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RESEARCH ARTICLE

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Monitoring the endemic ornamental fish *Pterapogon kauderni* in Bokan Kepulauan, Banggai marine protected area, Indonesia

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Abstract. The Banggai cardinalfish *Pterapogon kauderni* is a species of national and international conservation concern. Established in November 2019, the Banggai marine protected area (MPA) in Central Sulawesi, Indonesia covers most of the endemic range of this ornamental fish. The third repeat survey (T2 monitoring) under the National Action Plan for Banggai Cardinalfish Conservation (NAP-BCFC) was carried out in October 2019 at eight sites in the Bokan Kepulauan region within the MPA. The T2 monitoring used the standard NAP-BCFC belt transect method. Data were collected on *P. kauderni* abundance (by size class: recruits, juveniles, adults) and microhabitat (sea urchins, sea anemones, hard corals, and others). Data were evaluated with respect to the T0 (2017) survey and T1 (2018) monitoring at the same sites, as well as previous surveys in 2004 (2 sites) and 2012 (4 sites). The data show wide between-site variation in *P. kauderni* and microhabitat parameters, with one subpopulation at very high risk of extirpation. Trends included declines over time in *P. kauderni*, sea urchin and sea anemone abundance, with an increase since 2017 in hard coral microhabitat use by adult *P. kauderni*. We recommend evaluation of other *P. kauderni* populations in Bokan Kepulauan and specific site or zone-based actions. However, we conclude that the most urgent priority for *P. kauderni* conservation in Bokan Kepulauan is protection of key microhabitat through a moratorium on sea urchin and sea anemone collection in *P. kauderni* habitat.
Keywords: Banggai cardinalfish, endangered species, marine conservation, microhabitat, monitoring, ornamental fishery, CITES

Introduction

The Banggai cardinalfish *Pterapogon kauderni* (Koumans 1933), commonly referred to by the abbreviation BCF (Ndobe *et al*., 2005), is a small apogonid with an extremely limited native distribution of approximately 5000 km^2 (Vagelli, 2011). Most of this endemic distribution lies within the new Banggai MPA officially established on 27 November 2019 under Ministerial Decree of the Minister for Marine Affairs and Fisheries of the Republic of Indonesia Number 53/KEPMEN-KP/2019. The decree specifically states conservation of the Banggai cardinalfish and its habitat in the rationale for establishing the MPA. While the Banggai MPA covers 8566.4913 km^2 in the waters around Banggai, Banggai Laut and Banggai Kepulauan Districts, Central Sulawesi Province, Indonesia, the total natural (endemic) habitat of *P. kauderni* within the MPA is limited to less than 30 km^2 around less than 30 islands in the Banggai Archipelago (Fondation Franz Weber, 2017; Vagelli, 2011).

The unusual life history of *P. kauderni* (Ndobe *et al*., 2013a; Vagelli, 2011) is thought to be responsible for the extremely fine genetic population structure observed (Bernardi & Vagelli, 2004; Hoffman *et al*., 2005; Vagelli *et al*., 2009; Ndobe, 2013). Although data on *P.*

kauderni genetic population structure are limited, combining these existing data with inferences based on physical and ecological barriers to natural demographic and genetic connectivity indicates a minimum of 21 demographically and genetically distinct subpopulations (*sensu* IUCN, 2012), most likely more than 30 (Moore *et al.*, 2017; Ndobe *et al.*, 2018a, 2019). Most (potentially all) of these subpopulations are likely to meet criteria for an Evolutionarily Significant Unit (ESU) as defined by (Moritz, 1994; Waples, 1995, 2008). As was highlighted in a study commissioned for the 30th CITES (Convention on the International Trade in Endangered Species of Wild Fauna and Flora) Animals Committee meeting in 2018 (Ndobe *et al.*, 2018a), each of these subpopulations/putative ESUs should be considered as a separate management unit or, in fisheries management terms, a separate stock.

The attractiveness of *P. kauderni* to the marine aquarium hobby has led to heavy exploitation of many populations by the ornamental fishery since the mid-1990's (Kolm & Berglund, 2003; Lunn & Moreau, 2004; Moore *et al.*, 2011, 2020a; Ndobe & Moore, 2008; Ndobe *et al.*, 2005, 2013a, 2018a; Vagelli & Erdmann, 2002). The marine ornamental trade has also been responsible for most of the known introduced populations outside the *P. kauderni* endemic range, although several are the result of government programs, for example the Ambon introduced population (Wibowo *et al.*, 2019). While only the Lembeh Straits introduced population is reported as invasive and potentially detrimental to native species (Carlos *et al.*, 2014; Erdmann & Vagelli, 2001), none can be classified as "benign introductions" under IUCN (2012) criteria (Moore *et al.*, 2020a; Ndobe *et al.*, 2018a).

