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Hunting in the seas: population status and community perspectives on giant clams (Tridacnidae) and Napoleon wrasse (*Cheilinus undulatus*), endangered marine taxa of the Wallacea Region, Indonesia

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Abstract. Giant clams (Tridacnidae) and the Napoleon wrasse (*Cheilinus undulatus*) are valued fisheries commodities for local consumption and trade. Heavy exploitation has greatly reduced their abundance in the Wallacea Region. This study on giant clam and Napoleon wrasse around Sulawesi is based on data from biophysical (SCUBA diving) and socio-economic surveys from 2004 to 2016 in the Spermonde Archipelago and around Selayar Island, South Sulawesi; and in Central Sulawesi (primarily in the Togeian Islands) between 2001 and 2015. Giant clam population abundance declined, with some larger species (*Tridacna gigas*, *T. derasa*, *T. squamosa*, *Hippopus porcellanus*) no longer found at many sites. Despite increasing awareness regarding the protected status of giant clams, exploitation has continued, including mass collection for traditional festivals in the South Sulawesi islands. Specifically intended for export, fishing uses destructive methods, Napoleon wrasse abundance also declined. Habitat (coral reef) degradation likely also had a negative impact. Low densities could threaten reproductive success. Effective protection measures are needed to rebuild depleted giant clam and Napoleon wrasse populations. This is done to promote the natural process of reproduction and recruitment, and degraded habitat should be rehabilitated through passive or active coral reef restoration. *Ex-situ* (hatchery) breeding and restocking could speed the recovery of depleted giant clam populations.

1. Introduction

Recognized as a "mega-biodiversity" nation [1], Indonesia has made official commitments to conserving the "wild profusion" on which so many people depend for their livelihoods. In particular, Presidential Decree No. 43 of 1978 ratified the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Therefore, exploitation and (primarily international) trade of the species listed in CITES Appendices should follow CITES guidelines. Species listed under CITES Appendix II include the Napoleon Wrasse *Cheilinus undulatus* (since 2004 [2]) and all giant clams in the family Tridacnidae (since 1983 – *Tridacna gigas*, *T. derasa*; since 1985, other Tridacnidae [3]). Furthermore, national regulations to protect or regulate these species have been in place for several decades, albeit with some amendments. All Tridacnidae are fully protected under regulations PP No 7/1999 and P No 8/ 1999. The exploitation of the Napoleon wrasse *Cheilinus undulatus* was limited under the Ministry of Agriculture regulation No. 375/Kpts/IK.250/5/95 Until



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replaced by Decree of the Minister for Marine Affairs and Fisheries No. 37/KEPMEN-KP/2013 in 2013. These regulations restrict trade to juvenile *C. undulatus* between 1kg and 3kg in weight.

The international wildlife trade is one of the main threats to both marine and terrestrial biodiversity. The avowed aim of CITES and the associated national and international mechanisms is to prevent the extinction of listed species due to international trade in whole animals or plants (alive or dead) or any products derived therefrom. The live reef food fish trade (LRFFT) is a major threat to *C. undulatus* across much of its range, including the Togeian Islands in Central Sulawesi [4] and the Spermonde Archipelago in South Sulawesi [5]. In addition to export-oriented fisheries and trade, capture for subsistence or for domestic markets is prevalent and a major threat to many populations of threatened and protected species, including *C. undulatus* (albeit generally to a lesser extent than for export [6]) and tridacnid clams [3]. In addition to export-oriented fisheries for live *C. undulatus*, such local exploitation is reported from several coastal areas and island groups in Central Sulawesi for both *C. undulatus* and all tridacnid clams present. High levels of consumption of tridacnid clams in the island groups around South Sulawesi have also been reported.

This study focused on giant clams (Tridacnidae) and Napoleon wrasse (*Cheilinus undulatus*) in the Spermonde and Selayar Islands in South Sulawesi and the Togeian Archipelago in Central Sulawesi. In addition to the population status of these taxa, the study aimed to describe exploitation patterns and other factors affecting their abundance, and elucidate community perspectives regarding these species and their habitat.

