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Research Article

Habitat Reduction and Population Structure of Endangered Asian Arowana (*Scleropages formosus*) Golden Red in Riau Sumatra, Indonesia

Arief Anthonius Purnama[1,2,3*], Tsugiyuki Masunaga[1,2]

[1]*Faculty of Life and Environmental Sciences, Shimane University, Matsue 6900823, Shimane prefecture, Japan*
[2]*United Graduate School of Agricultural Sciences (UGSAS), Tottori University, Tottori-shi 6808553, Tottori Prefecture, Japan*
[3]*Faculty of Teacher Training and Education, University of Pasir Pengaraian, Rokan Hulu Regency 28557, Riau Province, Indonesia*

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ABSTRACT

This research was conducted in the arowana golden red Conservation Area (AgrCA) in Riau Province Rokan Hulu Regency, Sumatra, Indonesia from 2020 to 2023. The primary objective was to elucidate the population structure of arowana golden red in the midst of ongoing habitat degradation resulting from land use changes in AgrCA. Land use changes were analyzed by satellite imagery through the QGIS application. We collected population sampling data for arowana golden red by using 'fish net', 'fish trap', and 'fish scoop-net'. A comparison of satellite images taken in 2017 and 2021 revealed a reduction in swamp area by 664 ha (from 921 to 257 ha) and a decrease in swamp forest by 116 ha (from 264 to 148 ha). The conversion of swamp and swamp forests into oil palm plantations within the AgrCA has significantly diminished the natural habitat of the arowana golden red. Although there has been decreasing in swamp and swamp forests in AgrCA, the water quality in the AgrCA has remained suitable for the life of the arowana golden red. The population of arowana golden red was found to be 14-44 individuals year^{-1} in 2021-2023 with various sizes. Arowana golden red is most prevalent during the rainy season (July-December). Preserving the remaining swamp and swamp forests is paramount, representing a top priority. Immediate ex-situ conservation efforts are imperative, taking preemptive measures in case the arowana golden red can no longer inhabit its natural habitat.

1. Introduction

Freshwaters are especially susceptible to changes arising from 'the tragedy of the commons'. Scant consideration is given to the need to conserve aquatic biodiversity or preserve ecosystems when conflicting human interests are at stake. In many instances, only the freshwater resources that remain after fulfilling human needs are allocated to sustain ecosystems. This issue of the Anthropocene stems from lax regulations governing water abstraction, pollution, impacts of global climate change, overexploitation of biological resources, the introduction of alien (introduced or non-native) invasive species, and the land-use changes (Dudgeon 2019; Birk *et al.* 2020). Freshwater biodiversity has been a paramount focus of international conservation efforts since 2005. Numerous studies and initiatives have been undertaken to ensure its sustainability, encompassing species identification, habitat analysis, and conservation management (Dudgeon *et al.* 2006; Strayer and Dudgeon 2010; Darwall *et al.* 2018; Flitcroft *et al.* 2019; Reid *et al.* 2019; Su *et al.* 2021; Albert *et al.* 2021; Maasri *et al.* 2022). Nevertheless, it is evident that freshwater biodiversity is currently in decline. As a result, there is an urgent need for the most effective measures to assess the current population and habitat conditions (Keong 2015; Radinger *et al.* 2019; Harper *et al.* 2021).

* Corresponding Author
E-mail Address: ariefanthoniuspurnama@gmail.com

The Asian arowana (*Scleropages formosus*) is a freshwater species from the family Osteoglossidae (Kottelat *et al.* 1993). There are several color varieties of Asian arowana. The green variety is commonly distributed in Vietnam, Myanmar, Cambodia, Thailand, Malaysia, and Indonesia (Kalimantan and Sumatra). The red varieties, including super red, blood red, or chilli red, are seen only from upstream of the Kapuas River and surrounding lakes in western Borneo, Indonesia. The gold cross-back variety and Bukit Merah blue variety are found only in Perak, Malaysia (Alex 2010; Yue *et al.* 2019). The golden-red variety was found in Rokan Hulu (Purnama and Masunaga 2023) and Kampar District (Okamoto *et al.* 2023), Indonesia.

Asian arowana are experiencing pressure from decreasing habitat and population (Kottelat 2011; Kartamihardja *et al.* 2014; Pamungkas and Prayogo 2019). Overfishing and the destruction of its natural habitats were the major reasons of the decrease (Fernando *et al.* 1997). Pouyaud *et al.* (2003) reported that super red arowana fish in Lake Sentarum, Kalimantan experienced a drastic population decline as a result of deforestation. The deforestation increased pH and turbidity of the lake, and the effect was more influential in the decline of arowana than the overfishing in this case. In Sumatra, deforestation raised by 7.54 million ha during the period 1990-2000 and an additional 2.51 million ha of forest was lost from 2000 to 2010, which was one of the factors decreasing arowana habitat (Margono *et al.* 2012).

