Importance of monitoring an endangered endemic species - intra-species biodiversity perspectives on the Banggai cardinalfish conservation and trade

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Abstract. The Banggai cardinalfish Pterapogon kauderni is a marine ornamental fish with an exceptionally limited natural (endemic) distribution with IUCN Red List status Endangered. An object of national and global concern, conservation efforts have been hindered by misconceptions regarding key concepts (e.g. endemcity) and a lack of routine and standardised monitoring of P. kauderni populations, fishery and trade. This study approached P. kauderni conservation, including sustainable exploitation, from an intra-species biodiversity perspective, based on IUCN definitions and the evolutionarily significant unit (ESU) concept, with a focus on the importance of monitoring. Analysis of monitoring data combined with knowledge of the unusual life-history and unusually fine-scale genetic structure of P. kauderni were used to identify monitoring priorities and methodological recommendations to support holistic P. kauderni management at the ESU level, within the endemic range. Some implications of introduced wild populations and captive breeding were also evaluated. The analysis highlights the need for an inter-disciplinary approach and inter-sectoral collaboration in monitoring for management. In particular, to combine information from field surveys with trade data (e.g. Fish Quarantine records), and to keep long-term records, to avoid shifting baselines due to the current typically limited periods of data availability.

1. Introduction
One of a growing number of fish species considered threatened with extinction in the wild [1,2]. The Banggai cardinalfish Pterapogon kauderni IUCN Red List status is Endangered [3]. Exploited for the marine aquarium trade since its “re-discovery” in the mid 1990’s, by the year 2000 the species was considered at risk of extinction [4]. Often referred to (and traded) under the abbreviation BCF, the Banggai cardinalfish has both an exceptionally small native range for a marine fish (circa 5000 km² [5]) and an exceptionally fine-scale genetic population structure (at spatial scales as small as 2 km), indicating reproductive isolation between many populations [6–8]. Both are likely related to the unusual life-history [9–11] of this paternal mouthbrooder with direct development [5,10,11], no pelagic phase and extreme philopatry [12]. Associated with benthic organisms which serve as protective microhabitat [13–15], P. kauderni abundance and reproductive success are strongly correlated with the availability of protective microhabitat [16], requiring a holistic approach to conservation [17,18]. The conservation status of P. kauderni is arguably inseparable from the ornamental fish trade and governance issues [9,17–21].
While *P. kauderni* has become an object of national and global concern \[18,22,23\], conservation efforts have been hindered by misconceptions regarding key concepts (e.g. endemicity) and a lack of routine and standardised monitoring of *P. kauderni* populations, fishery and trade \[18\]. This study approached *P. kauderni* conservation, including sustainable exploitation, from an intra-species biodiversity perspective, based on IUCN definitions \[24\] and the evolutionarily significant unit (ESU) concept \[25\], with a focus on the importance of monitoring.

2. Methods

Monitoring data from biophysical surveys (2004-2018) and transhipment (trade) data (2008-2018) were assessed and compared. These data were evaluated in the context of *P. kauderni* conservation, combined with knowledge of the unusual life-history, unusually fine-scale genetic structure of *P. kauderni*, as well as some implications of introduced wild populations and captive breeding. Based on this analysis, monitoring priorities and methodological recommendations were formulated to support holistic *P. kauderni* management at the ESU level, within the endemic (natural) range of this fish.

3. Results and Discussion

3.1. IUCN Definitions, the evolutionarily significant unit (ESU) concept and *P. kauderni*

The International Union for Conservation of Nature and Natural Resources (IUCN) Red List defines criteria for assessing the conservation status of species based on risk of extinction in the wild: Least Concern (LC); Near Threatened (NR); Vulnerable (VU); Endangered (EN); Critically Endangered (CR); Regionally Extinct (RE), Extinct in the Wild (EW), Extinct (EX), and Data Deficient (DD). Using IUCN Red List criteria, the conservation status of *P. kauderni* assessment in 2007 \[3\] states: “[..] based on the very small area of occupancy (AOO), the severe fragmentation and the ongoing continuing decline (local extirpations and marked decrease in population size in recent years) due to exploitation for the international aquarium trade, this species is assessed as Endangered under Criterion B”. The assessment also states that “*Pterapogon kauderni* is a rare example of a marine fish with an extremely limited geographic range”. In this context, it is important to understand a number of terms which are often used loosely but which have very specific meanings in IUCN conservation status assessments and the associated conservation discourse (Table 1).

