Stock Assessment of **Octopus in Four Regions of the Philippines and Nationally**

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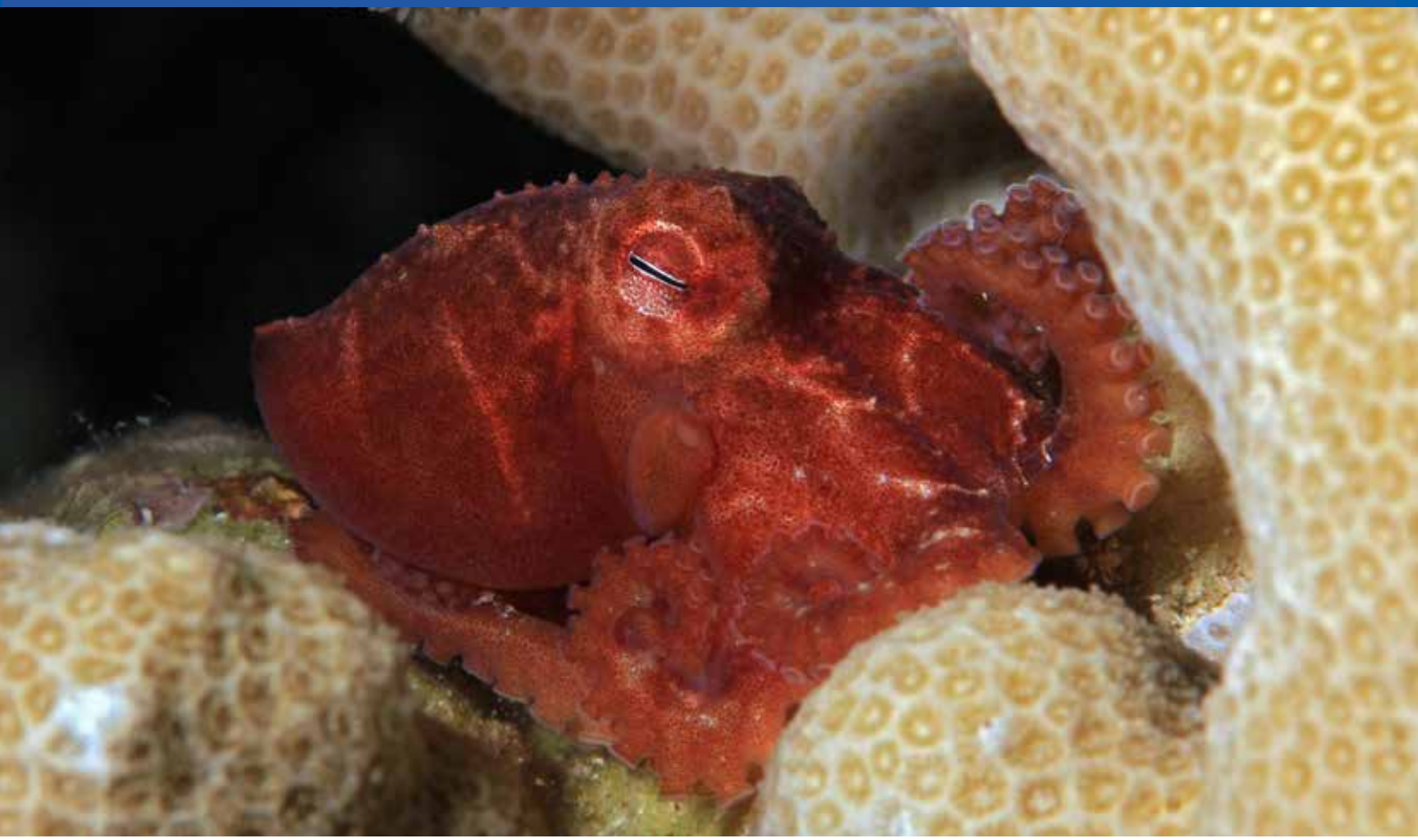

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Contents

1. Introduction

Scientific stock assessment is a key bio-mathematical tool in the understanding of the population dynamics of fished stocks, estimation of their productivity and establishment of management programs aimed at their sustainable exploitation. Stock assessment is currently helping rebuild fisheries worldwide by achieving exploitation rates at or below the maximum sustainable yield (MSY) in half of the most studied ecosystems [1]. Thus although most of the assessed stocks worldwide require rebuilding [1], Hilborn and Ovando found that fisheries that are scientifically assessed and actively managed according to results of assessments are typically in good condition or recovering from over-fishing [2]. Nevertheless, the latest report of the state of world fisheries by FAO [3, 4] indicated that within the subset of stocks that have been assessed, the percentage of those exploited at biologically sustainable rates continued declining, reaching 65.8% in 2017. This decline can be reversed by active management based on scientific estimations of the limits of productivity of fish stocks. Fishing according to biologically sustainable rates may also help fishers obtain better economic gains because well managed fisheries could achieve better market access and more consistent yields, and provide a more stable environment for investment and lower borrowing costs, usually connected to certification by independent organizations.

Octopus fisheries are a special case because octopus stocks are short-lived, with fast dynamics, and their exploitation is usually conducted by small-scale fisheries. Thus data collection tends to be deficient, making them data-poor or data-limited fisheries that require specialized tools for their assessment. This is the situation in octopus fisheries in the Philippines where the fishing is conducted by numerous artisanal fishers and the only available information corresponds to landings by regions and the national total, mostly at annual time steps, though some of it has been made available at quarterly time steps. For stock assessment purposes in this study, the data has been aggregated to the annual time steps.

To complete the stock assessment of octopus fisheries in the Philippines, a number of companies in the supply chain that aggregate most of the production of small-scale octopus fishers collaborated to put together databases with quarterly or annual production data in gross tonnage from a total of eight regions. Four of the eight regions were selected due to their importance in total production and the availability of longer time series of landings. The four regions selected were Region 9 and BARMM, Region 13, Region 5, and Region 4B.

The fact that the only available data are landings by region and nationally at annual or quarterly time steps severely

constrains the choice of stock assessment methods that could be employed. There is a strong argument that landings data *per se* are not sufficient to conduct a stock assessment [5]. Although the above is essentially true, the statement could be moderated by saying that landings data alone are not sufficient to conduct *objective* and *robust* stock assessment. The absence of other types of data such as fishing effort, scientific surveys and biological composition, means that the assessment would have much stronger assumptions introduced by the analyst as compared to an assessment carried out with any of those data in addition to landings. Currently there are two stock assessment methods published in mainstream scientific journals that provide stock assessment results with landings data alone. These are the method of Froese et al. [6] and the method of MacCall [7]. The latter method is more firmly grounded in population dynamics theory. Unfortunately, it is not an option for the present case because its mathematical results are based on (i) the life history of stocks that are long-lived and (ii) long time series of landings that start from the beginning of the fishery. None of those conditions are met by the octopus fishery in the Philippines. The octopus is a short-lived species and time series of landings for all the regions are short. FAO records of octopus landings in the Philippines start in 1970, while in the available data, the earliest year is 2003 from Region 9 + BARMM.

Given the above considerations regarding the poor nature of the available information, data from the four selected regions and the national total were analyzed to determine the abundance and exploitation status of the octopus stock using the stock assessment methodology of Froese et al. [6]. In addition to assumptions in the modelling that are specific to the data and the method (listed below), two general assumptions apply:

1. The landings recorded as octopus are believed to be composed of a number of different species but are principally a single species, most likely to be *Octopus cyanea*.

2. Octopus stocks in the several regions may have some degree of connectivity, but a large part of population dynamics is controlled by local forces. Thus, the national stock is a meta-population that can be studied on the aggregate as well as separately in each region.

2. Materials and Methods

A conventional stock assessment would use data composed of, at least, long time series of landings and fishing effort data. Biological data on mean size or weight in the catch is also very common and easy to add to the database. A data-rich stock assessment would also use data on discards, length and/or age composition of the fished organisms, as well as fishery independent data to inform on abundance trends (such as those collected during research surveys and mark-recapture experiments). The existence of these varied sources of data helps the robustness and objectivity of stock assessment because it decreases the need to introduce assumptions whose validity cannot be verified objectively. However, in the present case the only available data are short time series of landings from some regions. Therefore the methodology described below and used to assess the octopus stocks in the Philippines lacks robustness and is not objective. It is heavily impacted by assumptions that replace missing data. These assumptions are itemized at the end of each subsection below.

