Assessing Bali sardine stock status using real-time electronic catch landing data recorder and time series catch database

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Abstract. Digitalization of capture fisheries data becomes inevitable in the present and future time. The use of Information and Communication Technology (ICT) in the fisheries sector is widely applied, creating a bigger and better database. Development of the database offers the utilization of Big Data and Decision Support System (DSS) to provide robust analysis, simulate better scenarios, formulate recommendations, and propose management measures to support successful fisheries management in achieving sustainability and profitability objectives. Bali Strait sardine stock estimation has been conducted several times through several approaches and techniques. This study will combine the available times series catch and effort data from published statistic landing data and publications with real-time data from electronic catch monitoring in Muncar and Pengambengan fishing port. The sardine stock and fishery status estimation were analyzed using a stock-production model incorporating covariates (ASPIC), a Nonequilibrium surplus-production model to data on fish catch and relative abundance. Another purpose of this study is to increase stakeholder participation through a smart dashboard system that enables automatic data analysis, faster recommendations socialization, and engagement. Increased stakeholder participation in fisheries management will be a crucial factor in achieving operational and successful fisheries management.

Keywords: Bali Strait; digital diary; sardine fishery; small-scale

1. Introduction
FAO has conveyed the importance of data and information quality in fisheries management policy formulations and recommendations. Certain attributes need to be fulfilled to meet good quality data criteria and useful for fisheries management purposes, and support data to support better resources management [1]. However, capture fisheries data collection, especially small-scale fisheries, needs to improve the quality of data collection, both in terms of resolution and data coverage. Detailed information related to capture fisheries will be needed to understand the existing phenomenon related to the fisheries resources and formulate the level of fish resource utilization that ensures sustainability and provides optimal economic benefits.

Technology disruption affects many sectors worldwide, including the fisheries sector, development of technology to acquired and storing the data digitally using Information and Communication
Technology (ICT) or smartphone application creating a bigger and better database, data analysis and potentially support capture fisheries need of traceability, compliances to the regulations [2]. Development of the database offers the utilization of Big Data and Decision Support System (DSS) to provide robust analysis, simulate better scenarios, formulate recommendations, and propose management measures to support successful fisheries management in achieving sustainability and profitability objectives [3].

Sardine fishery in Bali Strait is an important fishery in Indonesia; sardines catch has been contributed to Bali Strait surrounding areas economy, increase the livelihood, and provide job opportunities to Muncar in East Java and Pengambengan in Bali Province. Sardine fishery still considers small-scale fisheries; it is dominated by purse seine fishery, two main purse seine categories, i.e., twin boat purse seine known as “slerek” and single boat purse seine also known as “gardan” or “tubanan”.

Sardine stock estimation has been conducted several times through several approaches and techniques, from 1977 until 2018 (figure 1). Many initiations, joint research, and studies have been conducted from 1999 until 2016, resulting in scientific findings and management policies and recommendations. However, the result of the analysis, management plan, and regulations still not yet implemented [4]. Sardines fishery (also known as lemuru) management plan was enacted in 2016, but the regulation's implementation also remains challenging.

![Figure 1. Some results of Bali sardine stock status.](image)

This study presents a programming model through a stock-production model incorporating covariates (ASPIC) using the combination from published data, catch landing, and the result of digital data catch recorder initiation. The model is then used to estimate the target reference figure, the optimal harvesting level (Maximum Sustainable Yield or MSY) present in tons, and the optimal effort of the sardine fishing fleet ($f_{MSY}$) in the number of trips. Both references then compare with the database from near real-time electronic landing applications, namely MICT-L, a tablet application operated by the fishing-port officer that provides faster queries and more detailed catch and effort data to monitor and review the current exploitation level of Sardine in Bali Strait. The monitoring and review results then display on a dedicated dashboard in a simple form to increase the level of understanding and awareness from the stakeholders about the sustainable level of fisheries resource exploitation.
2. Material and methods

The location of this study was Bali Strait Indonesia, two major landings base were selected as catch data sources, Muncar fishing port in East Java and Pengambengan fishing port in Jembrana Bali (figure 2). Muncar fishing port is managed by the East Java Province Government, while Pengambengan fishing port is managed and under the Ministry of Marine Affairs and Fisheries (MMAF).

