

EXPANSION OF OIL PALM PLANTATIONS IN THE ASIAN AROWANA (*Scleropages formosus*) GOLDEN RED CONSERVATION AREA IN RIAU PROVINCE, INDONESIA AND ITS EFFECTS ON SOIL EROSION AND WATER QUALITY

Arief Anthonius Purnama^{1,2,3*}, Tsugiyuki Masunaga^{1,2}

¹Faculty of Life and Environmental Sciences, Shimane University, Matsue 6900823, Shimane Prefecture, Japan.

²United Graduate School of Agricultural Sciences (UGSAS), Tottori University, Tottori-shi 6808553, Tottori Prefecture, Japan.

³Faculty of Teacher Training and Education, University of Pasir Pengaraian, Rokan Hulu Regency 28557, Riau Province, Indonesia.

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EXPANSION OF OIL PALM PLANTATIONS IN THE ASIAN AROWANA (*Scleropages formosus*) GOLDEN RED CONSERVATION AREA IN RIAU PROVINCE, INDONESIA AND ITS EFFECTS ON SOIL EROSION AND WATER QUALITY. The study was conducted due to rapid land use change driven by oil palm expansion in the Arowana Golden Red Conservation Area (AgrCA) in Riau Province, Indonesia. The study assessed the expansion of oil palm plantations and their influence on the environment of AgrCA. Using satellite imagery in 2017 and 2021, we found that oil palm plantations expanded from 2,234 ha (60.4% of the total area of AgrCA) in 2017 to 2,752 ha (74.4%) in 2021 by the conversion of swamps and swamp forests. The soil erosion rate estimated by a USLE method ranged from 5.26 to 186.34 t ha⁻¹ yr⁻¹ in the AgrCA. The soil erosion rates of oil palm plantations were the same as those under other agricultural land uses such as other plantations, mixed farms, and horticulture. Cleared land (land clearing or replanting area) that had not yet been planted exhibited the highest soil erosion rates. To mitigate the risk of soil erosion, it is crucial to replant oil palm trees on the cleared land as soon as possible. Water bodies adjacent to old oil palm plantations and the cleared land exhibited low levels of dissolved oxygen and were considered very trophic regarding phosphate concentrations. The low water quality was probably caused by the residual effects of fertilization in the old oil palm plantations.

Keywords: Land use change, soil erosion, endangered species, habitat.

PERLUASAN PERKEBUNAN KELAPA SAWIT DI KAWASAN KONSERVASI AROWANA GOLDEN RED (*Scleropages formosus*) DI PROVINSI RIAU, INDONESIA DAN PENGARUHNYA TERHADAP EROSI TANAH DAN KUALITAS AIR. Penelitian ini dilakukan karena perubahan penggunaan lahan yang cepat akibat perluasan perkebunan kelapa sawit di Kawasan Konservasi Arowana Golden Red (AgrCA) di Provinsi Riau, Indonesia. Penelitian ini mengevaluasi perluasan perkebunan kelapa sawit dan pengaruhnya terhadap lingkungan AgrCA. Dengan menggunakan citra satelit pada tahun 2017 dan 2021, kami menemukan bahwa perkebunan kelapa sawit meluas dari 2.234 ha (60,4% dari total luas AgrCA) pada tahun 2017 menjadi 2.752 ha (74,4% dari total luas AgrCA) pada tahun 2021 melalui konversi rawa dan hutan rawa. Laju erosi tanah yang diperkirakan dengan metode USLE berkisar antara 5,26 hingga 186,34 t ha⁻¹ thn⁻¹ di AgrCA. Laju erosi tanah pada perkebunan kelapa sawit sama dengan laju erosi tanah pada penggunaan lahan pertanian lainnya seperti perkebunan lainnya, pertanian campuran, dan hortikultura. Lahan yang dibuka (lahan yang sedang dibersihkan atau lahan sedang peremajaan) dan belum ditanami menunjukkan tingkat erosi tanah tertinggi. Untuk mengurangi risiko erosi tanah, sangat penting untuk menanam kembali pohon kelapa sawit di lahan yang telah dibuka sesegera mungkin. Badan air yang berdekatan dengan perkebunan kelapa sawit tua dan lahan yang telah dibuka menunjukkan tingkat oksigen terlarut yang rendah dan konsentrasi fosfat yang sangat tinggi. Rendahnya kualitas air kemungkinan disebabkan oleh efek residu dari pemupukan di perkebunan kelapa sawit tua.

Kata kunci: Perubahan penggunaan lahan, erosi tanah, spesies terancam punah, habitat

*Corresponding author e-mail: ariefanthoniuspurnama@gmail.com

I. INTRODUCTION

Indonesia is one of the leading countries in global palm oil production. In 2019, Indonesia's palm oil production reached 42.86 million tons, accounting for 57% of the world's total palm oil production, which was 74.58 million tons (FAO, 2022). Only 35% of Indonesia's palm oil is consumed domestically, while the remaining 65% is exported worldwide. In 2010–2020, Indonesia's palm oil exports were distributed across various regions, including Asia (64.72%), the EU (16.29%), Africa (13.59%), America (5.30%), and Oceania (0.07%) (Bogheiry, Thaha, & Rahmah, 2023).

The prominent position of Indonesia in palm oil production is attributed to the extensive expansion of oil palm plantations in the country. This expansion has been remarkable, surging from 0.13 million ha in 1970 to 15.38 million ha in 2022 (Directorate General of Estate, 2022). The conversion of numerous forests, peatlands, coastal areas, and other natural landscapes into oil palm plantations, has contributed to increased palm oil production. While this conversion has led to environmental impacts, Indonesia has concurrently experienced significant economic benefits from this thriving agricultural sector (Ayompe, Schaafsma, & Egoh, 2021; Meijaard et al., 2020; Monitor, 2023; Srisawasdi, Tsusaka, & Cortes, 2023).

Indonesia has witnessed the conversion of natural forests into oil palm plantations in pursuit of increased economic gains. However, conversion of natural areas is widely believed to be the primary threat to nature, leading to global declines in species abundance, diversity, and ecosystem health. Despite extensive research into the drivers of these global changes, there remains a need for the effective preservation of biodiversity across various species and habitats (Davison, Rahbek, & Morueta-Holme, 2021). The United Nations introduced the 2030 Agenda for Sustainable Development, encompassing the Sustainable Development Goals (SDGs), calling upon nations to balance between economic, social, and environmental

aspects to promote sustainable development (United Nations Development Group, 2017).

The transition of natural areas to oil palm plantations in Indonesia has had detrimental effects on biodiversity. Sumatran orangutans (*Pongo abelii*) and Bornean orangutans (*Pongo pygmaeus*) are on the brink of extinction due to the expansion of oil palm plantations (Nellemann, 2007; Swarna & Tisdell, 2009; Tan, Lee, Mohamed, & Bhatia, 2009). Furthermore, Sumatran elephants (*Elephas maximus sumatrensis*), Sumatran tigers (*Panthera tigris sumatrae*), and Sumatran rhinoceros (*Dicerorhinus sumatrensis*) face critical threats due to these developments (Danielsen et al., 2009; Sheil et al., 2009). Indonesia is a nation renowned for its mega-biodiversity and high national biodiversity index (NBI). The country's actions and policies are crucial for preserving this biodiversity (Keong, 2015; Von Rintelen, Arida, & Häuser, 2017).

