



UNIVERSITÀ DEGLI STUDI DI PADOVA
Dipartimento di Biomedicina Comparata e Alimentazione
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*Management and welfare of ornamental fish
in the global market trade: A case study of Banggai cardinalfish*

Supervisor
Dr. Francesco Bordignon

Laureanda/Submitted by
Margherita Casiraghi
Matricola n./Student n.
2033610

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INDEX

Abstract	3
Introduction	4
Discussion	7
Chapter 1: An overview on the Banggai cardinal fish	7
1.0 <i>Taxonomy and morphology</i>	7
1.1 <i>Geographical range</i>	8
1.2 <i>Habitat</i>	8
1.3 <i>Reproduction</i>	9
1.4 <i>Diet</i>	9
1.5 <i>Water chemistry</i>	9
1.6 <i>Diseases</i>	10
Chapter 2: The use of welfare indicator to assess fish welfare during and after trade	11
2.0 <i>Animal-based welfare indicators</i>	11
2.1 <i>Environment-based welfare indicators</i>	12
2.2 <i>A checklist proposal of welfare indicators tailored to the Banggai cardinalfish</i>	12
2.3 <i>Suggestions for score improvement</i>	16
Chapter 3: Trade stages of the Banggai cardinalfish from capture to retail	19
3.0 <i>Wild fish collection</i>	19
3.1 <i>Holding facility/quarantine</i>	19
3.2 <i>Transport</i>	21
3.3 <i>Wholesaler/retailer</i>	21
Chapter 4: Suggestions to improve the sustainability and welfare in fish trade	22
4.0 <i>Banngai cardinalfish gardens</i>	22
4.1 <i>Captivity breeding programs</i>	23
4.2 <i>Shifting consumer behaviour</i>	24
Conclusion	26
Bibliography	27

Abstract

This dissertation explores the welfare challenges within ornamental fish trade with a particular focus on Banggai cardinalfish. The central research question of the dissertation was: How is the welfare of the Banggai cardinalfish impacted by the international ornamental trade, and how can we improve it across the supply chain?

Banggai cardinal fish was chosen as a symbolic representation of the challenges within the ornamental fish trade because of its low reproductive and dispersal rate, extremely restricted endemic range, and reliance on benthic organisms, which are themselves endangered, for survival. Despite being listed as endangered by the IUCN, the species has received minimal conservation attention, with no comprehensive monitoring systems in place. Despite the significant economic value and the potential of the trade to support low-income coastal communities, this market is often associated with destructive and harmful fishing methods, such as cyanide fishing, inadequate transport conditions, and poor management practices throughout the supply chain.

Through a comprehensive review of scientific literature this dissertation aims to emphasise the need for improved welfare standards, proposing tailored welfare indicators to assess and enhance fish welfare throughout the whole chain of operations. To promote sustainable practices, this dissertation advocates for community driven initiatives, such as habitat restoration through the implementation of Banggai cardinalfish gardens and the implementation of captive breeding programmes aimed at reducing pressure from wild populations.

In essence, this review calls for a holistic approach to balance animal welfare, conservation efforts, and economic interests. Engaging every stakeholder across the supply chain, while promoting consumer awareness, and working alongside local communities are the core elements for a more sustainable future. This work aims to not only address the pressing welfare and ecological issues facing the Banggai cardinalfish but also to serve as a broader model for sustainability within the ornamental fish trade.

Introduction

The marine ornamental fish trade started to become a common practice in Sri Lanka during the early 1950s. Then, it experienced a rapid growth in the 1970s, expanding at an average annual rate of approximately 14% (Lal et al., 2021).

Today, this industry generates over a billion dollars globally each year (Jones et al., 2021) and accounts for the trade of 81% of all marine ornamental fish species (1764 species in 131 families) (CITES, 2024). An average of 3.8 million Kg of marine ornamental fish were traded globally each year from 2012 to 2021. (CITES, 2024). Despite the significant volume of trade, data transparency remains limited. In Europe, between 2021 and 2023, only 48% of the marine ornamental fish was documented at the species level. In the United States (the largest importer by tonnage), during the same period, less than 0.2% of species were classified by species or genus (CITES, 2024).

Overall, the marine ornamental fish trade is often described as “low impact, low volume, high value” (OATA, 2018). However, the term “low impact” is ambiguous. In fact, a clear understanding of this trade is still lacking, and without reliable, continuous data, it is nearly impossible to quantify the industry’s real environmental and ecological footprint. In addition, the impacts of fish collection remain largely unknown (Dee et al., 2019). A recent CITES workshop held in Brisbane in May 2024 highlighted this data gap as a critical barrier to comprehensive analysis. In fact, current statistics are often incoherent or inaccurate. For example, Spain is listed as a top exporter despite its minimal involvement in the trade (CITES, 2024).

Similarly, the concept of “low volume” is difficult to quantify. One reason is that accurate mortality rates throughout the supply chain are unavailable due to the sensitivity of such information (Wabnitz, 2003). In addition, the amount of fish traded is typically measured by weight rather than number (Wabnitz, 2003), and it is unclear whether this weight includes the bag and the water (gross weight) or just the fish (net weight). These varying units of measurement creates room for misinterpretation.

Finally, describing the trade as “high value” raises questions about who truly benefits. Managed sustainably, this economy could enhance the livelihood of rural, low-income, coastal communities. However, the price disparity between the source and the consumer highlights the inefficiency and inequality of the trade. While a fisherman will earn around 0.10 USD per fish, retail prices can reach up to 12 USD per fish (Wabnitz, 2003). The main reason for this discrepancy is the high cost attributed to the air transport, which can account for half to two-thirds of the retail price (Wabnitz, 2003).

Increased care and understanding of this “hidden” ecosystem could benefit local communities by generating revenue to low-income countries, marine biodiversity conservation, and encourage sustainable tourism. A sustainable trade could create a vital link between consumers' expectations and the marine environment.

However, achieving this requires greater transparency in the trade, higher welfare standards, and increased accountability for all stakeholder involved.

Improving welfare standards during each phase of the trade —capture, transport, holding/quarantine, and retail—not only benefits the caught fish by reducing mortality rate but also has economic benefits, potentially raising profits and improving the livelihoods of these low-income coastal communities.

