extension of the surplus production model used here also assumes the limitations ascribed to all surplus production models. Moreover, the approach assumes that the catch rates from monitoring activities conducted in **Region 6** is representative and reflects the abundance of the stock impacted by the combined fishing effort from **Regions 5, 6, and 7** (during the years 1991-1995, 2011, and 2012). It is noted that the simple extension of the method presented here is viewed as widely applicable to **NSAP** data for other species and regions. The **NSAP** system is plagued by the lack of total catch and total effort data across regions countrywide.

Reproductive biology information for 2011-2012 from Mesa *et al.* (2018) was used for the estimation of length at first maturity (L_m) and peak months of **GSI** (%) and % mature individuals for **BSC** in the Visayan Sea. This included information for 3,487 **BSC** individuals comprising 223 premature crabs, 1,595 females, and 1,669 males. Tabulated data (presented in Figure 21 of Mesa *et al.*, 2018) giving the proportion of mature female **BSC** by length group were made available by Region 6 staff to workshop participants. After discussing the context of the data, equations 9, 10, and 12 were used to estimate the L_m = 11.5 cm value for BSC in the Visayan Sea. The viability of using this as minimum size limit in Regions 5, 6, and 7 was discussed, and ways to increase acceptance and enforcement of such measures by fishers and various stakeholders were considered. The participants concede that enforceability of such measures among BSC fishers will be a main challenge.

Analysis of GSI (%) by month shows bimodal peaks annually, the major peak occurring in April and a minor one occurring about October (see Figure 19 of Mesa *et al.*, 2018 for comparison purposes). Similar results were obtained in analysis of monthly % mature female BSC – with a major peak observed in April and a minor one in October (see Figure 18 of Mesa *et al.*, 2018 for comparison purposes). Analysis of recruitment patterns using the routine in ELEFAN II of FiSAT (and using the growth and mortality parameters and LF data in Mesa *et al.* 2018) indicate continuous recruitment of BSC throughout the year, with peaks of almost equal strength in April and September. The maturity and recruitment pattern results are largely consistent. The recruitment peak in September was attributed to erroneous slow growth in the early life stages of BSC when back-projecting the cohort using the von Bertalanffy growth parameters (such that the origin of the recruitment peak in September may have actually been in October, owing to very fast growth of BSC in its early life). The utility of using April as a closure month was discussed by the workshop participants. It was deemed as a viable closure month candidate for BSC in the Visayan Sea. It offers substantive effort reduction (1/12 or 8.3% for a month of closure), combined with relative ease of enforcement associated with total closure in a fishery (such as BSC) where social, economic, and political challenges to direct effort reduction can be considerable. Timing the closure with annual boat and gear maintenance, and coordinating livelihood schemes for impacted fishers with the Department of Social Welfare and Development, the National Anti-Poverty Commission, and private and NGO partners, should make the feasibility of implementing temporal or area closures more viable.

The relative Y/R analysis was done using parameters derived from 2018 NSAP Region 6 LF data for the Visayan Sea BSC stock. The parameters used were as follows: L_{inf} = 22.0 cm; K=1.19/year; M=2.18/year; M/K = 1.83; F = 4.87/year; Z = 7.05/year; current E = 0.69. The apparent l_c = 10.4 cm leading to apparent c = l_c/L_{inf} = 0.47 as derived from the LF data were not used (given the fact that the LF data emanates from various gears with different selectivity). Instead, the current l_c was estimated from Figure 22 of Mesa *et al.* (2018), which provided an l_c value of about 9.75 cm from LF distribution of bottom-set gillnets and crab pots/traps (the dominant gears exploiting BSC in the Visayan Sea). Moreover, given the length-at-first-maturity results given above, L_m = 11.5 cm (corresponding to c = 0.52) was deemed the ideal l_c for the BSC fisheries. Analysis of the (Y/R)' isopleth diagram indicate (Y/R)' is maximized at about c =0.46 and E_{max} = 0.71, with $E_{0.5}$ = 0.35 and $E_{0.1}$ = 0.61. The use of E_{max} = 0.71 was considered unviable, as it leads to very low abundance levels (corresponding to (B/R)' at only 18% of that at virgin stock level). The use of $E_{0.1}$ was considered unviable for the same reason; so it was $E_{0.5}$ = 0.35 that was chosen as an ideal exploitation reference point.

Overall, the results of the (Y/R)' isopleth diagram analysis show substantive overfishing of the Visayan Sea BSC stock, requiring considerable fishing effort reduction (about 49% from E of 0.69 in 2018 down to $E_{0.5}$ = 0.35) and an increase in size at capture (from l_c = 9.75 cm to l_c = L_m = 11.5 cm). Increasing l_c to L_m = 11.5 cm (*i.e.* from c = 0.46 to c = 0.52) leads to only a 3% decrease in (Y/R)' but a 10% increase in (B/R)'. Reducing E from the 2018 level of 0.69 to 0.35 reduces (Y/R)' by about 20%, but increases (B/R)' by about 32%, which substantially improves catch rates and incomes, and reduces the risk of recruitment overfishing. As previously noted, the current E = 0.69 value leads to (B/R)' of only about 18% of that at virgin stock level – a very depressed abundance and catch rate level.

The theory behind the L_{BAR} method was discussed with workshop participants. It was noted that the method produces **Z** and **F** estimates given length composition inputs. Moreover, the method produces no reference points independently, but is an alternative method (to catch curves) for estimating **Z** and **F**. There was consensus that the method may be revisited and used when there is a need to provide alternative estimates of **Z** and **F.**

The concept behind the **SPR** method was covered and discussed with workshop participants. The lack of selectivity and fecundity functions precludes the current use of the method using **NSAP BSC** data from **Regions 5, 6, and 7**. A consensus was reached to revisit the method after these functions become available, mindful that recruitment variability does not affect length composition inputs when using the method.

The **LBB** method was used with the following data inputs and assumptions: annual **LF** data of **BSC** for the years 2014 – 2018 (inclusive) from **NSAP Region 6**; the **LF** data are combined for various gears exploiting **BSC**. The **LF** data with lengths above 22.3 cm were excluded (based on L_{inf} values obtained from ***www.Sealifebase.org***, **LF** data above 22.3 cm are probably erroneous). The priors used were: L_{inf} = 22.7 cm; **M/K** = 1.5; **Z/K** = 4.45; **F/K** = 2.95; selectivity from aggregated annual **LF** samples, L_c = 9.44 cm. The results obtained, for the median across years (95% confidence limits in parentheses) were: L_{inf} = 23.0 cm (22.7-23.4 cm); L_c = 9.44 cm; L_{opt} = 15.2 cm; L_{opt}/L_{inf} = 0.66; L_{c_opt} = 14.0 cm; L_{c_opt}/L_{inf} = 0.61; **M/K** = 1.55 (1.32-1.86); **F/K** = 5.02 (4.67-5.48); **Z/K** = 6.35 (6.06-6.69); **F/M** = 3.45 (2.63-4.48); B/B_0 = 0.102; B/B_{MSY} = 0.204. The **(Y/R)'** for the median across years is only 39% of **(Y/R)'** at **MSY**.