2.1 Data

Processing companies that according to experts currently comprise over 90% of all landings purchased from fishers cooperated, providing their time series of total annual landings. Five of these companies further provided their data disaggregated by location, which allowed the building of time series for regions, as detailed in Table 1. The companies that did not specify the region of origin of their product were assumed to provide national totals, aggregated over all regions of origin. Furthermore, the Philippines Statistical Authority (PSA) provided data by region and the national total for the period 2012-2018, and Asuncion de Guzman kindly provided her consolidated data of exports from the Bureau of Fisheries and Aquatic Resources' annual fishery profiles. In addition we also obtained the most current time series from FAO FishStat database v. 4.00.8, which spanned a much longer time horizon (1970 to 2018) than any of the other time series.

Table 1:

Sources of raw landings data by regions and processing company (anonymized) as aggregated by the companies. PSA: Philippines Statistical Authority. FAO: Food and Agriculture Organization of the United Nations. BFAR: Bureau of Fisheries and Aquatic Resources of the Philippines.

Region	Locations	Data Origin	Years
1	Pangasinan	Industry	2011-18
3	Zambales	Industry	2011-18
4A	Batangas, Quezon	Industry	2011-18
4B	Palawan, Mindoro-San Jose	Industry	2011-18
4B	Manila-Palawan	Industry	2016-18
4B	Palawan	Industry	2013-18
5	Bicol	Industry	2011-18
5	Bicol	Industry	2016-18
5	Manila-Bicol-Samar-Coron	Industry	2013-18
BARMM	Sulu	Industry	2003-18
9 + BARMM	Zamboanga-BARMM	Industry	2016-18
9 + BARMM	Zamboanga-BARMM	Industry	2009-18
9 + BARMM	Zamboanga-BARMM	Industry	2009-18
13	Surigao-Caraga	Industry	2013-18
National		Industry	2013-18
National		Industry	2014-18
National		Industry	2013-18
National		Industry	2009-18
National		PSA	2012-18
National		BFAR	2001-17
National		FAO	1970-18

The data in the two underlined location entries in Table 1 were aggregated over locations spanning different regions. In the first instance, Manila and Palawan's data were aggregated but these locations are fairly close and Palawan had further data so these data were classified under Region 4B. In the second instance, Manila, Samar and Coron's data (all in central Philippines except Samar) were aggregated with Bicol (also in central Philippines). Since Bicol from Region 5 had additional specific data, these aggregated data were included in Region 5.

For each of the seven regions in Table 1 we compiled the total landings by adding the landings of each processing company. We also added the regional totals of the companies into a national total that spanned the period 2003 to 2018. The regional totals and the various national totals are shown in Figure 1. The data from the companies that reported totals by regions, including the four regions of interest (4B, 5, 9 and 13), were used in stock assessment as shown in the figure.

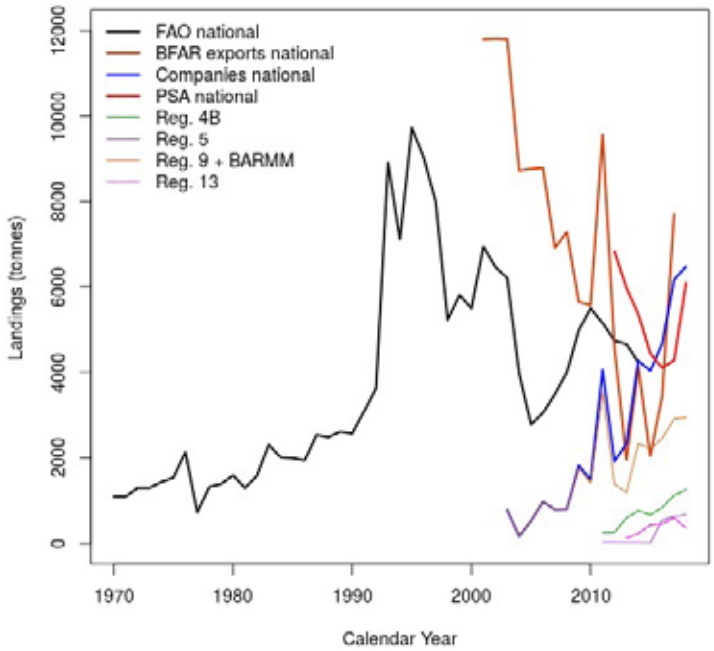

Figure 1:

Curated octopus landings time series in four regions and at the national level in the Philippines from the Food and Agriculture Organization (FAO, 1970-2014), Bureau of Fisheries and Aquatic Resources (BFAR, 2001-2017), companies' reports to this project (2003-2018), and the Philippines Statistical Authority (PSA, 2012-2018, as communicated by Asuncion de Guzman in email dated Friday, July 24, 2020).

The national total to be used requires closer examination prior to their use in stock assessment. First, Figure 1 shows that the time series provided by the PSA correlates well with FAO's and companies data, although they seem to have a 1-year lag. These data are not going to be used in stock assessment at the national level on the grounds that they seem to have a lag, it is a very short time series and does not connect well with totals from FAO, companies, or BFAR exports. Second, we note that national totals from companies' data are incomplete from 2011 backwards since they are much lower than FAO's national total and BFAR exports' national total. In fact, from 2012 backwards, the companies' national total is equal to the total of Region 9 + BARMM reported by just one company. Third, also

noteworthy is the fact that since 2001 and up to 2010 BFAR exports' national total is much higher than FAO's national total. These observations suggest building two alternative time series of national landings: 1) FAO (1970-2014) + Companies (2015-2018) and 2) BFAR (2001-2017) + Companies (2018).

Regarding the FAO + Companies time series, we note that in 2014 the companies' total is close to FAO's total (4,279,230 kg and 4,238,000 kg, respectively), which most reasonably could be interpreted as showing that starting in 2014 the sum of the companies' reported total is a good approximation to the true national total. After 2014, companies' totals are higher than FAO's totals especially in 2017 and 2018 (Figure 1). Therefore, it appears that companies' totals are more complete than FAO's totals in the latest years. The practical implication is that concatenation of part of FAO's time series, the part covering the period 1970 to 2014, with the companies' totals from 2015 to 2018, produces the longest and probably better time series of landings for national-level stock assessment.

Regarding the BFAR + Companies time series, landings are higher than any other series except in three years (2013, 2015, 2016) when landings in this time series are lower than either FAO's or companies' totals. Instead of replacing those three years with the higher values from the other time series, it would seem prudent to keep the integrity of BFAR's time series and just append the last year (2018) from companies' total. So this is what it was done to complete the second time series of national totals.

Considering the nature of the available data described above, assumptions with regard to these data were as follows:

3. Landings by companies that did not specify region of origin are aggregated at the national level.

4. Concatenation of FAO time series of national landings between 1970 and 2014 and the aggregated landings processed by all companies between 2015 and 2018 produces a first close approximation to the true national landings time series from 1970 to 2018.

5. Concatenation of BFAR time series of national landings between 2001 and 2017 and the aggregated landings processed by all companies in 2018 produces a second close approximation to the true national landings time series from 2001 to 2018.

6. If there are landings in the regions before the reported landings time series provided by companies, these are lower than the landings during the periods reported by the companies.

7. Discards are a small fraction of landings and/or most discarded octopus are returned to sea alive and able.

Assumption 3 is necessary because if these landings not assigned to any region were from a specific region instead of national aggregates, they would need to be included in the assessment of that region, which is not possible because the region is unknown. Also, it should be noted that a few of the locations' data were aggregated across regions (see the explanatory text below Table 1) which

will affect the regional assessments with regards to Region 4B and 5.

