Determination of the optimum effort for small scale fisheries in Bulukumba regency

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Abstract. This study aims to determine the catch per unit effort (CPUE) or abundance, maximum sustainable yield (Cmsy), optimum effort (Emsy), catch quota, utilization level, and effort of yellowfin tuna (\textit{Thunnus albacarez}) for small scale fisheries in Bulukumba Regency, using a surplus production method, as well as time-series data for 11 years. According to the results, the CPUE or abundance average, Cmsw, Emsw, and catch quota, were about 4.4284 ton/unit, 720 tons, and 576 tons, respectively. Meanwhile, the sustainable production with actual production showed overfishing, except for 2010 and 2015, while the production data for 2016 – 2020 were unavailable. In addition, the average MSY utilization, catch quota, and average effort levels were 61.9512 %, 77.4397 %, and 86.8352%, respectively. Theoretically, the MSY utilization levels for all years were about 100%, except for 2010 (1.4494 %) and 2015 (23.7581%), as well as 2012, where the value exceeded 100% (364.7357%), while the catch quota for all years was above 100 %, except for 2010 (1.8062 %) and 2015 (29.6976 %). However, the two production data values were unavailable for 2016 – 2020. Also, the effort levels fluctuated while almost all the half values were below 100 %.

1. Introduction
Fisheries utilization in water bodies, particularly capture fisheries production is influenced by several factors, for instance, stock availability, fishing effort level, and other factors, including natural mortality, however, production factors (effort level) have the biggest influence \cite{1}. Furthermore, fish stock availability is influenced by several factors, including birth, growth, mortality, and migration. The individual growth of fish refers to any increase in length as well as weight within a certain period, while population growth refers to a rise in the number of individual fishes, and these are both influenced by internal and external factors, for instance, feed portion and availability, the ratio of individual fish to available feed, temperature, dissolved oxygen, water quality, as well as fish age, size and gonad maturity \cite{2}.

The foremost aim of fisheries resource management is to maintain the stock availability of fisheries resources, and this requires estimation with high validity, however, this is faced with several complexities in tropical areas, including fish characterized with multispecies as well as fisheries
business with characterized fleet performance [3].

Yellowfin tuna (Thunnus albacares) are big pelagic fish distributed in tropical regions, including Ternate, Bulukumba, as well as Bali, and subtropical regions [4], easily captured by several fishing gears, with first motion as well as high demand, and are, therefore, a major targeted catch. These species are not only caught using trawlers and big ships but also simple tools like pole and line, driftnet, and hand line, as in artisanal fisheries [5].

Bulukumba Regency is one of the regencies in South Sulawesi using a tuna fishing center, with yellowfin tuna as the main catch. The production of these species is categorized as annual availability, and the species are caught by small-scale fishermen at Ekatiro Kelurahan, Bontotiro Subdistrict, Bulukumba Regency, South Sulawesi, using a hand line.

Therefore, this study aims to determine the catch per unit effort or abundance, maximum sustainable yield (Cmsy), optimum effort (Emsy), number of catches allowable, utilization and effort level of yellowfin tuna (Thunnus albacares) for these fishermen, based on production and fishing gear data for eleven years, obtained from the Fisheries and Marine Office, Province of South Sulawesi, Makassar [6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16].

2. Material and Method
2.1. Study location and study period
This study was conducted from February 2021 - May 2021, in Bulukumba Regency for small-scale fisheries at villages or kampong serving as the fishing centers, with a case study at Ekatiro Kelurahan, Bontotiro Subdistrict, Bulukumba Regency. The figure shows a map of the study location.

![Figure 1. A map of the research location.](image)

2.2. Method
This study used a surplus production analysis to determine the catch per unit effort or fish abundance, maximum sustainable yield (Cmsy), optimum effort (Emsy), number of catches allowable, as well as the utilization and effort level according to [17, 18, 19], based on time series data for 11 (eleven) years.

2.2.1. Data collection. Data was collected through a literature review of related reports, statistical data from relevant agencies, and other online information, as well as interviews with respondents. The data collected was a time-series data of yellowfin tuna production and hand line capture for 11 years (2010 – 2020), from the Fisheries and Marine Office, South Sulawesi Province [6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16].
2.2.2. Data analysis.
1. Surplus production analysis.

A surplus production analysis was performed to estimate the total catch and/or catch per unit effort (CPUE) based on species as well as the fishing effort for several years, and this value must vary substantially for the included time.

