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MORALITY BEFORE KNOWLEDGE

RFN–FWI research 2021: The impact of land cover and climate change on food sovereignty

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ABSTRACT

Background: Small-island food systems are tightly coupled to forests, coastal waters, and customary tenure. In the Aru Islands (Maluku, Indonesia), rapid land-cover change and a warming, more variable climate may erode sago-based subsistence and marine protein supplies, undermining food sovereignty. **Methods:** This study integrates geospatial and social approaches: one-class SVM mapped sago (10-m) from multispectral, radar, terrain, and rainfall predictors, ecological niche modeling (MaxEnt) estimated seasonal fishing grounds from oceanographic drivers, an accessibility (travel-time) model quantified community access to sago, land cover was classified (Random Forest) and projected to 2050 with the PLUS model, statistically downscaled CMIP6 GCMs (SSP2/SSP5) provided 2050 climate anomalies, and a Rapid Rural Appraisal in Desa Lorang documented food practices and gendered roles. **Findings:** Current sago covers ~14,344.82 ha, concentrated in Aru Selatan Timur, Aru Selatan, and Aru Tengah; access ranges from ~15 minutes to ~9 hours, yielding 95 surplus and 7 deficit villages for sago. Fishing potential peaks May–October; models achieved AUC ≈0.82. Since 2015, agriculture has contracted and forest loss/degradation accelerated; business-as-usual projections indicate natural forest may fall to ~31% of Aru by 2050, with built-up land expanding and sago shrinking to ~3,025 ha. Climate projections show +0.7–1.4 °C warming and slight mean rainfall decline (≈−85 mm yr^{-1}), especially in western Aru. **Conclusion:** Forest conservation, tenure recognition, education/health access, and policies valuing sago and diversified local foods are essential to safeguard Aru's food sovereignty under climate and land-use pressures. **Novelty/Originality of this article:** Provides the first island-scale, integrative quantification linking machine-learning sago mapping, seasonal fisheries, accessibility, land-cover trajectories, climate risk, and gendered social dynamics to food sovereignty in a small-island context.

KEYWORDS: accessibility; food sovereignty; gender roles; land-cover change; small islands.

1. Introduction

"There is no food security without peace and no peace without food" (Cousin, as cited in WFP). Food sovereignty is when every individual, nation, and union of nations has the right to define their own agricultural and food policies without interference from other countries. This includes the right to prioritize local agricultural production, farmers have the right to plant, consumers have the right to choose their food products including how those foods are processed, the state has the right to protect its agricultural products from low prices and imported goods, the people have the right to participate in agricultural policymaking, and the essential role of women farmers is recognized (La Via Campesina, 2003). Food sovereignty is a concept that presents not only food security for consumers but

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also justice for farmers who produce it, including assurance that government policies favor the people.

The history of the food sovereignty concept began when La Via Campesina, the international small farmers movement, introduced the idea of food sovereignty as an alternative to the concept of food security that had previously been adopted by Food and Agriculture Organization (FAO) and countries around the world during the World Food Summit 1996. La Via Campesina argued that the concept of food security only emphasizes the availability of and access to food, which ultimately relies on market mechanisms that do not guarantee the welfare of farmers and local agricultural products (La Via Campesina, 2003; Bernstein, 2017). Therefore, food sovereignty and food security are two very different concepts and have significantly different implications.

The concept adopted by Indonesia tends to align with food security. The general formulation of food security for 2006 to 2009, Food Security Council (2006) stated that food security will be achieved when food is available in sufficient quantities and evenly distributed to all people, and every person has both physical and economic access to food for a healthy and productive life. This concept of food security is manifested within Indonesia's food regime. While the international food regime began with monocultural systems and plantations producing export commodities, continued with the food surplus in the United States, in Indonesia it took the form of the Green Revolution and food self-sufficiency. The current food regime in Indonesia is characterized by food imports, land grabbing, oil palm expansion, and the food estate program (McMichael, 2009, 2013).

