Markov chain model for demersal fish catch analysis in Indonesia

Firdaniza*, N Gusriani

Department of Mathematics, Faculty of Mathematics and Natural Sciences, Padjadjaran University, Jl.Raya Bandung-Sumedang km 21 Jatinangor, 45363 Indonesia. Tel./Fax. +62-22-7794696

*Corresponding author: firdaniza@unpad.ac.id

Abstract. As an archipelagic country, Indonesia has considerable potential fishery resources. One of the fish resources that has high economic value is demersal fish. Demersal fish is a fish with a habitat in the muddy seabed. Demersal fish scattered throughout the Indonesian seas. Demersal fish production in each Indonesia’s Fisheries Management Area (FMA) varies each year. In this paper we have discussed the Markov chain model for demersal fish yield analysis throughout all Indonesia’s Fisheries Management Area. Data of demersal fish catch in every FMA in 2005-2014 was obtained from Directorate of Capture Fisheries. From this data a transition probability matrix is determined by the number of transitions from the catch that lie below the median or above the median. The Markov chain model of demersal fish catch data was an ergodic Markov chain model, so that the limiting probability of the Markov chain model can be determined. The predictive value of demersal fishing yields was obtained by calculating the combination of limiting probability with average catch results below the median and above the median. The results showed that for 2018 and long-term demersal fishing results in most of FMA were below the median value.

1. Introduction

As an archipelagic country, Indonesia has the potential of marine and fishery resources that can improve the Indonesian economy. The Government of Indonesia has been divided the Fisheries Management Area (FMA) into 11 regions. Each FMA has provided fish catches that vary according to geographical location.

One of the fish resources that boost Indonesia's economy is demersal fish. Demersal fish is a fish with a habitat in the muddy seabed. Although demersal fish does not become the target of Indonesian exports, but this fish is very popular with the community because it tastes good and the price is quite affordable. Some types of demersal fish are black pomfret, silver pomfret, halibut, baramundi, red snapper, jack travelie, hairtail, giant cat fish and others. During the period of 2005-2014 demersal fish production was quite varied and contributed an average of 130 thousand tons each year. Most demersal fish were caught in the Java sea and Karimata straits, Natuna sea and South China Sea [1].

The study conducted related to the results of fish catch, namely the prediction of potential areas of pelagic fishing in Mamuju district [5]. To predict a value in the future, various methods can be used, such as the Markov chain or times series. Markov chain method has been used in stock price prediction [2], in predicted fishing results in India [3], predicted dominant fish catch areas in India [6].

[1] [2] [3] [4] [5] [6]
In addition to the study of catch areas, research on the prediction of fish catch is also necessary because it will have an impact on Indonesian exports. In this study the Markov chain method will be used to analyze the demersal fishing results in Indonesia. The objective is to know the predictions of demersal fishing results across Indonesia’s FMA. This is expected to be useful for the government (Marine Affairs and Fisheries) in taking policy for future anticipation if the catch is decreased.

2. Markov Chain Model

The Discrete-time Markov chain is a stochastic process with the nature that the future state depends only on the present state of being free from the past.

**Definition 1.** Let \( \{X(n), n = 0,1,2,\ldots\} \) is a discrete time stochastic process with state space \( i = 0,1,2,\ldots \), if

\[
P\{X(n + 1) = j | X(0) = i_0, X(1) = i_1, \ldots, X(n - 1) = i_{n-1}, X(n) = i\}
= P\{X(n + 1) = j | X(n) = i\} = p_{ij}
\]

For all \( i_0, i_1, \ldots, i_{n-1}, i, j \) and \( n \), then the process is called the discrete-time Markov chain of, and \( p_{ij} \) is called transition probability [4].

**Definition 2.**

The one-step transition probability matrix of a Markov chain is defined as \( P = [p_{ij}] = \begin{bmatrix} p_{00} & p_{01} & p_{02} & \cdots \\ p_{10} & p_{11} & p_{12} & \cdots \\ p_{20} & p_{21} & p_{22} & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix} \)

where \( p_{ij} \geq 0 \) and \( \sum_{j=0}^{\infty} p_{ij} = 1, \ i, j = 0,1,2,\ldots \)

The n-step transition probability can be calculated using the Chapman-Kolmogorov equation. In matrix form can be written as \( P^n = P^r \cdot P^{n-r} \) [4].

2.1. State Classification

For a Markov chain, if there is only one class of communication, the Markov chain is said to be irreducible. This means that all the existing state communicate with each other.

