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Biogeography and Diversity of *Lobophyllia*, an Ornamental Coral Traded in the Coral Triangle

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Abstract. The coral reefs in the Coral Triangle (CT) are the most biodiverse in the world, but are exposed to growing anthropogenic and natural threats. The collection of corals for export in the marine ornamental trade has been going on for almost 40 years in Indonesia, but recently (in early 2018) it was stopped by the government under an indefinite moratorium. *Lobophyllia* is one of the more intensively exploited corals, with a total quota of 2500 pieces/year. Within the Indonesian CT area (ICTA), very little is known regarding the diversity, population status, and distribution of *Lobophyllia*, at either unexploited or intensively exploited sites. Therefore, this study aimed to determine the species diversity, population status, and distribution of coral *Lobophyllia* at several Indonesian coral reef locations. Primary and secondary data were collected on the coral *Lobophyllia*, both at sites exploited by ornamental coral collectors and at unexploited sites. Primary data were obtained from coral reef surveys that took place under various programs over the period 1998-2017 at 25 locations in the ICTA. *Lobophyllia* was found to be widespread on Indonesian coral reefs. Although 9 species were recorded, only brightly coloured colonies measuring 10-25 cm were exploited. Indonesia classified *Lobophyllia corymbosa* and *Lobophyllia* spp. (multispecies) as export trade target commodities. As a result, some species of *Lobophyllia* targeted as ornamental corals have become very rare at exploited sites compared to on unexploited reefs. If coral exploitation continues to be halted (moratorium), it is expected that depleted *Lobophyllia* populations, especially at exploited locations, could recover naturally.

1. Introduction

Coral reef habitats around the world only cover 0.1 percent of the earth's surface, but they are widely recognised as supporting the highest biodiversity of any marine ecosystem. The basis of a coral reef ecosystem is the reef structure formed by coral animals secreting their limestone skeletons, including the hard coral *Lobophyllia*. Like all organisms, hard corals experience life and death cycles, however the skeletons of dead corals support the accretion of coral reef habitats. Tropical coral reefs in the Indo-West Pacific, experience relatively fast accretion due to the high volume and biodiversity of corals and other calcifying organisms. The Indo-West Pacific area represents 75% of the world's coral reefs and is the global centre of biodiversity for several taxa including corals, fish and crustaceans.



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However, unsustainable utilization has threatened the existence of this ecosystem, resulting in increasing degradation and declining fisheries resources.

Coral reef organisms have long been sought after for the ornamental aquarium fishery and trade. Indonesia has been the major exporter of ornamental corals from the 1980s to 2017. Over that period, the global trade in live coral continued to increase by between 12-30% per year [1]. About 35 non-tropical developed countries import ornamental corals from Indonesia to fulfil demand from the marine aquarium hobby [2]. Since 1982 the ornamental export coral quota from Indonesia is allocated to ten provinces, and is generally around 1 million pieces of coral per annum with a peak of around 1.2 million. However, ornamental coral quotas are now being cut as a result of the decline in coral populations at collection sites [3].

Lobophyllia is a coral genus that has been traded for around 40 years. *Lobophyllia* ornamental coral quotas recommended by the Indonesian Institute of Science (LIPI), the relevant Scientific Authority, comprise two taxa namely *Lobophyllia corymbosa* and *Lobophyllia* spp. The use of *Lobophyllia* spp. as a designation means there is no limit on the species of this genus that can be collected and traded. In addition to the genus *Lobophyllia*, other genera within the Mussidae family targeted by the trade include *Blastomussa*, *Cynarina*, *Scolymia*, and *Symphyllia*. These large-polyped corals tend to have attractive colouration and structures, and therefore they are in great demand.

