Population trends of Banggai cardinalfish in the Banggai Islands, Central Sulawesi, Indonesia

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Abstract. The Banggai cardinalfish (BCF) (Pterapogon kauderni) is endemic to the Banggai Archipelago, Indonesia and has received international attention due to the decline in its population. As the sole range state, Indonesia has a responsibility to conserve the BCF through initiatives for its sustainable management. To inform management and evaluate management effectiveness, a research program has been set up to monitor BCF populations at 24 sites. The initial (T₀) baseline survey in 2017 was followed by the first annual monitoring (T₁) in 2018. At each site, data collected in 6 belt transects (20 x 5m) comprised BCF density by size class, and microhabitat density (sea urchins and sea anemones). The Students t-test was applied to test for significant differences in BCF population density between T₀ and T₁ results, and correlation with influencing factors was evaluated using multiple regression (α = 0.05). The overall adult population trend was positive, despite declines in BCF density at some sites. BCF density was positively correlated with both sea urchin and sea anemone densities; however, the correlation with sea anemone density was stronger. These results reinforce the importance of protecting sea anemone and sea urchin microhabitat, as part of a holistic approach to rehabilitating and sustaining BCF stocks.

1. Introduction
The decline in Banggai cardinalfish (Pterapogon kauderni Koumans, 1933) populations in the Banggai Archipelago, Central Sulawesi, Indonesia, is an issue which has attracted worldwide attention. Traded as a marine ornamental fish, mainly for export, there are strong indications that intensive collection is a major cause of this decline [1-5]. This small, attractive fish is among the top 10 tropical marine species imported into the US [6].

Other threats than that can have a significant negative impact on BCF populations include habitat loss and degradation due to human activities such as coastal development and destructive fishing [7-9]. The BCF associates with benthic organisms (microhabitat), especially sea urchins, sea anemones,
and hard corals [10-13], which can also be affected by local human activities [14]. Besides, anthropogenic climate change [15, 16] and natural disasters such as earthquakes, tsunamis, and extreme weather events [17] can also impact BCF populations both directly and through impacts on BCF microhabitat abundance.

Within the sole range state of Indonesia, the endemic distribution of *P. kauderni* is limited to 30-34 km² of shallow-water habitat, spread across around 5,000 km² in the Banggai Archipelago, Central Sulawesi Province and a few islands off Taliabu, North Maluku Province [2]. Based on data from 2001-2004, the total native (endemic) BCF population was estimated at 2.4 million, corresponding to an average density of 0.07 fish/m² [2, 18]. Around 10 years later, the total native BCF population was estimated at 1.5-1.7 million, or an average density of 0.05/m² [3]. Monitoring from 2010-2012 also indicated declining Banggai cardinalfish populations at several sites [5]. Based on The Nature Conservancy (TNC) criteria [19] the Banggai cardinalfish is intrinsically vulnerable to extinction [20]. Furthermore, the lack of a pelagic phase [21] and sedentary habit [22] of the BCF result in an extremely limited capacity for dispersal and make the BCF highly vulnerable to serial extirpation [17]. To date, at least two BCF populations have been extirpated within the native range of the species [2, 3].

In 2007, the conservation status of the BCF was evaluated based on International Union for Conservation of Nature (IUCN) criteria, and the species listed as Endangered in the IUCN Red List [23]. Meanwhile, BCF continued to be captured to meet the demand of the international ornamental fish market [5, 24]. In 2013, over 150,000 BCF were shipped from Luwuk, in Central Sulawesi. Shipments to export centers recorded by the Fish Quarantine service in 2015 and 2016 were around 500,000 BCF/year, with an unknown volume of unrecorded shipments [4, 25].

