Depik Jurnal Ilmu-Ilmu Perairan, Pesisir dan Perikanan (2021) 10(3): 251-259

DEPIK
Jurnal Ilmu-Ilmu Perairan, Pesisir dan Perikanan
Journal homepage: www.jurnal.unsyiah.ac.id/depik

Microhabitat association and population status of the Luwuk introduced Banggai cardinalfish (*Pterapogon kauderni* Koumans, 1933) population

Novalina Serdiati[1], Abdul Gani[2], Deddy Wahyudi[3], Abigail Mary Moore[4], Samliok Ndobe[1,*]

[1]*Faculty of Animal Husbandry and Fisheries, Universitas Tadulako, Kampus Bumi Tadulako, Palu 94118, Sulawesi Tengah, Indonesia.*
[2]*Faculty of Fisheries, Universitas Muhammadiyah Luwuk Banggai, Luwuk 94712, Sulawesi Tengah, Indonesia.*
[3]*Sekolah Tinggi Perikanan dan Kelautan, Kampus Madani, Palu 94118, Sulawesi Tengah, Indonesia.*
[4]*Graduate School, Universitas Hasanuddin, Jl. Perintis Kemerdekaan km 10, Makassar 90245, Sulawesi Selatan, Indonesia.*

ARTICLE INFO

Keywords:
Banggai cardinalfish
Endangered species
Diadema
Microhabitat,
Monitoring
Ornamental fishery
Local regulation

DOI: 10.13170/depik.10.3.23501

ABSTRACT

The Banggai cardinalfish *Pterapogon kauderni* is the Indonesian national marine ornamental fish mascot, and an object of national and international conservation concern. The endemic population of this species is limited to the Banggai Archipelago in Central Sulawesi, Indonesia and a few nearby islands in North Maluku. In addition, introduced populations have become established, mainly along ornamental fish trade routes. The National Action Plan for Banggai Cardinalfish Conservation (NAP-BCFC) calls for monitoring and management of all *P. kauderni* populations. A survey of the Luwuk introduced *P. kauderni* population was carried out in October 2021. Data were collected at three sites with established *P. kauderni* populations: the ferry harbour, public harbour (Teluk Lalong) and a recreational area on the nearby coast (Kilo 5). *P. kauderni* were recorded by microhabitat association and size class (recruits, juveniles, adults). Data collected were compared with data from previous surveys where available. With the exception of one group in a sea anemone at Kilo 5, all *P. kauderni* were associated with *Diadema* sea urchins (*D. setosum* at all sites; *D. savignyi* at Kilo 5). At Kilo 5 *P. kauderni* the population structure indicates the possible capture of market-sized juveniles. Overall abundance was also lower compared to the polluted but unfished harbours. The proportion of recruits was significantly negatively correlated with the ratio of adult *P. kauderni* to *Diadema* urchins. The results will inform regional legislation currently in preparation to support sustainable management of *P. kauderni* populations, habitat and microhabitat in Central Sulawesi, as well as contributing to NAP-BCFC targets.

Introduction

The Banggai cardinalfish *Pterapogon kauderni* Koumans, 1933 is a small apogonid with an unusual life history lacking a pelagic dispersal phase (Ndobe *et al*., 2013a; Vagelli, 2011). The vast majority of the native (endemic) distribution of this species lies within the Banggai Archipelago Central Sulawesi Province, Indonesia. This extremely limited native distribution covers approximately 5000 km^2 with around 24-30 km^2 of native habitat in the coastal ecosystems of around 34 islands in Banggai Laut and Banggai Kepulauan Districts (Fondation Franz Weber, 2017; Vagelli, 2011). The still recent Banggai MPA officially established on 27 November 2019 covers 8566.4913 km^2 (MMAF-RI, 2019), including most of the *P. kauderni* endemic range (Moore *et al*., 2021; Ndobe *et al*., 2019).

Traded globally as a marine ornamental fish since around 1995, exploitation levels of the *P. kauderni* endemic population were considered excessive by 2000 (Allen, 2000), and by 2007 this species was listed as Endangered in the IUCN (International Union for the Conservation of Nature) Red List (Allen and Donaldson, 2007). While the ornamental fishery has led to or contributed to the depletion of endemic *P. kauderni* populations (EC-PREP 2005; Kolm and Berglund, 2003; Lunn and Moreau, 2004; Moore *et al*., 2011, 2021; Ndobe and Moore, 2008;

* Corresponding author.
Email address: samndobe@yahoo.com

p-ISSN 2089-7790; e-ISSN 2502-6194
Received 27 November 2021; Received in revised from 28 December 2021; Accepted 29 December 2021
Available online 30 December 2021

Ndobe *et al*., 2013a, 2013b, 2018a, 2020; Vagelli and Erdmann, 2002; Wiadnyana *et al*., 2020), the marine ornamental trade has also been responsible for introducing *P. kauderni* outside its native range.

Likely one of the first introduced populations to be formed was the *P. kauderni* population in Luwuk harbour, which was already well established in 2000/2001 (Vagelli and Erdmann, 2002). Other sites in Central Sulawesi Province include several sites within the Banggai Archipelago but outside the native (endemic) distribution, in particular Bakalan (Moore *et al*., 2017b; Ndobe *et al*., 2017), Paisulimukon and Lumbi-Lumbia (Yahya *et al*., 2012), Palu Bay (Ndobe *et al*., 2013a; Syahril *et al*., 2020) including Mamboro (Moore and Ndobe, 2007) and Kadongo (Ndobe, 2013c), as well as reported but as yet unverified sites in Parigi Moutong Province, Tomini Bay (Moore, 2017). Other introduced *P. kauderni* populations in Indonesia include Tumbak (EC-PREP, 2005) and Lembeh Strait in North Sulawesi, sites in and around Kendari, Southeast Sulawesi (Kusumawardhani *et al*., 2019; Moore *et al*., 2011), Ambon Bay in Maluku (Wibowo *et al*., 2019), several sites in Bali (Lilley, 2008; Putra *et al*., 2021; Putra and Putra, 2019; Mustika *et al*., 2012) and possibly sites in Sumatra and other regions of Indonesia (Ndobe *et al*., 2018a).

