

Evaluation of *Sardinella lemuru* Resource Status at the Nusantara Fisheries Port (NFP) Pengambangan

**I Ketut Wija Negara^{1,2*}, I Wayan Restu¹, Made Ayu Pratiwi¹, Diah Ayu Safitri³, Andi Mannoengi⁴,
Bagus Sudananjaya⁴, Made Ageng Astika⁴, and I Nyoman Sudiarsa⁵**

¹Aquatic Resources Management, Faculty of Marine Science and Fisheries, Udayana University, Bali, Indonesia

²Aquatic Resources Department, Faculty of Fisheries and Marine Science, Diponegoro University, Semarang, Indonesia

³Fisheries Science, Fisheries and Marine Faculty, Airlangga University, Surabaya, East Java, Indonesia.

⁴Nusantara Fishing Port (NFP) Pengambangan, Bali, Indonesia

⁵Marine and Fisheries Polytechnic of Jembrana, Pengambangan, Bali, Indonesia

*Corresponding author: wijanegara@unud.ac.id

Abstract. The lemuru (*Sardinella lemuru*) fishery at Pengambangan Nusantara Fishing Port (NFP) is vital to the local economy but faces challenges from fluctuating catches, potentially linked to overexploitation. This study evaluates the sustainability status of this fishery using the Ecosystem Approach to Fisheries Management (EAFM) framework. Research conducted from May 2024 to July 2024 employed a mixed-methods approach, including direct observation, surveys, and interviews with 110 fishers, alongside biological data from 2,653 fish specimens. A multi-criteria analysis was used to calculate a composite sustainability index. The overall assessment yielded a score of 73,33 ('good' status), indicating that fisheries management at PNFP is generally satisfactory. However, critical issues were identified: a declining trend in fish size and inadequate management of Endangered, Threatened, and Protected (ETP) species. The study concludes that while the fishery is currently well-managed, urgent interventions are needed. Key recommendations include enforcing regulations on minimum catchable size and net mesh selectivity, alongside strengthening monitoring, control, and surveillance (MCS) to combat illegal, unreported, and unregulated (IUU) fishing and ensure long-term sustainability.

Keywords: EAFM; Fisheries resources; PPN Pengambangan; *Sardinella lemuru*

I. INTRODUCTION

Lemuru fish (*Sardinella lemuru*) is one of Indonesia's high-value fishery commodities, especially in the waters of the Bali Strait, which has abundant potential resources [1]. The center of lemuru fishing in Bali is located in the Pengambangan area, with a fishing base at PPN Pengambangan [2]. As one of the largest fisheries ports in Bali, NFP Pengambangan plays a critical role in supporting fishing activities for many local fishermen and fisheries industry players, with lemuru fish being the leading commodity [3].

Based on the 2022 annual report of PPN Pengambangan, lemuru fish dominated the catch, contributing 90% of the total catch [2]. This abundance has encouraged the emergence of processing industries, such as canning and fish meal factories, in the Pengambangan

and Muncar areas [4]. There is high demand from both the processing industry and the local market. As a result, overfishing has occurred, consistent with declines in fish populations and future catches [2].

The sustainability of small pelagic fisheries like lemuru has become a pressing concern in Indonesia, especially in the Bali Strait, where fishing pressure continues to intensify. Previous research has often focused on isolated aspects of the fishery, such as catch per unit effort (CPUE) trends [1], spatial catch distributions linked to oceanographic variables [3,4], and biological parameters including size at maturity and population dynamics [5,6]. More recent studies have begun applying the Ecosystem Approach to Fisheries Management (EAFM) framework in Indonesian waters, emphasizing integrated management across ecological, social, and governance dimensions [7]. Nevertheless, many applications remain generalized,

lacking port-specific, multi-indicator assessments that combine quantitative biological data with direct stakeholder input.

Given these gaps, assessing the status of lemuru resources at NFP Pengambangan is essential to ensure the long-term sustainability of the fishery and the communities that depend on it. This study aims to evaluate lemuru resources using a scientific approach that analyzes catch data, biological parameters, and relevant environmental factors. By clarifying the current status of the stock, this research seeks to formulate effective and sustainable management recommendations that support fisher welfare and maintain the ecological balance of the aquatic ecosystem around NFP Pengambangan.