2. Methods

This study compiled published (secondary), and unpublished (primary) data from surveys carried out in archipelagos around Sulawesi under various government programs and during academic research activities. The surveys in the Spermonde and Selayar Islands in South Sulawesi were conducted between 2004 and 2006. Surveys in the Togeian Archipelago in Central Sulawesi were carried out in 2002, 2007, and 2015 on three coastal ecosystems, with a focus on protected and priority conservation species including *Cheilinus undulatus* and tridacnid clams [7,8]. Socio-economic participatory and rapid rural appraisal methods used included Knowledge Attitude and Perception (KAP) interviews, Key Informant Interviews (KII), Focus Group Discussions (FGD), and direct observation as described in [7]. In South Sulawesi, the structured interview template in Table 1 was also used. Similar questions were used in the Togeian KAP studies. Respondents in these surveys included both men and women from island communities, predominantly from fishing families, and ethical guidelines on human subjects (as described in [7]) were followed.

Methods used in biophysical surveys on habitat condition and protected species presence/abundance included Reef Check line intercept and belt transects, manta tows [9], and timed swim surveys. In 2015 coral diversity was recorded to the genus level using the Indo-Pacific CoralFinder. Surveys of *C. undulatus* and giant clam populations around Karumpa Island, Kalaotoa Island, Madu Island, and the Pasi Tambena reef in Selayar District (Figure 1) were conducted by two or more observers using a 30 minute timed swim survey method in 2017. The area surveyed by each observer was typically around 300 meters long by 10 meters wide. Any Napoleon wrasse or giant clams seen were recorded and photographed if within camera range; substrate was recorded as live coral, dead coral, or another biotic substrate. In all surveys, the dominant types of damage to coral reefs were recorded as indicators of the main causes of habitat degradation.

Biophysical and socio-economic data were analyzed descriptively. Data tabulation and graphical analyses were conducted in Microsoft Excel (Microsoft Office 2010). Coral condition based on percentage live coral cover used the scale in [9]: excellent > 75%; good: 50-75%; average: 30-50%; poor: 10-30%; very poor: < 10%.

Table 1. Structured interview template used in South Sulawesi.

Question	Most common answers ^a
Where do you obtain information on protected and endangered species?	a. government; b. law enforcement officers; c. other fishers; d. general public; e. university (lecturers/students)
What marine species are protected?	a. Napoleon wrasse; b. Manta rays; c. whale sharks; d. dolphins/whales; e. giant clams
In your opinion, how has the abundance of Napoleon wrasse/ giant clams changed?	a. increased; b. remained more or less the same; c. decreased
Do you think the condition of Napoleon wrasse/giant clam habitat is	a. good; b. average, same as usual; c. somewhat degraded or damaged; d. poor/very poor
How often are Napoleon wrasse/giant clams collected?	a. daily; b. weekly c. monthly d. seasonal; e. annual; f. occasional
For what purpose are Napoleon wrasse/giant clams collected?	a. to sell; b. for home consumption; c. for special occasions (feast-days, celebrations); d. for decoration
Is there any local conservation of are Napoleon wrasse/giant clams?	a. protected status; b. surveillance; c. they can be freely taken
Are there any sanctions imposed for collecting Napoleon wrasse/giant clams?	a. there are sanctions (explain); b. there are no sanctions
How are species threatened with extinction protected?	a. take forbidden by government; b. warnings given by community members; c. arrest by law enforcement officers; d. imprisonment
What conservation measures could be taken?	a. protection of habitat; b. strong surveillance; c. outreach and awareness raising; d. (captive) breeding

^a These categories were to guide the enumerators in recording responses. Respondents could answer freely; don't know and other were options for all questions