Most of the known introduced *P. kauderni* populations are along ornamental fish trade routes (Ndobe *et al*., 2018a). However, some are the result of other human activity; for example the Ambon introduced population (Wibowo *et al*., 2019) was founded through government programs. These introduced populations cannot be classified as "benign introductions" under IUCN (2012) criteria, most seem to qualify as "wild subpopulations resulting from introductions outside the natural range" which should be assessed (IUCN, 2019). Their potential for contributing to conservation of the species is limited due to genetic diversity conservation issues (Ndobe *et al*., 2018a) Nonetheless, to date only one introduced population (Lembeh Strait, North Sulawesi) is reported as invasive and potentially detrimental to native species (Carlos *et al*., 2014; Erdmann and Vagelli, 2001; Vagelli, 2011), while several introduced populations have contributed to research on *P. kauderni* biology and ecology (Moore *et al*., 2020a, 2020b; Ndobe *et al*., 2008, 2013c, 2013d, 2018b; Syahril *et al*., 2020).

As a member of the cardinalfish family Apogonidae, *P. kauderni* follows the typical apogonid reproductive strategy of paternal mouthbrooding (Vagelli, 2017). However, the unusual trait of direct development means that post-larval *P. kauderni* (recruits) are released from the male parent's mouth around 7-10 days after hatching (Ndobe *et al*., 2013a; Vagelli, 1999; Vagelli and Volpedo, 2004). The recruits are highly vulnerable to cannibalism by con-specific adults as well as predation from other carnivorous species (Ndobe *et al*., 2013a, 2013b, 2013c). Within its native and introduced habitat, *P. kauderni* is associated with and highly dependent on benthic organisms which serve as protective microhabitat (Moore *et al*., 2011, 2012, 2020b; Ndobe *et al*., 2013a, 2013b, 2013c; Vagelli, 2011). While the association with each microhabitat organism or potential symbiont is facultative, sufficient suitable microhabitat for each life history phase is essential to maintain healthy *P. kauderni* populations, and in particular for reproductive success.

The change in relative importance of the three main microhabitat types, i.e. sea urchins, sea anemones, and hard corals (Ndobe *et al*., 2008, 2013, 2017; Vagelli, 2011) between *P. kauderni* life stages is known as an "ontogenetic shift" in microhabitat preference (Vagelli, 2004). While *P. kauderni* recruits and small juveniles frequently take refuge in sea anemones and other anemone-like Cnidaria (e.g. *Heliofungia actiniformis* and *Cassiopea* sp.), larger juveniles and adults are often found in (mostly branching and foliose) hard corals, and all life stages associate with Diadematid sea urchins (Moore *et al*., 2011; Moore *et al*., 2019a; Ndobe *et al*., 2020; Ndobe *et al*., 2013c; Vagelli, 2004, 2011). Diadematid sea urchin microhabitat includes *Diadema setosum*, *D. savignyi*, and possibly *D. clarki* as well; *Echinothrix diadema* and *E. calamaris*; and more rarely *Astropyga* sp. (Moore *et al*., 2019a; Ndobe *et al*., 2013b, 2020; Ndobe *et al*., 2018b; Talbot *et al*., 2013; Wiadnyana *et al*., 2020).

Twice proposed for listing under CITES Appendix II, the Indonesian Government National Action Plan for Banggai Cardinalfish Conservation (NAP-BCFC) (Rusandi *et al*., 2016) includes monitoring of both endemic and introduced *P. kauderni* populations. Annual monitoring in the Banggai Archipelago took place in 2017 (T0), 2018 (T1) and 2019 (T2) (Ndobe *et al*., 2020; Wiadnyana *et al*., 2020). While some populations showed stable or increasing trends, at other sites *P. kauderni* and/or microhabitat continued to decline or remained very low, with some sub-populations considered at risk of extirpation (Ndobe *et al*., 2020). The planned T3 monitoring was postponed from 2020 to 2021 due to the Covid-19 pandemic. As the National Marine

Ornamental Mascot of Indonesia, and in line with the NAP-BCFC, management of all *P. kauderni* populations is clearly a matter of concern. Meanwhile at the regional level, the process of drafting a Provincial Government Regulation on the sustainable management of Banggai cardinalfish populations, habitat and microhabitat in Central Sulawesi Province is underway and requires data for both endemic and introduced populations, including the introduced *P. kauderni* population sites in Luwuk City, Banggai District.

Materials and Methods

Three *P. kauderni* introduced population sites in Luwuk City, Banggai District, Central Sulawesi Province were surveyed in October 2021. The coordinates of these three sites are given in Table 1, together with the dates of previous published observations at similar or nearby coordinates. Screenshots and photographs of the sites are shown in Figure 1. Data were collected from at least six 100 m^2 transects per site, following the methodology commonly used in several *P. kauderni* survey and monitoring studies since the early 2000's, including the T0 to T2 monitoring under the NAP-BCFC (Ndobe *et al*., 2020).

