Optimization of coral reef conservation based on coral larval dispersion using hamiltonian path (case study: Bunaken National Park)

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Abstract. Bunaken sea is one of the fisheries source for Manado and around it. But unfortunately, some studies have shown that the coral reefs in some parts of Bunaken Sea have been deteriorating. Some of the causes are coral retrieval, illegal fishing using explosive and poison, marine pollution, and sea temperature increase. Deteriorated reef can be recognized through the color becomes white or known as coral bleaching. In order to preserve coral reefs, there are some factors that can be learned. One of the factors is the location of the healthy coral reefs and can produce coral larval to help recovery process of the deteriorated reefs. Based on some research, coral larval dispersion will be modelled using Graph Theory that is objects connectivity, especially the Hamiltonian Path. Reef spots are represented by vertices and dispersion paths are represented by edges. Based on research, the first location that must be conserved is M23 because it gives good impact and has high possibilities to help recovery of the other 16 locations. Research about determine the coral larval dispersion path can be used to help coral reef conservation to minimize the time and budget, also can support the development of marine, fisheries, and tourism.

1. Introduction

Bunaken National Park is measured to have an area about 75,265 ha. There are 5 islands in this national park, those are Naen, Bunaken, Manado Tua, Siladen, and Mantehage Island, also small islands around it [1].

There are three islands adjacent each other, namely Bunaken Island, Manado Tua Island, and Siladen Island. Bunaken National Park geographically include in “Coral Triangle”. It’s because the “coral triangle” connects the Papua, Philippines, and Pacific Ocean. And in this “Coral Triangle” there are thousands of fish species who’s live inside the coral reef.

The diversity of fish and coral reef species inside the Bunaken National Park are the background from Manado City Government to make this area as Marine Tourism area and as National Park by the Central Government. Bunaken Sea is one of the fisheries source for Manado and around it. But unfortunately, some studies have shown that the coral reefs in some parts of Bunaken Sea have been deteriorating [2].
Some of the causes are coral retrieval, illegal fishing using explosive and poison, marine pollution, and sea temperature increase. Deteriorated coral reef can be recognized through the color. The color of the deteriorated coral reef becomes white or known as coral bleaching.

In order to preserve coral reefs, there are some factors that can be learned. One of the factors is the location of the healthy coral reefs and can produce coral larval to help recovery process of the deteriorated reefs [3]. The return of a coral reef ecosystem to a functional state after mass bleaching mortality will depend on successful reproduction and recolonization by remaining corals and by corals from outside the ecosystem [4]. This research is centered on coral larval dispersion from each healthy reefs spot and see if its path reach the deteriorated reef. If coral larval can reach the deteriorated reef, then there are possibilities that they can help the recovery of the declined reefs.

Based on some research [5] and [6], formed a theoretical foundation that benthic marine organism affected by the ocean currents and larval.

Based on some research [7] and [8], coral larval dispersion will be modeled using Graph Theory that is Hamiltonian Path. In Graph Theory, especially the objects connectivity. Reef spots are represented by vertices and dispersion paths are represented by edges.

There are 17 sustainable development goals, and one of it is life below water. So, this research can help the development on marine sciences, fisheries, and tourism.

Based on the background explained above, the problem to be solved is how to optimize the model of coral reef conservation based on coral larval dispersion?

This study aims to optimize the conservation of the coral reef based on coral larval dispersion using the Hamiltonian Path. The result of study is to help coral reef conservation policies to minimize the time and budget for the government in Indonesia, especially Sulawesi Utara.

2. Graph Theory

Definition 2.1 : A graph \( G = (V, E) \) consists of \( V \), a nonempty set of vertices (or nodes) and \( E \), a set of edges. Each edge has either one or two vertices associated with it, called its endpoints. And edge is said to connect its endpoints [9].

2.1. Connectivity

A walk in a graph is a sequence (not necessarily distinct) vertices \( v_1, v_2, ..., v_k \) such that \( v_i v_{i+1} \in E \) for \( i = 1, 2, ..., k - 1 \). Such a walk is sometimes called a \( v_1 - v_k \) walk, and \( v_1 \) and \( v_k \) are the end vertices of the walk. If the vertices in a walk are distinct, then the walk is called a path [10].

2.2. Hamiltonian Path

Definition 2.2 : A simple path in a graph \( G \) that passes through every vertex exactly once is called a Hamilton path. That is, the simple path \( x_0, x_1, ..., x_{n-1}, x_n \) in the graph \( G = (V, E) \) is a Hamilton path if \( V = \{x_0, x_1, ..., x_{n-1}, x_n\} \) and \( x_i \neq x_j \) for \( 0 \leq i \leq j \leq n \) [9].

3. Research Methodology

Data used in this paper are secondary data obtained from [11] and [12]. Method used in this paper is literature review and the sources used are obtained from books, journals, and articles from the internet. And the steps are:
1. Collect the data,
2. Determine the location of coral reefs and coral dispersal paths,
3. Determine the vertices as the location of coral reefs and the edges as the coral dispersal paths,
4. Make the Hamiltonian Path from the vertices and edges which has been determined,
5. Determine the most optimal location (vertex) from the Hamiltonian Path.
4. Result and Discussions

4.1. Dispersion Model using Hamiltonian Path

Based on ocean current data from Badan Informasi Geospasial (BIG) [11] and coral reefs data from Reef Base [12], a graph which represents reefs locations as vertices and coral larval dispersal paths as edges can be constructed. Each square on the map (Figure 1) is represented as a vertex so there are 49 vertices formed in the graph.

