Banggai cardinalfish and its microhabitats in a warming world: a preliminary study

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Abstract. Global changes in the Anthropocene are affecting marine ecosystems in many ways, including alterations in long-established inter-species relationships. The Banggai cardinalfish Pterapogon kauderni, a species of global conservation concern, is highly dependent on benthic organisms serving as microhabitat. The objective of this study was to evaluate the effects of global change, in particular rising sea temperature, on P. kauderni and three key associated microhabitats: hard corals (Scleractinia), sea urchins (Diadematidae), and sea anemones (Actinia). Data collected before, during, and after the 2016 global coral bleaching event from P. kauderni habitat in the Banggai Archipelago, including coral bleaching (by genus) and P. kauderni (by life stage) microhabitat association (species or genus, coral life-form), were complemented by a literature review. While coral bleaching and mortality was less severe than in many other regions, hard coral genera and life-forms preferred by P. kauderni were disproportionately affected, and P. kauderni hosting sea anemones also bleached. Coral, sea urchin and sea anemone reproduction, larval development, and recruitment may be negatively affected. Likely post-settlement effects on sea urchin and sea anemone growth and survival are unclear. Direct impacts on P. kauderni are likely, including metabolic rate change with consequences for growth and longevity. Indirect impacts (e.g. changes in plankton composition and abundance, increased storm frequency/severity) will affect P. kauderni and all its microhabitats. This evaluation for P. kauderni, its key microhabitat groups, and their association, points towards increased need for both conservation action and research to fill identified knowledge gaps.

1. Introduction

Global change in the Anthropocene [1,2] is affecting marine ecosystems in many ways [3], including alterations to sea water physical and chemical properties [4] [5] and even shifts in ocean circulation. Such wide-ranging changes affect ocean productivity [6], species distributions [7,8], and can contribute to defaunation [9], in what has been dubbed the 6th great extinction event [10]. While by no means the only parameter of importance, temperature plays a major role in determining the distribution and health of species, communities, and ecosystems[8,11,12,13]. Furthermore, as observed in terrestrial ecosystem, changes in marine environments are likely to alter or disrupt long-established inter-species relationships [3,14].
One widespread phenomenon of particular concern in equatorial to sub-tropical coastal waters is the increased frequency, severity, and extent of coral bleaching events [15]. Bleaching occurs in Cnidarians, especially scleractinian corals [16], but also sea anemones [17,18,19] when the symbiosis between the host and symbiotic photosynthetic Symbiodinium dinoflagellates is disrupted [20,21], with potential negative impacts on associated fish species [17,22,23,24]. The mechanisms and factors affecting temperature-related bleaching are a focus of active research, not least because of the deleterious effect on associated organisms of bleaching-related mortality [13], and the potential for synergy with other impacts of global change [25].

The Banggai cardinalfish Pterapogon kauderni is a small marine fish with unusual life history traits [26,27]. Considered at risk of extinction within its extremely limited endemic range [28], P. kauderni is highly dependent on benthic organisms serving as microhabitat [29,30]. The objective of this study was to evaluate the effects of global change, in particular the increase in mean sea temperature and increasing frequency and severity of high temperature anomalies, on P. kauderni and the three key microhabitats with which this fish associates: hard corals (Scleractinia), sea urchins (Diadematidae), and sea anemones (Actinia).

2. Materials and Methods

2.1. Survey sites and data collection methods

We collected data on coral condition and diversity from 6 sites in the shallow-water (0-5m depth) habitat of P. kauderni in the Banggai Archipelago, Central Sulawesi, Indonesia before, during and after the 2016 global coral bleaching event (Table 1, Supplementary Data S1). Using a swim survey method [31], coral colony genus [32], life-form [33] and bleaching status [34], and water temperature were recorded. Data on P. kauderni population and microhabitat associations collected within belt transects (20 x 5 m, 100m²) [31] comprised the number of P. kauderni by life stage (based on standard length (SL): recruit: <18mm SL; juvenile: 18-35 mm SL; sub-adult/adult: >35mm SL) associated with each microhabitat: hard corals (colony genus [32], life-form [33]); sea urchins and sea anemones (genus, where possible species); and other (lowest possible taxonomic level).