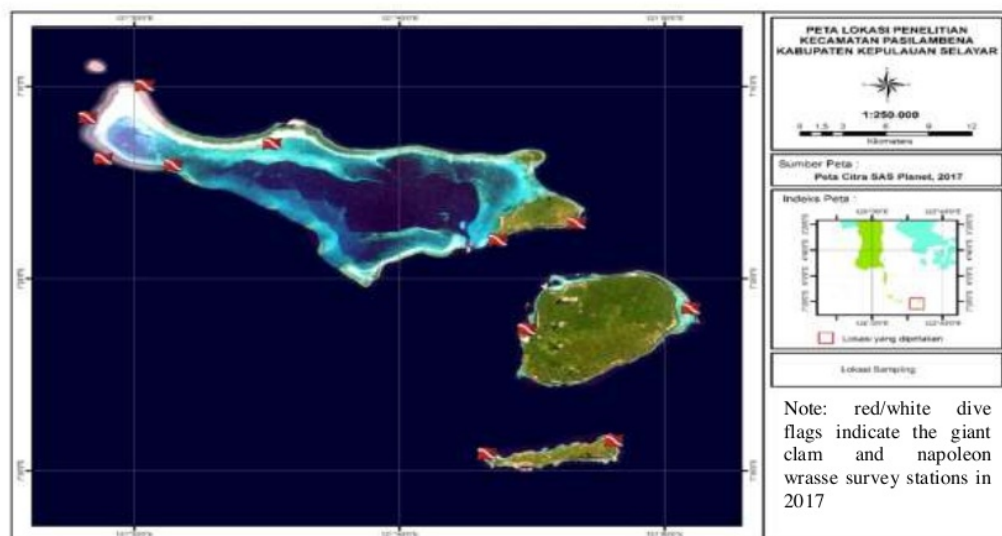


Figure 1. Survey stations at Karumpa Island, Kalaotoa Island, Madu Island, and the Pasi Tambena reef in Selayar District, South Sulawesi, Indonesia.

3. Results

3.1. Condition of Cheilinus undulatus and tridacnid clam habitat

Data on coral reef ecosystems, the main habitat of both *C. undulatus* and tridacnid clams (Table 2), show a decline in average live coral cover overtime in the Togeian Archipelago. The coral diversity survey in 2015 identified 51 genera, with 32 to 42 genera present per site. Coral bleaching was also observed during this survey. Less than 5% of coral colonies were fully bleached, but close to 50% of colonies were either paler than on previous surveys (1999-2008) or exhibited abnormally coloration. Abnormal pale fluorescent coloring of many coral colonies (most prevalent in the genus *Acropora*) and CoralWatch categories 1 (fully bleached) or 2 (very pale) were particularly noticeable in the genera *Stylophora* and *Seriatopora*.

Table 2. Synopsis of data on a live coral cover in the Togeian Archipelago from 1989 to 2015.

Year	1989	1995 ^a	1997 ^a	1998 -2002	2007	2015
Liver coral cover (%)	45-75	46-76	21-54	4-65	3-49	Mostly
Condition category [9]	Average to Excellent	Average to Excellent	Poor to Good	Very Poor to Good	Mean Poor (Very Poor to Average)	Poor (Very Poor to Good ^c)
Sources	[10]	[11]	[11]	[12,13] ^b	[8] ^b	^b
Recorded Changes 1998-2004 (Monitoring data in [14])	The decline in % live coral cover		Increase in % dead coral cover			
	Overall	Mean annual rate	Overall	Mean annual rate		
	12.6	2.1	8.4	1.4		

^a Time series at the same sites; ^b Moore, unpublished (primary) data; ^c Good only at Fadhilla Cottages house reef (privately-enforced no-take zone) where coral cover more than doubled from 2006 to 2015

The 2017 data from Selayar District (Figure 2) indicate high between-site variability. Only bare dead coral (including coral rubble) is shown in Figure 2. However, some dead coral rock or rubble was covered by the other biotic categories such as soft corals, algae, and sponges.