| No. | Term                  | Definition [24]                                                                 |
|-----|-----------------------|----------------------------------------------------------------------------------|
| 1   | Benign introduction   | An attempt to establish a taxon, for the purpose of conservation, outside its recorded distribution but within an appropriate habitat and ecogeographical area; a feasible conservation tool only when there is no remaining area left within a taxon’s historic range |
| 2   | Endemic taxon         | A taxon naturally found in any specific area and nowhere else. This is a relative term in that a taxon can be endemic to a small island, to a country, or to a continent. |
| 3   | Natural range         | Range of a taxon, excluding any portion that is the result of an introduction to a region or neighbouring region. The |
| 4   | Subpopulations        | Geographically or otherwise distinct groups in the (global) population between which there is little demographic or genetic exchange |
| 5   | Taxon                 | A species or infraspecific entity whose extinction risk is being assessed         |
| 6   | Wild population       | A population within its natural range in which the individuals are the result of natural reproduction (i.e. not the result of human-mediated release or translocation); if a population is the result of a benign introduction that is now or has previously been successful (i.e. self-sustaining), the population is considered wild |
Based on the IUCN definitions (Table 1), it is clear that *P. kauderni* is an endemic species within the natural (native/endemic) range of this taxon. Outside this range, *P. kauderni* is not, and cannot be considered as, an endemic species. Within the natural range of *P. kauderni*, it is likely that Evolutionarily Significant Units (ESUs) *sensu* [25] inferred based on genetic (mostly mtDNA) population characters [6–8,26] and on likely (geographical and ecological) barriers to dispersal [27] are all subpopulations in the IUCN Red List sense (Figure 1).

![Figure 1. Pterapogon kauderni natural (endemic) range and ESUs inferred based on genetic (numbers 2-21) [6–8,26] or geographical and ecological data (numbers 22-30) [27]](image)

As highlighted in the IUCN Red List assessment [3], *P. kauderni* is exceptionally vulnerable to local extinction (extirpation), with effectively no likelihood of natural replenishment. Each extirpation is likely to entail the loss of unique genetic (and possibly phenotypic) diversity [5,28]. Since the early 2000’s, several native *P. kauderni* subpopulations (suspected ESUs) are known to have been extirpated or reduced to levels likely dooming them to extinction [5,9,18,19]. Each known or suspected subpopulation/ESU should be considered a separate unit for conservation management purposes [25], and as a stock in a fisheries management context [29,30].

Isolated subpopulations can become genetically distinct due to a variety of mechanisms [29–31]. In addition to preventing extirpation of subpopulations known or likely to be ESUs, care should be taken to avoid non-natural mixing of these subpopulations. If differential evolution has been adaptive rather than stochastic, such mixing may entail a loss of fitness, in particular through outbreeding depression, described as the “loss of fitness resulting from intraspecific hybridization caused by the disruption of either intrinsic gene interactions or interactions of genes and environment” [31]. Disruption of locally
adapted genotypes may occur in F1 generations but is likely to have a greater (negative) effect in F2 and subsequent generations. Efforts should also be made to maintain each ESU above levels at which inbreeding depression could become a threat to reproductive success and subpopulation viability.

Genetic swamping is one phenomenon with potentially negative effects which could result from the mixing of *P. kauderni* ESUs, in particular in the context of “restocking” schemes proposed in the National Action Plan (2017-2021) for *P. kauderni* conservation [22]. Genetic swamping can occur when a relatively large number of individuals from a different source are introduced into a depleted (remnant) natural population [31]. The introduced genotypes or alleles may increase in frequency relative to the original (native) genotypes or alleles with or without hybridisation, either because they have a fitness advantage or simply because they outnumber natives. Such swamping can lead to a preponderance of maladaptive phenotypes/genotypes that decrease the mean fitness [32]. In the *P. kauderni* context, this could be a concern if wild-caught *P. kauderni* or captive bred descendants from one ESU (or a mixture of ESUs) should be released into any ESU within the natural distribution.