Meanwhile, the Schaefer method [17, 18] based on production data and effort in time series was used to determine sustainable production, using the formula below.

\[
Y_t = aE_t + bE_t^2
\]

Where,
- \(Y_t\) represents Sustainable production
- \(a\) denotes intercept or maximum CPUE
- \(b\) signifies slope
- \(E_t\) indicates effort for a certain year to \(t\)

The productivity or CPUE for each year was determined by dividing both sides with the effort, to obtain the equation below.

\[
\frac{Y}{E_t} = a + bE_t
\]

Subsequently, the utilization level, maximum sustainable yield, and optimum effort, by inputting the values of \(a\) and \(b\).

Maximum sustainable production (MSY) level:

\[
Y_{MSY} = -\frac{a^2}{4b}
\]

The effort of MSY:

\[
E_{MSY} = \frac{a}{2b}
\]

The number of catches allowable was then calculated using the formula by [18], as shown below.

Number of catches allowable = 80% x MSY

The percentage utilization level was also calculated using the formula by [19], as shown below.

\[
\text{Utilization level (\%)} = \left(\frac{C_i}{C_{MSY}}\right) \times 100\%
\]

Where,
- \(C_i\) represents the annual catch for a certain year (ton), and
- \(C_{MSY}\) denotes sustainable catch (ton).

The percentage effort level was then calculated from the utilization level, using the formula below.

\[
\text{Effort level (\%)} = \left(\frac{E_i}{E_{MSY}}\right) \times 100\%
\]

Where,
- \(E_i\) denotes the annual catch effort for each year (unit)
- \(E_{MSY}\) indicates the optimum catch effort (unit)

All secondary data were obtained from related reports, journals, and relevant institution data.
3. Result and discussion

3.1. Catch per unit effort (CPUE), maximum sustainable yield (MSY), optimum catch effort, and Number of allowed catches of yellowfin tuna (Thunnus albacares) at Bulukumba Regency

Yellowfin tuna (Thunnus albacares) is the main catch of fishermen in Ekatiro Kelurahan, Bontotiro Subdistrict, Bulukumba Regency, characterized by yellow fins at the sides of the upper as well as lower body (Figure 2), and is a cosmopolitan species, distributed in tropical and subtropical waters [4]. These fishermen use ship at ≤ 10 gross tonnage, including small scale fisheries equipment (Figure 3). In addition, these species are the most distributed in tropical waters (23° north latitude - 23° south latitude) and in the hot water pockets in subtropical waters, and was estimated by [20] to have a size of catch 30-180 cm (fork length) in the Indian Ocean, at juvenile phase with skipjack (Katsuwonus pelamis) as well as bigeye tuna (Thunnus obesus) schools.

![Figure 2. Yellow fin tuna (Thunnus albacares) caught by fishermen at Ekatiro Kelurahan, Bontotiro Subdistrict, Bulukumba, to be sold at the market of Makassar, for export.](image1)

![Figure 3. The fishing vessel used by fishermen at Ekatiro Kelurahan, Bontotiro Subdistrict, Bulukumba Regency.](image2)

The time series on production and fishing effort of fishermen at Ekatiro Kelurahan, Bontotiro Subdistrict, Bulukumba Regency for the last 11 years were unavailable. Therefore, the CPUE, MSY, optimum effort, utilization, and effort level were calculated based on the scope of Bulukumba Regency. Table 1 and Table 2 shows the production (tons), fishing effort, and CPUE of yellowfin tuna as well as the hand line fishing gear (units) used within the regency in the past 11 years. According to the table, the production of yellowfin tuna and the amount of hand line fishing gear used increased every year. The highest and least production values were 2,625.2 tons in 2012, and 0 tons in 2016 to 2020 respectively, while the highest and least number of hand lines were 394 in 2018 and 15 units in 2015, respectively. Furthermore, there was a fluctuation in the annual CPUE or abundance and fishing effort (units) for the last 11 years (2010 – 2020), with an average value of 4,4284 ton/unit, and the least as well as highest values of 0 ton/unit for 2016 – 2020, and 24,7660 ton/units in 2012, respectively. Table 1 and Table 2 also shows a downward trend in the CPUE or abundance of yellowfin tuna within the Bulukumba Regency for each year. These CPUE values did not account for other factors, including oceanography, environment, biology, and meteorology/climatology.
Table 1. The production and effort of yellowfin tuna Production and effort of yellowfin tuna (*Thunnus albacares*) and hand line (2010 – 2020) from the Fisheries and marine Office, Province of South Sulawesi, 2011 – 2021.

