Disasters and biodiversity: case study on the endangered endemic marine ornamental Banggai cardinalfish

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Abstract. Disasters are notoriously unpredictable; they can strike anytime, anywhere. However, in this Anthropocene Epoch, humanity has increased the likelihood of many disasters, as well as their likely severity and socio-ecological impacts, with implications for the future of natural resources; in particular, marine ecosystems and biodiversity, and the human communities who rely on them. This case study focussed on the Banggai cardinalfish (Pterapogon kauderni), a unique species of global conservation concern, and its native habitat in the Banggai Archipelago, at the centre of the Coral Triangle (CT) global marine biodiversity hotspot. To evaluate future risks and implications, we looked back to the past, including an overview of what is known regarding the origins and evolution of this species and its habitat, as well as past natural disasters in the Banggai Archipelago, Central Sulawesi, Indonesia. We then reviewed current status and trends affecting the likelihood of exposure and the vulnerability of endemic P. kauderni populations and habitat, overall and at the evolutionary significant unit (ESU) scale, to disasters caused by tectonic phenomena, disasters related to weather and anthropogenic climate change (e.g. mass coral bleaching, sea level rise), and the synergies between disaster impacts and localised human activities. Finally, we considered management options with potential for mitigating disaster risk and increasing resilience, with benefits for both biodiversity and human welfare, as well as avenues for future research. We conclude that local action can buy time, but it is likely that the eventual fate of this "flagship" species, as well as the human communities of this equatorial archipelago, depend on effective global action to curb the drivers of anthropogenic climate change.

1. Introduction
Disasters are notoriously unpredictable; they can strike anytime, anywhere. Nonetheless, while predicting precise timing or strength is still beyond current scientific capability, specific areas can be identified as at high or low risk from certain types of disaster, for example disasters related to plate tectonics such as earthquakes and tsunamis [1]. However, in this Anthropocene era humanity is altering the biosphere [2], in ways which are likely to increase the frequency and/or the severity of
extreme natural phenomena capable of causing disasters (e.g. storms, temperature anomalies) [2,3], as well as the socio-ecological impacts of a wide range of disasters[1,2,3]. These changes have implications for the future of natural resources, in particular, marine ecosystems and biodiversity, and the human communities who rely on them [4,5,6,7].

Phenomena classified as disasters can impact terrestrial [8] and marine [7] biodiversity, and may cause or contribute to population declines [9] or even extirpation [10]. Synergistic interactions between chronic anthropogenic stresses and extreme events (disasters) are likely to increase the negative impacts of both [7]. In the past, phenomena which today would be classified as disasters are thought to have played a significant role in species extinction, and may do so in the current "6th mass extinction" [11]. Furthermore, the complexity, pervasiveness and negative consequences for humanity of biodiversity loss at multiple scales are increasingly recognised [12]. There is thus not only a need to incorporate biodiversity in disaster planning, but also to consider disasters as a risk factor in biodiversity conservation.

This case study on disasters in the context of biodiversity focussed on the Banggai cardinalfish (*Pterapogon kauderni*), a unique species of global conservation concern [13], listed as Endangered in the IUCN Red List [14]. The native habitat of *P. kauderni*, in the Banggai Archipelago, Central Sulawesi, Indonesia [15], is at the centre of the Coral Triangle (CT) global marine biodiversity hotspot [16]. It is also within a region with a complex geological history [17] at high risk of natural disasters such as earthquakes and tsunamis [1,18]. The aims of the study were to evaluate the likelihood of exposure and the vulnerability of endemic *P. kauderni* populations and habitat to a range of disasters.