Assumption 4 and 5 are troubling. Conventional wisdom is that national total landings reported to FAO are generally different from true totals. This could be even more serious in small-scale fisheries where data recording is less complete. Generally, FAO totals are suspected to be lower than true totals because of incomplete observations of landings and the possible existence of significant discards. Accordingly, in Figure 1 the most recent national totals from companies are always higher than FAO's totals and BFAR's totals are always higher than FAO's totals from 2001 to 2011. Therefore, results of stock assessment with these data alone should be taken with great caution.

Assumption 6 is necessary for modelling reasons. Froese et al.'s method [6] will define biomass histories that are compatible with the observed landings history and other assumptions concerning the life history of the resource. If there were landings prior to the start of the data and these were higher than those observed in the data the method would yield potentially severe underestimation of true biomass and parameters of the life history.

Assumption 7 is probably safe given (i) the nature of the catch in octopus fisheries, consistent of a few individuals per unit of effort, (ii) survival of octopuses discarded, and (iii) the relatively high value of each individual octopus. The fact that fishers may retain octopus of low commercial value for personal consumption does not affect this assumption much as long as the vast majority of fished octopus are commercialized.

2.2 Methodology

The methodology of stock assessment employed in this study was developed by Froese et al. [6] and it is called the CMSY method. It is based on the aggregated surplus production concept of biomass dynamic models [8]. Froese et al. start from the idea that landings time series are produced by biomass time series and stock's productivity. Having available the time series of landings and postulating the degree of productivity as a probabilistic hypothesis, their method solves for the biomass time series over Monte Carlo realizations of the productivity hypothesis. Next, having Monte Carlo realizations of the biomass time series, other management-useful fisheries quantities such as exploitation rate, maximum sustainable yield (MSY) and derived biological reference points, can be calculated. Froese et al. connect productivity to resilience and define the latter explicitly through bands of the intrinsic population growth rate in Schaeffer's logistic model,

$$B_{t+1} = B_t + B_t r \left(1 - \frac{B_t}{K}\right) - C_t \qquad (1)$$

where B is biomass, t is year, r is the intrinsic population growth rate, K is the

carrying capacity of the environment, and *C* is the annual total landings. Having specified the initial biomass in the time series, population dynamics is completely determined by the pair of parameters *{r, K }*.

The process starts by defining whether the assessed stock is of high ($0.6 < r < 1.5$), intermediate ($0.2 < r < 0.8$), low ($0.05 < r < 0.5$), or very low resilience ($0.015 < r < 0.1$). Unpublished work of stock assessment of *Octopus vulgaris* in Spain and Mauritania (pers. comm.) completed by this author have shown that under Froese et al.'s definition of resilience, octopus stocks are high-resilience stocks. Another species from warm waters, *Octopus maya,* was assessed as having *r* within the intermediate and high-resilience stocks range [9]. In cold, sub-Antarctic waters, the stock of *Enteroctopus megalocyathus* also has an *r* within the intermediate and high-resilience stocks range [10]. Thus in this work the octopus stock in the Philippines were defined as high-resilience stocks. The process continues by realizing that even though *r* may fall in the pre-defined range for high-resilience stocks, many *{r, K }* pairs would determine negative landings in some years. Those *{r, K }* pairs predicting such outcome are evidently wrong. Therefore, the CMSY method filters out all *{r, K }* pairs producing any negative landings. Next, a prior range for *K* is defined by assuming that (i) the largest landing in the time series is less than *K*, which provides an absolute lower bound for *K,* and (ii) that there is a relationship between *K* and the ratio of the maximum landings over *r* providing both lower and upper bounds for *K*. This relationship can be modulated by multiplying the ratio with positive constants to define situations of severely depleted stocks or situations of moderately depleted stocks at the end of the time series. Examination of Figure 1, which shows a non-decreasing trend in the national landings during the last two decades (and still increasing landings in the regions) supports the notion that octopus stocks in the Philippines have not been severely depleted. Thus the analysis assumes a moderate degree of depletion at the end of the time series (2018), which in turn allows definition of a viable biomass range at the beginning, mid and terminal years.

All those conditions (the ranges of *r*, *K*, and biomass) permit the definition of a region of viable points in the two-dimensional space defined by the *{r, K }* pair. More precisely, Froese et al. set the following restrictions to filter the viable *{r, K }* pairs: a) predicted biomass by *{r, K}* pairs cannot be less than 0.01 *K,* b) predicted biomass by *{r, K }* pairs cannot fall outside a prior range in any of the intermediate years, and c) predicted biomass by *{r, K }* pairs cannot fall outside the prior biomass range in the final year.

Finally, from the viable sets of the *{r, K }* pairs, the method by Froese et al. selects those pairs within a neighborhood of highest *r* values. The logic behind this is that in fact *r* is the maximum population growth rate, the rate of growth when the stock is at low biomass and has the potential to grow at nearly exponential rates. Thus the wide set of viable *{r, K }* pairs can be narrowed down further to the subset of higher *{r }*.

Considering the nature of the CMSY methodology by Froese et al., assumptions with regard to population dynamics and stock productivity were as follows:

8. Octopus stocks in the Philippines are high-resilience stocks, having an intrinsic rate of population growth higher than 0.8 year^{-1}.

9. The productivity function of octopus stocks in the Philippines is symmetric with respect to biomass (Schaeffer type of logistic growth).

10. The carrying capacity of the environment *K* is higher than the highest annual landing in the landings time series.

11. Octopus stocks in the Philippines have experienced a moderate degree of depletion.

12. There is a relation between *K* and the *max(landings)/r* ratio which defines viable ranges for *K* when the assumption of a moderate degree of depletion applies.

13. The true value of *r* from all the viable *{r, K }* pairs is in the neighborhood of higher *r* values.

At least some of these assumptions are unlikely to be true so results reported here should be taken with caution, as preliminary results pending better analysis with more complete data. These assumptions are necessary given the data and the logic of the method but this pragmatic consideration must not be understood as an endorsement of their validity.

Assumptions 8 and 9 could be examined in the light of research by this author with *Enteroctopus megalocyathus* in southern Chile [10], and *O. vulgaris* in Spain and Mauritania. As remarked previously, these results support Assumption 8. However, due to the scarcity of published work in the stock assessment and population dynamics in octopus stocks, there is not yet a critical mass of research to rely confidently on this assumption. Concerning Assumption 9, in the Spanish and Mauritanian cases the symmetry parameter in Pella-Tomlinson model was near the symmetry value, while in the southern Chile case this parameter determined a productivity function with a maximum productivity at low biomass. Probably the results with *O. vulgaris* are more relevant to this case which would suggest that the assumption holds. However, since the symmetry parameter is a power parameter, small deviations from symmetry have a disproportionate impact on the symmetry of the productivity curve and on management-useful quantities, such as the MSY and the biomass that produces the MSY. Thus the assumption of a symmetric productivity function is a serious shortcoming.

Assumptions 10 and 11 draw support from the fact that there is no report of fishery collapse during the study period. However, there are many realistic scenarios where the landings history of regions and nationally could have been produced by little or substantial depletion instead of moderate depletion. Therefore results reported here are conditional on the unverified assumption of moderate depletion. Without data of at least fishing effort it seems impossible to determine the degree of depletion in an objective manner within the stock assessment model. For instance, MacCall's depletion-corrected average catch (DCAC, [7]) also requires the determination of depletion degree outside of the model.

Assumption 12 postulates proportionality relationships between maximum observed landings and the product of *r* and *K* (eqs. 3 and 4 in Froese et al. [6]) that come about from empirical results of Monte Carlo simulations. This empirical relationship is used to set bands of prior values for *K*. This assumption lacks theoretical support. It could be true for the specific conditions of the simulations in Froese et al. [6] and not in general. Thus this is a further unverified assumption that could easily not hold for the present applications. Assumptions 10-12 all rely ultimately on the observed landings history, the single source of data for the method. The landings history in this particular case has its own problems, as noted when examining Assumptions 3-7 in the previous sub-section.

Finally, **Assumption 13** has some merit considering the nature of parameter *r* in logistic population growth models. However, once again it should be noted that realistic scenarios could indeed be construed with lower *r* by being willing to accept higher *K*.

