Contrasting reef fish diversity and abundance in the Derawan Islands: A multi-temporal observations

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Abstract. Derawan Island, East Kalimantan Province, is located in the coral triangle, the center of mega biodiversity of the world's marine life, including reef fish. In this study, reef fish data were collected from 1994, 2003, and 2019 at six islands (Panjang, Derawan, Samama, Sangalaki, Kakaban, and Maratua) in Derawan Islands using the Underwater Visual Census (UVC) technique. The analysis results focused on herbivores, carnivores, and corallivores reef fish show that the total species diversity and abundance in 1994, 2003, and 2019 amounted to 116 species (5,268 fish/ha), 93 species (2,664 fish/ha), and 104 species (5,332 fish/ha), respectively. Those reef fishes decreased from 1994 to 2003 due to overexploitation but increased again in 2019, especially Acanthurid, Scarid, and Lutjanid fish taxa, possibly due to local government conservation regulations. Biodiversity and abundance were found higher in the Kakaban and Maratua Islands for herbivorous fish (>25 species, >3,500 fish/ha) followed by carnivores and corallivores (±20 species, ±2,000 fish/ha) than in other islands. The diversity of corallivores, herbivores, and carnivores was moderately correlated with live coral cover with R2 of 0.78, 0.77, and 0.61, respectively, but low for fish abundance. Long-term reef fish monitoring is necessary to know coral reef health in this area.

1 Introduction

Derawan Islands, located in the Berau District, East Kalimantan Province, has a lot of uniqueness. It lies on the western side of Makassar Strait and is strongly influenced by the Indonesian Throughflow (ITF), the major tropical oceanic exchange current between the Pacific and Indian Oceans, which has high water productivity due to the occurrence of the periodic deep-sea upwellings [1]. Meanwhile, the seas of the Derawan Islands are also influenced by major river outflows from the Berau River and tributaries. The strong

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nearshore-offshore oceanographic gradient makes the Derawan Islands a diverse and dynamic environment with river deltas, mangroves, seagrass beds, shelf and oceanic coral reefs, AND pelagic waters [1].

Situated inside the coral triangle areas, Derawan Islands is rich in species diversity of hermatypic corals, including reef fishes of 444 and 872 species, respectively. There are about eight species of seagrasses with two species of sea turtles, the green turtles (Chelonia mydas) and hawksbill (Eretmochelys imbricata), that nest and forage around the Derawan Islands as well as nine species of cetaceans [1]. In addition, a famous saltwater lake on Kakaban Island is inhabited by four species of unique endemic jellyfish [2].

However, although the Derawan Islands are rich in marine flora and faunas, this region faces many threats due to unfriendly exploitation of marine resources such as the use of explosives, potassium cyanide, and other destructive gears, overexploitation, severe sedimentation in the water caused by mining and logging activities, mangrove conversions for making aquaculture ponds [2]. Furthermore, the available data and information about the marine resources in this region are scarce, for example, fish resources, mainly reef fish. Thus, it isn't easy to manage those resources sustainably without data.

This study aims to reveal the marine resources of the Derawan Islands by focusing on the diversity and abundance dynamics of coral fish with emphasis on three groups of coral fish: the herbivorous fish (Families Acanthuridae, Scaridae, and Siganidae), Carnivores (Haemulidae, Lethrinidae, Lutjanidae, and Serranidae (carnivores), and corallivores (Chaetodontidae). Those reef fish groups are usually used as coral reef health indicators through long-term monitoring.

2 Materials and methods

2.1 Study sites and times

This study was conducted in Derawan Islands, Berau District, East Kalimantan Province (white shade areas in Figure 1). There were 11 observation stations: stations 1 and 2 (Maratua Is), Stations 3 and 4 (Derawan Is), Stations 5 and 6 (Kakaban Is), Stations 7 and 8 (Panjang Is), Station 9 (Sangalaki Is) and Stations 10 and 11 (Samama Is) (Table 1; Figure 1).