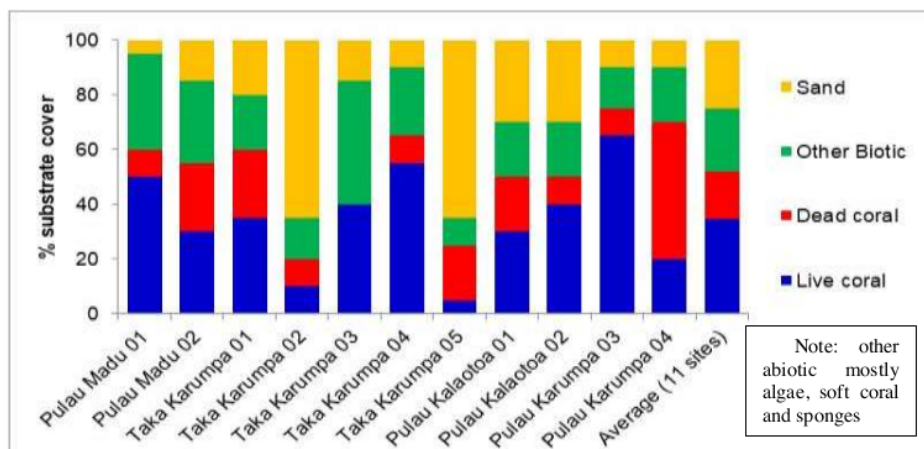


Figure 2. Condition (substrate composition) of *C. undulatus* and tridacnid clam habitat at 11 sites in Selayar District in 2017

3.2. Condition of Cheilinus undulatus and tridacnid clam populations

The densities of *C. undulatus* recorded in Selayar District (Table 3) are higher than those observed during surveys in the Togeian Islands in 2002-2015, while for tridacnid clams, the densities were

somewhat higher in the Togeian Islands. Nonetheless, compared to ReefCheck data collected in 1999 at four sites (Moore, unpublished data), the abundance of giant clams other than *Tridacna crocea* (the most common species) in the Togeians was considerably lower by 2002 and declined further in 2007 and 2015. The exception was the Fadhillah Cottages house reef at Pangempa (a privately-enforced no-take zone), where tridacnid clam abundance increased from 2002 to 2015. Signs of *Tridacna crocea* extraction were clearly visible in 2002, 2007, and 2015, with crowbars or similar instruments used to break apart the massive coral colonies (typically *Porites*) in which they were embedded.

Table 3. Synopsis of *Cheilinus undulatus* and tridacnid clam survey data from Selayar (2017) and Togeian Islands in 2007

No.	Site name	Coordinates		Number of individuals/transect	
		South	East	<i>C. undulatus</i>	Tridacnidae
1.	Madu Island	07° 28' 35.20"	121° 43' 30.51"	0	11
2.	Madu Island	07° 29' 05.40"	121° 43' 30.51"	0	10
3.	Taka Karumpa	07° 14' 22.78"	121° 37' 15.15"	1	15
4.	Taka Karumpa	07° 13' 50.43"	121° 34' 26.82"	1	20
5.	Taka Karumpa	07° 14' 12.26"	121° 30' 03.33"	1	25
6.	Taka Karumpa	07° 09' 52.55"	121° 29' 28.77"	1	23
7.	Taka Karumpa	07° 11' 29.23"	121° 29' 41.77"	0	26
8.	Kalaotoa Island	07° 22' 56.14"	121° 44' 31.27"	1	8
9.	Kalaotoa Island	07° 22' 02.51"	121° 44' 51.85"	0	12
10.	Karumpa Island	07° 17' 05.88"	121° 46' 37.04"	1	15
11.	Karumpa Island	07° 17' 44.54"	121° 44' 04.78"	0	12
Average density (individuals/hectare) in Selayar (2017)				1.82	53.64
Average density (individuals/hectare) in Spermonde (2005)				No data	34.8
Average density (individuals/hectare) in Togeian Islands (2002-2007)				< 1	101 ^a

^an Over 90% *Tridacna crocea*

3.3. Community perception of protected species and their use of coral reef condition

The datasets from the three locations were somewhat different, however common themes emerged. A synopsis of key results regarding protected species knowledge and use is shown in Table 4.

Table 4. Data on protected species knowledge and use by island group and year.

