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Dynamic model of fisheries management system and maritime highway program in Makassar Strait

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Abstract. This research motivated by the existence of a sea highway (*Tol Laut*) program in the Makassar Strait that will build a number of ports. Port development must be supported by the fisheries management system that can utilize fish resources maximally and sustainably. Otherwise, it will fail and harm the country. The research aimed to create and simulate dynamic models of fisheries systems supported by the maritime highway program in the Makassar Strait. Data collection on environmental parameters, nutrients, phytoplankton and zooplankton abundance, catches, and gastric contents analysis has been conducted. The dynamic models that are built consist of 4 sub-models, namely: (1) Plankton Productivity sub-model; (2) Pelagic Fisheries sub-model; (3) Demersal Fisheries sub-model and (4) Economy and Maritime Highway sub-model. The simulated scenario is different capture quota in planktivores, omnivore, carnivore, and demersal fishes. The result of simulation by using a dynamic model revealed that there are differences in fish population dynamics based on the catch rate and the provision of port facilities. The development of the Maritim highway program that synergizes with the determination of catching quotas can increase the revenue of around 5 to 28 billion rupiahs per month per district during 120 months in 11 districts/cities on the coast of Makassar Strait.

1. Introduction

The fisheries sector is one of the main focuses in accelerating Indonesia's economic development in the Sulawesi Corridor. The strategic position of the Makassar Strait as one of the regional regions that have fisheries resources needs careful planning so that the development program synergizes in achieving targets. Moreover, the existence of a maritime highway program with a high-cost port development plan can be detrimental to the country if it is not supported by fish resources that can be utilized sustainably. Poor planning will cause a failure [1] in the program because it is based on two main reasons: (1) multispecies multi-gear fish resources are very dynamic because they are influenced by multi factors [2], therefore requiring studies that are careful and accurate for estimating dynamics for the long run [3]; (2) Infrastructure such as ports and roads that are permanent are built to support the maritime highway program because if the placement is wrong, it will cause inefficiency or a waste of state finances. For this reason, studies are needed that are able to estimate the dynamics of resources at various catch rates for a long time. If fishes resources can not be utilized sustainably, the maritime highway program will also fail. Therefore, research to support accurate planning is needed at this time.

Research on fisheries management systems that are integrated with the Maritim highway program in the Makassar Strait has never been conducted. Partial research on the theme of capturing species [4] and certain fishing gears [5-8] has been carried out. Although there have been many studies conducted before, the fact is that the management of fisheries resources is still failing due to overfishing in water in Indonesia. Research that leads to sustainable management models using various approaches such as bio-economy [9], ecosystems [10], has also been proven to have not provided significant improvements. For this reason, a new innovation needs to be made in changing approaches and paradigms in capture fisheries management.

There is a gap from previous research because the approach and analysis use a static approach, while fish resources undergo rapid population changes and dynamics. This makes it difficult to make accurate predictions in the long run. The use of dynamic models in several countries in the management of fish resource management has been shown to provide better and profitable results [11-13]. Previous research that used a dynamic model approach was still limited to the pelagic fisheries system and only in one district in the Makassar Strait, Barru District [14]. This research develops with a wider scope of area in all Regencies in the Makassar Strait in South Sulawesi Province and includes demersal fisheries.

Trophic level approach and the use of dynamic models in this study will complement previous studies and reduce the weaknesses of static analysis with the application of dynamic systems so that a better output can be obtained and able to overcome problems in maximum and sustainable exploitation of fish resources. This research can refine and develop prior knowledge by producing new methods that are more comprehensive in nature and more accurate estimates because it uses a dynamic system. This new knowledge can overcome weaknesses in static systems that were widely used before. The current research aims to create a dynamic model of a sustainable fisheries management system through accurate fisheries system planning to support the sea highway program in the Makassar Strait.

2. Research method

2.1. Data collection and analysis

This research has been conducted from May 2018 to October 2019. Data collection on environmental parameters was executed in the coastal waters of Pinrang, Barru, and Bantaeng Districts, while collecting data of catch and observation of gastrict contents have done at 5 fishing centers in each district (11 districts or cities) where borders the Makassar Strait in South Sulawesi Province.

