An Ecological and Social Approach to Banggai Cardinalfish Conservation Management

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Abstract. The Banggai cardinalfish (Pterapogon kauderni, Koumans 1933) is a restricted range coral reef associated fish endemic to shallow waters (under 5m) around the Banggai Archipelago, Indonesia. Listed as "Endangered" in the IUCN Red-List, the international marine aquarium trade and habitat degradation are considered major threats. After the (unsuccessful) proposal for listing under CITES Appendix II in 2007, Indonesia developed a national conservation action plan for P. kauderni. Banggai cardinalfish conservation is also included in the Indonesian national Coral Triangle Initiative plan. A district marine protected area (MPA) including 10 islands was established in 2007 by Decree of the Banggai Kepulauan District Head with conservation of P. kauderni as the primary goal at two of these islands: Banggai and Togong Lantang. With no pelagic phase and high site fidelity, the Banggai cardinalfish exhibits a level of genetic structure unusual in a marine fish. We suggest that management units should be based on genetically determined sub-populations (stocks). We are undertaking research to identify and characterise these units from biological (genetic/microsatellite DNA), ecological (population/habitat/micro-habitat) and socio-economic (including fishing ground) aspects. Initial results reveal that there is no P. kauderni population at Togong Lantang and the district MPA design is poor from a *P. kauderni* conservation perspective, especially in terms of genetic diversity. Using the conservation planning tool, MARXAN, we will provide science-based zoning options with management units and conservation targets based on genetic population structure.

Key words: Pterapogon kauderni; Genetic diversity; MPA effectiveness; MARXAN; Banggai

Introduction

Indonesia is located in the heart of the Coral Triangle, one of three major global biodiversity regions, ranking alongside the Amazon and Congo basins. As a signatory to the Convention on Biological Diversity (CBD), Indonesia is committed to biodiversity conservation. The high level of anthropogenic pressure (direct and indirect) means that an increasing number of species are at risk of extinction and there is growing concern about aquatic species, as reflected in a recent review of the IUCN Red List; recent proposals to CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora); additions to the list of species protected in Indonesia under the Appendix to Law PP No7/1999; and the Census of Marine Life - CoML (http://www.coml.org). This concern is increasingly extended to the conservation of genetic diversity within species (e.g. Conover et al. 2006).

One factor which tends to affect within species genetic diversity is the level of reproductive isolation between populations. In extreme cases, this can mean that there is no gene flow for many generations. Isolated populations or sub-populations tend to become genetically distinct due to a variety of mechanisms (Bertorelle *et al.*, 2009). It is now widely considered that, in the conservation management of species with reproductively (therefore genetically) isolated populations, each such population should be treated as a separate management unit. This is specifically so in the case of marine fish, where each such unit can be considered as a separate stock (Reis *et al.*, 2009; Rocha *et al.*, 2007). Sustainable management of marine fisheries resources, including the use of Marine Protected Areas (MPA) and MPA networks as a fisheries management tool, should be based on these genetic sub-populations or stocks (Palumbi, 2003).

As pointed out by Hellberg (2007), the development of technology for genetic (DNA) analysis now enables the identification of such units or stocks using a variety of approaches. One powerful support tool is GenBank, a global database of DNA and other proteins, hosted by several sites (e.g. http://www.ncbi. nlm.nih.gov/genbank/). A number of other tools (e.g. software for genetic data analysis) are available and many can be accessed for free at this and other sites.

One marine species of conservation concern is the Banggai cardinalfish Pterapogon kauderni (Koumans, 1933), a small (maximum standard length \pm 65 mm SL) reef-associated member of the Apogonidae (cardinalfishes), listed as Endangered in the IUCN Red List since 2007. Based on Vagelli (2005), the endemic distribution (Fig. 1) is limited to the southern part of the Banggai Archipelago and a few nearby islands ($\pm 5,500$ km²), with ± 34 km² of available habitat and an estimated endemic population of ±2.4 Traded internationally as a marine million. ornamental since the 1980's (Ndobe and Moore, 2009), introduced P. kauderni populations have become established at several sites along the long and complex trade routes (see Fig.1).



Figure 1: Known endemic and introduced *P. kauderni* populations

A paternal mouthbrooder with direct development, (Vagelli, 1999), there is no pelagic dispersal phase in the *P. kauderni* life-cycle, and *P. kauderni* exhibits a high site fidelity (Kolm *et al.*, 2005). These factors, combined with relatively low fecundity (Vagelli, 2005) make the species vulnerable to extinction.