Discussing food sovereignty in Indonesia cannot be limited merely to farmers and the agricultural paddy field system. Indonesia, a country with 82.8 million hectares of forest, equivalent to 43.4 percent of its total area, still has many forest areas managed by indigenous communities spread across various regions. Indigenous peoples are also food producers who contribute to Indonesia's rich food diversity. The food sovereignty systems of indigenous communities that maintain local food diversity rely heavily on the existence and sustainability of forests.

The Aru Islands, although merely a small cluster of islands in the middle of the Arafura Sea, possess extraordinary natural wealth stored in their forests and seas, which are still well preserved by the indigenous communities of the Aru Islands. Administratively, the Aru Islands are part of a regency in Maluku Province, but bioregionally, in terms of socioeconomics, ecology, and biology, they are closely linked to the Papua region (Barri et al., 2019). Based on terrestrial ecoregion data, the Aru mainland is dominated by karst hills and coastal plains covering 5,706.61 km^2 and 1,267.95 km^2 respectively. In addition, several unique and important ecoregions are also found, including structural plains, karst formations, and fluvial landscapes. The Aru Islands have an Af-type climate according to the Köppen climate classification (Arnfield, 2017), and the seasonal climate variability in the Aru Islands is strongly influenced by monsoon winds, which also affect the livelihood patterns of the Aru people in meeting their primary needs.

The Aru Islands are also rich in flora and fauna, particularly Australasian species such as kangaroos and other marsupials. Like Papua, the Aru Islands are also the habitat of the bird of paradise (*cenderawasih*), giving them very high biodiversity potential. The International Union for Conservation of Nature (IUCN) records that there are 31 species of mammals, 7 species of amphibians, and 47 species of reptiles found in the Aru region, ranging from non-threatened to highly endangered species. The relatively extensive coastal plains in the Aru Islands also contribute to the abundance of mangrove vegetation along the coasts of the smaller islands. This has a positive impact on ecosystem balance, environmental services, and the livelihood of the Aru indigenous communities (Forest Watch Indonesia (FWI) & *Pusat Pengkajian dan Pengembangan Wilayah* (P4W), 2020).

Most indigenous peoples in Indonesia are in a transition phase from hunter-gatherers to farmers, and some have entered the early stages of agriculture. They plant various food crops for their own consumption and generally not for commercialization (Koizumi et al., 2012). The indigenous communities in Aru are also in a transition phase; they have begun cultivating crops to meet their food needs, although hunting remains a source of protein.

The livelihoods of the Aru indigenous people still depend almost entirely on nature. During the west monsoon season, the majority of Aru people go to sea to obtain protein sources. Conversely, during the east monsoon season, the Aru people tend to carry out activities on land such as farming and hunting (FWI & P4W, 2020). Therefore, the Aru people depend heavily on natural resources throughout the year.

Threats from various aspects are also faced by both the region and the people of the Aru Islands. Deforestation and climate change as global issues have become serious problems for the balance of the ecosystems in the Aru Islands. These problems can increase the risk and vulnerability of biodiversity to extinction (Dirzo et al., 2014) and can also lead to a decline in the quality of life of the Aru people, including threatening the food sovereignty systems of the Aru indigenous communities. Air temperature data from the Global Historical Climate Network (Fan & van den Dool, 2008) show a systematic increase from 1948 until now (2021) in the Aru Islands, with a constant historical increase of approximately 0.032 °C per year. This indicates that within a span of 100 years, the Aru Islands could experience an air temperature rise of 3.2 °C. This increase in temperature will affect the phenology of plants and animals, decrease biodiversity populations, increase the frequency of extreme climate events, reduce the availability of clean water, and degrade environmental quality (Buis, 2019). Deforestation or forest degradation can also worsen climatic conditions through carbon emission contributions (Warren et al., 2016). Forest loss in the Aru Islands has increased from 2000 to 2021 based on satellite imagery data (Hansen et al., 2013), with losses ranging between 103 ha and 4,218 ha.

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As a small island region, Aru also possesses highly dynamic environmental stability, and any excessive exploitation will directly affect the availability of resources. Policies promoting the expansion of extractive industry investment since the issuance of Law Number 11 of 2020 on Job Creation in Indonesia have the potential to threaten food sovereignty, nutrition, and climate resilience for small island communities, including those in Aru. Natural resources available to local people will become meaningless if communities do not have access to them, whether due to government policies on land use and forest governance or due to other environmental pressures. Accessibility to primary food sources also remains a major challenge for communities in the Aru Islands.

