International Journal of Geotourism Science and Development (IJGSD)
Vol.3 Issue 02, Dec 2023, pp: 88-100
ISSN: 2985-3575 (print) |ISSN: 2964-3481 (online)
DOI: https://doi.org/10.58856/ijgsd.v3i2.33

Geological Heritage, Biodiversity and Culture Linkage in Raja Ampat Geopark: An Introduction

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Article Info

Article history:
Received Aug 19, 2023
Revised Sept 22, 2023
Accepted Nov 25, 2023

Keywords:
Geological Heritage, Biodiversity, Culture Linkage

ABSTRACT

Raja Ampat became globally known since researeh results revealed the magnificence of its marine biodiversity that was incomparable, and became the best tourism diving destination. As part of the Geopark, understanding of science and knowledge from various fields has been gradually revealed and curated in Raja Ampat. This article will be an introduction to the disclosure of the relationship between geological heritage, biodiversity, and culture in the Raja Ampat Geopark, synthesized through literature studies, interviews and ground checks conducted by various parties. As a result, at least three relations was explained, i.e. (1) the historical biogeographic events of Raja Ampat determined the form of thirteen terrestrial ecosystems and the present of endemic species; (2) the geological heritage of dolines and lagoons creates unique ecosystems for certain marine species; (3) also interconnectivity between nature and the cultural values passed down by Raja Ampat's ancestors that documented in various forms, like wisdom, folklore and art rocks. In conclusion, we also identified challenges and future directions regarding this emerging field, of which has been adapted into ecotourism implementation within Geopark Raja Ampat.

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1. INTRODUCTION

Raja Ampat was endorsed as a UNESCO Global Geopark in 2022, after previously being the Raja Ampat National Geopark, with geological study conducted by the Geological Survey Center in 2017 which revealed that Raja Ampat has geological significance in rocks unit, fossils, landscapes, and unique geological process. Since then, Raja Ampat has been known for its karst landscape scattered at the Earth's equator, which was later enshrined in its slogan "The Emerald Karst of The Equator".

The Raja Ampat Geopark is part of the Raja Ampat Regency, Southwest Papua Province, which is home to 64,141 people spread over 121 sub-districts (Raja Ampat Regency Statistics, 2021). As an archipelago, The Raja Ampat Regency is mostly covered by marine, with about 89% of the total area of this regency, that consists of 2,713 islands, with four main islands of Waigeo, Misool, Batanta, and Salawati. This area is also Indonesia's international border area, with Fani Island at District Ayau Islands as the front island bordering this country and the Republic of Palau in the Pacific.

Raja Ampat has the highest number of marine biodiversity compared to other areas that have previously been known; with 456 types of coral, 699 mollusks, and at least 1,084 reef fish, where 60% of the coral reefs are known to be in good or very good condition (McKenna, Allen, and Suryadi, 2001). In addition to disclosing these data, through the Marine Rapid Assessment Program (RAP) the name Raja Ampat was immediately recognized as the center of the world's marine biodiversity..

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However, long before that, Raja Ampat was already an attractive place for researeh with the discovery of various records about Raja Ampat since the 19th century written by Europeans. It is recorded that France made 3 explorations through the L'Uranie voyage in 1818-1819, La Coquille in 1823, and L'Astrolabe in 1826, which was carried out by Quoy & Gaimard, and Cuvier & Valenciennes. The British also explored the area around the 1860s, through the explorations of William Dampier and Alfred Russell Wallace. This exploration is very famous, and the name Dampier itself is immortalized as the name of the strait that connects the two main islands, Waigeo and Batanta. The Dutch followed by sending Peter Bleeker in 1868 and Weber and de Beaufort in the early 1900s, who uncovered many species of fish (Lamatenggo, 2018).

The long history and facts highlighting the natural characteristics of Raja Ampat make this area important, so that numerous multi-level organizations from sub-national to international work in Raja Ampat Regency with various interests, most of which are based on nature conservation issues. Being part of the Geopark, the understanding of science and knowledge about Raja Ampat potential and wealth from other fields, such as geoscience and culture, is also revealed and curated gradually. This certainly has the potential to be used as a basis for area management of public information content that can increase the capacity of local communities. However, these existing studies are still linear from one or two disciplines that focus on solving certain problems. Meanwhile, to face current development challenges, a transdisciplinary approach is an important step to be able to see Raja Ampat as a whole, as an area that has geological, biological, and cultural heritage, which is inhabited by humans.

Finally, this paper intends to provide examples of the results of Raja Ampat geology, biology and culture studies that can be linked to one another. The outcome can be used as an introduction, to be developed or implemented not only as a work program or further researeh ideas, but also as interesting public information content to introduce the Raja Ampat Geopark to local communities.

Method

2. METHODS

This researeh methodology uses qualitative methods. Data collection uses literature studies, interviews and ground checks conducted by various parties.