II. METHODS

Location

The research was conducted in Nusantara Fisheries Port (NFP), Pengambangan, Jembrana Regency, Bali. Data collection was conducted from May 2024 to July 2024, 3 times in a 3-month period. Each data collection was conducted with an interval of 14 days.

Procedure and Data Collection

The focus of this study is biological and fisheries data, which are required to analyze the six key indicators within the fish resource domain (Table 1) using the framework established by the National Working Group on the Ecosystem Approach to Fisheries Management [5]. The overall research procedure, illustrating the sequential steps from data collection to sustainability assessment, is presented in Figure 1.

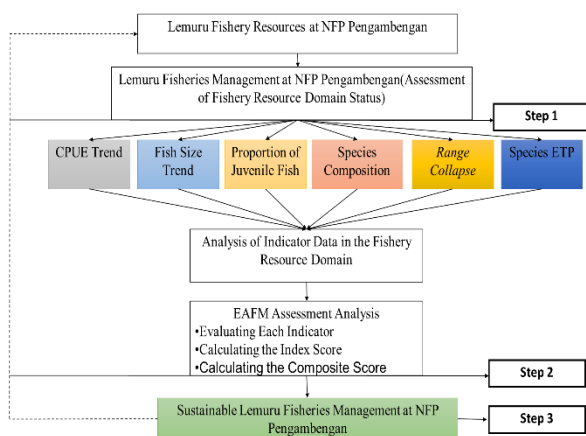


Figure 1. Procedure Research of EAFM

This study employed a descriptive, quantitative methodology. Data collection tools included stationery items, such as books and pens/pencils, as well as rulers and measuring boards. These tools were used to sample 100

fish per observation, for a total of three observations and 300 lemuru fish (*Sardinella lemuru*). Measurements focused on specimens obtained from purse seine fishing gear operating out of PPN Pengambangan.

Table 1.
Types and Sources of Data Collection

| Indicators | Type | Data Source |
|-----------------------------|-----------|---|
| CPUE trend | Secondary | Nusantara Fisheries Port (NFP) Pengambangan Report |
| Fish Size Trend | Primary | Direct observation |
| Proportion of Juvenile Fish | Primary | Direct observation and interview |
| Species Composition | Primary | Observation and interview |
| Range collapse | Primary | Observation and interview |
| Species ETP | Primary | Observation and interview |

Data Analyst

The equation used to calculate the CPUE value is as follows:

$$CPUE = \text{Catch}/\text{Effort} [6]$$

Description: CPUE is catch per unit effort (kg/trip); Catch is catch (kg)

Effort is fishing effort (trip).

Proportion of juvenile fish caught. Based on the NWG EAFM module [5], the proportion of juvenile fish caught is calculated using the following equation:

$$PCy = C_{yi}/C_{tot} \times 100\% [5]$$

Description: Pcy is the proportion of juvenile fish caught (%); C_{yi} is juvenile fish caught in gear i (tons); C_{tot} is the total catch in gear i (tons).

EAFM Analysis

Indicator Criteria Assessment

This study assessed each indicator using a simple Likert scale, a straightforward yet effective tool for gauging respondents' attitudes, opinions, and perceptions in fisheries research. The socioeconomic survey used questionnaires and interviews, common tools in fisheries research, to collect data from 100 ship crew members. The determination of the weight value of each indicator based on the fish resources domain (Table 2) is in accordance with the provisions of the EAFM module [5]. The interpretation of each indicator's score is that a higher score indicates a better category.

Determining Index Values

Weighting indicators within the fish resource domain by their level of influence (importance) is an important step in data analysis. The weight assigned to an indicator is determined by its level of direct or major influence on the entire domain [5]. The amount of index value in each domain is determined by the following equation:

$$\text{Cat-I} = \text{Sat-i} \times \text{Wat-I} [5]$$

Description: Cat-I is the index value of the i-th attribute/indicator; Sat-I is the score of the i-th attribute/indicator; Wat-I is the weight of the i-th attribute/indicator






Determining the EAFM Composite Score

The assessment of indicators in EAFM is a complex multi-criteria system with the ultimate goal of producing a composite index that describes the overall level of success of fisheries management in accordance with the principles of EAFM (Ecosystem Approach to Fisheries Management). The composite index converts the total value of each EAFM domain. This process is necessary to obtain a standardized boundary of the conversion value of the 1-100 scale to facilitate the categorization of each EAFM domain. The total index values obtained were analyzed using the arithmetic mean to calculate a simple composite index (Table 2). The composite value of each indicator is determined by the formula:

$$\text{NK} = (\text{Cat}/\text{Cat-max}) \times 100 [5]$$

Description: NK is a composite value; Cat is the total index value of all indicators; Cat-max is the maximum total index value.

