The role of mangrove, seagrass and coral reefs for coral reef fish communities

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Abstract. We examined the effect of mangrove, seagrass meadows, reef characteristics, and complexity of seascape heterogeneity on reef fish assemblages in Ternate, Natuna and Bintan-Indonesia. The analytical approach of seascape ecology was undertaken, using field survey data of reef fish community and maps of mangrove covers and habitat benthic. The fish data had been collected during reef health monitoring in 2015 through the Coral Reef Rehabilitation and Management Program-Coral Triangle Initiative. Map of benthic habitats and mangroves was provided by Indonesia’s data custodians in 2015-2016. Generalized Additive Models were performed to analyze non-linear and non-monotonic relationships. The results showed that mangroves and seagrasses were essential for reef fishes, and as expected, reef characteristics were also important. Accordingly, the conservations of coral reefs should consider mangrove and seagrass protection and vice versa. Therefore, this information could be considered for managers of marine protected areas (MPA) to better practice MPA management.

1. Introduction
Mangroves and seagrasses are perceived as feeding, spawning, and nursery grounds for many kinds of coral reef fishes. Indeed, up to 107 publications have provided substantial evidence to the theory that most coral reef fish species (~80%) are multi-habitat users [1]. Therefore, the studies on reef fish communities’ responses to their environment should be expanded from single to multi-habitat, incorporating spatial context. Research questions are not about how fish communities correlate with the biotic and abiotic factors within the site samplings, but it should be about how spatial heterogeneity of reef flat structuring the reef fish communities. To address the latter question, a combination of landscape ecology and reef fish ecology offers promise answers. Forman and Godron [2] defined ‘landscape’ as a heterogeneous land area composed of a group of interacting ecosystems made up of pieces of land having homogeneous features, called habitat patches. Landscape ecology focuses on 1) structure: the relationship between landscape heterogeneity and community structure of organisms; 2) function: the interactions of landscape elements through material and energy transfers, and organism movements; 3) change: the alteration in the structure and function of landscapes [2]. In the context of the marine ecosystem, Wedding et al.[3] thus, adopted the conceptual and analytical framework of landscape ecology, using the term ‘seascape’ instead of ‘landscape.’ Seascapes are defined as spatial heterogeneity and seafloor dynamics either in two or three dimension representatives [4].

In the case of Indonesia, Unsworth et al. [5] provided a basis for research into the relationships between three coastal ecosystems (mangroves, seagrass beds, and coral reefs) and coral reef fishes, based on data collected in Wakatobi, part of the Coral Triangle. They noted that mangroves in that location have an ecological function as feeding grounds, not nursery habitats for reef fishes, as commonly perceived, due to high tidal ranges. Therefore, the responses of reef fish to mangroves in
spatial context will be unique. In the current study, we are going to use the concept and analytical approaches of landscape ecology to examine the relationships between mangrove or seagrass patches and the reef fish communities within a spatial context. Further, we test the synthesis evidence revealed from previous studies, such as testing the following key elements: 1) the influence of reef patch characteristics (area and edge) on the reef fish; and 2) the effect of landscape/seascape complexity on the reef fish.

2. Methodology

2.1 Study Location

The reef fish survey is a part of the Reef Health Monitoring (RHM) carried out by the Coral Reef Management Program-the Coral Triangle Initiative (COREMAP-CTI). For the current study, three selected locations, including Ternate, Bintan, and Natuna (figure, 1). Ternate reefs are in the heart of the coral triangle and near proximity to the populated area (Ternate City, the capital of North Maluku Province). Bintan is a name for group of islands and the capital city for Kepulauan Riau Province, located in western Indonesia, outside of the coral triangle. Located close to Singapore, these islands are among the world’s busiest shipping lanes. Natuna reefs are also outside of the coral triangle, but it is relatively remote, situated south of the South China Sea. There are mangrove forests adjacent to the coral reef in the three locations, although Bintan has more extensive mangrove areas than others. Seagrass meadows occur only in Bintan and Ternate, while mixed habitats and sand coverage are found in all locations. Therefore, these study locations offer an excellent opportunity to answer the proposed research questions, particularly the relationships between mangrove or seagrass patches and reef fish communities. The total number of stations for fish survey account for 46 stations, distributed in Bintan (14), Natuna (18), and Ternate (14).