Ecologically speaking, the genus *Lobophyllia* is one of the dominant constituents of hard coral communities, and can comprise up to a third scleractinian corals communities. This genus is easily recognized based on visual clues such as the colour and shape of the skeleton, but the phylogeny of this taxon remains partially unresolved [4]. There is little known about the biology and ecology of the genus *Lobophyllia*, in particular with respect to disease, bleaching, competition, predators, and reproduction. Visual observations indicate that, several types of *Lobophyllia* spp. corals in Indonesia can live in extreme environmental conditions, including muddy substrates, areas with high sedimentation and eutrophication. *Lobophyllia* is one of the genera reportedly vulnerable to algal overgrowth [5]. *Lobophyllia* corals are broadcast spawners with external fertilization, producing many planktonic propagules which can be transported over long distances before settlement [6]. The review by the International Union for Conservation of Nature (IUCN) in 2010 placed the coral species *Lobophyllia corymbosa* in the Least Concern conservation status category [7]. Following the general principles of broadcast spawning scleractinian coral life cycles, ocean currents may carry planulae to widely dispersed suitable substrates [8]. In order to evaluate the situation of *Lobophyllia* in Indonesian waters, this paper summarizes information from various sources including published research and field surveys, as a basis for further research. This study focussed on the diversity and biogeography of *Lobophyllia* corals targeted for the aquarium trade in Indonesia.

2. Methods

Data on the biogeography and diversity of the coral genus *Lobophyllia* were obtained from field surveys (primary data) on coral reefs at 25 locations across Indonesia from 2000 to 2016, including 160 dives. The presence of coral species from the genus *Lobophyllia* were recorded at each site based on quantitative surveys of coral reefs in many areas of Indonesia. Biogeographic surveys and collection of data on the diversity of *Lobophyllia* corals used various methods in accordance with the needs of survey programs, including swim surveys with identification, quadratic transects, line transects, underwater photo transects (UPT), and reef rapid assessment. Secondary data were obtained from various scientific journals and research reports from COREMAP II coral reefs, P2O-LIPI, Foundations and Universities. Specifically, the coral trade quota data was obtained from the South Sulawesi Conservation Agency (KSDA) in 2016. The discussion of coral export quota data was limited to the period 2010-2016 and quantitative data on Indonesia's coral export quota is not published so the discussion of ornamental coral trade was limited to the province of South Sulawesi.

3. Results and discussion

3.1. *Lobophyllia* Diversity

The genus *Lobophyllia* belongs to the Mussidae family, with 16 recognised species from all over the world. This is a higher than the numbers of recognised species in the genus *Symphyllia* (7) and *Acanthastrea* (12) [9]. Common growth forms are *phaceloid* and *flabellomeandroi*. In general, corals in the Mussidae family have large polyps of more than 40 mm in diameter, and despite some similarity to *Symphyllia*, *Lobophyllia* is generally relatively easy to recognize. The phylogeny of the Mussidae family is far from being resolved, and the inclusion of conspecific populations of different geographical origin can present a challenge when redescribing the taxonomy and systematics of scleractinian corals [4].

Under a taxonomic revision based on genetic analysis in 2012 [10], species formerly classified within the Mussidae family have been re-classified as members of the Lobophyllidae family. The name change from Mussidae to Lobophyllidae was determined based on molecular and morphological analysis aiming to establish the evolutionary relationships between species [10]. A dendrogram of the Lobophyllidae based on Budd et al [10] (Figure 1) shows that the *Lobophyllia* species form a distinct clade within the Lobophyllidae with low genetic distance and do not form clearly demarcated clusters. However there are still constraints and uncertainties regarding the placement of some species within the genera of the Lobophyllidae family.

