Optimization of FADs-based tuna fishing in the Fishing Port of Pondokdadap, East Java, Indonesia

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Abstract. The Minister of Marine Affairs and Fisheries Regulation number 26/2014 has decreed that the distance between FADs should not be less than 10 nautical miles and should not be installed to make a fence effect. Highly dense FADs that are deployed with not enough distance between them in a certain period will change the movement pattern of tuna. This study aims to obtain information on the actual data of FADs deployed in the southern waters of East Java, to estimate the deployment area and to provide a recommendation on the ideal number of FADs deployed in these waters. The FAD deployment area has been estimated to be 219,792 km\textsuperscript{2} or 21,979,200 ha. Based on this estimation, it is calculated that the ideal number of FADs installed in these waters is 814 units. Estimates of the optimal number of tuna fishing units are carried out using linear goal programming (LGP) which suggests 380 units of sekoci (fishing vessel) as the optimal unit number that can operate annually at the Fishing Port of Pondokdadap, Malang Regency. The number of sekoci currently operating at this port is 644 units.
1. Introduction

Fish aggregating devices (FADs) or rumpon are widely used in small-scale tuna fisheries. This tool is proven to be able to increase catch efficiency, even though the size of the captured fish is highly variable. The development of the use of FADs is followed by the development of tuna fishing businesses that uses various types of fishing gear. This rapid development has become increasingly counter-productive to fishing efficiency and may have a negative impact on fish resources [1, 2].

The current level of FADs utilization shows a rapid increase from year to year. This can be seen by the increasing number of ships carrying out capture operations around FADs. Application of FADs technology as a fishing aid has its advantages and disadvantages. In the short term, the presence of FADs will increase fishermen's income, while in the long term it may have negative impacts on the fish stock, the sustainability of fish resources, catch production and ultimately on the welfare of the fishermen themselves.

Fishermen in the Fishing Port of Pondokdadap generally catch fish by sailing in their sekoci to use their fishing gear around FADs. The types of fishing gear that are commonly carried consists of taber fishing lines, troll line, kite fishing lines, tomba fishing lines, batuan fishing lines, coping fishing lines, and handlines [3]. The various types of fishing gear are intended to allow fishermen to be able to catch fish in different water current conditions, changing wind conditions, and to adjust to the type and size of fish they find when fishing. The main target fish caught by the sekoci fishermen include tuna, skipjack tuna, and little tuna.

The purpose of this study was to determine the optimal number of FADs and tuna fishing fleet units based at the Fishing Port of Pondokdadap, East Java. The basic idea to establish the framework of thinking for this study was the increased number of FADs installed, which may lead to an increase in fishing activity.

2. Materials and methods

2.1. Data collection

This research was conducted from August to September 2017 at the Fishing Port of Pondokdadap, Malang Regency, East Java, Indonesia. Position of FADs was obtained from fishermen who landed their catch at the fishing port. Secondary data on the four years production (2013-2016) of five main fish species landed at fishing ports were obtained from local institutions under the East Java Marine Affairs Agency.

2.2. Data analysis

Determination of the distance and number of FADs refers to the Minister of Marine Affairs and Fisheries Regulation Number 26 of 2014. The regulation states that FADs should be installed at a distance of at least 10 nautical miles from one to another. Data analysis for optimization was performed by Linear Goal Programming (LGP) [4, 5] which was run on the LINDO 6.1 programming language software. The constrained optimization model was chosen because the regression model used was linear and with not exceeded boundary conditions (constraints). LGP is used to solve problems with more than one objective function. The objective function is to minimize the deviation of the target that has been set by taking into account various existing constraints, which are then referred to as objective constraints.

3. Results and discussions

3.1. Optimization of FADs number

In this study, the position of deployment of FADs in the southern waters of East Java was recorded. The result is presented in Figure 1. The Minister of Marine Affairs and Fisheries Regulation Number 26 of 2014 has determined that the distance between the FADs installed is not less than 10 nautical miles and not installed to produce a fence effect (should be installed in a zig-zag manner). The
position of FADs that are installed too close to each other will increase the density of the number of FADs installed, which will result in the number of FADs exceeding the water area capacity, resulting in the decreasing yield and fish size caught by the fishermen, as well as altering the movement patterns of tuna [7, 8]. Therefore, to ensure that FAD installation activities take into account the sustainability of tuna resources, the determination of the ideal number of FADs installed in the waters south of East Java will be based on this principle.

Figure 1. Actual map of the area of deep sea FADs installation in the south of East Java waters [6].

The area of the FAD installation is 219,792 km$^2$ or 21,979,200 hectares [6]. Based on this area, it is known that the ideal number of FADs installed in these waters is 814 units. The criterion used for the proper number of FADs is the distance influenced by the FADs, which is 9.26 km, and the area of the unit per FAD, which is 270 km$^2$ [2]. The presence of FADs installed at sea negatively influences the behaviour of tuna. There is a behavioural tendency for tuna when associated with FADs to become unable to move freely, which causes a decline in genetic quality, producing an ecological trap effect, as the tuna become trapped around the FADs and are unable to migrate freely [9]. Skipjack tuna around the FADs are generally found to have empty stomach contents. It means that skipjack tuna generally forage around the FADs. However, fishing time was also found to be influential on tuna eating habits [10].

Tuna near FADs has the potential to experience suboptimal individual growth. This is because these fish have a smaller chance to get food in nature compared to fish that are not around FADs. The small chance of getting food is due to increase competition for food between individuals [11]. Growth of individuals that are disrupted over the long term will cause growth overfishing, resulting in tuna stock in nature to have a smaller size structure. Growth overfishing can be defined as harvesting fish before they have reached a socially optimal size [12].