3.2. Introduced populations and non-natural movements of *P. kauderni*

Releases of *P. kauderni* outside its natural distribution are reported at 15 sites within Indonesia mostly in connection with the marine ornamental trade [18]. None of these releases comply with IUCN guidelines for species conservation or qualify as benign introductions. Those which have been extant for more than one (founder) generation do, however, qualify as wild populations. While these populations could conceivably serve to some extent as an “insurance” against extinction, unless the ESU of origin is well-documented they should not be used for “restocking”, an activity called for under the national action plan [22]. Clearly this caveat regarding the ESU of origin also applies to captive populations held in *ex-situ* facilities. Furthermore, the descendants of a small captive population will have a limited genetic pool, and are thus intrinsically at risk of inbreeding, may well become adapted to captive conditions in ways which make them less fit in a natural (wild) environment, and represent a potential biosecurity hazard as they may carry pests or diseases not present at the site of release [33]. Introduced populations are also vulnerable to extirpation, as exemplified by the plight of the Palu Bay *P. kauderni* population [34] after the 2018 tsunami [35,36].

Non-natural movements (capture and release of fish) within the *P. kauderni* natural range should be avoided, with the possible exception of sites where considerable genetic mixing is known to have occurred (e.g. Bone Baru [18,37]) or subpopulations have been extirpated (e.g. Liang Island [18,19]). In both cases, biosecurity should still be a concern, while in the latter case, ideally efforts to reintroduce an extirpated subpopulation/ESU should endeavour to source fishes from nearby site(s) with similar environmental conditions, as these are likely to be well adapted and closest in genetic characteristics to the original subpopulation.

3.3. Monitoring of *P. kauderni* populations and trade

Considerable attention has been focused on the risk of Banggai cardinalfish extinction due to the marine aquarium trade. By 2001 the volume in *P. kauderni* traded from the Banggai Archipelago was estimated to be around 700,000-1.4 million fish/year [38]. More recent estimates vary depending on methods and data sets used [5,18–20] but provide strong indications that, despite changes in volume and trade routes, from 2008 to 2013 the total annual volume was in general lower than during the late 1990’s and early 2000’s [19,20]. In 2010, an agreement on a quota of 15,000 per month for *P. kauderni* from the Banggai Archipelago² allocated a quota of 5,000 fish/month to each of the three major routes in operation at that time (via Manado, Luwuk, and Kendari, Figure 2A). There is no record of a legally binding formalisation of this multi-stakeholder agreement, but several *P. kauderni* shipments in excess of the quota were seized and released to the wild, including 2000 fish in 2011².

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1 http://www.bkipm.kkp.go.id/bkipmnew/event/read/204/perentuan-kuota-ikan-banggai-cardinal-fish-(bcf)-di-banggai-kepulauan
2 http://103.93.191.108/bkipmnew/event/read/411/progress-report-satker-banggai-kepulauan-tahun-2010.html
Major changes in trade routes have occurred over the past 15 years or so (Figure 2A and Figure 2B). These have included a sharp decline in *P. kauderni* transiting through Manado from 2009 to 2014, with no shipments recorded after 2015. Concurrently, there was a sharp increase in *P. kauderni* dispatched from Kendari beginning in 2012 and intensified after 2014.

Prior to 2008, *P. kauderni* leaving the Banggai Archipelago (mainly by sea) were not recorded[20]. Official Fish Quarantine Service figures from 2008-2018 show the recorded (and thus legal) volume of outgoing *P. kauderni* shipments from the Banggai Archipelago (Luwuk/Banggai Station) and from other *P. kauderni* trading centres (Figure 3). The vast majority of these shipments were to export centres, primarily Denpasar but also Jakarta. The increased volume in dispatches from Kendari indicates a large and growing proportion of unreported (and thus automatically illegal) trade. Logically, most of the fish dispatched from Kendari (Figure 3) must have been sourced from the natural *P. kauderni* range, as none of the (known) introduced populations in that area (or elsewhere) could realistically produce such high volumes over several years. Less than 1% of these fish could have come from the minimal recorded (and thus legal) shipments to Kendari from Luwuk/Banggai since 2012.