![Figure 2. Location of the study area.](image)

2.1. Data source

The analysis used four catch effort data sources, published yearly catch effort data by Sari et al. [5], a doctoral thesis by Zulbainarni [6], monthly landing data from Muncar and Pengambengan fishing port statistic report, and daily catch landing electronic recorder from MICT-L application. Both time-series data from a doctoral thesis and statistic data are tabulated in a yearly basis resulted yearly catch and effort data from 1980 until 2019, a total of 40 years of complete yearly catch effort data. Catch data represented in ton while the fishing effort was standardized into the number of trips.

Although some studies recommend incorporating the impact of the environment to standardize the catch per unit of effort (CPUE) [6-8], no catch per unit of effort (CPUE) standardization was performed during the analysis, detail CPUE standardization will be subject of another study using a complete set of environmental data. After considering the fluctuation of the CPUE, only 11 years (2009 – 2019) of the data were used as input in the ASPIC simulation. Moreover, data from 2010, 2017, and 2018 were excluded from the analysis since there is a high catch in 2010 and very low catches in 2017 and 2018.

2.2. Analysis method

The analysis for this paper uses a non-equilibrium biomass dynamics model. A general formulation of the fish biomass dynamics model, as described or used by Polacheck et al. [9], Chen and Montgomery [10], and Walters et al. [11], are

\[ B_{t+1} = B_t + g(B_t) - C_t \] (1)
Where:
- $B_t$ = the exploitable biomass at the beginning of year $t$ (in ton);
- $B_{t+1}$ = the exploitable biomass at the beginning of year $t+1$ (in ton);
- $g(B_t)$ = surplus production as a function of biomass at year $t$ (in ton);
- $C_t$ = the catch during year $t$ (in ton).

The surplus production model $[g(B_t)]$ used in this paper was selected between logistic model of Schaefer [12], and Fox [13, 14] as follows:

The Schaefer model:

$$g(B_t) = r.B_t (1-B_t/K)$$

(2)

The Fox model:

$$g(B_t) = r.B_t \left[ \frac{1-ln(B_t)}{ln (K)} \right]$$

(3)

Where:
- $r$ = the intrinsic growth rate parameter (per year).
- $K$ = the average biomass level prior to exploitation (coefficient no unit).

Catch per unit effort at year $t$ ($U_t$) is used as an index of relative abundance for year $t$ and the relationship between $U_t$ and $B_t$ is:

$$U_t = q \cdot B_t$$

(4)

Where: $q$ = the catchability coefficient (coefficient no unit).

Estimation of the production parameters used least square method with 20,000 trials of Monte Carlo simulation and 2,000 trials of bootstrapping. The analysis was undertaken by using ASPIC program developed by Prager [15-17] (figure 3).

2.3. Stock review conceptual framework

Combining the MSY and $f_{MSY}$ levels from the model and digital landing recorder from MICT-L, we could conduct a real-time stock review and monitoring (figure 3). Daily, weekly, monthly, and annual monitoring are easily conducted from MICT-L database system. Yearly catch effort ($C_t$ and $f_t$) from MICT-L will be inputs for the following year's model estimation development, and the results will be
used as a baseline for next year (MSY_{t+1} and f_{MSY_{t+1}}). The estimation will be conducted annually at
the beginning of the management year (1st January) and the result will be used as input for the management
until December 31st, same iteration and cycles every year.

Figure 4. Data flow and analysis.

3. Results and discussion

3.1. Results

3.1.1. Development of fishing effort, catch, and catch per unit effort. Sardines fisheries have been
developing in Bali Strait since the 1950s and getting more intense with the adoption of the purse
seine fishing gear in the mid-1970s [18]. From the recorded landing data since 1980s, the CPUE trend has
fluctuated in the last 30 years. CPUE fluctuations tend to be pattern-less and there appears to be a very
high gap at some periods. Despite very high fluctuations, CPUE values tend to increase from the 1980s
to the early 2000s and have decreased thereafter (figure 5).