The method for analyzing was used analysis of variance (ANOVA) to compare environmental parameters, nutrients, and abundance of plankton between the three districts observed [15]. The relationship between the abundance of plankton with environmental parameters was analyzed by using multiple linear regression analysis. The determination of the trophic level is based on the analysis of gastric contents using the TrophLab 2K program refer to the preview study [16]. Catch rate calculated from catch and gear data. Overall data and analysis results are synthesized for using dynamic model equations

2.2. Model concept and building

The first step in model building is the conceptual formulation. Formulation of a dynamic model concept referred to by several authors. The basic concept of this dynamic model is based on the basic theory of energy transfer through the food chain that affects fish biomass at each trophic level [17-19]. The amount of energy that reaches each trophic level is greatly influenced by the support of biomass in the trophic below. Plankton, as the primary producer, has an important role in providing food biomass for fish at a higher level. Primary production biomass produced by phytoplankton determines the amount of fish production in an area of water. Because plankton abundance is influenced by environmental conditions, especially nutrients and dynamics, so the environmental parameters also ultimately affect fish production [20]. Plankton's primary production has certain limitations and carrying capacity so that it has a certain carrying capacity in producing fishes biomass.

If overfishing is done on low-level trophic fish, it will break the food chain and cause degradation of fish populations in higher trophic due to lack of food resources [21,22]. This will disrupt the preservation of fish resources and is economically unprofitable because usually, fish at low trophic levels such as planktivores fish have a much lower economic value compared to carnivorous fishes at higher trophic. Building and simulating of dynamic models is done by using Stella 5.0 software and refer to the method that has been implemented [14].

2.3. Model scenario and simulation

In accordance with the objectives of this research, this dynamic model will be conducted by selecting several alternative scenarios related to the purpose of determining the catch rate that enables the sustainable use of fishes resources. Scenarios to be simulated include:

1. The catch rate differs from pelagic fish in one or several species of fish (according to trophic levels) at 25%, 50%, and 100% of the current catch rate. This percentage of catch rate is adjusted according to the length of time of capture.
2. The demersal fishes catch rate are 50-60%, 61-70%, and 71-80%.
3. Application of restocking with a proportion of 1.0-3.0%. 3.1-5.0% and 5.1-7.0% of the demersal fish population.
4. Maritim highway program development scenarios in the existing condition (1), 2 collecting ports on Barru and Bantaeng (2), and 4 collecting ports on Bulukumba, Bantaeng, Barru, and Pinrang (3).

All of these scenarios will be simulated in 10 years (120 months) with intervals or time steps every month.

3. Result

3.1. Model design and structure

The design and structure of the dynamic model were built using Stella 5.0 software consisting of 4 sub-models, namely: (1) Plankton Productivity sub-model; (2) Pelagic Fisheries sub-model; (3) Demersal Fisheries sub-model and (4) Economy and Maritim Highway Program sub-models. The Plankton Productivity sub-model includes phytoplankton and zooplankton, which are influenced by environmental and predation parameters. This sub-model clarifies the dynamics of phytoplankton and zooplankton abundance. The effect of growth and predation greatly determines the increase and reduction in plankton abundance.

The Pelagic Fisheries sub-model includes all components of pelagic fish at all trophic level levels that is consisted of planktivorous fish, omnivore fish, carnivore fish, including higher carnivore fish. Planktivor fish consumes plankton production to growth, and omnivore fish consumes plankton and planktivor fish while carnivore fish consumes both planktivor and omnivore fish. Each compartment (stock) of fish is influenced by growth inflow, and fish enter as a factor that increases the population while natural death, capture, and predation by trophic fish on it is an outflow that causes a decrease in fish population biomass.

The Demersal Fisheries sub-model covers the overall demersal fish population that is affected by growth and recruitment (inflow) while catching, and natural death (outflow) affects the biomass decline in demersal fish populations. The amount of capture quota affects every stock of both pelagic and demersal fish. The Economic and Maritime Highway sub-model is a simple sub-model that includes changes in income calculated from the revenue from the sale of caught fish and expenses for operational costs, including taxes. The design and structure dynamic model is shown in Figure 1.