The marine ornamental fish trade is often characterised by unsustainable and harmful practices, such as cyanide fishing. This method, used to stun fish for easier capture, could significantly increase their mortality rate. In fact, it is estimated that 75-80% of Banggai cardinalfish die before export (Pompon et al., 2019), with mortality rates rising to 90% when accounting for the entire supply chain up to the retailer (Murray et al., 2005). High mortality is partly due to the long transport times (up to 72 hours) (Vanderzwalmen et al., 2020). During transport, mortality rates of 25-30% have been observed (Conant, 2015). This is exacerbated by stressors such as abrupt photoperiod changes from confinement in sealed boxes, which could disrupt metabolic activity. Additionally, fish are usually starved to prevent water pollution, while sedatives and antibiotics are added to the water to mitigate disease and avoid physical damage. Although fish are initially placed in oxygen-saturated environments in order to withstand long travels, many could experience hypoxic conditions by the time they reach their final destination. These combined stress factors could make the ornamental fish trade not only unsustainable but also highly detrimental to the welfare of the species involved.

This dissertation will focus on the major welfare and management issues and possible solutions related to the ornamental fish trade, with a special focus on a particular species, Banggai cardinalfish (*Pterapogon kauderni*), for several reasons. First, the ornamental fish trade is an extremely complex and intricate topic. Therefore, a more focused approach could benefit both the reader and the bibliographic research, with a narrower subject allowing for more concrete conclusions. Second, the choice of the Banggai cardinalfish is based on its unique status as one of the few marine fish species that has been studied sufficiently to replicate its reproductive cycle in captivity, yet it is still primarily sourced from the wild. Banggai cardinalfish is listed as endangered by IUCN and has experienced a population decline of up to 90% since the 1990s (Center for Biological Diversity, 2021). The species' slow reproductive rate compounds the effects of overexploitation, highlighting the severity and complexity of the situation.

This case study was intended to serve as a tool to balance economic interests, conservation efforts, and an improved welfare of the fish being traded. The central research question of the dissertation was: How is the welfare of the Banggai cardinalfish impacted by the international ornamental trade, and how can we improve it across the supply chain? In detail, this bibliographic dissertation aimed at providing an overview of existing scientific literature on the assessment and enhancement of fish welfare, with a special focus on Banggai cardinalfish, using a holistic approach that considered every

stage of the trade, with the ultimate goal of offering practical and effective potential solutions. This review focuses on scientific literature published over the past two decades, with an emphasis on recent studies (<5 years) to provide an accurate perspective on current issues. Sources were selected from a variety of databases such as ScienceDirect, PubMed, CITES, and Google Scholar, using keywords such as “ornamental fish welfare”, “Banggai cardinalfish”, “welfare indicators”, “ornamental fish trade”, and “ornamental fish supply chain”. Only peer-reviewed articles and primary research studies were included to enhance reliability. Reviews were selected based on their relevance to the research question and their potential contribution to understanding welfare practices throughout the ornamental fish supply chain, with a particular focus on the Banggai cardinalfish.

This dissertation is structured as follows: Chapter One provides a general overview of the Banggai cardinalfish ethology, ecology and trade. Chapter Two offers a comprehensive summary of Operational Welfare Indicators (OWIs), used nowadays in aquaculture practices to assess fish welfare, examining why they are not implemented in the ornamental fish trade yet, and suggesting a framework for an OWIs table specific to the Banggai cardinalfish. Chapter Three analyses each stage of the trade — capture, transport, holding facility/quarantine, wholesaler, and retailer—highlighting the Banggai cardinalfish situation in the global aquarium trade. Then, Chapter Four presents possible proposals to improve welfare and reduce the environmental pressure on wild Banggai cardinalfish populations, contributing to a more balanced and responsible approach to the trade of this species (Kasim, 2013). Finally, the conclusions summarise the key findings and reflect on the broader implications of the Banggai cardinalfish trade.

Discussion

Chapter 1: An overview on the Banggai cardinalfish

This dissertation focused on the Banggai cardinalfish (*Pterapogon kauderni*), a prime example of unsustainable trade practices and insufficient clarity and communication among stakeholders. Despite being listed as endangered by IUCN and recognized as an ornamental emblem of Indonesia, this species faces limited conservation action. In 2007, in response to growing awareness of the trade issues, Indonesia developed a multi-year Banggai cardinalfish action plan. However, no comprehensive monitoring system has been implemented since (Kasim, 2013). It is estimated that between 50,000 and 118,000 Banggai cardinalfish are exported monthly (Pietoyo et al., 2016), with a population decline of approximately 90% since the 1990s (Center for Biological Diversity, 2021). Understanding population dynamics is challenging due to inconsistent methods and locations of abundance assessment over the years (Kasim, 2013). While reliable statistics is scarce, the species limited range, low dispersal, low fertility, and dependence on benthic organisms—which are themselves in decline—underline the severity of the situation.

1.0 Taxonomy and morphology

The Banggai cardinalfish is a small (up to 8 cm) marine bony fish belonging to the family Apogonidae. Its colours are vibrant, and it is characterised by contrasting black and light bars with spots over a silver body (Figure 1). Each fish has a unique colour pattern, allowing for non-invasive individual identification. Distinctive features include a tasselled first dorsal fin, a deeply forked caudal fin, and elongated second and anal dorsal fin rays. While there is no obvious sexual dimorphism, males have slightly larger mouths relative to their body size due to their role as paternal mouthbrooders.



Figure 1. The Banggai cardinalfish (Credits to Francesco Ricciardi)

1.1 Geographical range

The endemic range of the Banggai cardinalfish is limited to a small area, with a maximum potential habitat of around 23 km² (Kasim, 2013). Its distribution is restricted to the shallow waters around 34 of the 67 islands of the Banggai Archipelago in central eastern Sulawesi, Indonesia. This limited distribution creates genetically isolated populations with low reproductive capacity. In fact, this fish has low fertility and reproductive rate, exhibiting only a few male brooding cycles per year, each producing up to 59 eggs (Conant, 2015). Additionally, the lack of a pelagic larvae stage restricts gene flow and limits the species dispersal, further isolating populations.

The combination of limited endemic range, low dispersal, and high site fidelity exacerbates its vulnerable conservation status. Genus confinement to a small area increases the likelihood of a bottleneck effect; a single natural disaster could lead to significant genetic drift. Severe bottlenecks have already reduced abundance of the species, a trend that is likely to continue without a reduction in anthropogenic pressures.

1.2 Habitat

In its natural habitat, the Banggai cardinalfish is found in shallow seagrass beds and coral reefs (<6 metres deep). The species has a symbiotic relationship with benthic organisms, relying on their presence for shelter, feeding, and protection. This microhabitat is essential to allow Banggai cardinalfish to complete its biological cycle. However, these habitats are rapidly diminishing due to anthropogenic activities, including sedimentation, overexploitation, and climate change.