3. RESULT AND DISCUSSION

Based on the literature review and qualitative data collection, the results of this study will be presented in two parts. The first part is examples of studies or stories that have been successfully linked between disciplines:

Geology, Biology, and Culture. The second part is the identified challenges and future directions for implementing a transdisciplinary approach in the Raja Ampat Geopark.

Part 1 - Examples of linkage between Geology, Biology and Culture in Raja Ampat

Curating information to ensure knowledge sharing between institutions, and basically with local communities, is one of the Raja Ampat Geopark's efforts to increase the efficiency of local people's access to knowledge and capacity regarding the potential of their area, which was previously only available in advance information (Septiana, Samodra, and Lamatenggo, 2023). In this process, various information is also obtained, which can not only be related to folklore or traditional ceremonies being practiced, but also between these advanced information, which can increase and strengthen the important value of the areas that become geosites. The following are examples among stories that can link the Raja Ampat's geological heritage with its biological and cultural phenomena.

1. The biogeography of the islands originating from different tectonic plates forms terrestrial ecosystems and endemic species in Raja Ampat, whose protection is conveyed through the local wisdom of Raja Ampat's ancestors.

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The name of Raja Ampat was first revealed to the world through its marine biodiversity, but it's specialty is also shown by the phenomenon of its terrestrial ecosystem and biodiversity, where this area is right on the Sorong Fault. The Sorong Fault is an active and extensive zone of implied lateral shear, which is a confluence of three tectonic plates, namely the Australian, Eurasian, and Pacific plates, which consist of many plate fragments, such as the Philippine Sea Plate, the Bird's Head Plate, Halmahera and the Maluku Sea Plate. This zone is one of two major faults created by the convergence of the Australian and Pacific plates, which has been involved in many major earthquakes (Supartoyo, Surono, and Putranto, 2014).

The plate shifting events that occurred from the Middle Oligocene (30 Mya) to the Early Pliocene (5 Mya) era, which is illustrated in Figure 1, is a record of biogeographic history, which is also responsible for the composition of the islands that make up the terrestrial ecosystem in Raja Ampat today (Marshall and Beehler, 2007; Hall, 2002; Polhemus, 2007 in Prado, 2022). The plate collision line that becomes the Sorong Fault is in the strait between the islands of Batanta and Salawati. The fault branches at the west and separates Kofiau Island, so that the Raja Ampat arehipelago is divided into 3 groups.

These biogeographic events affect the form of ecosystem and biodiversity of Raja Ampat. Even though it does not demonstrate strong geographic separation in the coral community type, differences were shown in the terrestrial of the island, where ultramafic and limestone substrates form a distinctive plant community (TNC, WWF, and Raja Ampat Regency Government, 2022). Finally, the three island groups separated by the Sorong Fault, each of which shows unique-different terrestrial ecosystems and biodiversity.

Study on habitat diversity, conducted by Fauna & Flora International - Indonesia Programme in 2019, revealed at least 13 habitat types were found scattered in the terrestrial of the main islands in Raja Ampat. The Pacific Plate in the northern area, represented by Waigeo Island and Misool. The Australian plate in the south is represented by Salawati and Misool. Meanwhile, the Eurasian Plate in the west is represented by Kofiau Island. The distribution of habitats on the main islands can be seen in Table 1 (FFI's IP, 2019).

Four typical habitats found throughout the Raja Ampat area are: 1) Mangrove Ecosystems; 2) Semi-Permanent Swamps; 3) Beach Forest; and Limestone Hills. Mangrove ecosystems are formed in coastal parts that are affected by active tides and in large river areas. Semi-permanent swamp ecosystems appear behind mangroves, on the banks of freshwater lakes, or in the form of sago swamps. Some coasts consist of Beach Forest ecosystems. Whereas in other parts and most of the small islands, in the form of the Limestone Hills, that clearly indicated by clusters of vegetation which are usually filled with Hydriastele palm trees, as well as other species that can grow in low nutrient substrate conditions which are generally gummy and have a relatively small leaf, such as Euphorbiaceae, Moraceae, Calophyllaceae, and Clusiaceae.

One of the unique geological heritages of Raja Ampat is the exposure of 148-million-ycar-old ultramafic rocks in Waigeo (Management Body of Raja Ampat Geopark, 2017), which then forms a distinctive area, namely the Ultrabasic ecosystem. This ecosystem is characterized by vegetation in the form of dense and low stands of trees, tending to form a sapling forest on a soil substrate that is low in nutrients but high in metals, such as Nickel. Species that can survive the extreme conditions found in this area include Ploiarium sessile, Exocarpus latifolius, Gymnostoma rumphianum, Decaspermum bracteatum, Myrsine swampensis, including species from Calophyllum and Dillenia.

Drastically different conditions are shown by the ecosystems on the islands originating from the Australian tectonic plate, which are marked by the discovery of savanna and grassland ecosystems. The common stand community found in this area is Melaleuca leucadendra (eucalyptus tree), where this species and ecosystem form are not found on islands from the Pacific and Eurasian plates.