The methodology to conduct this analysis is available as a script in the statistical programming language *R* [11,12]. The curated databases and modelling objects are stored in a workspace. Both the script and workspace are available for examination and use.

3. Results

3.1 Region 4B

The landings history of octopus in Region 4B shows harvesting increasing linearly (Figure 2, panel A). This landings history, plus the assumption of high resilience of octopus stocks, yields a very wide cloud of viable *r, K* pairs (Figure 2, panel B). Most examples in Froese et al. [6] show a triangular cloud with decreasing spread as *r* increases. The fact that this does not happen in the present application is a reflection of wider statistical uncertainty due to the short time series of landings and no decreasing trend at any time after the initial rise.

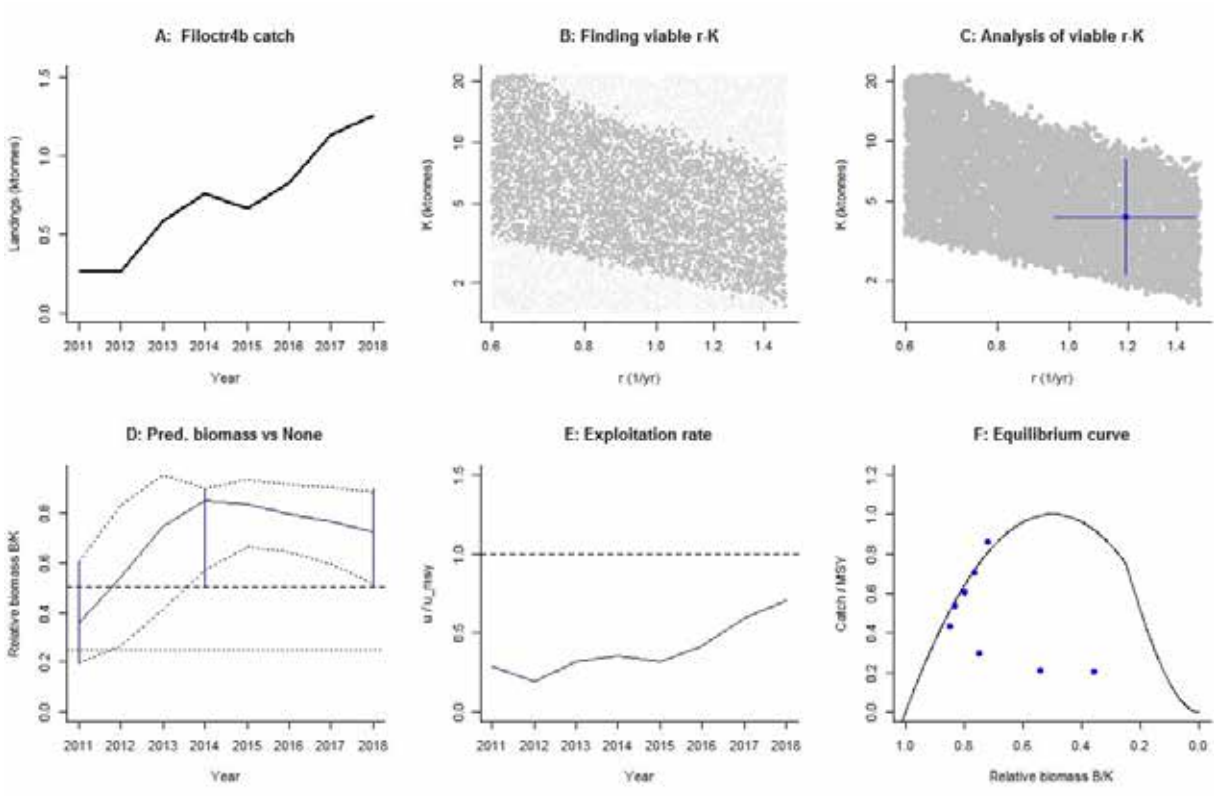

Figure 2:

Stock assessment of octopus in Region 4B, Philippines, using the CMSY method. A: Landings time series. B: Whole set of viable *r, K* pairs, with filtered cloud in darker gray. C: Filtered cloud of viable *r, K* pairs and selected high-*r* values with 95% confidence bands in *r* and *K* (blue cross). D: Estimated relative biomass time series (continuous blue line), 95% confidence bands (dotted lines), maximum sustainable yield (straight dashed line) and its lower 95% lower bound (straight dotted line), and prior ranges for biomass (vertical lines) set by assuming moderate degree of depletion. E: Relative exploitation rate (blue line) and the maximum sustainable relative exploitation rate (straight dashed line). F: Expected exploitation rate (parabola) and observed exploitation rate (blue dots) as a function of relative biomass.

Table 2:

Descriptive quantities and parameter estimates in the stock assessment of octopus in Region 4B, Philippines, using the CMSY method (95% CI in parentheses).

Quantity	Value
Range of years	2011-2018
Starting range of *K* (tonnes)	1429-21440
Mean, maximum and last year landings (tonnes)	719, 1259, 1072
Estimated *r* ($year^{-1}$)	1.191 (0.957, 1.482)
Estimated *K* (tonnes)	4265 (2189, 8312)
Estimated MSY (tonnes)	1270 (527, 3061)

As a result of this wide spread of viable *r, K* pairs, the 95% confidence interval for *K* is also very wide, ranging from 2,000 to over 8,000 tonnes (Figure 2, panel C, blue vertical line and Table 2) (the range of *r* is fixed by the definition of the stock as high resilience). This original statistical uncertainty translates into wide confidence bands for relative biomass in the most recent years, although all values within the confidence bands are above the biomass that produces the MSY conditional on the Shaeffer model (Figure 2, panel D). This would mean that the exploitation of the stock in Region 4B was being conducted in biologically sustainable fashion up to 2018, not yet reaching or crossing safe limits. However, exploitation rate has been increasing slowly towards the maximum sustainable exploitation rate, apparently likely to reach the maximum within the next few years, as projected from simply looking at the rate of increase, *ceteris paribus* (Figure 2, panel E). This finding is also reflected in the equilibrium parabola, with observed exploitation rate getting close to the maximum (Figure 2, panel F).

The wide uncertainty bands are also apparent in the wide margins for the carrying capacity *K* and not so much for the intrinsic rate of population growth (Table 2). The upper bound for *K* is four times the lower bound. As a direct consequence the MSY (defined as *rK*/4 under the Schaeffer logistic model) can be as low as 527 tonnes or as high as 3,061 tonnes (95% confidence bands). This [527, 3061] 95% confidence interval and the estimated MSY amounting to 1,270 tonnes can be compared with the latest total landings as reported by the companies, which in 2018 reached approximately 1,072 tonnes.

3.2 Region 5

The landings history of octopus in Region 5 shows harvesting was virtually null until 2015 and then it increased sharply in just three years (Figure 3, panel A). This landings history is inadequate for modelling based on landings data alone, even under the present, fairly accommodating methodology. Thus the cloud of viable *r, K* pairs (Figure 3, panel B and C) is uninformative.