2. Method

This study was based largely on secondary (published or in press) data on the origins and evolution of *Pterapogon kauderni*, the current condition of endemic *P. kauderni* populations and habitat, as well as past natural disasters in the Banggai Archipelago, Central Sulawesi, Indonesia. Unpublished (primary) as well as published data collected during field surveys in the Banggai Archipelago and preliminary observations made during on-going *ex-situ* research at Hasanuddin University were also included in the analysis. Data were analysed descriptively to evaluate risk levels and identify management options with potential for mitigating disaster risk and increasing resilience, with benefits for both biodiversity and human welfare, as well as avenues for future research.

3. Results and discussion

3.1. The Banggai cardinalfish and its native habitat

The Banggai Archipelago in Central Sulawesi Province, Indonesia is recognised as an area of high marine biodiversity [19], currently divided into two districts (Banggai Kepulauan and Banggai Laut). Over 90% of the endemic distribution of the Banggai cardinalfish (*Pterapogon kauderni* Koumans 1933) lies within this archipelago [15], which originated as a micro-plate from Australasia [17]. It has been hypothesized that *P. kauderni* evolved from an Australian apogonid ancestor during the isolation of the archipelago prior to the collision with other Sulawesi plate fragments [15].

This evolutionary history could account for the unusual life history [20,15] and extremely fine scale genetic population structure [22,23] of *P. kauderni*. As a paternal mouthbrooder with direct development [15], *P. kauderni* lacks a pelagic larval dispersal phase. On release from the male parent's buccal cavity, the young resemble miniature adults and immediately seek protective microhabitat [15]. Post-release, the sedentary habitat of *P. kauderni* has been described as "extreme philopatry" [23]. Coupled with the shallow (to around 5m depth) near-shore habitat and strong association with benthic symbiotic microhabitat organisms (primarily urchins of the Genus *Diadema*, sea anemones, and some scleractinian corals) [15,20], these traits can explain the fact that *P. kauderni* populations in neighbouring islands, or even nearby embayments separated by stretches of coastline unsuitable as habitat, can display distinct genetic [21,22] and morphometric [24] traits, indicative of reproductive isolation and hence independent evolution/adaptation over time-scales as long as 100,000 years [22].
The attractive form and behaviour of *P. kauderni* led to popularity in the marine aquarium trade and hobby in the 1990's, with exploitation quickly reaching dangerously high levels [14,15,20]. This species is, by nature, intrinsically vulnerable to extinction, fulfilling 6 out of 8 criteria developed by the Nature Conservancy for identifying species at high risk: (i) Economic value; (ii) Easy to catch; (iii) Low reproductive capacity; (iv) Exploited and/or at risk throughout life-cycle; (v) Limited distribution; (vi) Limited habitat within distribution [25]. Furthermore, *P. kauderni* fulfils all 5 criteria in regulation PP60/2007 for (full or limited) protection under the Indonesian Ministry of Marine Affairs and Fisheries (MMAF) [13]. Meanwhile, *P. kauderni* habitat (coral reef and seagrass ecosystems) and microhabitat (specifically *Diadema* urchins, sea anemones, corals) are also under chronic (and in many cases increasing) threat from a wide range of human activities across the Banggai Archipelago [25,26,27].

The traits and conditions described above make *P. kauderni* especially vulnerable to serial loss (extirpation) of local populations, with no natural re-population method for extirpated populations. The fine-scale genetic structure and reproductive isolation mean that many local populations are likely to constitute separate Evolutionarily Significant Units (ESUs) [13,28,29], and should be considered as separate management units for both fisheries management and biodiversity conservation.

In addition to the IUCN Red List status of Endangered [14], *P. kauderni* has twice been proposed for CITES Appendix II listing and the CITES Animal Committee is monitoring the progress in Indonesia with respect to *P. kauderni* conservation [13]. Current initiatives include a National Plan of Action (2017-2021) (NPOA) for *P. kauderni* conservation, (very) limited [13] protection under Minister Decree Kepmen 49/2018, and spatial management in the form of a marine protected area (Banggai Dalaka MPA) established by a decree of the Governor of Central Sulawesi Province (KepGub 523/635A/Dis.Kan GST/2017), in which *P. kauderni* (populations and habitat) constitute one of four conservation priorities. This MPA comprises over 90% of known native *P. kauderni* populations and several of the many introduced populations, formed through release by traders along the ornamental fishery trade routes [13]. In this context it is vital that activities under the NPOA and MPA management adopt an ESU-based approach to maintain *P. kauderni* genetic diversity as well as preventing extinction at the species level.