A small, sedentary fish with essentially no means of defence, *P. kauderni* is highly dependent on protective microhabitat, i.e. benthic organisms with which the "BCF" lives in facultative symbiosis (Moore *et al.*, 2012; Ndobe *et al.*, 2013b, 2013c; Vagelli, 2011). Although a wide range of microhabitats are reported, the three most common and arguably most important are sea urchins of the Family Diadematidae; sea anemones; and hard corals, mostly branching and foliose life-forms (Moore, 2019; Ndobe *et al.*, 2013b, 2017; Vagelli, 2011). A paternal mouthbrooder with direct development (Vagelli, 1999), post-larval *P. kauderni* (generally referred to as recruits) are released from the male parent's mouth around 7-10 days after hatching (Vagelli & Volpedo, 2004; Vagelli, 1999; Ndobe *et al.*, 2013a). These recruits are at considerable risk of predation, including cannibalism by con-specific adults (Ndobe *et al.*, 2013a, 2013c).

The relative importance of each microhabitat type varies between *P. kauderni* life-stages, a phenomenon known as "ontogenetic shift" (Vagelli, 2004). Sea anemones and the anemone-like mushroom coral *Heliofungia actiniformis* are particularly important for *P. kauderni* recruits and small juveniles, corals for larger juveniles and adults, and sea urchins for all life-stages (Moore, 2019; Moore *et al.*, 2012; Ndobe *et al.*, 2013b, 2013c; Vagelli, 2004, 2011). The importance of diadematid sea urchins is reflected in local names such as the Bajo *bebese tayung* meaning small sea urchin fish (Ndobe *et al.*, 2005). At least two (Ndobe *et al.*, 2018b) and possibly more (Moore *et al.*, 2019a) species of the genus *Diadema* serve as *P. kauderni* microhabitat. Association of *P. kauderni* with the genus *Echinothrix* also appears to be relatively common (Moore, 2019; Moore *et al.*, 2019a; Ndobe *et al.*, 2013a, 2018b), while association with *Astropyga* has been reported when this genus was present (Moore, 2019; Moore *et al.*, 2019a; Ndobe *et al.*, 2018b; Talbot *et al.*, 2013).

Listed as Endangered in the IUCN (International Union for the Conservation of Nature) Red List (Allen & Donaldson, 2007), *P. kauderni* has been twice proposed for listing under CITES Appendix II. The Indonesian Government has compiled a National Action Plan for Banggai Cardinalfish Conservation (NAP-BCFC) (Rusandi *et al.*, 2016). One action under the NAP-BCFC for 2017-2021 is annual monitoring of selected *P. kauderni* populations. The initial (T0) survey took place in October 2017 and the first monitoring (T1) in October

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2018. Eight of these monitoring stations are in the Bokan Kepulauan Sub-District of Banggai Laut District. The second (T2) monitoring was conducted in October 2019.

Materials and Methods

The eight annual Banggai cardinalfish (BCF) monitoring sites in Bokan Kepulauan Sub-District are shown on the map of the new Banggai MPA, extracted from Ministerial Decree No. 53/KEPMEN-KP/2019 (Figure 1).