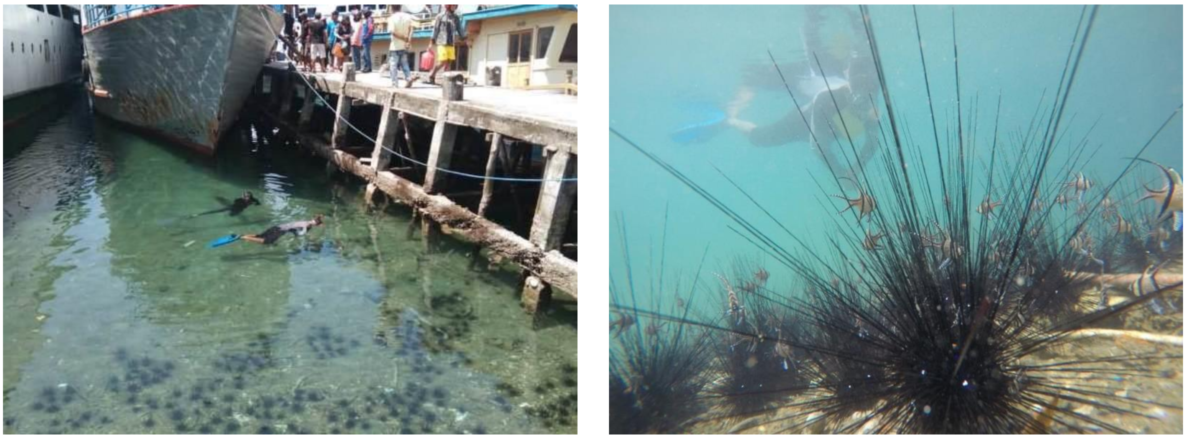
The belt transect method is illustrated in Figure 2. All surveys were completed by buddy pairs using snorkelling equipment (sites 1 and 2) or SCUBA (site3). Data collected for each group of *P. kauderni* (BCF) in each transect included the number of *P. kauderni* by size class and the microhabitat association of the group. The three size classes were based on standard length (SL): recruit (SL<18 mm); juvenile (18 mm≤ SL≤ 35 mm); and adult (SL>35 mm). Microhabitat was recorded by type: sea urchin, sea anemone, hard coral, soft coral, seagrass and other. For sea urchins and sea anemones, the number of individuals and the species were also recorded.

Table 1. Site coordinates and years of previous *P. kauderni* (BCF) observations in Luwuk

No	Site	Coordinates		Previous BCF observations				
		Latitude S	Longitude E	2001[a]	2007[b]	2012[c]	2016[d]	2017[e]
1	Luwuk ferry harbour	0° 57' 4.8"	122° 47' 48"	-	-	-	-	-
2	Teluk Lalong public harbour	0° 56' 54.7"	122° 47' 45"	X	X	-	-	X
3	Kilo 5 beach recreation area	0° 58' 57"	122° 47' 18"	-	-	X	X	X

[a]Vagelli and Erdmann (2002); [b]Vagelli (2011); [c]Talbot *et al.* (2013); [d]Moore *et al.* (2017b); [e]Moore *et al.* (2019a).

Site 1: Luwuk inner harbour, called the ferry harbour



Site 2: Luwuk outer harbour, known as Teluk Lalong

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Site 3: Kilo 5 beach recreational area south of the harbour area in Luwuk City

Figure 1. Photographs illustrating conditions at the three 2021 *P. kauderni* survey sites in Luwuk.

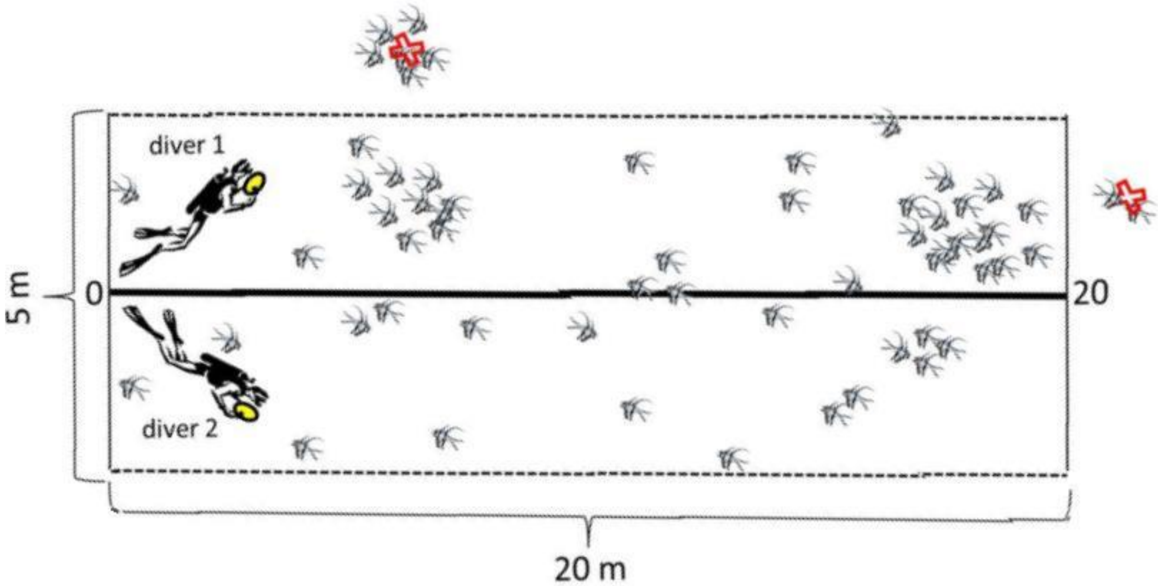

Figure 2. Belt transect used for surveying *P. kauderni* populations and microhabitat association in Luwuk (adapted from (Wibowo *et al.*, 2019).

All data collected were tabulated and statistical analyses were implemented in Microsoft Excel 2010. The results were evaluated with respect to previous survey/monitoring data where available (see Table 1). Differences between the three sites in mean *P. kauderni* density per transect (fish/100m^2) and the mean percentage of each life stage present were subjected to analysis of variance (ANOVA), as were differences in mean sea urchin density per transect (urchin/100 m^2) and mean number of fish per urchin. Statistical significance was evaluated at the 95% levels of confidence (a = 0.05) and post-hoc t-tests implemented after testing for equal/unequal variance if significant differences were found.

Results

Pterapogon kauderni population data

The synopsis of the belt transect data on *P. kauderni* populations (Table 2) shows that abundance and age class structure of *P. kauderni* varied considerably between sites. The two harbour sites had a higher overall density and a significantly higher percentage of juvenile *P. kauderni* than the Kilo 5 site.

Microhabitat association of *P. kauderni*

The synopsis of the belt transect data on *P. kauderni* microhabitat associations (Table 3) shows that almost all *P. kauderni* were associated with sea urchins of the genus *Diadema*. The exception was one transect at the kilo 5 site where the *P. kauderni* present (11 recruits, 2 juveniles and 2 adults) were associated with an anemone of the species *Heteractis crispa*. This sea anemone (at a depth of around 5 m) can be seen in Figure 1 (bottom right).