Dr. (HC) Ir. Soekarno once declared that food represents the life and death of a nation. Hence, food has a substantial contribution to achieving community welfare on local, national, and global scales. However, in-depth studies on food systems in eastern Indonesia, particularly in Aru, focusing on both protein and carbohydrate fulfillment, remain rare.

Since 2005, Forest Watch Indonesia (FWI), together with several partners, has established the #SaveAru coalition, which began as a response to development plans that were inconsistent with the needs of local communities. Over time, FWI has also conducted several studies on the anthropology and socioeconomic systems of the Aru people. Recognizing the importance of food in relation to land-cover and climate change, FWI has committed to conducting further studies focusing on food sovereignty in the Aru Islands.

FWI now seeks to understand how food sovereignty systems function within the Aru indigenous communities through observations of their interactions with the surrounding ecosystems and through the multidimensional movement of energy chains, encompassing social, economic, cultural, and ecological dimensions within a scientific framework. The study also aims to explore the essential role of women in achieving food sovereignty in Aru and to evaluate potential global threats to Aru communities, particularly regarding access to food resources. This study therefore aims to identify sago as the main food commodity based on remote sensing data using a machine learning approach, to estimate potential fishing and hunting zones during different seasonal periods in the Aru region, to calculate the accessibility of local communities to sago and analyze the roles of men and women in the Aru Islands, to review the impacts of climate change on food sovereignty, and to analyze the food sovereignty system in Lorang Village, Central Aru District, Aru Islands.

2. Methods

2.1 Identification of sago plants

The one-class support vector machine (SVM) method was used by employing sago distribution point data from field surveys conducted in specific years, combined with environmental parameters derived from satellite imagery. The sago plant distribution data were obtained through surveys using handheld GPS devices, Android mobile applications, and observations using unmanned aerial vehicles (drones). This study utilized a combination of passive satellite data (multispectral) and active data (radar), along with spatial data on soil types, to estimate areas that have the potential for sago cultivation with a spatial resolution of ten meters. The details of the predictors used are described in Table 1.

Table 1. Predictors used in the model

Dataset	Predictor	Number of data	Source	Resolution
Sentinel-2A	Spectral reflectance	10	European Space Agency	10–20 meters
	Enhanced Vegetation Index (EVI)	1		
	Soil-Adjusted Vegetation Index (SAVI)	1		
	Index-based Built-up Area Index (IBI)	1		
Landsat 8 TIRS	Surface temperature	1	National Aeronautics and Space Administration	100 meters
Shuttle Radar Topography Mission (SRTM)	Elevation	1	National Aeronautics and Space Administration	30 meters
	Slope	1		
	Aspect	1		
	Northness	1		
	Eastness	1		

Sentinel-1C	VV	1	European Space Agency	10 meters
	VH	1		
CHIRPS	Precipitation	1	Climate Hazards Center – University of California, Santa Barbara	5 km

Several predictor datasets were obtained from different satellites with varying spatial resolutions, requiring the harmonization of spatial resolution through resampling and spatial interpolation techniques. For precipitation data from CHIRPS, spatial interpolation using the Thin Plate Spline technique was applied to achieve a uniform resolution of ten meters. In addition, resampling was performed on datasets that did not originally have a spatial resolution of ten meters.

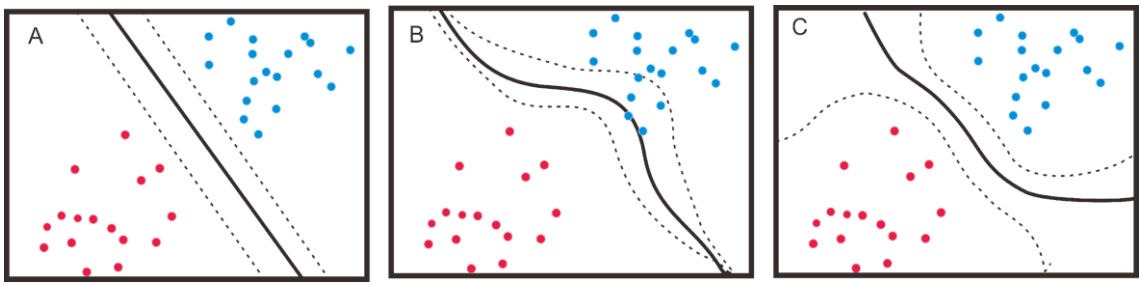


Fig. 1. Illustration of class division based on several SVM algorithm kernels (a) Linear; (b) Polynomial, and (c) Radial Basis Function (RBF)