Because of rapid decrease of the population, the Asian arowana has held an "Endangered" status on the International Union for Conservation of Nature and Natural Resources (IUCN) Red List since 2006 (Dawes 2006; Yue *et al.* 2019). It has also been included in 'Appendix I' of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) since 1975. Additionally, it has been recognized as a protected species in Indonesia as declared by the Government of The Republic of Indonesia in 1999.

Studies conducted over the past 40 years on the Asian arowana have provided significant insights into its distribution, evolution, genetics, genomics, reproduction, growth, and diseases (Greenwood *et al.* 1966; Yue *et al.* 2004; Olivares *et al.* 2013; Yue *et al.* 2019; Huggins *et al.* 2022). These findings are invaluable for both conservation efforts and aquaculture development. There has been trials of setting conservation area and activities such as rule designation on prohibition land use change around arowana habitat and counselling on protected arowana in natural habitat for communities living around arowana habitat (Regent of Rokan Hulu 2009; Pouyaud *et al.* 2003). However, the overfishing and the destruction of the arowana natural habitats continued and declined the wild populations of the Asian arowana (Fernando *et al.* 1997; Pouyaud *et al.* 2003).

Rokan Hulu is an area of natural habitat of arowana golden red. The area was originally covered by natural forest and has been extensively converted into oil palm plantations over the past five decades. To preserve the arowana golden red in its natural habitat amidst these land use changes, the Regent of Rokan Hulu Regency designated a 3,700 ha area as the arowana golden red Conservation Area (AgrCA) in 2009. At the time of its designation, AgrCA land use comprised 2,345 ha of oil palm plantations, 978 ha of swamp and 389 ha of swamp forests (Regent of Rokan Hulu 2009). Swamp and swamp forest were the arowana golden red habitat. Unfortunately, despite its conservation rule, land use changes have persisted. In our previous research, we identified the decrease of the swamps and swamp forests to 921 ha and 264 ha, respectively by 2017 (Purnama and Masunaga 2023).

In 2020, we have identified the aquatic biodiversity (fish, benthos, and zooplankton) in AgrCA by taking overall sampling covering the swamp, swamp forest, and river in the area. Where the sampling site consists of the Kualu Hulu (west), middle Mahato (north), middle Torganda (south), and Torganda (east) sites. We found the diversity of aquatic organisms in AgrCA to be comparable to or higher than other areas in Malaysia and Indonesia, such as Aceh province and Kalimantan. On the other hand, we found arowana golden red only in the middle Mahato (north) swamp forest of 31 individuals, which retains the largest swamp forest in AgrCA compared to other sites, where arowana golden red was no longer found due to the conversion of swamps and swamp forests to oil palm plantations (Purnama and Masunaga 2023). Although no scientific reports exist documenting the number and population of arowana golden red before our research began in 2020, according to seven local fishermen in Rokan Hulu, they could catch about 50 arowana golden red per year around year 2000 in all 4 sites above mentioned in AgrCA (personal communication). This information exhibited the decline trend of the population and the habitat area of arowana golden red.

The preservation of the arowana golden red's habitat is crucial to ensuring its survival and preventing its extinction in the wild. Moreover, a comprehensive study of its wild population is essential to provide data for analyzing genetic differences, population

structure, and the relationships among Asian arowana populations (Yue *et al.* 2019). In an effort to provide a fundamental study into the existence of the arowana golden red population within its natural habitat, our research aimed to assess the effects of habitat reduction and analyze the population structure of the arowana golden red following these changes. From 2021 to 2023, we conducted population observations in AgrCA to evaluate the influence of land use changes on habitat area and population structure. Additionally, this study explored possible conservation measures to protect the arowana golden red in its natural habitat.

2. Materials and Methods

2.1. Study Area

The study area in middle Mahato in AgrCA, arowana golden red observation and water sampling sites are shown in Figure 1.