Geographical uniqueness that limits the distribution of species, resulting in the formation of endemism (species that can only be found in certain locations) is also an interesting biological phenomenon in Raja Ampat. Moreover, in today's conservation, taxon rarity and endemism receive equally important attention. At least 400 tree species have been recorded, of which at least 6 of them are endemic to Raja Ampat, including Wallaceodoxa raja-ampat, Alstonia beatricis, Guioa waigeonensis, and Rhododendron cornubovis.

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Figure 1. Tectonic reconstruction of the New Guinea region in the Middle Oligoccne (30 Mya) (left), in the Middle Miocene (15 Mya) (middle), and in the Early Pliocene (5 Mya) (right). (Hall, 2002; Polhcmus, 2007; ©Prado, 2022)

Table 1. Thirteen habitat types were found on the main islands, which represent the 3 main tectonic plates within the Raja Ampat Geopark area. (FFI's IP, 2019)

HABITAT TYPE	*Islands of the Pacific plate*		*Islands of the Australian plate*		*Islands of the Eurasian plate*
	WAIGEO	BATANTA	MISOOL	SALAWATI	KOFIAU
Mangrove [a]	✔	✔	✔	✔	✔
Semi-Permanent Swamp [a]	✔	✔	✔		✔
Beach Forest [a]	✔	✔	✔	✔	✔
Limestone Hills [a]	✔	✔	✔	✔	✔
Ultrabasic [b]	✔				
Savanna [c]			✔	✔	
Grassland [c]			✔	✔	
Riparian	✔	✔		✔	
Hill Forest	✔	✔		✔	
Pseudomontana	✔				
Lowland Forest: Alluvial	✔	✔	✔	✔	
Lowland Forest: Sandy Soil	✔		✔		
Sub Montana Forest	✔			✔	

Table description: [a)] Typical habitat that is always found throughout the area in Raja Ampat; [b)] Habitat found only on the islands of the Pacific Plate; and [c)] Habitants that characterize the Australian continental plate.

In the Bird Taxa (Avifauna), 6 species endemic to Raja Ampat were found, which are not only endemic to the region, but endemic to the island. This means that the distribution of these species is limited to one island, not found on neighboring islands, or locations in other parts of the world. Cicinnurus respuhlica (Wilson's Bird of Paradise) is one of the endemic birds found only on Waigeo and Batanta Islands, which was later enshrined in the logo of Southwest Papua Province. Apart from that, there are also Tanysiptera ellioti and Symposiachrus julianae, which are endemic to Kofiau Island, which are representatives of the Eurasian plate.

The Raja Ampat herpetofauna also exhibits an interesting phenomenon of endcmicity. Three species of lizards from the genus Varanus were found, separated into three different species, which are endemic to each island. Varanus resingeri (Yellow Tree Monitor) is endemic to Misool Island, Varanus macraei (Blue tree monitor), which is endemic to Batanta Island, and Varanus boehmei (Bohme's monitor), which is endemic to Waigeo Island.

The endemic animal of the Mammal taxa is represented by the Waigeo Cuscus (Spilocuscus papuensis), which is endemic to Waigeo Island. However, another interesting phenomenon was demonstrated by the discovery of Dorcopsis muelleri, the Esem wallaby, a type of marsupial that is characteristic of the Australian continent, which is not found on islands from other continental plates.

The condition of the diversity of ecosystems and mega-biodiversity of Raja Ampat proves the richness of its geological heritage. This is the reason most of the areas in Raja Ampat are in the form of nature reserves. However, efforts to protect the area and its biodiversity is already become a culture passed down by Raja Ampat's ancestors through its local wisdom "The Forest is Mother, the Ocean is the Father, and the Coast is the Child", which is so synonymous with the nature conservation concept, which protects an area while respecting also the inter-connectivity of each ecosystem as a whole.

2. Landscape dolina or karst lagoon, a geomorphological characteristic, become a suitable habitat for exotic marine biota.

One of Raja Ampat's geological heritage is the diversity of landscapes in the form of dolines. This landscape formed through a dissolution process that occurs in limestone to form a system of cavities and cavities that enlarge to form a network of caves, whose roofs eventually collapse to form depressions. This

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depression between karst hills (dolinas) can be found in abundance in Raja Ampat, some are on land, some are in the ocean, and some are on the beach (Samodra, et al., 2021).

There are at least more than 200 marine lakes with karst submerge characteristics worldwide, most of which are found in four main locations: Bahamas, Palau, Vietnam, and Indonesia (Dawson et al., 2009). At least 55 marine lakes are specifically found in Raja Ampat, 14 in Wayag and Gam, and more than 40 in Misool (Purba, et aL, 2018). Of the total marine lakes recorded in the world, only 22 lakes are the habitat of jellyfish, of which 15 are found in Indonesia, namely: 3 lakes in Bcrau, Kakaban East Kalimantan; 1 lake in Togean, Central Sulawesi; and 9 in Raja Ampat, Southwest Papua (Maas et al, 2020).