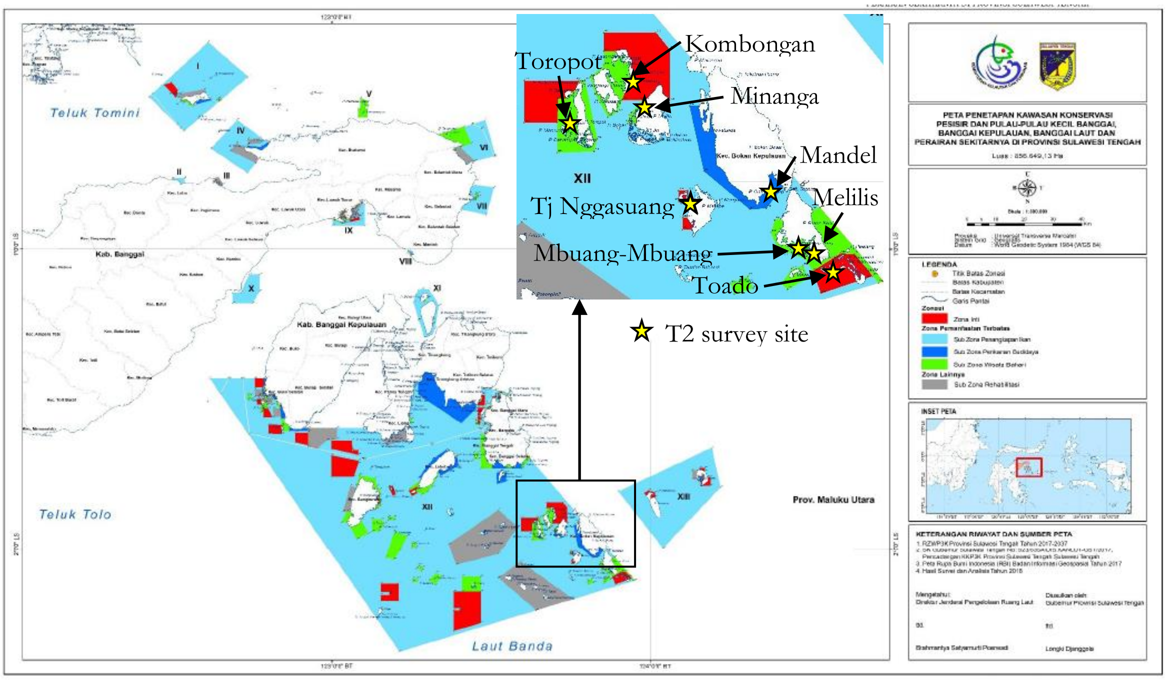

Figure 1. Basemap: Official map of the new Banggai MPA. Insert: the 8 Bokan Kepulauan monitoring sites. Colour codes: red = core zone; Restricted use zone: light blue = fishing sub-zone; dark blue = mariculture sub-zone; green = marine tourism sub-zone; Other zones: grey = rehabilitation sub-zone

Table 1 provides coordinates of these sites and the years in which data has been collected under the National Action Plan for Banggai Cardinalfish Conservation (NAP-BCFC). Sites at which similar surveys were conducted in 2004 (Ndobe *et al.*, 2005) and 2012 (Ndobe, 2013; Ndobe *et al.*, 2013b) are also shown.

Table 1. Monitoring site coordinates and data collection years at each site

No	Site	Coordinates		Year of BCF Survey/Monitoring				
		Latitude S	Longitude E	2004[a]	2012[b]	2017[c]	2018[d]	2019[e]
1	Toado	02º04'52.4"	123º54'28.7"	-	Y	Y	Y	Y
2	Melilis	02º04'37.5"	123º52'19.7"	-	-	Y	Y	Y
3	Mbuang-Mbuang	02º04'19.0"	123º52'10.4"	-	[f]	Y	Y	Y
4	Mandel	01º59'51.9"	123º50'32.8"	-	-	Y	Y	Y
5	Tj Nggasuang	02º00'41.6"	123º46'22.0"	Y	Y	Y	Y	Y
6	Minangga	01º55'31.9"	123º42'28.7"	-	-	Y	Y	Y
7	Kombongan	01º52'47.4"	123º41'23.0"	-	Y	Y	Y	Y
8	Toropot	01º56'33.6"	123º38'03.5"	Y	Y	Y	Y	Y

[a] (Ndobe *et al.*, 2005); [b] (Ndobe *et al.*, 2013b); [c] Baseline T0; [d] Monitoring T1; [e] Monitoring T2
[f] Different coordinates from T0-T2 monitoring – therefore not directly comparable

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The T2 monitoring (third annual survey under the NAP-BCFC) was conducted in October 2019 using the standard belt transect method previously used in the T0 NAP-BCFC baseline survey (Ndobe *et al*., 2018a) and the T1 monitoring (Wiadnyana *et al*., 2020). This method is very similar to that used in previous surveys (e.g. Ndobe *et al*., 2005, 2013b). During the T2 monitoring, data were collected from at least six 100 m^2 transects per site (Figure 2), with seven transects placed at two sites (Toado and Tj Nggasuang), thus making a total of 50 transects.

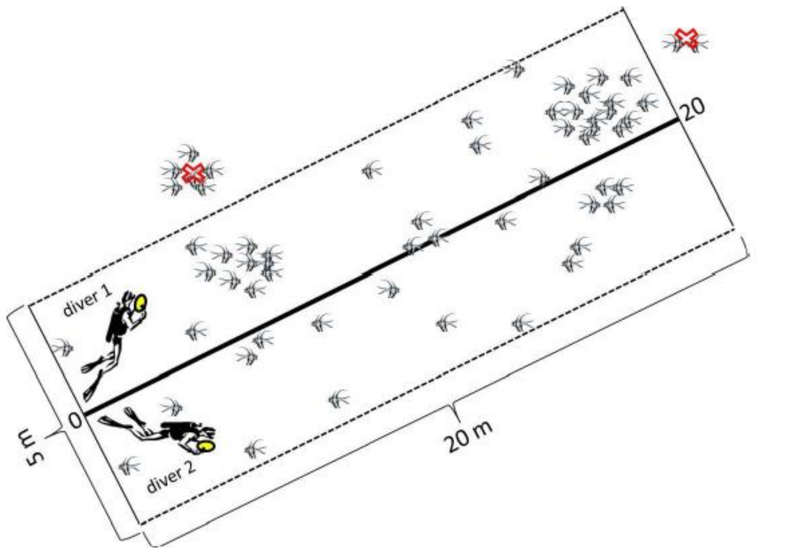

Figure 2. Belt transect used for monitoring BCF (Wibowo *et al*., 2019). Following NAP-BCFC guidelines, each observer collects data in a 2.5 m wide strip, one to the left and one to the right of a 20m tape laid approximately parallel to the shoreline in BCF habitat. Note: for each group of BCF within the transect, the number of individuals in each size class is counted and associated microhabitat type(s) noted. Sea urchins and sea anemones within the transect are counted.