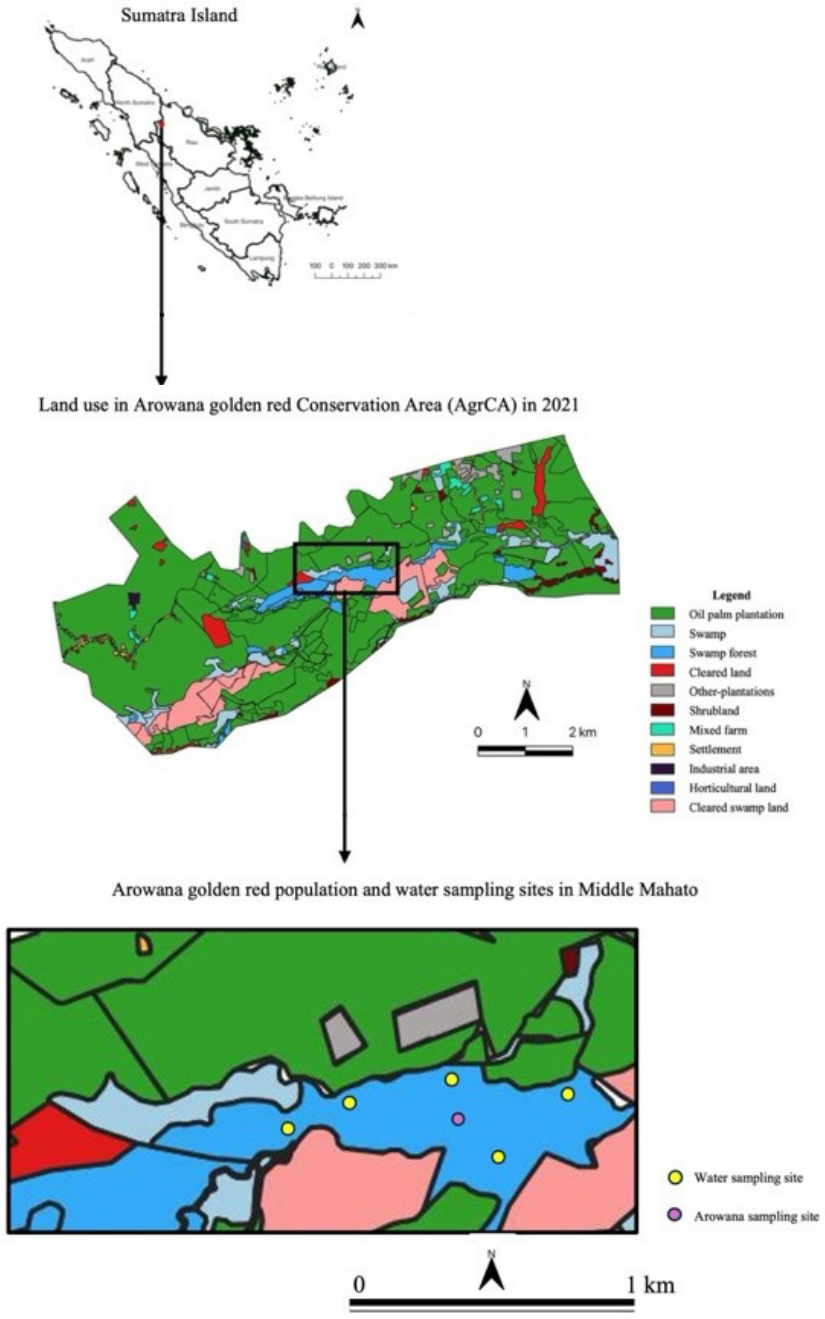

Figure 1. The study area in middle Mahato in AgrCA

2.2. Estimation of Arowana Golden Red Habitat Area

We assumed land types of swamp and swamp forests were the arowana golden red habitat area. In order to estimate the area size, we conducted a mapping of those land types using QGIS 3.20.2 (QGIS Development Team 2021). The polygon map of AgrCA was obtained from the decree of the Regent of Rokan Hulu, number 169 in 2009 (Regent of Rokan Hulu 2009). To ensure georeferencing, we aligned it with the Indonesian Geospatial map, which can be accessed at https://tanahair.indonesia.go.id/portal-web. For our analysis, we used a Digital Terrain Model (DTM) map from Google Earth Pro recorded in 2017 and 2021. This DTM map was converted into a Digital Elevation Model (DEM). We then 'clipped' the DEM map and overlaid it with the AgrCA polygon map. The resulting map was digitized into a shapefile format (shp), and area calculations were tabulated using Microsoft Excel. To ensure accuracy of the land type mapping, ground surveys were conducted, and the location coordinates were recorded using a Garmin GPSMAP 64s GPS device (Garmin, Olathe Kansas, USA).

2.3. Arowana Golden Red Population Sampling

The discovery site of the arowana golden red in AgrCA was previously published by Purnama and Masunaga (2023). The site is located in the Middle Mahato site of AgrCA, which contains the largest portion of the remaining swamp forest in the AgrCA (Figure 1). Given this context, the present study focused on detailed observations of both water quality and the arowana golden red population in this specific area.

The arowana golden red sampling period was conducted from January 2021 to June 2023, with samples collected every three months, covering different seasons in Indonesia: the dry season (January–June) and the rainy season (July–December). To optimize the chances of capturing arowana golden red for population sampling, we employed three types of fishing gear: 'fish net' (320 × 150 × 160 cm, 1.5 cm mesh), 'fish trap' (90 × 60 × 50 cm, 2 cm mesh), and 'fish scoop-net' (diameter 30 cm, 1.5 cm mesh). A total of 30 fish nets and 30 fish traps were deployed at the Middle Mahato site, with distances of 10-20 meters between each fish net and fish trap. After a fishing of 1-3 days, the gear was checked for catches. The fish scoop net was utilized when the fish was directly spotted, and great care was exercised, as missing the fish meant it would not reappear. All observations were conducted at night, as arowana golden red is a nocturnal species.

Given the rarity and difficulty of catching arowana golden red, we applied an additional method: data collection from local fishermen who were illegally catching arowana golden red. Seven active fishermen were interviewed, and we obtained data from them monthly. The arowana golden red caught was verified by checking the capture location and taking photographs. It is important to note that the 'capture-re-capture' method with tagging and marking was not used due to the high potential risk of mortality for arowana golden red and the potential conflict it could create with local fishermen.