The results obtained, for the last year 2018 (95% confidence limits in parentheses) were as follows: L_c = 10.1 cm (10.1-10.2 cm); L_c/L_{inf} = 0.45 (0.443-0.448); L_{mean}/L_{opt} = 0.79; L_c/L_{c_opt} = 0.72; **F/K** = 4.8 (4.22-5.17); **F/M** = 3.1 (2.36-3.84); **Z/K** = 6.3 (5.9-6.69); B/B_0= 0.11 (0.076-0.144); B/B_{MSY} = 0.30 (0.209-0.396); **(Y/R)'** in 2018 is only 44% of **(Y/R)'** at **MSY**. Overall, the **LBB** method results indicate very high exploitation rates (**F/M** = 3.1) and low length at first capture (L_{mean}/L_{opt} = 0.79; L_c/L_{c_opt} = 0.72) leading to very low biomass levels compared to those at **MSY** (B/B_{MSY} = 0.30) and virgin stock levels (B/B_0 = 0.11). This leads to low **(Y/R)'** level in 2018 (only 44%) of that which can be obtained at **MSY**. The results using the **LBB** method should be taken as preliminary in nature. An attempt to refine the results should be made using separate **LF** data for individual major gears used to exploit the **BSC** stock (compared to aggregating **LF** data for all the gear types). It is noted, however, that the results from the **LBB** method (using 2014-2018 **LF** data) are consistent with those indicating substantive overfishing using other methods discussed above (surplus production using 1991-1995 and 2011-2012 yield and effort data, and **(Y/R)'** analysis using 2018 parameters). It appears that the fishing effort for **BSC** (from the early 1990s to 2018) has increased considerably, and the overfishing problem has worsened during this period, requiring effort reduction by about a third (28-33%) in 2012 to about half (49%) by 2018. Moreover, increasing length-at-first-capture closer to L_{c_opt} is desirable. As the L_{c_opt} value may be unacceptably high (requiring an increase in L_c = 10.1 cm by 28%) for many stakeholders, using L_m = 11.5 cm as L_c may be a viable compromise.

The theory behind the **CMSY** method was covered by workshop participants. However, the lack of total catch data (for 10 consecutive years required by the method) from the **BSC** stock in the Visayan Sea precluded the use of the method in deriving reference points. Nevertheless, exercises were run using catch data from **Region 6**, principally to familiarize workshop participants with the method and its various priors (**r** range; **k** range; B_t/k at the beginning or end of catch time series) and input requirements (catch time series for 10 consecutive years). The results of the exercise (**r**; **k**; **MSY**; F_{MSY}; B_{MSY}; B_R) were not used in making conclusions about the **BSC** fisheries in the Visayan Sea, as they do not represent valid results from representative catch time series inputs.

Consensus was reached on likely next steps in the use of the **CMSY** method. Evidently, there is a need to "mine" the sources of total catch data for **Regions 5, 6, and 7**. It was emphasized that the data required is total extraction or catch from the Visayan Sea **BSC** stock. It was also noted that the CMSY method requires a minimum of 10 years continuous or consecutive total catch data. Use of the CMSY method will be revisited when the required catch time series data become available (in the near term, one-to-three years).

The theory behind the AMSY method was covered by workshop participants. The data used for the method exercise was CPUE data for the years 1991-2002, with 1991-1996 CPUE data from Mesa *et al.*, 2018 and CPUE data for 1996-2002 interpolated from the CPUE equation results from Schaefer (1957) modeling above. The priors used were as follows: r range = 0.78-1.78; kq range = 0.406-1.060; B_{2002}/k range = 0.15-0.40. The key results (95% confidence limits in parentheses) were as follows: r = 1.13 (0.788-1.58); kq = 0.531 (0.372-0.878); MSYq = 0.15 (0.093-0.277); F_{MSY} = 0.563; F_{2001}/F_{MSY} = 1.68; B_{2002}/B_{MSY} = 0.41. Overfishing is evident from the method results, with fishing mortality in 2001 in excess by 68% of that necessary to harvest MSY. Moreover, BSC stock biomass in 2002 is only 41% of the biomass needed to generate MSY. It is emphasized that the results are considered preliminary, until method documentation is peer-reviewed and published (and given the interpolation used to produce the data time series required). Note, however, that the preliminary results are consistent with the overfishing diagnosis from other methods given previously, requiring substantive fishing mortality reduction (of 68%) to get to F_{MSY} level by about 2002. Evidently, next steps in using the method require continuation of data collection, such that 10 consecutive years (at least) of CPUE data for the BSC stock in the Visayan Sea is generated (as required by the AMSY method for reliable results). There is a need to revisit the AMSY method when the 2011-2020 CPUE time series for BSC in the Visayan Sea becomes available, in the next three-to-five years.

The theory behind the MULTIFAN-CL concept was covered by workshop participants. The lack of spatial and tag-recapture data, among others, precluded the use of the method in deriving reference points. The method will be revisited in the medium term (three-to-five years) when data needs (spatial info, tag-recapture data, etc.) become available. In addition, the EwE concept was also covered by the workshop participants. The lack of data inputs required by the method precluded its use to derive reference points. The method will be revisited in the medium term (three-to-five years) when data sourced from fisheries ecosystems similar to the Visayan Sea become available.

The 12 simple ratio indicators will be completed in the near term (within six months to one year) to complement the assessments completed above. Involving simple ratio computations, assessments using the 12 simple ratio indicators were assigned as a take-home assignment for completion by workshop participants after they return to their respective duty stations.

4.3) KEY RESULTS AND FOLLOW-UP ACTIONS

The assessments provided in the previous subsection indicate that the BSC stock in the Visayan Sea is highly overfished. Surplus production modeling (using Y/f versus f data for 1991 – 2012) shows that effort reduction of 28-33% from 2012 effort level is needed to return to catch rates generated at MSY. The (Y/R)' assessment (using 2018 growth and mortality parameters derived from BSC Region 6 data) indicates the need for substantive reduction of fishing effort by about half (49%) of 2018 effort level and an increase in length-at-first-capture to 11.5 cm (=L_m) from the current 9.75 cm to optimize (Y/R)' at viable (B/R)' that is risk-averse to recruitment overfishing. Analysis of maturity data (using 2011-2012 reproductive biology data from NSAP Region 6) and recruitment patterns (from Mesa *et al.,* 2018) point to the month of April as a viable closure month (potentially offering a 1/12 or 8.3% effort reduction if the fishery is closed for a month). The length-at-first maturity (=L_m) was estimated (from 2011-2012 data from NSAP Region 6) at 11.5 cm, which may be a viable minimum size limit to let the BSC spawn before being exploited.

The use of new analytic approaches was largely impacted by the lack of appropriate data for their use in deriving reference points and credible assessments. For those which were viable to use, the results derived were largely consistent with those obtained via conventional analysis approaches. The **LBB** method results, using annual length frequency (**LF**) data from 2014 to 2018, also indicate very high exploitation rates (**F/M** = 3.1) and low length at first capture (L_{mean}/L_{opt} = 0.79; L_c/L_{c_opt} = 0.72), leading to very low biomass levels compared to those at **MSY** (B/B_{MSY} = 0.30) and virgin stock levels (B/B_0= 0.11). This leads to low **(Y/R)'** level in 2018 (only 44% of that which can be obtained at **MSY**). Overfishing is also evident from the **AMSY** method results, with fishing mortality by 2001 in excess by 68% of that necessary to harvest **MSY**. Moreover, **BSC** stock biomass in 2002 is only 41% of the biomass needed to generate **MSY**. The **AMSY** results are preliminary in nature due to limitations in the **BSC** data input requirements for the method (1991-1995 catch rate data and interpolations for 1996-2002 catch rates). Note, however, that the preliminary results from the **AMSY** method are consistent with the overfishing diagnosis from other methods given previously, requiring substantive fishing mortality reduction (of 68%) to get to F_{MSY} levels by about 2002. Overall, the results from conventional and new analysis approaches indicate that the fishing effort for **BSC** (from the early 1990s to 2018) in the Visayan Sea has increased considerably, and the overfishing problem has worsened during this period, requiring effort reduction by about a third (28-33%) in 2012 to about half (49%) by 2018. Moreover, increasing length-at-first-capture closer to L_{c_opt} is in order. As these may be too high (increasing L_c = 10.1 cm by 28%) for many stakeholders, using =L_m = 11.5 cm as L_c may be a viable compromise.