**Figure 1. Vertices based on map**

Coral reefs locations which were represented as vertices are reefs in three islands: Manado Tua, Bunaken, and Siladen. As can be seen in Figure 1, all the coral reefs in Manado Tua have been in high threat. In Bunaken, almost all its reefs have been in very high threat. While in Siladen, all its reefs have been in very high threat.

**Figure 2. Graph from location of coral reefs**

- Source
- Sink
- Isolated Vertex

15 hamiltonian paths plotted are:
1. M8 → M3 → M4 → M1 → M2
2. M8 → M3 → M4 → M5 → M6 → M7
3. M9 → M10
4. M13 → M12
5. M17 → M18 → M19 → M20 → M21 → M22 → B5
6. M17 → M18 → M19 → M20 → M16 → B1 → B2 → B3 → S3 → S1 → S2
7. M23 → M20 → M16 → B1 → B2 → B3 → S3 → S1 → S2
8. $M_{23} \rightarrow M_{20} \rightarrow M_{15} \rightarrow B_1 \rightarrow B_2 \rightarrow B_3 \rightarrow S_3 \rightarrow S_4 \rightarrow S_5$
9. $M_{23} \rightarrow M_{20} \rightarrow M_{21} \rightarrow M_{22} \rightarrow B_5$
10. $M_{23} \rightarrow B_9 \rightarrow B_6 \rightarrow B_7$
11. $B_4 \rightarrow B_6$
12. $B_8 \rightarrow S_9 \rightarrow S_8$
13. $B_{14} \rightarrow B_{15}$
14. $B_{16} \rightarrow B_{17}$
15. $S_7 \rightarrow S_8$

From the graph formed on Figure 2, out of the 49 vertices, 10 vertices were chosen as sources, i.e. spots for the first act for conservation locations. Reefs restoration might be done in these 10 sources as initial acts in order to provide healthy reefs in these locations. Once the reefs in these locations restored, they can produce healthy larval and release them to ocean currents. The larval released will then use the ocean currents as transportation and reach other reefs in their paths. When they reach the damaged reefs, they will help restore the reefs in sexual reproduction. The reefs in the larval paths that absorb larval were then set as Sinks. From Figure 2, it can be seen that there are 33 sinks indicated in the graph modeled.

From the graph modeled with 10 sources, i.e. $M_8, M_9, M_{13}, M_{17}, M_{23}, B_4, B_8, B_{14}, B_{16}$ and $S_7$, 15 hamiltonian path can be plotted. The paths are 15 dispersal paths of the larval that were assumed can help the restoration process of the 33 sinks, i.e. $M_1, M_2, M_3, M_4, M_5, M_6, M_7, M_{10}, M_{12}, M_{16}, M_{18}, M_{19}, M_{20}, M_{21}, M_{22}, B_1, B_2, B_3, B_5, B_6, B_7, B_9, B_{15}, B_{17}, S_1, S_2, S_3, S_4, S_5, S_6, S_8$, and $S_9$.

4.2. Deteriorated Coral Reef Recovery Analysis

It can be assumed that by putting the 10 sources in beginning acts of conservation, the 33 sinks can be restored too. Thus, the number of reefs that can be cured will be 42 locations.

There are some spots in which although the reefs have been restored would not significantly affect other locations because there is a small possibilities that the ocean currents will connect them directly. Reefs spots which are not affected or affect other spots were then identified as Isolated Vertices. These isolated vertices are $M_{14}, M_{15}, M_{11}, B_{10}, B_{11}, B_{13}$, and $B_{12}$. Thus, these 7 locations have to be preserved one by one distinctly.

In order to optimize conservation time and budget, spot that has to be conserved first is $M_{23}$. This will affect 16 other locations in the same path. The second spot that has to be preserved is $M_{17}$ because this will affect other 15 locations in the same path. The next one is $M_8$ since it will affect 7 other locations. Consequently, $B_8$ has to be preserved for it affects 2 other locations. Whereas, locations that affect to 1 location only are $M_9, M_{13}, B_4, B_{14}, B_{16}$, and $S_7$. Eventually, the last spots to be conserved are the isolated vertices for they do not significantly influence restoration process in other locations.

5. Conclusion

Based on analysis result and literature review we can conclude that the first location that must be conserved is $M_{23}$ because it gives good impact and has high possibilities to help recovery of the other 16 locations.

6. Recommendation

Recommendation in this paper is we need more research and further development about locations of the coral reef, species of coral reef, sea current based on season, and coral health level. When doing conservation, we need cooperation between university, government especially Ministry of Tourism, Ministry of Maritime Affairs and Fisheries, and investors. I hope this paper can support the development of marine, fisheries, and tourism. Research about determine the coral larval dispersion path can be used to help coral reef conservation to minimize the time and budget.
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