Sea urchins, a crucial element of this ecosystem, support coral reef resilience by grazing on algae, which otherwise threaten coral health. Both juveniles and adult cardinalfish use sea urchins for shelter, camouflaging among the urchins' spines. Sea urchins are declining due to overharvesting for food, and rising ocean temperature associated with climate change pose additional threats. When temperatures exceed 31 °C, the symbiotic relationship between urchins and cardinalfish shifts, with the former may beginning preying on Banggai cardinalfish (Kasim, 2013) (Animal Welfare Institute, Center for Biological Diversity, & Defenders of Wildlife, 2021).

Sea anemones in particular have a crucial role in the recruitment of juveniles, reducing cannibalism and predation. They too have been impacted negatively by bleaching events.

With a decrease in anemones and sea urchins, branching corals are becoming more and more essential for Banggai cardinalfish. They provide shelter mostly to large juveniles, sub-adults, and adults. In addition to bleaching events, an increase in sedimentation from direct human activity has changed the equilibrium of this vital ecosystem. In fact, because of the hydrology and water quality changes, we have an increase in the starfish population, which predate on corals. This ecological imbalance is further exacerbated by an increase of algal growth, that leads to an excess in nitrate, that ultimately translates into dead zones.

1.3 Reproduction

The Banggai cardinalfish exhibits an uncommon reproductive strategy: direct development. Unlike most bony marine fish, which have a pelagic larval stage, this species develops directly from egg to juvenile. Eggs are large with a high-density yolk, providing nutrition during the brooding period. Due to parental care during mouth brooding, juveniles experience lower mortality than species with a larval stage (Calado et al., 2017).

This monomorphic species exhibits courtship behaviours such as trembling and flashing, with spawning peaks synchronised to the lunar cycle (Kasim, 2013), particularly around the full moon (Conant, 2015). Once paired, fish exhibit increased aggression toward conspecifics, especially females.

After fertilisation of the eggs, males experience a brooding period of 25-28 days. In this time, they do not eat and release dead or malformed embryos from their mouth to protect the healthy ones. Males are restricted to have a maximum of 640 offspring in their lifetime. Of these offspring, only 5% will survive adulthood (Conant, 2015).

1.4 Diet

Banggai cardinalfish are opportunistic carnivores, feeding on small crustaceans, fish, invertebrates, and zoobenthos. In captivity, its diet should be well-balanced to meet their metabolic needs. Preparations could vary from fresh to frozen feeds like brine shrimp (*Artemia salina*), and mysis (*Mysis sp.*). Dry food such as pellets and flakes require gradual acclimation for wild-caught individuals, a process that can take years.

A study by Lini Aquaculture training Center (LATC) in Bali (Hulu et al., 2020) identified abalone at 20% of the fish body weight as the optimal diet to support growth. This is most likely due to its higher protein content compared with other potential feeds such as squid and trash fish, increasing its palatability and effectiveness for growth.

1.5 Water chemistry

Optimal water chemistry for Banggai cardinalfish includes parameters such as temperature, salinity, hardness, nitrogen compounds, and dissolved oxygen (DO). As ectotherms, their metabolic activity depends on ambient temperature. The optimal range is 26-28°C, although reproduction may require slightly higher temperatures. Warmer water decreases oxygen solubility and increases metabolic demands, making regular, small meals ideal for meeting these needs.

The species thrives with DO levels between 5.5-7.1 mg/L but can reproduce at slightly lower levels (4.3 mg/L). Changes in DO, often due to sedimentation, pollution, and habitat degradation, pose a significant threat to these shallow-water inhabitants (Pompon et al., 2019). Additionally, ammonia,

toxic at high concentrations, requires adequate oxygen for nitrification, underscoring the interconnectedness of nitrogen compounds and DO levels.

Water hardness, primarily due to calcium and magnesium ions, stabilises pH and supports osmotic balance. Optimal hardness for Banggai cardinalfish ranges from 9-12° dGH, with pH at 8.2-8.4. Ammonia and nitrite levels should be maintained within 0.039-0.195 mg/L and 0.046-0.221 mg/L, respectively (Pietoyo et al., 2016).

Salinity is crucial for maintaining physiological balance, with optimal levels between 27-30 ppt. Higher salinity decreases DO and inhibits nitrifying bacteria, thus impacting ammonia conversion and increasing hypoxia risk. In studies, 27 ppt has been identified as optimal for egg production and juvenile survival (Pompon et al., 2019). Protein skimmers aid in maintaining water quality by removing nitrogenous waste, reducing ammonia buildup.

1.6 Diseases

Throughout the trade, Banggai cardinalfish are susceptible to various diseases, most uncommon in their wild populations, primarily due to poor water quality and stress. Megalocytivirus (iridovirus) infection is common, causing lethargy, appetite loss, discoloration, and, at later stages, rapid opercular movements and surface-breathing. Vibriosis is another common disease, leading to darkening, ulcers, and abnormal swimming. Antibiotics are often used preventively to curb disease spread during transport, though this could weaken fish immune systems and pose environmental risks due to improper disposal of contaminated water.

Chapter 2: The use of welfare indicator to assess fish welfare during and after trade

Welfare indicators are non-invasive, easy to perform, individual assessments to evaluate animal welfare. They can either be direct (animal-based) or indirect (environment-based). Nowadays, operational welfare indicators (OWI) have started to be adopted for the assessment of farmed fish, whereas there is no application within the ornamental fish trade. This gap exists mainly because ornamental fish are much smaller than those farmed for human consumption, making the practical application of OWI challenging. Additionally, the ornamental fish industry's economic structure and smaller-scale operations create difficulties in adopting these methodologies. While OWIs have been shown to be effective in large-scale settings such as aquaculture facilities, their implementation in the ornamental fish trade still present several obstacles

2.0 Animal-based welfare indicators

Behaviour

Behavioural observations are pivotal in assessing animal welfare but often remain underutilised (Jones et al., 2021). Accurate interpretation requires the observer to distinguish between normal and abnormal behavioural patterns.

Feeding behaviour is considered a reliable indicator of fish welfare, though fish are usually starved during transport to maintain water quality. When feeding occurs, indicators such as feeding latency and feed intake provide valuable insights.