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Table 2. Belt transect data on *P. kauderni* populations at three sites in Luwuk City. Superscripts indicate significantly different means (α = 0.05).

Parameter	Ferry harbour	Teluk Lalong	Kilo 5	Total
Number of transects	6	22	16	44
Total *P. kauderni*	513	1611	403	2527
P. kauderni/100m^2 - mean	85.50[a]	73.23[a]	25.19[b]	183.9
P. kauderni/100m^2 - SD	33.52	71.78	34.49	139.8
% transects with recruits	100	59.09	62.50	65.91
% transects with juveniles	100	95.45	56.25	81.82
% transects with adults	100	95.45	93.75	95.45
% recruits - mean	29.43[ns]	7.64[ns]	35.73[ns]	16.54
% juveniles - mean	52.44[a]	47.92[a]	27.79[b]	45.63
% adults - mean	18.13[a]	44.44[b]	36.48[b]	37.83

Table 3. Belt transect data on *P. kauderni* microhabitat association at three sites in Luwuk City. Superscripts indicate significantly different means (α = 0.05).

Parameter	Ferry harbour	Teluk Lalong	Kilo 5	Total
Number of transects	6	22	16	44
Total *Diadema* spp.	382	674	830	1886
Diadema/100m^2 - mean±SD	63.7±43.9[ns]	30.6±28.5[ns]	51.9±36.3[ns]	42.9
% transects with *D. setosum*	100	100	100	100
% transects with *D. savignyi*	0	9.1	62.5	27.3
Sea anemones	0	0	1	1
% *D. setosum*	100	99.41	81.57	91.68
% *D. savignyi*	0	0.59	18.43	8.32
Fish/urchin: mean±SD	1.34±0.7[a]	2.39±2.0[b]	0.49±0.50[c]	1.34

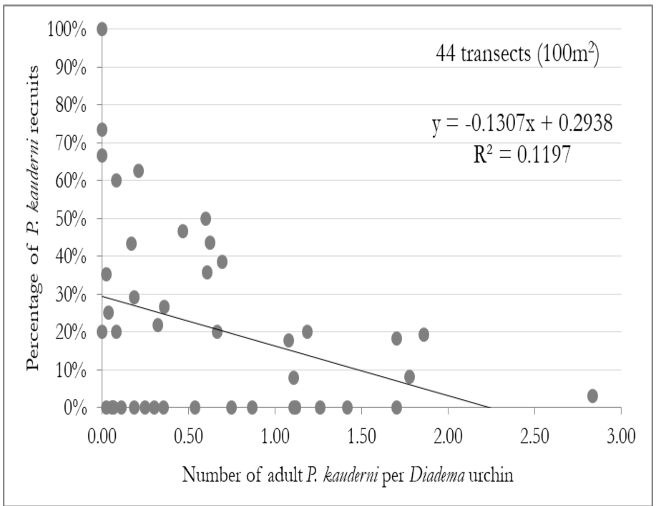

Figure 3. Plot of the percentage of *P. kauderni* recruits against the number of adult *P. kauderni* per *Diadema* urchin at three introduced population sites in Luwuk with linear regression equation

There was no significant correlation between the percentage of recruits and the total number of fish/urchin ($p > 0.05$). Taking the full data set (all three sites aggregated), regression of percentage of recruits against the number of adult *P. kauderni*/sea urchin by transect showed a significant negative correlation ($p < 0.05$), i.e. the percentage of recruits was higher in groups where sea urchins were less densely populated by adult *P. kauderni* (Figure 3). However, the data points were widely scattered within the lower left quadrant and linear regression provides a poor fit with $R^2 \approx 0.12$.

Diadema density varied between and within sites, but the between site difference in mean sea urchin density was not significant ($p > 0.05$). The species composition of the *Diadema* sea urchin flocks differed between the three sites. All urchins in the inner ferry harbour were identified as *D. setosum*, while *D. savignyi* was also present at the other two sites. In Teluk Lalong, the four *D. savignyi* observed were split between two transects, each with two individuals. At the Kilo 5 site, *D. savignyi* was widespread but less abundant than *D. setosum*. An example of a mixed flock can be seen in Figure 1 (bottom left), where the urchin close to the centre at the bottom of the photograph shows typical *D. savignyi* colouration, as described in Moore *et al.* (2019).

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Discussion

Although *P. kauderni* spawning can occur in every month (Prihatiningsih and Hartati, 2012; Vagelli, 2011), length-frequency-based population dynamics analysis indicates that *P. kauderni* recruitment success peaks in September-November (Ndobe *et al.*, 2013a). This survey was carried out during the predicted reproductive peak, and therefore the relatively high percentage of recruits is not surprising. However, the significant difference between the percentage of juveniles at Kilo 5 compared to the two harbour sites may indicate fishing pressure. While it is possible that this unusual population structure is related to past reproductive success (or lack thereof), it is noteworthy that the size range with a low relative abundance is the size range sought after in the marine ornamental trade. The Luwuk populations were originally founded due to the trade, and it is not unlikely that traders may, at least occasionally, exploit this population.

Despite the striking difference in the mean proportion of recruits, the lack of statistical significance is due to high inter-transect variability. Nonetheless, the lower mean proportion of recruits in the harbour populations, especially in Teluk Lalong (Table 2), may indicate that these *P. kauderni* populations are reaching or have reached the carrying capacity for *P. kauderni*, specifically based on microhabitat abundance. The lack of a significant correlation between proportion of recruits and total *P. kauderni* relative density in the sea urchin microhabitat indicates that recruit survival is most likely not influenced by competition for resources such as suitable prey. The significant negative correlation between proportion of recruits (a proxy for reproductive success) and the relative density of adult *P. kauderni* in the sea urchin microhabitat is consonant with previous studies, as a higher density of adults will mean a higher likelihood of cannibalism, thought to be a major factor in *P. kauderni* population dynamics (Ndobe *et al.*, 2013a, 2020; Ndobe *et al.*, 2013c). However, the distribution of the data indicates a non-linear relationship, with all points lying below a concave curve bending down from a maximum of 100% recruits and zero adults/urchin to approach the x axis as the asymptote of zero recruits at around 3 adults/urchin. This indicates that there is a limit above which increasing the density of adults precludes reproductive success.