Data were collected for each group of *P. kauderni* (BCF) in each transect. BCF were counted by size class based on standard length (SL), with three classes: recruit (SL<18 mm); juvenile (18 mm≤ SL≤ 35 mm); and adult (SL>35 mm). Microhabitat associations of each group were recorded by type: sea urchin, sea anemone, hard coral, soft coral, seagrass and other, following the NAP-BCFC guidelines. The number of individual sea urchins and sea anemones present within the transect were also counted.

In addition to these standard data, microhabitat associations were mostly recorded at a higher level of taxonomic resolution than that mandated in the NAP-BCFC guidelines. Genus and (where possible) species were noted for sea urchins and sea anemones. For hard corals, GCRMN Lifeform (English *et al*., 1997) and (where possible) genus (Kelley, 2011) were noted. “Other” category microhabitats were identified to the lowest possible taxonomic level (biotic) or described (abiotic).

Monitoring data were tabulated and analysed descriptively in Microsoft Excel 2007. The results were compared with previous survey/monitoring data and evaluated in the context of the Banggai MPA established by KepMen 53/2019 on 27 November 2019. Linear model analysis was implemented using the lm function in R version 3.6.0, in the RStudio version 1.1.456 environment. The input parameters were site, year, mean number of *P. kauderni* (recruits, juveniles, adults and all sizes/total), number of sea urchins and number of sea anemones per transect. Data were input from 8 sites in 2017 (T0), 2018 (T1) and 2019 (T2, this study), 4 sites in 2012 (Ndobe, 2013) and 2 sites in 2004 (Ndobe *et al*., 2005). Significance was evaluated at 95%, 99% and 99.9% levels of confidence (P< 0.05. 0.01 and 0.001, respectively).

Results

Abundance of *P. kauderni* and associated microhabitat

The synopsis of T2 BCF monitoring data from 8 sites in Table 2 shows that abundance of *P. kauderni* varied considerably between sites. Microhabitat abundance and association also differed markedly.

Table 2. Monitoring data (T2, 2019) from 8 sites in Bokan Kepulauan - mean abundance per transect (100m^2) of *P. kauderni* and key microhabitat

No.	Site	*Pterapogon kauderni* (BCF)				Microhabitat	
		Recruit	Juvenile	Adult	Total	Sea urchin	Anemone
1	Toado	20.0	237.7	93.4	351.1	1.3	2.6
2	Melilis	61.3	30.2	35.2	126.7	53.7	0.3
3	Mbuang Mbuang	31.0	21.8	23.0	75.8	24.3	0.5
4	Mandel	13.6	0.0	1.9	15.4	0.0	2.1
5	Tj Nggasuang	1.7	27.0	49.8	78.5	19.2	0.0
6	Minangga	9.8	24.3	15.2	49.3	0.0	2.7
7	Kombongan	26.7	25.2	40.2	92.0	0.0	1.7
8	Toropot	102.0	93.8	148.5	344.3	23.0	0.7
Average (50 transects)		32.6	60.0	50.8	143.3	14.6	1.4

Correlation between *P. kauderni* and microhabitat abundance

The linear model (lm) found no significant correlation ($p>0.05$) or weak correlation ($r^2 < 0.2$) for most possible linear models. In general, the most parsimonious models (one ~ one, or one ~ two factors) gave the highest R^2 and lowest P values. The value of R indicates the proportion of observed variance explained by the model. A synopsis of the most significant correlations (statistically and in terms of ecological relevance) is shown in Table 3.

Table 3. Significant correlations between model parameters (lm function in R)

No.	Linear model	*P* value	R^2	*R*	Remarks
1	Urchins ~ Year	< 0.001	0.83	0.91	Decline. Year + Site gave $R^2 \approx 0.93$
2	Anemones ~ Year	< 0.001	0.65	0.81	Decline. Year + Site gave $R^2 \approx 0.86$
3	All BCF ~ Year	< 0.05	0.31	0.55	Decline. Groups: 2004/12, 2017-19
4	Recruits ~ Urchins	< 0.01	0.23	0.48	Positive correlation
5	Juveniles~Anemones	< 0.001	0.43	0.66	Positive correlation
6	All BCF~Anemones	< 0.001	0.35	0.59	Positive correlation

Graphics in Figure 3 show relationships tested under the linear model, in the form of boxplots (numeric variable versus nominal factor) or linear regression plots (two numeric variables). The decline in sea urchin and sea anemone abundance is clearly visible in Figures 2a and 2b.