Another behaviour that should be kept under control is aggression. Banggai cardinalfish are considered to be semi-aggressive. They show territorial aggressive behaviour with members of the same species, so high stock density tanks should be avoided to prevent fights. However, a lack of aggressive behaviours can also be used to assess bad welfare. Banggai cardinalfish's aggressive behaviour peaks during mating season, and can be present when two individuals come together for the first time to establish hierarchy. When choosing stock density we need to keep in mind the fact that Banggai cardinalfish is a social animal that lives in groups between 2 and 200 individuals in the wild. In captivity, living in groups of 6-10 individuals (with proper enrichment and resources being provided) reduces stress as they find comfort in their social group, it helps them reduce territoriality, and it improves feeding success. If the observer notices natural social behaviours like schooling behaviour and regular foraging patterns the stock density is optimal. If the signs of stress are displayed including reduced feed intake, lack of social interaction, and increased territoriality amongst conspecifics, there is a high chance that the stock density is too low. High stock densities are characterised by abnormal behaviour such as fin clamping, erratic swimming, hiding excessively, strict pecking order, extreme aggression and competition for resources. Besides, there will also be a higher risk of transmitting diseases as the water will deteriorate faster.

Swimming behaviour provides us with useful information about the welfare of fish. The most common abnormal behaviours are excessive speed, vertical swimming, erratic swimming, frequent change of direction, shoaling distances, and group swimming cohesion. The observation of these behaviours should be on an individual level to avoid false indications.

Morphological assessments

Morphological assessments, such as observing reddening of the skin, colour change, ulcerations, scale loss, and eye state, also provide an effective and easy way to evaluate welfare.

Within the farmed fish industry another animal-based measure OWI used is the count of opercular movement that is calculated through advanced technologies such as telemetry systems. They work through sensors attached to the fish's fin, such as bio loggers or SmartTags. It is an extremely useful resource as it can give real-time continuous, accurate data on the fish welfare. However, in the case of Banggai cardinalfish, and most ornamental fish for that matter, the small size of the fins makes it extremely challenging to not interfere with the natural behaviour of the fish, making it an inadequate tool. Moreover, the costs are high, and for the scale of the ornamental fish market it is an unsustainable cost.

2.1 Environment-based welfare indicators

Environment Based measures, on the other hand, use indirect measures to assess the fish's welfare.

Water pH, Dissolved Oxygen, Ammonia levels, Temperature, and salinity are useful indicators that can be used to evaluate the environmental compatibility with the species at hand. As we mentioned in chapter 1.5 water quality is essential for the wellbeing of the fish.

2.2 A checklist proposal of welfare indicators tailored to the Banggai cardinalfish

Since the ornamental fish trade lacks standardized welfare assessment methods, the present dissertation aims to propose a simple, user-friendly checklist to serve as a foundation tool both for assessing and improving fish welfare, using Banggai cardinalfish as a fish model. This approach acknowledges the varied education levels of stakeholders and aims to encourage widespread participation. A set of animal-based (Table 1) and environment-based (Table 2) indicators were suggested, along with a scoring system on a scale from 0 to 3:

- 0: Ideal condition
- 1: Not ideal
- 2: Requires monitoring and possible action
- 3: Immediate action needed

Table 1. Animal-based welfare indicators and scoring criteria to be used for welfare assessment in Banggai cardinalfish during trade.

Measure	Score	Criteria
Body condition	0	Well-proportioned, no bloating/emaciation, smooth skin.
	1	Slight abdominal protrusion; normal activity/feeding.
	2	Thinning flanks, moderate bloating, reduced activity.
	3	Severe bloating/emaciation, visible bones, reduced mobility/appetite.
Scale loss	0	Intact, healthy skin.
	1	Minimal, focal scale loss without reddening/abrasions.
	2	Mild, multifocal scale loss with possible reddening/abrasions.
	3	Extensive scale loss, visible skin damage.
Reddening	0	No reddening; skin appears normal.
	1	Mild, focal reddening.
	2	Moderate, multifocal reddening.
	3	Severe, diffuse reddening.
Ulcerations	0	No ulceration.
	1	Mild, superficial ulceration. Outer skin and scale layer is penetrated.
	2	Moderate ulceration. Lesion penetrates through dermis (<1 cm)
	3	Severe ulceration. Lesion penetrate through skin and muscle.
Skin colour	0	No colour change.
	1	Mild, localised colour change.
	2	Moderate, multifocal colour change.

Measure	Score	Criteria
	3	Severe extensive colour change.
Eye state	0	Clear eyes with intact corneas.
	1	Minor cloudiness or slight dullness in eye(s).
	2	Mild cloudiness or exophthalmos (bulging).
	3	Severe exophthalmos, excessive cloudiness, or discolouration.
Aggression	0	No excessive aggression or damage.
	1	Increased or complete lack of signs of aggression.
	2	Moderate signs of aggression or visible physical damage.
	3	Severe signs of aggression, significant physical damage.
Feeding behaviour	0	Normal feeding with no competition.
	1	Occasional competition or aggression during feeding.
	2	Increased competition, not all fish have access to feed.
	3	Severe competition. Dominant individuals monopolise feed.
Swimming behaviour	0	Natural swimming patterns.
	1	Occasional deviations and restricted movements.
	2	Increase in erratic swimming, frequent bumping among individuals
	3	Constant erratic or vertical swimming, shoaling distances.

Table 2. Environment-based welfare indicators and scoring criteria to be used for welfare assessment in Banggai cardinalfish during trade.

Measure	Score	Criteria
pH	0	8.2–8.4
	1–3	Deviations from ideal range.
Dissolved Oxygen	0	5.5–7.1 mg/L
	1–3	Levels outside the ideal range.
Temperature	0	26–28°C
	1–3	Deviations below 24°C or above 31°C.
Ammonia	0	0.039–0.1 mg/L
	1–3	Increasing ammonia concentrations.
Salinity	0	27–30 ppt
	1–3	Levels below 24 ppt or above 35 ppt.

Separate sections for animal-based and environment-based indicators are provided above. Then, a table (Table 3) providing a checklist for the assessment of the welfare of Banggai cardinalfish is proposed hereafter. The animal-based checklist should be used daily, while the environmental-based one can be implemented weekly. A trial period is recommended to determine the optimal frequency of use.

Table 3. Checklist proposal for the assessment of the welfare of Banggai cardinalfish during trade using animal-based and environment-based welfare indicators.