Morphological parameters, such as total length (TL) and body depth (BD), were measured and recorded for the arowana golden red obtained. We classified them into the following categories: Small/Fry (TL: 3-5 cm, BD: 1-2 cm), Medium/Larvae (TL: 5.1-9 cm, BD: 2.1-4 cm), Large/Juvenile (TL: 9.1-16 cm, BD: 4.1-7 cm), Big/Juvenile (TL: 16.1-20 cm, BD: 7.1-8 cm), and Super Big/Adult/Brooder (TL: >20 cm, BD: >8.1 cm) (Yue *et al.* 2019).

2.4. Water Sampling and Analysis

Water sampling was carried out in five places close to the arowana golden red discovery site (Figure 1), with distances between sampling sites ranging from approximately 200-300 m. Water sampling and analysis were performed from October 2021 to June 2023, with samples collected every three months, coincided with the time of arowana golden red sampling. During the water sampling, we also measured water temperature and depth at the water surface.

Two liters of water were collected at each site and were subjected to comprehensive analysis, encompassing parameters such as pH, total suspended solids (TSS), total organic carbon of TSS, dissolved oxygen (DO), turbidity, ammonia (NH_4-N), total nitrogen (TN), phosphate (PO_4), potassium (K), and. The water quality analysis adhered to the standard methods outlined in the American Public Health Association (APHA 2005). We cross-referenced the water quality data for the arowana golden red habitat with the established water quality standards for arowana habitats, as detailed in Regulation Minister of Marine and Fishery of the Republic of Indonesia.

3. Results

The comparison of swamp and swamp forest areas between 2017 and 2021 is depicted in Figure 2. We observed that the swamp and swamp forests in