Table 1. Survey sites and scope of survey data

| Site No. | Name       | Coordinates (WSG 84) | Swim Survey 2014 | Swim Survey 2016 | Swim Survey 2017 | Swim Survey 2018 | Belt Transects |
|----------|------------|----------------------|-------------------|-------------------|-------------------|-------------------|----------------|
| 1        | Liang      | 1°33'03"N 123°14'26"E | Y                  | Y                 | Y                 | Y                 | 10             |
| 2        | Popisi     | 1°30'27"N 123°31'20"E | Y                  | Y                 | Y                 | Y                 | 10             |
| 3        | Bone Baru  | 1°31'56"N 123°29'27"E | Y                  | Y                 | Y                 | Y                 | 10             |
| 4        | Tinakin Laut | 1°36'04"N 123°29'14"E | Y                  | Y                 | Y                 | Y                 | 10             |
| 5        | Tolokibit  | 1°42'48"N 123°31'36"E | Y                  | Y                 | Y                 | Y                 | 30             |
| 6        | Kapela     | 1°42'52"N 123°34'45"E | Y                  | Y                 | Y                 | Y                 | 10             |

*aSome data presented in [35]; bSome data presented in [30] and [36]

2.2. Data analysis

We tabulated both primary and secondary data and performed descriptive analyses. Quantitative and graphic analyses were conducted in Microsoft Excel 2010. Our results were compared with and discussed in the context of other research on the taxa and processes involved.

3. Results and Discussion

3.1. P. kauderni microhabitat associations

The microhabitat associations of P. kauderni by life stage class (Table 2) strengthen the ontogenetic shift hypothesis [37,38]. A high proportion (93.4%) of P. kauderni associated with sea anemones were
recruits or small juveniles, while 100% of fish associated with scleractinian corals other than *Heliofungia actiniformis* were adult, sub-adult, or large juveniles. All size classes (totaling 65% of all fish surveyed) were associated with Diadematid urchins, mainly of the genus *Diadema* (*D. setosum* and *D. savignyi*) [39], as well as *Echinotrix* spp. (tentatively identified as *E. calamares* and *E. diadema*) and *Astropyga* sp. The sea anemones most common as microhabitat for *P. kauderni* recruits and juveniles were *Actinodendron* spp., *Heteractis crispa*, and *Stychodactyla gigantea* (the latter two locally collected for human consumption), followed by *Entacmea quadricolor*. Apart from *Actinodendron* sp., clownfishes (genera *Amphiprion* and *Premnas*) were often observed co-habitating with *P. kauderni* in host anemones. With the exception of two large groups close to *Actinodendron* sp. and *E. quadricolor*, the majority (90%) of adult *P. kauderni* close to anemones (1-3 fish) included a brooding male. This might indicate preparation for release of recruits by the male [40] and possible readiness to prey on the recruits by other adult/sub-adult fish [41].

Table 2. Microhabitat associations of *P. kauderni* by life-stage class (belt transect data 2017-2018)

| Microhabitat/Taxon | Life-Form | *P. kauderni* Recruit (n) | *P. kauderni* Juvenile (%) | *P. kauderni* Adult (%) |
|--------------------|-----------|----------------------------|----------------------------|-------------------------|
| Hard coral (16.8% of total) | ACB | 1438 | 4.7% | 26.5% | 68.8% |
| Acropora spp. | CS | 1047 | 0.0% | 23.9% | 76.1% |
| Goniopora spp. | CB | 113 | 0.0% | 15.9% | 84.1% |
| Stylophora/Seriatopora spp. | CMR | 101 | 0.0% | 57.4% | 42.6% |
| *Heliofungia actiniformis* | CF/CB | 75 | 89.3% | 5.3% | 5.3% |
| Other hard corals* | DU | 102 | 0.0% | 50.0% | 50.0% |
| Diadematidae (65.0% of total) | DU | 5566 | 34.8% | 28.7% | 36.5% |
| *Diadema* spp. | CM | 5379 | 34.4% | 29.0% | 36.5% |
| *Echinotrichia* spp. | DU | 176 | 43.2% | 19.9% | 36.9% |
| *Astropyga* sp. | DU | 11 | 72.7% | 18.2% | 9.1% |
| Anemones (12.1% of total) | AN | 1036 | 46.3% | 47.1% | 6.6% |
| *Heteractis crispa* | AN | 222 | 73.4% | 24.8% | 1.8% |
| *Stychodactyla gigantea* | AN | 126 | 46.8% | 50.0% | 3.2% |
| *Entacmea quadricolor* | AN | 120 | 59.2% | 25.0% | 15.8% |
| *Actinodendron* spp. | AN | 509 | 34.0% | 58.7% | 7.3% |
| Other anemones b | AN | 59 | 23.7% | 69.5% | 6.8% |
| Other microhabitat (6.1% of total) | DC/RKC | 522 | 1.7% | 32.4% | 65.9% |
| Dead coral | OT | 73 | 0.0% | 20.5% | 79.5% |
| Other biotic | OT | 206 | 0.0% | 48.5% | 51.5% |
| Other abiotic/none | OT/SD | 243 | 3.7% | 22.2% | 74.1% |