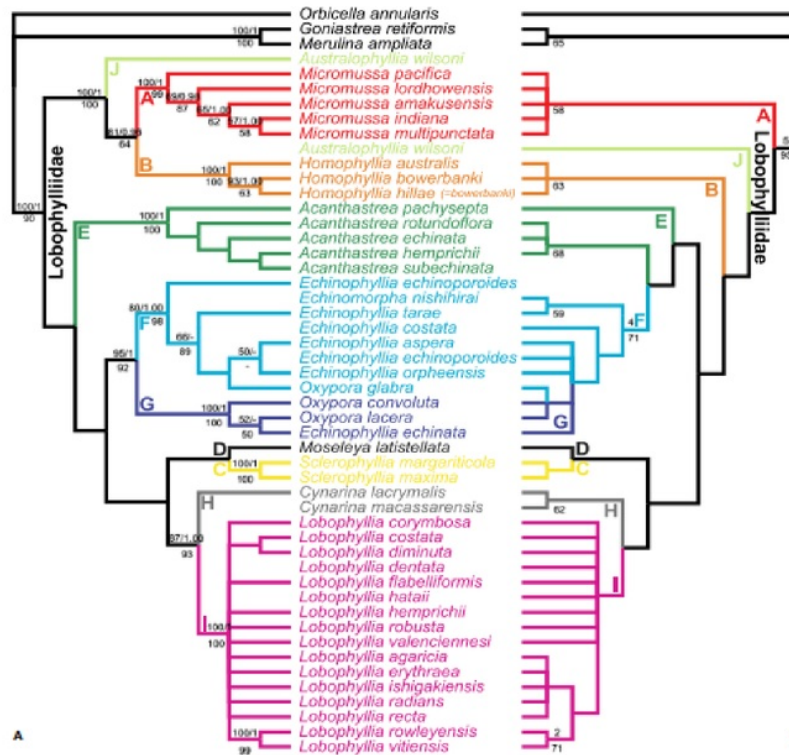


Figure 1. Lobophyllidae phylogenetic dendrogram [10]

A more recent taxonomic revision [11] used phylogenetic methods including micromorphology characteristics to detect low-level homoplasy within the Lobophyllidae. This combined molecular and morphological phylogenetic tree analysis indicated that *Symphyllia*, *Parascolymia*, and *Australomussa* may be synonymous with *Lobophyllia*. Based on the molecular analysis, the Lobophyllidae family appeared monophyletic at the genus level, however *Lobophyllia pachysepta* should be transferred to Acanthastrea. This study concluded that the Lobophyllidae (Mussidae) family, with 11 genera comprising 54 species, needed to be re-analysed [11]. Huang *et al.* [11] classified and identified 16 species of the genus *Lobophyllia*: *L. corymbosa*, *L. costata*, *L. diminuta*, *L. dentata*, *L. flabelliformis*, *L. hatai*, *L. hemprichii*, *L. robusta*, *L. valenciennesi*, *L. agaricia*, *L. erythraea*, *L. inshigakeiensis*, *L. radians*, *L. recta*, *L. rowlensis*, and *L. vitiensis*, but not *L. pachysepta*, *L. serratus*, and *L. dentate*. A study by the Indonesian Institute of Science (LIPI) [12] noted that 9 species were identified: *Lobophyllia diminuta*, *L. pachysepta*, *L. serratus*, *L. corymbosa*, *L. hemprichii*, *L. dentatus*, *L. hatai*, *L. flabelliformis*, and *L. robusta*. All species of the genus *Lobophyllia* reported from anywhere in the world have also been recorded in Indonesia. The Marine RAP surveys in the Togean-Banggai and Raja Ampat areas recorded 6 species of the genus *Lobophyllia*, namely *Lobophyllia corymbosa*, *L. flabelliformis*, *L. hatai*, *L. hemprichii*, *L. robusta*, and *L. pachysepta* [13,14].

3.2. Biogeography of *Lobophyllia*

There are two main biogeographical models proposed to explain observed coral species distributions, namely the dispersal model, where species arise in so-called diversity centres and are then dispersed by currents, and the vicariance model where species arise from differential evolution in reproductively isolated populations [15]. These two models are not necessarily exclusive. For example, the so-called 'vortex model' [16] emphasizes the importance of currents in determining the movement of species away from diversity or speciation centres, while also allowing for allopatric speciation (by divergence) at isolated peripheral locations. While it is important to recognise that stochastic events can affect species distributions, enabling the founding or extirpation of populations, this model agrees with the observed global distribution of species richness [16].