Suitable shallow-water habitat (coral reefs, reef flats and seagrass beds under 5 m depth) tends to be discontinuous and with the lack of natural dispersal mechanisms intuitively there is a high probability of genetic isolation occurring. Significant genetic population structure in *P. kauderni* has been observed at the level of the Banggai Archipelago (Hoffman *et al.*, 2004 &2005; Bernardi and Vagelli, 2004) and at a fine scale around Bangkurung Island (Vagelli *et al.*, 2009), with genetically distinct stocks separated by as little as 2-5km. Local extinctions are therefore likely to result in the total loss of genetic strains.

The near-shore shallow habitat and sedentary habit make *P. kauderni* extremely easy to catch, and by 2001 the trade volume was estimated to be around 700,000-1.4 million fish/year (Lunn and Moreau, 2004). Considerable international attention has been focussed on the risk of extinction due to the marine aquarium trade (e.g. Bruins *et al.*, 2004). A proposal for listing *P. kauderni* under CITES by the United States of America in 2007 was withdrawn. Indonesia opposed the listing and made a commitment to the sustainable management of this species, including the development of a sustainable ornamental fishery. The Banggai Cardinalfish Action Plan was developed by local and national stakeholders (Ndobe and Moore, 2009), and Banggai cardinalfish conservation is a goal in the National Coral Triangle Initiative Action Plan. Since 2007, there have been improvements in the management of the fishery but growing threats from habitat and especially micro-habitat loss (Ndobe *et al.*, 2008; Moore *et al.* 2011) have not yet been addressed.

A district (MPA) was declared in 2007 by the Banggai Kepulauan District Head (SK Bupati 540/2007). This MPA is a network of 10 islands, two of which (Banggai and Togong Lantang) are designated specifically for the conservation of the Banggai cardinalfish. This MPA is still in the planning phase and there is a need for data to inform the mandatory planning process, particularly zonation. Most of the islands in the MPA are small with few if any permanent inhabitants, but the zonation of Banggai Island, with an area of around 294km², over 37,000 inhabitants, and 27 villages in 4 sub-districts, will be especially challenging.

To be effective, conservation management and in particular MPA zonation should not only take into account biodiversity at the ecosystem, species and genetic levels but also economic and social factors (Ardron *et al.*, 2010). Furthermore, relevant data need to be analysed in a way which is relevant to management needs and presented in a user-friendly format which non-scientist stakeholders can use. This is often achieved through the use of an electronic spatial database or Geographical Information System (GIS) and related data products (e.g. maps).

Based on the biological/ecological and socioeconomic context, we consider genetic units or stocks to be important for *P. kauderni* conservation, both from a fisheries management point of view and in the context of the Banggai Kepulauan District MPA planning and management. We are developing an approach for the identification of these stocks and their incorporation into the MPA zonation planning process. We also evaluated the District MPA in terms of its potential for conservation of *P. kauderni* populations and genetic diversity.

Material and Methods

The MARXAN software is one commonly used and powerful tool for MPA planning (Loos, 2006) which can incorporate fisheries concerns (Klein *et al.*, 2008). The planning area is divided into planning units, each of which is assigned attributes which will be used to evaluate its potential contribution to conservation (features) and the outlay or loss to other sectors associated with conserving it (costs). MARXAN analyses spatial and spatial-linked data to produce zonation scenarios which achieve user-driven targets for the conservation of specific features (e.g. habitats or species), for the least possible "cost".

We consider each genetically defined *P. kauderni* sub-population or stock as a separate "feature". This approach, to be applied initially to areas within the district MPA designated for *P. kauderni* conservation (Banggai and Togong Lantang Islands), requires a number of data layers as inputs, including the spatial distribution, habitat and population status of these *P. kauderni* stocks. Initial data regarding *P. kauderni* biogeography and genetic structure were obtained from a literature search supplemented by observation and key informant interviews conducted during 2011. Proposed planning unit size (2km diameter) was determined by the smallest known distance between known genetically distinct stocks.

Eleven polymorphic micro-satellite loci were identified by Hoffman *et al.* (2004) and the genetic information stored in GenBank. Two of these (Pka06 and Pka11) were selected by Hoffman *et al.* (2005), Kolm *et al.* (2005) and Vagelli *et al.* (2009) as providing the best power for genetic population data studies. Key parameters are given in Table 1.