3.2. Dinamic model simulation

After the dynamic model has been simulated, it is found that the population of phytoplankton and zooplankton occurred fluctuations forming monthly oscillations with repeated periods of each year (Figure 2). The results of the model simulation in the pelagic catch rate scenario (planktivorous, omnivorous and carnivorous) as existing conditions (100%) that changes in the population of planktivorous and omnivorous fish as shown in Figure 3a. With the current catch rate, if left unchecked, there will be significant population degradation and collapse after 30 months. If the catch rate is reduced to half (50%) of the current catch rate at all trophic levels, the population decline is not as fast as in the catch rate scenario 100% (Figure 3b). Furthermore, if the pelagic fishes catch rate is reduced to 25% of the current catch rate, it is seen that there is an increase in the population of all fishes species over time (Figure 3c).

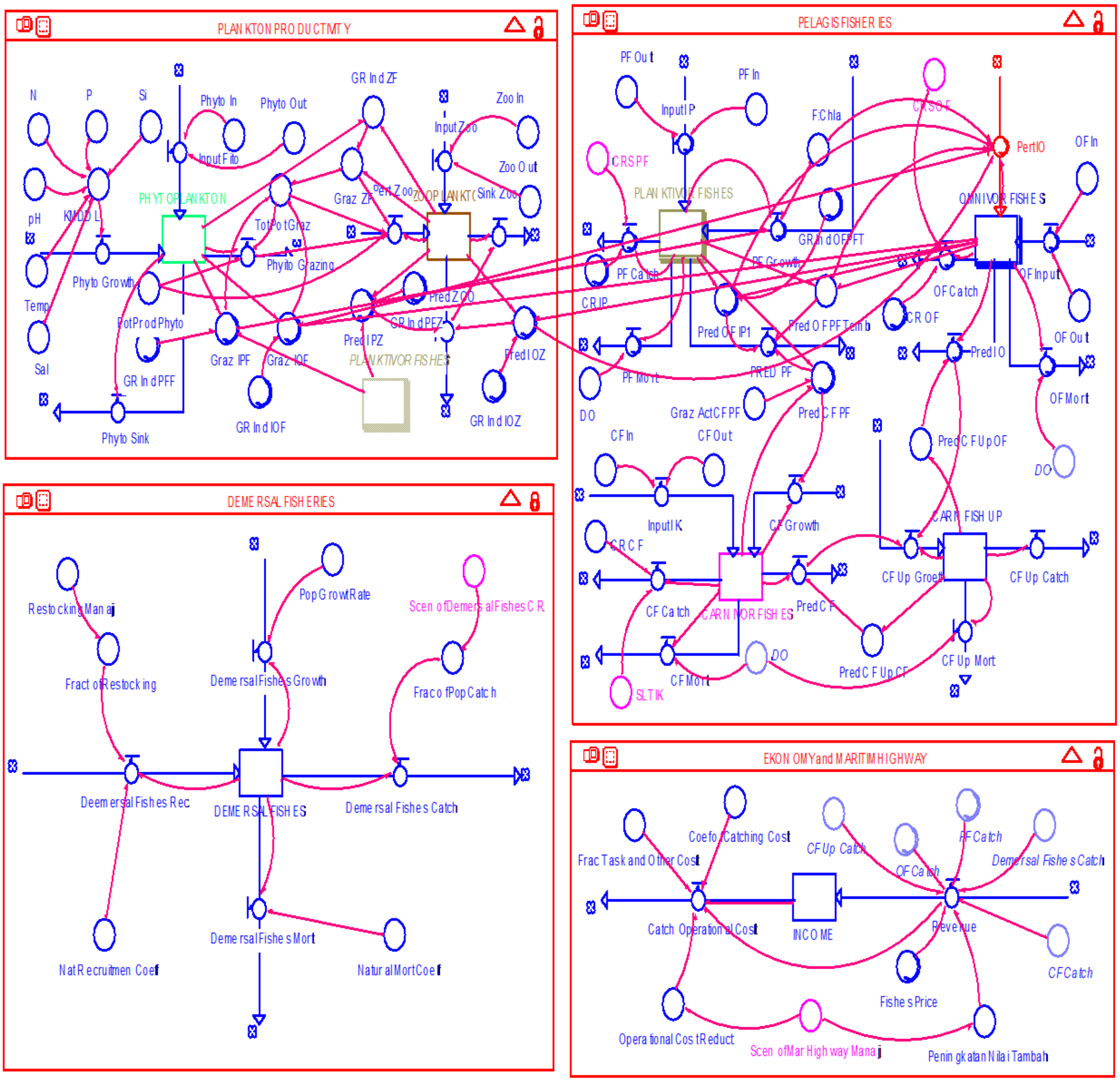


Figure 1. Integrated dynamic model diagram (biology-ecology and economics) based on trophic level.