Parameterization is required before performing predictions using machine learning. This study employed a one-class type SVM algorithm (Karatzoglou et al., 2004) because it aimed to estimate only one type of object, namely sago plants, with the following parameters: Kernel: RBF, Gamma: 1 divided by the square root of n, where n is the number of predictors used, and nu: 0.5. The resulting output consisted of binary data (sago and non-sago areas) and sago probability values. Model evaluation was conducted using an error matrix.

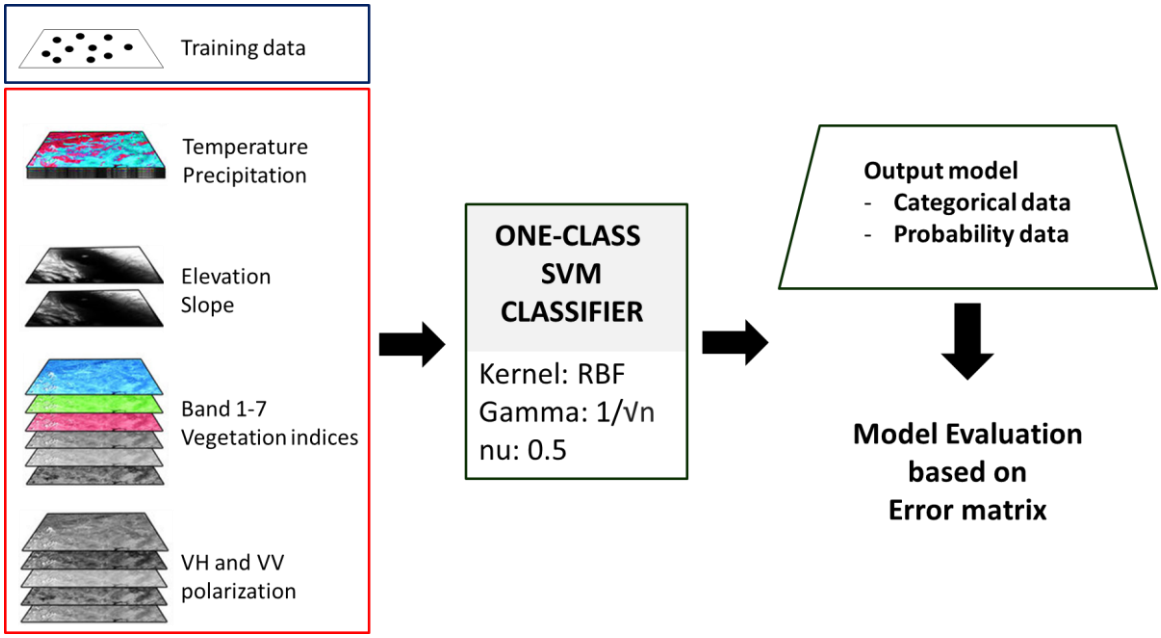


Fig. 2. Scheme for identifying sago plants in the Aru Islands

2.2 Spatial estimation of fishing potential

The productivity of marine fisheries catches in the Aru Islands does not remain high throughout the year. Only during certain seasons can the catch adequately meet the protein needs of the Aru communities. The spatial movement of marine fish is strongly influenced by ocean currents, sea water parameters, and chlorophyll-A concentration in the sea (FAO, 2008; Geronimo et al., 2018; Marpaung et al., 2018). To examine the potential for fish catches, the study area was defined within a radius of 250 kilometers from the geographic center point (centroid) of the Aru Islands.