The sea urchin densities observed in this study are relatively high compared to recent data from several other *P. kauderni* population sites, but consonant with historical data from this and other *P. kauderni* population sites (EC-PREP, 2005; Moore *et al.*, 2019a; Ndobe *et al.*, 2013a, 2013b; Ndobe *et al.*, 2018a). With regards to microhabitat other than *Diadema*, two of the sites (the ferry harbour and Teluk Lalong harbour) are highly degraded sites, with no other benthic organisms known to serve as *P. kauderni* microhabitat seen during the survey. At the Kilo 5 site, data on coral reef habitat condition was limited to visual record. However, when compared to similar visual records from 2017 to 2019 (Moore and Ndobe, unpublished data), there is a noticeable increase in dead and broken coral, with much less live coral of the type commonly used as microhabitat by adult *P. kauderni*, i.e. mainly branching and foliose forms. Coral bleaching was recorded at Kilo 5 in 2016 (Moore *et al.*, 2017b) and an outbreak of the coral predator *Acanthaster planci* was seen to the south of Kilo 5 in 2017-2018 (Moore, unpublished data). During this study some bleached and recently dead (pure white) colonies were observed, as well as extensive coral rubble and some recently broken corals. However, the cause of the decline in potential *P. kauderni* coral microhabitat is unknown, and in 2017 all *P. kauderni* were associated with *Diadema* urchins despite the presence of apparently suitable coral microhabitat (Moore *et al.*, 2019). Sea anemones were already relatively scarce at the Kilo 5 site in 2017 (Moore *et al.*, 2019), and the only sea anemone seen during this study was at a depth of around 5 m, below the depth at which most *P. kauderni* and *Diadema* were found.

The cause of this decline two of the three main *P. kauderni* microhabitats is not known and calls for further investigation, and possibly active management intervention, especially in view of the recreational value of the Kilo 5 site. The sea anemones which host clownfishes (genera *Amphiprion* and *Premnas*) and *P. kauderni* are thought to have density-dependent fertilisation, meaning that depleted populations might be unable to recover naturally; furthermore, these relatively long-lived, slow-growing animals also tend to recruit at irregular intervals (Hobbs *et al.*, 2013; Scott, 2017). As suggested for sites in the endemic *P. kauderni* distribution (Moore *et al.*, 2020a; Ndobe *et al.*, 2018a), stock enhancement of sea anemones might be an option, including through asexual propagation of sea anemones such as *Stichodactyla gigantea*, *Heteractis crispa* and *Entacmaea quadricolor*, but not the genus *Actinodendron* (Moore *et al.*, 2020a).

The dominance of *D. setosum* within the Luwuk harbour and presence of *D. savignyi* at Kilo 5 (≈8%

of urchins seen) was also observed in 2017 (Moore *et al*., 2019). The percentage of *D. savignyi* at the Kilo 5 site (18.2%) was higher than in 2017. Four *D. savignyi* were recorded in the outer harbour area where the 2017 study recorded 100% *D. setosum* (Moore *et al*., 2019). These data indicate that *D. savignyi* is well established in this area, particularly in the more exposed and less polluted coastline facing the Peleng Strait. These observations are consonant with earlier studies reporting that *D. savigny*i seems less able to adapt to polluted and otherwise degraded habitat than *D. setosum* (Bronstein and Loya, 2014; de Beer, 1990; Pearse, 1998).

The relatively high ratio of sea urchins to fish at the Kilo 5 site indicates that this site might be a potential donor site to support the BCF Garden approach to *P. kauderni* conservation, specifically the recovery of depleted endemic populations. This concept is based on the premise that recovery of microhabitat populations will promote natural recovery of *P. kauderni* populations by reducing mortality of recruits and small juveniles from predation, including cannibalism (Moore *et al*., 2017a, 2020b; Ndobe *et al*., 2018a). However, sea urchins can host many species other than fishes, including many invertebrates (Magnus 1967; Coppard and Campbell 2004). Furthermore, associated species can vary between sea urchin taxa, including between *D. savignyi* and *D. setosum* (Grygier and Newman, 1991; Ponder and Gooding, 1978). The risk of pests and diseases which could be transported and affect target sites could be higher for animals from a more polluted environment (Kim *et al*., 2005), such as urchins from the harbour sites, although Kilo 5 is also within the urban environment and likely exposed to sewage and other potential sources of pathogens. Furthermore, climate change and other anthropogenic impacts are predicted to affect host-pathogen relations, mostly in ways deleterious to the host (Byers, 2021). Therefore, a preliminary study on the biosecurity risks should be considered before moving any organisms, in particular sea urchins, to other sites, especially in the generally less polluted waters of the Banggai Archipelago.

Conclusion

This survey of three Banggai cardinalfish (*Pterapogon kauderni*) introduced population sites in Luwuk highlights the role of microhabitat, in particular sea urchins, in supporting reproductive success, specifically recruit survival. The lack of sea anemones at the Kilo 5 site is a cause for concern, and requires further investigation to determine the cause. The condition of the coral reef was not evaluated quantitatively but the observed damage is a cause for concern, especially as Kilo 5 is a popular area for recreation, including snorkelling and diving. The abundance of *Diadema* sea urchins makes Luwuk a potential donor site for heavily depleted sea urchin populations in the Banggai Archipelago. Such interventions should ideally refer to historical data on the species present (*D. setosum* and/or *D. savignyi*) at target sites, in particular, in the context of applying the BCF Garden concept for *P. kauderni* population recovery through habitat and microhabitat rehabilitation. Biosecurity should, however, be a concern, especially if transporting sea urchins from the polluted harbour environments is considered. Further research is also needed to verify whether or to what extent the Kilo 5 *P. kauderni* population is fished for the marine aquarium trade, and whether or not there is a need for regulation of both fishing and future releases.

Acknowledgments

This research was supported by an Applied Research grant from the Indonesian Directorate of Research and Community Service Directorate General of Research and Development of the Ministry of Research, Technology and Higher Education under contract No. 302/E4.1/AK.04.PT/2021, sub-contract No. 916.f/UN28.2/PL/2021. The authors also wish to thank all who took part in or supported field research activities as well as the preparation and publication in this manuscript.