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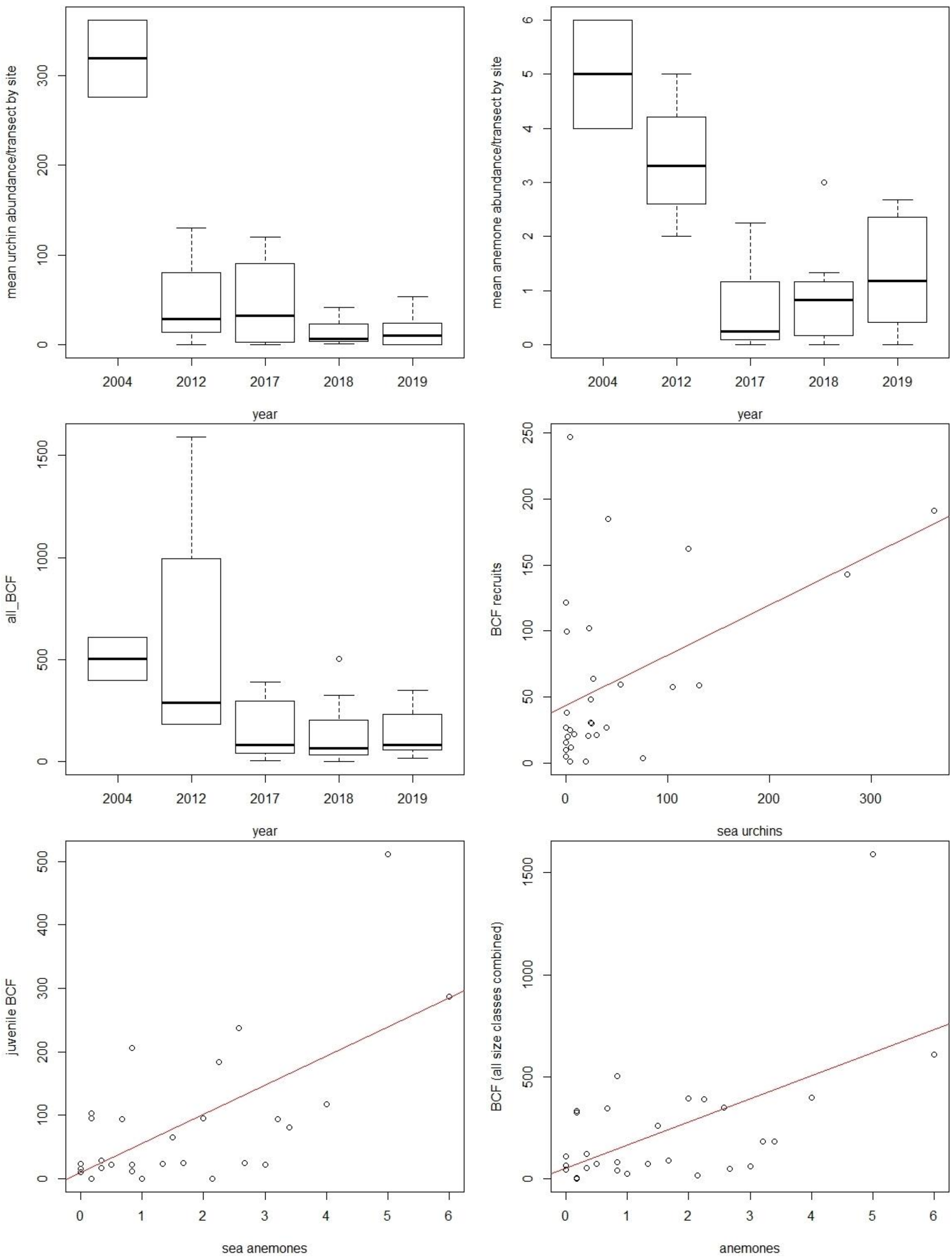

Figure 3. Graphs displaying significant correlations (P < 0.05) between model variables: a. sea urchin abundance by year; b. sea anemone abundance by year; c. *Pterapogon kauderni* (BCF) abundance by year; d. BCF recruit abundance versus sea urchin abundance; e. juvenile BCF abundance versus sea anemone abundance; f. all BCF abundance versus sea anemone abundance.

Changes in *P. kauderni* microhabitat associations

The percentage of *P. kauderni* associated with each microhabitat class by year (all sites and *P. kauderni* size classes aggregated) shows an ongoing decline in association with sea

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urchins (Figure 4). A shift in the species composition of sea urchin communities also occurred, with an increase in both the absolute abundance of *Echinothrix* and the relative abundance of this genus compared to *Diadema*. The proportion of *P. kauderni* associated with hard corals increased from 6% to 27.4% from 2017 to 2019. A small proportion of these coral-associated fish were recruits and small juveniles, all of which were associated with the anemone-like mushroom coral *Heliofungia actiniformis*. In 2019, the proportion of *P. kauderni* recruits associated with *H. actiniformis* varied by site from 0% at four sites to 17% at the Minanga site, representing just under 5% of all recruits recorded (n = 1639).