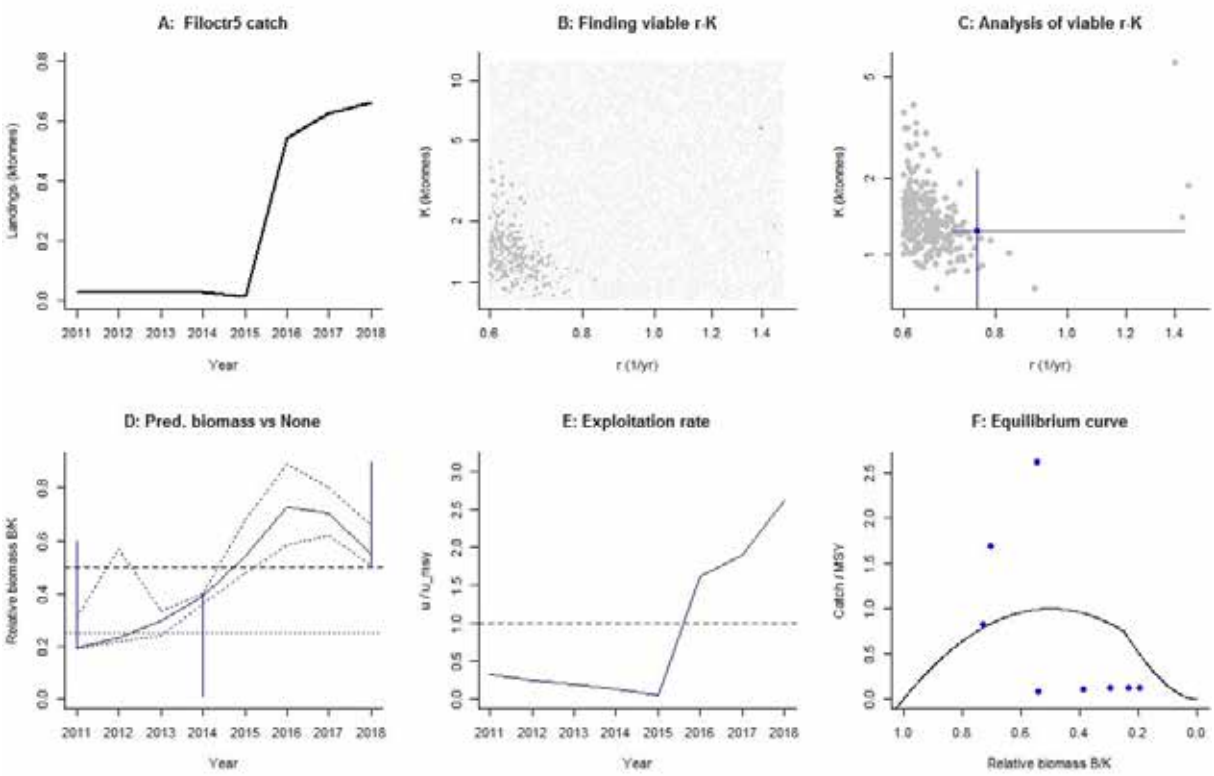

Figure 3:

Stock assessment of octopus in Region 5, Philippines, using the CMSY method. A: Landings time series. B: Whole set of viable *r, K* pairs, with filtered cloud in darker gray. C: Filtered cloud of viable *r, K* pairs and selected high-*r* values with 95% confidence bands in *r* and *K* (blue cross). D: Estimated relative biomass time series (continuous blue line), 95% confidence bands (dotted lines), maximum sustainable yield (straight dashed line) and its lower 95% lower bound (straight dotted line), and prior ranges for biomass (vertical lines) set by assuming moderate degree of depletion. E: Relative exploitation rate (blue line) and the maximum sustainable relative exploitation rate (straight dashed line). F: Expected exploitation rate (parabola) and observed exploitation rate (blue dots) as a function of relative biomass.

Table 3:

Descriptive quantities and parameter estimates in the stock assessment of octopus in Region 5, Philippines, using the CMSY method (95% CI in parentheses).

Quantity	Value
Range of years	2011-2018
Starting range of *K* (tonnes)	815-12220
Mean, maximum and last year landings (tonnes)	244, 663, 611
Estimated *r* ($year^{-1}$)	0.760 (0.704, 1.184)
Estimated *K* (tonnes)	9043 (5793, 14115)
Estimated MSY (tonnes)	2693 (1727, 4200)

Results regarding the condition of the stock are contradictory. Biomass is at the size that produces the MSY (= *K/2*) (Figure 3, panel D) and the MSY is much higher than last year's landings, but exploitation rate (Figure 3, panel E and F) is well above its MSY level.

3.3 Region 9 + BARMM

The landings history of octopus in Region 9 + BARMM (Figure 4, panel A) plus the assumption of high resilience of octopus stocks, yields a very wide cloud of viable *r, K* pairs (Figure 4, panel B). The large uncertainty is a reflection of the short time series of landings and no sustained decreasing trend after the initial rise.

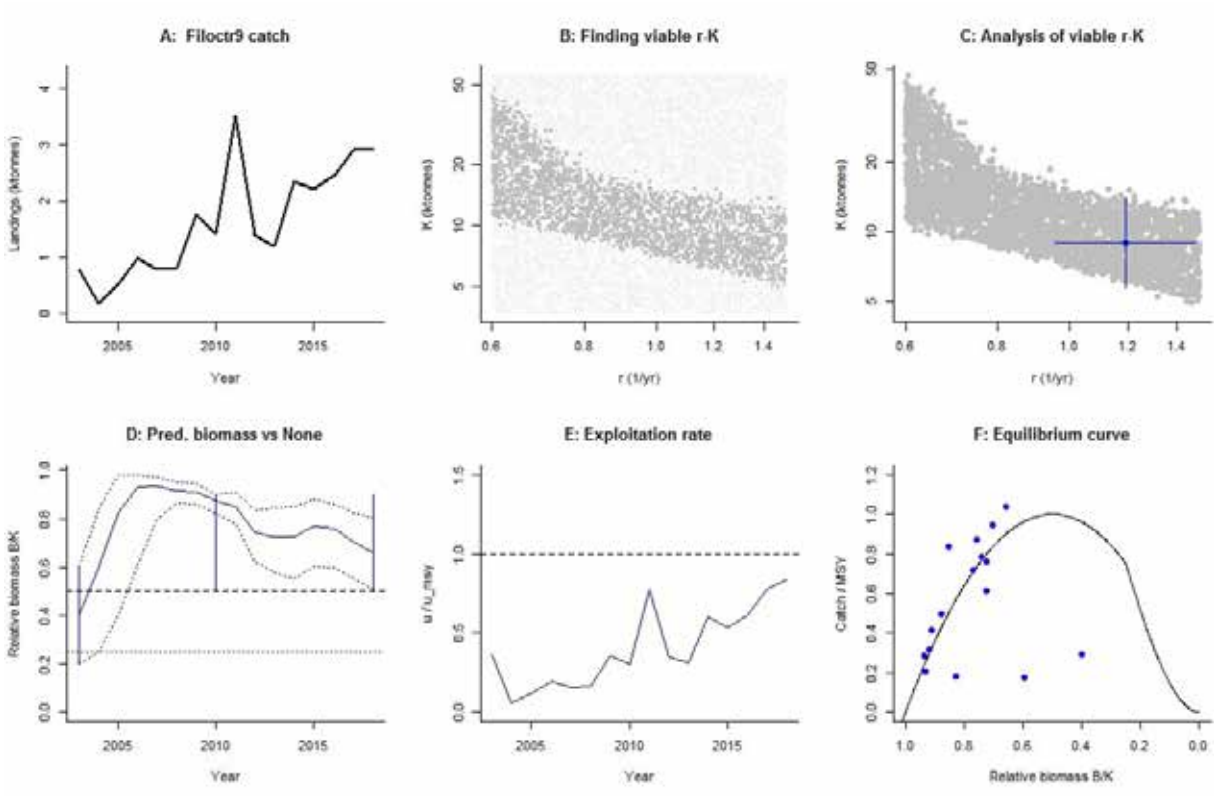

Figure 4:

Stock assessment of octopus in Region 9 + BARMM, Philippines, using the CMSY method. A: Landings time series. B: Whole set of viable *r, K* pairs, with filtered cloud in darker gray. C: Filtered cloud of viable *r, K* pairs and selected high-*r* values with 95% confidence bands in *r* and *K* (blue cross). D: Estimated relative biomass time series (continuous blue line), 95% confidence bands (dotted lines), maximum sustainable yield (straight dashed line) and its lower 95% lower bound (straight dotted line), and prior ranges for biomass (vertical lines) set by assuming moderate degree of depletion. E: Relative exploitation rate (blue line) and the maximum sustainable relative exploitation rate (straight dashed line). F: Expected exploitation rate (parabola) and observed exploitation rate (blue dots) as a function of relative biomass.

Table 4:

Descriptive quantities and parameter estimates in the stock assessment of octopus in Region 9+BARMM, Philippines, using the CMSY method (95% CI in parentheses).