One of the jellyfish lakes is now part of the Geosite of the Raja Ampat Geopark, namely RA-25 Jellyfish Lake, Lcmankana, in Southeast Misool, Figure 2. An atoll in arehipelagic karst complex at southeast of east coast of Misool Island is a dissolving landscapes-origin involving Zaag Limestones of Middle Eocene-Oligoccne age, that uplifted at the end of Pleistocene to form an old lagoon surrounded by conical limestone hills. (Management Body of Raja Ampat Geopark, 2017). Based on the studies conducted, this dolina has unique characteristics because it is not too broad (1.25 ha), with a depth of 18 m (the deepest among other marine lakes in Raja Ampat), and other characteristics that cause it to have a meromictic condition, namely stratification in its water bodies, which are not found in other marine lakes in Raja Ampat which are holomictic (mixed throughout the water column, from surface to bottom) (Purba, et al, 2018).

The species of jellyfish that live in marine lakes in general in Raja Ampat is Mastigias papua, but only one similar haplotype has been observed in marine lake Palau, namely M. papua etpisoni. So, it can be said that genetically and morphologically, the jellyfish population in Raja Ampat is highly structured, with private haplotype records that are unique to this region and have the potential to represent new subspecies (Maas, et al, 2020).

Another interesting thing about the jellyfish population at this geosite is the very low genetic diversity, which could be due to a lack of strong in situ divergence or small population size, but also indicates that the marine lakes of Raja Ampat were recently colonized (Maas, et al, 2020). This is in line with the physical characteristics of the lake which are considered classified as a young lake, compared to the lakes in Palau which can reach a depth of 60 m (Purba, et al., 2018).

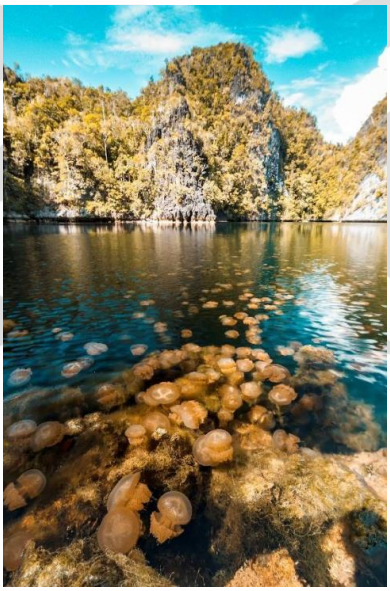


Figure 2. Geosite RA-25 Jellyfish Lake, Lcmankana, Southeast Misool, Raja Ampat Geopark (©Management Body of Raja Ampat Gcopark)

This is another example of the relationship between Raja Ampat Earth's heritage, which geomorphological characteristics of the dolina landscape in Lcmankana and several other areas in Raja Ampat then

become a suitable habitat for jellyfish, which are endemic genetically and are thought to be a new subspecies that have not been described. So from a geological and biological point of view this area has important value, with challenges as one of the leading tourist spots in Raja Ampat, which of course has its own impact. Through a transdisciplinary approach like this, which is then implemented in the management of this area, it is hoped that not only this area and its important value will continue to be protected but also could become an economic potential for local communities that can be utilized in a sustainable manner.

Not only on Misool, the southern side of Raja Ampat, interesting stories related to geological characteristics with exotic biota can also be obtained by exploring far to the north of the Earth's Equator, to be precise in the Wayag Lagoon, which is the RA-14 Karst of Wayag geosite. Wayag Islands composed of limestones of the Waigeo Formation are included in the Selpcle Village area, West Mainland Waigeo District. This area has islands of various shapes and sizes scattered in a vast lagoon, where the genesis of hills is influenced by geological structures (joints, faults), limestone types and its local stratigraphy (Management Body of Raja Ampat Geopark, 2021).

Located right on the Equator, the location of the Raja Ampat islands is in the shallow waters of the Halmahera Sea (depth < 200 m), which is also the western edge of the Pacific Ocean. In this area, the North Equatorial Counter Current (NECC), South Equatorial Current (SUC), the New Guinea Coastal Current (NGCC), the New Guinea Coastal Under Current (NGCUC), and the Mindanao Current (MC) form the Halmahera Eddy, the phenomenon of ocean eddies anticlockwise (anticyclonic), that regulates the transport of nutrient-rich water (Christian, et al, 2004) and influences the monsoon system in Indonesia (Ramadhan et al., 2020). On the other hand, this area is not influenced by the monsoon rainfall system, but has a local pattern, which shows a dry and wet season pattern that is the opposite of the monsoon rainfall type (BMKG, 2019).