The BCF is the first marine ornamental fish to become an international issue concerning the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), with proposals for CITES Appendix II listing in 2007 and 2016. Furthermore, based on an assessment conducted in 2014-2015 [26], the United States government listed *P. kauderni* as a threatened species under the Endangered Species Act (ESA) in January 2016. At the 17th CITES Conference of Parties (CoP), a resolution was passed calling on Indonesia take steps to implement steps to conserve the BCF, and to ensure that international trade did not cause a decline in (native) wild populations.

To safeguard and ensure the continued existence of BCF populations in the waters around the Banggai Islands, the Ministry of Maritime Affairs and Fisheries (MMAF) issued Decree of the Minister of Marine and Fisheries Number: 49/KEPMEN-KP/2018 concerning the Establishment of Banggai Cardinal Fish Restricted Protection Status. This Decree was one management step to restore BCF populations within the native distribution of the species, as part of the National Action Plan for Banggai Cardinalfish Conservation (NAP-BCF) [27]. In addition, a Regional Marine Conservation Area was established through Decree of the Governor of Central Sulawesi No. 523/635A/DIS.KANLUT-GST/2017. With an area of 869,059.94 ha, this marine protected area (MPA) comprises around 90% of the BCF endemic distribution.

To support the management of this fish in the waters around the Banggai Islands in Central Sulawesi, it is vital to evaluate and monitor the condition of Banggai cardinalfish stocks. Therefore, the NAP-BCF calls for annual BCF population surveys. This study covers the initial (*T₀*) survey in 2017 (collection of initial/baseline data) and the first annual monitoring survey (*T₁*) in 2018. Through comparing the results of these two surveys, this study evaluates the status and trends of representative BCF populations in the Banggai Archipelago before and after initial management steps were implemented.

2. Methods

Field surveys were conducted in October 2017 (*T₀*) and November-December 2018 (*T₁*). Data were collected at 24 sampling locations (BCF population sites) within the Banggai Archipelago (Figure 1).
**Figure 1.** Map showing the 24 data collection sites in the Banggai Archipelago, Central Sulawesi Province, Indonesia.

Banggai cardinalfish (BCF) and microhabitat (sea urchins and sea anemones) abundance were estimated through visual surveys by pairs of divers (with SCUBA or snorkeling equipment) using a belt transect method. Each transect was 20 m long and 5 m wide (100 m$^2$) with 6 randomly placed replicates giving a total survey area of 600 m$^2$ per site. BCF were counted by size class based on standard length (SL): recruits < 1.8 cm SL; juvenile 1.8-3.5 cm SL, adults > 3.5 cm SL. Microhabitat association of each BCF was recorded (soft corals = SC; hard corals = HC; seagrass = SG; sea urchins = SU; sea anemones = SA, other = OT). Sea urchins and sea anemones were also counted.

BCF density was calculated per transect, site, and overall. Significance was evaluated at $\alpha = 0.05$. The correlation between BCF and microhabitat abundance was evaluated through multiple regression.

**3. Results**

**3.1. Banggai cardinalfish (BCF) density**

The density of BCF populations, overall and by size category, varied greatly between sites in both surveys. Mean abundance of adult-sized BCF was higher in 2018 than in 2017, while BCF recruits and juveniles were more abundant in 2017 (Table 1).
Table 1. BCF density by size category (24 sites).

| Value       | BCF density (T0) (fish/m$^2$) | BCF density (T1) (fish/m$^2$) |
|-------------|-------------------------------|-------------------------------|
|             | Recruit | Juvenile | Adult | Recruit | Juvenile | Adult |
| Minimum     | 0.003   | 0.000    | 0.023 | 0.013   | 0.000    | 0.000 |
| Maximum     | 2.108   | 4.220    | 1.940 | 2.470   | 2.055    | 2.808 |
| Mean        | 0.479   | 0.596    | 0.479 | 0.390   | 0.419    | 0.560 |

Sites with particularly abundant BCF populations were Bone Baru Village, Toado and Toropot, with mean BCF densities of 6.35, 4.48 and 3.29 fish/m$^2$, respectively. No juveniles were observed at the Mandel site in either year, and no adults were seen at Tj Nggasuang in 2018 (Figure 2).