Quantity	Value
Range of years	2003-2018
Starting range of *K* (tonnes)	3693-55400
Mean, maximum and last year landings (tonnes)	1633, 3530, 2770
Estimated *r* ($year^{-1}$)	1.191 (0.957, 1.842)
Estimated *K* (tonnes)	9043 (5793, 14116)
Estimated MSY (tonnes)	2693 (1727, 4200)

As a result of this wide spread of viable *r, K* pairs, the 95% confidence interval for *K* is also very wide, ranging from 6,000 to over 14,000 tonnes (Figure 4, panel C, blue vertical line and Table 4) (the range of *r* is fixed by the definition of the stock as high resilience). This original statistical uncertainty translates into wide confidence bands for relative biomass in the most recent years, although all values within the confidence bands are above the biomass that produces the MSY conditional on the Shaeffer model (Figure 4, panel D). This would mean that the stock in Region 9 + BARMM has been exploited in biologically sustainable fashion up to 2018. However, the exploitation rate has been increasing steadily towards the maximum sustainable exploitation rate, apparently likely to reach the maximum within the next three years, 2019 to 2021, as projected from simply looking at the rate of increase, *ceteris paribus* (Figure 4, panel E). This finding is also reflected in the equilibrium parabola, with an observed exploitation rate very close to the maximum (Figure 4, panel F).

As stated above, the data from this region does not yield precise estimates under the model (Table 4). The intrinsic rate of population growth *r* is close to 1.2 and the carrying capacity of the environment is over 9,000 tonnes with a wide 95% confidence interval, where the lower bound is about one third of the upper bound (Table 4). Consequently, the MSY, estimated at 2693 tonnes, also has a wide confidence interval. Furthermore, the estimated MSY is very close to last year's landings.

3.4 Region 13

The landings history of octopus in Region 13 (Figure 5, panel A) plus the assumption of high resilience of octopus stocks, yields a typical triangular cloud of viable *r, K* pairs (Figure 5, panels B and C), common to many applications of Froese et al's[6]

method. In fact, this application of the method to this region's data yielded the most precise parameter estimates (Table 5). Stock biomass currently is at the level that produces the MSY (Figure 5, panel D), exploitation rate has been close to the maximum sustainable exploitation rate (Figure 5, panel E) and the production parabola shows the stock at the maximum (Figure 5, panel F).

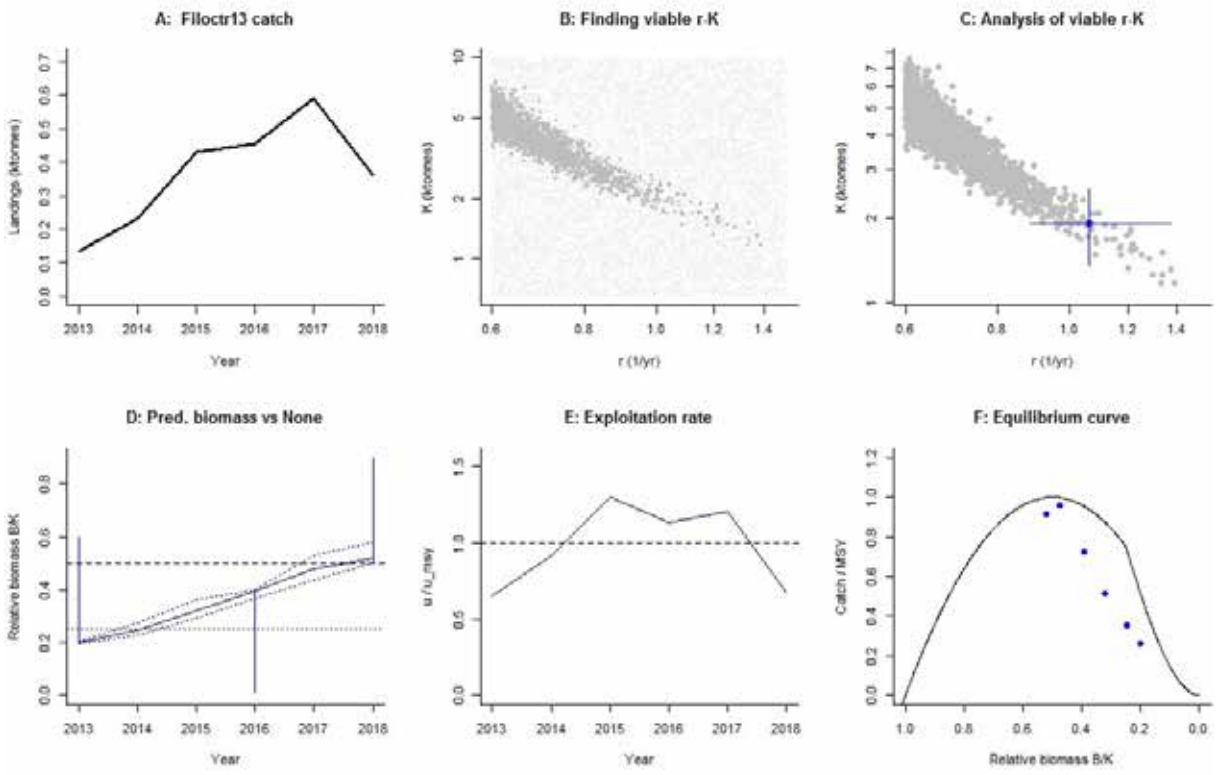

Figure 5:

Stock assessment of octopus in Region 13, Philippines, using the CMSY method. A: Landings time series. B: Whole set of viable *r, K* pairs, with filtered cloud in darker gray. C: Filtered cloud of viable *r, K* pairs and selected high-*r* values with 95% confidence bands in *r* and *K* (blue cross). D: Estimated relative biomass time series (continuous blue line), 95% confidence bands (dotted lines), maximum sustainable yield (straight dashed line) and its lower 95% lower bound (straight dotted line), and prior ranges for biomass (vertical lines) set by assuming moderate degree of depletion. E: Relative exploitation rate (blue line) and the maximum sustainable relative exploitation rate (straight dashed line). F: Expected exploitation rate (parabola) and observed exploitation rate (blue dots) as a function of relative biomass.

The data from this region yields precise estimates under the model. The intrinsic rate of population growth *r* is close to 1 and the carrying capacity of the environment is over 1,800 tonnes with a fairly narrow 95% confidence interval,

where the lower bound is half of the upper bound (Table 5). Consequently, the MSY, estimated at 505 tonnes, also has a narrow confidence interval. The estimated MSY is very close to last year's landings.

Table 5:

Descriptive quantities and parameter estimates in the stock assessment of octopus in Region 13, Philippines, using the CMSY method (95% CI in parentheses).

Quantity	Value
Range of years	2013-2018
Starting range of *K* (tonnes)	657-9853
Mean, maximum and last year landings (tonnes)	367, 592, 469
Estimated *r* ($year^{-1}$)	1.105 (0.910, 1.412)
Estimated *K* (tonnes)	1837 (1296, 2476)
Estimated MSY (tonnes)	505 (414, 622)

3.5 National

In this case there are two time series of landings data: (1) FAO (1970-2014) + Companies total (2015-2018) and (2) BFAR (2011-2017) + Companies total (2018). I have conducted the assessment with both time series as there was no information on which one was more reliable.

Results using FAO + Companies total landings are shown in Figure 6 and Table 6. National landings show a generally increasing trend with an intermediate period of substantially higher landings, reaching a maximum of around 10,000 tonnes, and a recent increasing trend from a lower level to over 6,000 tonnes in the last year (Figure 6, panel A). The cloud of viable *r, K* values is quite narrow (Figure 6, panels B and C) but it yields a moderately wide interval for *K* (blue vertical line in (Figure 6, panel C). Stock biomass was higher than the biomass that yields the MSY (= *K/2*) until the intermediate period of high landings, when it dropped below *K/2,* but then it recovered to *K/2* between 2006 and the last year of the times series, 2018 (Figure 6, panel D). The exploitation rate (Figure 6, panels E and F) also shows the stock recovering to the levels at the MSY.

FAO + Companies total landings time series yields precise estimates under the model. The intrinsic rate of growth *r* is close to 1 and the carrying capacity *K* is over 25,000 tonnes with a relatively narrow 95% confidence interval: the upper bound is just 30% higher than the lower bound (Table 6). Consequently, the MSY, estimated at 6,154 tonnes, also has a

narrow confidence interval. The estimated MSY is higher but very close to last year's landings.