Demersal fishes population in the catch rate scenario 0.71 to 0.80 (pessimis scenario) or according to the current catch rate combined with very low restocking policy scenarios shows a decrease in demersal fishes population over time. The same thing happens when the capture rate scenario of 0.61 to 0.70 (moderate scenario), which is dominated by a restocking policy, is also still experiencing a decline but not as fast as in the previous scenario. When the catch rate scenario of 0.5 to 0.6 is combined with a maximum restocking policy, the pelagic fishes population increases until the end of the simulation time (Figure 4 a, b, and c). The results of the simulation in the pessimis scenario (planktivor fish, omnivore fish, and carnivore fish were caught the same as the current catch rate, demersal fish caught between 0.7 to 0.8 and no additional ports), so the accumulation of net income for 120 months reached Rp 238,003,697,041. When simulating moderate scenarios conducted (planktivor fish, omnivore fish, and carnivore fish are caught half or 0.5 of the current catch rate, demersal fish are caught between 0.6 to 0.7 and an additional 2 unit ports in Barru and Bantaeng) the accumulated net income for 120 months reaches Rp. 7,081,897,493,536. The simulation results in the pessimistic scenario (planktivorous fishes caught 0.25 from the current catch rate, omnivorous fishes caught at the current rate, omnivorous fishes caught at a rate of 2 times the current rate, demersal fishes caught between 0.5 to 0.6 and no additional ports 4 units of sea namely Bulukumba, Bantaeng, Barru, and Pinrang) an accumulated net income of Rp. 30,418,843,459,685. The accumulated net income (after deducting expenses) each year in 3 simulated scenarios is summarized in Table 1.

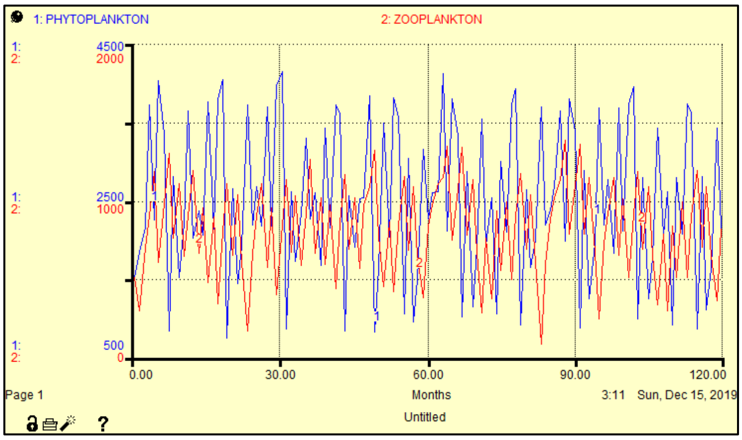
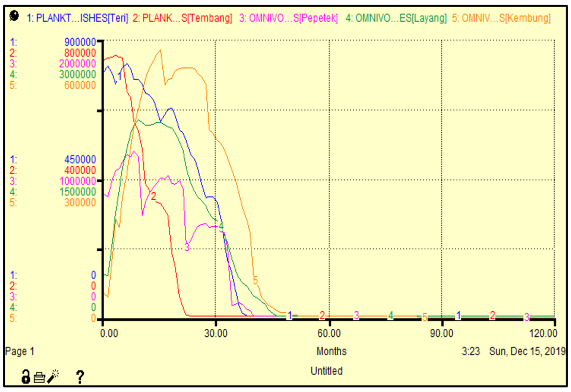
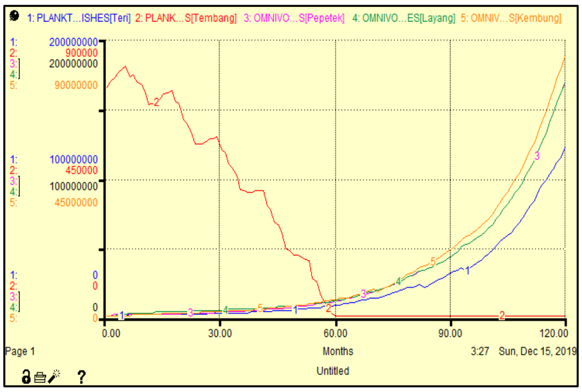