Lobophyllia corals are spread across the coral reefs of the Pacific Ocean to the Red Sea, from the Southern Great Barrier Reef to Japanese waters. The distribution of *Lobophyllia* corals follows a dispersal model which has enabled these corals to colonise coral reef habitats all over Indonesia (Figure 2). *Lobophyllia* is an opportunistic reef-building coral that can live in a wide variety of water conditions, from sometimes muddy coastal waters to the clear waters of offshore reef habitats. Almost all *Lobophyllia* species are adapted to cope with muddy habitat, because these corals are able to sweep away the sediments that fall into the polyps.



Figure 2. Biogeography of *Lobophyllia* in Indonesia.

Although Indonesia is within the Indo-West Pacific area with the highest concentration of *Lobophyllia* species, according to Veron [9], the species *L. diminuta* is not commonly found in Indonesia, except in Maluku and Papua. The species *L. serratus* is reported to be limited to areas of Indonesia east of the Wallacea line, including the Makassar Strait, Lombok Strait, Nusa Tenggara (Lesser Sunda), Banda Sea, Tomini Bay, South China Sea and Halmahera [12]. The most common species found in Indonesia are *Lobophyllia corymbosa*, *L. flabelliformis*, *L. hatai*, and *L. hemprichii*, as recorded from surveys in the Kapoposang conservation area, Spermonde Islands and Maumere Bay.

3.3. Exploitation in the marine ornamental trade

The legal collection of coral for international trade is based on the quota set by the Indonesian Ministry of Forestry and Environment. Pressure from the increasing exploitation of coral reef organisms has caused an on-going decline in the condition of coral reef ecosystems and in the abundance of many reef-associated species. This high level of exploitation was triggered by a demand for uncontrolled coral reef economic commodities. The decline of coral populations and loss of certain types has occurred as a result of *de facto* uncontrolled exploitation, despite efforts to implement the collection/trade quotas. However, since 2017, the Minister for Marine Affairs and Fisheries has placed a moratorium on all licenses for the international trade of ornamental corals from Indonesia. Therefore, there are no post-2016 data on coral export quotas. South Sulawesi is one of the ten previously licensed ornamental coral reef exploitation areas in Indonesia. The quota for corals in 2010-2011 was more than 200 thousand pieces, but the policy mechanisms for determining the quotas resulted in a decrease to around 180 thousand from 2012 to 2016 (Figure 3).

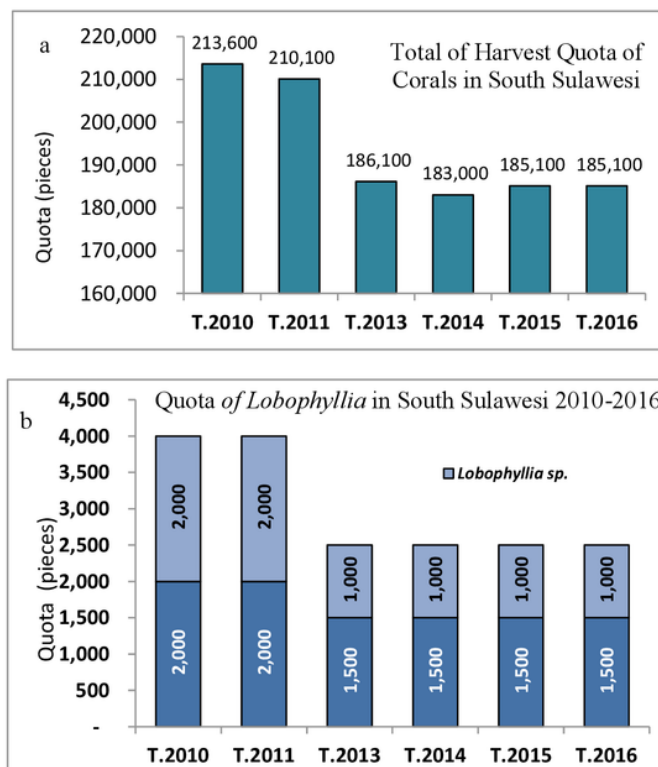


Figure 3. Quotas for South Sulawesi 2010-2016: (a) all types of coral combined; (b) *Lobophyllia*