Results using BFAR + Companies total landings are shown in Figure 7 and Table 7. National landings show a generally decreasing trend between 2001 and 2013, similar to the FAO + Companies total landing series during the same period, although at a higher level (Figure 7, panel A). The cloud of viable *r, K* values is more spread than in the case of the FAO + Companies total landing series (Figure 7, panels B and C) and the interval for *K* (blue vertical line in Figure 7, panel C) includes much higher values. This is a natural consequence of higher annual landings in the BFAR + Companies total landings. Results show that the stock biomass has been less than the biomass that yields the MSY (= *K/2* under the assumption of a Schaefer production function) until 2014 but then it has been recovering to *K/2* between 2015 and the last year of the times series, 2018 (Figure 7 panel D). The exploitation rate (Figure 7, panel E) and the production curve (Figure 7, panel F) also show the stock recovering to the levels at the MSY.

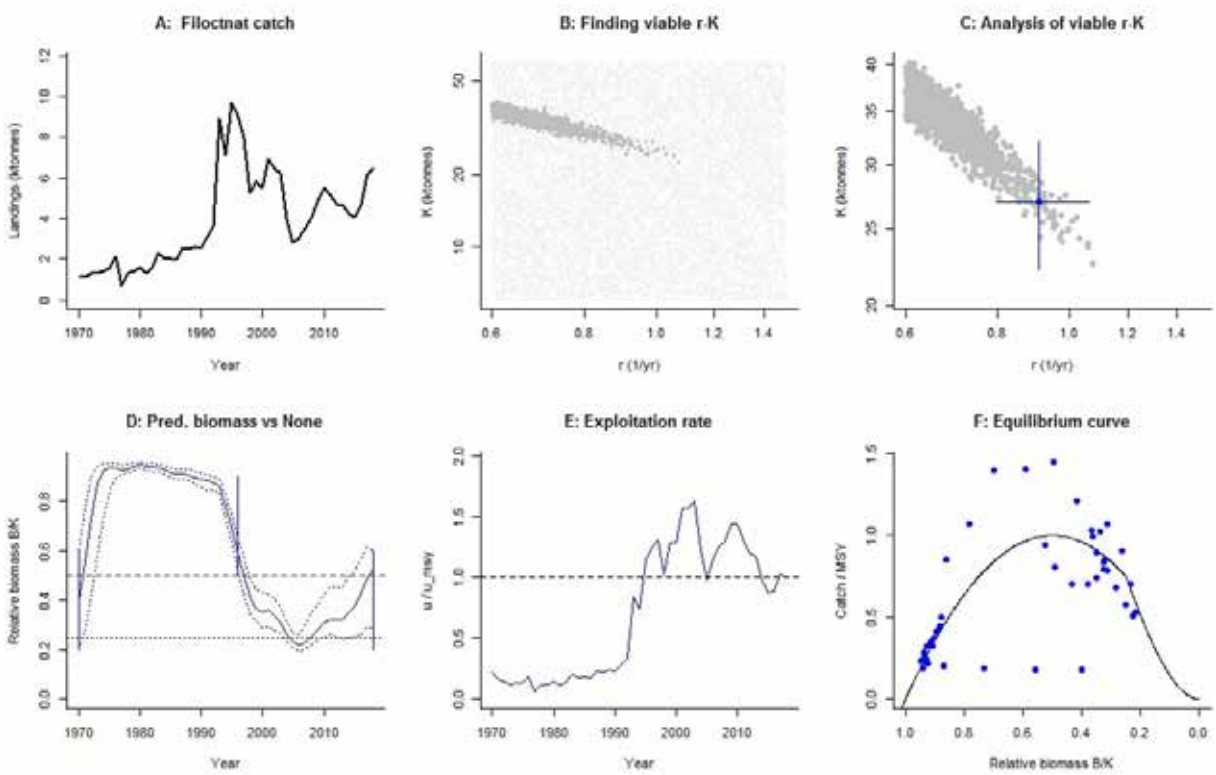

Figure 6:

Stock assessment of octopus stock in the Philippines using FAO + Companies total landings and the CMSY method. A: Landings time series. B: Whole set of viable *r, K* pairs, with filtered cloud in darker gray. C: Filtered cloud of viable *r, K* pairs and selected high-*r* values with 95% confidence bands in *r* and *K* (blue cross). D: Estimated relative biomass time

series (continuous blue line), 95% confidence bands (dotted lines), maximum sustainable yield (straight dashed line) and its lower 95% bound (straight dotted line), and prior ranges for biomass (vertical lines) set by assuming moderate degree of depletion. E: Relative exploitation rate (blue line) and the maximum sustainable relative exploitation rate (straight dashed line). F: Expected exploitation rate (parabola) and observed exploitation rate (blue dots) as a function of relative biomass.

BFAR + Companies total landings yields some precise estimates under the model. The intrinsic rate of growth *r* is close to 1 with a narrow 95% confidence interval and the carrying capacity of the environment *K* is over 41 thousand tonnes with a fairly wide 95% confidence interval: the upper bound is nearly double the lower bound (Table 7). The MSY is estimated at close to 10 thousand tonnes with a moderately wide 95% confidence interval and estimated MSY is nearly double the value of last year's landings (Table 7).

Table 6:

Descriptive quantities and parameter estimates in the stock assessment of octopus in the Philippines using the FAO + Companies total landings and the CMSY method (95% CI in parentheses).

Quantity	Value
Range of years	1970-2018
Starting range of *K* (tonnes)	5943-59433
Mean, maximum and last year landings (tonnes)	3875, 9729, 5776
Estimated *r* ($year^{-1}$)	0.970 (0.833, 1.234)
Estimated *K* (tonnes)	25366 (19097, 30854)
Estimated MSY (tonnes)	6154 (5647, 6707)

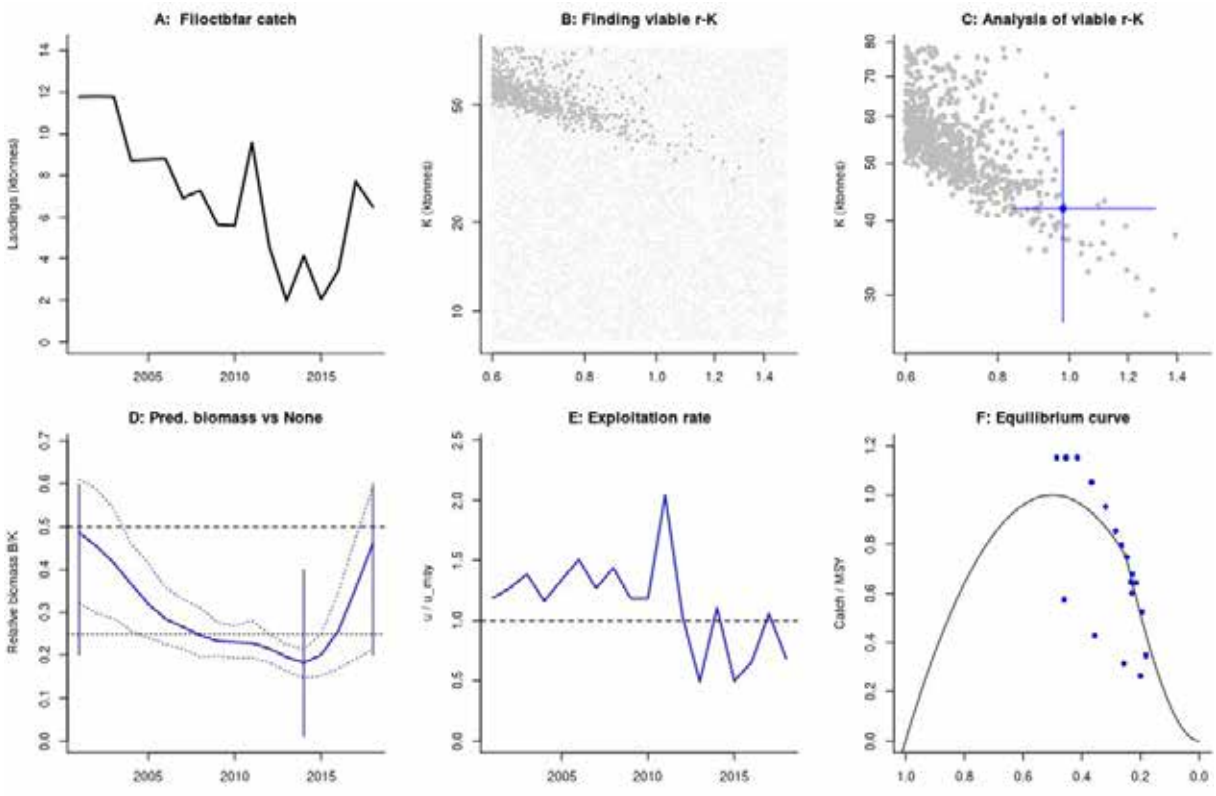

Figure 7:

