Distribution Modelling of Porites (Poritidae) in Indonesia

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Abstract. Porites (Poritidae) is one of the most temperature induced bleaching-resistant coral genera. Therefore, their presence is essential for coral reefs to survive when facing the threat of climate change. Species distribution modelling for Porites corals could provide predictive maps of species distribution in various scenarios, and therefore provided the input for decision support tools. Distribution Model will cover coral reefs in Indonesia, using maximum entropy. Data from field observations collected by TERANGI Foundation since 2002 in various places of Indonesia, Indonesia Institute of Sciences since 1999, specimen data from GBIF, and other various sources were used as the only current input for the analysis. Environmental variables were derived from satellite imageries and oceanographic models, such as HYCOM, LANDSAT 8, MODIS AQUA, and GEBCO. Genera identification were based on Suharsono (2017). The results found that the model was well-performed with AUC value of 0.9747 and if compared to the null distribution, it was considered statistically significant (AUC = 0.7348). Jackknife analysis indicated that the environmental variables with the biggest contributions were substrate type, bathymetry, and mean of chlorophyll A concentration.

1. Introduction

Scleractinian corals, the building blocks of coral reefs, have symbiotic association between the animal host (corals) and dinoflagellate algae symbiont (also known as zooxanthellae), that provide more than 90% of its organic carbon through photosynthesis[1]. The relationship between corals and their zooxanthellae are vulnerable to environmental stressors, such as thermal stress, that can lead to the loss of zooxanthellae and their photosynthetic pigments [2][3]. The world has experienced several mass bleaching events, such as in 1983, 1997-1998, 2010, and 2015-2016[4][5][6][7][8]. Hoegh-Guldberg[5][9] even predicts that coral reefs will disappear as a result of global warming, based on the assumption that corals are living close (within 1 - 2°C) to their maximum thermal limits, that generation times are too long to allow for adaptation over the required time frames, and there is insufficient genetic diversity in existing symbiont and corals. Therefore, thermal induced bleaching is considered as the main drivers of global reef degradation [9].

There are differences in the susceptibility of coral taxa to thermal stress [10]. Fast growing corals, such as Acropora and Pocillopora are susceptible to thermal stress, but Porites is considered more resistant to thermal induced bleaching [11]. Porites is also less sensitive to high CO₂ and high temperature treatment in the laboratories [12]. Baird and Marshall [13] found that after a severe bleaching incident, 88% of Acropora hyacinthus, 32% of A. millepora, 15% of Platygryradaedala died, but no death were recorded in Porites lobata. Therefore, the presence of this genus is important for reefs to survive global warming.
Unlike coral cover, there are limited data on coral genera to date. Only several institutions currently have such data, including: The Indonesia Institute of Science, TERANGI Foundation, Wildlife Conservation Society Indonesia Programme, and several universities. This augments difficulties to coral conservation and management and causing the zonation process to become ignorant to coral diversity. Species distribution modelling are widely used in a range of fields and applications including regional biodiversity assessments, spatial conservation prioritisation, evolutionary biology, epidemiology, global change biology, and wildlife management [14]. SDM can provide predictive maps of species distribution in various scenarios, and therefore provide the input for decision support tools (i.e. MARXAN)[15]. SDM has also been used on corals, such as Acropora cervicornis in the Caribbean [16][16], and therefore SDM can be developed for Porites.

Even though there are numerous modelling techniques used in SDM, Maximum Entropy (Maxent) modelling is the most used. Maxent consistently outperforms other presence-only modelling packages including Ecological Niche Factor Analysis (ENFA)[17][18]. Therefore, the objective of this research is to create Porites distribution map using Maxent to support coral reefs conservation and management in Indonesia.

2. Methods

This research was conducted in Jakarta, Belitung Island and Karimun Jawa (Figure 1). Data from GBIF, Yayasan TERANGI, PPO LIPI, and other sources were obtained in Jakarta. Species occurrence data were obtained in Belitung Island and Karimun Jawa Island for model testing and evaluation. Coral genera occurrence from museum specimens were obtained from GBIF. Genera occurrences from field observations were collected from COREMAP LIPI and Yayasan TERANGI.