![Figure 2](image_url)
3.2. Comparison between $T_0$ and $T_1$ BCF density data by BCF size class

An unpaired sample t-test was used to test the difference in the mean density values between the $T_0$ and $T_1$ surveys for each BCF size category (2-tailed, $\alpha = 0.05$). The Saphiro Wilk normality test indicated the need for a transformation to satisfy the assumption of data normality, which was achieved through transformation of the data using the function $f(x) = x^{-1}$ (Table 2).

For each BCF size class, a t-test was conducted to test the null hypothesis of no difference in mean BCF density between the $T_0$ and $T_1$ surveys (alternative: there is a difference in mean BCF density between the $T_0$ and $T_1$ surveys). The mean densities were only significant (null hypothesis rejected at $\alpha = 0.05$) for the adult BCF size class (Table 3), where mean density increased by 17% from 0.48 to 0.56 fish/m$^2$.

Table 2. Saphiro Wilk normality test results for raw and transformed BCF density data.

| Parameter tested          | Shapiro-Wilk – raw data |           | Shapiro-Wilk – transformed data |           |
|---------------------------|-------------------------|-----------|---------------------------------|-----------|
|                           | Statistic | df | Sig. | Statistic | df | Sig. |
| Recruit Density $T_0$     | 0.789 | 24 | 0.000 | 0.850 | 9 | 0.075 |
| Recruit Density $T_1$     | 0.569 | 24 | 0.000 | 0.912 | 9 | 0.334 |
| Juvenile Density $T_0$    | 0.637 | 24 | 0.000 | 0.827 | 9 | 0.410 |
| Juvenile Density $T_1$    | 0.742 | 24 | 0.000 | 0.910 | 9 | 0.314 |
| Adult Density $T_0$       | 0.813 | 24 | 0.000 | 0.894 | 9 | 0.219 |
| Adult Density $T_1$       | 0.745 | 24 | 0.000 | 0.990 | 9 | 0.996 |

Table 3. T-test results – the difference in mean BCF density values between the $T_0$ and $T_1$ surveys.

| BCF size class       | Equal variances assumed or not assumed | Levene's Test for Equality of Variances | t-test for Equality of Means | 95% Confidence Interval |
|----------------------|----------------------------------------|----------------------------------------|------------------------------|-------------------------|
|                      |                                        | F | Sig. | t | df | Sig. (2-tailed) | Mean difference | Std. Error difference | Lower | Upper |
| Recruit              | assumed                                | 0.012 | 0.914 | -1.541 | 35 | 0.132 | -1.237 | 0.803 | -2.867 | 0.393 |
|                      | not assumed                            | -1.495 | 26.973 | 0.147 | 0.827 | -2.935 | 0.461 |
| Juvenile             | assumed                                | 5.33 | 0.027 | 0.503 | 38 | 0.618 | 0.507 | 1.008 | -1.534 | 2.549 |
|                      | not assumed                            | 0.532 | 33.447 | 0.598 | 0.507 | 0.953 | -1.431 | 2.446 |
| Adult                | assumed                                | 16.74 | 0.000 | 2.484 | 34 | 0.018 | 2.223 | 0.895 | 0.404 | 4.043 |
|                      | not assumed                            | 2.862 | 25.115 | 0.008 | 2.223 | 0.777 | 0.624 | 3.824 |

3.3. Correlation between BCF density and microhabitat density

Multiple linear regression analysis of BCF density ($Y$) by age class against sea urchin density ($X_1$) and sea anemone density ($X_2$) (Table 5) shows significant correlations with both microhabitats, however, anemone abundance appears to have a greater influence on BCF density compared to sea urchin abundance (Table 4). The correlation between juvenile BCF density with the abundance of both sea urchins and sea anemones could explain nearly 70% of variability in this size class. BCF recruit and adult densities only correlate significantly with sea anemone abundance, explaining around 40-50% of the variability in abundance of these size classes.
Table 4. Multiple linear regression of BCF density by age class against microhabitat densities.