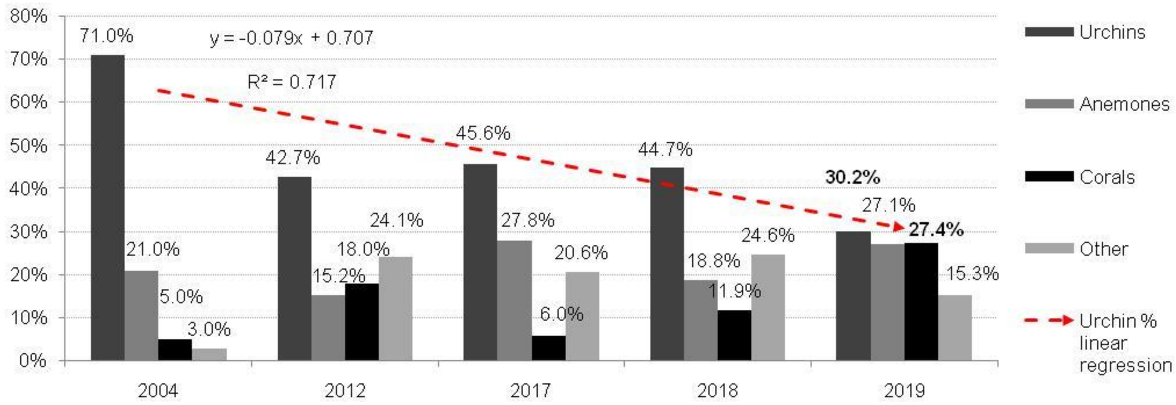

Figure 4. Percentage association of *P. kauderni* in Bokan Kepulauan with four microhabitat types (2004-2019)

There was no clear trend in the proportion of *P. kauderni* associated with sea anemones. The relatively small changes in proportion over the period 2017-2019 seemed to follow the sea anemone abundance trends (overall and at site level). However, the species of anemone present at the monitoring sites changed over time. There was an increase in the proportion of fire anemones (genus *Actinodendron*) and a decline in the diversity and abundance of the other nine *P. kauderni* host anemone species (Table 4).

Table 4. *Pterapogon kauderni* sea anemone microhabitat diversity from 2012-2019

No.	Species	2012	2017	2019	Trend
1	*Actinodendron* sp.	X	X	X	Increase
2	*Entacmaea quadricolor*	X	X	X	Fewer
3	*Heteractis crispa*	X	X	X	Fewer
4	*Heteractis magnifica*	X	X*	X*	Sharp decline
5	*Heteractis malu*	X*			No longer seen
6	*Heteractis aurora*	X*			No longer seen
7	*Stichodactyla gigantea*	X	X	X*	Sharp decline
8	*Stichodactyla haddoni*	X			No longer seen
9	*Stichodactyla mertensii*	X	X*		No longer seen
10	*Macrodactyla doreensis*	X	X	X*	Sharp decline

* One or very few individuals observed

Discussion

Despite considerable variation between the 8 monitoring sites in Bokan Kepulauan, overall the monitoring data show declining trends in the abundance of *Pterapogon kauderni* and that of key microhabitat organisms (sea urchins of the genus *Diadema* and nine out of ten host sea anemone species). The shift in microhabitat association towards hard corals mirrors the decline in populations of the sea urchins *Diadema setosum* and *D. savignyi* (Figure 4). While this shift demonstrates the adaptability of adult *P. kauderni*, overall the results reinforce the view that recruit and juvenile survival is highly dependent on sea urchin and sea anemone microhabitat. Although *P. kauderni* recruitment success peaks in September-November (Ndobe *et al*., 2013a), spawning occurs every month (Vagelli, 2011; Prihatiningsih & Hartati, 2012). With year-round reproduction, the significant correlation between anemone abundance and the abundance of juvenile *P. kauderni* as well as total *P. kauderni* population abundance likely reflects the cumulative effects of survival of many successive cohorts. Such a cumulative effect could explain the lack of significant correlation between sea anemone abundance and recruit abundance in this study, despite strong empirical evidence for the importance of host anemones in *P. kauderni* reproductive success, specifically with regard to recruit survival (Ndobe *et al*., 2013c; Vagelli, 2004). Survey timing is crucial to observing or missing the presence of new recruits. For example, in 2019 very few recruits were observed at Toado, despite relatively high abundance of sea anemones; however an exceptionally large number of brooding males were observed. Thus, had the survey been made a few days later, the results would likely have been very different with respect to recruits, but not for other size classes.