Freshwater biodiversity has been the overriding international conservation priority since 2005. Given the critical importance of freshwater ecosystems, efforts to study and safeguard them are ongoing to ensure their sustainability (Albert et al., 2021; Birk et al., 2020; Darwall et al., 2018; Dudgeon et al., 2006; Flitcroft, Cooperman, Harrison, Juffe-Bignoli, & Boon, 2019; Maasri et al., 2022; Reid et al., 2019; Strayer & Dudgeon, 2010; Su et al., 2021). One of the freshwater fish species in Indonesia is the Asian arowana (*Scleropages formosus*) variety golden red. This fish was found initially in Rokan Hulu Regency of Riau Province, Indonesia.

The Asian arowana golden red is highly sought after and is considered valuable due to its exotic and precious nature. Unfortunately, over the past 30 years, its popularity has led to significant overexploitation of its natural habitat (Fernando et al., 1997). As a result of its declining numbers, the Asian arowana golden red has been categorized as an endangered species on the International Union for Conservation of Nature and Natural Resources (IUCN) Red List since 2006 (Dawes, 2006; Yue, Chang, Yuzer, & Suwanto, 2020). Furthermore,

the Asian arowana golden red has been on Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) since 1975. It has also been recognized as a protected species in Indonesia as declared by the Government of The Republic of Indonesia in 1999.

Initially, the Rokan Hulu Regency was covered by a natural forest. However, over the last five decades, the area has been cleared and converted into oil palm plantations. The Central Statistics Agency of Riau Province reported an increase in the oil palm plantation area in Rokan Hulu from 208,47 ha in 2012 to 267,84 ha in 2021 (Central Statistics Agency of Riau Province, 2022). This transition has boosted the community's economic income but has exerted significant pressure on the habitat of the Asian arowana golden red. In response to these challenges, the Regent of Rokan Hulu designated the Arowana Golden Red Conservation Area (AgrCA), spanning approximately 3,700 ha, in 2009. However, as the designation of this area as a protected zone to preserve the habitat of the Asian arowana golden red progressed, the outcomes have not been promising. Despite the conservation efforts in the AgrCA, the expansion of oil palm plantations has continued. The swamps and swamp forests within the AgrCA, which serve as the natural habitat of the Asian arowana golden red, have been drained and converted into oil palm plantations.

A previous study conducted in the AgrCA (Purnama & Masunaga, 2023) on aquatic organisms identified 47 species with a total of 424 individuals: 7 genera of benthos, 11 species of planktonic algae, and 29 species of fish. The diversity index was in the range of 0.46–2.45 in 2020, which was comparable to or higher than that in other areas in Kalimantan, Aceh province, and Malaysia. However, swamp forests, which are the habitat of the Asian arowana golden red, only covered 7.0% of the area (264 ha) in 2017, and only 31 Asian arowana golden red individuals were found in the AgrCA in 2020.

These land use changes, accompanied by the drying and clearing of the land, may increase soil erosion. The eroded materials entering water bodies have the potential to alter the condition of aquatic environments and biodiversity (Issaka & Ashraf, 2017). Purwanto et al. (2019) and Agustina and Dewi (2020) measured soil erosion rates in oil palm plantations located in Palangkaraya, Central Kalimantan, and Muara Enim, South Sumatra, respectively. However, no studies, including the aforementioned ones, have examined the effects of oil palm plantations on soil erosion and the surrounding environment.

Considering the importance of the AgrCA to protect aquatic biodiversity, including the Asian arowana golden red, it is crucial to understand and mitigate the impacts of land use changes on water quality. In the present research, we investigated the influence of land use changes in the AgrCA from 2017 to 2021, estimated soil erosion rates, and analyzed the effects of land use changes on water quality. This study provides the first integrated assessment linking multi-temporal land-use change (2017–2021), soil erosion modeling, and water quality dynamics within a designated AgrCA in Riau, Indonesia.

II. MATERIAL AND METHOD

A. Study Site

The present study was conducted in the AgrCA (Figure 1). For the water quality analysis, water sampling sites were established where the Asian arowana golden red still existed and the original vegetation (i.e., swamp forest) still dominated. Starting in 2020, we set up three types of water sampling sites in Middle Mahato. They were waterbodies adjacent to 1) oil palm plantations of varying ages (OP1: aged 1–7 years, OP2: aged 8–15 years, and OP3: aged 16–20 years), 2) cleared land, and 3) swamp forests. The term “cleared land” refers to the cleared land that was previously old oil palm plantations and was being replanted with oil palms. Oil palm farmers have cleared the old