Under these conditions, Raja Ampat has very rich and productive waters, located right in the heart of the World Coral Triangle which recognizes as a global center of marine biodiversity (Allen, 2008), also as one of the eight biological-economic coral reef regions in the world (Speers, et aL, 2016). The Raja Ampat Regency Government then enhanced protection in this area by declaring this entire arehipelago as a "Sanctuary for Sharks and Rays" in September 2012, through regional-law, PERDA 9/12, which also explicitly forbids the capture of any shark, ray, whale, dugongs, sea turtles, or endemic species in Raja Ampat waters (Beer, 2015).

These multi-layered protection efforts of various parties intended to protect Raja Ampat's natural preservation, and still pay attention to the welfare of the local community, which makes protected fauna a tourist attraction, which is now worldwide. This is the right step, because in 2022, researeh reveals that the Wayag Lagoon area is “the world first confirmed” nursery ground for manta rays, Mohula alfredi. This researeh reinforces the results of previous results which stated that this area met criteria for nursery of elasmobranchs, which found that the manta juvenile species were common in the area compared to other lagoons (Setyawan ct.al, 2022). The same researeh also suspects that the area is a pupping ground (a place to lay eggs) for this species.

The Wayag Lagoon is part of the Wayag-Quoy-Urainc group of islands which form a SW-SE trending alignment, which is controlled by faults which are the main geological structures in Waigeo, which also form escarpments or steep walls on the hills in the area. This area is scattered with tower-built limestone islands forming a kind of lagoon, the bottom of which is overgrown with coral (Management Body of Raja Ampat Geopark, 2017).

Manta ray prey on large amounts of zooplankton, so they depend on the dynamic pelagic oceans. Based on Setyawan et.al (2020), in late Mareh to early May, juvenile Manta rays were not found in the lagoon, which were thought to have swum out of the lagoon area, heading to the highly productive loose waters after the end of the northwest monsoon. This was supported by studies on the temperature and salinity conditions of the Halmahera Sea waters which stated that phytoplankton blooms caused by upwelling due to monsoons and currents have affected those periods (Suharyo et al., 2020).
Based on studies from various scientific disciplines above, it is known that the geological features of the Wayag arehipelago which form calm waters provide a safe space for young manta ray juveniles, not only from currents and sea breeze conditions in the wider sea area, but also from the predators.

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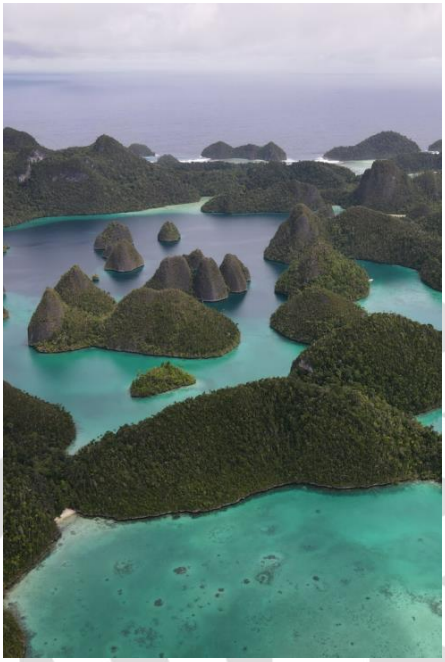


Figure 2. Geosite RA-14 Karst of Wayag, West Waigeo, Raja Ampat Geopark (©Management Body of Raja Ampat Geopark)

3. The unique geology that inspired folklore and the Austronesian painting on karst walls, is a cultural heritage that is preserved in Raja Ampat.

Once upon a time, during the Hongi War era, there lived a husband and wife who were the ancestors of the people of Raja Ampat. At that time, people lived in tribes that did not know religion and were mutually hostile to one another. One night, the husband and wife decided to rest on their boat, in a location in the middle of Kabui Bay. So that the boat didn't move, they thrust a long stick into the ocean floor, which are usually used to propel ships in shallow waters (called tokong/ belo in local language) and tic their ships with ropes.

When they were fast asleep, suddenly the husband woke up because he was startled by the sound of an enemy coming to attack. Amid his panic, the husband took a machete and swung it to sever the ropes and release their boat to run away. Unfortunately, the machete hit his wife's and wounded her to death. The tokong wood, which witnessed the event, then turned into a towering rock, shaped like stuck wood, which we can still see today and has become a tourist attraction "Batu Pcnsil" in Kabui Bay.

This story is told by Frans Waiganyom, an elder in the Wawyai indigenous village, which has also been written into a children's book. Raja Ampat: Myths, Legends & Heroism (Arman, 2019). This story is an example of how the culture in Raja Ampat is very close to the natural surroundings, and how indigenous people pay attention to the characteristics of the rocks around them.

Scientifically, this southwestern area of Waigeo, which is formed by the mainland and Gam Island, is occupied by small islands (sea-stacks) composed of the limestones of the Waigeo Formation. NE-SW trending joints border some of the island, forming a vertical wall with an average height of 10 m and NE-SW fault, for example, locally formed Batu Pensil. Part of the limestone surface is covered by a thin layer of orange to dark red ocher that is formed by the solution escaping through cracks and some limestones are supposed to contain iron and magnesium. Various sizes of islands in a fairly-large bay scattered at shallow waters between 10-20 m deep, some islands have unique shapes, such as pencils, human faces and so on.