Figure 2. Changes of phytoplankton and zooplankton abundance over 120 months based on model simulation results.



a



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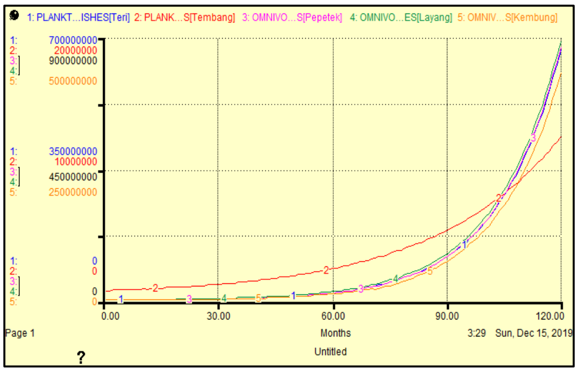
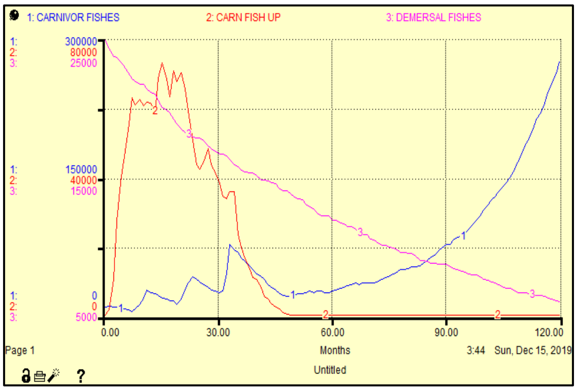
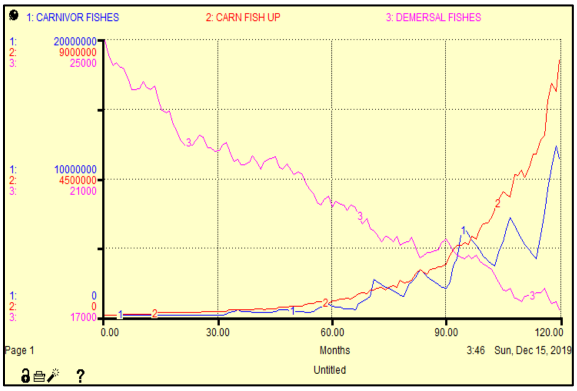


c

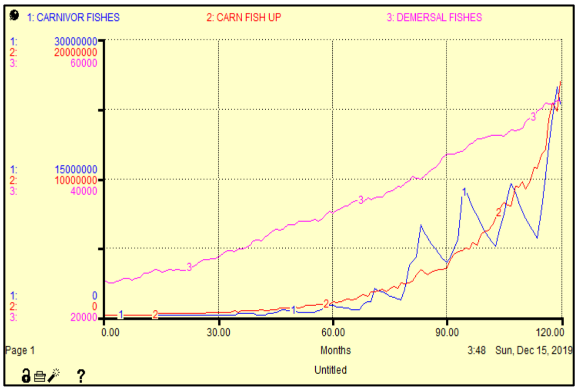
Figure 3. Changes in biomass populations of planktivorous and omnivorous fishes for 120 months based on the results of models simulation in the scenario of pelagic fish catch rates of 100% (a), 50% (b), and 25% (c).



a



b



c

Figure 4. Changes in biomass population of carnivorous fish, higher carnivorous fish, and demersal fish for 120 months based on model simulation results in the pelagic catch rate scenario 100% (a), 50% (b) and 25% (c).

Table 1. Accumulated income (Billion Rupiah) every year based on the results of dynamic model simulation on 3 scenarios (pessimistic, moderate, and optimistic).