Figure 1. Map of study locations and stations. (top) three study locations. (bottom) stations in Natuna with the zoom out of a station (in the centre of a circle with a radius of 1000 meters or seascape).
2.2 Fish survey
Data of reef fish communities comes from the book reports of RHM, the year 2015 [6–8]. Reef fish surveys were conducted using the Underwater Visual Census, a standard method for RHM, by collecting reef fish data around the permanent transect lines. All the fishes were identified and counted around the line; the total biomass was also estimated. Only two categories of fishes were surveyed, indicator and targeted fishes, representing the reefs’ health status. The indicators include Chaetodontidae, which commonly consumes a coral's polyps, while the targeted fishes are economically important species, including Haemulidae, Lutjanidae, Lethrinidae, Scaridae, Serranidae, and Siganidae. The fish data sets were also regrouped into two feeding behaviours (herbivore and carnivore). Most of these fishes are diurnal, and thus the fish surveys during the day-time could be assumed to be representative of the fish community.

2.3 Benthic habitat and mangrove mapping
The maps of benthic habitat and mangrove forests for the study locations have been available, provided by the data custodians for corals and seagrass (Research Center for Oceanography, Indonesian Institute of Sciences), and mangroves (Directorate General of Watershed Management and Protected Forest, Ministry of Environment and Forestry). Sentinel-2 imagery acquired in 2015 was used for benthic habitat mapping in Natuna, while it was acquired in 2016 for mapping in Bintan and Ternate. Sentinel-2 provides high-resolution optical imagery, and it has a blue band that is essential for benthic habitat detection [9]. The detection of benthic habitat was undertaken using unsupervised classification. Before this step, the effect of the atmospheric and water column was reduced by using Dark Object Subtraction (DOS) [10] and Depth Invariant Index (DII) [11]. The benthic habitat maps have been assessed using ground truth data, and the final product of benthic habitat mapping is on the 1:50000 scale. The map of Indonesian mangrove (scale 1:50000) was created based on Landsat 8 OLI imagery, acquired in 2010 (Bintan and Natuna) and 2015 (Ternate), using visual interpretation and on-screen digitization.

Before conducting seascape pattern analysis, the GIS shapefiles of benthic habitats and mangroves were combined into a single shapefile, and then it was converted into raster using QGIS v.3.14.1. The raster file was resampled into a pixel size of 7x7 m² and projected into UTM WGS84. Seascape pattern analysis was carried out at a scale of 1000 m, which is the maximum scale selected in previous studies, for example [12]. This scale was measured for radius with a coordinate of 46 stations at its center (figure. 1), forming a circle around a station. The circle of each station represented a ‘seascape,’ and each seascape (n=46) was analyzed using the R package of ‘Landscapemetrics’ [13]. To examine the effect of mangrove on reef fish, the metric selected was only nearest to the stations. Area and perimeter of seagrass patches were selected for detecting the relationship between seagrass meadows and reef fish [14]. The area and edge of reef patches were the metrics to examine the influence of reef characteristics on the fish assemblages [12], while Shannon’s diversity index was selected as a representative metric of reef complexity [3], and see table.1 for seascape metrics.