In this study, we used firstly the observation data collected during the Derawan Islands expedition conducted in 1994 using the Research Vessel (R/V) of Soerja Atmadja belonging to the Agency of Research and Development Center for Marine Resources Ambon, Indonesian Institute of Sciences (LIPI). Secondly, the data from the cruise of R/V Baruna Jaya VII in 2003, and the third was during the implementation of the COREMAP CTI project in 2019.

2.2 Work procedures

2.2.1 Reef fish data collection

The reef fish data collection method used in this study is the Underwater Visual Census Method (UVC) developed by the Asean-Australia Project [3,4]. The equipment used is diving equipment (SCUBA), underwater stationery, and a roll meter ruler. A 70 m long transect line was placed parallel to the beach or shoreline, then reef fish was censused along the transect line with observations at a distance of 2.5 m to the left and 2.5 m to the right from the transect line so that the total area observed in each UVC is 70 m x (2.5m + 2.5m) = 350 m² (Figure 2). Observations were made at depths between 5 - 7 meters.
The collected reef fish data by UVC in 1994 and 2003 were divided into three groups [4]: (i). The Indicator group is the reef fish belonging to only one Family (Chaetodontidae, the butterfly fish) that is used to indicate the health of coral reefs since they are strongly associated with a good condition of live corals; (ii). The Target group is the consumable and economically valued fish, so they are the most exploited by the fishers; (iii). The Major group is the fish that do not belong to those two groups above. Generally, they have small sizes and beautiful colors, so they are well-known as ornamental or aquarium fish [4]. This method has become a standard operating procedure (SOP) for monitoring reef fishes in the Great Barrier Reef, Australia [5], which is then well used in many other tropical countries [6]. During the UVC transect, some identification books are used as references [7-11].

However, since the COREMAP CTI programs changed in 2015, the previous three reef fish classification systems were replaced again into three groups: (1) Corallivores, the group fish that are still the same as the indicator fish; (2) Carnivores fish; the fish that are the same with target fish, but limited only to four families of Haemulidae, Lethrinidae, Lutjanidae, and Serranidae, and Herbivores that restricted to three families of Acanthuridae, Scaridae, and Siganidae. Therefore, reef fish data in 1994, 2003, and 2019 were analyzed using the classification based on the protocol of COREMAP CTI.

![Fig. 1. Map of Derawan Islands (East Kalimantan Province) showing the UVC stations denoted by numbers (DERC01 to DERC11).](image1.png)

![Fig. 2. Illustration of UVC method for collecting reef fish's biodiversity, abundance, and stock assessment.](image2.png)
Table 1. Coordinates of the UVC in each station.

<table>
<thead>
<tr>
<th>Stations No.</th>
<th>Locations</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>DERC 01</td>
<td>Northeast of Maratua Is.</td>
<td>2.28006</td>
<td>118.60307</td>
</tr>
<tr>
<td>DERC 02</td>
<td>West of Maratua Is.</td>
<td>2.21624</td>
<td>118.57993</td>
</tr>
<tr>
<td>DERC 03</td>
<td>West of Derawan Is.</td>
<td>2.29277</td>
<td>118.23479</td>
</tr>
<tr>
<td>DERC 04</td>
<td>Northeast of Derawan Is.</td>
<td>2.29150</td>
<td>118.26238</td>
</tr>
<tr>
<td>DERC 05</td>
<td>Northeast of Kakaban Is.</td>
<td>2.15264</td>
<td>118.54030</td>
</tr>
<tr>
<td>DERC 06</td>
<td>Southwest of Kakaban Is.</td>
<td>2.13927</td>
<td>118.52253</td>
</tr>
<tr>
<td>DERC 07</td>
<td>West of Panjang Is.</td>
<td>2.35846</td>
<td>118.18907</td>
</tr>
<tr>
<td>DERC 08</td>
<td>Wast of Panjang Is.</td>
<td>2.36914</td>
<td>118.21959</td>
</tr>
<tr>
<td>DERC 09</td>
<td>West of Sangalaki Is.</td>
<td>2.08313</td>
<td>118.39446</td>
</tr>
<tr>
<td>DERC 10</td>
<td>West of Samama Is</td>
<td>2.12893</td>
<td>118.32226</td>
</tr>
<tr>
<td>DERC 11</td>
<td>East of Samama Is</td>
<td>2.13890</td>
<td>118.33705</td>
</tr>
</tbody>
</table>