### 3.2. Tectonic disasters in the Banggai Archipelago

The origins and geological complexity of the Banggai Archipelago and surrounding tectonic plates [17][18] make this area intrinsically at risk from earthquakes and tsunamis of a magnitude sufficient to be classed as disasters. The most recent major tectonic disaster was an earthquake of magnitude on 4 May 2000 with an epicentre at 1.105°S/123.573°E, depth 26 km, followed by a tsunami and several quakes of lesser magnitude (https://earthquake.usgs.gov/earthquakes/eventpage/usno0009sh). In addition to loss of human life and property, this event resulted in some physical damage to *P. kauderni* habitat. Some corals were broken and there may have been some loss or gain of habitat due to altered bathymetry (uplifting or subsidence) at some sites. However the effect of these direct impacts on *P. kauderni* populations appears to have been relatively minor compared to the indirect impacts mediated by human post-disaster activity [25].

The case of Liang, based on a study in 2004 [25] and surveys from 2012 to 2018 [15,26,30], is illustrative of this paradigm. The jetty in Liang harbour was completely destroyed, as were many homes. Post-disaster reconstruction materials (primarily coral "rock") were almost entirely sourced from the coral reef around the two small islands protecting the harbour from wind and weather. Prior to the event, *P. kauderni* populations were thriving both in the harbour and around the islands. In 2004, *P. kauderni* were still thriving among the ruins of the old jetty in the harbour, but the extreme degradation due to the coral mining had reduced the island population to just one group of 11 individuals, with extirpation confirmed in 2014. The lack of re-colonisation by *P. kauderni* (last confirmed as absent in May 2018) is unsurprising given the depth (20-30m) and lack of microhabitat in the channel between the harbour and the islands. In addition, the Liang harbour population, thriving
in the post-disaster conditions, has subsequently declined sharply due to overexploitation of microhabitat, especially the urchins *Diadema setosum* and *Diadema savignyi* [27,30].

The severity of earthquake associated tsunami disasters in this area is predicted to increase due to sea level rise (http://thinkhazard.org/en/report/1532-indonesia-sulawesi-tengah). However, from a biodiversity viewpoint, and specifically with respect to *P. kauderni* populations, the impact is likely to depend mostly on human actions post-disaster, thus indicating a need for factoring biodiversity concerns into disaster preparedness planning.

### 3.3. Climate-related disasters in the Banggai Archipelago

Climate-related disasters which have or could occur in the Banggai Archipelago and could affect *P. kauderni* populations include severe weather events and (high) temperature anomalies. Historically, this region has a relatively stable Equatorial climate, outside typhoon and hurricane belts [16]. Nonetheless, severe weather does occur, especially during the southeast monsoon, and can cause human fatalities [25]. Furthermore, in 2004 severe weather was perceived as more frequent and less predictable (outside the “normal” windy seasons) [25], a trend which has increased according to local fishermen (Moore, unpublished data, 2018).