The current study has produced reference points and assessments for the Visayan Sea **BSC** stock up to a certain level of progress. These results can still be improved and refined, given other available **BSC** data in **NSAP Regions 5, 6, and 7**. Assessment process guidelines (in addition to the method guidelines provided for each analysis approach) were discussed with workshop participants to guide future "next steps" or follow-up actions beyond the current study. These "next steps" or follow-up guidelines are outlined for each analysis approach in **Annex 4**, after providing a summary of the main assessment results from each method. Assessments and reference points are not static guides and should be refined and improved with the availability of new data, information, and analysis covering the Visayan Sea **BSC** stock/fisheries. Such is consistent with the "adaptive approach" and the principle of "using the best available scientific evidence" in fisheries management. Overall, however (directions for results refinement and improvement notwithstanding), the **BSC** reference points and assessments given in this study are deemed sufficiently conclusive to be able to proceed with recommendations to right-size fishing effort, increase **BSC** capture sizes, and introduce closed seasons/areas.

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www.fishbase.org (accessed 13 May 2019) Fishbase goes Fishbayes.

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www.q-quatics.org (Quantitative Aquatics, accessed 06 Sept. 2019) on "Use of **CMSY** Tool for the Assessment of Philippine Stocks" workshop (4-8 March 2019), for **CMSY** and **AMSY** methods, software, and related materials.

www.seafdec.org (accessed 24 May 2019) Oceans Project and electronic traceability updates on the work of the Southeast Asian Fisheries Development and Educational Center.

www.sealifebase.org (accessed 24 May 2019) on taxonomy, distribution, and biology of *Portunus pelagicus*.

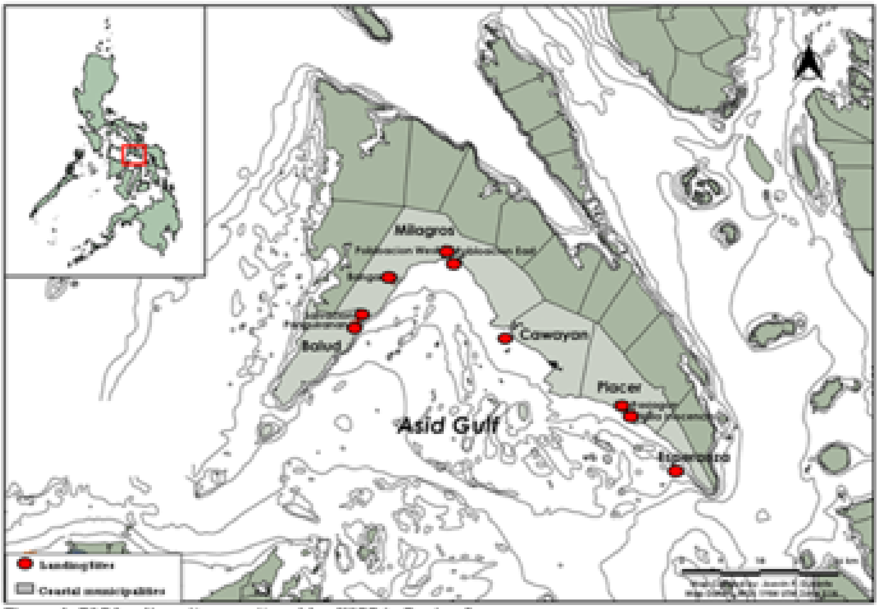

Figure 1. BSC landing sites monitored by NSAP in Region 5.

Figure 2. BSC landing sites monitored by NSAP in Region 6.

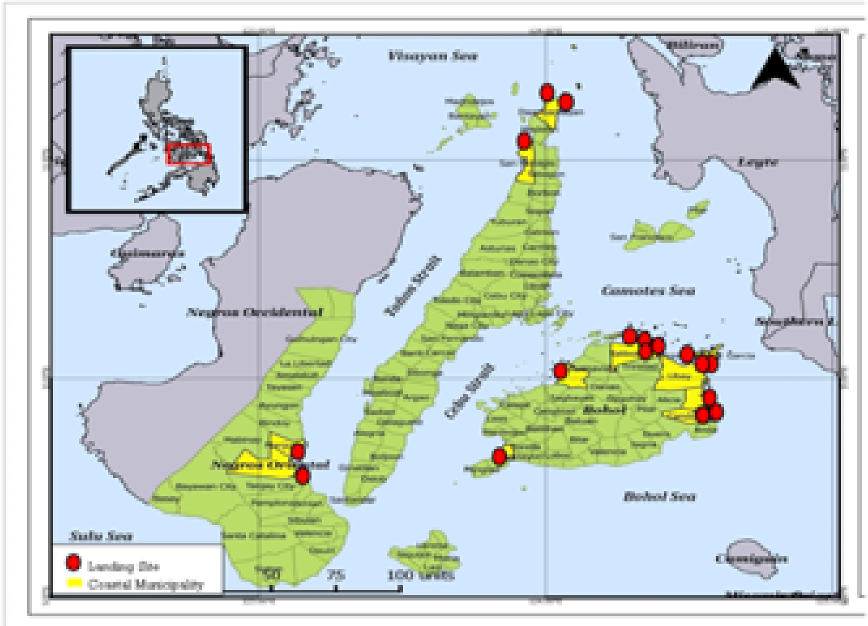

Figure 3. BSC landing sites monitored by NSAP in Region 7.

Annex 1. Chronology of Various Work and Activities Undertaken During the Course of the Consultancy from 27 May to 31 October 2019

PHASE 1: DATA REVIEW AND EVALUATION

- *25 May* – Finalize flight and hotel bookings for the first trip to Iloilo (27 May – 01 June); coordination with **NSAP Region 6** project leader, Ms. Sheryll Mesa, on trip objectives, schedule, field visit, logistics and **BSC** data context/details, and completed analyses.

- *27 May* – Travel from Manila to Iloilo via PR2143 (1000-1630 hrs); hotel check-in (1630 hrs); coordination meeting with Mr. A. Vargas (Consultant's Research Assistant) on **Regions 5, 6, and 7** liaison requirements, training phase, and assistance provision to consultant; coordination communications with **NSAP Region 6** Project Leader Ms. Mesa (1700-2000 hrs).

- *28 May* – Literature search on blue swimming crabs; draft initial outline of consultancy report (0800-1200 hrs); meeting with Ms. Sheryl Mesa of **NSAP Region 6** and Mr. A. Vargas on **NSAP** data collection, processing, management, and database, as well as initial discussions on appropriate reference points and field visit plan (1300-1700 hrs).