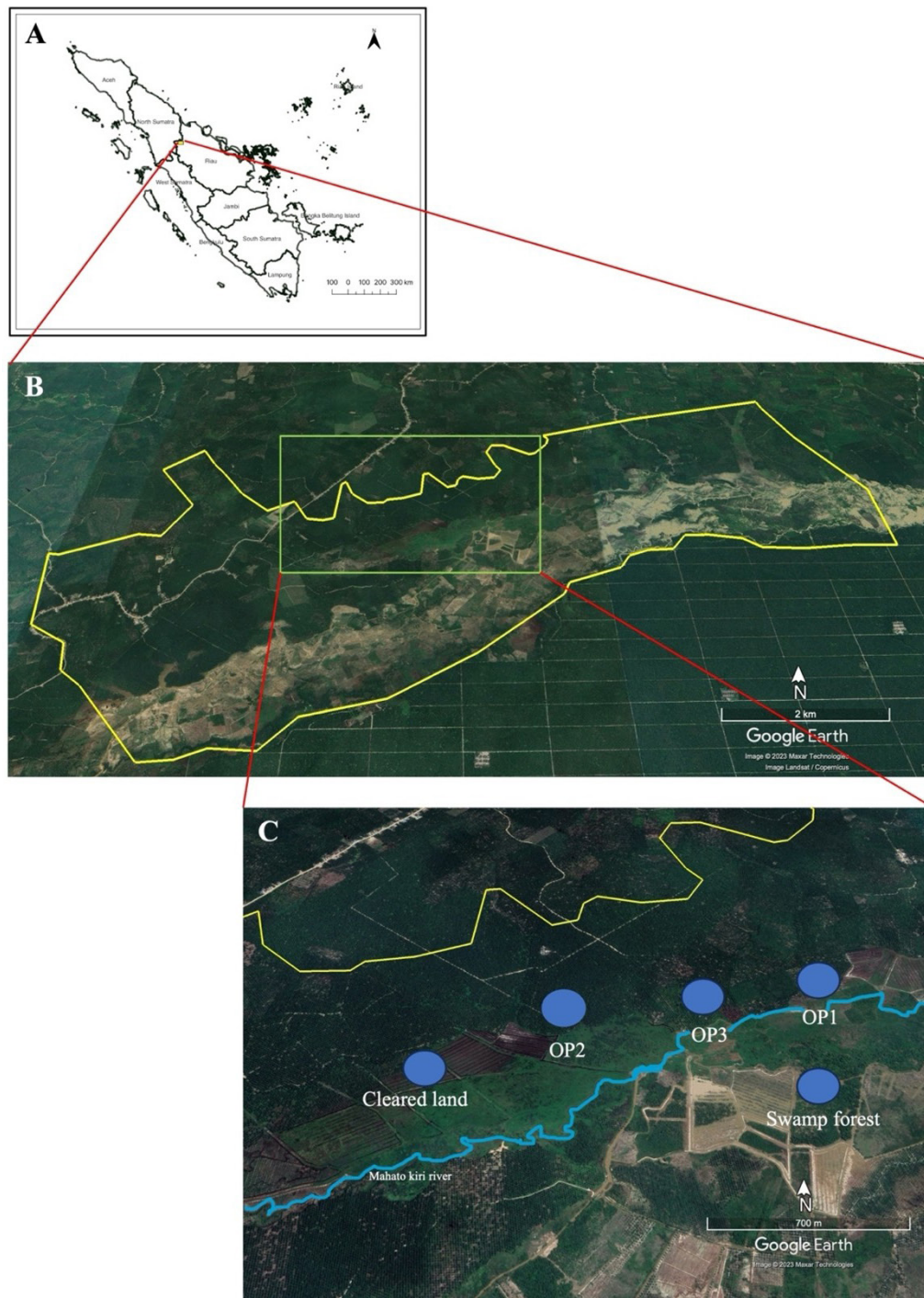


Figure 1. Map of AgrCA and research sampling site

oil palm fields with the age more than 20 years by cutting and chopping the old palms using machines. The chopped stems were then spread across the land and left to decompose. On the cleared lands, few grasses were observed even after 2 years of the land clearance (Figure 2).

On the land use types of “settlement” and “industrial area”, the house and industrial area properties (courtyard) were utilized for a traditional home garden (so-called Pekarangan, i.e. home garden consisting with orchard trees, small crop field and/or grasses (Figure 3).



Figure 2. Cleared land more than 2 years after clearance (foreground)



Figure 3. A farmer's house with home garden, so-called Pekarangan in Indonesia, in settlement area

B. Data Collection

1. Key Resource Assessment of Perum Perhutani's Cajuput Oil Business

The land-use change mapping was performed using QGIS 3.20.2 (García-Álvarez, Camacho Olmedo, Paegelow, & Mas, 2022). The polygon boundary of the Asian Arowana

Golden Red Conservation Area (AgrCA), covering approximately 3,700 ha, was obtained from Regent of Rokan Hulu Decree No. 169 of 2009 (Regent of Rokan Hulu, 2009). The boundary was georeferenced and overlaid with the Indonesian geospatial reference map (Indonesian Geospatial, 2022). Land-use

data for 2017 and 2021 were derived from Google Earth Pro Digital Terrain Model data and processed into digital elevation model (DEM) layers. The DEM layers were clipped to the AgrCA boundary and overlaid with the conservation-area polygon, after which land-use classes were digitized and their respective areas calculated. The resulting spatial data were exported as shapefiles (.shp), and area calculations were tabulated using Microsoft Excel. Land-use classification followed the categories established by the Ministry of Agrarian Affairs of the Republic of Indonesia (2009), with modifications to reflect the specific conditions of oil palm plantations and swamp areas (Table 3). Field surveys were conducted to validate the mapped land-use classes, and geographic coordinates were recorded using a Garmin GPSMAP 64.

The Universal Soil Loss Equation (USLE) has been widely utilized by researchers to estimate soil erosion across various environments. To assess the applicability of the USLE in the present study, we referenced the work of Agustina and Dewi (2020), who validated the method within oil palm plantations through comparison with actual measurements in Muara Enim Regency, Indonesia. Their findings demonstrated that erosion rates

predicted by the USLE closely corresponded with those measured in field plots (4 m × 20 m) established on slopes of 5°, 10°, and 15°, under rainfall conditions of less than 43.5 mm day⁻¹. Notably, the average daily rainfall in the present study area from 2012 to 2021 remained within this range. Furthermore, we found that the results obtained using the USLE in the present study were comparable to the values reported in previous studies Anasiru (2015), Purwanto et al. (2019), and Agustina and Dewi (2020), which conducted field measurements of soil erosion, as detailed in the Results section. Therefore, we determined that the USLE was applicable for the present study. The calculation of USLE is.

$$A = R \times K \times L \times S \times C \times P \dots\dots\dots(1)$$

where: A is the average annual soil loss per area unit (t ha⁻¹ yr⁻¹), R is the average rainfall erosivity factor (MJ mm ha⁻¹ h⁻¹ yr⁻¹) in 10 years, K is the soil erodibility factor (t ha h MJ⁻¹ mm⁻¹), L is the slope length factor, S is the slope steepness factor, C is the land use factor, and P is the support and conservation practices factor. R was analyzed using the Lenvain equation (Asdak, 1995, DHV Consulting Engineers, 1989):

$$R = 2.21 \text{ Precip}^{1.36} \dots\dots\dots(2)$$

Table 1. Monthly rainfall in Arowana golden red Conservation Area (2012 – 2021)

Years	Months											
	January	February	March	April	May	June	July	August	September	October	November	December
2021	290.3	180.8	253.3	482.3	365.5	224.1	147.8	187.1	179.1	334.6	405.3	307.3
2020	153.1	108.2	129.6	233.9	177.1	160.9	255.6	219.3	148.1	270.5	304.7	138.3
2019	274.3	93	67.1	203.1	226.2	311.1	23.9	68	23	284.8	273.6	242.3
2018	80.7	18.6	227.5	55.6	303.1	202.4	128.2	75.6	107.6	442.8	493.4	274.1
2017	338.2	354.4	370.2	386.2	401.5	296.9	119	148.3	28	73.5	255.2	388.8
2016	258.1	192.8	177.9	332.4	220.7	105.1	272.7	43.7	274	159.1	511.4	168.8
2015	139.9	11.1	333.5	129.3	140.3	98	13.5	300.1	61	64.7	380.9	317.1
2014	255.9	18.6	181.5	348.3	225.9	140.2	175.5	105	141.6	362.9	328.2	297.6
2013	120.9	325	339	176.9	126.9	53.5	140.3	183.7	146.6	469.7	453.4	541.5
2012	102.5	211.8	329	202.4	190.1	165.5	235.6	97	185.8	228.9	443.4	241.1

Source: Indonesian Meteorology, Climatology and Geophysical Agency (Indonesian Agency for Meteorological, Climatological and Geophysics, 2022)

where: Precip is the monthly rainfall over 10 years (mm/month). Rainfall data were collected from the Indonesian Meteorology, Climatology and Geophysical Agency (Indonesian Agency for Meteorological, Climatological and Geophysics, 2022) (Table 1). Soil type classification was sourced from the Food and Agriculture Organization (FAO) (Food and Agricultural Organization of the United Nations, 2022). A field soil sampling was conducted to confirm soil type. We collected soil samples at OP1, OP2, OP3, and cleared land using a random method, for a total of 4 soil samples. All the soil samples were analyzed at the Soil Laboratory, Agricultural Modernization Testing and Application Installation (IP2MP) - West Sumatra.