| Habitat metric                | Abbreviation | Description                                                                 | Min  | Max    |
|------------------------------|--------------|------------------------------------------------------------------------------|------|--------|
| **Mangrove effect**          |              |                                                                              |      |        |
| Distance to mangrove         | DistoM       | The nearest distance (meters) from the coordinate of stations to the edge of | 55.99| 21882.1|
|                              |              | the closest mangrove habitats                                               |      |        |
| **Seagrass effect**          |              |                                                                              |      |        |
| Seagrass area                | SeA          | The total area (ha) of seagrass patches in the seascape                      | 0   | 80.64  |
| Seagrass edge                | SeED         | The sum of the perimeter (m) of all seagrass patches within a seascape       | 0   | 30334.27|
| **Reef effect**              |              |                                                                              |      |        |
| Coral area                   | CA           | The total area (ha) of coral reef habitat in the seascape                     | 3.99| 147.65 |
| Coral edge                   | CED          | The sum of the perimeter (m) of all coral reef patches within a seascape     | 71.38| 31516.13|
| Mix habitat area             | Camp         | The total area (ha) of mix habitat in the seascape                           | 0   | 116.02 |
| Mix habitat edge             | CaED         | The sum of the perimeter (m) of all mix habitat patches within a seascape    | 0   | 33765.23|

Table 1. The selected habitat metrics, its descriptions, and data ranges.
2.4 Statistical analysis
Generalized additive models (GAMs) were a selected statistical analysis to examine the correlations between the reef fish assemblage and seascape metrics. GAMs were selected because the raw data demonstrated non-linear and non-monotonic relationships between the response and explanatory variables. Before carrying out GAMs, data exploration was conducted to assess potential outliers, homogeneity, and collinearity of the explanatory variables following a basic protocol in [15]. Pearson’s correlations were performed to assess autocorrelation and the potential correlation between response and the explanatory variables. GAMs were performed purposively, examining the selected predictors according to the previous study.

To perform GAMs, some parameters were transformed with logarithmic and square root and fitted using Gaussian distribution. In this case, one explanatory variable for each model for simple interpretation. Akaike information criterion (AIC) and $R^2$ were provided for model comparisons. All statistical analyses and plots were developed using R program and the packages: mgcv [16], visreg [17], and gamm4 [16].

3. Results and Discussions
Examining the effect of seascape structures on the assemblage of reef fish in Indonesian reefs is a challenging task. Our results indicated that the objectives of the current study were only partially achieved (table 2). The parsimonious models have low values for $R^2$ and most of these are less than 0.2. Also, there was no evidence that seascape complexity correlated to the reef fishes. However, the results indicated that mangrove, seagrass, and coral reef characteristics influenced fish abundances and diversity. These findings provide directions that are worth further investigations. For instance, before examining the effect of seascape structures on reef fishes, study locations should be classified based on the degree of human activities, tidal range, and reef systems. Human activities, like fishing pressure, could have strong influences on certain reefs, and it thus confounds the relationships between explanatory parameters and reef fishes [18]. Tidal currents are essential for fish movements, and thus, the patterns of habitat utilizations closely relate to tidal ranges. The fish-habitat associations found in the microtidal area cannot be generalized in the mesotidal area [1]. In the tropical Atlantic, mangroves, seagrass meadows, and coral reefs commonly occur in the same area, but mangroves and seagrass are absent in some locations in the Indo-Pacific, as found in our study [1]. The variability of our reef systems may be problematic and cause difficulties in analysis and interpretation.

Table 2. Parsimonious models correlating reef fish abundance and biomass, including functional groups, and the examined seascape metric.