2.2.2 Reef fish stock assessment

Two steps have to be taken in assessing the reef fish stock. The first step is to make the shallow bathymetric map in the range of 0-25 m, which assumes that this depth range is the habitat of the reef fishes, so they exist and are distributed at those depths. The shallow waters of Derawan Islands were mapped utilizing data from the general bathymetric chart of the oceans (GEBCO) provided by the British Oceanographic Data Center (BODC). The resolution of these data is 30 arc-second grids (926 m × 926 m) [12]. The second step is to classify the shallow bathymetric and calculate each area (A) according to their depth ranges of 2-5 m, 5-10 m, 10-15 m, 15-20 m, 20-25 m, and > 25 m, respectively. Waters with a depth of <2 m is excluded from further calculations. Those are influenced by the tidal. The consumed reef fish density (D) with economic values for both carnivores and herbivores fish data was obtained from the UVC method (Figure 2).

Thus, the standing stocks (S) of carnivores and herbivores reef fish were assessed using the equation:

$$S = A \times D$$  \hspace{1cm} (1)

S = Standing stock of reef fishes in terms of the number of fishes or fish biomass (kg or tons);
A = The areas obtained from the bathymetric map and
D = The density (fish/ha) of carnivores and herbivores reef fish.

To get the biomass of carnivorous and herbivorous fish, it is necessary to convert fish length into biomass using the fish length and weight relationship equation as follows:

$$W = a \times L^b$$  \hspace{1cm} (2)

W = Fish biomass (kg or ton), L = Total length, a and b = the growth coefficient of fish.

The fish’s total length (TL) can be estimated using the equation below:

$$TL = (TL_{\text{min}} + TL_{\text{max}})/2 \hspace{0.5cm} \text{or} \hspace{0.5cm} TL = 0.65 \times TL_{\text{max}}$$  \hspace{1cm} (3)

TL_{\text{min}} and TL_{\text{max}} are the minimum and maximum of the fish's Total length.

Here, the information on TL and the fish growth coefficient (a and b) of many carnivores and herbivores were obtained from many literature sources [13-19].
2.2.3 Coral cover data collection

On the same transect line with the reef fish data collection, observations were also made for the condition of the coral reefs in the form of live coral cover and other benthic habitats such as DA (Dead Coral), DCA (Dead Coral covered by Algae), SC (Soft Coral), SP (Sponge), FS (fleshy Seaweed), OT (Other biotas), R (Rubble), S (Sand), SI (Silt) and RK (Rock). The coral reef condition can be determined based on the covers of living coral. The Coral reefs are in bad, medium, good, and excellent condition if the percent covers of the live coral is <25%, 25-50%, 50-75%, and > 75%, respectively [3,4].

3 Results and discussion

3.1 Reef fish species diversity

Regarding species diversity, we found 116, 93, and 104 species of the three groups (Corallivores, carnivores, and herbivores) reef fish in Derawans Island during the 1994, 2003, and 2019 observations, respectively. Figure 3 shows the graphs of species diversity of reef fishes, including the corallivores, carnivores, and herbivores in each observation site of Maratua, Kakaban, Panjang, Derawan, Samama, and Sangalaki Islands.

Looking at this graph at first glance, it seems nothing special. Nonetheless, there appears to be a tendency for species diversity to decrease from 1994 to 2003, mainly the herbivores fish in all observation sites, but increase again in 2013. The herbivorous reef fish diversity in 1994, 2003, and 2019 ranged from 20-36, 6-17, and 18-27 species, with an average value of 25, 13, and 23 species, respectively. The species that dominate this group are Ctenochaetus striatus and Zebrasoma scopas (Family Acanthuridae), Scarus sordidus, and S. dimidiatus (Family Scaridae), while the other herbivore fish species of the Siganidae family did not dominate at all.