State \( i \) and \( j \) are said to communicate with each other, if there is \( n \geq 0 \) such that \( p^n_{ij} > 0 \) and \( p^n_{ji} > 0 \).

State \( i \) is said recurrent if and only if \( \sum_{n=1}^{\infty} p^n_{ii} = \infty \).

State \( i \) is called periodic with period \( d(i) \), if

\[
d(i) = \text{greatest common divisor} \{n | p^n_{ii} > 0, n \geq 1\}.
\]

If \( d(i) = 1 \), then state \( i \) is called aperiodic.

2.2. Stationary Distribution

A Markov chain is ergodic if irreducible, positive recurrent, and aperiodic. Ergodic's Markov chains have limiting probabilities, \( \lim_{n \to \infty} p^n_{ij} = \pi_j, i, j = 0,1,2,\ldots \) which is free from the initial state \( i \). \( \{\pi_j\} \) is called the stationary distribution (steady state) of the Markov chain [4].

3. Methodology

Demersal fishing results has changed every period and its catching area. Discrete time markov chain can model problems with data that changes with time.

Demersal fishery data obtained from the Directorate of Fisheries Fishing Ministry of Marine Affairs and Fisheries Indonesia, the data is compiled by year and FMA. Assume that the number of Markov chain states were 2, i.e., state 1: the number of catches below the median value, and state 2: the number of catches above the median value. For each FMA it has been done the same steps figure:

a. Determine the state "1" and state "2" of each demersal fish catch data based on the value of the captured median.

b. Calculate the number of transitions from state "1" to state "2" and vice versa.
c. find the transition probability matrix
d. Check if Markov chain is ergodic
e. Determine the stationary distribution of the markov chain

4. Result and Discussion

According to Minister of Marine Affairs and Fisheries Regulation no. PER.18 / Men / 14 and PER.01 / Men / 09 on fisheries management area (FMA), it is mentioned that FMA in Indonesia has been divided into 11 FMA, that is; (1) Malacca Strait and Andaman Sea, (2) Hinda Ocean in West Sumatera and Sunda Strait, (3) Indian Ocean to Southern Java South to Nusa Tenggara, Savu Sea and West Timor Sea, (4) Karimata Strait, Sea (7) Tolo Bay and the Banda Sea, (8) Tomini Bay, Maluku Sea, Halmahera Sea, (5) Seram Sea, and Berau Bay, (9) Sulawesi Sea and North Halmahera Island, (10) Cendrawasih Bay and Pacific Ocean, (11) Aru Gulf, Arafuru Sea, East Timor Sea. The map of Indonesia’s FMA is shown in Figure 1.

![Figure 1. The map of Indonesia’s FMA](image)

Data of demersal fish catch were shown in table 1 below:

Table 1. Production of demersal fish catch at 11 Indonesia’s FMA in 2005-2014 (ton)

| FMA      | 2005  | 2006  | 2007  | 2008  | 2009  | 2010  | 2011  | 2012  | 2013  | 2014  |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| FMA571   | 106440| 107166| 122221| 113179| 113179| 109064| 105279| 139161| 140692| 149551|
| FMA572   | 115057| 116891| 138983| 142455| 154072| 145982| 134324| 167895| 178400| 167446|
| FMA573   | 78383 | 71997 | 63698 | 60373 | 54719 | 65199 | 56753 | 58438 | 60565 |       |
| FMA711   | 155331| 161485| 177191| 206442| 202364| 213977| 203843| 199866| 202706| 222175|
| FMA712   | 261739| 277106| 259945| 304202| 259808| 266271| 266545| 276757| 307715| 314485|
| FMA713   | 129183| 123830| 130337| 145305| 162579| 154833| 162167| 155768| 156477| 164766|
| FMA714   | 46931 | 37227 | 55020 | 40516 | 38818 | 46944 | 44851 | 38037 | 50485 | 72145 |
| FMA715   | 17058 | 22763 | 19799 | 17653 | 15773 | 23571 | 24165 | 26984 | 27540 | 26955 |
| FMA716   | 26014 | 21071 | 28015 | 29233 | 33193 | 36724 | 38236 | 37823 | 45573 | 42474 |
| FMA718   | 210705| 211048| 210449| 179286| 178796| 296883| 246255| 221103| 224974| 194498|

3
Figure 2. Graph of demersal fish catch in 11 FMA 2005-2014

From the data was determined median for each FMA. The median value of each FMA was presented in Table 2.