The LS factor accounts for the influence of topography on soil erosion. The slope length factor (L) represents the effect of slope length on erosion, while the slope steepness factor (S) reflects the impact of slope gradient. In

this study, the LS factor was estimated using a digital elevation model (DEM) from the data of Indonesian Agency for Geospatial Information (2021). The calculation of the LS factor requires both flow accumulation and slope steepness. Flow accumulation was derived from the DEM using watershed delineation techniques, while slope steepness was calculated directly from the DEM by the Desmat and Grover (1996) method in QGIS. The slope gradient (%) and slope length (m) can be accurately determined and combined with the incline of the DEM to form a LS factor. The equation used to compute this parameter was recommended by Morgan (2009).

$$LS = (x/22.13)^n (0.065 + 0.045 + 0.0065s^2) \dots\dots(3)$$

where: x is the slope length (m), n is the index value percentage slope categories (<1%: 0.2; 1 - 3 %: 0.3; 3 - 5 %: 0.4; 5 - 20 %: 0.5; >20%: 7.10), and s is the slope gradient (%). Based on

Table 2. C and P-factor values

Land use type	C value	P value	Author/Source
Oil palm plantation	0.2	1	Asdak (1995), Regulation of the Minister of Forestry of The Republic of Indonesia (2009)
Swamp	0	0	-
Swamp forest	0	0	-
Cleared land	0.9	1	Regulation of the Minister of Forestry of The Republic of Indonesia (2009)
Other-plantations	0.2	1	Asdak (1995), Regulation of the Minister of Forestry of The Republic of Indonesia (2009)
Shrubland	0.4	1	Asdak (1995), Regulation of the Minister of Forestry of The Republic of Indonesia (2009)
Mixed farm	0.4	1	Asdak (1995), Regulation of the Minister of Forestry of The Republic of Indonesia (2009)
Settlement	0.3	1	Regulation of the Minister of Forestry of The Republic of Indonesia (2009)
Industrial area	0.3	1	Regulation of the Minister of Forestry of The Republic of Indonesia (2009)
Horticultural land	0.2	1	Asdak (1995), Regulation of the Minister of Forestry of The Republic of Indonesia (2009)

the Regulation of the Minister of Forestry of The Republic of Indonesia (2009), the LS value can be converted into the following categories: Flat (0-0.25), slope (>0.25-1.20), rather slope (>1.20-4.25), steep (>4.25 - 9.50), very steep (>9.25). Soil erodibility (K), which measures the influence of physical and organic properties on the soil's susceptibility to erosion.

The soil type in the AgrCA is classified as *Plinthic Acrisols*. Based on finding Alim & Anggraini (2021), the K value in Rokan Hulu ranges from 0 to 0.39; we referred to and identified K value in AgrCA as 0.29. The C and P value was decided based on Indonesian Centre for Irrigation Research and Development (Asdak, 1995) and the Regulation of the Minister of Forestry of The Republic of Indonesia (2009), considering land surface conditions. We adopted the C value of land category “Bareland (bare soil + no-till)” of the Regulation, where this category is similar to clear land in our study

that is not being cultivated. Cleared land has a C value of 0.9; settlement and industrial area have a C value of 0.3; shrubland and mixed farm have a C value of 0.4; and oil palm plantation, other plantation, and horticultural land have a C value of 0.2 (Table 2).

The lowest C value was in oil palm plantations, other plantations, and horticultural land and the highest C value was in cleared land, settlements, and industrial areas. A C value of 1 indicates the absence of ground cover, while a C value close to 0 indicates well-protected soil cover and management (Pham, Degener, & Kappas, 2018). The P value for all land uses was 1, which implies poor conservation practices. P values range from 0 for good conservation practices to 1 for bad conservation practices (Ganasri & Ramesh, 2016).

Quantum GIS (QGIS) software was used to generate erosion maps. The analysis of the soil erosion estimation model from QGIS

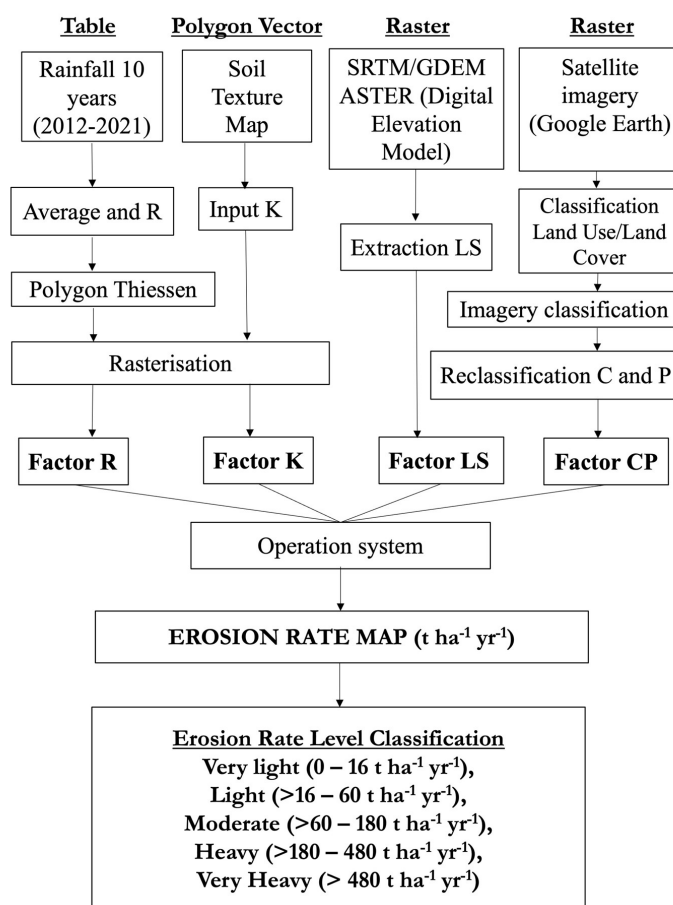


Figure 4. Soil erosion estimation model through Quantum GIS (QGIS)

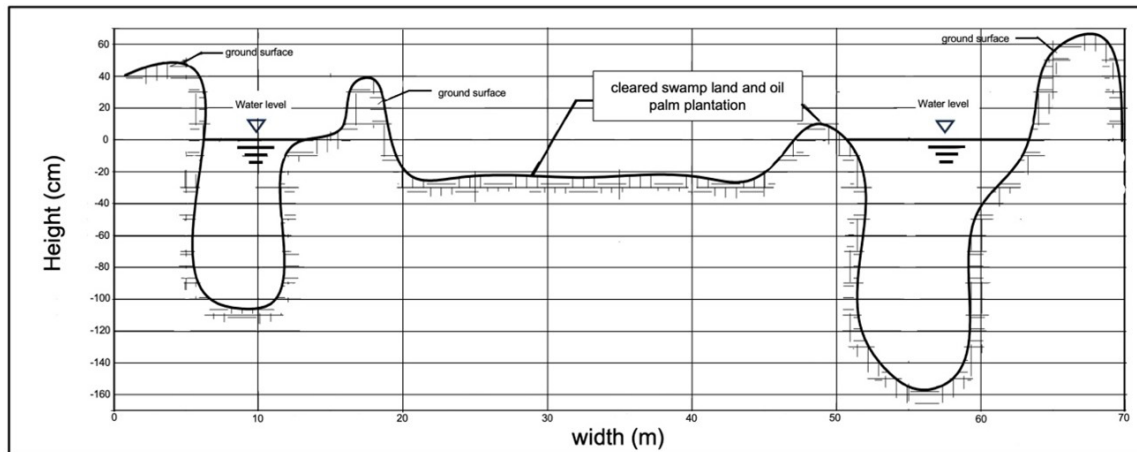


Figure 5. Cross-section in formed swamp and swamp forests, and new oil palm plantation in AgrCA