Stock assessment of octopus stock in the Philippines using BFAR + Companies total landings and the CMSY method. A: Landings time series. B: Whole set of viable *r, K* pairs, with filtered cloud in darker gray. C: Filtered cloud of viable *r, K* pairs and selected high-*r* values with 95% confidence bands in *r* and *K* (blue cross). D: Estimated relative biomass time series (continuous blue line), 95% confidence bands (dotted lines), maximum sustainable yield (straight dashed line) and its lower 95% lower bound (straight dotted line), and prior ranges for biomass (vertical lines) set by assuming moderate degree of depletion. E: Relative exploitation rate (blue line) and the maximum sustainable relative exploitation rate (straight dashed line). F: Expected exploitation rate (parabola) and observed exploitation rate (blue dots) as a function of relative biomass.

Table 7:

Descriptive quantities and parameter estimates in the stock assessment of octopus at the national level, Philippines, using BFAR + Companies total landings and the CMSY method (95% CI in parentheses).

Quantity	Value
Range of years	2001-2018
Starting range of *K* (tonnes)	7876-78757
Mean, maximum and last year landings (tonnes)	7060, 11821, 5880
Estimated *r* ($year^{-1}$)	0.980 (0.838, 1.306)
Estimated *K* (tonnes)	41844 (26998, 56983)
Estimated MSY (tonnes)	10254 (7611, 13814)

4. Discussion

There is little scientific research published on the stock assessment of octopus stocks. Regarding Assumption 9 above, that the productivity parabola is symmetric, in one published study [10] this parabola was fairly asymmetric and the several results presented in this report (for instance, Fig. 7) also show hints of asymmetry. This affects the estimation of the MSY and therefore it has implications to management. The solution to this shortcoming of the CMSY method is to code a more general productivity function, such as the Pella-Tomlinson logistic model,

$$B_{t+1} = B_t + B_t r\left[1 - \left(\frac{B_t}{K}\right)^{p-1}\right] - C_t \quad (2)$$

where an additional parameter, the symmetry *p*, permits flexibility in the shape of the function. However, given the available data, which is the landings time series exclusively, it would be practically impossible to estimate a further parameter in the productivity function, namely the symmetry *p*. Nevertheless the important point to note is that the MSY and other management-relevant parameters could

change substantially if *p* departs from perfect symmetry, as suggested from the scant previous research on octopus stock assessment and population dynamics.

Within the logic and numerous unverified assumptions of the methodology available for stock assessment given the poor nature of the data, none of the regions or the national level assessment results show evidence of overfishing. The exception is Region 5, whose results are unreliable due to the uninformative landings time series. For that region no conclusion can yet be drawn with regards to stock status. In the remaining regions, the stock is either being exploited at the maximum sustainable level (Region 13) or approaching the maximum sustainable level (Regions 4B and 9 + BARMM) from lower exploitation rates. For all three regions with more reliable results (Regions 4B, 9 + BARMM, and 13) the situation of exploitation indicates that measures must be taken to slow down the rise in landings or to freeze these altogether at the level of the last year of available data (2018), pending better data to apply more robust and objective stock assessment methodologies.

At the national level, results of assessment using the longer time series of landings (FAO + Companies totals) show the national stock very close to maximum sustainable exploitation, whereas results using the shorter time series of landings (BFAR + Companies total) suggest that further increases in landings are sustainable, even double as much as in the last year of available data (2018). Thus it is critical to discern which of the two time series of landings is more reliable. First, it should be noted that results of assessment with both time series show the stock moving in the same direction, which is recovering to the biologically optimum biomass. Their difference was in the absolute size of the stock. Second, the Precautionary Principle dictates that, the FAO+companies analysis should carry more weight, especially as there are several unknown factors in the Philippines octopus fisheries. Third, when examining the regional results, all of them pointing in the direction of a stock that is already being exploited close to or at the maximum sustainable level, it appears that results at the national level obtained with the longer FAO + Companies time series are more reliable because they are consistent with regional results. This consideration has the caveat that the very short time series of regional data (and possible incomplete records) may not be sufficiently reliable either. Fourth, results with the longer time series are statistically more solid because they produce much narrower 95% confidence intervals, particularly for the maximum sustainable yield. This consideration is especially relevant when taking into account that the data available for assessment are poor and, accordingly, the methodology implemented for assessment is more dependent on unverified assumptions. Therefore, it seems clear that, having these two assessments at the national level, the assessment based on the longer time series of landings (FAO + Companies total) should be used to determine management measures ensuring sustainability.

5. Conclusions

1. A database of regional and national landings of octopus in the Philippines has been built and curated and is now available for stock assessment studies.

2. A stock assessment methodology and its code in the R language of statistical programming, as well as binary storage of the database and programming objects, is now available for continued use as more data are collected.

3. Given the identified issues with the catch-only assessment method CMSY applied here, improvements in stock assessments, and in the objectivity, robustness and reliability of subsequent management advice, are possible through further data collection for key data sets.

4. Under strong assumptions and rather wide confidence intervals, the octopus stocks in Region 4B, 9 + BARMM and 13 of the Philippines appears as not overfished, but their exploitation levels approach and are already close to the maximum sustainable yield.

5. There are insufficient data to obtain results from Region 5 of the Philippines.

6. Under strong assumptions and fairly narrow confidence intervals, the octopus stock at the national level in the Philippines appears as not overfished but its exploitation level is already at the maximum sustainable yield.

7. The importance of the quality of the catch (landings) history in determining the outcome of the assessment of stock status and subsequent management advice has been clearly demonstrated. This identifies the need to focus greater efforts on improving the quality of catch (landings) data going forward, as well as trying to better define the historic time series of regional and national landings data.

6. Management Advice

This management advice is exclusively connected to the biological condition of the stock in Regions 4B, 5, 9 + BARMM, 13 and at the national level in the Philippines. Thus it is made without consideration of the wider context of the fishery, such as social and economic indicators, among others.

1. Initiate a permanent programme to collect, validate and digitally store effort data for the octopus fishery. The effort data should be recorded at a fine temporal and spatial scale to enable development of more robust octopus stock assessments. The scale at which effort data are collected should align with that of the landings data (but may be at finer scale) specifically to enable the development of a reliable measure of change in octopus abundance to be produced so as to support the application of more robust assessment methodologies.

2. Improve the collection, validation and digital storage of landings data for the octopus fishery. This should include collecting more comprehensive landings data at finer temporal and spatial scales (aligned with future effort data collection).

3. Considering the rate of increase in recent landings (to 2018) from Regions 4B, 5, 9 + BARMM, 13 and at the national level, and their proximity to their estimated values of Maximum Sustainable Yield (MSY), establish a programme to slow down the increase in landings and stabilize them pending further management-focused research using improved data and more robust stock assessment methods.

4. Given the apparent inconsistencies among the various sources of data that could be used to describe the landings (and thus the catches) of octopus in the Philippines, the various data sources should be re-interrogated and re-analyzed in order to develop one or more catch histories that are likely to be representative of what was actually taken. This work should also prepare advice and recommendations to ensure higher quality catch and/or landings data are collected in the future.

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List of Figures

List of Tables

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