Table 2.
 EAFM Composite Value (Flag Modeling)

| Composite Value Range | Flag Model | Description |
|-----------------------|---|-------------|
| 1-20 |  | Very Bad |
| 21-40 |  | Bad |
| 41-60 |  | Medium |
| 61-80 |  | Good |
| 81-100 |  | Excellent |







Source: [5].

III. RESULTS AND DISCUSSION

A comprehensive evaluation shows that the lemuru fish resources at Pengambengan Nusantara Fishing Port (PPN) are in a “good” status (Table 3), indicating the successful implementation of sustainable fisheries management principles. The results of the evaluation of lemuru fish resources at PPN Pengambengan are presented in the following table. This data provides a comprehensive overview of the current state of the fishery.

The EAFM composite scores for the *Sardinella lemuru* fishery at NFP Pengambengan fall within the “good” category, suggesting an overall satisfactory management status. This finding indicates consistent performance, as it aligns with the “good” category score of 70 reported by Larasati et al. (2025). Key positive indicators, such as stable catch per unit effort (CPUE) and a catch composition dominated by the target species, suggest that the fish population is being maintained and harvesting operations are efficient. However, an indicator-by-indicator comparison with previous research reveals critical vulnerabilities that the aggregate score obscures. Notably, concurring findings of a declining fish size trend and a high proportion of juvenile fish (>50%) in the catch suggest overfishing for growth and recruitment, respectively.

Table 3.
 Composite Value of Each Indicator in the Fish Resources Domain

| No | Indicator | Composite Score | Flag Model | Category in applying EAFM |
|----------------|----------------------------------|-----------------|---|---------------------------|
| 1 | Standardized CpUE | 66,67 |  | Good |
| 2 | Fish size trend | 33,33 |  | Bad |
| 3 | Proportion of juvenile fish | 66,67 |  | Good |
| 4 | Species composition of catch | 100 |  | Very good |
| 5 | Range collapse of fish resources | 66,67 |  | Good |
| 6 | ETP species | 33,33 |  | Bad |
| Average | | 73,33 | | Good |

These patterns directly threaten population regeneration and the long-term sustainability of fish stocks. They also indicate a significant disconnect between composite performance scores and urgent biological risks within these fisheries. This aligns with broader scientific concerns about the masking effect of aggregate sustainability scores, which often obscure critical failures at the subsystem level. These findings align with studies by Ye, Link, and Costello, reinforcing global warnings about the cumulative impacts of overfishing and biodiversity loss on marine ecosystem resilience [17][20].

To address these vulnerabilities, there must be a transition from the current satisfactory, albeit reactive, management regime to a proactive, adaptive, and strictly enforced Ecosystem Approach to Fisheries Management

(EAFM) system. This includes technical measures, such as enforcing minimum catch size regulations and improving the selectivity of fishing gear. It also includes strengthening governance chains and market interventions to eliminate incentives for unsustainable practices. Ultimately, the path to long-term sustainability depends on effectively reconciling short-term economic interests with absolute ecological demands—a challenge requiring integrated policy action, continuous monitoring, and inclusive stakeholder engagement, as emphasized in the EAFM framework for complex tropical fisheries [18].

Catch Per Unit Effort (CPUE) Trend

The assessment of the CPUE (Catch Per Unit Effort) trend indicator aims to estimate a proxy for stock abundance in the Bali Strait. It measures the catch (in tons) obtained per fishing trip [2]. The data spans from 2015 to 2024 for lemuru stocks in the Pengambengan PPN, as shown in Table 4.

Table 4.