The fishery and trade enabling large-scale illegal movements of *P. kauderni* to Kendari are not recorded in any government or (known) non-government data sets. They are, however, consonant with survey data on trends in *P. kauderni* abundance indicating sharp declines (from 2012 to 2018) in several subpopulations in the southern part of the Banggai Archipelago [17,18,27,40].

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**Figure 2.** Main *P. kauderni* trade routes/transhipments: A. 2004 [39]; B. 2014-2018 (B) [based on [18] and Moore & Ndobe, unpublished data]
Figure 3. Fish Quarantine data on *P. kauderni* transhipments from the Banggai Archipelago (Banggai/Luwuk) and other major trading centres from 2008 to 2018 [Data source: downloaded (June 2017 & July 2019) from http://www.bkipm.kkp.go.id/bkipmnew/stats/]

Data collected in October 2017 and May 2018 (Table 2) show low *P. kauderni* abundances (density) and depletion of the juvenile size class (the target size for the ornamental fishery) at five sites where illegal collection and shipment from the Banggai Archipelago is suspected. At these sites, the juveniles present were mostly below the 25mm lower limit of the ornamental fishery target range [17,18,27].

Table 2. Population density and size-ages structure of *P. kauderni* at 14 sites in 2017-2018 (mean values over a minimum of 10 x 100m² transects)

| No | Site Name | Recruits | Juveniles | Adults | Total | % juvenile *P. kauderni* |
|----|-----------|----------|-----------|--------|-------|------------------------|
| 1  | Popisi    | 0.12     | 0.32      | 0.73   | 1.18  | 27.55%                 |
| 2  | Bone Baru | 0.24     | 0.47      | 0.47   | 1.19  | 39.88%                 |
| 3  | Tinakin Laut | 0.13     | 0.42      | 0.42   | 0.97  | 43.08%                 |
| 4  | Monsongan | 0.15     | 0.06      | 0.10   | 0.31  | 23.71%                 |
| 5  | Tolokubit* | 0.29     | 0.07      | 0.16   | 0.53  | 14.00%                 |
| 6  | Kapela/Matanga | 0.07   | 0.14      | 0.49   | 0.71  | 20.17%                 |
| 7  | Toropot   | 1.29     | 0.79      | 0.44   | 2.51  | 31.27%                 |
| 8  | Kombongan* | 0.12    | 0.10      | 0.16   | 0.38  | 25.26%                 |
| 9  | Minangga  | 0.49     | 0.33      | 0.14   | 0.95  | 34.34%                 |
| 10 | Tj Nggasuang* | 0.57   | 0.20      | 0.29   | 1.06  | 18.75%                 |
| 11 | Mandel*   | 0.03     | 0.00      | 0.03   | 0.05  | 0.00%                  |
| 12 | Mbuang-Mbuang* | 0.26   | 0.10      | 0.05   | 0.40  | 24.38%                 |
| 13 | Melilis*  | 0.20     | 0.11      | 0.04   | 0.35  | 32.48%                 |
| 14 | Toado     | 0.98     | 1.94      | 1.02   | 3.94  | 49.30%                 |
| Overall | 0.38 | **0.33** | 0.29 | 1.00 | **33.23%** |
| Suspected illegal fishing sites 2017 (marked with*) | 0.25 | **0.09** | 0.13 | 0.47 | **19.04%** |
Two policy changes seem to be causally related to the trends in Figure 3. Firstly, a decree by the Banggai Laut District Head banning ornamental fisheries in this district in 2013 was viewed with disfavour by fishers, traders, and line agencies. At the time it was considered that this regulation would be counterproductive, restricting the legal ornamental fishery and trade and driving an increase in illegal ornamental fishery and trade activities. Secondly, the new Regional Autonomy Law (UU 23/2014) transferred jurisdiction of inshore waters (0-4 nm from the high tide line) from district to provincial level, resulting in a collapse of what marine and fisheries surveillance and enforcement had existed in this area, resulting in a sharp increase in many illegal activities, including illegal fishing and shipments of both food and ornamental fish from the southern part of the Banggai Archipelago to Kendari [17,18,27].