is shown in Figure 4. The integration of the USLE method with GIS efficiently predicts the intensity of soil erosion and its spatial distribution (Nyesheja et al., 2019; Amellah & el Morabiti, 2021; Vijith, 2012; Saswattecha, Hein, Kroeze, & Jawit, 2016; Sestras et al., 2023). Erosion rates were classified into five classes: level I (very light: $0-16 \text{ t ha}^{-1} \text{ yr}^{-1}$), level II (light: $>16-60 \text{ t ha}^{-1} \text{ yr}^{-1}$), level III (moderate: $>60-180 \text{ t ha}^{-1} \text{ yr}^{-1}$), level IV (Heavy: $>180-480 \text{ t ha}^{-1} \text{ yr}^{-1}$), and level V (very heavy: $>480 \text{ t ha}^{-1} \text{ yr}^{-1}$) (Minister of Forestry, 2009).

Soil erosion was not estimated for swamps, swamp forests, or cleared swamp land, or for oil palm plantations developed in swamps, swamp forests, or cleared swamp land. This was because the USLE is not applicable to the concave areas between canals (Figure 5), where the land was submerged by overflowed canal water during heavy rainfall events.

2. Water Sampling and Analysis

We collected and analyzed surface water samples at OP1, OP2, OP3, and cleared land, approximately 1 m from the riverbanks to assess water quality. At the sites, we measured water temperature and depth. Simultaneously, we collected 2 L of river water using a sample bottle, which was then transported to the laboratory for analysis.

Water samples were analyzed for pH, total suspended solids (TSS), dissolved oxygen (DO), turbidity, ammonia ($\text{NH}_3\text{-N}$), total nitrogen (TN), phosphate (PO_4), potassium (K), and sediment total organic carbon. All water-quality analyses followed the standard procedures of the American Public Health Association (APHA, 2005).

Sampling was conducted from 2020 to 2023 at three-month intervals, with two sampling events during the dry season (January–June) and two during the rainy season (July–December) each year. Five replicates were collected for each sampling event. Sampling locations represented three land-use categories: oil palm plantations (OP1, OP2, and OP3), cleared land, and swamp forest. Measured water-quality parameters were compared with the water-quality criteria for Asian arowana golden red habitat specified in Regulation of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia No. 12/PERMEN-KP/2015. Water pollution status and trophic conditions were further assessed according to the Indonesian national water-quality standards for river environments established under Government Regulation of the Republic of Indonesia No. 22/PP/2021.

Water quality standards from the Water Analysis Manual, Tropical Aquatic Biology Program, Biotrop, Southeast Asian Regional

Centre for Tropical Biology (Wardoyo, 1982) were used. One-way analysis of variance (ANOVA) and Duncan's multiple range test (DMRT) were used to analyze the differences between sampling sites for PO_4 parameters.

III. RESULT AND DISCUSSION

A. Result

1. Expansion of Oil Palm Plantations in The AgrCA in 2017–2021

In 2017, oil palm plantations covered an area of 2,234 ha. Between 2017 and 2021, there was a notable increase in the area dedicated to oil palm plantations, resulting in an expansion of 518 ha, bringing the total to 2,752 ha. All conversions took place on land formerly covered by swamps and swamp forests. Consequently, the swamp area decreased by 664 ha (from 921 ha to 257 ha), and the swamp forest area decreased by 116 ha (from 264 ha to 148 ha). By 2021, oil palm plantations had the highest coverage at approximately 74%, while swamp

forests covered approximately 4%. The land use change from swamps and swamp forests to cleared swamp land accounted for 258 ha.

Other land use categories, such as other plantations, shrublands, mixed farms, settlements, cleared land, industrial areas, and horticultural land, remained relatively stable in their coverage, with a combined total area of less than 90 ha. Detailed information regarding land use and the corresponding areas is provided in Table 3, and a visual representation is presented in Figure 6.

2. Estimated Soil Erosion Rates in Respective Land Uses in 2021

As all land conversions into oil palm plantation or cleared swamp land took place on land formerly covered by swamps and swamp forests where the USLE was not applicable, we estimated soil erosion rates only in 2021. The rainfall erosivity value (R) in the AgrCA was $1,903.62 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ yr}^{-1}$. The LS value ranges from 0 to 1.56 (Figure 7).