- *29 May* – Field visit to Community Fish Landing Center in Bgy Mangorohoro, Ajuy, Iloilo to observe fisheries landings, field data collection, and reproductive biology data collection by field enumerators; drop plans to visit other landing places, given fiesta celebration in these localities (0500-1400 hrs); wrap-up meeting with Ms. Mesa and Mr. Vargas on observations and clarifications regarding data collection, transmission, encoding, audit, and management (1400-1800 hrs).

- *30 May* – Coordination meeting with Ms. Mesa and **NSAP Region 6** staff regarding data transmission/submission from field enumerators, encoding, audit, management, treatment, and processing. Available data, analysis options, and potential reference points were also discussed (0900-1400 hrs). Meeting with Mr. Vargas on data review follow-up items, **Regions 5 and 7** requirements, and training phase coordination needs and preparations (1400-1700 hrs).

- *31 May* – Finalize preliminary outline of consultancy report; literature search and review of local blue swimming crab studies and publications (0900-1200 hrs); review of **NSAP** "system" description and publications, visit to Southeast Asian Fisheries Development Center (**SEAFDEC**) and University of the Philippines in the Visayas (UPV) library/staff on reference points and **NSAP** impressions, including **BSC** study suggestions (1300-1700 hrs).

- *01 June* – Review of **NSAP** publications and documentation references, atlas of Philippine fisheries describing **NSAP** data collection, management, and database (0800-1200 hrs); hotel check-out and travel back to Manila via PR2144 (1300-1930 hrs, flight delayed 1.5 hours).

- *03 June* – Work on references section of consultancy report; further literature search and key references review on target, limit, and precautionary reference points and methodological approaches (Spawning Potential Ratio or **SPR**); communication exchanges with Ms. Mesa and Mr. Vargas on data time series; **BSC** landing sites and map of landing sites (0900-1800 hrs).

- *04 June* – Work on references section of consultancy report; further literature search and key references review on use of reference points, interpretation, and methodological approaches (**L_{BAR}, LBB**); communication or clarification exchanges with Ms. Mesa and Mr. Vargas on data collection and management (0900-1900 hrs).

- *05 June* – Further literature search and key references review on reference points provision and approaches/methods (surplus production, yield-per-recruit and relative yield-per-recruit models). Synopsis of **Phase 1** (Data Review and Evaluation) findings and recommendations (0900-1800 hrs).

- *06 June –* Synopsis of data review/ evaluation findings and recommendations; key references review on reference points provision and approaches/methods (Fox, yield-per-recruit and relative yield-per-recruit models); draft preliminary **Phase 1** report elements (0900-1800 hrs).

- *07 June –* Individual conferences/ calls with various **NSAP** staff based at **NFRDI-NSAP** Office, Quezon City, and **NSAP Regions 5 and 7** regarding **NSAP** data collection/ management and database situation/status; draft preliminary **Phase 1** report elements (0900-1800 hrs).

- *08 June –* Draft preliminary **Phase 1** report elements; transmit to Ms. Mesa (**NSAP Region 6**) with copy to Mr. Alonso and Mr. Villela (**SFP**) for review and edit suggestions (0900-1700 hrs).

PHASE 2: ANALYSIS OPTIONS AND GUIDELINES

- *14 June –* Letters of request to **BFAR Regions 5, 6, and 7** for permission to use **NSAP** regional data; compose, send, and follow-up respective letters of request. Coordination exchanges with Ms. Mesa and Mr. Vargas on letters of request and access to regional data; clarification exchanges with **BFAR Regions 5, 6, and 7** staff and officials (0800-1700 hrs).

- *28 June –* Review **Region 5** data submissions (aggregated annually for 2017 and 2018). Exchanges with **NSAP Region 5** staff and officials (Ms. Lanzuela, Ms. Mesa); request resubmission of monthly **LF** data in lieu of annual aggregated data for 2017 and 2018 (0900-1700 hrs).

- *11 July –* Review resubmitted **NSAP Region 5 BSC LF** data for 2017 and 2018. Meetings (on the side of the Oceans Planning Workshop at CEC, UP Los Banos, Laguna) with: the Oceans Project on Electronic Catch Documentation and Traceability (ECDT) developments in the Philippines; Mr. Jun Torres on **NSAP** and database developments/issues; and Mr. El Cinco on assistance in trainings for **BSC** reference points elaboration (1000-1400 hrs, plus additional 5 hours travel to and from the workshop venue).

- *14 July –* Travel to Baguio City for **NSAP** Mid-Year Review & Planning Workshop @ Eurotel Baguio City; update exchanges with **NSAP** organizers (1000-1700 hrs).

- *15-16 July –* Meetings (intermittent on the side of **NSAP** Mid-Year Meeting) with **NSAP Regions 5, 6, and 7** staff on **BSC** data collection, management, and issues/challenges; **BSC** data access and use approvals by **Regions 5, 6, and 7** officials; overview of **BSC** consultancy objectives and training; updates on **NSAP** work and database; meetings with Mr. Jun Torres and **NFRDI**/**NSAP** national staff on **NSAP** work progress, central database, and schedule of training under the consultancy to avoid conflicts with **NSAP** activities (1000-1400 hrs and 1700-1900 hrs).

- *17 July –* Travel back from Baguio City to Manila (0900-1700 hrs).

- *08 August –* Survey of literature and references on applicable stock assessment models given available **BSC** data and technical backgrounds of **NSAP Regions 5, 6, and 7** staff. Communication exchanges with Mr. Torres, Ms. Mesa, and Mr. Vargas on applicable models (1300-1700 hrs).

- *09 August –* Continue survey of literature and review of references on applicable stock assessment models given available **BSC** data and technical backgrounds of **NSAP Regions 5, 6, and 7** staff (0900-1700 hrs).

- *13 August –* Training program drafting; coordination with Mr. Vargas and Mr. E. Cinco (Training Assistant) on program, schedule, and related logistics (1300-1700 hrs).

- *16 August –* Finalize Mr. E. Cinco engagement as Training Assistant; continue coordination with Mr. Vargas, Ms. Mesa, and Mr. Cinco on training preparations and logistics. Work on **Phase 1** draft report edits/revisions

(0900-1700 hrs).

- *17 August* – Coordinate data requirements (for **Regions 5, 6, and 7** training exercises) to be brought by regional training participants; coordinate internet access and software/apps requirements for training program with Mr. Vargas and Ms. Mesa; continue revisions/edits on **Phase 1** draft report (0900-1700 hrs).

- *19 August* – Phone conference with Mr. Cinco on concepts, exercises, data needs from participants, logistics, and software requirements for **LBB**, **CMSY**, and **AMSY** sessions during the training in Iloilo; revise consultancy report outline, given latest references review and consultations with **NSAP** stakeholders; work on point summary of **Phase 2** activities undertaken to date (0900-1700 hrs).

- *20 August* – Phone conference with Mr. Vargas on the outcome of update meeting with Ms. Mesa regarding the training agenda, venue, logistics, and related matters. Revision of training agenda to include only PM of 25 September to late PM of 27 September per inputs from Ms. Mesa given participants' availability, other **NSAP** activities and budget for the training. Email the revised training agenda to Mr. Vargas with copy to Ms. Mesa and Mr. Cinco for comments and guidance. Revisit surplus production (Schaefer and Fox) references (0900-1700 hrs).