An example of potential impacts on *P. kauderni* populations occurred in early 2018. An unseasonable severe storm affected the village of Monsongan, on the west coast of Banggai Island, causing damage to the village, including houses on stone (coral “rock” and other) platforms, and even the platforms themselves, as well as boats and other gear. Wave action not only shifted large stones, a variety of benthic marine organisms were also tossed ashore, including considerable numbers of *Diadema* urchins, as well as (far fewer) fish. While some *P. kauderni* undoubtedly perished during the event itself, the massive loss of key microhabitat seems to have had an impact lasting well beyond the event itself. In May-June (2-3 months later), the effects of disturbance and mortality on *Diadema* were still visible, with few urchins (approximately 10%-25% compared to October 2017), mostly juveniles, and occupying a much reduced spatial extent. *P. kauderni* population abundance was similarly reduced, with an adult/sub-adult-dominated size structure. The apparent loss of several (monthly) cohorts, with recent recruits and small juveniles absent in most groups, indicates several months of almost total reproductive failure. The missing cohorts may be, at least partly, due to direct mortality of juveniles from physical processes during the event. However mortality was likely high both during and after the storm, due to the elevated risk of predation (including cannibalism of *P. kauderni* recruits/juveniles) during disturbance to and subsequent dearth of protective microhabitat [31].

While healthy *P. kauderni* populations (ESUs), as well as *P. kauderni* microhabitat/symbionts, should rebound from such stochastic events, severe weather events could increase the risk of extirpation for ESUs already or subsequently depleted by other factors, including fishing pressure on *P. kauderni* and/or key microhabitat. Furthermore, efforts by human communities to prevent damage from rising sea surface levels, storm surges, and coastal abrasion generally, tend to result in the degradation or even the loss of *P. kauderni* habitat and (especially scleractinian coral) microhabitat.

Rising sea temperatures are a feature of global change in the Anthropocene, including increases in the frequency and severity of thermal anomalies [2,4,5]. These global waves of coral bleaching can be considered as disasters affecting people and nature. There is evidence that the 2016 bleaching event was the worst to date in Indonesian waters [32], including those of the Banggai Archipelago, where corals and sea anemones bleached (partially or completely) as sea temperatures reached 32-33°C with peaks at 34°C [33]. Observed bleaching and subsequent inferred mortality indicate a disproportionately high impact on the coral genera and life-forms serving as microhabitat for (predominantly adult) *P. kauderni*, as well as on sea anemones inhabited by recruits/small juvenile *P. kauderni* [33].

Temperature–related beaching is thus likely to have a direct impact on habitat quality and on both adult and juvenile *P. kauderni* microhabitat availability, and thus on both reproductive potential and success. In addition, the elevated temperatures during such events may have a deleterious impact on *P. kauderni* individual fitness and even survival. While the experimental observations and data analysis
are still on-going, preliminary results of ex-situ experiments in temperature-controlled microcosms indicate that at temperatures above 31-32°C P. kauderni may experience loss of condition (emaciation, Figure 1A) and increased mortality, although the proximate causes and underlying mechanisms are as yet unknown. Furthermore, the symbiosis with Diadema setosum appears to be affected, with an increase in incidences of predation on P. kauderni by D. setosum (Figure 1B) at higher temperatures.

Figure 1. A. Emaciated adult P. kauderni after 1 week at 33°C (note the concave shape of the normally convex upper body); B. Predation of D. setosum on P. kauderni in a microcosm maintained at 33°C.

3.4. Risk analysis: exposure and vulnerability

An evaluation of the likelihood of exposure and the vulnerability of endemic P. kauderni populations and key microhabitat to three types of disasters (Table 1) indicates several areas of known risk and vulnerability. It also highlights many areas where further research is required to enable a comprehensive evidence-based evaluation.

Table 1. Overview of likely exposure and vulnerability of P. kauderni and its key microhabitats to four categories of potential disasters

| Disaster - natural and/or anthropogenic (exposure) | Type of impact | Vulnerability to negative effects<sup>bc</sup> |
|-----------------------------------------------|----------------|----------------------------------|
| A. Tectonic (1)                               |                | BCF    DD  AN  HC |
| Earthquakes, tsunamis                        | Direct physical damage/mortality | L  M  U  M |
| Changes in elevation/topography/bathymetry   | Change in habitat extent and nature (uplifts/subsidence) | L-M  L-M  L-M  M |
|                                              | Effects of human survival and rebuilding activities | H  H  H  H |
| B. Ocean temperature/ SST (3) -> Bleaching (1→2) | Metabolism/physiology/risk of exceeding thermal tolerance/ acclimation capacity/disruption of symbioses | U  U  U  H |
|                                              | Disruption of food chains | U  U  U  H |
| C. Extreme weather (1→2)                     | Physical damage/mortality | L  M-H  U  M |
|                                              | Elevated risk of predation on/mortality of recruits | H  -  -  - |