Parameter	Pk06	Pk11
GenBank	AY530933	AY530936
Accession		
Sequences (5'-3')	*AAGGTTCCACT	*CACACGCACT
	TCCATCTACT	GATGTTT
	TCGGTCTTCCAC	CGCAGTATCTT
	CAATAA	AGCTGTTC
Annealing	53.5	56
Temp (°C)		
Repeat	(GATA) ₆	$(GT)_{12}A(GATA)_5$
Clone size	218	288

Table 1. Parameters for the two selected micro-satellite loci Pka06 and Pka11 (from Hoffman *et al.*, 2004)

Samples for genetic population analysis were collected in December 2011 at six sites around Banggai Island, along with data on P. kauderni populations, habitat and microhabitat using the transect method in Ndobe et al. (2008). Sampling sites (Fig. 2) were selected based on coral reef and seagrass distribution, bathymetry, exposure to severe wave action and local knowledge as well as genetic sampling results in Vagelli et al., 2009 (2 sites in the north and northwest of Banggai Island) and Hoffman et al., 2005 (2 sites in the south and southwest). The 2 sites in each of these data sets exhibited distinct genetic characteristics based on the Pk06 and Pk11 micro-satellites, however published data do not seem sufficient to compare the two data sets. Samples collected for genetic analysis (using the Pka06 and

Pka11 loci) consisted of tail fin clippings (as described in Kolm *et al.*, 2005) from 30 randomly selected adult *P. kauderni* at each site. These were preserved in 95% technical grade alcohol and analysis in the laboratory began in April 2012.



Figure 2. December 2011 Banggai Island sampling sites

Results

Pterapogon kauderni distribution

The 2011 sampling expedition revealed that Togong Lantang (Fig. 3), the only island other than Banggai Island designated for *P. kauderni* conservation, does not in fact have a *P. kauderni* population. There is a large population of *Sphaeramia nemtopterus*, another cardinalfish which under certain conditions (e.g. among mangrove roots as in this case) bears a strong resemblance to *P. kauderni*. It is likely that the (non-local) MPA survey team misidentified this species as *P. kauderni*. Though this may seem unlikely to ichthyologists familiar with both species, the authors have on several occasions been told of *P. kauderni* populations outside the endemic distribution which turned out to be *S. nemtopterus*.

Genetic Population Structure

Analysis of genetic distance based on mtDNA data by Bernardi and Vagelli (2004) indicated a reproductive isolation period of around 800,000-160,000 years between the islands of Bangkurung and Banggai. This is consistent with known sea level variation, as prior to this period most of the known P. kauderni distribution, including the two islands of Banggai and Bangkurung, would have been joined by shallow waters suitable as Banggai cardinalfish habitat. Suspected population breaks and eastwards limits of P. kauderni distribution around Banggai Island based primary secondary ecological and and on geographical data combined with information from fishermen (local knowledge) are shown in Fig. 2. The

east coast of Banggai Island is exposed to the full force of the East Monsoon. At the most easterly known site (Matanga) for which *P. kauderni* survey/monitoring and socio-economic data are available, populations are severely impacted each year, generally recovering during the changeover and West Monsoon periods. Other suspected population breaks are areas where the underwater topography is sheer or very steep, with little or no shallow-water habitat suitable for *P. kauderni* and at which according to local people (especially *P. kauderni* fishers), there are no "*Capungan*" (the local name for *P. kauderni* in Banggai language).

Overview of biophysical and socio-economic data

Initial assessments of the biophysical and socioeconomic survey and monitoring data indicate a substantial decline in P. kauderni micro-habitat, especially Diadema sea urchins and sea anemones. There were two apparent reasons for this decline: an increase in the harvest of invertebrates (including sea anemones and sea urchins) for human consumption, and an increase in the use of Diadema urchins as feed for carnivorous fish destined for the live reef fish trade: the latter often in connection with illegal trade in the Napoleon wrasse Cheilinus undulatus. There were strong indications of declining P. kauderni populations at sites where Diadema urchins and/or sea anemone populations had been heavily harvested, including sites where P. kauderni is not exploited for the ornamental fish trade.

Bone Baru (see Fig. 2) in the north of Banggai Island is arguably the major *P. kauderni* fishing village in the Archipelago. A community MPA has been established in this village and the ornamental fishers in Bone Baru are actively supportive of *P. kauderni* conservation. This MPA will be a "Lock In" (fixed conservation zone) for the MARXAN application, however it cannot be considered in terms of genetic (stock) diversity conservation as the Banggai cardinalfish at the site are largely unsold fish captured from many different sites (stocks) released in the community MPA. For this reason, the village was not included as a genetic sampling site.