- *22 August* – Review surplus production references. Draft surplus production modelling write-up and technical guidelines for consultancy report. Review training exercise options on surplus production modelling and **RP**s. Email exchanges and phone conferences with Mr. Vargas (on training venue and logistical arrangements) and Mr. Cinco on training session needs for **LBB**, **CMSY**, and **AMSY** (0900-1700 hrs).

- *23 August* – Continue drafting surplus production modelling write-up and technical guidelines for consultancy report. Review training exercise options on surplus production modelling and **RP**s. Review yield- and relative yield-per-recruit references. Draft yield- and relative yield-per-recruit write-up and technical guidelines for consultancy report (0900-1700 hrs).

- *24 August* – Continue drafting yield- and relative yield-per-recruit write-up and technical guidelines for consultancy report. Review training exercise options for relative yield-per-recruit modelling and **RP**s (0900-1700 hrs).

- *26 August* – Review recruitment pattern references. Draft recruitment pattern write-up and technical guidelines for consultancy report. Review training exercise options on recruitment pattern and **RP**s (0900-1700 hrs).

- *27 August* – Editing/revision round for completed portions of consultancy report. Supplement data review write-ups with latest findings about **NSAP** national system. Coordination exchanges with Mr. Vargas on flight, hotel, and logistical arrangements for joint analyses and training exercises in Iloilo on 24-28 September. Coordination with Mr. Cinco on **LBB**, **CMSY**, and **AMSY** section write-ups and exercises (0900-1700 hrs).

- *28 August* – Review L_{BAR} method literature search and references. Draft L_{BAR} portion of the write-up for consultancy report. Follow-up communication exchanges with Mr. Vargas and Mr. Cinco on matters covered during 26 and 27 August, above (0900-1700 hrs).

- *29 August* – Continue L_{BAR} references review and corresponding write-up in consultancy report. Follow-up clarification exchanges with Mr. Vargas and Mr. Cinco on matters covered during 26 and 27 August (above) (0900-1700 hrs).

- *30 August* – Review **SPR** literature search and references. Draft **SPR** write-up for consultancy report (0900-1700 hrs). Finalize flight and hotel bookings for 24-28 September Iloilo trip to conduct **BSC** training and joint analyses.

- *31 August* – Continue review of **SPR** references and corresponding consultancy report write-up. Edit/revision round of (entire) completed consultancy report and joint analysis/

training program for language, references, and consistency. Communication exchanges with Mr. Cinco on **LBB**, **CMSY**, and **AMSY** portions of consultancy report. Coordination exchanges with Mr. Vargas on program and handouts to produce for the upcoming joint analyses/ training in Iloilo. (0900-1700 hrs).

- *02 September –* Revisit **BSC** references; rewrite relevant **BSC** write-up in consultancy report. Communication exchanges with Mr. Cinco, Mr. Vargas, and Ms. Mesa on training data/software and logistical arrangements, plus write-up/report inputs. Coordination exchanges with Mr. Villela on second report submission and training updates. (0900-1700 hrs).

- *03 September –* Revisit **BSC** literature search and references; rewrite relevant consultancy report sections considering global and local **BSC** publications (0900-1700 hrs).

- *04 September –* Revisit "**NSAP** system" literature search and review key references; rewrite **NSAP** overview sub-section of the consultancy report. Communication exchanges with Mr. Vargas (hotel and training logistical arrangements) and Ms. Mesa (training week schedule, **BSC** data for **Regions 5 and 6**, measures to obtain **Region 7 BSC** data, data confirmations/clarifications). (0900-1700 hrs)

- *05 September -* Revisit supplemental methods literature search and review key references (Ecopath with Ecosim or **EwE**, **MULTIFAN-CL**, simple overfishing and ecosystem indicators). (0900-1700).

- *06 September –* Write supplemental methods subsection of consultancy report. Coordination with Mr. Cinco regarding **Regions 5 and 6** length frequency data and use for training exercises. Coordination exchanges with Mr. Vargas on training venue, hotel arrangements, and handouts. (0900-1700 hrs).

- *09 September –* Review of literature search and key references about the **LBB** method (0900-1700 hrs).

- *10 September –* Continue review of key references on the **LBB** approach. Coordination with Mr. Cinco on **LBB** concept, overview lecture, and technical guidelines for training phase in Iloilo. Write up **LBB** subsection of consultancy report (0900-1700 hrs).

- *11-12 September –* Review of literature search and key references on the **CMSY** and **AMSY** approach. Write up **CMSY** subsection of consultancy report. Coordination with Mr. Cinco on theory, overview lecture, and technical guidelines for **CMSY** of training phase in Iloilo (0900-1700 hrs).

- *12-13 September –* Continue review of key references on **AMSY** approach. Coordination with Mr. Cinco on **AMSY** concept, overview lecture, and guidelines for training phase in Iloilo. Write up **AMSY** sub-section of consultancy report (0900-1700 hrs).

- *16-17 September –* Review entire consultancy report to date; editing/revision of technical contents and language for clarity/ conciseness. Note potential reference points that may be derived in joint analyses exercises in Iloilo with **NSAP** teams of **Regions 5, 6, and 7** (given available data and applicable analysis approaches). Use as input to outline Phase 3 report elements.

PHASE 3: TRAINING AND JOINT ANALYSES

- *18 September –* Preparation of lecture notes and joint analyses requirements for Day 1 of training phase in Iloilo – Fisheries Management, Reference Points, Surplus Production, **SPR**, Maturity Data. Coordination exchanges with Mr. Cinco and Mr. Vargas on joint analyses exercises, report elements, and logistical arrangements (1300-1700 hrs.).

- *19 September –* Preparation of lecture notes and joint analyses requirements for Day 2 of training phase in Iloilo – Recruitment Seasonality, **L_{BAR}**, Relative Yield-Per-Recruit. Coordination exchanges with Mr. Cinco and Mr. Vargas on joint analyses exercises and training handouts/USBs (0900-1700 hrs.).

- *20 September –* Preparation of lecture notes and joint analyses requirements for Day 3 of training phase in Iloilo – **LBB**, **CMSY**,

AMSY, Supplemental Approaches, Wrap-up, and Follow-Up Matters. Coordination exchanges with Mr. Cinco and Mr. Vargas on exercises and logistical arrangements (0900-1700 hrs.).

- *24 September –* Depart residence for NAIA Terminal 2 at 1000 hrs. Flight from Manila to Iloilo via PR2143 at 1435 hrs. Hotel check-in at 1700 hrs. Coordination with **BFAR Region 6** officials and training preparations and logistical arrangements from 1730 to 2000 hrs.

- *25 September –* Coordination with **NSAP** national and **Region 6** officials and training preparations and logistical arrangements (0800-1200 hrs.). Implement Day 1 activities of training and joint analyses agenda, see **Annex 2** (1300-2000 hrs.).

- *26 September –* Implement Day 2 activities of training and joint analyses agenda, see **Annex 2** (0800-2000 hrs.).

- *27 September –* Implement Day 3 activities of training and joint analyses agenda, see **Annex 2** (0800-2000 hrs.).

- *28 September –* Wrap-up meeting with selected **Region 6** officials and **NSAP** Project Leaders (0900-1200 hrs.). Hotel check-out at 1200 hrs. and departure for the airport at 1300 hrs. Return from Iloilo to Manila via PR2144 at 1625 hrs. Transfer from NAIA 2 to residence (1800-1930 hrs.).