References

Allen, G.R. 2000. Threatened fishes of the world: *Pterapogon kauderni* Koumans, 1933 (Apogonidae). Environmental Biology of Fishes, 57: 142. https://doi.org/10.1023/A:1007639909422

Allen, G.R., T.J. Donaldson. 2007. *Pterapogon kauderni*. The IUCN Red List of Threatened Species 2007. https://doi.org/10.2305/IUCN.UK.2007.RLTS.T63572A12692964.en.

Bronstein, O., Y. Loya. 2014. Echinoid community structure and rates of herbivory and bioerosion on exposed and sheltered reefs. Journal of Experimental Marine Biology and Ecology, 456: 8–17. https://doi.org/10.1016/j.jembe.2014.03.003.

Byers, J.E. 2021. Marine parasites and disease in the era of global climate change. Annual Review of Marine Science, 13(1): 397-420. https://doi.org/10.1146/annurev-marine-031920-100429.

Carlos, N.S.T., A.B. Rondonuwu, V.N.R. Watung, 2014. Distribusi dan kelimpahan *Pterapogon kauderni* Koumans, 1933 (Apogonidae) di Selat Lembeh bagian timur, Kota Bitung. Jurnal Ilmiah Platax, 2(3): 121-126.

de Beer, M. 1990. Distribution patterns of regular sea urchins (Echinodermata: Echinoidea) across the Spermonde Shelf, SW Sulawesi (Indonesia). In C. de. Ridder, P. Dubois, M.C. Lahaye, M. Jangoux (Eds.). Echinoderm Research, Balkerna, Rotterdam. (pp. 165-169).

EC-PREP. 2005. The Indonesian ornamental fish trade: case studies and options for improving livelihoods while promoting sustainability in Banggai and Banyuwangi. Network of Aquaculture Centres in Asia, Bangkok. https://enaca.org/enclosure.php?id=756.

Erdmann, M.V, A.A. Vagelli. 2001. Banggai cardinalfish invade Lembeh Strait. Coral Reefs, 20(3): 252-253. https://doi.org/10.1007/s003380100174.

Fondation Franz Weber. 2017. AC29 Inf. 20. The distribution, population condition and conservation status of *Pterapogon kauderni* in 2015. Report for the 29th CITES Animals Committee Meeting (pp. 1-15). Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), Gland.

Grygier, M.J., W.A. Newman. 1991. A new genus and two new species of Microlepadidae (Cirripedia: Pedunculata) found on Western Pacific diadematid echinoids. Galaxea, Sesoko Marine Science Center, 10: 1-22.

Hobbs, J.A., A.J. Frisch, B.M. Ford, M. Thums, P. Saenz-Agudelo, K.A. Furby, M.L. Berumen. 2013. Taxonomic, spatial and temporal patterns of bleaching in anemones inhabited by anemonefishes. PloS One, 8(8): e70966. https://doi.org/10.1371/journal.pone.0070966.

IUCN. 2012. Guidelines for application of IUCN Red List Criteria at regional and national levels Version 4.0. International Union for Conservation of Nature and Natural Resources, Gland.

IUCN. 2019. Guidelines for Using the IUCN Red List Categories and Criteria. Version 14. IUCN Standards and Petitions Committee. In IUCN Red List (Version 14). International Union for Conservation of Nature, Gland.

Kim, K., A.P. Dobson, F.M.D Gulland, C.D. Harvell. 2005. Diseases and the conservation of marine biodiversity. In E.A. Norse, L.B. Crowder (Eds.). Marine Conservation Biology: The Science of Maintaining the Sea's Biodiversity. Island Press, Washington DC. (pp. 149-166).

Kolm, N., A. Berglund. 2003. Wild populations of a reef fish suffer from the "nondestructive" aquarium trade fishery. Conservation Biology, 17(3): 910–914. https://doi.org/10.1046/j.1523-1739.2003.01522.x.

Kusumawardhani, N.R., U.Y. Arbi, Aunurohim. 2019. Analisis preferensi habitat ikan capungan Banggai (*Pterapogon kauderni*) di lokasi introducksi perairan Kendari, Sulawesi Tenggara. Prosiding Seminar Nasional Kelautan XIV Fakultas Teknik dan Ilmu Kelautan, Universitas Hang Tuah, Surabaya. (pp. B2 47-59).

Lilley, R. 2008. The Banggai cardinalfish: An overview of conservation challenges. SPC Live Reef Fish Information Bulletin, 18: 3-12.

Lunn, K. E., M.-A. Moreau. 2004. Unmonitored trade in marine ornamental fishes: the case of Indonesia's Banggai cardinalfish (*Pterapogon kauderni*). Coral Reefs, 23(3): 344-351. https://doi.org/10.1007/s00338-004-0393-y.

MMAF-RI. 2019. Keputusan Menteri Kelautan dan Perikanan Republik Indonesia Nomor 53/KEPMEN-KP/2019 tentang Kawasan Konservasi Pesisir dan Pulau-Pulau Kecil Banggai, Banggai Laut, Banggai Kepulauan, dan Perairan Sekitarnya di Provinsi Sulawesi Tengah. Ministry of Marine Affairs and Fisheries of the Republic of Indonesia, Jakarta.

Moore, A., S. Ndobe. 2007. Discovery of an introduced Banggai cardinalfish population in Palu Bay, Central Sulawesi, Indonesia. Coral Reefs, 26(3): 569. https://doi.org/10.1007/s00338-007-0227-9.

Moore, A., S. Ndobe, M. Zamrud. 2011. Monitoring the Banggai cardinalfish, an endangered restricted range endemic species. Journal of Indonesian Coral Reefs (JiCor), 1(2): 99-113.

Moore, A., S. Ndobe, A.-I. Salanggon, Ederyan, A. Rahman. 2012. Banggai cardinalfish ornamental fishery: the importance of microhabitat. Proceedings of the 12th International Coral Reef Symposium, Cairns, Australia, 9-13 July 2012, 13C. http://www.icrs2012.com/proceedings/manuscripts/ICRS2012_13C_1.pdf.