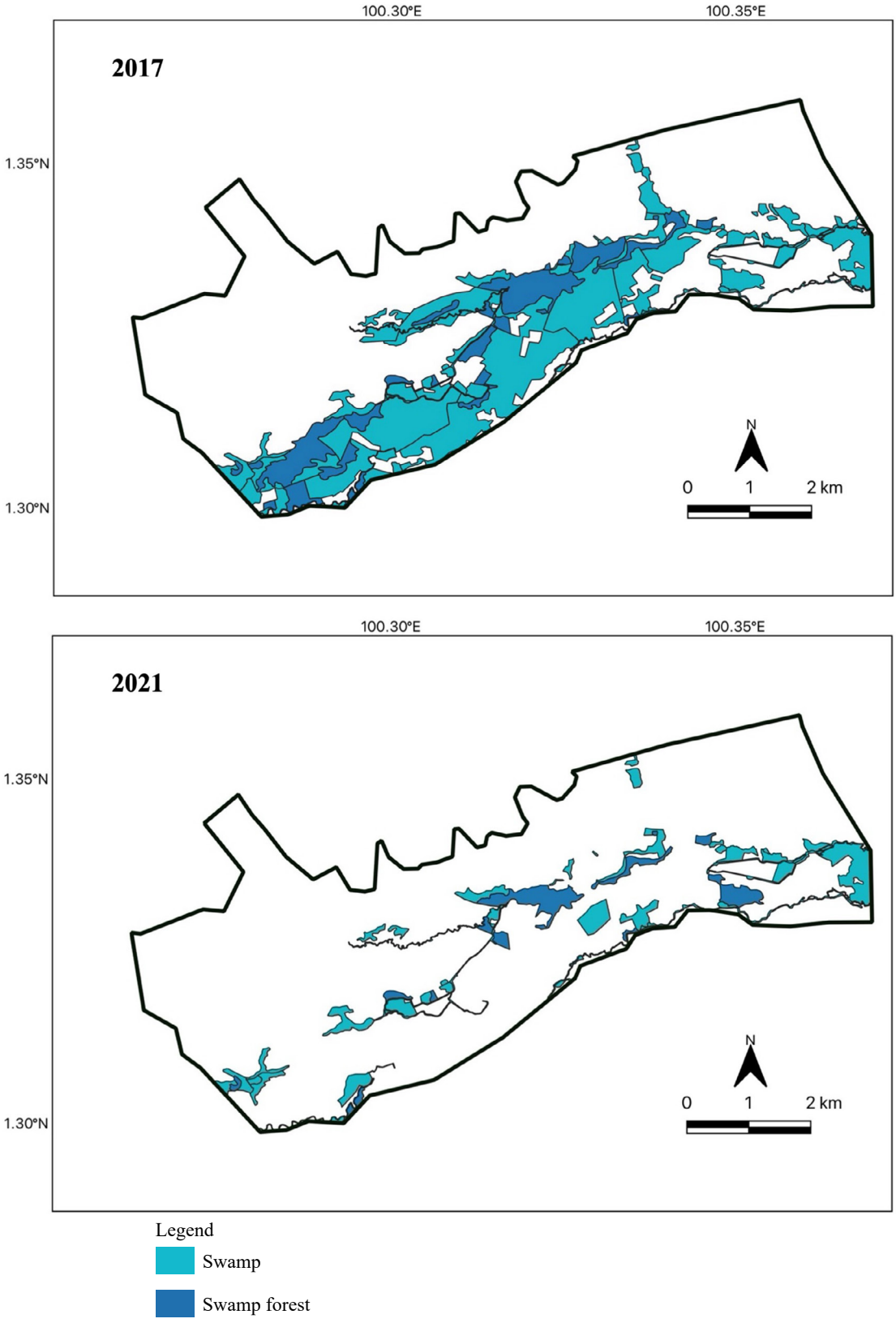

Figure 2. Distribution of swamp and swamp forest in AgrCA in 2017 and 2021

AgrCA have been altered through the construction of drainage canals. Approximately two to four years after this modification, these areas became dry and were converted to new oil palm plantations. The swamps and swamp forests in AgrCA currently amounted to 405 ha in 2021. Over the period from 2017 to 2021, there was a reduction in the swamp area by 664 ha (from 921 to 257 ha) and in the swamp forest by 116 ha (from 264 to 148 ha). The swamp forest in the middle Mahato area, the finding site of arowana golden red, was the remaining 42 ha. The comparison swamp and swamp forest in 2009, 2017 and 2021 is shown in Table 1.

These conversions have reduced the habitat area of the arowana golden red. It's worth noting that, despite the presence of water bodies, i.e. canals, surrounding the converted land, arowana golden red was not found in the canals during the research. Images of dried swamp and swamp forests are shown in Figures 3, 4 and 5.

In the swamp forest where the arowana golden red existed, pandan/rasau plants (*Pandanus helicopus*) were found, as shown in Figure 5. These plants have roots and leaves that are typically submerged in swamp water. They provide essential breeding spots and offer protection from predators such as crocodiles and humans. However, when the swamp forest was drained by the construction of the canals, these plants ceased to grow near the canals. Consequently, the arowana golden red no longer utilized the canals as their home range or territory.

We recorded 82 individuals of arowana golden red in the AgrCA from 2021 to 2023. We observed individuals of varying sizes and numbers in different months (period) of the year. The captured number in each size class of arowana golden red is shown in Table 2.

In middle Mahato, we found 24 and 44 arowana golden red in 2021 and 2022, respectively. And, from January to July 2023, 14 individuals were found. Notably, the higher number of individual was found during the October-March period (Table 2). Over the course of the study, 33 individuals were observed in October-December. During the period from January to March, we found 30 individuals of the arowana golden red. In the April-June period, 13 individuals were observed, and period of July to September, only 6 individuals were found (Table 2). Although the periodic fluctuations in the number and the size of arowana golden red individuals were found, they could be influenced by unobserved factors, such as mortality, predators, and unrecorded capture by local people, in the present study.

Table 1. Swamp and swamp forest covered in arowana golden red Conservation Area

Land use type	Area (ha)		
	2009	2017	2021
Swamp	978	921	257
Swamp forest	389	264	148
Total	1367	1185	405

While there has been decreasing in swamp and swamp forest areas in AgrCA, the water quality in the AgrCA has remained within the "good" category according to arowana habitat water standard. None of the water parameters exceeded the quality standards for the arowana golden red habitat, as shown in Table 3. Likewise, when compared to other areas, namely Kuala Hulu, middle Torganda, and Torganda, all water areas in AgrCA are still considered suitable for the survival of the arowana golden red (Table 4).

4. Discussion

Land fragmentation in AgrCA appears to be a key factor isolating the arowana golden red population in middle Mahato, where swamp forest still remains 42 ha (Figure 2). In most other sites (Kualu Hulu, middle Torganda and Torganda), the swamps have been drained and replaced with oil palm plantations. According to local residents, these land use changes have occurred with minimal or no oversight from relevant authorities. The lack of effective supervision and counseling on the ecological importance of this area poses a serious threat to the sustainability of the arowana golden red population.

However, despite these challenges, there remains a chance for the arowana golden red to survive in this habitat. The preserved swamp forest in middle Mahato offers a refuge and essential resources necessary for the species' survival and regeneration. Arowana golden