Indicator	Tank Number	Fish Number	Date	Score (0-3)
<i>Animal-based (daily)</i>				
Body condition score				
Skin lesions				
Skin colour				
Eye conditions				
Aggression				
Feeding behaviour				
Swimming behaviour				
<i>Environment-based (weekly)</i>				
pH				
Dissolved Oxygen				
Temperature				
Ammonia				
Salinity				

2.3 Suggestions for score improvement

Body condition score

Ensure the diet is species-specific and appropriate for the life stage of the fish. Make sure that at feeding times all individuals have access to food and consume it. If some individuals don't eat, it could indicate that feeding acclimation was not carried out properly, with a new diet introduced too quickly instead of through a gradual transition. Fish are very reluctant to try new food, so starting with feeds similar to what they are accustomed to in their natural habitat is preferable to minimise stress and ensure correct alimentionation. A more nutrient-dense (protein and lipids) diet like abalone at 20% of the fish's body weight is recommended as this diet has been proven to be optimal to maximise growth in Banngai cardinalfish, and because of the high protein content it is also very palatable, making the shift to a new diet easier (Hulu et al., 2020). Also minimising handling as much as possible is preferable to decrease levels of stress (Clark et al., 2018). If the problem persists, check water quality parameters to ensure they are optimal. Seek veterinary advice for persistent issues. If needed, isolate the problematic (low body condition score) fish to mitigate disease spreading.

To summarise it is very important to provide a balanced diet, esure optimal and stable water quality parameters, perform regular checks on the fish by trained staff, and early intervention are essential to improve the welfare and body condition score of Banngai cardinal fish (Clark et al., 2018)

Scale loss/redding/ulceration

The first step to decrease the level of scale loss experienced by the fish in your tank is by understanding the root cause of the problem. Scale loss can derive from physical injury, poor handling practices, environmental stressors, and trauma. In case of physical trauma, remove sharp or rough objects from the tank, and minimise handling. If necessary, use a becker to move the fish. Avoid overcrowding and implement enrichments such as hiding spots to mitigate the onset of aggressive behaviour. If scale loss is derived from environmental stressors check water quality parameters (especially dissolved oxygen levels) and also light intensity (natural lights are less stressful for the fish). Make sure to acclimate the fish to the new water quality parameters gradually to minimise the level of stress. Moreover, make sure to eliminate debris and uneaten food which could irritate the skin of the fish. If the problem persists, remove affected fish from the tank and place them in a separate quarantine tank to minimise disease spread and allow for easier treatment. Bathe with mild antiseptics to reduce infection risk. For example, immerse the fish in salt baths (3 grams per litre for 10-15 minutes) to create a slightly hypertonic environment to reduce the load of external parasites, disinfect minor abrasions or wounds, and promote healing by reducing osmotic stress (Kane, 2005). The use of antibacterial or antifungal can also be used if infection is suspected, but it is best to follow the veterinarian instructions not to overload the fish with the wrong medications, which could act as a

stressor themselves. Provide high-quality, nutrient-dense feed to support immune function and skin regeneration.

Colour change

Reduce stress factors (high stock density, absence of hiding spots). Provide high-quality, nutrient-dense (protein, lipids) feed to support the immune system and ensure the maintenance of physiological functions. Make sure water quality parameters are optimal as a sudden or drastic change in any of these values can trigger stress which in turn can result in pale or blotchy skin coloration due to disrupted physiological balance. For example, low oxygen levels cause hypoxia which in turn can manifest with darker or duller gill colouration (Kane, 2005). As previously mentioned, a gradual acclimatisation is essential to reduce stress levels and minimise, among other side effects, colour change. Avoid overcrowding and ensure hiding spots or tank enrichments to mitigate aggressive behaviours. Provide a diet rich in carotenoids such as spirulina to enhance natural pigmentation. Use high-quality feeds with essential fatty acids, vitamins A and E, to promote overall health and vivid coloration (Kane, 2015). If all parameters are optimal and the problem persists, the colour change could be caused by Megalocytivirus (iridovirus) or Vibriosis, which are common diseases in captive Banggai cardinalfish. The first can lead to lightening and the second to darkening of the skin.

Eye conditions

As mentioned before it is good practice to make sure stock density is appropriate, and hiding spots are present as eye problems could be an aftermath of increased aggression within the tank. This is most likely possible if the injury is present only in one eye. However, if the problem is present in both eyes it could be systemic, and if the problem is present in more fish in the tank it could involve the whole aquarium. To reduce stress and support healing ensure water quality parameters are optimal (see ranges in environment based welfare indicators as reference). In case of oversaturation you might observe little bubbles around the eye(s) or skin of the fish. The first step in this case is to identify the cause of the supersaturation and adjust it. You could improve surface agitation to allow excess gas to get released into the atmosphere, and/or decrease water temperature slightly to decrease gas solubility. Handle the affected fish as little as possible to avoid stress, and try to reduce other external stressors such as intense lighting (Chong et al., 2022). Another common problem in aquarium fish is exophthalmos. In this case it is still very important to make a distinction if it is present only in one or both eyes. If bilateral, it could be a chronic bacterial disease known as mycobacteriosis, and it usually shows up with other symptoms such as ulcers, lethargy and loss of appetite, weight loss. Other causes could be an excess of nitrates, lack of vitamin A in the diet (leading to a weaker immune system), parasitic or bacterial (non-mycotic) infections, or even trauma (Kumaratunga et al. 2022).

Aggressive behaviour

In case of excessive aggressive behaviour provide additional hiding spots to avoid competition for shelter. During feeding make sure all individuals have access to feed and there are no dominant individuals monopolising resources. Adjust stocking density in the tank and/or change pairs or remove

aggressive individuals. Dividing pairs during the spawning period can be a solution to decrease aggressive behaviour as well, as during this time the aggression is at its peak.

Feeding behaviour

If feeding latency is very long, and there is plenty of debris from uneaten food, reduce feed intake or make sure the fish in your tank is acclimated to the feed you are offering. On the other hand, if aggression during feeding time is elevated, and some individuals are not able to eat, increase feed given. If every fish eats but they seem emacipated and show high aggressive behaviour, make sure the diet is well balanced, with a high level of protein and lipid content.