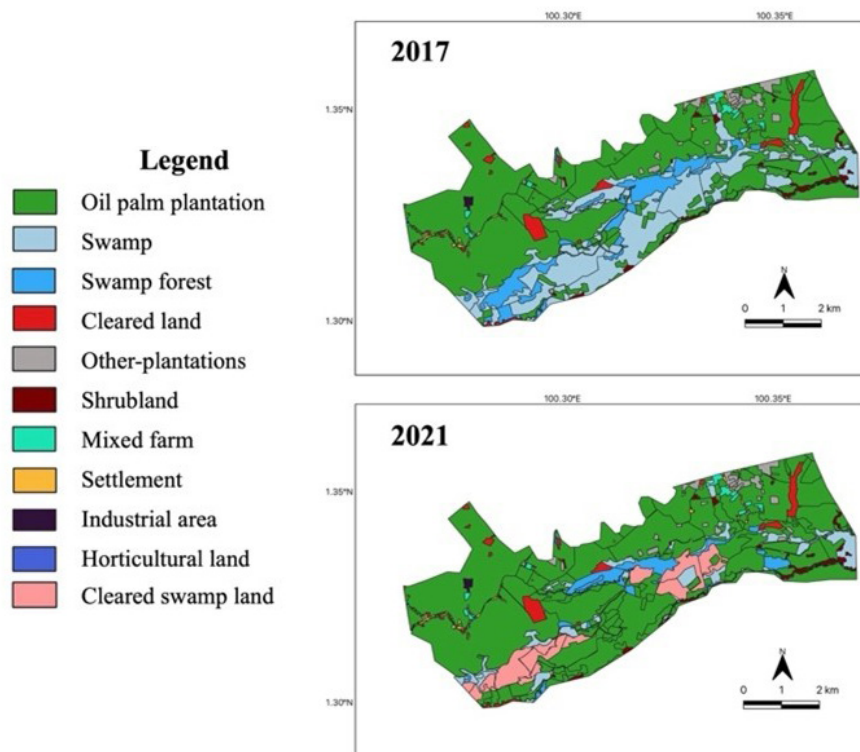


Figure 6. Land use change during 2017 to 2021 in AgrCA

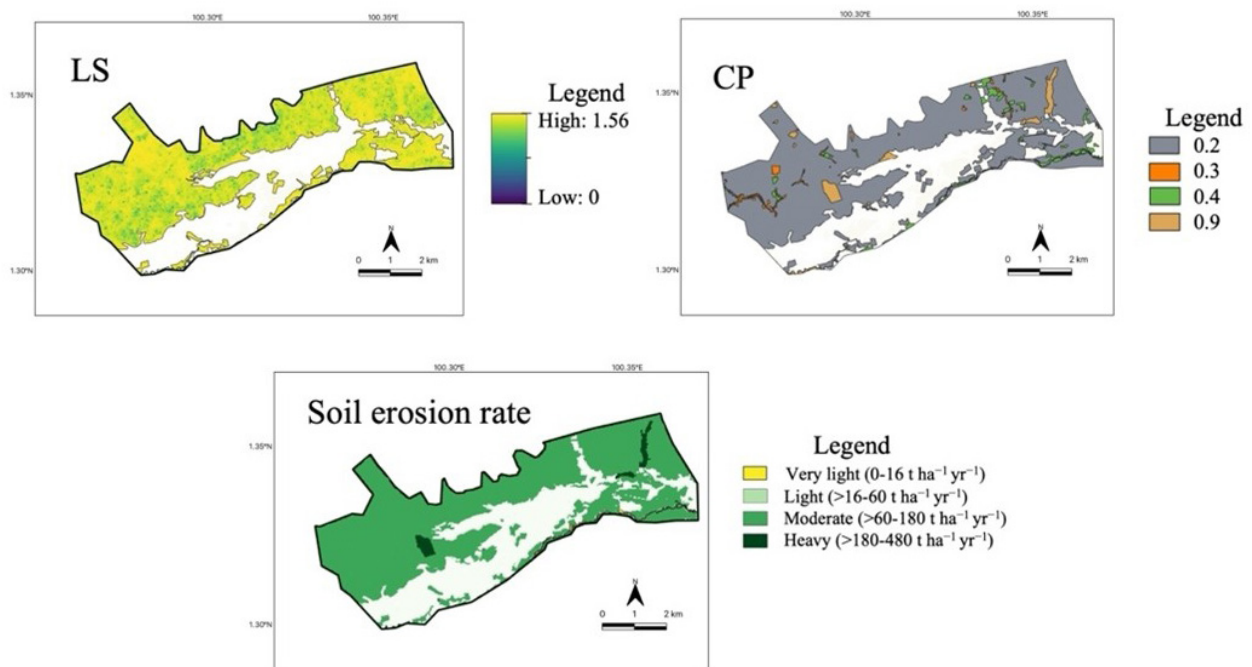


Figure 7. MAP of LS, CP, and soil erosion rate in AgrCA

Table 3. Land use cover changed in AgrCA

Land use type	Area (ha)		Covering (%)	
	2017	2021	2017	2021
Oil palm plantation	2234	2752	60.4	74.4
Swamp	921	257	24.9	6.9
Swamp forest	264	148	7.1	4.0
Cleared land	85	85	2.3	2.3
Other-plantations	76	76	2.1	2.1
Shrubland	47	52	1.3	1.4
Mixed farm	36	36	1.0	1.0
Settlement	29	29	0.8	0.8
Industrial area	6	6	0.2	0.2
Horticultural land	2	2	0.1	0.1
Cleared swamp land	0	258	0.0	7.0
Total	3700	3700	100.00	100

The soil erosion rate ranged from 5.26 to 186.34 t ha⁻¹ yr⁻¹ (Table 5). In general, land coverage (C) influenced the soil erosion rate in the AgrCA. Relatively high soil erosion rates were observed in the area of cleared land, where 142.11 – 186.34 t h⁻¹ yr⁻¹. Settlements and industrial areas exhibited similar soil erosion

rates ranging from 61.22 to 101.12 t ha⁻¹ yr⁻¹, and 66.08 to 109.34 t ha⁻¹ yr⁻¹, respectively. Agricultural areas, including oil palm plantations (60.16–158.29 t ha⁻¹ yr⁻¹), other plantations (60.17–128.20 t ha⁻¹ yr⁻¹), mixed farms (60.16–118.34 t ha⁻¹ yr⁻¹), and horticultural land (60.66–115.18 t ha⁻¹ yr⁻¹), displayed similarly

high erosion rates. In contrast, shrubland exhibited relatively low erosion values, ranging from 5.26 to 61.16 t ha⁻¹ yr⁻¹.

3. Water Quality

Table 4 shows the average values of water quality parameters of selected sampling sites at swamp forest, oil palm plantation, and cleared land. In general, the water parameters were classified as “not polluted,” except phosphate (PO₄) and dissolved oxygen (DO), according to the water quality standard for the

environment of the Southeast Asian Regional Centre for Tropical Biology. Dissolved oxygen was classified as “lightly polluted” for all sites, and the phosphate level was classified as “very trophic” in OP3 and cleared land. Water quality measurements were compared among the sites, and only the PO₄ concentration showed significant differences, with the concentration in OP3 and cleared land being significantly higher ($P < 0.05$) than that in other sites. However, the water quality was habitable for arowana.

Table 4. Average of water quality parameters in AgrCA during 2020 - 2023 (Mean $\pm$ standard deviation)

Parameters	Unit	Standard for environment	Standard for arowana***	Swamp forest	Oil palm plantation			
					OP 1 (aged 1-7 years)	OP 2 (aged 8-15 years)	OP 3 (aged 16-20 years)	Cleared land
Temperature	°C	25 - 33*	20 - 30	28.00 $\pm$ 2.17	29.25 $\pm$ 0.96	29.50 $\pm$ 0.58	28.5 $\pm$ 1.00	28.40 $\pm$ 2.19
pH	-	6 - 9*	5.5 - 7.5	5.38 $\pm$ 0.44	5.26 $\pm$ 0.47	5.43 $\pm$ 0.33	5.28 $\pm$ 0.33	5.37 $\pm$ 0.25
Total Suspended Solid	mg L ⁻¹	Not polluted (≤ 50)*	≤ 50	0.06 $\pm$ 0.04	0.08 $\pm$ 0.03	0.09 $\pm$ 0.05	0.34 $\pm$ 0.52	0.06 $\pm$ 0.05
Depth	cm	-	100 - 200	178.00 $\pm$ 65.03	106.25 $\pm$ 25.79	109.75 $\pm$ 31.32	194 $\pm$ 24.25	119.60 $\pm$ 22.26
Dissolved Oxygen (DO)	mg L ⁻¹	"Lightly polluted" (4.5 <, ≤ 6.4)**	≥ 4	5.87 $\pm$ 1.60	5.98 $\pm$ 0.36	5.22 $\pm$ 2.29	6.32 $\pm$ 1.12	6.27 $\pm$ 1.10
Turbidity	NTU	-	-	160.50 $\pm$ 27.03	97.01 $\pm$ 59.17	77.90 $\pm$ 37.00	117.48 $\pm$ 60.77	111.67 $\pm$ 172.78
Ammonia (NH ₃ N)	mg L ⁻¹	Not polluted (≤ 0.50)*	≤ 1	0.20 $\pm$ 0.13	0.23 $\pm$ 0.02	0.22 $\pm$ 0.09	0.16 $\pm$ 0.10	0.11 $\pm$ 0.03
Total Nitrogen	mg L ⁻¹	Not polluted (≤ 15)*	≤ 20	4.94 $\pm$ 1.02	3.92 $\pm$ 1.23	3.97 $\pm$ 1.29	4.37 $\pm$ 1.40	4.52 $\pm$ 2.61
Phosphate (PO ₄)	mg L ⁻¹	"trophic" (0.05 <, ≤ 0.10)** "very trophic" (0.10 <, ≤ 0.20)**	≤ 1	0.09 $\pm$ 0.06	0.07 $\pm$ 0.05	0.06 $\pm$ 0.03	0.13 $\pm$ 0.45	0.16 $\pm$ 0.10