- *30 September –* Work with A. Vargas on finalizing *Figures 1-3*. Reruns and reconfirmation of analyses results with Mr. Cinco on **LBB**, **CMSY**, **AMSY**, and **Y/R** methods (0900-1700 hrs).

- *01 October –* Work on abbreviations and acronyms section of the report (0900-1700 hrs). Rerun Schaefer (1957) and Fox (1970) analyses to validate and refine results.

- *02 October –* Continue reruns and reconfirmation of results with Mr. Cinco. Consolidate analyses results for the various methods. Consolidate "next steps" guidelines for the assessment process. Communication exchanges with Ms. Mesa on **Y/R** and other results and follow-up actions (0900-1700 hrs).

- *03 October –* Draft joint analyses and reference points subsection of the report. Work with A. Vargas and S. Mesa on training participants list and *Figures 1-3* (0900-1700 hrs).

- *04 October –* Continue drafting joint analyses and reference points subsection of the report. Coordination with A. Vargas on participants list and communications with **NSAP Regions 5, 6, and 7** on follow-up actions. Rerun relative **Y/R** and **B/R** analyses to refine results. (0900-1700 hrs).

- *05 October –* Continue rerun of relative **Y/R** and **B/R** analyses to refine results. Draft relative **Y/R** and **B/R** results portion of the report given new inputs/data. (0900-1700 hrs).

- *07 October* – Rerun of **LBB** analysis with Mr. Cinco. Draft **LBB** results portion of the report. (0900-1700 hrs).

- *08 October –* Rerun **CMSY** and **AMSY** analyses to refine results with Mr. Cinco. Draft **CMSY**, **AMSY** results and follow-up actions (**Annex 4**) of the report. (0900-1700 hrs).

- *09 October –* Communication exchanges with Mr. Vargas and **NSAP Region 6** staff on training participants list. Draft **Annex 3** of the report. (0900-1700 hrs).

- *10 October –* Draft Executive Summary section of the report. Finalize **Annex 2** and **3** of the report. (0900-1700 hrs).

- *11 October –* Proofread the entire report. Address revision/edit suggestions from **SFP** Science Division. (0900-1700 hrs).

- *14 October –* Continue proofreading of the entire report. Address revision/edit suggestions from **SFP** Science Division. Report pagination and enhancements (0900-1700 hrs).

- *15 October –* Last round of proofreading of the entire report. Transmit draft consultancy report to Ms. Mesa and Mr. Villela with copy to Mr. Alonso for review/comments and suggestions.

Annex 2. NSAP *Training on Blue Swimming Crab (*BSC*) Reference Points (RPs) and Fisheries Management*

NSAP Regions 5, 6, and 7

25-27 September 2019

Organized by the Bureau of Fisheries and Aquatic Resources, Regional Office No. 6

Madison Hotel, San Agustin, Iloilo City

PROVISIONAL AGENDA

Objectives:

1. Review conventional/traditional and new/potential approaches to fisheries stock assessment for the provision of reference points in the management of BSC in Regions 5, 6, and 7.
2. Utilize available data from NSAP Regions 5, 6, and 7 using applicable analytic approaches and guidelines to derive relevant reference points for BSC management.

DATE/TIME	ACTIVITY	RESPONSIBLE/LEAD PERSON/S
25 September 2019		
9:00 AM – 1:00 PM	Arrival of participants, hotel check-in, registration, and preparatory meetings and activities	NSAP Project Leaders and Staff (Regions 5 & 7), Albert Vargas, Gerry Silvestre, El Cinco
1:00 – 1:30 PM	Opening remarks, introductions, training objectives/scope, fisheries management, and reference points	Ms. Sheryll Mesa, Gerry Silvestre
1:30 - 5:30 PM	Lecture and exercises/ guidelines on surplus production, SPR and maturity data, and RPs	Gerry Silvestre
26 September 2019		
8:00 – 8:15 AM	Recap of Day 1 activities	NSAP Project Leader
8:15 - 10:00 AM	Lecture and exercises/ guidelines on L_{BAR} and recruitment seasonality and RPs	

10:00 AM- 12:00 PM	Lectures and exercises/ guidelines on yield- and relative yield-per-recruit Methods and RPs	Gerry Silvestre
12:00 - 1:00 PM	Lunch Break	c/o **BFAR Region 6**
1:00 - 5:00 PM	Continue ... yield- and relative yield-per-recruit Methods & RPs	Gerry Silvestre
5:00 - 6:30 PM	Dinner Break	c/o **BFAR Region 6**
6:30 - 8:30 PM	Catch-up Atelier (as needed) on Day 1 & 2 topics	Selected NSAP Project Leaders & staff, Gerry Silvestre, El Cinco, Albert Vargas
27 September 2019		
8:00-8:15 AM	Recap of Day 2 activities	NSAP Project Leader
8:15 AM - 12:00 PM	Lectures and exercises/ guidelines on **LBB**, **CMSY** & **AMSY** Methods and RPs	El Cinco, Gerry Silvestre
12:00 - 1:00 PM	Lunch Break	c/o **BFAR Region 6**
1:00 - 5:00 PM	Continue... lectures and exercises/guidelines on **LBB**, **CMSY**, **AMSY** & Supplemental Methods and RPs	El Cinco, Gerry Silvestre
5:00 - 5:30 PM	Closing program, wrap-up & follow-up matters	Ms. Sheryll Mesa, Gerry Silvestre
6:30 - 8:30 PM	Catch-up Atelier (as needed) on Day 2 & 3 topics	Selected NSAP Project Leaders & staff, Gerry Silvestre, El Cinco, Albert Vargas
28 September 2019		
8:00 AM - 12:00 PM	Hotel check-out and departure for home base	NSAP Project Leaders and staff (Regions 5 & 7), Gerry Silvestre, El Cinco

Annex 3. List of Training and Joint Analyses Workshop Participants
NSAP *Training and Joint Analyses Workshop on* BSC *Reference Points and Fisheries Management*

NSAP Regions 5, 6, and 7

Madison Hotel, San Agustin, Iloilo City

September 25-27, 2019

NAME	POSITION	ORGANIZATION
Sheryll Mesa	NSAP 6 Project Leader	BFAR Region 6, Muelle Looney, Iloilo City
Angel Joy V. Lombres	Data Encoder	BFAR Region 6, Muelle Looney, Iloilo City
Marimar Cabilogan	Data Encoder	BFAR Region 6, Muelle Looney, Iloilo City
Amelyn G. Melligo	Data Encoder	BFAR Region 6, Muelle Looney, Iloilo City
Diana M. Dela Cruz	Data Encoder	BFAR Region 6, Muelle Looney, Iloilo City
Jessa Mae Roga	Data Encoder	BFAR Region 6, Muelle Looney, Iloilo City
Melchor J. Mabot	Support Staff	BFAR Region 6, Muelle Looney, Iloilo City
Matt Doyola	NSAP 6 Assistant Project Leader	BFAR Region 6, Muelle Looney, Iloilo City
Leslie G. Beren	Enumerator	BFAR Region 5, Fabrica Bula, Camarines Sur
Roy B. Montelegre	Enumerator	BFAR Region 5, Fabrica Bula, Camarines Sur
Weldren Aquallo	Enumerator	BFAR Region 5, Fabrica Bula, Camarines Sur