The carnivore reef fish group diversity, from three periods of observation and in all observation sites, shows that the species diversity in 1994, 2003, and 2019 ranged from 11 to 22, 8 to 23, and 7 to 16 species with an average of 17, 15 and 12 species, respectively (Figure 3). The diversity of this group gradually decreased in those years, while the dominant species were Lutjanus decussatus, Cephalopholis urodeta, Lutjanus fulvus, C. cyanostigma, and Macolor macularis.

Meanwhile, the corallivore reef fish group from 1994, 2003, and 2019 in all observation sites (Figure 3) showed that the species diversity gradually decreased from the ranges of 15-21, 6-20, and 7-15 species with an average of 17, 14, and 11 species, respectively. The species diversity pattern of this group is similar to the carnivore group, which shows a tendency to decrease. Chaetodon kleinii, C. vagabundus, C. Trifasciatus, Heniochus various, and C. Baronessa are the dominant species in this group.

3.2 Reef fish abundance (density)

In terms of abundance (fish/ha), Figure 4 shows the total abundance of each herbivore, carnivore, and corallivore group. A total abundance of 5,268, 2,664, and 5,332 fish/ha during the sampling periods of 1994, 2003, and 2019, respectively. From this figure, again, the herbivore group dominated the abundance of reef fish in Derawan Is. The abundance of this group in 1994 ranged from 1560-5680 fish/ha with an average of 3080 fish/ha. The range of abundance in 2003 decreased to 267-923 fish/ha with an average of only 647 fish/ha, while in 2019, the abundance ranged between 2543-3500 fish/ha with an average of 2983 fish/ha, which indicates an increasing of 4.5 times higher than 2003 or nearly back to the abundance of 1994. An abundance of 3000 fish/ha was found in Samama Is in 2019, Kakaban Is in 1994,
and Maratua Is in 1994 and 2019. The high abundance of herbivore group dominated by the species of *Ctenochaetus striatus*, *Zebrasoma scopas*, *Acanthurus pyroferus* (Family Acanthuridae), *Scarus sordidus*, *S. niger* and *S. dimidiatus* (Family Scaridae). None of the species within the Family Siganidae dominated the herbivore group.

Fig. 3. Reef Fish species diversity of herbivores, carnivores, and corralifores in each sampling site during three observation periods.

Fig. 4. The abundance (Number of individual fish/specimen) of herbivores, carnivores, and corralifores reef fishes in each sampling site during three observation periods.
The reef fish abundance of the carnivore group 1994 was 500-1240 fish/ha with an average of 950 fish/ha. In 2003, the abundance of this group decreased to the range of 336-1243 fish/ha with an average of 733 fish/ha, while in 2019, the abundance increased again to the range of 300-1600 fish/ha with an average of 881 fish/ha. The abundance of carnivore groups higher than 1000 fish/ha was found in Panjang Is in 1994 in Sangalaki and Maratua Is in 2019, which indicated that this group of fish recovered from previous years. The species of Lutjanus decussatus, Cephalopholis urodeta, L. fulvus, C. cyanostigma, and Macolor macularis dominate the high abundance of the carnivore group. None of the species from the Family of Haemulidae and Lethrinidae dominated this fish group.

The reef fish abundance of the corallivore group in 1994 was 1040-2060, with an average of 1426 fish/ha. In 2003, the abundance of this group decreased in the range of 592-2420 fish/ha with an average of 1290 fish/ha, while in 2019, the abundance increased again to the range of 986-2043 fish/ha with an average of 1430 fish/ha that a little bit higher even than in 1994. The abundance of corallivore groups higher than 1000 fish/ha was found in Derawan Is in 2003 and 2019, Panjang Is in 1994 and 2019, Sangalaki Is in 1994 and 2023, and Maratua Is In 1994 and 2019. The corallivore group has only one family (Chaetodontidae); thus, the species that dominated this group were Chaetodon kleinii, C. vagabundus, C. trifasciatus, Heniochus varius and C. baronessa.