The fishing potential was identified using marine biota macroecological modeling based on ecological niche modeling. Several marine biota commonly targeted for fishing include pelagic fish, groupers, clams, and crabs. Presence data for these marine species were obtained through field surveys using handheld GPS devices, Android mobile applications, and publicly accessible data sources (for example, ZPPI Sipandora Lapan). The maximum entropy algorithm (Maxent; Phillips et al., 2006) was used to estimate fishing potential during different seasons. The environmental factors used to predict areas that have the potential to become fishing zones in the Aru Islands are presented in Table 2.

Table 2. Predictors used in the modeling of fishing potential

Predictor	Resolution	Unit	Source
Sea Surface Temperature	0.08°	°C	HYCOM
Chlorophyll-A	0.04°	mg/cm^3	JAXA; GCOM-C
Sea Surface Salinity	0.08°	psu	HYCOM
Wave Speed	0.08°	m/s	HYCOM
Bathymetry	500 m	m	GEBCO

The predictor data presented in Table 2 have highly diverse spatial resolutions, ranging from 300 meters to 9 kilometers. To ensure consistency among datasets, spatial interpolation using the Ordinary Kriging technique was applied, following the spatial resolution of the bathymetry data, which is approximately 500 meters. Furthermore, resampling was performed on all datasets that did not originally have a spatial resolution of 500 meters to standardize the entire dataset.

2.3 Community accessibility to food commodities

Community accessibility to food commodities, namely sago plants, was analyzed based on travel time calculations following the method of Weiss et al. (2018). The datasets used to construct the surface friction characteristics included road networks, rivers and water bodies, topographic conditions such as slope and elevation, and land cover. The main function of this accessibility model was to estimate the travel time required to reach reference locations, in this case, sago areas, by considering several relevant parameters. SRTM data were used to obtain topographic information (Farr et al., 2007), while land cover data from GlobCover provided information on land use and vegetation (Baetens et al., 2019). Additionally, OSM data were used as the dataset for road and river networks, and the detailed mechanism of the accessibility model can be accessed from GIS_ID (2021). Subsequently, the most optimal catchment area representing community access to sago plants in the Aru Islands was analyzed using cost allocation, with sago plant locations as the source data and travel time as the cost parameter.

In addition, we aimed to gain a deeper understanding of the food balance in the Aru Islands by using a statistical approach that considered both population data and the potential availability of local food resources. The analysis referred to the productivity of sago in the form of dry flour, estimated at 14,150 kilograms per hectare, as an indicator of local food production capacity. Meanwhile, the maximum average annual consumption of sago per person was approximately 60 kilograms, based on field observations in Lorang Village, where each household consumed about 150 kilograms of sago every three months.

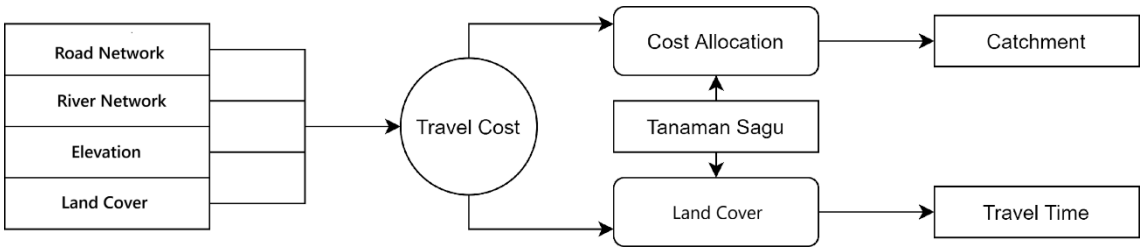


Fig. 3. Mechanism of the sago accessibility model in the Aru Islands

2.4 Social study

The social study aimed to observe food culture and livelihood characteristics of the community in Lorang Island, Aru Islands, using the Rapid Rural Appraisal (RRA) method. RRA is an intensive, iterative, exploratory, and rapid study of rural conditions conducted by a small interdisciplinary team of researchers using a combination of specifically selected methods, tools, and techniques to enhance understanding of rural situations, with a primary focus on extracting local knowledge and integrating it with modern scientific understanding (S. W. Grandstaff, T. B. Grandstaff, and C. W. Lovelace, 1987, as cited in W. Gunawan, 2008).