Besides being documented through folklore stories told by the ancestors as described above, the culture in Raja Ampat is also illustrated in art rock which is found in several places in this region. In researeh conducted by Leihitu and Pcrmana (2019), which was conducted at 10 sites found in Lcnmakana, Nutonton, Sunbayo, and Sunmalelcn in Misool.

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Through this researeh it is known that Raja Ampat art rock is part of the Austronesian Painting Tradition (APT), which was made around 4,000 years ago. Apart from being found in the distribution area of Austronesian speakers, these paintings are also located in remote and difficult to reach areas but can still be seen from a distance. The painted images also generally show Austronesian Neolithic culture, namely hand stencils, geometric motifs (especially the circle/sun symbol), active anthropomorphic figures, artifact motifs, such as two different types of adzes stones, and boat motifs, as shown in Figure 4.

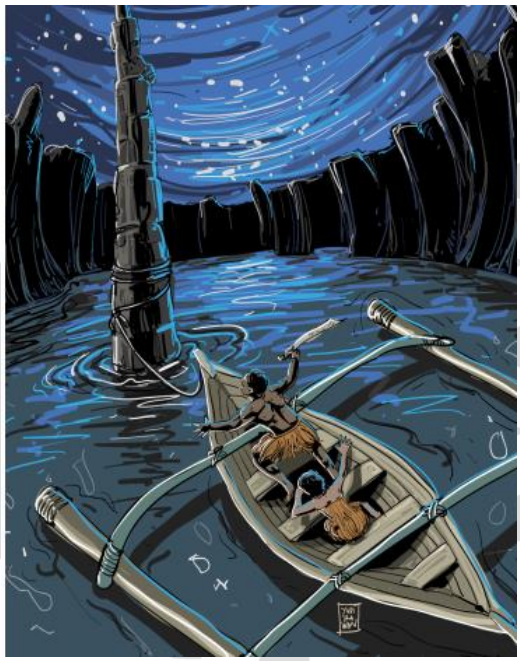


Figure 3. Illustration of Batu Pensil (batu, means rock; pensil, means pencil) story in book Raja Ampat: Myths, Legends & Heroism (Arman, 2019)

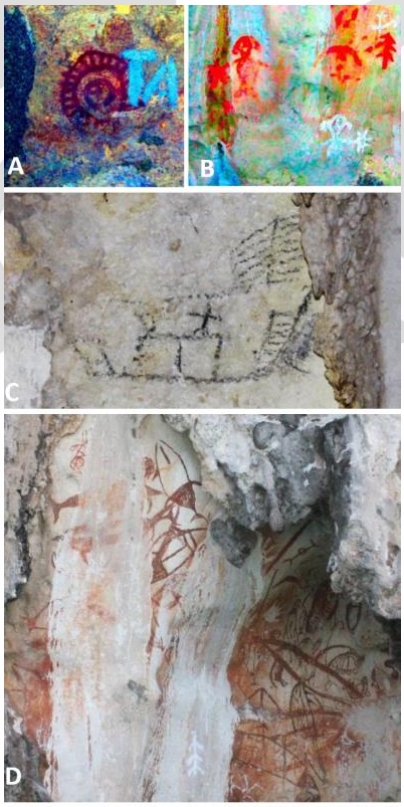


Figure 4. (A) Disc or the Sun motif on Sunmalelen. (B) Human motif on Sunbayo. (C) Boat motif on Sunmalelen. (D) Picture of marine fauna, such as several types of sea fish, dolphins, and turtles on Sunbayo. (©Irsyad Lcihitu, 2018)

This shows that since prehistoric times the people of Raja Ampat have been closely related to the geological phenomena around them, which then merged into a culture that was passed on to their children and grandchildren. In addition to creating stories of origin about something, inspired by the rock forms around them, they also record notes about the nature they observe daily through paintings on rock walls.

Part 2 - Identified challenges and future directions for implementing a transdisciplinary approach in the Raja Ampat Geopark

Through the Geoscience and Gcopark Programme, Raja Ampat has now become part of the UNESCO Global gcopark, with geological structures, such as joints and faults that facilitate erosion and result in the formation of distinctively shaped limestone islands (UNESCO, 2023). Being one of 195 geoparks from 48 countries, Raja Ampat Gcopark shows its commitment to celebrating its Earth Heritage and Sustaining its local community. Therefore, this is one of the efforts of the Raja Ampat Regency Government in finding solutions and answering to the various challenges currently being faced.