Sardinella lemuru Catch Per Unit Effort (CPUE) Trend

| Year | Catch (ton) | Effort (trip) | CPUE (ton/trip) |
|---------|-------------|---------------|-----------------|
| 2015 | 16.038 | 2.801 | 5,72 |
| 2016 | 7.150 | 1.438 | 4,97 |
| 2017 | 77 | 1.224 | 0,06 |
| 2018 | 1.154 | 4.186 | 0,27 |
| 2019 | 16.003 | 6.141 | 2,60 |
| 2020 | 18.101 | 6.302 | 2,87 |
| 2021 | 13.748 | 4.469 | 3,07 |
| 2022 | 11.010 | 4.260 | 2,58 |
| 2023 | 8.570 | 3.133 | 2,73 |
| 2024 | 22.054 | 3.033 | 7,27 |
| Total | 113905 | 36987 | 32,14 |
| Average | 11390,5 | 3698,7 | 3,214 |

Source: Nusantara Fisheries Port (NFP) Pengambengan, 2025

The CPUE trend for *Sardinella lemuru* at PPN Pengambengan (Figure 2) reveals a clear, concerning pattern, divided into three phases. The Drastic Decline Phase (2015–2018) saw a sharp decline in CPUE from 5.72 tons per trip in 2015 to 0.06 tons per trip in 2017, suggesting either severe seasonal failure or a sharp decline in the fish population. Although CPUE recovered slightly to 0.27 tons per trip in 2018, it remained critically low, with annual production failing to reach 5,000 tons from 2016 to 2018. This trend aligns with the findings of Larasati et al. [2], who reported an average annual decrease in CPUE of 14.62% and noted significant interannual fluctuations. Thus, both studies corroborate a pattern of

long-term decline in catch efficiency, underscoring underlying instability in the lemuru stock despite periodic recoveries.

The catch per unit effort (CPUE) trend for *Sardinella lemuru* over the past decade (2015–2024) shows a slight long-term decline, with an average annual decrease of less than 25%. This pattern aligns with the findings of Larasati et al., who reported a gradual decline in CPUE at Pengambengan from 2013 to 2022. However, the CPUE dynamics can be broken down into distinct phases. First, there was a drastic decline from 2015 to 2018. Then, there was a gradual recovery from 2019 to 2023, during which the CPUE rose from 2.60 to 3.07 tons per trip with minor fluctuations. Finally, there was a sharp increase in 2024 to 7.27 tons per trip, indicating high annual abundance. While increasing CPUE may reflect improved fishing efficiency, stock recovery, or favorable environmental conditions, the 2024 spike must be interpreted within sustainable yield boundaries.

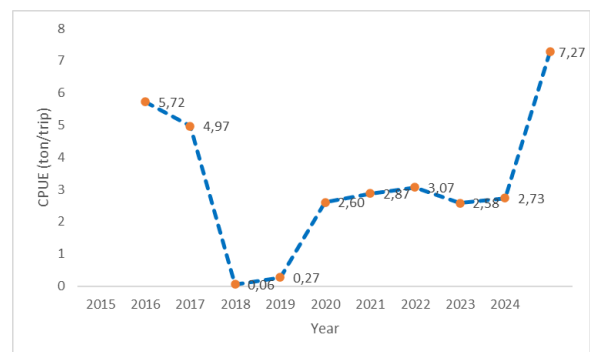


Figure 2. CPUE of *Sardinella lemuru* in PPN Pengambengan.

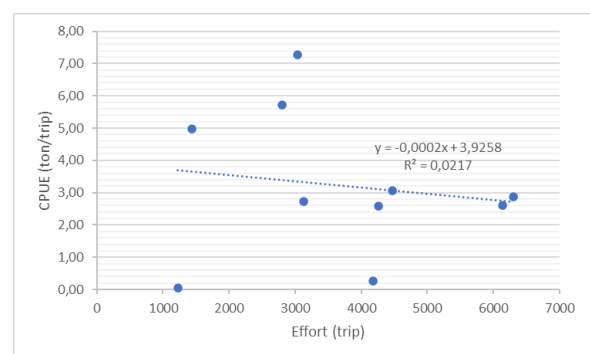


Figure 3. Scatter plot relationship between fishing effort and the CPUE of *Sardinella lemuru* in PPN Pengambengan 2015–2024.