The *Lobophyllia* corals exported from South Sulawesi are divided into two categories, namely *Lobophyllia* sp. and *L. corymbosa* each of which had a separate quota each year from 2010 to 2016. The quota for *L. corymbosa* was generally higher than for *Lobophyllia* sp. In 2010 and 2011, the quota for each of the two categories was the same 2000 pieces. From 2012-2016 the quota for *L. corymbosa* was reduced to 1500, while the quota for *Lobophyllia* sp. was reduced to 1000 pieces.

In addition to *Lobophyllia*, other live coral genera that are exploited for the marine ornamental trade include: *Euphyllia*, *Goniopora*, *Acropora*, *Trachyphyllia*, *Catalaphyllia*, *Heliopora*, *Heliopora*, *Montipora*, *Stylophora*, *Seriatothoa* and *Fungia* [1]. Most of these coral genera are exploited in the Spermonde Archipelago, South Sulawesi, as well as Kendari in Southeast Sulawesi, Lampung and Rembang in Central Java [17]. The results of a study by the EU Traffic Team and NOAA in 2001 [17] revealed that several rare coral species or genera can be found in the Spermonde Archipelago, including *Catalaphyllia*, *Cynarina*, *Trachyphyllia*, *Blastomussa*, *Euphyllia* and *Hydnophora*. These genera are included in the list of corals with restricted quotas, in particular *Catalaphyllia jardinei* which has been restricted since 1998.

The collection of ornamental corals for export in Indonesia started in 1985 [18], and Indonesia became the main exporter of coral in the world. In 1999, the United States imported 900,000 pieces (36%) of coral from Indonesia, whereas in 2000 imports increased to 2 million pieces (64%). The Indonesian Government issued quotas for the live coral trade in an effort of to avoid excessive exploitation. As a result of these restrictions, the quota for corals exported from Indonesia was gradually reduced from 963,000 pieces in 2000 to 770,590 pieces in 2007. Meanwhile in South Sulawesi the 1998 volume of 169,002 pieces was reduced to 108,450 pieces in 1999. The South Sulawesi coral quota was increased again in 2001 to 225,900 pieces, and reduced again to around 123,400 pieces in 2006.

Research on the ecology of populations (stocks) and the determination of quotas for the ornamental coral trade in the Spermonde Archipelago [19] found that, in line with the market demand for ornamental corals, fishermen were competing to find the highly priced coral species, while wild populations were diminishing. However, for economic reasons, the fishermen would collect all types of corals that could be sold. In the perspective of fishermen from the Spermonde Archipelago (Makassar City and Pangkep District), ornamental corals are just another source of livelihood like sea cucumbers, fish, trochus, and seaweed. The *de facto* unregulated collection of ornamental corals has caused sharp declines in the populations of certain species, which are now extremely rare and some have even been extirpated from certain locations, especially the high-value corals.

In this context, the policy of the Minister for Marine Affairs and Fisheries of placing a moratorium to stop the trade of ornamental corals from Indonesia is considered positive, because in many locations, several species of ornamental corals had become rare. This moratorium should help to maintain coral reef biodiversity, promoting the survival and recovery of depleted populations.

4. Conclusion

Recent phylogenetic analyses have increased the number of recognised species in the genus *Lobophyllia* from 9 species to 16 species worldwide, due to changes in the taxonomy of the genus *Symphylia*. The distribution of *Lobophyllia* species is spread from the Pacific Ocean to the east coast of Africa and the Red Sea. In Indonesia, *Lobophyllia* is widespread, especially in the Coral Triangle region, eastern Indonesia. The ornamental coral trade has brought about a decline in population abundance and biodiversity. *Lobophyllia* quotas have been decreased due to over exploitation.

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