The results of this study reinforce the view that certain relationships are non linear, in particular the relationship between *P. kauderni* and microhabitat abundance and the correlation between adult *P. kauderni* abundance and recruit survival. With respect to the relationship between sea urchin abundance and total *P. kauderni* abundance, previous research found a strong and significant correlation, but only in a certain range of urchin densities (Ndobe, 2013), with very little impact below or above this range. The observed recruit versus adult abundance data indicate a positive relationship at low *P. kauderni* densities, which reaches a plateau at around 50 individuals/100m^2 followed by a long declining tail at higher densities. This would be consonant with an increasing prevalence of cannibalism at higher densities, as implied by (Moore, 2019; Ndobe, 2013; Ndobe *et al*., 2013c), especially where protective microhabitat is a limiting factor. Such a pattern would account for the strong negative relationship between overall *P. kauderni* density and the relative abundance (proportion) of recruits reported by previous research (Ndobe, 2013; Ndobe *et al*., 2013c), which at first glance appears contradictory to the intuitive assumption that more adults will produce more offspring.

These data further reinforce the need for a holistic, subpopulation or ESU-based approach to conserving the Banggai cardinalfish and its habitat/microhabitat, as recommended *inter alia* by (Moore *et al*., 2017; Ndobe *et al*., 2013b, 2018a; Wiadnyana *et al*., 2020). Such an approach is vital, to conserve the species within its native (endemic) range, but also the intra-species biodiversity of *P. kauderni*. In the context of the new Banggai MPA, the zonation status of each site is also a key factor to be considered, as this will limit the options allowed or likely to receive support for managing each subpopulation/ESU (Table 5).

Table 5. Bokan Kepulauan BCF monitoring site zonation and subpopulation status

Site status			*P. kauderni* subpopulation status	
No	Site Name	Zone	ESU probability	Population trend
1	Toado	Core	Very high	Stable/slight decrease
2	Melilis	Marine tourism	Most likely both part of one ESU	Both sites relatively stable, slight increase
3	Mbuang-Mbuang	Marine tourism		
4	Mandel	Aquaculture	Very high	High risk of extirpation
5	Tj Nggasuang	Fishing	Very high	Recovering from near-extirpation in 2018
6	Minangga	Marine tourism/ Fishing	Very high	Slight decrease
7	Kombongan	Marine tourism	Very high	Recovering
8	Toropot	Marine tourism	Very high	Stable/slight increase

As shown in Table 5, it is very likely that the eight monitoring sites in Bokan Kepulauan comprise seven subpopulations, each of which has a very high likelihood (based on genetic and/or biogeographical data) of qualifying as an ESU (Moore, 2019; Moore *et al*., 2017). The majority (five sites, 4 putative ESUs) are wholly or (in the case of Minanga) partly in the marine tourism sub-zone of the restricted use zone. The remainder are each in a different zone or sub-zone. There are several other subpopulations in Bokan Kepulauan Sub-District, at least two of which, around the islands of Sonit and Tempaus, have a very high likelihood of being ESUs based on genetic data as well as their extreme (in the context of *P. kauderni*) geographic isolation (Vagelli *et al*., 2009; Ndobe *et al*., 2011; Moore *et al*., 2017). The reported *P. kauderni* population distributions around these two islands occur in both core and fishing zones, and an assessment of these populations is highly recommended.

Opportunities for involving the existing community tourism group in Mbuang-Mbuang, the community coast-watch (*Pokmaswas*) groups in the area, and other community actors should be maximised, especially as this area is remote with poor or as yet non-existent telecommunications and limited accessibility. In addition, since the revised Regional Autonomy law (UU 23/2014) was implemented, there has been no *de facto* surveillance and enforcement of fisheries and coastal/marine resource related regulations. Specific recommendations by site or group of sites are outlined below.

The unique Toado site in the core zone is in relatively good condition, with a close to stable *P. kauderni* population. Effective enforcement of core zone regulations and regular monitoring (a permitted activity with official permission) are recommended. Although, as for all endemic *P. kauderni* populations, the long-term outlook is dire unless anthropogenic climate change can be effectively limited (Moore, 2019; Moore *et al*., 2019b, 2019c), with appropriate protection the short-term outlook for this population can be considered good.

The sites in marine tourism zones (Mbuang-Mbuang, Melilis, part of Minanga, Kombongan and Toropot) could all be described as in average condition, having suffered significant degradation but still able to support relatively robust *P. kauderni* populations. The greatest threat to *P. kauderni* populations at these sites appears to be declines in microhabitat abundance. As reported in previous years, the main driver of these declines appears to be collection (gleaning), mostly for human consumption. Recommendations include the promulgation of specific regulations to limit or place a moratorium on *Diadema* and sea anemone collection, accompanied by implementation mechanisms and awareness building.