Total *P. kauderni* observed | 8562 | 29.1% | 30.8% | 40.1% |

* Genera and life-form: *Hydnophora* (CB); *Montipora* (CB/CF); *Porites* (CB); *Goniopora* (CS); *Echinopora horrida* (CB); *Lobophyllia* (CS); and *Millepora* (CME, branching form). b *H. magnifica*, *S. haddoni*

Observed microhabitat associations indicate significant plasticity in *P. kauderni* ontogenetic microhabitat associations, particularly for sub-adult and adult fish. Nonetheless, it is clear that hard corals are an important microhabitat for larger juveniles, sub-adult and adult *P. kauderni*. In 2018, we found strong indications confirming the increased exploitation of *Diadema* sp., mostly for human consumption, is the main driver of declining urchin populations across much of the *P. kauderni* endemic range [29,30,41]. This decline is arguably increasing the importance of scleractinian corals, at
least for larger *P. kauderni* size classes. In addition to impacts on *P. kauderni* populations, especially reproductive success [27,29,40], the decline of these important herbivores may have negative consequences for coral reef resilience [42,43].

### 3.2. Cnidarian bleaching impacts on *P. kauderni* habitat and microhabitat

Coral genera and life-forms most commonly used as *P. kauderni* microhabitat were among the taxa most visibly affected by the 2016 bleaching event (Table 3). At each site, some genera recorded in 2014 and or 2016 (mostly taxa severely bleached in 2016 [36]) were less abundant or not found in 2017 and/or 2018, indicating the 2016 bleaching event impacted both coral cover and biodiversity.

| Site          | Microhabitat | Sample (n) | CoralWatch Condition (% of colonies) | Sea T°C (°C) Past |
|---------------|--------------|------------|--------------------------------------|------------------|
| Bone Baru     | yes          | 43         | 18.60, 32.56, 23.26, 16.28, 4.65, 4.65 | 31-32 27-30      |
| Kapela        | yes          | 62         | 14.52, 33.87, 38.71, 9.68, 3.23, 0.00 | 31-32 27-31      |
| Tolokibit     | yes          | 65         | 20.00, 44.62, 9.23, 13.85, 12.31, 0.00 | 32-33 28-30      |
| Liang         | yes          | 140        | 39.29, 39.29, 17.14, 4.29, 0.00, 0.00 | 32-33 27-31      |
| Overall (N=682) | yes     | 310        | 27.42, 38.39, 20.65, 9.03, 3.87, 0.65 | 31-33 27-31      |

The Acroporidae have been considered especially vulnerable to temperature-related stress and bleaching [44]. While all observed genera within this family were affected, we observed higher bleaching and mortality in the genera *Stylophora* and *Seriatopora* than in *Acropora* and *Pocillopora*. An extreme case was the (possibly temporary) extirpation of *Stylophora* and *Seriatopora* at the Kapela site, where 100% of colonies bleached in 2016 and both genera were absent in 2017. *Porites* showed a life-form related response; in 2016, bleaching was more widespread and severe in colonies with large polyps and branching forms, and many did not survive to 2017 or 2018, while massive or semi-massive colonies seem more resistant and resilient. These results are similar to long term trends reported from the Great Barrier Reef [45]. The data in Table 3 show that the coral genera and life-forms serving as *P. kauderni* microhabitat were disproportionately affected by the 2016 global bleaching event. Furthermore, the possibly transient higher than normal seawater temperatures in 2018 at Tolokibit (32-34°C) affected more potential *P. kauderni* microhabitat than other corals. Bleaching was observed with ≈10% of colonies partly fully bleached (CW1) and around 25% very pale (predominantly CW2). *Acropora*, the surviving branching forms of *Porites*, and the few remaining *Stylophora* colonies were the most commonly affected.

Sea anemones totally or partially bleached inhabited by *P. kauderni*, with or without resident clownfishes, were observed at Bone Baru in 2016, and at Tolokibit in both 2016 and 2018, and at other sites in the Banggai Archipelago [36]. A growing body of research indicates that, while anemone bleaching may have adaptive benefits (through *Symbiodinium* clade shifts [18,46]) for the host anemone, there are negative effects on resident clownfishes [47], in particular in terms of increased metabolic rate [23] and possible disruption of settlement [22]. Such effects might also impact *P. kauderni*, in particular the vulnerable recruit and small juvenile size classes, especially if collection of either host anemones or resident fish occurs [48].
3.3. Observed and anticipated impacts of global change on \textit{P. kauderni} and its microhabitats

Although very little research has been published on the species involved, empirical and experimental research on similar taxa indicates that various aspects of global climate change may have direct or indirect negative impacts on \textit{P. kauderni} and key microhabitats (diadematid sea urchins, sea anemones and corals) at several life-stages (Table 4). Where inference has been drawn from research on other taxa, the substantial differences reported in responses of closely related, even congenic sympatric species [50], indicate a need for further research at species level, as well as in the context of the symbiotic relations and wider ecosystem concerns relevant to \textit{P. kauderni} conservation.