Supporting research information collected at the study site consisted of quantitative data, including data on consumption, production, and prices of production and consumer goods. Qualitative data were also gathered, encompassing production processes, ownership of production tools, local wisdom related to food sources, and the history of production. The data collection methods used included individual interviews, group discussions, and in-depth interviews. Using the approach of Bernstein (2010), four key questions were applied to examine the social relations of production and reproduction: Who produces food in Lorang Island? Who performs the labor within the food system chain in Lorang Island? How is access to food managed? What do the people of Lorang Island do with their production output? Finally, to complement these, an additional question related to food sovereignty and climate change was included: What changes have occurred over the past few years in food production processes, and how have the people responded to them? FWI derived these five questions into structured questionnaire tables and a list of guiding interview questions.

2.5 The role of women in the food sovereignty system of the Aru Islands

FWI recognizes that women play an essential role in the issue of food sovereignty in the Aru Islands. Indigenous communities in relation to forest governance have often been viewed as homogeneous units; however, the division of labor between men and women in food production activities significantly shapes local food sovereignty strategies. In conducting the food sovereignty study, FWI sought to analyze the specific roles of each gender in relation to food production through a descriptive analysis of women's roles within the local supply chain, including activities such as sago processing, fishing, hunting, and farming.

2.6 The impact of climate and land cover change on food sovereignty

In projecting climate change, the study focused solely on sago as the main local food commodity in the Aru Islands. Climate change projections were conducted using datasets from Global Circulation Models (GCMs) that had undergone statistical downscaling using the Delta method (Navarro-Racines et al., 2020) to capture the regional characteristics of the Aru Islands more precisely. The GCM data used were derived from a multimodel ensemble of the sixth assessment report of the IPCC, specifically MIROC6, MIROC-ES2L, and MRI-ESM2.0 (Tatebe et al., 2019; Yukimoto et al., 2019; Hajima et al., 2020). This sixth assessment report of the IPCC has adopted the latest scenarios that integrate socioeconomic pathways with greenhouse gas concentration levels (Riahi et al., 2017), focusing on two scenarios: the mitigation scenario (SSP2) and the business-as-usual scenario (SSP5) for the

period 2041–2060. Based on these data, we evaluated climate change using the standardized Euclidean distance (Williams et al., 2007). In addition, we assessed the potential for deforestation in the Aru Islands through a simulation of land cover change using the Patch-generating Land Use Simulation (PLUS) model (Liang et al., 2021) to project land cover conditions in 2050 under a business-as-usual scenario. Land cover was identified using Landsat 8 satellite imagery and classified with the Random Forest algorithm, applying a number of trees equal to 1000 (Breiman, 2001).

3. Results and Discussion

3.1 General condition of food in the Aru Islands, Maluku Province

According to Law Number 18 of 2012 concerning Food, food security is defined as a condition in which food is sufficiently available for the nation and for individuals. This is reflected in the availability of food in adequate quantity and quality that is safe, diverse, nutritious, evenly distributed, and affordable, while not contradicting religious beliefs, customs, and local culture, enabling people to live healthy, active, and productive lives in a sustainable manner. National food policies in Indonesia, ranging from the Green Revolution to the Rice Intensification Program, the Merauke Integrated Food and Energy Estate (MIFEE), and the current Food Estate initiative, have primarily focused on the concept of food security. The underlying objective has been to ensure the availability of food for all citizens, often at the expense of recognizing Indonesia's vast diversity of local food systems.

In addition, the national policy-making process, which remains predominantly top-down, has yet to fully accommodate the diversity of staple foods across Indonesia. This can be seen in the overarching national strategies that focus heavily on rice as the main food commodity, despite rice not being the staple food for eastern Indonesian communities (Suismono & Hidayah, 2011). As a result, eastern communities, particularly those in the Aru Islands, have been indirectly "encouraged" to consume rice in a manner similar to western Indonesian societies. This rice-oriented policy has the potential not only to alter the traditional staple foods of eastern Indonesia but also to disrupt the indigenous food systems that are deeply rooted in local rights over land, territory, natural resources, and community sovereignty.