Parameters	Unit	Standard for environment	Standard for arowana***	Swamp forest	Oil palm plantation			Cleared land
					OP 1 (aged 1-7 years)	OP 2 (aged 8-15 years)	OP 3 (aged 16- 20 years)	
Potassium (K)	mg L ⁻¹	-	-	0.05 ± 0.02	0.05 ± 0.02	0.05 ± 0.02	0.06 ± 0.02	0.03 ± 0.01
Sediment Total	%	-	-	0.17 ±	0.12 ±	0.10 ±	0.02 ±	0.04 ±
Organic Carbon				0.04	0.05	0.03	0.01	0.02

Notes: *Indonesian national water quality standards for the river environment in Regulation of Republic of Indonesia Number 22/PP/2021; **Water quality standards for environment in Water Analysis Manual Tropical Aquatic Biology Program, Biotrop, Southeast Asian Regional Centre for Tropical Biology (Wardoyo, 1982); ***Water quality standards for Arowana habitat in Regulation Minister of Marine and Fishery the Republic of Indonesia Number 12/PERMEN-KP/2015.

Table 5. Estimated soil erosion rates of respective land uses in 2021

Land use type	t ha ⁻¹ yr ⁻¹
Oil palm plantation	61.19 - 158.29
Swamp	Not estimated
Swamp forest	Not estimated
Cleared land	142.11 - 186.34
Other-plantations	60.17 - 128.20
Shrubland	5.26 - 61.16
Mixed farm	60.16 - 118.34
Settlement	61.22 - 101.12
Industrial area	66.08 - 109.34
Horticultural land	60.66 - 115.18
Cleared swamp land	Not estimated

B. Discussion

1. Effects of Oil Palm Plantation Expansion on Environmental Quality in The AgrCA

In the AgrCA, 60.4% of the land had already been converted to oil palm plantations in 2017. Swamps and swamp forests were intensively converted to oil palm plantations, and thus their area decreased from 32.0% in 2017 to 10.9% in 2021 (Table 3). The expansion of oil palm plantations has led to the reduction of swamps and swamp forests that are the habitat

of the Asian arowana golden red in the AgrCA. Although the influence of the expansion on soil erosion was not discussed in the present study since the USLE was not applicable, it resulted in the reduction of the arowana habitat area by drying the swamp land.

The expansion of oil palm plantations possibly increased soil erosion rates through the land-clearing process, i.e., the status of cleared land, before oil palm planting (Flores et al., 2020; Sahat, Yusop, Askari, & Ziegler, 2016;

Satriawan, Harahap, & Karim, 2015). Cleared land was susceptible to soil erosion due to no plant coverage and the soil erosion rates were estimated to range from 142.11 to 186.34 t ha⁻¹ year⁻¹ (Table 5). In general, oil palm plantations older than 20 years are cleared for re-plantation in this region, and the cleared land is left bare for 2–4 years. Areas with more oil palm plantations had more cleared land. This situation could increase soil erosion in the AgrCA in the future, although an increase in cleared land area was not observed in the study period.

The presence of ground cover is crucial for protecting soil from erosion. According to Sahat et al. (2016), the presence of trees and grasses in oil palm plantations can reduce soil erosion rates by up to 67%. We strongly advise farmers not to leave land cleared for a long time. Quickly re-planting trees could reduce the heavy soil erosion levels in the AgrCA.

2. Effects of Soil Erosion on Water Quality

Soil erosion in Agricultural areas in AgrCA 60.16–158.29 t ha⁻¹ yr⁻¹. Anasiru (2015) recorded a maximum soil loss of 316.9 t ha⁻¹ from a mixed plantation plot (2 m x 22 m) in Gorontalo, Sulawesi, during the rainy season from March to July 2012. The rainfall patterns and amounts in that study were generally comparable to those in AgrCA. The primary soil types in Gorontalo were Andosols and Podzols, which likely had comparable or lower K factors than those in AgrCA.

The estimated soil erosion rates in AgrCA were lower than the values reported by Anasiru

(2015). However, the estimated erosion rates for oil palm plantations in AgrCA, ranging from 60.16 to 158.29 t ha⁻¹ yr⁻¹, were higher than those measured by Purwanto et al. (2019) (15.03 to 16.70 t ha⁻¹ yr⁻¹) in Palangkaraya, Central Kalimantan, and by Agustina and Dewi (2020) (5 to 47 t ha⁻¹ yr⁻¹) in Muara Enim, South Sumatra. The higher soil erosion rates in AgrCA could be attributed to variations in the soil erodibility factor (K) and slope length (L). In Muara Enim and Palangkaraya, the soil types were Latosols, with K factors of 0.12 and 0.07, respectively (Asdak, 1995). In contrast, our study used a K value of 0.29 for Plinthic Acrisols, representing an approximately 2.5 to 4 times difference in K factors. Additionally, Purwanto et al. (2019) and Agustina and Dewi (2020) measured soil erosion rates in plots with slope lengths of 20 m and 25 m, whereas the oil palm plantations in AgrCA had slope lengths ranging from 100 m to 300 m. For the oil palm plantations in AgrCA with a slope length of 100 m, the estimated soil erosion rates ranged from 61.19 to 84.68 t ha⁻¹ yr⁻¹. Considering the higher K and L values, the soil erosion rates estimated in the present study were comparable to those reported by Purwanto et al. (2019) and Agustina and Dewi (2020).

Although the water quality was judged as habitable for Arowana, the expansion of oil palm plantations probably influenced the water quality. Erosion has transported soil organic matter into nearby water bodies, with the amount of erosion varying across different land uses, thereby affecting water quality differently.

Table 6. Areal sizes of soil erosion rates levels in AgrCA

Soil erosion rate *	Area (ha)	Area percentage (%)
I: Very light (0-16 t ha ⁻¹ yr ⁻¹)	16	0.43
II: Light (16-60 t ha ⁻¹ yr ⁻¹)	31	0.84
III: Moderate (60-180 t ha ⁻¹ yr ⁻¹)	2415	64.70
IV: Heavy (180-480 t ha ⁻¹ yr ⁻¹)	53	1.30

Notes: *Regulation of procedure for preparing a forest rehabilitation technique plan and land rehabilitation of watershed areas Number: P. 32/Menhut-II/2009 (The Minister of Forestry of the Republic Indonesia, 2009).