| Response Variable | AICs   | $R^2$ | edf  | p-value | Models                                                                 |
|-------------------|--------|-------|------|---------|----------------------------------------------------------------------|
| **Mangrove effect** |        |       |      |         |                                                                      |
| Lutjanidae abundance (Lut) | 112.98 | 0.12  | 1.5  | <0.001  | Log(Lut)~sqrt(DistoM), GAM family=Gaussian                           |
| Carnivorous fish biomass (Carb), only Bintan | 25.09  | 0.18  | 1.8  | <0.001  | Log(Carb)~sqrt(DistoM), GAM family=Gaussian                          |
| **Seagrass effect** |        |       |      |         |                                                                      |
| Number of species (Nspec) | 152.59 | 0.16  | 1.0  | 0.004   | Sqrt(Nspec)~sqrt(SeA), GAM family=Gaussian                          |
|                           | 113.55 | 0.42  | 2.6  | <0.001  | Sqrt(Nspec)~Log(SED), GAM family=Gaussian                           |
| Herbivorous fish abundance (Herb) | 130.17 | 0.15  | 1.0  | 0.005   | Log(Herb)~sqrt(SeA), GAM family=Gaussian                           |
|                           | 113.55 | 0.42  | 2.6  | <0.001  | Log(Herb)~Log(SED), GAM family=Gaussian                           |
| **Reef effect** |        |       |      |         |                                                                      |
| Number of species (Nspec) | 153.29 | 0.14  | 1.0  | 0.006   | Sqrt(Nspec)~CA, GAM family=Gaussian                                  |
| Herbivorous fish abundance (Herb) | 131.13 | 0.14  | 1.8  | 0.027   | Log(Herb)~CA, GAM family=Gaussian                                  |

3.1 Effect of mangrove and seagrass habitats
The mangrove patches close to coral reefs seem essential for carnivorous fishes' habitat in our study sites (figure 2). In the aggregated data of three locations, Lutjanidae abundance is higher if the stations were farther from mangroves. The same pattern was also found in carnivorous fish biomass, but only on Bintan data, which has an extensive mangrove area. This is contradictory with the finding in the
tropical Atlantic where mangroves are nursery areas for Lutjanidae (snappers), Serranidae (grouper), and Scaridae (parrotfish) [19]. Consequently, several fish species' biomass is higher within coral reefs located near mangroves [20]. However, mangroves may act as a refuge during the day and the place for foraging [21]. The complexity of mangrove root structures provides better protection. Therefore, reef fish movement to the adjacent mangroves may be a reasonable explanation for a low abundance in carnivorous fish in the coral reef that existed close to the mangrove area in our study.

Like many other studies [22, 23], seagrass habitats influence reef fish communities and contribute to herbivorous fish abundance (figure 3). However, either the number of species or the abundance of herbivorous fish were low in the focal reefs with larger seagrass area than smaller ones, conflicting with previous studies [7, 8]. A possible explanation is that fish communities in a reef exhibited diel migration during day-time from coral reef to seagrass [24]. A greater seagrass beds area provides more spaces for fishes for hunting and hiding in the adjacent seagrass. Thus, the number of fish species or the abundance of herbivorous fish around coral reefs (stations) were observed lower than the larger area of seagrass beds. An alternative explanation is that there are many zeroes affecting the model performances. These two reasons are just hypotheses and should be further investigated.
species (figure 4). This relationship is trivial because it has been reported for more than two decades. Nevertheless, only the abundance of herbivorous fish was associated with the coral reef area. The possible explanation is that carnivorous fish experiences overfishing, as expected in a previous study [18] and reported in Spermonde and Komodo Islands [25]. These fishing pressures are not similar between these two locations, and thus it gave to irregular patterns in the change of reef fish community.

Figure 4. Coral reef area

4. Conclusions
The current study results have demonstrated the importance of three coastal ecosystems (mangroves, seagrass meadows, and coral reefs) in structuring reef fish abundance and diversity. Most species of reef fish are multihabitat users. One result increases the generality that the coral reef area supports the reef fish community. On the other hand, the findings an opposite view with the general belief that the seagrass area positively correlates with reef fish. We postulate that these were likely caused by the confounding factors, such as fishing pressures, that its intensity is still difficult to be estimated. Therefore, further study should elucidate these factors.

Although our study results cannot be considered conclusive, this study highlights the importance of multihabitat analysis for the ecological study of reef fish. Also, coral reef management in the concept of MPA is not enough without considering mangroves and seagrass management.

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