The flowchart of the research is shown in Figure 2. Coral occurrence data were collected from museum specimens from GBIF [19], observation data from various reports, and field observations and stored in a PostGIS database. Museum specimen data collected from GBIF and observation data were filtered and free from bias to obtain high quality data using R and Rgbif[20]. Biased data from GBIF, such as those having their coordinates rounded, missing or impossible coordinates, uncertain taxonomy, and other errors would be omitted from the analysis [21][22].
Environmental variable datasets were prepared using GEE from various Earth observation data and models [23]. The environmental variables included benthic habitat type from satellite images; bathymetry from GEBCO; chlorophyll A concentration, normalised fluorescence line height, salinity, water velocity, and sea surface temperature from HYCOM and MODIS Aqua[24][25][26]. All environmental variables were exported using the same projection, resolution, and spatial extent to a Microsoft Azure Virtual Machine. Using R, all rasters in TIFF format were converted to ASC to be the input for Maxent.

Maxent modelling estimated the probability of habitat suitability for a certain species based on the maximum entropy due to environmental conditions [27]. According to Phillips et al. [28] given the probability distribution of pi, the information entropy (H) of the distribution is:

$$ H = -\sum_{i=1}^{N} p_i \ln(p_i) $$

The goal is to calculate the probability (p) of presence (y=1) or absence (y=0) along gradient of environmental covariates (z) [29]. Maxent only requires present data, which are mostly available in museum collections[27]. All occurrence and environmental data were used as the inputs for Maxent version 3.4.1 (https://biodiversityinformatics.amnh.org/open_source/maxent/) to model predicted coral distributions. Default model parameters would be used as they have performed well in other studies and validated on a wide range of datasets (a convergent threshold of 10-5, maximum iteration value of 500 and a regularisation multiplier of 1)[30]. Threshold feature used is 10 percentile training presence. Models were ran with three fold cross validation, where the present locations were split into training data for model fitting and test data for model evaluation, with each run consisted of 265 occurrences data, and then averaged [31].

Model evaluation was based on the Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC), that is, a rank-based analysis that showed a randomly chosen presence site is
ranked above a random background site[32][37]. The AUC were compared with 99 null models to find the significance of *Porites* distribution model [33]. The other model output was the Jackknife analysis, which reviewed the gain of each environmental variables against a species’ distribution. From this analysis, influences of each variable were identified [27].

3. Results

*Porites* distribution was successfully modelled with 217,185.323 km² of total habitable area. The genus was distributed almost evenly on all coral reefs in Indonesia. The distribution of *Porites* is shown in Figure 3.

![Figure 3. Map of *Porites* distribution in Indonesia.](image)

Based on the result, the model was well-performed with the test AUC value of 0.9747 and AUC standard deviation of 0.003. According to Swets [34], AUC value higher than 0.9 is considered very good. The top 5% of the 99 null distributions’ AUC is 0.7348, therefore the *Porites* distribution model’s AUC is considered to be statistically significant. Both *Porites* distribution model’s AUC along with the 99 null distribution’s AUC can be seen in Figure 4.
**Figure 4.** Area under the curve (AUC) of the receiver operating characteristic (ROC) of *Porites* distribution model’s (top) and comparison between AUC values of the 99 null distribution models and the *Porites* distribution model’s (bottom).

Environmental variables with the highest contribution towards gain were substrate type, bathymetry, and curvature; with contribution of 38.4%, 31.2%, and 11.8% respectively. Based on the importance of the variables, bathymetry, curvature, and mean of sea surface elevation were the most significant variables. The percentage contribution and permutation of importance for each variable is given in Table 1. Evaluation of the variable’s importance was also done using Jackknife analysis. Bathymetry was the variable with the highest contribution towards gain when used, and gave the highest decreased when
omitted. Substrate type and minimum of chlorophyll A concentration were the next important variables. The results of the Jackknife analysis is tabulated in Figure 5.