Chapter 3: Trade stages of the Banggai cardinalfish from capture to retail

3.0 Wild fish collection

The collection of wild Banggai cardinalfish is very little documented in scientific literature, making it very hard to write a comprehensive overview of this species. A widespread, although illegal and destructive, method of fish collection involves the use of sodium cyanide. It is estimated that 70% of fish captured for the aquarium trade have been poisoned with cyanide (Mak et al., 2005). This technique, introduced in the 1960s, uses a cyanide-water solution sprayed into coral crevices to stun the fish, making them easier to catch. Although not lethal at low concentrations, a very high mortality rate is associated with this method of capture. It is estimated that an average of 75-80% of Banggai cardinalfish die before export (Pompon et al., 2019) and up to 90% when considering the entire supply chain (Murray et al., 2005). This happens because cyanide is a rapidly absorbing acidic chemical that inhibits oxygen uptake, impacting not only fish but also the surrounding marine life, particularly corals (Murray et al., 2005). The poison disrupts coral-algae (zooxanthellae) symbiosis, contributing to bleaching, a phenomenon responsible for the loss of 14% of the world's coral reefs between 2009 and 2018 (Souter et al., 2021). Sodium cyanide also endangers fishermen's health, causing symptoms varying from headaches, paralysis, or death upon exposure (Mak et al., 2004). Efforts to detect cyanide poisoning in marine ornamental fish using thiocyanate as a biomarker have faced challenges due to species-specific metabolic differences, limiting reliable detection methods (Murray et al., 2005).

Sustainable alternatives to cyanide include handpicking fish with small nets. For sedentary species like Banggai cardinalfish, living in colonies of 20-200 individuals with strong fidelity to their home range, this method is viable and environmentally friendly. While being more time consuming, this method allows for a sustainable collection practice, without negatively affecting the health of the marine ecosystem and the fisherman involved. Other collection techniques, such as tubular nests used in Sri Lanka, involve strategically trapping fish in coral burrows with minimal harm.

After capture, fish have to be slowly brought to the surface (3 m every 30-40 minutes) to avoid swim bladder rupture from pressure changes (Wabnitz, 2003). A quicker alternative involves piercing the swim bladder with a sterilized hypodermic needle, a safe practice if done correctly.

3.1 Holding facility/quarantine

Capture fish are transported to the holding facility in singular bags or in bigger plastic containers. In some cases, Banggai cardinalfish are transferred to holding pens near the shore until sold. However, these pens, where fish are rarely fed or maintained, see mortality rates as high as 50% (Conant, 2015). The holding facility in the country of origin is usually operated by the exporter, who is responsible for the collection of the species based on customer demand. Within the holding facility, quarantine can

last from a few hours to several months (Wabnitz, 2003). To move the fish from two different water bodies, an acclimation period should be provided to minimise the stress induced by the changes of the water parameters. One effective method is known as drip method, through which fish are acclimated to their new environment by gradually equalizing water parameters one drop at the time. Close observation of the fish should be performed during this time, checking every 5 minutes the salinity, temperature and conductivity. Nets should be avoided to decrease injury rates to scales or fins, preferring the use of becker for fish transfer. Once acclimated, fish are stocked in shallow (<30cm) plastic-lined tanks with a translucent fibreglass roof, within seawater recirculating aquaculture systems (RAS). RAS ensures good water flow and filtration, due to biological filtration (e.g bio balls and sand) or to the presence of protein skimmers which are generally cheaper for smaller systems, and relatively easy to maintain. Within this setup there are also degassing towers, which help remove excess of CO₂ and other waste gases, and an aeration system used to re-oxygenate the tanks to maintain a stable value of DO. This structure also allows disinfection and sterilisation, thanks to UV or ozone treatment, which are essential to prevent diseases such as megalocytivirus or vibriosis. Optimal water quality is essential for minimizing mortality and ensuring profitability. In fact, if water quality parameters are not optimal, mortality rates rise dramatically, drastically reducing the net income of the exporter, leading to a higher and unsustainable demand to make up for the losses. For each tank, a status paper has to be present stating tank number, arrival date, origin, shipping box number, destination, tank manager, mortality, and treatment.

Within holding facilities fish are starved for up to 48 hours (Wabnitz, 2003) prior to shipping to avoid water pollution.

In many cases, antibiotics are used as a preventive measure to avoid spread of infection. However, they can be considered as a stressor (Wabnitz, 2003). In addition, the excessive or inappropriate use of antibiotics can lead to pathogen resistance and a weakening of the immune system, exacerbating the already high mortality rate. When antibiotics are used in the water, a proper disposal protocol should be put in place, as the free release of these chemicals is a hazard for environmental safety. During this time, it is also essential to set up appropriate stocking densities, as high densities can lead to excessive aggressive behaviour, feed competition, excess metabolic waste (e.g. ammonia), stress, and mortality rate. Similarly, low stocking density can lead to stress and increase territoriality. The behaviour of the Banggai cardinalfish should be monitored closely during this period to prevent spreading of diseases amongst healthy individuals and prevent collateral damages. Enrichment and/or hiding spots should be placed in each tank to minimise aggressive behaviour and stress. Another method to help with behavioural acclimation is to put blue-black film to tarnish the sides of the tank. Moreover, mutualistic species might be added to the tank both to reduce stress, but also to decrease the chance of diseases. In fact, using cleaner fish in quarantine tanks is becoming a more popular method known as bio-quarantine. The idea behind this methodology is that cleaner species like cleaner shrimp (*Lysmata*

amboinensis) will feed on the parasites present in fish, avoiding parasite load and reducing the use of chemicals to control them.

3.2 Transport

Once an order has been issued, Banngai cardinalfish are placed in individual double polyethylene bags filled with $\frac{1}{3}$ water and $\frac{2}{3}$ oxygen. At times, to extend the duration the oxygen levels are increased to the level of oversaturation which in turn could lead to an increased mortality rate. The sealed bags are then placed into an insulated cardboard box filled with polystyrene. In fact, an additional stressor that fish endure during transport is mechanical disturbance due to noise and vibrations. In addition, an important aspect that needs to be kept in mind is also that travels can last up to 72 hours (Cole et al., 1999), time in which the fish will be placed in a box in the dark. The endogenous rhythm is synchronised thanks to normal photoperiod, and the absence of light for an extended period of time could negatively affect internal processes such as locomotor activity and metabolic rate. As stated in the water quality chapter, temperature is an essential parameter to ensure the normal physiological body functioning of the fish, so especially during longer travels, ice packs or heating pads may be kept in the box to help stabilise the temperature throughout shipping. Shipping labels must include information such as country of origin, travel time, recipient location, shipping type, boxing type, presence of air or oxygen cylinder, presence of chemical resin for chemical pollutants, presence of heating pads, and quarantine documents. Air freight accounts for up to two-thirds of the landed price, significantly contributing to the price discrepancy between fishermen and retailers (Wabnitz, 2003).