Species are known to be protected	Percentage of respondents (%)			
	Togeian Archipelago			Spermonde
	2002	2007	2015	2005
Marine turtles	0	50	100	9
Tridacnid clams	0	0	100	22
<i>Cheilinus undulatus</i>	0	75	100	43
Manta rays & whale sharks	0	0	33	26
Main use - tridacnid clams				
Home consumption	100	100	75	100 ^a
To sell	33	50	40	25 ^b
Main use – <i>C. undulatus</i>				
Home consumption	100	50	50	60
To sell	50	50	33	47

All use of protected spp. (in PP No. 7/1999)

Home consumption	100	100	75	No data
To sell	75	75	67	No data

^a Includes own use from a few times a year to most days and large numbers for traditional festivals/ceremonies; ^b market-driven, collection when buyers request clams

In the Spermonde Archipelago, data were also collected on the frequency of giant clam collection and use. Just over half of the respondents (56.25%) only rarely collected giant clams, while a substantial number collected them more frequently, roughly once a fortnight (6.25%) or every day, and 6.25% only collected giant clams when there was to be a traditional celebration or ceremony. A quarter of respondents took part in the collection as an economic activity, but only when there was demand from a buyer (25%).

In Selayar, the majority of respondents, especially the fishers, considered that the abundance of Napoleon wrasse *C. undulatus* was declining, although a few thought there had not been much change recently. None thought that *C. undulatus* populations were increasing. Knowledge regarding the protected status was confused, with some believing that the species was fully protected, while others considered that only trade (especially international trade) was regulated. Keeping captured *C. undulatus* in pens until they could be sold was still common here in 2017, as it was in the other two island groups during all earlier surveys.

3.4. Community perception on coral reef value, condition, and threats to coral reefs

Community perception on coral reef habitat condition, the value of coral reefs, and threats to coral reef habitat are shown by island group and year in Table 5.

Table 5. Synopsis of community perception data regarding coral reef habitat.

Question or aspect	Percentage of respondents (%)				
	Togean Archipelago			Spermonde	Selayar
	2002	2007	2015	2005	2017
What are the uses or values of coral reefs that you know?					
Fishing ground/fish habitat	100	100	100		
Building material	5	36	33	No data	No data
Coastal protection	0	4	45		
Recreation (including tourism)	0	17	60		
What condition are local reefs in, or has condition changed?	No data	Decline	Decline	Decline	Poor 60% Fair 40%
What current activities do you think can damage the coral reefs in your area?					
Destructive fishing - explosives	100	100	100		
Destructive fishing - poisons ^a	65	100	100		
Coral mining – for construction	65	58	75	No data	No data
Invertebrate collection (<i>T. crocea</i> , <i>Haliotis</i> sp., etc.)	25	0	50		
Anchor damage	0	42	50		

^a Poisons reported from the Togeans include potassium cyanide, traditional poisons (e.g., crushed roots), household products and agricultural chemicals (e.g., pesticides)

3.5. Community perception of protection/conservation mechanisms, surveillance, and enforcement

The data collected on Community perception regarding conservation activities, regulations, surveillance, and enforcement (Table 6) differed in scope between the study areas, despite some overlap. Respondents from the Togean Islands all knew of recent infractions to regulations (especially regarding destructive fishing). As awareness of regulations grew (see Table 4 as well as Table 6), the list of reported infractions also grew

Respondents in the Togean Islands were also asked whether there was any kind of conservation (site/habitat or species oriented) activity they would like to be implemented in their area or to take part in. In 2002, most respondents said they would like there to be activities to improve the state of their coastal resources, but they didn't know enough to suggest concrete activities. Some responses to this open question in 2007 (2015 responses were very similar) included ecosystem restoration (coral reefs and mangroves), protection of aquaculture (e.g., seaweed farming) areas, and development of mariculture of valuable species.

Table 6. Community perception data on protection/conservation mechanisms, surveillance, and enforcement by island group and year

Question or aspect	Percentage of respondents (%) ^a				
	Togean Archipelago			Spermonde	Selayar
	2002	2007	2015	2005	2017
Do you know of any form of (coral reef) habitat protection or conservation in your area?					
None	100	33	0		
Marine protected area (official)	0	67	100		
Ban on bomb fishing	75	100	100		
Ban on poison fishing	45	100	100		
Ban on coral mining	35	100	100		
Traditional (spatial or temporal)	0	25	0		
Species-related regulations	0	75	100		
Are there any sanctions for offenders, and have they been applied?					
Don't know of any	50	17	0		0
Yes, but not/rarely applied	50	50	50	50	67
Yes, sanctions applied at least once recently	0	25	50	50	33
Is there any surveillance/enforcement in place, and is it effective?					
No surveillance/enforcement	0	0	0	50	
Ineffective/counterproductive	100	80	50		
Partially effective	0	20	33	50	100