**Table 1.** Contribution of each variable towards model gain and its permutation of importance.

| No. | Long Variable Name                                      | Short name               | Percent contribution | Permutation importance |
|-----|--------------------------------------------------------|--------------------------|----------------------|------------------------|
| 1   | Substrate type                                         | substrate                | 38.4                 | 0.6                    |
| 2   | Bathymetry                                             | bathymetry               | 31.2                 | 85.5                   |
| 3   | Curvature Minimum concentration of Chlorophyll A       | curvature                | 11.8                 | 5.4                    |
| 4   | Mean of Sea Surface Temperature                        | salmean                  | 3.1                  | 0.2                    |
| 5   | Minimum of sea surface temperature                     | sstmin                   | 1.8                  | 0.1                    |
| 6   | Maximum of salinity                                    | salmax                   | 1.6                  | 0.7                    |
| 7   | Mean concentration of Chlorophyll A                    | chmean                   | 1.5                  | 0.6                    |
| 8   | Mean of sea surface elevation                          | hssemean                 | 1.5                  | 2.3                    |
| 9   | Mean of normalised fluorescence line height            | nflhmax                  | 0.9                  | 0.2                    |
| 10  | Mean of sea surface elevation                          | hssemax                  | 0.8                  | 1.3                    |
| 11  | Mean of eastward sea water velocity                    | hswvemean                | 0.8                  | 0.1                    |
| 12  | Mean of Sea Surface Temperature                        | sstmean                  | 0.6                  | 0.3                    |
| 13  | Mean of normalised fluorescence line height            | nflhmean                 | 0.5                  | 0.2                    |
| 14  | Maximum of particulate organic carbon                  | pocmax                   | 0.4                  | 0.2                    |
| 15  | Minimum of eastward sea water velocity Minimum of northward sea water |
| 16  | Mean of scalar water speed                             | scalarmax                | 0.2                  | 0.2                    |
| 17  | Slope                                                  | slope                    | 0.2                  | 1.4                    |
| 18  | Mean of scalar water speed                             | scalarmean               | 0.2                  | 0                      |
| 19  | Minimum of scalar water speed                          | scalarmin                | 0.2                  | 0.1                    |
| 20  | Maximum of northward sea water velocity                | hswvumax                 | 0.1                  | 0                      |
| 21  | Minimum of particulate organic carbon                  | pocmin                   | 0.3                  | 0.1                    |
| 22  | Maximum of normalised fluorescence line height         | nflhmin                  | 0                    | 0                      |
| 23  | Mean of northward sea water velocity                   | hswvuemax                | 0.1                  | 0                      |
| 24  | Minimum of salinity                                    | salmin                   | 0.1                  | 0                      |
| 25  | Maximum of scalar water speed                          | scalarmax                | 0.2                  | 0                      |
| 26  | Minimum of particulate organic carbon                  | pocmean                  | 0                    | 0                      |
| 27  | Minimum of normalised fluorescence line height         | nflhmin                  | 0                    | 0                      |
Figure 5. Result of the Jackknife analysis of the importance of environmental variables towards model gain.

Another output of the model were the response curves of each variable towards habitat suitability. *Porites* preferred shallow water habitat. While it preferred to live on coral dominated reefs, it can also thrive in sand dominated reefs. Based on slope and curvature, *Porites* also preferred a slight inclination...
and little curvature variations, as well as warm water with mean sea surface temperature between 26 - 32°C. The full results of Porites’s responses to the environmental variables are available in Figure 6.
Porites were present on all focused areas, such as Seribu Islands, Belitung Island, and Karimun Jawa Island. Porites were also distributed evenly in Derawan Island, Bunaken Island, North Minahasa, Lembeh Island, and Raja Ampat. However, they were predicted to be absent in Jakarta Bay. This genus distribution in all focused areas can be seen in Figure 7.
Figure 7. *Porites* distribution in all focus areas, Belitung Island (top left), Jakarta Bay (top right), Karimun Jawa Islands (middle left), Derawan Islands (middle right), Bunaken, Likupang, and Lembeh Island (bottom left), and Raja Ampat (bottom right).

4. Discussions

Our *Porites* distribution model performed very well, since it has high AUC values for both training and testing data. Models with AUC larger than 0.75, such as the resulting model, is considered useful, informative, and indicative of good accuracy [35][30][32]. The AUC of the top 5% of the null models, generated from randomised presences, was 0.7348, which was much smaller than *Porites* model’s AUC, and therefore it was considered statistically significant [33]. Such robust model could be used for conservation prioritisation, targeting of incentive funding, and habitat maintenance and restoration [36].
Porites distribution model could play critical roles in decision making process especially in dealing with decision uncertainties [37].