Sheila Mae B. Basco	Enumerator	BFAR Region 5, Fabrica Bula, Camarines Sur
Eufemia Londorial	Data Encoder	BFAR Region 5, Fabrica Bula, Camarines Sur
John Christina L. Brezuela	Enumerator	BFAR Region 5, Fabrica Bula, Camarines Sur
Gaddy P. Villaflor	Enumerator	BFAR Region 4A, NIA Road, Quezon City
Ma. Bernadette Caabay	Enumerator	BFAR Region 4A, NIA Road, Quezon City
Elmar M. Villafor	Data Analyst	BFAR Region 4A, NIA Road, Quezon City
Princess Mae A. Loresto	Enumerator	BFAR Region 4A, NIA Road, Quezon City
Bruna Abrenica	NSAP 7 Project Leader	BFAR Region 7, Arellano Blvd., Cebu City
Analuz M. Bernales	Data Analyst	BFAR Region 7, Arellano Blvd., Cebu City
Leonard O. Rios	Enumerator	BFAR Region 7, Arellano Blvd., Cebu City
Eliaquin D. Exchamador	Enumerator	BFAR Region 7, Arellano Blvd., Cebu City
Kent James D. Ampit	Enumerator	BFAR Region 7, Arellano Blvd., Cebu City
Dante P. Maguilan	Enumerator	BFAR Region 7, Arellano Blvd., Cebu City
Maria Leah D. Orlans	Enumerator	BFAR Region 7, Arellano Blvd., Cebu City
Mary Jane M. Fajardo	Enumerator	BFAR Region 7, Arellano Blvd., Cebu City
Michell B. Rivera	Enumerator	BFAR Region 7, Arellano Blvd., Cebu City
Cherry Lyn C. Ibanez	Enumerator	BFAR Region 7, Arellano Blvd., Cebu City
Marinelle Espino	Project Director	Philippine Association of Crab Processors, Inc.

Francisco Torres Jr.	NSAP National Coordinator	National Fisheries Research and Development Institute
Gerry Silvestre	Consultant	Sustainable Fisheries Partnership
Elviro Cinco	Consultant Support Staff	
Albert Vargas	Consultant Support Staff	

Annex 4. Joint Analyses Results and Assessment Process Guidelines Outlining Follow-Up Actions for Improvement of Reference Points Derived in this Study

Surplus Production Method

- The extension method results are as follows: (1) A_{ratio} using the Schaefer (1957) model was 0.51, with $(Y/f)_{now}$ = 47.2 kg/panel and $(Y/f)_{MSY}$ = 92.2 kg/panel; (2) A_{ratio} using the Fox (1970) model was 0.71, with $(Y/f)_{now}$ = 50.0 kg/panel and $(Y/f)_{MSY}$ = 70.2 kg/panel; (3) $f_{(\%)}$ using the Schaefer (1957) model was -32.8%, with f_{now} = 28,258 panels and f_{MSY} = 18,988 panels; and (4) $f_{(\%)}$ using the Fox (1970) model was -28.5%, with f_{now} = 28,837 panels and f_{MSY} = 20,624 panels. Overall, the results indicate substantive overfishing that has led to catch rates much lower than those generated at MSY, and requiring substantive fishing effort reduction of -28.5% to -32.8% of fishing effort levels in 2012.

- Next steps: Reference points indicate the need to reduce fishing effort by 28-33%. Explore the viability of measures to reduce fishing effort with management authorities, fishers and various stakeholders. (To be done in the next 3-6 months).

- Mine the catch and effort data for Region 6 for other years (beyond 2012) and then rerun the Schaefer (1957) and Fox (1970) method extension used in the workshop. Compare the results and see if the longer time series improves the assessment outputs. (To be done within one year).

- Mine the catch and effort data for Regions 5 and 7, and then rerun the Schaefer (1957) and Fox (1970) model with more complete total catch and total effort data time series for Regions 5, 6, and 7 (combined). Compare outputs to the results derived using only Y/f modeling for selected years done in this study. (To be done in one year.)

Maturity Data, Minimum Size Limits, and Recruitment Patterns

- Reference point indicates that length at-first-maturity size (L_m) in BSC is 11.5 cm for the entire Visayan Sea. Explore utility of this L_m as minimum size limit with management authorities, fishers, and various stakeholders. (In the next 3-6 months.)

- Consensus closure month is April, given analysis of monthly GSI (%), monthly % mature, and recruitment patterns.

- Examine L_m variability across years and areas (Regions 5, 6, and 7 separately). (To be done in near term, 1-2 years.)

- Examine closure month/period (variability) across years and areas (using data for Regions 5, 6, and 7 separately). (To be done in near term, 1-2 years.)

Relative Y/R Analysis

- Relative Y/R analysis was done using parameters derived from 2018 NSAP Region 6 LF data for the Visayan Sea BSC stock: L_{inf} = 22.0 cm; K=1.19/year; M=2.18/year; M/K = 1.83; F = 4.87/year; Z = 7.05/year; current E = 0.69; apparent l_c = 10.4 cm; apparent $c = l_c/L_{inf}$ = 0.47; L_m = 11.5 cm.

- Analysis of the isopleth diagram indicate (Y/R)' maximum at c (=0.46) or l_c = 10.1 cm, and E_{max} = 0.71, $E_{0.5}$ = 0.35 and $E_{0.5}$ = 0.61.

- Analysis of (Y/R)' isopleth diagram from FiSAT shows substantive overfishing of the Visayan Sea BSC stock, requiring substantive fishing effort reduction (about 49% from E of 0.69 currently down to E = 0.35) and increase in size at capture (from l_c = 9.75 cm to $l_c = L_m$ = 11.5 cm). Analysis of the isopleth diagram indicates ideal c=0.46 and ideal E = 0.35 (from the current E = 0.69). Given the lack of selectivity studies, examination of Figure 22 in Mesa *et al.*, 2018 for size-at-capture by the main gears used for catching BSC (*i.e.*, bottom set gillnet, crab pot/traps) shows l_c = 9.75 cm or c = 0.44. A slight increase in l_c is needed, from l_c = 9.75 cm to l_c = 10.1 cm. Moreover, increasing l_c to L_m = 11.5

cm leads to only 3% decrease in (Y/R)' but a 10% increase in (B/R)'. Reducing E from the current 0.69 to 0.35 reduces (Y/R)' by about 20%, but increases (B/R)' by about 32%, which improves catch rates and income and reduces the risk of recruitment overfishing. The current E = 0.69 value leads to (B/R)' of only about 18% of that at virgin stock level.

- Next steps: Explore the viability of substantive reduction in effort (from E = 0.69 to $E_{0.5}$ = 0.35, or 49%) and increase in l_c to 11.5 cm (= L_m) with management authorities, fishers, and various stakeholders. (To be done in 3-6 months.)

- Generate (Y/R)' matrix at c of 0.05 to 0.85 (at 0.05 step sizes) and E from 0.05 to 0.85 (at 0.05 step sizes). Validate absolute (Y/R)' decline (if any) if c=0.52 (= l_c = 11.5 cm) is maintained and E=0.69 is reduced to 0.35. Validate (B/R)' increase with reduction in E to 0.35. Note (B/R)' = (Y/R)'/F. (To be done in the next 3-6 months.)