According to Nugraha et al. [8], the maximum sustainable yield (MSY) of lemuru in the Bali Strait is 25,107.32 tons per year, with a maximum permissible catch (MPC) of 20,085.86 tons per year. Even the elevated 2024 catch remains far below this annual threshold,

indicating that a one-year increase does not signify full stock recovery or the absence of overfishing pressure. This observation aligns with the broader assessment by Nugraha et al. [8], which highlighted a long-term decline in CPUE and identified critical management issues, including the use of non-selective gear with a 0.5-inch mesh size, which contributes to overfishing. Thus, while short-term recovery and high catch rates may occur, the fishery continues to operate below its historical and sustainable potential, reinforcing the need for proactive, science-based management.

Fish size trend

The assessment of fish size trend indicators aims to determine the impact of fishing activities, identify fishing patterns, and establish population parameters. Fish size data were collected by randomly sampling fish from fishing vessels that landed at PPN Pengambengan over a three-month period from May to July of 2024. Lemuru fish were divided into four categories, as shown in Table 5.

Table 5.
 Category of *Sardinella lemuru* size

| Category | Total Length (cm) |
|---------------|-------------------|
| Sempenit | <11 cm |
| Protolan | 11-15 cm |
| Lemuru | 15-18 cm |
| Lemuru kucing | >18 cm |

Source: [11][12]

Based on the established size categories for lemuru, the composition of the sampled fish was as follows: sempenit (less than 11 cm) 4%; protolan (11–15 cm) 48%; lemuru (15–18 cm) 39%; and lemuru kucing (greater than 18 cm) 9% (Figure 4). Nearly half of the total sample (48%) fell into the Protolan category. This is concerning because fish in this size range have only just reached or are approaching full maturity. This finding aligns with the species' biological references: the maximum length of lemuru is about 23 cm, and the length at maturity is reported to be 14–15 cm [13][14].

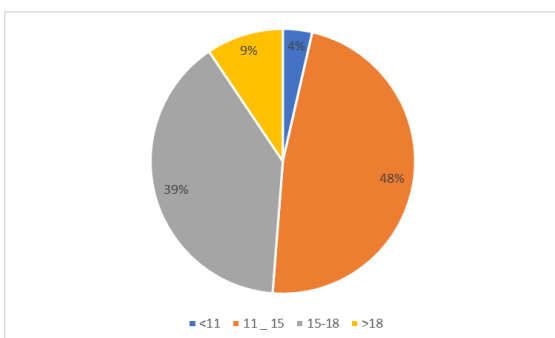


Figure 4. *Sardinella lemuru* size trend in PPN Pengambengan

The fishing methods used by fishermen at Pengambengan Fishing Port are the same as those used at Muncar Fishing Port. There are two distinct purse seine systems employed at the port: the two-boat system, in which two vessels work together to deploy and haul the net, and the one-boat system, in which a single vessel, usually a golek boat, operates the net independently. The most widely used fishing fleet at PPN Pengambengan consists of 12 m x 1.5 m x 1.5 m and 20.5 m x 5.5 m x 1.6 m vessels, and the nets range in size from 100 to 340 meters. The upper and lower mesh sizes range from 0.6 to 3.9 inches.

The fishermen at Pengambengan Fishing Port use the same fishing methods as those at Muncar Fishing Port. They employ purse seine systems, including two-boat and single-boat Golekan operations. The predominant fleet at Pengambengan comprises vessels measuring 12 m x 1.5 m x 1.5 m or 20.5 m x 5.5 m x 1.6 m that deploy nets ranging from 100 to 340 meters in length and with mesh sizes between 0.6 and 3.9 inches. These dimensions closely align with the gear specifications reported by Nugraha et al. [8], who recorded purse seine nets with a 0.5-inch mesh size in the Bali Strait.

Proportion of Juvenile Fish Caught

The proportion of juvenile fish is an important indicator for assessing the health of lemuru populations and the effectiveness of fisheries management [5]. It serves as an indicator of fishing pressure and reflects population structure. It also measures the impact on lemuru resources and the ecosystem as a whole. Figure 4 shows the results of identifying length and weight in lemuru at PPN Pengambengan.