Year	Pessimistic Scenario	Moderate Scenario	Optimistic Scenario
1	73.971	62.397	87.631
2	153.891	157.108	220.697
3	214.833	277.316	413.811
4	230.474	442.496	735.189
5	232.144	669.796	1272.650
6	233.608	1026.449	2273.872
7	234.821	1646.044	4203.109
8	236.015	2694.427	8085.262
9	237.073	4271.937	15406.302
10	238.004	7081.897	30418.843

4. Discussion

Oscillation pattern of phytoplankton and zooplankton in Figure 1 due to the influence of environmental factors, especially nutrients and the process of zooplankton predation on phytoplankton [23-24]. When nutrients are high, and light is sufficient as occur at the upwelling area, the phytoplankton population increases [25]. The next moment was followed by an increase in zooplankton population due to increased food availability in the form of phytoplankton. With the increasing zooplankton population, intensive predation occurs. Consequently, the population of phytoplankton as prey has decreased. Furthermore, this process repeats throughout the year. Plankton (Phyto and zoo) abundance obtained was slightly lower compared to the results of the preview study [26] that research in the coastal area at Makassar Strait. Decreasing of fishes biomass in the pelagic system that shows in Figure 2 is due to catching more or overfishing [27, mainly in planktivorous fishes, which is a support for omnivorous and carnivorous fishes populations. Several previous studies were found that the dynamics of pelagic fish populations are influenced by plankton and interactions between trophic in the ecosystem [28-29].

Fishes' population reduction rate became slower if the catch rate reduced to half of the current catch rate at all trophic levels (Figure 3b). Lower catch rate causes recruitment gives an opportunity to increase the population for the next period [30]. Profil of biomass curve fishes population seems to have a different shave if the catch rate of pegaic fisher reduced again to the lower level (25%), as presented in figure 3c. This is likely caused by the very low reduction in fishes population from fishing. This result shows that the influence of fishing more significantly rather than recruitment. This is different from the result found that the influence of recruitment more significantly to fishes population rather than other factors [31]. The curve pattern of carnivorous fishes tends to follow planktivorous and omnivorous fishes because carnivorous fishes are very dependent on the population of planktivorous and omnivorous fishes as its food. Changes in pelagic fish populations also affect the dynamics of demersal fish populations. Some previous studies state that almost the same thing is found in some areas. The difference in fishes population changes in each scenario has implications for the amount of income derived from the sale of fishes. Early overfishing causes a decrease in population so that in the long run, it is unprofitable, and fish populations are not utilized sustainably. Therefore, the management of the fisheries system is needed so that the resources can be used maximally and sustainably. Some previous studies have found and recommend the same thing [32-33].

The difference in simulated scenarios has implications for income differences as a result of changes in population and the amount captured in each trophic level of fishes. The difference in income as a simultaneous effect of the capture quota regulation scenario at each trophic level and the development of the sea highway causes a significant difference in revenue accumulation. Based on the simulation results as in table 1, it can be said that the simultaneous influence of the capture regulation (capture quota) and the development of a 2 unit port (moderate scenario) in the Makassar Strait could increase more than 6.84 trillion rupiahs or around 57.03 billion rupiahs per month if compared to letting catch rates like this one and no sea highway development (pessimis scenario). With the same calculation, when an optimistic scenario is implemented (capture quota and sea toll development), it can increase revenue accumulation of 30.18 trillion rupiahs or around 251.51 billion rupiahs per month when compared to letting catch rates like this one and no maritime highway program development (pessimis scenario). If divided equally among 11 districts, the moderate scenario increases around 5.18 billion rupiahs per month per district from the pessimis scenario, while the optimistic scenario can increase by 22.86 billion rupiahs per month per district from the pessimis scenario.

5. Conclusion

There are dynamics of environmental parameters that affect plankton productivity and fish growth in the sea. Different catch rates for fish at different trophic levels affect population dynamics and the sustainability of fish resources in the Makassar Strait. Planktivor fish play an important role in the fish food chain in the pelagic system. If the population of planktivor fish is caught too much, the population of omnivore and carnivore will decrease. The maximum and sustainable income will be obtained if the catch rate of planktivor fish is 0.25 times the current catch rate and double the catch in carnivorous fish. The development of a marine highway that synergizes with the establishment of capture quota can increase the revenue of around 5 to 28 billion rupiahs per month per district during 120 months.

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