One matter of concern is that a considerable proportion of the data in Figure 3 are no longer (at least publicly) available, with only 2018 and 2019 data online as of 15 August 2019. This loss of historical data can (and will, unless remedied) result in shifting baselines [41], leading to significant bias in future analyses, erroneous conclusions and inappropriate policies.

3.4. Towards an integrated approach to monitoring

The comparison of datasets in Table 2 and Figure 3 highlights the importance of integrated monitoring and evaluation for conservation and fisheries management. Combining the biophysical survey and recorded trade data, informed by other (including anecdotal) socio-economic data paints a more realistic picture compared to those which might be deduced from either data set alone. Specific recommendations for an integrated approach to monitoring *P. kauderni* conservation status and trade are summarised in Table 3, together with recommendations for research to support such a system.

**Table 3. Recommendations for integrated monitoring and research to support *P. kauderni* conservation**

| No | Component                                      | Additional details                                      | Key actors                                                                 | Supporting activities                                           |
|----|------------------------------------------------|--------------------------------------------------------|---------------------------------------------------------------------------|----------------------------------------------------------------|
| 1  | Governance/legal and institutional framework   | Specific body/agency Local regulations                  | Government, civil society, academia                                      | Development of frameworks/regulations                           |
| 2  | Data repository + data management system       | Reliable back-up, long-term user-friendly access       | Academia, civil society, government                                       | Collate historical data Design system                           |
| 3  | Shipment data – long-term time series on in-country and export movements | Improve accessibility and maintain historical time-frame (for *P. kauderni* to first data in 2008) | Fish Health & Quarantine Agency                                            | As above + link to export data                                  |
| 4  | Biophysical data: zones, ecology, seasonal factors, etc. | Complement annual *P. kauderni* surveys under National Action Plan | Academia, local communities, civil society, government                    | Basic research on biodiversity and ecology; applied research and pilot projects (e.g. BCF Garden [28]); training System design and pilot study/training |
| 5  | Citizen science: simple monitoring& reporting | MPA & subpopulation (ESU) levels + general              | Coast Watch groups & concerned public                                      | DNA study on ESUs MSC* or similar study on the *P. kauderni* fishery/trade Develop rights/based or other limited access fishery system |
| 6  | Traceability: participatory fisheries data with DNA tools for monitoring and verifications | Molecular biology (ESU) and socio-economic basis for management units | Academia, fishers, traders, government, NGOs, donors                       |                                                                                                                            |

*Marine Stewardship Council*
4. Conclusion
This study points towards the need for an inter-disciplinary approach and inter-sectoral collaboration in monitoring for management. In particular, the combined analysis of P. kauderni population surveys with trade data. Such an approach should be enshrined within the legal and organisational framework, in particular with respect to the Banggai Dalaka MPA. There is a need for a permanent (or at least long-term) data repository with reliable data back-up. Further recommendations include the application of information from molecular biology (in particular from research to delineate ESUs and support traceability) and ecological studies in management planning and monitoring design, which should maximise stakeholder participation. The study also highlights the need to maintain long-term records (e.g. Fish Quarantine records), in order to avoid a shifting baseline syndrome due to the current typically limited and changing periods of data availability.