The people of Aru, like most communities in eastern Indonesia, consume sago, which is processed into papeda and serves as their primary source of carbohydrates. During his expedition through eastern Indonesia in 1858, Alfred Russel Wallace documented the presence and use of sago, confirming that it is one of the oldest local food sources in the archipelago, particularly in eastern Indonesia. Wallace's observations on sago in Seram Island, Maluku, were especially detailed, highlighting its cultural and ecological importance. Jong & Widjono (2007) stated that approximately 50 percent of the world's sago potential is found in Indonesia, indicating that the presence of sago in the Aru Islands significantly contributes to global food resource potential.

An economic census conducted in 2005 showed that 93 percent of villages in Maluku derive their primary income from the agricultural sector, including food crops, plantations, fisheries, and forestry. The Aru Islands Regency is the second largest in Maluku Province in terms of dry land areas developed for agriculture and plantations, after West Seram Regency. Approximately 350 thousand hectares of dry land in the Aru Islands have been developed for food crops, while 22.5 thousand hectares have been used for plantation crops (Bustaman & Hutuely, n.d.).

However, three regencies in Maluku Province are classified as Priority I areas with a high level of food vulnerability. These three regencies are the Aru Islands, the Tanimbar Islands, and Southwest Maluku (see Figure 4). Food vulnerability is defined as a condition in which individuals or groups of individuals in a particular area are unable to obtain sufficient and appropriate food to live a healthy and active life. Food insecurity and vulnerability are measured using three indicators: Availability, accessibility, and utilization. Nevertheless, these indicators should be critically analyzed. The food availability indicator

is defined as the ratio of normative per capita consumption to the net production of major cereals and tubers, such as rice, corn, cassava, and sweet potatoes (Food Security Agency, 2020). At a glance, this indicator is not suitable for application in the Aru Islands, where sago serves as the main staple food. The sago staple food is not accommodated within this measurement framework.

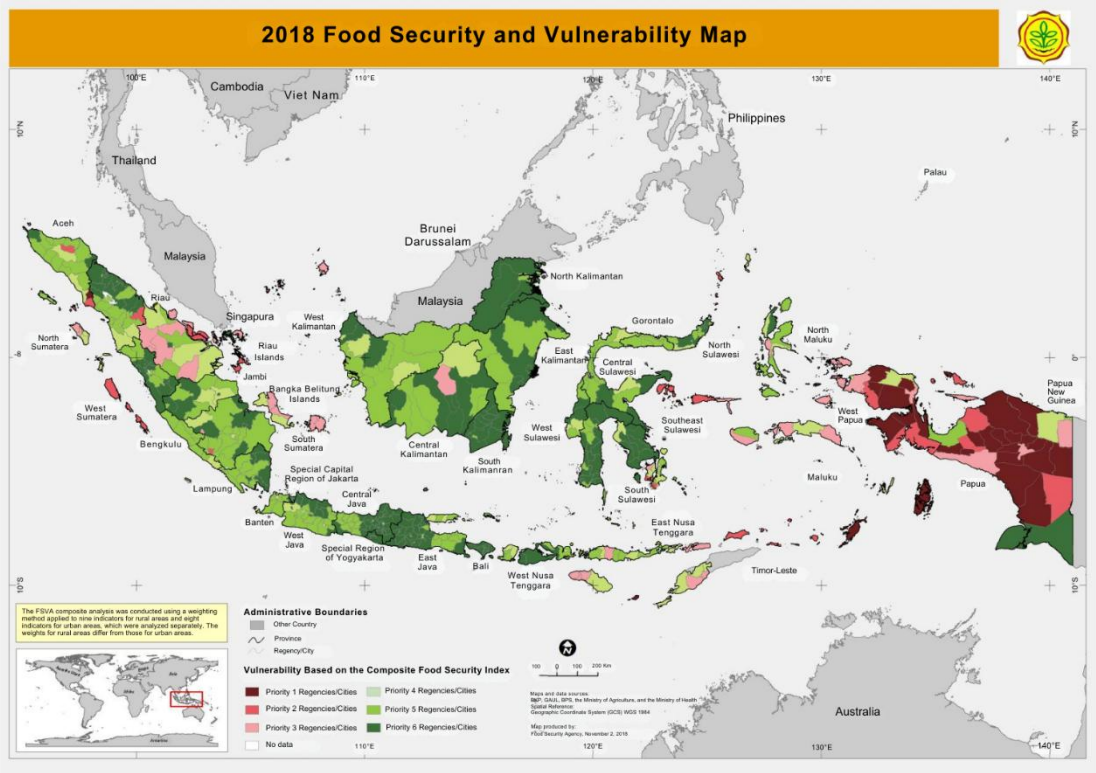


Fig. 4. 2018 food security and vulnerability map
(Food Security Agency, 2018)