Evaluation of the District MPA

Of the 10 islands included in the Banggai Kepulauan District MPA at least three islands/areas with known *P. kauderni* populations (Bandang Besar, Sonit and Panteh) are not designated for Banggai cardinalfish protection, while ironically one island without a *P. kauderni* population (P. Togong Lantang) has been designated for this purpose. Banggai Island is a major main fishing ground for the *P. kauderni* trade. The remaining 5 islands within the MPA are outside the known *P. kauderni* endemic distribution. An overlay

of the MPA with genetically distinct *P. kauderni* populations or stocks identified by Vagelli *et al.* (2009) is shown in Fig.3. Of the 17 genetic stocks identified by that study, 15 are outside the boundaries of the MPA.



Figure 3. Overlay of some genetic population data (Vagelli *et al.*, 2009) based on Pk06, the known *P. kauderni* endemic distribution and the District MPA 10 island network. The 2 islands designated for *P. kauderni* conservation are in bold type. Areas II, VI and IX are not so designated. Areas III, IV, V, VII and VIII are outside the endemic distribution area.

Discussion

Based on currently available data, the District MPA network design is poor from *P. kauderni* population and genetic diversity aspects. To be effective in conserving *P. kauderni* populations in general, the MPA will have to address the difficult issues associated with habitat and micro-habitat degradation, at least for the one island (Banggai) with a *P. kauderni* population currently designated for the conservation of this species, and ideally for all islands in the MPA with *P. kauderni* populations.

The vast majority of the known P. kauderni distribution and most of the known genetic diversity are outside the MPA boundaries. Despite this fact, effective conservation of the P. kauderni populations around the island of Banggai based on genetically determined units could make a significant contribution to the conservation of the species as a whole. From a genetic diversity perspective, the MPA could protect at least 4 distinct genetic stocks, the actual number should be known when the genetic population analysis for Banggai Island is completed (June/July 2012). Combining genetic, geological and ecological data, it should be possible to determine the boundaries between stocks, so that each MARXAN planning unit with a P. kauderni population can be allocated to a specific stock.

Hoffman *et al.* (2005) found a high level of genetic structure with significant divergence between seven sites, considered most likely due to highly restricted

gene flow rather than natural selection. The power of genetic analysis is reflected in the similar genetic composition of Tolokibit (see Fig 2) and Luwuk (see Fig 1). This finding concurs with social survey data (Ndobe and Moore, 2009) which revealed that a trade route from Tolokibit began in the 1980's and passed through Luwuk. Banggai cardinalfish were indeed released in Luwuk harbour by the traders involved. This shows the importance of relating socio-economic and biological data.

Despite the limitations identified, the approach suggested here should provide tools to enable optimisation of genetic conservation benefits for Banggai Island. If successful, the approach could be extended to the other islands with *P. kauderni* populations within the MPA. The approach could also be used to inform the designation of further areas for *P. kauderni* conservation. For example community MPAs or zonation associated with the proposed designation of the Banggai cardinalfish as a species with limited protection under legislation which is currently being developed.

The use of MARXAN for the conservation of within species genetic diversity will be a new application of the MARXAN tool. Once the genetic, biophysical (e.g. habitat & microhabitat) and socioeconomic (e.g. fishing grounds, key infrastructure, coastal development, aquaculture) data layers have been compiled into a GIS database, MARXAN can provide science-based options for achieving MPA conservation targets which are suggested or set by scientists and/or managers.

Initial runs will provide a basis for a discussion and consultation process. Suggestions from stakeholders can be entered into the GIS and factored in to further MARXAN RUNS to predict the effects of specific choices on conservation targets (e.g. specifically on conservation of BCF genetic diversity) or indeed to test the costs and benefits associated with changes in the conservation targets themselves. Thereafter, the GIS can be updated with new data and information (e.g. additional surveys or genetic analysis, planned infrastructure development etc), both before and after a management plan and management mechanisms are in place, including data from monitoring programs. It is hoped that this GIS will prove a valuable tool for adaptive management as well as conservation management planning within the Banggai Kepulauan District MPA, thus making a significant contribution to the achievement of Coral triangle Initiative goals, especially conservation of P. kauderni habitat/microhabitat, populations and genetic diversity.

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