References
[1] IUCN 2019 Summary Statistics IUCN Red List Threat. Species version 2019-1
[2] Noakes D L G and Bouvier L D 2013 Threatened fishes of the world: the end of a series Environ. Biol. Fishes 96 1135–49
[3] Allen G R and Donaldson T J 2007 Pterapogon kauderni IUCN Red List Threat. Species 2007 e.T63572A1 17 pages
[4] Allen G R 2000 Threatened fishes of the world: Pterapogon kauderni Koumans, 1933 (Apogonidae) Environ. Biol. Fishes 57 142
[5] Vagelli A A 2011 The Banggai Cardinalfish: Natural History, Conservation, and Culture of Pterapogon kauderni (Chichester, UK: John Wiley & Sons, Ltd.)
[6] Hoffman E A, Kolm N, Berglund A, Arguello J R and Jones A G 2005 Genetic structure in the coral-reef-associated Banggai cardinalfish, Pterapogon kauderni Mol. Ecol. 14 1367–75
[7] Bernardi G and Vagelli A A 2004 Population structure in Banggai cardinalfish, Pterapogon kauderni, a coral reef species lacking a pelagic larval phase Mar. Biol. 145 803–10
[8] Vagelli A A, Burford M and Bernardi G 2009 Fine scale dispersal in Banggai Cardinal fish, Pterapogon kauderni, a coral reef species lacking a pelagic larval phase Mar. Genomics 1 129–34
[9] Ndobe S, Soemarno, Herawati E Y, Setyohadi D, Moore A, Palomaes M L D and Pauly D 2013 Life History of Banggai Cardinalfish, Pterapogon kauderni (Actinopterygii: Perciformes: Apogonidae), from Banggai Islands and Palu Bay, Sulawesi, Indonesia Acta Ichthyol. Piscat. 43 237–50
[10] Vagelli A A and Volpedo A V 2004 Reproductive ecology of Pterapogon kauderni, an endemic apogonid from Indonesia with direct development Environ. Biol. Fishes 70 235–45
[11] Vagelli A A 1999 The Reproductive biology and early ontogeny of the mouthbreeding Banggai Cardinalfish, Pterapogon kauderni (Perciformes, Apogonidae) Environ. Biol. Fishes 56 79–92
[12] Kolm N, Hoffman E A, Olsson J, Berglund A and Jones A G 2005 Group stability and homing behavior but no kin group structures in a coral reef fish Behav. Ecol. 16 521–7
[13] Moore A, Ndobe S, Salanggon A-I, Ederyan and Rahman A 2012 Banggai Cardinalfish Ornamental Fishery: The Importance of Microhabitat Proceedings of the 12th International Coral Reef Symposium, Cairns, Australia, 9-13 July 2012 (International Society for Reef Studies (ISRS)) p 13C
[14] Ndobe S, Moore A and Jompa J 2018 A Tale of Two Urchins - Implications for In-Situ Breeding of the Endangered Banggai Cardinalfish (Pterapogon kauderni) Aquac. Indones. 19 65–75
[15] Moore A M, Ndobe S, Yasir I, Ambo-rappe R and Jompa J 2019 Banggai cardinalfish and its microhabitats in a warming world: A preliminary study IOP Conf. Ser. Earth Environ. Sci. 253
[16] Ndobe S, Widiasutji I and Moore A 2013 Sex Ratio and Pemangsaan terhadap Rekrut pada Ikan Hias Banggai Cardinalfish (Pterapogon kauderni) Prosiding Konferensi Akuakultur Indonesia pp 9–20
[17] Ndobe S, Moore A, Yasir I and Jompa J 2019 Banggai cardinalfish conservation: Priorities, opportunities, and risks IOP Conf. Ser. Earth Environ. Sci. 253 1–13
[18] Ndobe S, Yasir I, Moore A M, Biondo M V and Foster S J 2018 A study to assess the impact of international trade on the conservation status of Pterapogon kauderni (Banggai cardinalfish) (Gland)
[19] Ndobe S, Moore A, Salanggon A I M, Muslihuddin, Setyohadi D, Herawati E Y and Soemarno 2013 Pengelolaan Banggai cardinalfish (Pterapogon kauderni) melalui konsep Ecosystem-Based Approach Mar. Fish. 4 115–26
[20] Moore A, Ndobe S and Zamrud M 2011 Monitoring the Banggai Cardinalfish, an Endangered Restricted Range Species J. Indones. Coral Reefs 1 99–113