| BCF size class | Regression equation (t value)$^a$ | R$^2$ | F value $^a$ |
|----------------|-----------------------------------|-------|--------------|
| Recruit        | $Y_r = 0.183 + 0.127X_1 + 25.215X_2$ (1.50)$^a$ (1.03)$^a$ (3.08)$^*$ | 0.176 | (4.811)$^{**}$ |
|                | $Y_r = 0.262 + 23.339X_2$ (2.73)$^*$ (2.92)$^*$ | 0.157 | (8.540)$^{**}$ |
| Juvenile       | $Y_j = 0.044 + 0.303X_1 + 53.782X_2$ (90.36)$^*$ (2.43)$^*$ (6.47)$^*$ | 0.488 | (21.452)$^{**}$ |
| Adult          | $Y_a = 0.187 + 0.180X_1 + 32.626X_2$ (1.53)$^a$ (1.47)$^a$ (3.99)$^*$ | 0.266 | (8.136)$^{**}$ |
|                | $Y_a = 0.299 + 29.963X_2$ (3.18)$*$ (3.71)$*$ | 0.230 | (13.769)$^{**}$ |

$^a$ ns = not significant; $^* = $ significant at $\alpha = 0.05$ (F value > F critical); $^{**} = $ significant at $\alpha = 0.01$ (F value > F critical); $Y_r$, $Y_j$, $Y_a =$ recruit, juvenile and adult density; $X_i =$ sea urchin density; $X_r =$ sea anemone density.

4. Discussion

4.1. Banggai cardinalfish abundance

Inevitably, the abundance of BCF will vary between sites and from one year to another at each site due to stochastic factors as well as carrying capacity, which will be influenced inter alia by habitat condition and microhabitat abundance. The BCF density range in this study (0.013–8.268 fish/m$^2$) was greater than that reported by several other studies. For example 0.04–0.56 fish/m$^2$ in 2007 [28] and 0.29 - 3.00 fish/m$^2$ in 2010-2011 [29]. The highest BCF densities were recorded at three sites with special characteristics. Bone Baru Village and Toropot are both historically major ornamental fish (especially BCF) trading centers [1, 8]. Bone Baru has also been a focus for conservation efforts since 2006 [24]. Conservation efforts have been more recent and partial in Toropot, but positive impacts were already visible in 2017 (T4), with a significant recovery after severe depletion by 2012 [30], which seems to have been maintained in 2018 (T5). Toado is a special case with an unusual habitat/microhabitat (predominantly Rhizophora sp. prop roots) which makes capture very difficult, with a historically abundant BCF population [3, 25, 30].

Based on the density class classification in [30], the dominant BCF density trend from 2004 to 2012 was negative, however, several sites show a positive trend from 2012 to 2017-2018 (Table 5). The generally positive trends for sites 3-6 are typical of Banggai Island, where conservation efforts have been most intensive. The only site on this island with a negative trend from 2017 to 2018 is Tolokibit, where traditionally subsistence level sea urchin collection became commercialized around 2017, resulting in a drastic decline in sea urchin microhabitat by 2018 as well as disturbance likely to increase predation (including cannibalism [13]) of BCF recruits [25]. This negative trend is more severe than it would appear from the data shown, as in 2016 BCF density was in category 5, close to the high 2004 abundance (Abigail Moore, unpublished data).