All of the traits found in the model justified the widespread distribution of Porites in Indonesia and the surrounding waters. Based on the environmental contributions on the probability of presence, Porites thrived in both coral-dominated reefs and sand-dominated reefs, with a slight preference towards the previous. Its ability to live under various substrates was also observed in various areas, such as in Seribu Islands and Malang, Indonesia [38][39], and Colombian and Mexican Caribbean[40][41]. This genus has several life forms possibilities, such as encrusting, sub massive, massive, and branching that can cover most habitats [42][43]. Occupying both coral and sand dominated reefs could also attributed to Porites’ reproduction strategy that relied on asexual fragmentation, to acquire living space in a direction away from potential competitors [44]. During times of sedimentation, its skeletal density and strength would decrease, and the colony became prone to fragmentation, further promoting its reproduction [45]. This genus could also deter sediment as small as silt from smothering its polyps through proliferation of mucus, a trait required for living in sandy bottom [42].

Most habitable region for this genus was also found in shallow water above 30 m, but it could also inhabit the mesophostic zone (30 – 150m), such as observed by Klein et al. [46] and Bruckner and Dempsey[47] in the Red Sea. Porites can be a part of mesophostic coral ecosystems due to having Symbiodinium type C15 as the symbiont, which has strong photoacclimatory signal over depth [48]. Mesophostic coral ecosystems are reproductive refuge for Porites astreoides in the US Virgin Island from climate change and coastal development, since it can disperse both vertically and horizontally [49][50].

Environmental parameters related to particle suspended in water (chlorophyll concentration, fluorescence line height, and particulate organic carbon), water energy (sea surface elevation and water speed), sea surface temperature, and salinity only contributed very little towards model gain (<5% each). This implied that the probability of Porites’ presence is less influenced by those variables [51]. Carili et al.[52] found that common environmental factors, such as sea surface temperature, gave less influence to Porites’ growth than micro-scale physical variability and colony specific factors. If there are less suspended particle in the water column, this genus will be largely autotroph, but during times of sedimentation it would become mixatrophic and heterotrophic by feeding on planktons [53][45].

Porites can be found in most coral reefs in Indonesia and the surrounding shallow water, with total habitable area of 217,185 km² based on a 500 x 500 m pixel. On the other hand, based on our model, this genus could not succeed in Jakarta Bay (Figure 7). This could be attributed to two factors, which are available substrate type and water clarity. Estradivari et al. [38] found that the sea bottom of this area was smothered with sediment, so there was no preferable substrate type (coral reefs and sandy bottom) for this genus. Currently, 13 polluted rivers are dumping their sediments, heavy metals, liquid and solid wastes altogether, causing this area to have high sedimentation that lowered the possibility for corals to survive since they were unable to photosynthesize [54][55]. Sediment accumulation rate in Jakarta Bay was up to 0.852 cm/year [56]. Dedi and Ariffin [57] found that coral health disturbance which were affecting 37.96% of coral colonies in the nearby islands, were due to sedimentation. This condition would not be improved in the future, since Jakarta would experience coastal reclamation, that would increase the benthic sediment thickness to 2.49 m compared to 0.84 m today[58]. On the other hand, coral reefs in the north of Jakarta Bay (Seribu Island) tent to be in stable state[38][59]. It would be a challenge to stop the degradations from spreading to other parts of Seribu Islands.

The genus ability to withstand bleaching has been studied extensively[11][12][13][1][60]. One of the mechanisms is through storing more lipid and generate thicker tissues to increase the total energy available to survive bleaching events [61]. Other mechanism is called the phoenix effect, whereby remnant cryptic patches of tissue that survived bleaching events regenerate and rapidly overgrew adjacent dead skeleton, giving it the capacity to recover after severe partial mortality [62]. Porites colonies could also provide historical evidence of past bleaching events [52]. In addition, the genus’ preference for asexual fragmentation could also be used for coral transplantation [44]. Therefore, Porites distribution model can be used to select habitat restoration and donor site[16], monitor past and present bleaching event [44][63][64], and develop scenarios for conservation [36].
5. Conclusion
Coral reefs in Indonesia with *Porites* have a chance to survive the temperature-induced bleaching, since temperature contributed only a little towards model gain. *Porites* showed that its distribution is mainly influenced by substrate type, bathymetry and curvature. The model was very well-performed and could be used for marine spatial planning or conservation planning. Species Distribution Model could be used to complement field observations where data is scarce.

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