^a Numbers per section do not always add up to 100 as some respondents chose not to reply to certain questions and multiple replies were possible for some questions

The 2015 survey in the Togean Islands followed an anti-coral mining campaign. Direct observation revealed ongoing coral mining at or near all survey sites. However, many respondents said mining had stopped now. The Togean National Marine Park was declared in 2004. It is perhaps not surprising that there was an increase in knowledge regarding regulations. There was also a general increase in willingness to talk about illegal activities that (unlike most coral mining) could be blamed on other villages or outsiders. However, surveillance and enforcement were reported as minimal, often perceived as misdirected and/or unfair, and mostly ineffective.

Surveillance in the Selayar island group was generally absent, at best sporadic and ineffective. In both the Selayar island group and the Spermonde, any sanctions given were usually very mild, typically verbal warnings or (sometimes strongly worded) advice. Surveillance and (very mild) "enforcement" efforts deemed partially effective in Selayar include prevention of illegal activity by family/fellow community members (67%) or government officials (13%) without prosecution; meanwhile, 20% of respondents did mention enforcement with more than verbal sanctions.

4. Discussion

4.1. Condition of natural resources

The results of this study indicate that the resource base in the three island groups studied is in decline, in terms of habitat as well as the two commodities on which the study was focused. Although some reefs (particularly in Selayar) were still in good condition, there was a general perception of decline among respondents, more marked in older people with memories stretching back to times when the available data (e.g. [10]) indicate that reef condition was much better than during the surveys. Where sites were revisited, the observers also noticed a decline in coral cover and other indicators of reef health such as invertebrate and fish abundance and diversity.

The densities of the two focal taxa were low and declining in all three island groups. The Napoleon wrasse *C. undulatus* was especially scarce in the Togeian Islands in all three survey years. This is not surprising, given that in the mid-late 1990-s, this fish was already considered rare due to over-exploitation for the LRFFT [4]. This fish is long-lived, with late maturation, thought to be predominantly a protogynous hermaphrodite (maturing first as female with sex-change to male), and territorial habit except during mating when *C. undulatus* spawning aggregations form [6]. These life-history traits make *C. undulatus* intrinsically vulnerable to over-exploitation. Furthermore, reproduction could be impaired below a critical density range due to the scarcity of potential partners to form couples or viable spawning aggregations, especially where local extirpations occur, leading to fragmented populations [15]. Naturally scarce, *C. undulatus* adult densities exceeding 20 individuals/hectare have rarely been recorded [6]. However, a density of less than one individual per hectare is very low, and effective protection will be required to reverse the potentially fatal decline in *C. undulatus* populations around Sulawesi. Without a reduction (ideally cessation) of fishing effort, the so-called "Anthropogenic Allee Effect" [15] could spell doom for *C. undulatus* populations in these and other archipelagos around Sulawesi and in the Wallacea Region more generally.

While adult *C. undulatus* are typically sighted roaming along the reef crest, slope, or drop-offs, research in Palau indicates that juveniles have an ontogenetically distinct habitat preference, the main nursery habitat being shallow-water near-shore thickets of branching corals with fleshy macroalgae. Such habitats seem particularly vulnerable to both local impacts (e.g., destructive fishing) and global change (in particular temperature-related coral bleaching). Thus, both juvenile and adult habitat needs to be considered in efforts to promote *C. undulatus* recovery.

4.2. Community knowledge, perception, and practices

The data in Tables 4 to 6 indicate that knowledge transfer is much easier than and does not always entail appropriate changes in practices. This is especially clear in the Togeian data, where knowledge regarding protected species is now ubiquitous, but so is the continued exploitation of these species. Apart from the complex social and political interactions described in detail by Celia Lowe [4,16], many of which still obtain despite the fall of the *Order Baru* regime in Indonesia, this seems related to the basic mechanisms of learning: cognitive, affective and motoric. While the cognitive aspect is now mostly well developed, there appears to be a lack of effective engagement, which is needed to translate knowledge to action. While there is no easy answer to this challenge, involving children could be one key to open the hearts and minds of the parents and wider community as well. An example of this approach is the education boat Kalabia in Raja Ampat (<https://www.kalabia.net/>). A similar approach was proposed for the Togeian Islands in the early to mid-2000s but did not succeed in obtaining support from the government or alternative funding sources. Perhaps it is now time to revive this idea, supported by modern communications technology.