Table 4. Synopsis of some likely impacts of global change on \textit{P. kauderni} and its microhabitats

| Type of change                     | Type of impact                                                                 | Likelihood of negative effects$^a$ | Selected references |
|------------------------------------|-------------------------------------------------------------------------------|------------------------------------|---------------------|
| Seawater temperature               |                                                                               |                                    |                     |
| • higher averages, daily minima    | Metabolism/physiology/risk of exceeding thermal risk of exceeding thermal     | BCF yes DD yes AN yes HC yes       | [3], [5], [8], [11],|
|  and maxima                        | tolerance/acclimation capacity/disruption of symbioses                        | [17], [21], [22], [23], [49], [50]|
| • more frequent and longer         | Lower O2 availability                                                        | yes ? ? ? ?                        |                     |
|  extremes                          | Disruption of food chains                                                    | yes yes yes yes                    |                     |
| Weather patterns                   |                                                                               |                                    |                     |
| • more frequent/severe storms      | Physical damage/mortality/Elevated risk of predation on/mortality of recruits  | yes$^c$ yes$^c$ ? yes             | [8], [25], [41], [51], [52]|
| • precipitation patterns           | Water quality: salinity, pH, turbidity, pollution, etc. (direct/indirect on    | yes yes yes yes                   |                     |
|                                   | habitat)                                                                     |                                    |                     |
| Ocean acidification                |                                                                               |                                    |                     |
| • lower seawater pH                | Impaired calcification affecting skeleton growth and/or strength               | ? yes no yes                       | [5], [8], [11], [49], [53]|
| • lower aragonite saturation       | Lower larval survival/quality and/or settlement/competency                    | ? yes ? yes                       |                     |
|  and other chemical changes        |                                                                               |                                    |                     |
| Sea surface level rise             |                                                                               |                                    |                     |
| • increased depth                 | Reduction in habitat: seagrass meadows, coral reefs, mangroves$^b$ (drowning  | yes yes yes likely                | [8], [51], [52]    |
|  • changing coastlines             | and coastal squeeze)                                                         |                                    |                     |

$^a$ BCF = \textit{P. kauderni}; DD = Diadematidae; AN = sea anemones; HC = scleractinian corals

$^b$ Some large \textit{P. kauderni} populations inhabit \textit{Rhizophora} spp. prop roots on shallow sandbars [26], [27]

$^c$ Moore, unpublished data, 2018. \textit{Diadema} and some \textit{P. kauderni} thrown ashore during a storm in early 2018

Despite the observed bleaching and likelihood of growing impacts from global change, overexploitation and direct anthropogenic damage are currently the main immediate causes of \textit{P. kauderni} habitat/microhabitat degradation [30]. The majority of observed coral degradation (dead and/or broken corals) between 2016 and 2017/2018 was not due to coral bleaching. At Bone Baru, widespread destruction was caused by an increase in destructive fishing, mainly overturning and other physical damage during collection of abalone (\textit{Haliotis} sp.), gleaning and spearfishing. At Tolokibit, an \textit{Acanthaster planci} outbreak (noted in 2017) was a major cause of coral death, along with damage from gleaning at spring low tides. The exploitation of \textit{Diadema} and \textit{Tripneustes} urchins at Tolokibit was no longer subsistence gleaning, but a commercial activity with truckloads collected once or twice a month and sold at IDR 15,000 (just over US$1) for ten urchins.
3.4. Outlook and future research directions

Our study indicates that, while local anthropogenic activities pose an immediate threat, the future will bring increasingly complex challenges for the holistic and sustainable management of *P. kauderni*, its habitat and microhabitats. Local and global drivers are likely to act synergistically, reducing the chances of *P. kauderni* habitat and population rehabilitation or recovery through natural microhabitat recruitment processes. Further research on the scale and synergies between stressors is required to better understand and mitigate or adapt to global change. Actions to reduce or eliminate major threats, in particular those related to unregulated, unreported and destructive (over) fishing of shallow-water marine invertebrates are both possible and potentially aligned with current government policy [54]. While such measures are vital, effective climate change mitigation at all levels, further identification and sound, science-based approaches to local mitigation of the already unavoidable impacts of global change on the Banggai cardinalfish and its microhabitats are likely necessary to ensure the long-term future of this iconic species in its native range.

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