Raja Ampat Regency is an arehipelago where the land is only 20% of the total area. Based on data from the Raja Ampat Regency government (2020. Unpublished), only about 2.63% (246.14 km2) can be used for development, because more than 60% of this area is conservation area. So, it can be assumed that Raja Ampat in general has spatial limitations to develop its area, especially in terms of infrastructure.

In addition, Raja Ampat is an expensive area, not in terms of living costs but in accessibility/transportation. Geographically, this beautiful arehipelago limits connectivity between communities, where sea transportation is the main means of transportation for traveling from one village to another, which are usually separated between islands. Thus, most of the budget is used to purchase transportation fuel, and this condition causes the implementation of activities to also be affected, both in terms of budget and time.

On the other hand, numerous and multi-level organizations from sub-national to international work in Raja Ampat Regency, as the globally important marine area and world's class tourist destination. Hence, various studies related to the potential and impacts of the utilization of the Area can be obtained with advanced and reliable quality information. Nevertheless, another challenge arises through the gap of knowledge and capacities with communities that keeps distancing, which is being pursued through geoparks (Scptiana, et al, 2023).

To bring science closer to society and produce shared knowledge that is suitable for dealing with such complex problems, it is currently being advocated using inter- and transdisciplinary approaches (Rocha, 2020). This approach is also considered capable of responding to challenges in the disruption era, which is one of the focusing challenges which the Indonesian government puts more attention to (Fadilurahman et al, 2021). In addition, this approach is also able to help generate solutions to environmental challenges and enhance the uptake of researeh outputs, thereby contributing to advance sustainability in social-ecological systems (Kim, et al, 2022), and indicate an influence on the decision-making capacity of stakeholders, especially through social network building and the generation of knowledge relevant for action (Walter et al, 2007).

The following is an example regarding implementation using a transdisciplinary approach in the Raja Ampat Geopark area.

1. Implementation through Public Information System

Globalization has entered a new era called the 4.0 industrial revolution, which began in 2012 through internal engineering and internet of things (loT), where the existence of online-connected infrastructure is expected to be able to answer challenges in this era of disruption. A quality website (simple and easy to use) is a critical success factor, which also provides a 24-hour information space without holidays (Fadilurahman et al, 2021). Being part of the UNESCO Global Geopark, Raja Ampat is also required to have an official website that displays various information related to the area.

Integrating the public information system, online and offline, is one of the practices being carried out to maximize the online assets that are already owned. Various scientific data and information that have been collected from various institutions, are then packaged with attractive and simple graphic designs and

International Journal of Geotourism Science and Development (IJGSD)
Vol.3 Issue 02, Dec 2023, pp: 88-100
ISSN: 2985-3575 (print) |ISSN: 2964-3481 (online)
DOI: https://doi.org/10.58856/ijgsd.v3i2.33

layouts, as well as communicative. The content is then displayed offline on interpretation panels, as well as brochures and other information at the Geopark Information Center. The same material was also released online, through websites and cyberspace.

On each information panel posted on each geosite, a QR Code is available, which links directly to the website page related to the geosite, Figure 5. This aims to provide more detailed information regarding the area, which cannot be displayed through the panel.
However, even though it is still in the development stage, the use of conceptual and consistent interpretation panels throughout the Geopark Area will increase public awareness of the presence of Geoparks in general, especially on the exposure of important values for sites that are usually located near residential areas, or are frequently passed by, which often escape attention, even by local people. Awareness of the existence of a Geopark will increase efforts to protect/conserve geological sites that are vulnerable to vandalism by tourist/local people.
The integration of these panels into online information platforms also increases public access to detailed and advanced information regarding the features and reasons why the area was made as geopark site, which at once aim to increase the capacity of local communities and awareness of the features and potential they have in their "homeland".

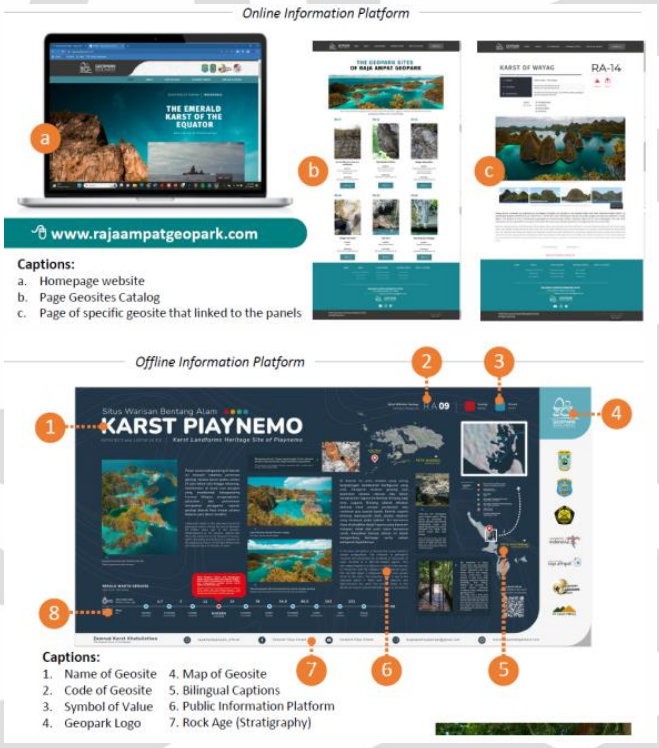


Figure 5. Online and offline information platform of Raja Ampat Geopark (©Management Body of Raja Ampat Gcopark)