CPUE of sardine catch in Bali Strait tends fluctuated 1980–2019. The highest total catch occurred in
2007, a total of 79,828 tons sardines were landed during that period from a total of 55,091 trips
conducted, after 2007 the catch was declining. The lowest catch occurred in 2017, only 131 tons of
sardines were landed from a total of 15,522 trips. Meanwhile, the minimum and the maximum CPUE
during 1980–2019 are 0.008 ton/trip and 4.863 ton/trip, respectively. The lowest CPUE occurs in 2017,
the highest CPUE occurred in 2003 (figure 5). The study from Zulbainarni [6], Purwanto [7], Puspasari
et al. [8], and Polacheck [9] explain that environmental variabilities are responsible for CPUE
fluctuations in Bali Strait, impact of the environmental variabilities on the total catch and CPUE was
higher than the fishing activities.

Figure 5. Bali sardines CPUE fluctuation from 1980–2019.
3.1.2. Production model of sardine fishery in Bali Strait. The values of parameters resulting from analyses of the production of sardine stock by using the Schaefer and the Fox models were presented in Table 1. Based on the result of the analysis, the Schaefer model was better since the goodness of fit to the data of this model (0.692) was higher than that of the Fox model (0.605). Therefore, the Schaefer model result was used as a sustainable harvesting level in this study.

The estimated optimum value of Bali Sardines biomass and production and the estimated optimum level of fishing mortality and fishing efforts are presented in Table 2. The analysis results indicate that the Bali Sardines stock could produce sustainable production at a maximum level of 28,540 tons/year, resulting from fishing mortality by 0.616. The optimum fishing effort is 10,790 trips/year.

Table 1. The estimated values of parameters and determination coefficients of the production model of sardine fishery in Bali Strait.

| Parameter       | Unit      | Schaefer Model | Fox Model |
|-----------------|-----------|----------------|-----------|
| \( r \)         | per year  | 1.233          | 0.278     |
| \( q \)         | 10\(^{-5}\) | 5.720          | 5.052     |
| \( K \)         | 10\(^{3}\) tons | 9.313          | 3.624     |
| \( R^2 \)       |           | 0.692          | 0.605     |

Table 2. The optimum value of sardine biomass and production, and the optimum level of fishing mortality and fishing efforts of sardine fishery in Bali Strait.

| Parameter (Symbol)               | Unit          | Point estimate | 80% lower | 80% upper | Point estimate | 80% lower | 80% upper |
|----------------------------------|---------------|----------------|-----------|-----------|----------------|-----------|-----------|
| Maximum sustainable yield (MSY)  | tons          | 28,540         | 17,310    | 67,680    | 37,120         | 40,550    | 89,970    |
| Fishing mortality at MSY (F\(_{MSY}\)) | 0.616        | 0.140          | 0.770     | 0.278     | 0.012          | 0.012     | 0.228     |
| Fishing effort at MSY (f\(_{MSY}\)) | 10,790        | 8,415          | 12,860    | 5,511     | 1,696          | 1,696     | 5,339     |
| Catchability coefficient (q)     | 10\(^{-5}\)   | 5.720          | 1.69      | 7.86      | 5.05           | 0.80      | 7.98      |
| Biomass at MSY (B\(_{MSY}\))     | tons          | 47,770         | 27,520    | 195,500   | 133,300        | 193,200   | 394,700   |

Figure 6. Kobe plot (above), relative biomass and fishing mortality and CPUE (below).
Catch per unit of fishing effort (CPUE) resulting from observation and estimation tends to decrease more than 1.0 ton/trip during 2009-2011, increasing significantly to the highest level in 2015, above 3.0 tons/year. After reaching a peak in 2015, the estimated CPUE level drops very deep until 2019. The development of fishing pressures and affected Bali Sardines biomass was shown from the plot of relative fishing mortality and relative fish biomass presented in figure 6.