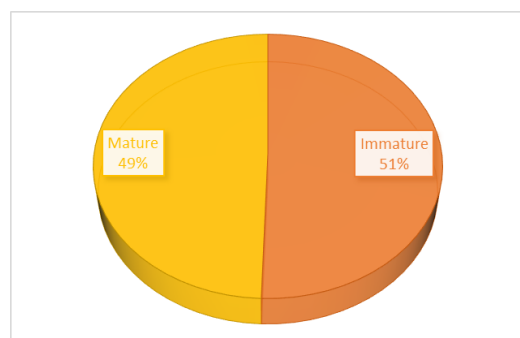


Figure 4. Proportion of Mature and Immature *Sardinella lemuru*

According to the research of Wujdi et al. [7], the fork length at first maturity of lemuru fish (*Sardinella lemuru*) in the Bali Strait is 13–14 cm. This size is a crucial biological threshold that separates the juvenile phase from the active, reproductive adult phase. However, the latest monitoring data shows an alarming trend: 51% of the catch

consists of immature fish, while only 49% consists of mature fish. The dominance of fish smaller than 13 cm disrupts the reproductive cycle ecologically and reduces the stock's ability to recover. If the proportion of immature fish in the catch remains above 50%, the exploitation of the juvenile stock will increase, accelerating a massive population decline.

This finding is crucial because it indicates a high risk to the sustainability of fisheries. A catch proportion of 30–60% of juvenile fish is considered unsustainable in the long term. Heavy exploitation of immature fish will certainly lead to a decline in the spawning stock, ultimately

reducing the number of new individuals entering the population each year. These conditions strongly indicate overfishing. This aligns with Nugraha's findings [8], which identified overfishing symptoms through a consistent downward trend in CPUE and a decline in the average size of fish caught. With a maximum sustainable yield (MSY) of 25,107.32 tons per year and a total allowable catch (TAC) of 20,085.86 tons per year, the current exploitation rate has exceeded the sustainability limit. This phenomenon underscores the need for immediate management intervention to prevent stock collapse from overfishing, both biologically and economically.

Table 6.
 Fish Size Trends in Lemuru (*Sardinella lemuru*) Catches at PPN Pengambangan

| Time | Total Length (cm) | | | | Average Weight (g) |
|--|-------------------|-------|-------|------|--------------------|
| | <11 | 11-15 | 15-18 | >18 | |
| May, 2024 | | 11,3 | 17,3 | 18,6 | 11 |
| June, 2024 | 10,6 | 12,4 | 16,8 | 19,1 | 13,2 |
| July, 2024 | 10,5 | 12,1 | 17,0 | 19,6 | 11,8 |
| Number of Samples (<i>Sardinella lemuru</i>) | 95 | 1264 | 1043 | 250 | |
| Percentage (%) | 4% | 48% | 39% | 9% | |

Catch Species Composition

The target species for purse seine fishing at Pengambangan Fishing Port is the lemuru fish (*Sardinella lemuru*). Other species, such as shortfin scad, largehead hairtail, kawalaka, and fringescale sardinella, are bycatch. Figure 3 shows the proportion of the target species in the total catch from 2019 to 2023.

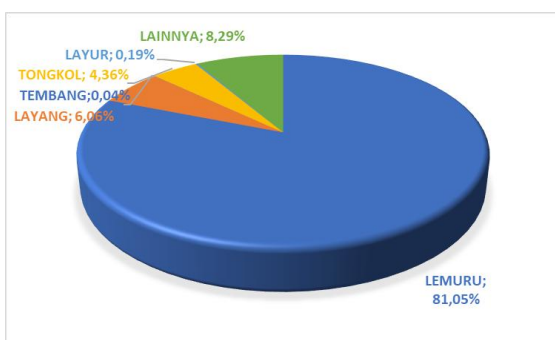


Figure 3. Species composition of catch in NFP Pengambangan during the period 2019-2023

Catches in the waters of the Bali Strait are significantly dominated by one species: the lemuru fish (*Sardinella lemuru*), which accounts for over 80% of the total catch. Consistent with these findings, previous research by Sartimbul et al. [19], indicates that the production volume of lemuru fish contributes 80–90% to the total production of small pelagic fish in the Bali Strait. Furthermore, Nugraha confirms that the lemuru fish is the leading small

pelagic fishery commodity in the region [8]. The rapid growth of the lemuru fishery is supported by local processing industries, including canning factories, fish meal production facilities, and cold storage facilities operating around the main landing sites in Muncar and Pengambangan.