3.3 Biomass and standing stock of herbivores and carnivores reef fishes

Figure 5 shows a shallow water bathymetric chart using the British Oceanographic Data Center (BODC). From the calculation, in the white shade box, the total depth areas from the ranges of 2-5, 5-10, 10-15, 15-20, and 20-25 m was 144,872 ha. It is assumed that the areas within the depth between 2 and 25 m are the habitat of reef fishes, where the reef fish exist and are distributed. Meanwhile, the areas in the depth of < 2 m are not accounted for because this depth was under the influences of the tide ranges, while in the depth of > 25 m are assumed to be dominated by the habitat of sand, in which the species diversity and abundance of coral reef are low so that it can be neglected.

Table 2 displays the standing stock of the herbivore and carnivore fish groups for the Derawan Islands. These fixed stocks were calculated based on the areas within the depth of 2-25 m that derived from the shallow water bathymetric chart of Figure 5, and the biomass of herbivore and carnivore fish group/ha, in which the biomass derived from the total number of fish in one ha x a*L^b. From this table, the total standing stocks of herbivores in which some herbivore fish are also consumable fish that have economic values was 54,295 tons, consisting of families Acanthuridae of 25,364 tons, Scaridae of 24,419 tons and Siganidae of 4,512 tons. Meanwhile, the total standing stock of carnivore was 17,689 tons, consisted of Haemulidae of 1,753 tons, Lethrinidae of 2,854 tons, Lutjanidae of 7,809 tons, and Serranidae of 5,273 tons.

3.4 Relationship between reef fish and living coral covers

In this study, we also want to know the relationship between the reef fish group and their habitat, which is indicated by the percent covers of the live corals. In this case, we used the data from 2019 because it is complete so that it can be analyzed compared to data in 1994 and 2003. The live coral cover percentages ranged between 26% (Maratua Is) and 74% (Sangalaki Is), with an average of 37%, indicating the coral reef in the Derawan Islands was in medium condition.

The analysis results show that the species diversity of the family Lutjanidae (carnivore), all herbivores and corallivores is strongly correlated with the percentage of living corals with coefficient determination (R²) of 0.86, 0.92, and 0.93, respectively, but show a weak
correlation with other family as well as the abundance of reef fishes with the $R^2 < 0.8$ (Table 3). Figure 6 displays the relationship with the high $R^2$

Fig. 5. Shallow bathymetric in the Derawan Island and surrounding waters.

<table>
<thead>
<tr>
<th>Reef Area (ha)</th>
<th>Herbivore Group</th>
<th>Biomass (Kg/ha)</th>
<th>Stock (Tons)</th>
<th>Carnivora Group</th>
<th>Biomass (Kg/ha)</th>
<th>Stock (Tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>144.872</td>
<td>Acanthuridae</td>
<td>175.1</td>
<td>25,367</td>
<td>Haemulidae</td>
<td>12.1</td>
<td>1,753</td>
</tr>
<tr>
<td></td>
<td>Scaridae</td>
<td>168.6</td>
<td>24,425</td>
<td>Lethrinidae</td>
<td>19.7</td>
<td>2,854</td>
</tr>
<tr>
<td></td>
<td>Siganidae</td>
<td>31.1</td>
<td>4,502</td>
<td>Lutjanidae</td>
<td>53.9</td>
<td>7,809</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Seranidae</td>
<td>36.4</td>
<td>5,273</td>
</tr>
<tr>
<td>TOTAL</td>
<td>54,294</td>
<td>TOTAL</td>
<td>17,689</td>
<td></td>
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</tr>
</tbody>
</table>
Table 3. The relationship between the species diversity, the abundance of various fish groups, and the percentage of living corals.