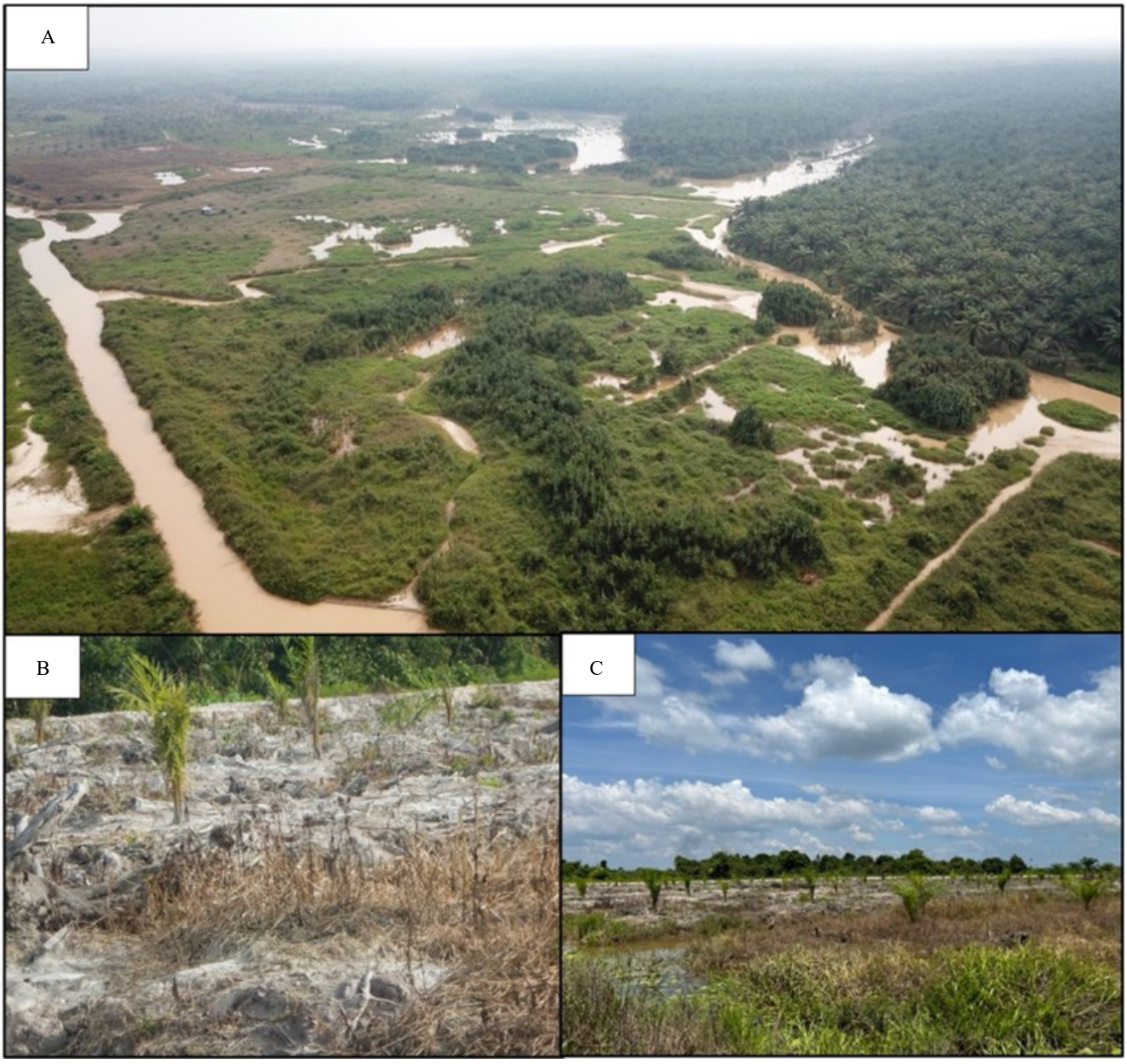

Figure 3. (A) Aerial photo of canals, dried swamp, and swamp forest, (B, C) new oil palm plantation in cleared swamp land

red in 'Super Big' in AgrCA is estimated to be over 2 years old (Yue *et al.* 2019). The fish species of arowana grow at a rate of 2-2.5 cm per month, allowing them to reach or exceed 20 cm in length within 2 years, and sexual maturity is generally attained between 2 to 4 years of age (Yue *et al.* 2019). We observed the presence of broodstock, 'Super Big' mature adults capable of reproduction, in each period although less than 5 individuals were found in each period (Table 2). The continuous observation of 'Small" arowana golden red in AgrCA revealed that broodstock individuals have survived despite the rapid reduction of the habitat