3.3 Wholesaler/retailer

Upon arrival, fish undergo veterinary inspections, often conducted by professionals lacking expertise in fish health, leading to misdiagnosis (Wabnitz, 2003). Fish must be gradually reintroduced to light and acclimated to the new water chemistry via slow drip acclimation. Once ready, the fish alone will be transferred into the new aquarium preferably with the use of a becker.

A major challenge in retail is transitioning fish to a new diet. In fact, a wild-caught fish, accustomed to live prey, must be trained to eat dried feed through a gradual process: fresh feed mimicking wild prey is replaced with frozen, then mixed with dried feed before switching to dried feed entirely. Each step is a long process, taking up to 2-3 weeks to complete. Some fish may never adapt to dried feed.

Mortality remains high throughout the trade chain, with around 90% of captured fish dying before reaching retailers (Murray et al., 2005).

Chapter 4: Suggestions to improve the sustainability and welfare in fish trade

Research on Banggai cardinalfish trade reveals significant gaps in information, comprehension, and communication among stakeholders, as well as limited understanding of the ecosystem's role in the trade model. Without a healthy population of Banggai cardinalfish trade cannot continue, and without income fishermen will have to find other ways to generate income that might have an additional impact on the ocean. However, most of the literature often suggests reducing trade and harvest numbers, which inevitably translates into reducing the income of already low-income communities. For any conservation strategy to be successful, it must be inclusive and beneficial to all stakeholders, particularly to fishermen who form the trade's backbone.

4.0 Banggai cardinalfish gardens

Inspired by Locally Managed Marine Areas (LMMA) currently operating in some parts of the Pacific, the concept of Banggai cardinalfish gardens is a community-driven initiative aimed at restoring the microhabitat of the endangered Banggai cardinalfish, to support their survival and reproduction. This type of action can be extremely beneficial not only for increasing the population of Banggai cardinalfish but also for the local communities that could be involved and find sustainable ways to maintain their livelihood and have an income. These gardens are small, protected areas where habitat restoration is the primary goal to ensure a healthy population of Banggai cardinalfish. This species, as mentioned throughout the present dissertation, rely on their symbiotic relationship with benthic organisms such as sea urchins, sea anemones, and corals. Therefore, the comprehensive restoration of such habitat is essential. To this purpose, a deeper understanding of the reproduction of these organisms is fundamental.

Sea anemones, vital for juvenile fish recruitment, reproduce asexually through fission, budding, or pedal laceration. The first step is that of identifying the species to propagate, which in the case of Banggai cardinalfish could be *Heteractis crispa* which not only is found in the natural endemic habitat of the species, but also shows high resilience during handling and transplantation (Randall and Fautin 2002; Ndobe et al., 2020). Once the species has been identified, growth in a controlled environment can be optimised by providing optimal lighting, water quality, and feed. When fully grown, the anemone needs to be acclimated to conditions that match destination and then manually divided and transplanted into the protected cardinalfish gardens for further propagation.

Sea urchins are essential shelters for Banggai cardinalfish. They can be cultivated through external fertilisation. A recent project aimed at restoring sea urchin *Diadema antillarum* was performed in the Caribbean and was awarded the prestigious RAAK award as the best applied group of research in the Netherlands (Wijers et al., 2023). During this study, adult urchins were kept in separate holding tanks and spawning was triggered by placing them at 5 °C higher than their thermoneutral zone. Once the eggs and sperm were produced and collected, fertilisation happened in the laboratory. The larvae were

then cultivated in 1 litre glass bottles that were kept in constant motion to increase survival rate with a method called shaker bottle cultivation. Once the cultivated larvae develop into juvenile sea urchins, they can be acclimatised and then released into restoration areas, cardinalfish gardens in this case. Although this study was performed in different settings, it holds potential to restore the key herbivores of coral reefs habitat and main shelter for Banggai cardinalfish.

Corals can reproduce both sexually by spawning eggs and sperm in the water column, and asexually with budding and fragmentation. Cultivation in nurseries or the creation of artificial reefs with materials like steel or concrete could mimic natural habitats (Razak et al., 2022). However, the lack of consistent documentation on coral restoration requires further evaluation of the effectiveness of these methods.

In addition to microhabitat restoration, an important factor to account for when designing Banggai cardinalfish gardens is the fish's unique reproductive ecology and that genetically distinct population, known as Evolutionary Significant Units (ESU) (Ndobe et al., 2019) exist. Conservation efforts should be focused on protecting ESUs to maintain genetic diversity, and the genetic stock data should be used to create distinct Marine Protected Areas (MPAs) to avoid genetic mixing.

This method calls for a holistic approach that will not only boost population growth, but also creates a sustainable economy for low-income, rural, coastal populations living in Indonesia. With that, an increased awareness and education on marine conservation will follow, leading to a natural diminishing of destructive harvesting methods. Further genetic management should also be performed, again creating more job opportunities for local researchers.

4.1 Captivity breeding programs

To meet the growing demand for Banggai cardinalfish, efforts should focus on increasing egg production through captive breeding programs. Banggai cardinalfish paternal mouth brooding behaviour limits spawning frequency, as the incubation lasts 25-28 days. One study performed in 2020 in the University of Tadulako (Safir et al., 2020) investigates how to improve breeding efficiency through masculinization employing the hormone 17α -Methyltestosterone. This hormone was administered through feed (*Artemia sp.*) to increase male fish proportion in Banggai cardinalfish populations. Although further research is recommended to optimise hormone dosing, the findings suggested that 17α -MT successfully increased the number of males by inhibiting a particular enzyme (aromatase) that has the ability to convert androgen into oestrogen, favouring male development.

Another promising method involves the use of artificial microhabitats, such as sea urchins made from eco-friendly materials like coir and cement. A study performed in 2022 used a randomised design consisting of 2 treatments with 8 units each. The first group was placed in a tank with live sea urchins (BBA), while the second with artificial ones (BBB). Both conditions had the same number of individuals, same water quality parameters that were checked regularly, as well as the same diet. The

results showed that even though the growth rate of BBB was relatively slower than BBA specimens, the treatment with artificial sea urchins showed a survival rate of 100% compared to 83% of BBA treatment. This success is attributed to reduced predation and lower ammonia levels in tanks with artificial habitats. Moreover, it is possible that the mismatch in captive behaviour of the two species might have resulted in a change in their mutualistic relationship, leading to intentional or unintentional injury and subsequent predation of Banggai cardinalfish. These findings suggest that artificial microhabitats could be effective in both captive breeding programs and wild habitat restoration.