Not only on the information content displayed, the language of communication used, or the use of technology that is easily applied by the user, but a transdisciplinary approach is also carried out on the identification of each area, to determine the use of materials and the type of panels used in each geosites. Of course, there is still a lot of improvement to be made, but we have started to take careful steps to minimize failures and increase effectiveness and efficiency both in terms of time and budget.

2. Implementation through Tourism and Special Interest Tour Guides

The Raja Ampat government enacted tourism and fisheries as leading sectors in the sustainable development of their areas. Based on the data of tourism online registration, it has recorded 4,973 international tourists and 752 domestic tourists visiting Raja Ampat throughout 2022. This number

decreased significantly after COVID 19, where the decline in international and domestic tourists reached 80% and 94%, respectively. (Raja Ampat Tourism Office, 2022).

Six main tourist attractions are offered by Raja Ampat, namely: 1) Diving and Snorkeling spots; 2) Geositc Viewpoint and Island Hopping; 3) Bird watching and Jungle Trekking; 4) Rock art and Caves; 5) Rivers and Waterfalls, and 7) Tourist Village, gcotourism activity become the main alternative for tourists who has short-time, limited budget, or do not intend to dive.

In 2017, five geopark site's infrastructure was improved, and more than 90 local people have been trained as local guides. Training/intcmship program also conducted and have trained more than 51 participants from local communities.

As explained in the previous section, about how scientific studies reveal the features of exotic biota in Raja Ampat, this later becomes the basis for managing the area which is then opened to become a tourist attraction.

For example, the Wayag lagoon, using the results of a study by Setyawan et al. (2022) is the basis for determining the zoning of the area, where there are core parts that may not be visited, and other parts that tourists may visit with strict regulations. Some of the things that become regulations include boat speed limits of less than 5 knots inside the lagoon and stipulated mooring areas for liveaboards far from known manta sites.

This study is of course socialized by the local government and stakeholders involved, to all parties working in the tourism industry, including tour guides, tour and travel service owners, tour transportation owners, and so on. So that all tourism business actors are not only required to comply but can also interpret the reasons why these regulations were enforced, and even participate in conveying and educating tourists who then visit the location.

The same thing has also begun to be applied to tourists visiting Jellyfish Lake, who are prohibited from using sunblock, snorkels, fins, and are prohibited from urinating, because it all can have a great impact on the jellyfish population that lives in these vulnerable locations. However, currently the local management there still needs to be developed, both in terms of further scientific studies, infrastructure, and the capacity of local guides, and this is the challenge and goal of developing the Raja Ampat Geopark.

Other examples are also shown in forest management, which is the habitat of endemic birds. Raja Ampat is also quite well known for its bird watching activity. The Forest Fanners Group (KTH) acts as a tour guide and applies a code of conduct when trekking in the forest for bird watching. They are local people who have been trained and certified to observe birds, so they not only know the species name (local and scientific name), but also can explain the types, behavior and uniqueness of the bird found there. This is also one of the success stories, in which sustainable ecotourism can provide alternative livelihoods, so those who were originally hunters, are now becoming tour guides on a conservation mission.

Of course, there are still many examples implemented through planning with a transdisciplinary approach in Raja Ampat. Some have already started to establish, some still need development, some need further study, and some are still ideas. However, it is a good basis, as an introduction, for developing Raja Ampat into a high-quality area.

4. CONCLUSION

Raja Ampat is a special area that was previously known for its rich biodiversity. However, later discovered that this was supported by geological phenomena that were no less interesting. Everything is recorded as culture, which is told through folklore stories and painted on karst cliffs as Austronesian Painting Tradition. This proves that multidisciplinary studies have contributed to the disclosure of Raja Ampat's potential, which has now become part of UNESCO Global Geopark.

This paper then also summarizes the challenges of developing this area. One of them is the spatial limitations which have an impact on limited development in Raja Ampat arehipelago, both physically and the capacity of local communities. So apart from going through collaborative steps, various implementation plans must be carried out through a transdisciplinary approach. This is expected to increase effectiveness and efficiency, both in terms of budget, human resources, and implementation time, because it can be assumed that Raja Ampat has limited room for error.

A transdisciplinary approach is a must in Raja Ampat to answer the challenges of the area. So that in implementing the regulation or activity, it is hoped that it will be right on target, not only from one issue, but also from various points of view. Through that way, all interests can be respected, which indirectly can be synthesized into a single idea that can facilitate each sectoral ego, which is also able to minimize potential conflict.

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