3.2. Optimization of tuna fishing
Tuna fish landed at the Fishing Port of Pondokdadap were caught using a hand line operated by a sekoci. The number of hand line fishing units in the fishing port in 2016 was 644 units. The yield
produced by 644 units of hand line was 561.94 tons. The analysis of fish landing data from the fishing port showed that the dominant types of fish caught by handline were tuna, little tuna, skipjack tuna, albacore tuna, and baby tuna. Table 1 shows the production of these five types of fish and the number of fishing units from 2013 to 2016.

Table 1. The production of tuna in the Fishing Port of Pondokdadap from 2013 to 2016.

| Year | Type of Fish       | Production (ton) |
|------|--------------------|------------------|
| 2013 | Yellowfin tuna     | 133.78           |
|      | Little tuna        | 0.92             |
|      | Skipjack tuna      | 11.23            |
|      | Albacore tuna      | 7.88             |
|      | Baby tuna          | 16.09            |
| 2014 | Yellowfin tuna     | 358.31           |
|      | Little tuna        | 15.54            |
|      | Skipjack tuna      | 282.47           |
|      | Albacore tuna      | 142.66           |
|      | Baby tuna          | 21.34            |
| 2015 | Yellowfin tuna     | 41.65            |
|      | Little tuna        | 0.00             |
|      | Skipjack tuna      | 22.66            |
|      | Albacore tuna      | 59.41            |
|      | Baby tuna          | 21.34            |
| 2016 | Yellowfin tuna     | 507.81           |
|      | Little tuna        | 1.84             |
|      | Skipjack tuna      | 36.15            |
|      | Albacore tuna      | 411.00           |
|      | Baby tuna          | 8.92             |

The variable that becomes the object of regulation is the hand line fishing or sekoci. The objective function in this study is to minimize the resources used to carry out fishing activities. Meanwhile, the resource limit used in this study is the average production of tuna landed in the fishing port over the past four years (2013 to 2016), ice and fuel supplies at type C fishing ports, and the number of fishermen of sekoci in the fishing port. The following are the objective functions and limiting functions used in this study:

- Objective function:
  \[ Z \text{ (minimum)} = DA1 + DB1 + DA2 + DB2 + DA3 + DB3 + DA4 + DB4 + DA5 + DA6 + DA7 + DB5 \]

- Limiting function:
  1. Average tuna production over the past four years:
     \[ 0.55X - DA1 + DB1 = 260.39 \text{ (tons/year)} \]
  2. Average little tuna production over the last four years:
     \[ 0.43X - DA2 + DB2 = 4.58 \text{ (tons/year)} \]
  3. Average skipjack tuna production over the past four years:
     \[ 0.31X - DA3 + DB3 = 88.13 \text{ (tons/year)} \]
  4. Average albacore tuna production over the past four years:
     \[ 0.61X - DA4 + DB4 = 155.24 \text{ (tons/year)} \]
  5. Average baby tuna production over the past four years:
     \[ 0.29X - DA5 \leq 29.27 \text{ (tons/year)} \]
  6. Standard distribution of ice for type C fishing ports (based on Decree of the Director General of Capture Fisheries Number 432 of 2008):

2.93X - DA6 ≤ 7,300 (tons/year)
7. Fuel distribution standard for type C fishing ports (based on Decree of the Director General of Capture Fisheries Number 432 of 2008):
   0.45X - DA7 ≤ 3,650 (tons/year)
8. Number of fishermen playing fishing or lifeboats at the Fishing Port of Pondokdadap:
   5X + DB5 ≥ 1,900 (people/year)

The formula in the constraint function is based on the constraints used in allocating resources, whereas, in this study, the constraints used are the average of tuna production, the average of small tuna production, the average of skipjack tuna production, the ice and fuel requirements, and the number of fishermen. The sign used in the constraint function will affect the deviation in the objective function formula. If the sign =, then the deviation is DA and DB; if the sign < the deviation is DA; if the sign > then the deviation is DB. Furthermore, formulas in the objective function are deviations that need to be optimized based on the constraint function.

The results of the LGP analysis show that the ideal number of sekoci units to operate from the Fishing Port of Pondokdadap is 380 units annually. Based on this, it is necessary to reduce 264 units of fishing vessels in the fishing port from the number of units that was present in 2016. The value 380 is the result of minimizing the existing deviations and is based on optimizing the available resources. In this study, the process of minimizing irregularities and optimizing available resources is carried out by executing object functions and constraint functions on the software.

Optimization to get the ideal amount of effort in tuna fishing activities based in the Fishing Port of Pondokdadap is important to ensure the sustainability of fish resources in the Indian Ocean. Indian Ocean is a tuna fishing area for fishermen living around the fishing port. Meanwhile, there is an overexploitation issue due to tuna fishing activities in the Indian Ocean waters. Yellowfin tuna in Indian Ocean has been overexploited, while bigeye tuna and albacore tuna have been fully exploited [13]. The level of effort needed to catch yellowfin tuna in the Indian Ocean waters has reached 111% of its optimal effort (in 2015), while the rate of effort for catching bigeye tuna and albacore tuna are 76% (in 2015) and 85% (in 2014) respectively.

4. Conclusion
The number of FADs that should be installed in the southern waters of East Java is 814 units, while the ideal number of sekoci fishing vessel units to be operating from the Fishing Port of Pondokdadap is 380 units annually.

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