4.3. The role of CITES in conserving *Cheilinus undulatus* and tridacnid clam resources

It is not clear that CITES has played any role (positive or negative) in the dynamics of the tridacnid clam fisheries and trade in the three island groups. The data in Table 4 to 6 and other data collected in these areas during the same surveys indicate that international trade plays a minor role in the exploitation of tridacnid clams in these areas. Exploitation is almost entirely for local purposes, mainly

for the consumption of the clam meat, and is deeply ingrained into the local culture. However trade in clamshells to Bali as curios was reported from the Togeans, as well as some sales of clamshells for other purposes such as mixing of clamshell powder with betel nuts for traditional chews in Tojo Una Una District (of which the Togeans Islands are apart), and some ornamental or craft uses were observed in all three island groups.

The LRRFT is a major factor driving exploitation of the Napoleon wrasse *C. undulatus*, and therefore CITES should play a crucial role in regulating and ensuring the sustainability of this trade. Data collected in these three archipelagos indicate that the regulations and the ways in which they are implemented have been ineffective in protecting the resource base. Most fish have left Indonesia unrecorded or misreported in terms of size, number of fish, or species. The use of poison fishing continues, albeit with an increasing number of variations in the poisons used, many of which are not (unlike potassium cyanide) explicitly illegal for use in capture fisheries. Undersized fish are grown out in pens, fed on mostly so-called trash fish. This feed is generally from bomb fishing but sometimes includes undersized pelagic fishes caught in purse seines and other legal fishing gears or other unsold fish. Oversized fish may be exported illegally, or if they die or are not sold live, they can be sold locally to the many *ikan bakar* (barbecued fish) restaurants or on local markets. CITES does not regulate these in-country uses of *C. undulatus*. It would seem that by providing a legal size range, the current regulations, in effect, enable exploitation throughout the life-cycle of this vulnerable fish. A complete moratorium on the exploitation of *C. undulatus*, until (if) populations recover, would seem called for, in the hope that it is not too late for natural processes to rebuild severely depleted stocks.

4.4. A role for aquaculture in conservation

Despite some reported successes, reliable captive breeding of *C. undulatus* is not yet a reality. The case is different with tridacnid clams. Reliable methods of inducing spawning, promoting fertilization, larviculture, rearing of juveniles, and release to the wild have all been developed and successfully trialed from a technical point of view [17]. The two main obstacles are the political will to support the activities, and community support in the form of not harvesting the juveniles released. A third obstacle that highlights the urgency of such intervention is the increasing difficulty in finding suitable broodstock for most species, as experienced by the giant clam hatchery on Barranglompo in the Spermonde Islands. If these obstacles can be overcome, ex-situ breeding could be bringing together adult clams, probably separated by distance from suitable breeding partners in the wild, in numbers sufficient to ensure genetic diversity, thus enabling them to reproduce. Rearing of the larvae and juveniles to a size where natural mortality from predation should be greatly reduced compared to natural recruitment processes could then be followed by the release of juvenile tridacnid clams to the wild. If well implemented over a wide enough area in each island group, such a program has the potential to accelerate the recovery of these endangered molluscs greatly.

2 Conclusion

Giant clams (Tridacnidae) and the Napoleon wrasse (*Cheilinus undulatus*) were already rare with declining trends in all study areas. It is likely that densities are now so low in some areas that, even if fishing pressure were removed, the chances of reproductive success, and thus natural replenishment, could be minimal. Degradation of coastal ecosystems, in particular, coral reefs, is not only a continuing threat to the remaining populations but also a barrier to rebuilding depleted populations. Effective protection measures are urgently needed, combined with passive or active coral reef restoration to promote natural reproduction and recruitment processes. Where suitable broodstock is available, ex-situ (hatchery) breeding and restocking with juveniles could accelerate the recovery of depleted giant clam populations.

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