Moore, A.M., S. Ndobe, J. Jompa. 2017a. A site-based conservation approach to promote the recovery of Banggai cardinalfish (*Pterapogon kauderni*) endemic populations. Coastal and Ocean Journal, 1, 63-72.

Moore, A.M., S. Ndobe, J. Jompa. 2017b. Fingerprints of the Anthropocene: the 2016 coral bleaching event in an equatorial archipelago. In M.T. Umar (Ed.), Proceedings of the 4th International Marine and Fisheries Symposium 2017, Universitas Hasanuddin, Makassar. (pp. 66–86).

Moore, A.M., A.C.M. Tassakka, R. Ambo-Rappe, I. Yasir, D.J. Smith, J. Jompa. 2019a. Unexpected discovery of *Diadema clarki* in the Coral Triangle. Marine Biodiversity, 49(5): 2381–2399. https://doi.org/10.1007/s12526-019-00978-4.

Moore, A.M., S. Ndobe, I. Yasir, R. Ambo-Rappe, J. Jompa. 2019b. Banggai cardinalfish and its microhabitats in a warming world: a preliminary study. IOP Conference Series: Earth and Environmental Science, 253: 012021. https://doi.org/10.1088/1755-1315/253/1/012021.

Moore, A.M., I. Yasir, R. Ambo-Rappe, S. Ndobe, J. Jompa. 2020a. Asexual propagation of two sea anemone taxa for Banggai cardinalfish microhabitat enhancement. IOP Conference Series: Earth and Environmental Science, 473: 012011. https://doi.org/10.1088/1755-1315/473/1/012011.

Moore, A. M., Yasir, I., Ambo-Rappe, R., Ndobe, S., Jompa, J. (2020b). Microhabitat preference of the Banggai Cardinalfish (*Pterapogon kauderni*): a behavioural experimental approach. *IOP Conference Series: Earth and Environmental Science*, *564*, 012019. https://doi.org/10.1088/1755-1315/564/1/012019

Moore, A.M., S. Ndobe, I. Yasir. 2021. Importance of monitoring an endangered endemic species - intra-species biodiversity perspectives on the Banggai cardinalfish conservation and trade. IOP Conference Series: Earth and Environmental Science, 681(1): 012120. https://doi.org/10.1088/1755-1315/681/1/012120.

Mustika, P.L., I.M.J. Ratha, S. Purwanto (Eds.). (2012). Bali Marine Rapid Assessment. (2012): RAP Bulletin of Biological Assessment Volume 64. Conservation International Indonesia, Denpasar.

Ndobe, S., A. Moore. 2008. Banggai cardinalfish: towards a sustainable ornamental fishery. In Riegle B., R.E. Dodge. (Eds.). Proceedings of the 11th International Coral Reef Symposium, Nova Southeastern University, Fort Lauderdale. (pp. 1026–1029).

Ndobe, S., Madinawati, A. Moore. 2008. Pengkajian *ontogenetic shift* pada ikan endemik *Pterapogon kauderni*. Jurnal Mitra Bahari, 2(2): 32–55.

Ndobe, S., E.Y. Herawati, D. Setyohadi, A. Moore, M.L.D. Palomares, D. Pauly. 2013a. Life history of Banggai cardinalfish, *Pterapogon kauderni* (Actinopterygii: Perciformes: Apogonidae), from Banggai Islands and Palu Bay, Sulawesi, Indonesia. Acta Ichthyologica et Piscatoria, 43(3): 237–250. https://doi.org/10.3750/AIP2013.43.3.08.

Ndobe, S., A. Moore, A.I.M., Salanggon, Muslihudin, D. Setyohadi, E.Y. Herawati, Soemarno. 2013b. Pengelolaan Banggai cardinalfish (*Pterapogon kauderni*) melalui konsep ecosystem-based approach [Banggai cardinalfish (*Pterapogon kauderni*) management: an ecosystem-based approach]. Marine Fisheries, 4(2): 115–126. https://doi.org/10.29244/jmf.4.2.115-126.

Ndobe, S., I. Widiastuti, A. Moore. 2013c. Sex ratio dan pemangsaan terhadap rekrut pada ikan hias Banggai cardinalfish (*Pterapogon kauderni*). In A. Sudaryono, D. Paramartha, A. Mufid (Eds.). Prosiding Konferensi Akuakultur Indonesia 2013, Masyarakat Akuakultur Indonesia, Solo. (pp. 9–20).

Ndobe, S., A. Moore, Nasmia, Madinawati, N. Serdiati. 2013d. The Banggai cardinalfish: an overview of local research (2007-2009). Galaxea, Journal of Coral Reef Studies, 15(Special Issue): 243–252. https://doi.org/10.3755/galaxea.15.243.

Ndobe, S., A.M. Moore, J. Jompa. 2017. Status of and threats to microhabitats of the endangered endemic Banggai Cardinalfish (*Pterapogon kauderni*). Coastal and Ocean Journal, 1(2): 73–82.

Ndobe, S., I. Yasir, A.M. Moore, M.V. Biondo, S.J. Foster. 2018a. A study to assess the impact of international trade on the conservation status of *Pterapogon kauderni* (Banggai cardinalfish). International Union for Conservation of Nature, Gland. https://cites.org/sites/default/files/eng/com/ac/30/Inf/E-AC30-Inf-16.pdf