The clownfish and *P. kauderni* hosting sea anemones are long-lived, slow-growing animals with low natural post-settlement mortality, thought to have density-dependent fertilisation and irregular recruitment (Hobbs *et al*., 2013; Scott, 2017). These traits make the host anemones intrinsically vulnerable to over-exploitation (Scott, 2017). While the clownfish-anemone symbiosis (Fautin & Allen, 1992) is arguably the best known, many other fish-anemone and invertebrate-anemone associations are reported (Fautin & Randall, 2002; Karplus, 2014; Mebs, 2009). This means that loss of sea anemones will not only negatively affect *P. kauderni* abundance and/or population resilience, but is likely to have wider biodiversity impacts. Passive conservation could be supplemented by active stock enhancement through asexual propagation of sea anemones, including *Stichodactyla gigantea*, *Heteractis crispa* and *Entacmaea quadricolor*, and most likely other host species, with the exception of the genus *Actinodendron* (Moore, 2019; Moore *et al*., 2020b). Recommendations include seeking potential donor sites and *in-situ* trials of active sea anemone rehabilitation at anemone-depleted non core-zone sites.

The sites in the fishing sub-zone (Tj Nggasuang and part of Minanga) both have the potential, if well-managed, to contribute to a sustainable ornamental fishery. Indeed, in 2004 Tj Nggasuang had been sustainably exploited with a three-month rotation period for several years, and had the highest *P. kauderni* density of any site surveyed (Ndobe *et al*., 2005). The density was in fact higher than that of the un-fished "pearl farm" site used as a control by, *inter alia*, Vagelli (2011) in estimating the potential density and total abundance of pre-exploitation *P. kauderni* populations. However, a sustainable fishery would only be an option if accompanied by microhabitat rehabilitation (at a minimum passive, i.e. moratorium on collection), with limits on the volume (based on monitoring) and timing (e.g. 3 month intervals) of ornamental fishing. As suggested in Ndobe *et al.* (2018a) and Moore *et al.* (2020a), rights-based fisheries with several fishing grounds per rights-holder (group or individual) would be one way to manage such a fishery efficiently and potentially sustainably from economic and ecological viewpoints.

Mandel, in the aquaculture sub-zone south of Bokan Island is a subpopulation/ESU on the verge of extirpation. The example of Tj Nggasuang indicates that recovery might still be possible. The *P. kauderni* habitat at the Mandel site is intensively gleaned, indeed gleaning activity was observed during the T2 survey. No live adult sea urchins were seen, although a few juveniles were sheltering in crevices and some empty shells were visible. In 2017, urchins of the genus *Diadema* were abundant at this site, with over 75 individuals/transect, a density higher than at any site in 2019 (Table 2); however, no juvenile *P. kauderni* were found, reportedly due to intensive harvesting for the ornamental trade. Each year (2017-2019), despite a continuous decline in the number of adults, recruits were produced; however, it would appear that these recruits did not reach adulthood. Whether this was due to microhabitat gleaning, the ornamental fishery, or a combination, it is hard to determine. While *P. kauderni* typically form larger groups, most of the remaining (13) adult fish at this site were in pairs (5 pairs and 3 lone fish), possibly a strategy to maximise breeding potential in such a depleted population. If this population is to survive, the most urgent recommendation is an immediate moratorium on microhabitat collection, in the hopes that this would enable sea urchin stocks to rebuild, protect the remaining anemones, and encourage recruitment. If extirpation does occur before or despite such efforts, then this is one case where there could be a rationale for a "benign" introduction *sensu* IUCN (2012). In such a case, fish to be released should be checked for health, and preferably come from a subpopulation (ESU) nearby (maximise likelihood of genetic similarity) or with similar environmental conditions (maximise likelihood of similar selection pressures or phenotypic adaptation).

Conclusion

Monitoring of eight Banggai cardinalfish (*Pterapogon kauderni*) sites (7 putative sub-populations to be considered as ESUs or stocks) in the Bokan Kepulauan Sub-District highlights the need to conserve microhabitat, in particular sea urchins and sea anemones, in order to maintain or rehabilitate *P. kauderni* stocks. Under the new MPA zonation, one subpopulation (stock or ESU) is in the core zone. Of the remaining 6 putative stocks in the restricted use zone, 5 stocks are the marine tourism and/or fishing sub-zones. Only one stock (Mandel) is in the aquaculture sub-zone and is in critical condition, at imminent risk of extirpation, while *Diadema* urchins have already been effectively extirpated at this site. While a moratorium on sea urchin and sea anemone collection is suggested for all *P. kauderni* habitat in the Bokan Kepulauan, it is especially urgent at this heavily gleaned site. Assessment of other *P. kauderni* subpopulations in Bokan Kepulauan is strongly recommended, in particular the subpopulations on Sonit and Tempaus, the remotest islands in the Bokan island group.

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