In 2008, the Bali Sardines fisheries were overfishing as the F value almost reached five times the F at an optimum level. As shown from the Biomass value, the stock was overexploited under the level of Biomass at an optimum level. There has not been much change in the stock abundance during the 2008-2019 period, had increased until almost reach the optimum biomass level in 2015, and then decreased until 2019. The fishing pressure decreased rapidly from 2008 to 2014, then increased until the last year of observation in 2019.

3.1.3. Catch Effort Monitoring. The MICT-L application is used to monitor the catch landing data at two main fishing ports, Muncar and Pengambengan, in real-time. Data collected in the form of catch per trip and is recapitulated every month to get the total monthly catch and total monthly trips, as seen in table 3. The MICT-L application also distinguishes Bali Sardines from the total catch so that further analysis can be carried out. A total of 2,035 landings in Muncar and 4,009 landings in Pengambengan were acquired and stored from January until September 2020.

The average number of fish landed in Pengambengan Fishing Port is higher than Muncar Fishing Port and the number of trips in the period of January to September 2020. The minimum and the maximum sardines catch during January until the September 2020 period show a similar pattern between Muncar and Pengambengan. Minimum sardines catch 76 tons and 18 tons in Muncar and Pengambengan, respectively, both occur in February 2020 period. The highest number of landed catches occurred in April. Muncar recorded a landing catch of 1,771 tons, while 3,4340 tons of fish landed in Pengambengan in the same month. The landing data shows that Bali Sardines dominate the landed catch, about 76% in Muncar, and 85% in Pengambengan from the total catch. This result was different from the study from [20] in 2007; Sardines season will occur in October while April was not a sardining season in Bali Strait.

| Month/2020 | Number of Trip (f) | Total Catch – TC (Ton) | Sardines Catch – SC (Ton) | Number of Trip (f) | Total Catch – TC (Ton) | Sardines Catch – SC (Ton) |
|--------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Muncar Fishing Port | Pengambengan Fishing Port | Muncar Fishing Port | Pengambengan Fishing Port | Muncar Fishing Port | Pengambengan Fishing Port | Muncar Fishing Port | Pengambengan Fishing Port |
| Jan | 220 | 436 | 108 | 170 | 754 | 200 |
| Feb | 348 | 530 | 76 | 441 | 571 | 18 |
| Mar | 269 | 546 | 302 | 548 | 1,348 | 1,146 |
| Apr | 408 | 1,771 | 1,554 | 780 | 3,430 | 3,273 |
| May | 205 | 361 | 313 | 444 | 1,283 | 1,174 |
| June | 159 | 561 | 525 | 591 | 1,118 | 1,094 |
| July | 155 | 433 | 420 | 536 | 1,122 | 1,103 |
| Aug | 215 | 799 | 765 | 333 | 812 | 804 |
| Sep | 56 | 346 | 346 | 166 | 718 | 715 |
| Total | 2,035 | 5,783 | 4,408 | 4,009 | 11,156 | 9,526 |

3.1.4. Stock Status Monitoring. Landing data from the MICT-L application can be used to monitor the status of stocks utilized by fishermen in real-time by referring to the results of a stock assessment that has been carried out. The MSY value set as a reference is 28,540 tons, while the f MSY is 10,790
trips. Landing and trip data are accumulated every month from both Fishing Ports and then compared with the MSY and effort at MSY as reference. The results were then interpreted as status and grouped into three color codes: 1. Green when the status is still below 80%; 2. Yellow when the status ranges from 80-100%; and 3. Red, when the status has exceeded 100% (table 4).

The results show that until September 2020, the total accumulated catch landed is still at a safe level, indicated by the status value of about 48.8%. The same thing happened to the accumulated number of fishing trips still at a safe level, indicated by the status value of about 56%. With this utilization status, it is expected that it will still be at a safe level in landing and fishing trips in the remaining three months.