According to the National Working Group on the Ecosystem Approach to Fisheries Management (EAFM) [5], fishing gear selectivity can be determined by the proportion of non-target fish (including unwanted and juvenile fish) relative to target fish. Traditionally, fisheries management has focused solely on specific fish stocks, without considering broader ecosystem dynamics and species interactions in aquatic environments. This more holistic approach is becoming increasingly relevant in the context of Indonesian inland fisheries, where fisheries systems are multispecies and have complex stock structures. Addressing this challenge requires management strategies that ensure the sustainability of fish resources and equitable benefits for all stakeholders [18].

Range collapse of fish resources

From 2019 to 2020, the lemuru population in the Bali Strait fishing grounds declined. Lemuru is a commercially important sardine species. The complexity of the lemuru loss requires a comprehensive approach to finding a sustainable solution. The collapse of fish resources in the PPN Pengambangan area has been relatively well-

documented through interviews and questionnaires with fishermen. Figure 4 shows the fishing ground map of fishermen in Pengambangan VAT.

According to fishing logbook data, most fishermen operating from the Pengambangan Nusantara Fishing Port (PPN) fish in the Indonesian Fisheries Management Area (WPPNRI) 573, specifically in the Bali Strait. This region is considered highly productive due to upwelling, which brings nutrient-rich deep-sea water to the surface, supporting the growth of plankton at the base of the food chain. Previous assessments revealed a relatively consistent fishing ground pattern, rated 2 on an ordinal scale, depending on the target species. In line with this, recent research by Prayitno et al. [21], confirmed that the relationship between fishing effort and catch per unit effort (CPUE) is positive; that is, any increase in fishing effort tends to increase CPUE.

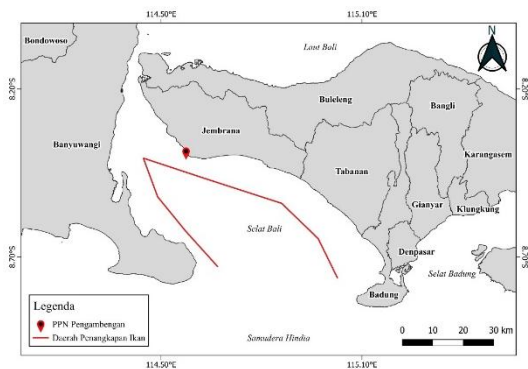


Figure 4. Fishing Area Map of Bali Strait

This indicator is evaluated to determine the impact of increased fishing pressure on fish resources [5]. A shrinking species range indicates a significant population decline, which can be caused by overfishing, climate change, habitat destruction, or a combination of these factors. A number of factors threaten the long-term viability of fish stocks, the most important of which are overfishing, habitat degradation, and climate change [20].

ETP Species (Endangered, Threatened, and Protected Species)

The ETP species indicator assessment aims to show whether ETP species are caught by fishermen as bycatch or primary targets. Data were collected through questionnaires given to experienced fishermen and skippers. The questionnaire included a list of ETP species listed in the CITES Appendix to help fishermen identify them.

A questionnaire was distributed to 99 fishermen. 47 fishermen reported catching many ETP (endangered, threatened, and protected) species ($\geq 20\%$). Three fishermen stated that their ETP catches were very high. 49

fishermen reported not catching ETP species. The most commonly reported ETP species included sharks, manta rays, turtles, dolphins, and dragonfish. The issue of ETP bycatch further complicates the sustainability of fishing in the Bali Strait. These findings align with those of a study by Larasati et al. [2], which found that Pengambangan fishermen capture ETP species by accident or by becoming entangled in purse-seine nets. Although fishermen report trying to release ETP species caught in their nets, the frequency of these incidents indicates a serious ecological risk. In the Indonesian context, this aligns with the EAFM framework's emphasis on minimizing ecosystem impacts, as highlighted by the National Working Group on EAFM and broader applications in tropical, multispecies fisheries [5].

IV. CONCLUSION

The fisheries management in NFP Pengambangan has performed well in supporting the principles of sustainable fisheries, as indicated by a composite index score of 73,33, which falls into the "good" category. However, there are two indicators within the fishery resource domain that require improvement, namely fish size trends and the status of Endangered, Threatened, and Protected (ETP) species, both of which are classified as suboptimal. To enhance fisheries management, strategic measures should be implemented, such as imposing size restrictions on harvested fish and regulating mesh size to maintain trends in fish size. Additionally, to protect ETP species, stricter monitoring and law enforcement against illegal fishing practices are necessary.

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