<sup>a</sup>Exposure: 1 = rare, 2 = frequent, 3 = potentially pervasive or chronic

<sup>b</sup>Vulnerability: L = low, M = medium, H = high, U = unknown

<sup>c</sup>BCF = P. kauderni; DD = Diadematidae; AN = sea anemones; HC = scleractinian corals
In addition to the factors evaluated in Table 1, sea surface level rise is likely to become a pervasive threat [2][3]. Although predominantly chronic or pervasive, non-linear changes or the exceeding of tipping points could result in events qualifying as disasters. These could include major changes in coastlines and coastal ecosystems (seagrass meadows, coral reefs, and mangroves) leading to a reduction in habitat extent or quality, for example through drowning and coastal squeeze [4,5]. Furthermore, it is clear that localised human activities will greatly affect disaster impacts on *P. kauderni* and its habitat, especially in the longer term.

3.5. Mitigation Options and Outlook

With respect to disasters, humanitarian aspects tend to be uppermost in the minds of both victims and aid providers. Nonetheless, because of the long-term consequences of environmental degradation, including loss or reduction of biodiversity [1,12], mitigation of impacts on biodiversity at all levels should be factored in to disaster management plans. In the context of *P. kauderni* conservation, to be effective, most measures should be aimed at the ESU level, to reduce the risk of irreparable loss of within-species biodiversity, as well as stochastic serial extirpation which could eventually threaten the native (endemic) population as a whole. Management options with potential for mitigating disaster risk and increasing resilience, with benefits for both biodiversity and human welfare, include the following: (i) ESU-based fisheries management, as outlined in [13,28]; (ii) protection for *P. kauderni* microhabitat, in particular through regulation of the currently unreported and unregulated fishery for *Diadema* spp.; (iii) effective habitat protection (coral reefs, seagrass meadows, some mangrove forests), with *P. kauderni* as a charismatic "flagship species"; (iv) holistic community-based rehabilitation of *P. kauderni* and its microhabitats at the ESU level, e.g. through the "BCF Gardens" concept [26,28]; (v) specific plans for post-disaster reconstruction to avoid the use of corals or other damage to *P. kauderni* habitat. Furthermore, any transfer of *P. kauderni* between ESUs should be avoided, except in exceptional circumstances (e.g. near-total extirpation) such measures could and should be implemented under the NPOA and Banggai Dalaka MPA management.

In order to support these measures, a comprehensive study to identify and delineate *P. kauderni* ESUs, based on genetic traits and supported by ecological and geographical data, should be considered a priority. However, as pointed out by [13,28], the lack of such a study should not prevent measures based on current known or inferred ESUs. Other priorities include further research on the symbiosis between *P. kauderni* and its microhabitats, under current and predicted conditions, and the application of existing and emerging knowledge pilot implementations to develop and refine recovery and rehabilitation concepts (e.g. "BCF Gardens" [26,28].

Despite the potential for preventive and remedial disaster mitigation measures, a wide body of existing literature on global change and preliminary observations on *P. kauderni* and its symbionts indicate that, under current trends, a combination of chronic changes and extreme events is likely to cause extirpations and the eventual extinction in the wild of this species within its native (endemic) range. We conclude that local action can buy time, but it is likely that the eventual fate of this "flagship" species, as well as the human communities of this equatorial archipelago, depend on effective global action to curb the drivers of anthropogenic climate change.

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