4.2 Shifting consumer behaviour

While changes at the beginning of the chain of operation are important to promote sustainable fishing methods and promote fish welfare throughout the trade, changes at customer level can also drive positive impacts, as the Banggai cardinalfish market comprises mainly private hobbyists (99%) (Lal and Kumar, 2021).

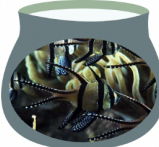
Public aquariums hold the opportunity to educate the public and spread awareness. Fish welfare is slowly being acknowledged. However, despite the extensively large body of evidence demonstrating that fish can experience emotions to some extent, possess nociceptors and can therefore experience pain, their sentience is still an area of controversy amongst the general public (Jones et al., 2021). Recurrent educational activities within the aquariums, together with more engaging information cards can help engage the public. In fact, research shows that active learning activities in public aquariums could enhance public engagement (Recchia, 2023). Together with a greater transparency on the chain of operations of the trade, learning activities at public aquariums can help inform the public about this hidden ecosystem so distant to ours.

Pet shops play a crucial role in consumer education. The creation of simple, standardised mini-guide on fish care and health can prevent welfare issues in home aquariums. As the mini guides should maintain a light tone, and be easy to read, additional information should be given to the customer about the specific set up of the tank which should be done prior to purchasing the fish (Figure 2). In this way, the retailer can ensure that all the important information relative to the wellbeing of the fish are given to the customer. Promoting responsible ownership through education and transparency can naturally shift consumer behaviour toward more sustainable practices.

Acclimate like a pro

Don't just toss them in!

Drip acclimate by slowly mixing tank water into their bag for 35-40 minutes, then use a becker to move them (**no nets** it hurts!). During this process, check on your friend every 10 minutes to make sure the water quality is good



Avoid crowding them


Weekly "Spa" Checks

Weekly tests are a small price to pay for a happy fish.

Make sure your parameters (DO, salinity, Hardness, pH, Temperature, Ammonia levels) are on spot!

Keep ammonia and nitrite close to zero!
 Ammonia (0.039-0.195 mg/L)
 Nitrite (0.046-0.221 MG/L)

Keeping Your Banggai Alive: A Guide for the Hopelessly Forgetful



PROTEIN SKIMMERS ARE AWESOME FOR KEEPING WATER FRESH AND CLEAN

Think posh private villa not sardine can

Good luck, fish parent!

Follow these tips, and your Banggai just might outlive your houseplants.

Tips to Avoid Accidental Fishicide

THE BASICS

Welcome to the Banggai Club!

Congratulation on your new finned best friend!
 Here is the parameters your fish needs to thrive:


Tank size: 75 litre per fish

Perfect pair: if you want two, don't just grab any two.
 These fish can get a little feisty if you pair the wrong sexes or introduce new faces.
 For a drama-free tank, look for already bonded pair

Good neighbours: Stick with peaceful species (hello Clownfish). **AVOID** aggressive species, and everyone will get along swimmingly.

Water Chemistry Cheat Sheet

This Isn't Tap Water, Folks!



Banggai need their water "just right"

Keep the temperature between 25-28°C.
 Anything colder, and your fish might give you the silent treatment forever.

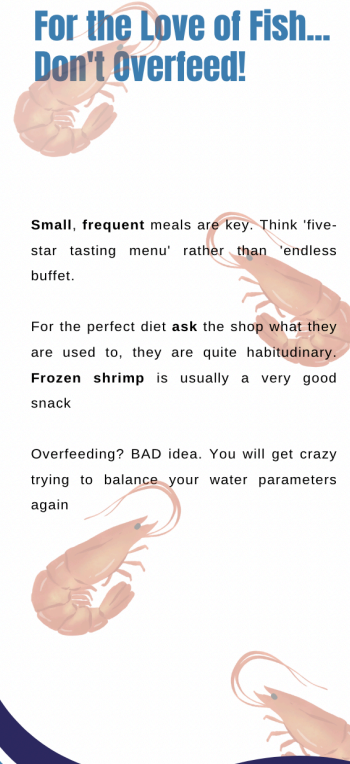
Dissolved oxygen: 5.5- 7.1 mg/L is the best environment they can ask for

Hardness: 9-12° dH will help your pH to stay stable

pH: 8.2-8.4 and they will thrive

Salinity: 27-30 ppt.

For the Love of Fish... Don't Overfeed!



Small, frequent meals are key. Think 'five-star tasting menu' rather than 'endless buffet.'

For the perfect diet **ask** the shop what they are used to, they are quite habitudinary. **Frozen shrimp** is usually a very good snack

Overfeeding? **BAD** idea. You will get crazy trying to balance your water parameters again

In the wild, their favourite hiding spot is sea urchins!
 Keep in mind they love some alone time, provide plenty **hiding spots** in your tank to make them feel home

Figure 2. Mini guide proposal to ensure proper fish care.

Conclusion

To summarise, the real impact of the ornamental fish trade on the welfare of Banggai cardinalfish remains underexplored, requiring further investigation. This dissertation aimed to shed light on this overlooked field, identifying welfare concerns throughout the trade chain—from capture to retail—and examining how these processes could affect both the behavioural and physical health of the fish.

Promoting a more sustainable and welfare-oriented trade chain is critical for the preservation of coral reef ecosystems, which are vital habitats for numerous marine species. The use of welfare indicators tables throughout the chain of operation can be beneficial both for the welfare of the fish and research efforts. Implementing such tables would provide key insights into the captive conditions of these fish within holding facilities, ultimately leading to higher welfare standards. Although these tools require further refinement and validation, they represent a first step toward improving the welfare of Banggai cardinalfish. Additionally, this method has the potential to extend to marine species currently traded, broadening its impact.

Locally-based captive breeding programmes also offer a potentially sustainable solution to meet trade demand, while reducing reliance on wild-caught specimens. By emphasizing local production and involving coastal communities in the process, these initiatives can foster a sustainable market, creating job opportunities in low-income rural areas, and increase community engagement in conservation. Similarly, the implementation of Banggai cardinalfish gardens—small, protected areas designed for habitat restoration—can serve as both a source of revenue and a platform for raising awareness, ultimately improving care for this species.

Ultimately, a holistic approach is necessary, involving shifts in industry practices, enhanced consumer awareness, and collaboration between stakeholders. Such efforts are essential to improve the welfare of Banggai cardinalfish within the trade and safeguarding this often overlooked ecosystem. Further research and refinement of welfare practices will be crucial in addressing the complex challenges these fish face. By adopting responsible and inclusive strategies, we can work toward a future where Banggai cardinalfish will thrive both in their natural habitat and in captivity.

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