Ndobe, S., J. Jompa, A. Moore. 2018b. A tale of two urchins - implications for *in-situ* breeding of the endangered Banggai cardinalfish (*Pterapogon kauderni*). Aquacultura Indonesiana, 19(2): 65. https://doi.org/10.21534/ai.v19i2.110.
Ndobe, S., Moore, A., Yasir, I., Jompa, J. 2019. Banggai cardinalfish conservation: Priorities, opportunities, and risks. IOP Conference Series: Earth and Environmental Science, 253, 012033. https://doi.org/10.1088/1755-1315/253/1/012033
Ndobe, S., K. Handoko, D. Wahyudi, M. Yasir, Y. Irawati, W.A. Tanod, A.M. Moore. 2020. Monitoring the endemic ornamental fish *Pterapogon kauderni* in Bokan Kepulauan, Banggai marine protected area, Indonesia. Depik, 9(1): 18–31. https://doi.org/10.13170/depik.9.1.15363.
Pearse, J.S. 1998. Distribution of *Diadema savignyi* and *D. setosum* in the tropical Pacific. In R. Mooi, M. Tellford (Eds.), Echinoderms: San Francisco, Balkema, Rotterdam. (pp. 777-782).
Ponder, W.F., U. Gooding. 1978. Four new eulimid gastropods associated with shallow-water diadematid echinoids in the Western Pacific. Pacific Science, 32(2): 157-181.
Prihatiningsih, S.T. Hartati. 2012. Biologi reproduksi dan kebiasaan makan ikan Banggai cardinal (*Pterapogon kauderni,* Koumans 1933) di perairan Banggai Kepulauan. Bawal, 4(1): 1-8.
Putra, I.N.G., I.D.N.N. Putra. 2019. Recent invasion of the endemic Banggai cardinalfish, *Pterapogon kauderni* at the Strait of Bali: assessment of the habitat type and population structure. Ilmu Kelautan: Indonesian Journal of Marine Sciences, 24(1): 15-22. https://doi.org/10.14710/ik.ijms.24.1.15-22.
Putra, I.N.G., N.L.P.R. Puspitha, E.W. Suryaningtyas. 2021. Spread beyond the border: small scale genetic structure of the introduced Banggai cardinalfish (*Pterapogon kauderni*) population in the Bali Strait. Ilmu Kelautan: Indonesian Journal of Marine Sciences, 26(3): 165–172. https://doi.org/10.14710/ik.ijms.26.3.165-172.
Rusandi, A., G.R. Lilley, S.R. Susanti. (Eds.). 2016. Rencana Aksi Nasional (RAN) Konservasi Ikan Capungan Banggai. Ministry of Marine Affairs and Fisheries R.I., Jakarta.
Scott, A. 2017. Sea anemones. In R. Calado, I. Olivotto, M.P. Oliver, G.J. Holt. (Eds.), Marine Ornamental Species Aquaculture, John Wiley and Sons Ltd, Chichester. (pp. 437–456). https://doi.org/10.1002/9781119169147.ch21b.
Syahril, M., R. Renol, A.M., Salanggon, D. Wahyudi, M. Akbar, Y.S. Adel, R. Hermawan, A.T. Aristawati, F. Finarti. 2020. Pemantauan ikan endemik Banggai cardinalfish (BCF) pasca tsunami di Teluk Palu. Monsu'ani Tano Jurnal Pengabdian Masyarakat, 3(2): 54-60. https://doi.org/10.32529/tano.v3i2.736.
Talbot, R., M. Pedersen, M.I. Wittenrich, M. A. Moe. 2013. Banggai cardinalfish: a guide to captive care, breeding, and natural history. Reef to Rainforest Media, LLC, Shellburne.
Vagelli, A.A. 1999. The reproductive biology and early ontogeny of the mouthbreeding Banggai cardinalfish, *Pterapogon kauderni* (Perciformes, Apogonidae). Environmental Biology of Fishes, 56: 79-92. https://doi.org/10.1023/A:1007514625811.
Vagelli, A.A. 2004. Ontogenetic shift in habitat preference by *Pterapogon kauderni*, a shallow water coral reef apogonid, with direct development. Copeia, 2004(2): 364-369. https://doi.org/10.1643/CE-03-059R2.
Vagelli, A.A. 2011. The Banggai cardinalfish: natural history, conservation, and culture of *Pterapogon kauderni*. John Wiley and Sons, Ltd., Chichester. https://doi.org/10.1002/9781119950387.
Vagelli, A.A. 2017. Mouthbrooders – the Banggai cardinalfish. In R. Calado, I. Olivotto, M.P. Oliver, G.J. Holt (Eds.). Marine Ornamental Species Aquaculture, John Wiley and Sons, Ltd., Chichester. (pp. 201-221).
Vagelli, A.A., M.V. Erdmann. 2002. First comprehensive ecological survey of the Banggai cardinalfish, *Pterapogon kauderni*. Environmental Biology of Fishes, 63(1): 1-8. https://doi.org/10.1023/A:1013884020258.
Vagelli, A.A., A.V. Volpedo. 2004. Reproductive ecology of *Pterapogon kauderni*, an endemic apogonid from Indonesia with direct development. Environmental Biology of Fishes, 70(3): 235-245. https://doi.org/10.1023/B:EBFI.0000033338.11355.f9.
Wiadnyana, N.N., S.R. Suharti, S. Ndobe, S. Triharyuni, G.R. Lilley, S. Risuana, D. Wahyudi, A.M. Moore. 2020. Population trends of Banggai cardinalfish in the Banggai Islands, Central Sulawesi, Indonesia. IOP Conference Series: Earth and Environmental Science, 420(1): 012033. https://doi.org/10.1088/1755-1315/420/1/012033.
Wibowo, K., U.Y. Arbi, I.B. Vimono. 2019. The introduced Banggai cardinal fish (*Pterapogon kauderni*) population in Ambon Island, Indonesia. IOP Conference Series: Earth and Environmental Science, 370(012041): 012041. https://doi.org/10.1088/1755-1315/370/1/012041.
Yahya, Y., A. Mustain, N. Artiawan, G. Reksodihardjo-Lilley, M.F. Tlusty. 2012. Summary of results of population density surveys of the Banggai cardinalfish in the Banggai Archipelago, Sulawesi, Indonesia, from 2007–2012. AACL Bioflux, 5(5): 303-308.

How to cite this paper:
Serdiati, N., A. Gani, D. Wahyudi, A.M. Moore, S. Ndobe. 2021. Microhabitat association and population status of the Luwuk introduced Banggai cardinalfish (*Pterapogon kauderni* Koumans, 1933) population. Depik Jurnal Ilmu-Ilmu Perairan, Pesisir dan Perikanan, 10(3): 251-259.