- Validate L_{inf}, K and M inputs (revisiting ELEFAN I and L_{BAR} methods used); see impacts on above (Y/R)' analyses if L_{inf}, K and M inputs vary (if at all). (To be done in the next 3-6 months.)

- Do selectivity studies; examine the impact of knife-edge selection on (YPR)' assessment results (given the wide selection of range for gears in Figure 22 of Mesa *et al.* 2018). Examine prevailing l_c for major gears exploiting BSC. (To be done in the near term, 1-2 years.)

L_{BAR} Method

- The theory behind the method was discussed; the method produces Z and F estimates given length composition inputs.

- Produces no reference points, but is an alternative method (to catch curve) for estimating Z and F.

- To be revisited when there is a need to provide alternative estimates of Z and F.

Spawning Potential Ratio (SPR) Method

- The theory behind the method was covered and discussed with workshop participants.

- Get selectivity function with size. (To be done in the near term, 1-3 years.)

- Get fecundity function with size. (To be done in the near term, 1-2 years.)

- Five-point scale maturity work for length-based SPR method. (To be done in the near term, 1-2 years.)

- Revisit method after above are available, careful that recruitment variability does not affect length composition inputs to the method. (To be done in the medium term 3-5 years.)

LBB Method

- Data inputs and assumptions: Annual LF data for the years 2014 – 2018 (inclusive)from NSAP Region 6. The LF data are combined for various gears exploiting BSC. The LF data with lengths above 22.3 cm were excluded (based on L_{inf} values obtained from Sealifebase. LF data above 22.3 cm probably erroneous.

- Priors: L_{inf} = 22.7 cm ; M/K = 1.5 ; Z/K = 4.45; F/K = 2.95; selectivity from aggregated annual LF samples, L_c = 9.44 cm

- Results, median across years (95% confidence limits in parentheses): L_{inf} = 23.0 cm (22.7-23.4 cm); L_c = 9.44 cm; L_{opt} = 15.2 cm; L_{opt}/L_{inf} = 0.66; L_{c_opt} = 14.0 cm; L_{c_opt}/L_{inf} = 0.61; M/K = 1.55 (1.32-1.86); F/K = 5.02 (4.67-5.48); Z/K = 6.35 (6.06-6.69); F/M = 3.45 (2.63-4.48); B/B_0 = 0.102; B/B_{MSY} = 0.204; (Y/R)' during median across years is only 39% of (Y/R)' at MSY.

- Results, for last year 2018 (95% confidence limits in parentheses): L_c = 10.1 cm (10.1-10.2 cm); l_c/L_{inf} = 0.45 (0.443-0.448); L_{mean}/L_{opt} = 0.79; L_c/L_{c_opt} = 0.72; F/K = 4.8 (4.22-5.17); F/M = 3.1 (2.36-3.84); Z/K= 6.3 (5.9-6.69); B/B_0 = 0.11 (0.076-0.144); B/B_{MSY} = 0.30 (0.209-0.396); (Y/R)' in 2018 is only 44% of (Y/R)' at MSY.

- Overall, the LBB method results indicate very high exploitation rates leading to very low biomass levels compared to those at MSY and virgin stock levels. This leads to low (Y/R)' level (only 39-44%) of that which can be obtained at MSY. Moreover, increasing length-at-first-capture closer to L_{c_opt} is in order. As these may be too high (increasing L_c = 10.1 cm by 28%) for many stakeholders, using L_m = 11.5 cm as L_c may be a viable compromise.

- Results using the LBB method should be taken as preliminary in nature. An attempt to refine the results should be made using separate LF data for individual major gears used to exploit the BSC stock (so that impacts of selectivity can be separated from impacts of fishing on the stock). (To be done in one year.)

- Conduct the selectivity studies for the major gears (bottom-set gillnet, crab pot/trap, etc.). When the selectivity functions become available, rerun LBB using the selectivity corrected LF data for the individual gears and total for all gears combined. (To be done in near term, 1-3 years.)

- It is noted, however, that the results from the LBB method are consistent with those indicating substantive overfishing using methods presented above.

CMSY Method

- The lack of total catch data (for 10 consecutive years) from the BSC stock in the Visayan Sea precluded the use of the method in deriving reference points for fisheries management. However, exercises were run using catch data from Region 6 (only), principally to familiarize workshop participants with the method and its various priors (r range; k range; B_t/k at the beginning or end of catch time series) and input requirements (catch time series for 10 consecutive years). The results of the exercise (r; k; MSY; f_{MSY}; B_{MSY}; BR) were not used in making conclusions about the BSC fisheries in the Visayan Sea, as they do not represent valid results from representative catch time series inputs.

- Next steps: Mine the sources of total catch data for Regions 5, 6, and 7. It is emphasized that the data required is total extraction for catch from the Visayan Sea BSC stock. Note also that the CMSY method requires a minimum of 10 years continuous or consecutive data. Revisit the method and rerun CMSY when the required catch time series data become available. (To be done in the near term, 1-3 years.)

AMSY Method

- Data inputs and assumptions: CPUE data for the years 1991-2002, with 1991-1996 CPUE data from Mesa *et al.*, 2018 and CPUE data for 1996-2002 interpolated from CPUE equation used in Schaefer (1957) modeling above.

- Priors used were: r range = 0.78-1.78; kq range = 0.406-1.060; B_{2002}/k range = 0.15-0.40.

- Results (95% confidence limits in parentheses): r = 1.13 (0.788-1.58); kq = 0.531 (0.372-0.878); MSYq = 0.15 (0.093-0.277); f_{MSY} = 0.563; F_{2001}/f_{MSY} = 1.68; B_{2002}/B_{MSY} = 0.41. Overfishing is evident from method results, with fishing mortality in 2001 in excess of 68% of that necessary to harvest MSY. Moreover, BSC stock biomass in 2002 is only 41% of the biomass needed to generate MSY.

- Method results are considered preliminary, until m B_{2002} ethod documentation is peer-reviewed and published. Note, however, that the preliminary results are consistent with the overfishing diagnosis from other methods, requiring substantive fishing mortality reduction (of 68%) to get to f_{MSY} level.

- Next steps: Continue data collection such that 10 consecutive years (at least) of CPUE data for the BSC stock in the Visayan Sea is generated (as required by the AMSY method for reliable results). Revisit and rerun the AMSY method when the 2011-2020 CPUE time series for BSC becomes available. (AMSY rerun to be done in medium term, 3-5 years.)

Supplemental Methods/Approaches

- **Multifan-CL** concept covered; method to be revisited in the medium term (3-5 years) when data needs (spatial info, tag-recapture data, etc.) become available.

- **EwE** concept covered; method to be revisited in the medium term (3-5 years) when data sourced from fisheries ecosystems similar to the Visayan Sea become available.

- Twelve simple ratio indicators to be completed in the near term (within one year) to complement detailed assessments completed above. Involving simple ratio computations, assessments using the 12 simple ratio indicators were assigned as a take-home assignment for completion by workshop participants.

Sustainable Fisheries Partnership wishes to acknowledge the generous support of the **Global Sustainable Supply Chains for Marine Commodities (GMC) project**. *GMC is an interregional initiative implemented by the Ministries and Bureaus of Fisheries and Planning of Costa Rica, Ecuador, Indonesia and Philippines, with technical support of the United Nations Development Programme (UNDP),* facilitated by the Sustainable Fisheries Partnership (SFP) and funded by the Global Environment Facility (GEF).

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