[21] Ndobe S, Moore A M and Jompa J 2017 Status of and threats to microhabitats of the endangered endemic Banggai Cardinalfish (Pterapogon kauderni) Coast. Ocean J. 1 73–82
[22] Rusandi A, Lilley G R and Susanti S R 2016 Rencana Aksi Nasional (RAN) Konservasi Ikan Capungan Banggai (Jakarta: Ministry of Marine Affairs and Fisheries R I)
[23] Conant T A 2015 Endangered Species Act Status Review Report: Banggai Cardinalfish, Pterapogon kauderni. 40 pages
[24] IUCN 2012 Guidelines for application of IUCN Red List Criteria at regional and national levels Version 4.0 (Gland, Switzerland and Cambridge, UK: International Union for Conservation of Nature and Natural Resources)
[25] Moritz C 1994 Defining ‘Evolutionarily Significant Units’ Trends Ecol. Evol. 9 373–5
[26] Ndobe S 2013 Biologi dan Ekologi Banggai cardinalfish, Pterapogon kauderni (Suatu Kajian dalam Upaya Pengelolaan Perikanan Berbasis Konservasi) (Brawijaya University)
[27] Moore A M 2019 Microhabitats of the Banggai cardinalfish (Pterapogon kauderni, Koumans 1933) in a holistic conservation context (Universitas Hasanuddin)
[28] Moore A M, Ndobe S and Jompa J 2017 A site-based conservation approach to promote the recovery of Banggai cardinalfish (Pterapogon kauderni) endemic populations Coast. Ocean J. 1 63–72
[29] Palumbi S R 2003 Population Genetics, Demographic Connectivity, and the Design of Marine Reserves Ecol. Appl. 13 S146–58
[30] Rocha L A, Craig M T and Bowen B W 2007 Phylogeography and the conservation of coral reef fishes Coral Reefs 26 501–12
[31] Baums I B 2008 A restoration genetics guide for coral reef conservation Mol. Ecol. 17 2796–811
[32] Donelson J M, Sunday J M, Figueira W F, Hobday A J, Johnson C R, Leis J M, Ling S D, Marshall D, Pandolfi J M, Pecl G, Rodgers G G, Booth D J and Munday P L 2019 Understanding interactions between plasticity, adaptation and range shifts in response to marine environmental change Philos. Trans. R. Soc. B 374 1–14
[33] Talbot R, Pedersen M, Wittenrich M I and Moe M A 2013 Banggai Cardinalfish: A guide to captive care, breeding, & natural history (Shellburne: Reef to Rainforest Media, LLC)
[34] Moore A and Ndobe S 2007 Discovery of an introduced Banggai Cardinalfish population in Palu Bay, Central Sulawesi, Indonesia Coral Reefs 26 569
[35] Moore A M, Ndobe S, Yasir I and Jompa J 2019 Disasters and biodiversity: Case study on the endangered endemic marine ornamental Banggai cardinalfish IOP Conf. Ser. Earth Environ. Sci. 253
[36] Moore A M, Tassakka A C M, Ambo-Rappe R, Yasir I, Smith D J and Jompa J 2019 Unexpected discovery of Diadema clarki in the Coral Triangle Mar. Biodivers. 49 1–19
[37] Ndobe S and Moore A 2013 Banggai cardinalfish (Pterapogon kauderni) populations (stocks) around Banggai Island, a geometric and classical morphometric approach PeerJ Prepr. 2013 1–31
[38] Lunn K E and Moreau M-A 2004 Unmonitored trade in marine ornamental fishes: the case of Indonesia’s Banggai cardinalfish (Pterapogon kauderni) Coral Reefs 23 344–51
[39] NACA-STREAM 2005 The Indonesian ornamental fish trade: case studies and options for
improving livelihoods while promoting sustainability in Banggai and Banyuwangi (Bangkok: Support to Regional Aquatic Resources Management (STREAM), Network of Aquaculture Centres in Asia (NACA) (STREAM))

[40] Wiadnyana N N, Suharti S R, Ndobe S, Triharyuni S, Lilley G R, Risuana S, Wahyudi D and Moore A M 2020 Population trends of Banggai cardinalfish in the Banggai Islands, Central Sulawesi, Indonesia IOP Conf. Ser. Earth Environ. Sci. 420 1–9

[41] Pauly D 1995 Anecdotes and the shifting baseline syndrome of fisheries Trends Ecol. Evol. 10 430