| Year | Production (ton) | Effort (unit) |
|------|-----------------|---------------|
| 2010 | 10,4106         | 106           |
| 2011 | 698,9106        | 106           |
| 2012 | 2,625,20        | 239           |
| 2013 | 699,7106        | 15            |
| 2014 | 699,7106        | 15            |
| 2015 | 171             | 15            |
| 2016 | 0               | 306           |
| 2017 | 0               | 101           |
| 2018 | 0               | 394           |
| 2019 | 0               | 74            |
| 2020 | 0               | 74            |

Table 2. The production, fishing effort, and catch per unit effort of yellowfin tuna (*Thunnus albacares*) in Bulukumba Regency.

| Number | Year | Production (ton) | Fishing gear (ton/unit) | Catch per unit effort (CPUE) |
|--------|------|-----------------|-------------------------|------------------------------|
| 1      | 2010 | \(^a\)10.4      | \(^a\)106               | 0.0981                       |
| 2      | 2011 | \(^a\)698.9     | \(^a\)106               | 6.5934                       |
| 3      | 2012 | \(^a\)2,625.20  | \(^a\)106               | 24.7660                      |
| 4      | 2013 | \(^a\)699.7     | \(^a\)239               | 2.9276                       |
| 5      | 2014 | \(^a\)699.7     | \(^a\)239               | 2.9276                       |
| 6      | 2015 | \(^a\)171       | \(^a\)15                | 11.4000                      |
| 7      | 2016 | 0               | \(^a\)306               | 0.0000                       |
| 8      | 2017 | 0               | \(^a\)101               | 0.0000                       |
| 9      | 2018 | 0               | \(^a\)394               | 0.0000                       |
| 10     | 2019 | 0               | \(^a\)74                | 0.0000                       |
| 11     | 2020 | 0               | \(^a\)74                | 0.0000                       |
| Average|      |                 |                         | 4.4284                       |

\(^a\) Fishries and Marine Office, Provincal of South Sulawesi, 2011 – 2021.

Figure 4 shows the results obtained using the Equilibrium Schaefer model [17, 18] for time series data of 11 (eleven) years (2010 – 2020), where an (intercept) and b (slope) values of 7.8125 and 0.0212, respectively were obtained. Meanwhile, the maximum sustainable yield (Cmsw), optimum fishing effort, and the number of catches allowable were discovered to be about 720 tons, 184 units of hand line, and 576 tons, respectively (Figure 5). The equation of graph obtained using the Schaefer method equation [17, 18] is shown below.

\[
Y = 7.8125E - 0.0212E^2
\]
Figure 4. CPUE and optimum fishing effort value of yellowfin tuna in Bulukumba Regency {according to Schaefer Method [17]}.

Figure 5. The CPUE, optimum fishing effort, and sustainable production of yellowfin tuna in Bulukumba Regency {according to Schaefer Method [17, 18]}. The sustainable catch quota was then fixed using the Schaefer Method equation. Table 3 shows the Fishing effort, actual production (tons), sustainable production (tons), and the number of catches allowable. Based on the table, yellowfin tuna were underexploited in 2010, but overfishing occurred in 2011-2015, while the production data for 2016–2020 were unavailable.
Table 3. The fishing effort, actual production, sustainable production, and number of catches allowed for yellowfin tuna (*Thunnus albacares*), in Bulukumba Regency.

| Year | Fishing effort (unit) | Actual production (ton) | Sustainable production (ton) | Number of catches allowable (ton) |
|------|----------------------|--------------------------|------------------------------|----------------------------------|
| 2010 | 106                  | 10.4                     | 589.9218                     | 471.9374                         |
| 2011 | 106                  | 698.9                    | 589.9218                     | 471.9374                         |
| 2012 | 106                  | 2,625.20                 | 589.9218                     | 471.9374                         |
| 2013 | 239                  | 699.7                    | 656.2223                     | 524.9778                         |
| 2014 | 239                  | 699.7                    | 656.2223                     | 524.9778                         |
| 2015 | 15                   | 171                      | 112.4175                     | 89.9340                          |
| 2016 | 306                  | 0                        | 405.5418                     | 324.4334                         |
| 2017 | 101                  | 0                        | 572.8013                     | 458.2410                         |
| 2018 | 394                  | 0                        | -272.8782                    | -170.3026                        |
| 2019 | 74                   | 0                        | 462.0338                     | 369.6270                         |
| 2020 | 74                   | 0                        | 462.0338                     | 369.6270                         |

The chart below shows the actual production tended to be higher from 2011 - 2015, while the production data for 2016 - 2020 were unavailable. Meanwhile, the sustainable production and number of catches tended to be similar in 2010 - 2014 with a value below the actual production (overfishing), except in 2010 where there was an under-exploitation, and in 2015 – 2020, where a fluctuation occurred (underexploited in 2016 - 2017, negative in 2018, and rising again in 2019 – 2020 to an under exploited condition), and this is due to the unavailability of certain production data.