Table 4. MICT-L catch status monitoring

| Month/2020 | ftotal (trip) | Cumf | Status (Cumf / fMSY) * | Color Code | SC (Ton) | CPUE (Ton/Trip) | Cum SC | Status (CumSC / fMSY) * | Color Code |
|-----------|--------------|------|------------------------|------------|----------|-----------------|--------|------------------------|------------|
| Jan       | 390          | 390  | 4%                     |            | 308      | 0.790           | 308    | 1.1%                  |            |
| Feb       | 789          | 1,179| 11%                    |            | 94       | 0.119           | 402    | 1.4%                  |            |
| Mar       | 817          | 1,996| 18%                    |            | 1,447    | 1.772           | 1,849  | 6.5%                  |            |
| Apr       | 1,188        | 3,184| 30%                    |            | 4,827    | 4.063           | 6,676  | 23.4%                 |            |
| May       | 649          | 3,833| 36%                    |            | 1,486    | 2.290           | 8,163  | 28.6%                 |            |
| June      | 750          | 4,583| 42%                    |            | 1,619    | 2.159           | 9,782  | 34.3%                 |            |
| July      | 691          | 5,274| 49%                    |            | 1,524    | 2.205           | 11,306 | 39.6%                 |            |
| Aug       | 548          | 5,822| 54%                    |            | 1,568    | 2.862           | 12,874 | 45.1%                 |            |
| Sep       | 222          | 6,044| 56%                    |            | 1,060    | 4.777           | 13,934 | 48.8%                 |            |
| Total     | 6,044        |      |                        |            | 13,934   | 2.306           |        |                        |            |

Note: *MSY = 28,540 ton, fMSY = 10,790 trips

Color Code: 
- Green = < 80%
- Yellow = 80 – 100%
- Red = > 100%

3.2. Discussion

Color codes indicate the current exploitation level of sardine fish in Bali Strait, this color code is generated from time-series data and near-real data, furthermore, the study shows that the combination between time series catch-effort data and near real-time digital catch recorder are powerful tools to monitor, review and present Bali sardine stock status in a more "easy digest" product consumed and easily understood by the stakeholders. Using a smart dashboard display dedicated to this purpose will open a new perspective in science communication and create possibilities for increasing participatory data collection, research, and management formulation and achieving collective awareness about sustainability from all stakeholders. The digital catch landing database also increases the data quality and could support good quality capture fisheries data described by Evans [1] and FAO [3].

Problems identification-related the establishment of fisheries management conducted by Ghofar [4], several suggestions involve the fishing community on participatory research and resource management planning. Using this study’s approach and other proper tools for participatory data collection, the stakeholders’ level of understanding, especially fishers, could be increased, and participatory fisheries management could be planned and implemented. One good example by Saville et al. [2] for the sea cucumber fishery, the fisher’s community decided to stop fishing activities and reduce the amount of catch when they directly observed the increasing cumulative catch and the result of stock level's review condition approaching red level.

Development of a decision support system (DSS) for Bali sardine fisheries required an understanding of the overfishing and how management measures can be conveyed and understood by all stakeholders, stock review and visualization is one of the steps in order to realize that, similar approach and results
with Sholahuddin et al. [21]. The continuation of digital landing recorder application will provide detailed data and information to establish a better analysis of the stock status.

4. Conclusion
Sardine fisheries stock analysis using existing time series data was successfully conducted and provided Bali Sardine fisheries sustainable harvesting level for further analysis and reviews. A combination of the model results with near real-time electronic catch landing data recorder from the MICT-L application has been proven as a practical tool to monitor the exploitation level and current stock status. Using these combination tools as the smart dashboard input will give an alternative way to engage with the stakeholders and increase their awareness and understanding of sustainability and long-run profitability. The study's result also potential to visualized management measures discussion and initiations in a better way shift from the high scientific jargon from the simulation into simple color code and percentage. This study will continue until 2022. This baseline time-series data analysis provides essential steps to better captures fisheries management development based on big data and decision support systems (DSS).

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