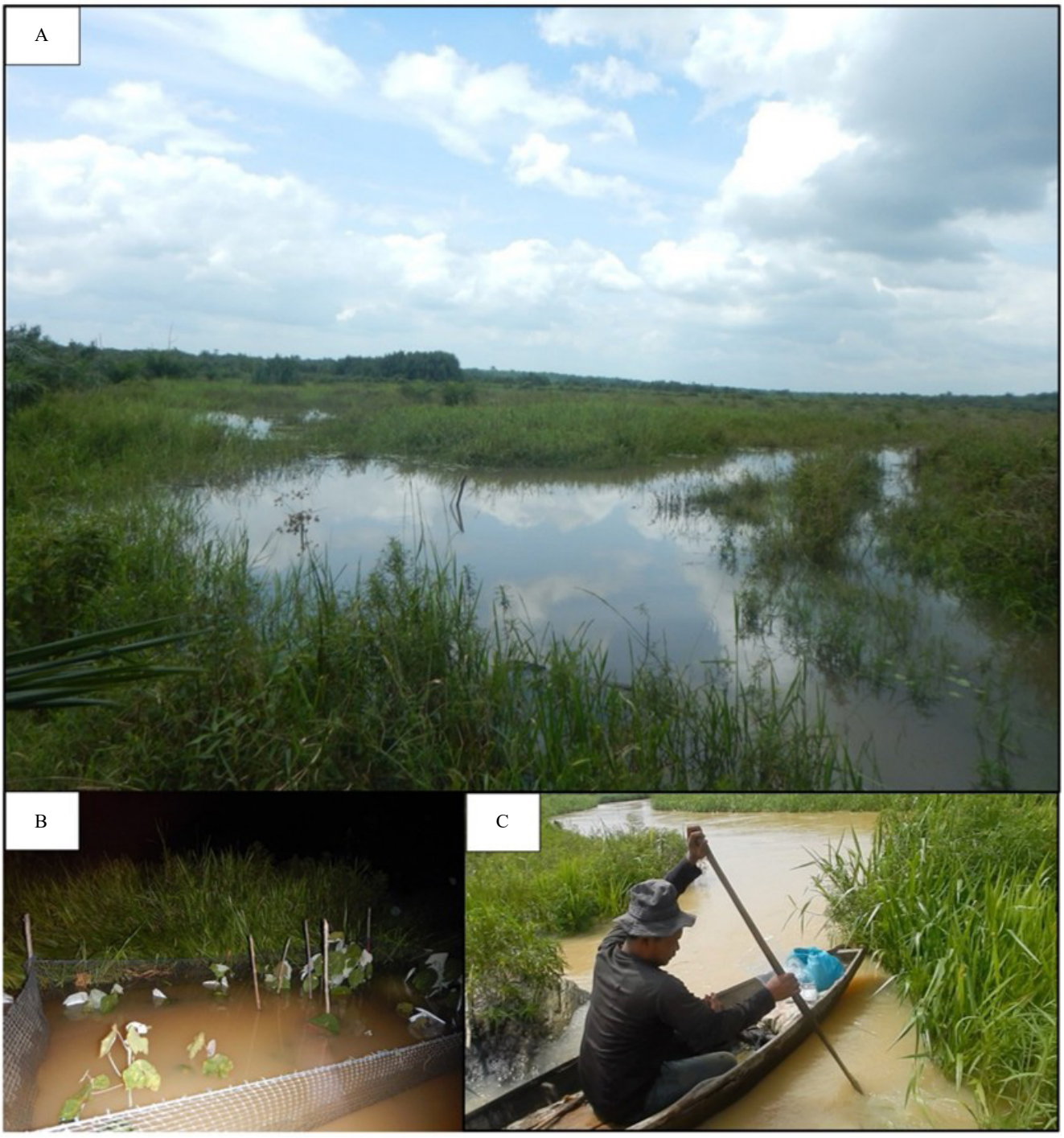

Figure 4. (A) Swamp, (B) fish net, and (C) fisherman activity in a swamp

in AgrCA from 2017 to 2021. Arowana, in a single spawning event, can produce 20-90 eggs, each with an average diameter of 1 cm. Arowana golden red prefer laying their eggs in areas with slow currents, typically around the roots of plants like pandan that are submerged in water (Yue *et al.* 2019). In this situation, pandan plants in the swamp forest and swamp areas play a crucial role, serving as barriers against strong currents and providing a suitable location for arowana golden red egg deposition. The loss of these plants with land use changes to fewer suitable locations for the arowana golden red to lay eggs, potentially reducing the species' regeneration.

Figure 5. (A) Aerial photo of swamp forest, (B) an arowana golden red finding site around pandan plants, (C) Arowana golden red in fishing trap (body length 40 cm)

Arowana incubates its eggs in the mouth of the male parent, after approximately 50 days, the eggs hatch and are released (Yue *et al.* 2019). When the eggs hatch, they are counted as "small" size individuals, which we observed during October to December 2021 and April to June 2023. Then, "small" individuals grow up into the "medium" phase after approximately 3-4 months. The "medium" arowana golden red were observed from October to December 2021, January to March and April to June 2022, and October to December 2022. Based on this observational data, we predict that the arowana golden red in AgrCA likely does not have a specific breeding period. Female arowana is known to produce eggs 1–3 times annually, while males can fertilize eggs whenever females are ready to spawn (Scott and Fuller 1976; Suleiman 2003). Our finding did not consistent with Urushido (1975), as cited in Yue *et al.* (2019), reporting that Asian arowana are seasonal breeders with a typical breeding season between July and November. While Chang (2009) reported that arowana can breed year-round in controlled pond environments provided an adequate supply of nutritious food. The arowana

Table 2. The arowana golden red population in 2021-2023

Year	Periods	Arowana golden red (∑ individual)				
		Small	Medium	Large	Big	Super Big
2021	January-March	-	-	-	-	-
	April-June	-	-	-	-	-
	July-September	-	-	1	-	-
	October-December	20	2	-	1	-
2022	January-March	-	20	8	-	-
	April-June	-	1	-	-	-
	July-September	-	-	1	1	3
	October-December	-	9	-	-	1
2023	January - March	-	-	-	-	2
	April - June	7	-	-	3	2
Total		27	32	10	5	8
Grand total				82		