Table 5. Changes in Banggai cardinalfish density since 2004 at seven monitoring sites.

| Site               | Density category [30]$^a$ | Trend/Change                  |
|--------------------|---------------------------|-------------------------------|
| No.                | 2004-2006 [30] | 2012 [30] | 2017/2018 |                      |
| Toropot            | 5                         | 1                         | 5/5       | Decline/Recovery    |
| Tj. Nggasuang      | 5                         | 1                         | 4/1       | Decline/Recovery/Decline |
| Bone Baru          | 4                         | 4                         | 5/5       | Stable/Increase    |
| Tinakin Laut       | 5                         | 5                         | 5/5       | Stable             |
| Monsongan          | 5                         | 5                         | 2/4       | Decline/Recovery   |
| Tolokibit          | 5                         | 4                         | 4/4$^b$  | Decline             |
| Liang              | 5                         | 3                         | 1/2       | Decline/Partial recovery |

$^a$ Density scale (d in fish/m$^2$): 1 = 0≤d<0.05; 2 = 0.05≤d<0.1; 3 = 0.1≤d<0.3; 4 = 0.3≤d<1.0; 5 = d≥1.0 [30].

$^b$ BCF density much lower in 2018 compared to 2017 collection [25].
The decline in the Liang population appears to be due to microhabitat loss through collection of both sea anemones and sea urchins (well documented) [17], possibly exacerbated by BCF collection events (unverified anecdotal evidence). The 2018 data show early but encouraging signs of recovery at this site, where conservation activities are being implemented.

With regards to most of the remoter sites in the southern Banggai Archipelago, the BCF density was generally low, with negative trends from 2017-2018 for some or all BCF size classes (Figure 2). Sites with particularly low abundance and/or sharp declines include Mandel, Mbuang-Mbuang, Minangga, and Tj Nggasuang. Between 2004 and 2012, the Tj Nggasuang site suffered severe degradation from destructive fishing, followed by partial recovery in BCF habitat and population in 2017 [25]. However, the 2018 data shows a decline in BCF abundance. These results are likely linked to the unreported (and therefore illegal) capture and transport of BCF by sea to Kendari, a trading center from which the official dispatch figures far exceed the capacity of the introduced BCF populations around Kendari Bay [4].

4.2. BCF density and microhabitat abundance
In general, more than 50% of BCF density variance could not be explained by the variables tested. Other variables are likely to include fishing pressure, alternative microhabitat (e.g. hard corals), and stochastic events (e.g. severe weather events). Nonetheless, the multiple regression results in Table 5 show a significant correlation between sea urchin and sea anemone abundance with juvenile BCF density, whereas for BCF recruits and adult density only correlates with sea anemone density. These results clearly highlight the importance of both microhabitats for BCF population maintenance and recovery and confirm the importance of sea anemones for BCF recruits, previously suggested by several studies [10-13]. Adult BCF density correlation with sea anemones is harder to explain, as adult BCF rarely associate with sea anemones [10-13], but could be related to improved reproductive success and thus higher numbers of all size classes [13].

About the sea urchin-BCF association, although sea urchin microhabitat is important for BCF conservation, this study appears to show a weaker relationship between BCF density and urchin abundance compared to earlier studies (e.g. [3, 8, 12, 13, 30]). Plausible explanations for this include the fact that, at the sites with the highest adult BCF populations in this study, many (most) adult BCF tend to associate with other microhabitat, including hard corals. Furthermore, at several sites sea urchin numbers were very low, well below historical levels (e.g. in 2004 [8]). These (and possibly other, unidentified) factors may well have contributed to the lack of significant association between adult BCF density and sea urchin abundance. However, recent data highlight the continued importance of Diadema sea urchins as BCF microhabitat [31, 32].

5. Conclusion
Banggai cardinalfish (BCF) were found at all survey sites and were particularly abundant at three sites in both years: Bone Baru Village, Toado and Toropot. The mean density of adult BCF increased; this could be an early indication of positive impact from conservation efforts, especially in the northern part of the Banggai Archipelago. However, there is a need for further efforts to conserve BCF populations in the southern (more remote) areas.

BCF density was positively correlated with sea urchin and sea anemone densities, with sea anemone abundance having a greater influence than sea urchin abundance. These results reinforce the need to conserve sea anemone and sea urchin populations as part of a holistic approach to the sustainable management of BCF stocks.

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