Table 2. The median value of the demersal fish catch for each FMA

| FMA      | Median   |
|----------|----------|
| FMA571   | 117700   |
| FMA572   | 144218.5 |
| FMA573   | 60469    |
| FMA711   | 202535   |
| FMA712   | 271651   |
| FMA713   | 155300.5 |
| FMA714   | 102388.5 |
| FMA715   | 45891    |
| FMA716   | 23167    |
| FMA717   | 34958.5  |
| FMA718   | 210876.5 |

After calculating the amount of displacement of each state, an transition probability matrix was obtained, $P = [p_{ij}]$ with $p_{ij} = \frac{n_{ij}}{n_i}$, $n_{ij}$ = number of transitions from state $i$ to state $j$, the number of transitions from state $i$.

From the available data we have obtained a transition probability matrix from the Markov chain for each FMA.

FMA571, FMA572, FMA713 : $P = \begin{bmatrix} 0.6 & 0.4 \\ 0.25 & 0.75 \end{bmatrix}$

FMA573, FMA715 : $A = \begin{bmatrix} 0.4 & 0.6 \\ 0.75 & 0.25 \end{bmatrix}$

FMA711, FMA712 : $B = \begin{bmatrix} 0.4 & 0.6 \\ 0.5 & 0.5 \end{bmatrix}$

FMA714 : $C = \begin{bmatrix} 0.6 & 0.4 \\ 0.5 & 0.5 \end{bmatrix}$
From the transition probability matrix it is seen that all states communicate with each other, so the Markov chain is said to be irreducible.

The next step, determine the periodicity of the Markov chain with the transition matrix $P, A, B, C, D,$ and $E$. The same is true for the matrices $A, B, C, D,$ and $E$. From $P, P^2, P^3, P^4$ we obtained $\sum_{n=1}^{\infty} p_{ij}^n = 1$, then state “1” and state “2” were recurrent state. So it was said the Markov chain is aperiodic and recurrent. The same is true for the matrices $A, B, C, D,$ and $E$.

The next step, determine the periodicity of the Markov chain with the transition matrix $P, A, B, C, D,$ and $E$. We obtained $d(0) = gcd\{1,2,3,\ldots\} = 1$, then state "0" was aperiodic.

It could be concluded that the Markov chain was aperiodic. For $n \to \infty$, we get $P^n = [0.3846\ 0.6154].$ Because every state of Markov chain was recurrent and aperiodic, then $p^n_{ij} \to \frac{1}{\mu_j}$. So we get $\mu = [\mu_0, \mu_1] = [2.6\ 1.63]$.

Because $\mu_0 = 2.6 < \infty$ and $\mu_1 = 1.63 < \infty$, then the Markov chain is said to be positive recurrent. Since the Markov chains were irreducible, positively recurrent and aperiodic, it was said to be ergodic Markov chains.

Since the Markov chain was ergodic, then a stationary distribution was $\pi = [0.3846\ 0.6154].$ This means for a Markov chain with a transition probability matrix $P$, the probability of demersal fish quantities above the median value was 0.6154.

In the same way, a steady state distribution for the transition probability matrix $A, B, C, D,$ and $E$ are:

For matrix $A$, $\pi = [0.5556\ 0.4444]$.

For matrix $B$, $\pi = [0.4546\ 0.5454]$.

For matrix $C$, $\pi = [0.5556\ 0.4444]$.

For matrix $D$, $\pi = [0.4096\ 0.5904]$.

For matrix $E$, $\pi = [0.4445\ 0.5555]$.

Long-term predictions of demersal fishing results for each FMA $\gamma = a_0 \pi_0 + a_1 \pi_1$

where $a_0 =$ average catch below median and $a_1 =$ average catch above median.
\( \alpha_3 \) = average catch above median  
\( \pi_0 \) = the probability of catch is below median  
\( \pi_1 \) = the probability of catch is above median

The predictions of demersal fish yields throughout FMA can be seen in the table 3.

| FMA  | Predicted catch results (ton) |
|------|------------------------------|
| 571  | 127783.9                     |
| 572  | 149983.7                     |
| 573  | 61462.66                     |
| 711  | 195929.4                     |
| 712  | 280967.5                     |
| 713  | 151254.1                     |
| 714  | 102240                       |
| 715  | 46295.91                     |
| 716  | 25843                        |
| 717  | 40166                        |
| 718  | 219918.7                     |

5. Conclusion
From the Markov model analysis, it was concluded that the demersal fish catch in some FMA was below the median value. This should be anticipated by the government with various efforts to make demersal fish production is always increasing.

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