Figure 6. The actual production, sustainable production, and the number of catches allowable for yellowfin tuna (*Thunnus albacares*) at Bulukumba Regency (According to Schaefer Method [17, 18]).

3.2. Utilization level of yellowfin tuna (*Thunnus albacares*) at Bulukumba Regency

Table 4 shows the MSY utilization level for all years was almost 100%, except in 2010 (1.4449%), 2015 (23.7581%), and 2012, where the value exceeded 100% (364.7357%), while the average value was about 61.9517%. In addition, the utilization of the number of catches allowable for all years almost exceeded 100%, except in 2010 (1.8062%) and 2015 (29.6976%), while the average level was about 77.4397%. This utilization of MSY and the number of catches allowable are influenced by the absence of production
data for 2016 – 2020, and range from 0.0000% - 364.7357 % and 0.0000% - 455.9197%, respectively. Meanwhile, the fishing effort level ranged 8.1408% and 213.8317%, and fluctuated in 2010 - 2020, with an average value of about 86.8352%. These values show almost all the utilization levels have approached 100%, with several values exceeding 100%, while over half of them was below 100%, although some reached 86.8352 %. Also, these values show the hand line fishing gear is highly effective (Table 4 and Figure 7).

Table 4. The utilization and effort level of yellowfin tuna (*Thunnus albacares*) in Bulukumba Regency.

| Year | Fishing Effort (unit) | Actual production (ton) | Utilization level of MSY (%) | Utilization level of number Allowed (%) | Utilization level of effort (%) |
|------|-----------------------|-------------------------|-----------------------------|----------------------------------------|-------------------------------|
| 2010 | 106                   | 10.4                    | 1.4449                      | 1.8062                                 | 57.5283                       |
| 2011 | 106                   | 698.9                   | 97.1026                     | 121.3783                               | 57.5283                       |
| 2012 | 106                   | 2.625.20                | 364.7357                    | 455.9197                               | 57.5283                       |
| 2013 | 239                   | 699.7                   | 97.2138                     | 121.5172                               | 129.7101                      |
| 2014 | 239                   | 699.7                   | 97.2138                     | 121.5172                               | 129.7101                      |
| 2015 | 15                    | 171                     | 23.7581                     | 29.6976                                | 8.1408                        |
| 2016 | 306                   | 0                       | 0                           | 0                                      | 166.0723                      |
| 2017 | 101                   | 0                       | 0                           | 0                                      | 54.8147                       |
| 2018 | 394                   | 0                       | 0                           | 0                                      | 213.8317                      |
| 2019 | 74                    | 0                       | 0                           | 0                                      | 40.1613                       |
| 2010 | 74                    | 0                       | 0                           | 0                                      | 40.1613                       |
| Average |                     | 61.9517                 | 77.4397                     | 86.8352                                |                               |

Figure 7. The utilization levels of MSY, number of catches allowed, and fishing effort of yellowfin tuna (*Thunnus albacares*) at Bulukumba Regency.

4. Conclusion and suggestions

4.1. Conclusion

The following conclusions were drawn based on the result and discussion.

1. The CPUE value or abundance of yellowfin tuna fluctuated between 0.0000 – 24.7660 ton/unit, with a downward trend each year, and a 4.4284 ton/unit average, while the fishing effort fluctuated with an
increasing trend each year, for the last 11 years (2010 - 2020).
2. The maximum sustainable yield, optimum fishing effort, and the number of catches allowable were 720 tons, 184 hand line units, and 576 tons, respectively, indicating over fishing, except in 2010 and 2015, while the production data for 2016 - 2020 were unavailable.
3. The MSY utilization level ranged from 0.0000% - 364.7357%, with an average of 61.9517%, while the Utilization level of the number of catches allowable ranged from 0.0000% - 455.9197%, with an average of 77.4397%. Theoretically, the MSY utilization level for all years was almost 100%, except in 2010 (1.4449%), 2015 (23.7581%), 2012, where the value exceeded 100% (364.7357%), and 2016-2020, where there was no available production data, while the counterpart for the number of catches allowable for all years almost exceeded 100%, except in 2010 (1.8062%), 2015 (29.6976%), %, and 2016-2020, where there was no available production data. Meanwhile, the effort level fluctuated, with almost half of the values below 100%.

4.2. Suggestion
Studies performed over a small scope or area, including data per location landed, village, district, and subdistrict, are required to obtain appropriate results for the actual site conditions.

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