<table>
<thead>
<tr>
<th>Fish Groups</th>
<th>Diversity</th>
<th>Abundance</th>
<th>Regression type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acanthuridae</td>
<td>$R^2 = 0.48$</td>
<td>$R^2 = 0.49$</td>
<td>Polynomial order 6</td>
</tr>
<tr>
<td>Scaridae</td>
<td>$R^2 = 0.34$</td>
<td>$R^2 = 0.16$</td>
<td>Polynomial order 6</td>
</tr>
<tr>
<td>Siganidae</td>
<td>$R^2 = 0.41$</td>
<td>$R^2 = 0.45$</td>
<td>Polynomial order 6</td>
</tr>
<tr>
<td>Haemulidae</td>
<td>$R^2 = 0.32$</td>
<td>$R^2 = 0.24$</td>
<td>Polynomial order 6</td>
</tr>
<tr>
<td>Lethrinidae</td>
<td>$R^2 = 0.47$</td>
<td>$R^2 = 0.22$</td>
<td>Polynomial order 6</td>
</tr>
<tr>
<td>Lutjanidae</td>
<td>$R^2 = 0.86$</td>
<td>$R^2 = 0.68$</td>
<td>Polynomial order 6</td>
</tr>
<tr>
<td>Serranidae</td>
<td>$R^2 = 0.52$</td>
<td>$R^2 = 0.75$</td>
<td>Polynomial order 6</td>
</tr>
<tr>
<td>All Herbivores</td>
<td>$R^2 = 0.92$</td>
<td>$R^2 = 0.52$</td>
<td>Polynomial order 6</td>
</tr>
<tr>
<td>All Carnivores</td>
<td>$R^2 = 0.29$</td>
<td>$R^2 = 0.65$</td>
<td>Polynomial order 6</td>
</tr>
<tr>
<td>Corallivores</td>
<td>$R^2 = 0.93$</td>
<td>$R^2 = 0.55$</td>
<td>Polynomial order 6</td>
</tr>
</tbody>
</table>

Fig. 6. The relationship between the live coral covers and species diversity of Lutjanidae (left), Chaetodontidae (middle), and all herbivore reef fishes (right).

4 Conclusions

The observation of species diversity and abundance of Herbivore, Carnivore, and Corallivore reef fish have been conducted in the Derawan Islands using UWC data collected in 1994, 2003, and 2019.

Both reef fish species diversity and abundance were likely to decline from 1994 to 2003 for all carnivore, corallivore, and herbivore groups. The decline might be associated with over-exploitation of reef fish sources during that time. However, the diversity and abundance tended to recover again between 2003 and 2019, particularly for the herbivore and corallivore groups, which returned nearly to the initial as in 1994. The increase in the reef fish stock was due to better environment management in Derawan Islands promoted by the local government.

The coral reef condition of Derawan Islands can be categorized as medium condition, with the live coral percentage in the ranges of 26% (Maratua Islands) to 74% (Sangalaki Islands) and an average of 37%. The living coral percentages were strongly correlated with the species diversity of Lutjanidae, Chaetodontidae, and all Herbivores, but not for fish abundance. Therefore, continuous monitoring is needed to maintain and conserve the coral reef ecosystem and reef fish in healthy conditions. Furthermore, it is recommended to establish a Marine Protected area (MPA), such as a no-take zone on every island within the Derawan Islands.
**Author Contributions:** S.W., F.D.H., H.A.W.C., and J.S. compiled and designed the research draft; Conducted field surveys to collect data on corals, reef fish, macrobenthos, and bathymetry according to their respective fields of expertise; Performed data analysis and wrote the first draft. S. is responsible for everything related to project administration and participating in data collection in the field; N., R.S., and M.H. prepare all survey equipment, assist during field surveys, and document all data collected. S.W. wrote and edited the research manuscript drafts and revised reviewed manuscripts. All authors contributed to the final manuscript and approved it.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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