Phosphate concentrations differ between land uses, with water bodies adjacent to OP3 and cleared land exhibiting higher phosphate levels compared to OP1 and OP2. Based on phosphate concentrations, the water in the swamp forests, OP1, and OP2 was classified as trophic, and it was classified as very trophic in OP3 and cleared land, as shown in Table 4.

The estimated soil erosion rates of 1 ha (100 m x 100 m) areas adjacent (10 m) to the water sampling sites were 147.44, 147.29, 154.92 and 153.76 t ha⁻¹ yr⁻¹ for OP1, OP2, OP3, and cleared land, respectively. The erosion rate was observed mostly at a “moderate” level, accounting for 64.70% of the area (Table 6). The higher phosphate concentration in OP3 and cleared land was probably caused by the excessive fertilization in oil palm plantations. The high phosphate levels were observed during the July–September period in water bodies near to OP3 and cleared land (Figure 8). Our analysis indicated that this increase in phosphate concentration was primarily due to the runoff from nearby oil palm plantations. Farmers commonly apply phosphate-containing fertilizers to oil palm plantations from July to September, which is the rainy season, to boost crop yields. The crop yield increased from around 500 kg ha⁻¹ in OP1 to around 1000 kg ha⁻¹ in OP2 (personal communication), and the farmers doubled the amount of fertilizers from OP1 to OP2. In older oil palm plantations, namely OP3, which were 16–20 years, the fertilizer was applied twice in the rainy season

(Table 7), although the yield was similar to that of OP2. The composition and frequency of fertilizer applied are shown in Table 7. The farmers practiced this fertilization management following local community suggestions. Fertilizer not absorbed by the oil palm trees likely accumulated in the soil and was carried away by soil erosion into water bodies in OP3. This could explain the elevated phosphate levels in the water. The higher phosphate concentration in the cleared land than in OP1 and OP2 (Table 4, Figure 8) indicated that the fertilizer runoff continued in the cleared land. This observation was consistent with the results of Comte et al. (2015). It is likely that this land still contains residual fertilizer that was not absorbed by the oil palm trees. In the absence of oil palm trees, a higher soil erosion rate occurred (Table 5) and probably washed the residual fertilizer into water bodies, leading to increased phosphate levels in the water bodies besides the cleared land.

The DO in water in the AgrCA ranged from 5.22 to 6.32 mg L⁻¹ (Table 4), which resulted in the water being classified as lightly polluted. Low oxygen levels can hinder the production of zooplankton and zoobenthos (Dudgeon et al., 2006), which are important components of the Asian arowana golden red food chain (Yue et al., 2020). Therefore, it is imperative to manage land use change in the AgrCA to protect water quality and sustain the Asian arowana golden red ecosystem.

Table 7. Composition and frequency of fertilizer applied in oil palm plantations in AgrCA

Site	Age (years old)	Average combination fertilizer (kg ha ⁻¹)					Frequency of fertilization (time ⁻¹ year ⁻¹) ^b
		TSP (Triple Super Phosphate) (P ₂ O ₅ : 46%) ^a	Urea (N:46%) ^a	KCl (Potassium chloride) (K ₂ O: 60%) ^a	Dolomite (CaO: 30%, MgO: 18%) ^a	Borate (B ₂ O ₃ : 46%) ^a	
OP1	1-7	49	58.5	58.5	250	4	1
OP2	8-15	97.5	117	117	500	6.5	1
OP3	16-20	97.5	117	117	500	6.5	2

Notes: a: guaranteed composition, b: in rainy season, July to September

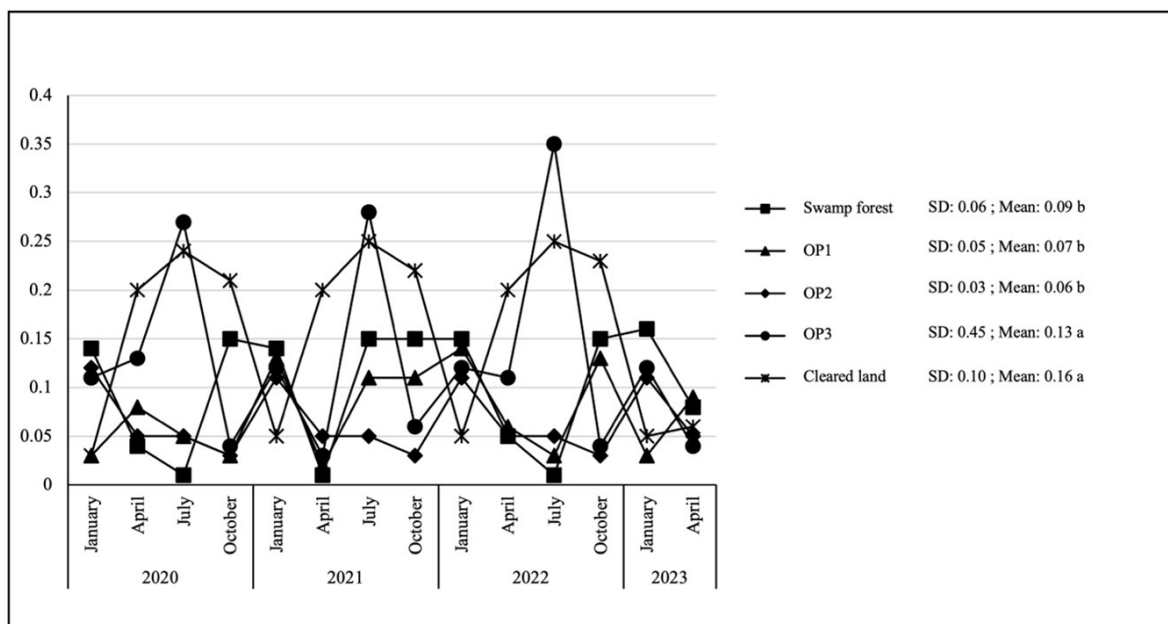


Figure 8. Phosphate concentration during 2020-2023 in different sites in AgrCA

IV. CONCLUSION

The expansion of oil palm plantations has led to the reduction of swamps and swamp forests that are the habitat of the Asian arowana golden red in the AgrCA. High soil erosion rates were observed in the area of cleared land. The present fertilizer management method used in the oil palm plantations caused water quality degradation. Water bodies adjacent to old oil palm plantations and the cleared land exhibited low levels of dissolved oxygen and were considered very trophic regarding phosphate concentrations. The water quality around the oil palm plantations was still at a habitable level for the Asian arowana golden red. However, further water quality degradation caused by the expansion of oil palm plantations could lead to biodiversity loss and negatively affect the balance of the aquatic ecosystems.

Future research should evaluate the long-term effects of oil palm expansion on the habitat quality, population status, and survival of the Arowana golden red. Particular attention should be given to the impacts of sedimentation, nutrient enrichment, and declining water quality on aquatic biodiversity. Studies are also needed to assess the effectiveness of

sustainable management practices, such as riparian buffer restoration, erosion control, and improved fertilizer management, in mitigating environmental degradation and maintaining suitable habitat conditions.

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