Small (total length (TL): 3-5 cm, body depth (BD): 1-2 cm), Medium (TL: 5.1-9 cm, BD: 2.1-4 cm), Large (TL: 9.1-16 cm, BD: 4.1-7 cm), Big (TL: 16.1-20 cm, BD: 7.1-8 cm), Super Big (TL: >20 cm, BD: >8.1 cm)

Table 3. Water parameters in middle Mahato in different periods in AgrCA

Parameters	Unit	Standard	Jul-Sep (n = 10)	Oct-Dec (n = 15)	Jan-Mar (n = 15)	Apr-Jun (n = 15)
Temperature	°C	20-30	28.33±3.51	28.00±1.00	28.44±1.26	30.00±0.84
Depth	cm	100-200	135.33±14.74	164.67±33.29	169.44±95.77	104.22±26.93
pH	-	5.5-7.5	5.51±0.34	5.05±0.22	5.69±0.16	5.42±0.07
Total organic matter of TSS	mg L^{-1}	50	0.18±0.25	0.04±0.06	0.05±0.01	0.07±0.02
DO	mg L^{-1}	≥4	6.95±0.50	5.94±0.72	5.57±1.00	6.74±1.25
Turbidity	NTU	-	218.78±75.53	105.84±81.41	113.99±73.40	83.12±87.12
Ammonia (NH4N)	mg L^{-1}	≤1	0.14±0.07	0.23±0.07	0.17±0.09	0.19±0.12
Total Nitrogen	mg L^{-1}	≤20	6.60±1.67	4.83±0.57	3.31±1.00	2.80±0.79
Phosphate (PO4)	mg L^{-1}	≤1	0.21±0.18	0.14±0.09	0.11±0.05	0.06±0.02
Potassium (K)	mg L^{-1}	-	0.05±0.01	0.06±0.03	0.06±0.01	0.03±0.01
Sediment Total Organic Carbon	%	-	0.10±0.05	0.08±0.06	0.09±0.06	0.12±0.12

- Mean ± standard deviation (Jan-Mar, Apr-Jun, Jul-Sep, and Oct-Dec during 2020-2023)
- Arowana habitat water standard: Regulation Minister of Marine and Fishery the Republic of Indonesia Number 12/PERMEN-KP/2015

Table 4. Water quality in AgrCA

Parameters	Quality standards	Sampling site			
		Kualu Hulu	Middle Mahato	Middle Torganda	Torganda
Temperate (°C)	20-30	28	28	28	28
pH	5.5-7.5	5	5	5	5
TSS (mg L^{-1})	-	0.14	0.10	0.14	0.15
Depth (cm)	-	244	90	122	182
DO (mg L^{-1})	≥4	4.4	4.1	4.4	4.4

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golden red finding site of the present study might have enough nutritious food, such as water insects and small fish in middle Mahato (Purnama and Masunaga 2023).

The middle Mahato swamp forest had an area of 42 ha in 2021 and was inhabited by arowana golden red ranging 14-44 individuals of all sizes recorded per year. This results in a density of approximately 0.33-1.04 individuals ha^{-1} $year^{-1}$. Comparatively, other areas inhabited by fish of the same genus, such as the Irian or Australian arowana/pearl arowana (*Scleropages jardinii*) found in the Maro, Kumbe, and Kimaam rivers in Papua, Indonesia, show higher densities. In these rivers, the density of broodstock (super big) sizes alone ranges from 1.17 to 2.59 individuals ha^{-1} $year^{-1}$, while other size classes (small, medium, large, and big) have densities between 72 and 170 individuals ha^{-1} year (Satria *et al.* 2016).

Although the population dynamic of the arowana golden red in the AgrCA was not analysed in the present study due to the data limitation, the results exhibited

that despite facing habitat reduction, the species has managed to survive year after year so far. However, further conversion of water environment with the expansion of oil palm plantation has risk to extinct the arowana golden red. These remaining individuals are critical for the species' future sustainability. Therefore, it is essential to preserve the remaining natural habitat and monitor land use change activities to ensure the continued survival of the species.

In conclusion, the land use change in AgrCA has led to the decline of the arowana golden red habitat. While the water quality of the remained habitat was still in good condition for arowana golden red living. The population of arowana golden red in AgrCA was found in 14-44 individuals during 2021-2023. Although the number is very small compared to pearl arowana (*Scleropages jardinii*) in Papua, the number of arowana golden red found in AgrCA that currently exists can be a successor to the sustainability of this species because each period the arowana golden red found consists of broodstock that has the potential to produce eggs. Likewise, with juveniles, the juvenile arowana golden red that was found has the potential to continue growing and can continue its generation.

Prioritizing the conservation of the remaining swamp and swamp forest in AgrCA is crucial to protect the endangered arowana golden red from the adverse effects of further land conversion. Establishing conservation habitats and maintaining well-regulated populations are essential steps to prevent the species from nearing extinction. This proactive strategy is fundamental to secure the long-term survival of the arowana golden red. Moreover, immediate implementation of ex-situ conservation measures is imperative, serving as a precautionary approach if the arowana golden red's natural habitats become uninhabitable. Such measures will pave the way for potential population restocking efforts in the future, contributing to the species recovery and conservation.

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