The second indicator, food accessibility, includes three components related to expenditure, the proportion of food expenditure, and the percentage of households with access to electricity. The reliance of the Aru indigenous communities on natural resources results in very limited monetary expenditures, as spending generally occurs only for goods that cannot be sourced from nature and for educational costs. Consequently, both of these indicators are more applicable to urban communities whose livelihoods are detached from direct utilization of natural resources to meet their needs. In contrast, the indigenous people of the Aru Islands continue to rely heavily on natural resources, particularly sago, as their main source of sustenance.

Sago plants are utilized by the people of the Aru Islands as a primary food source and the main supplier of carbohydrates, having long been proven to be the dominant local staple food. In the 1980s, research by Louhenapessy (2006) showed that 33 percent of Maluku residents consumed sago as their main staple food, 50 percent mixed sago with other tuber crops, and only 17 percent used rice as their primary staple. However, there has been a gradual shift in food consumption patterns from non-rice foods to rice-dominated diets in recent years. This transition has not significantly affected rural communities living on smaller islands, where people still rely on diverse staple foods such as corn, tubers, sago, and bananas. To substitute 15 percent of sago within the desired food consumption pattern for Maluku residents, equivalent to 135 kilograms of rice per capita per year, a harvested sago area of 22,387 hectares was required in 2006 and 24,128 hectares in 2007, assuming harvesting occurs once every two years (Susanto & Bustaman, 2006).

Available data describing the distribution of sago in the Aru Islands remain very limited. The most recent data from 2006, reported by Louhenapessy (2006), indicated that Maluku had a total sago area of 26,410 hectares. The distribution included Piru District with 320

hectares, Kairatu with 2,350 hectares, Amahai with 1,150 hectares, North West Buru with 240 hectares, North East Buru with 7,800 hectares, and the Aru Islands with 9,762 hectares. Based on the Agroecological Zone Map at a scale of 1:250,000, sago areas are found on Hydraquent, Tropaquent, and Fluvaquent soil types, leading to an estimated total potential area for sago development in Maluku Province of approximately 649,937.85 hectares. The distribution by regency includes 948.54 hectares in West Southeast Maluku, 5,161.78 hectares in Southeast Maluku, 104,640 hectares in Central Maluku, 34,887.50 hectares in Buru, 36,871.20 hectares in West Seram, 114,497.19 hectares in East Seram, 351,493.64 hectares in the Aru Islands, and 1,436 hectares in Ambon City (Susanto & Bustaman, 2006).

3.2 Spatial distribution and accessibility of sago plants in the Aru Islands

The spatial distribution of sago plants in the Aru Islands was identified using machine learning techniques applied to several optical satellite imagery datasets. The results of the analysis show that the distribution model performed very well, with an AUC value of 0.955 ± 0.012. The total sago area in the Aru Islands is estimated at 14,344.82 hectares. East South Aru District contains the largest area of sago, approximately 4,110.72 hectares, followed by South Aru with 3,616.37 hectares and Central Aru with 3,570.25 hectares. In contrast, South Central Aru District has the smallest sago distribution, with only about 121.34 hectares.

This area represents an increase of around four thousand hectares compared to the 2006 data reported by Louhenapessy (2006). Based on the estimated requirement to substitute 15 percent of sago within the desired food consumption pattern of Maluku residents (Susanto & Bustaman, 2006), this area is considered adequate, given that the required harvest area ranged between 22,000 and 24,000 hectares in 2006 and 2007. At that time, the total population of Maluku Province exceeded one million people, while the population of the Aru Islands was only about 102,000.

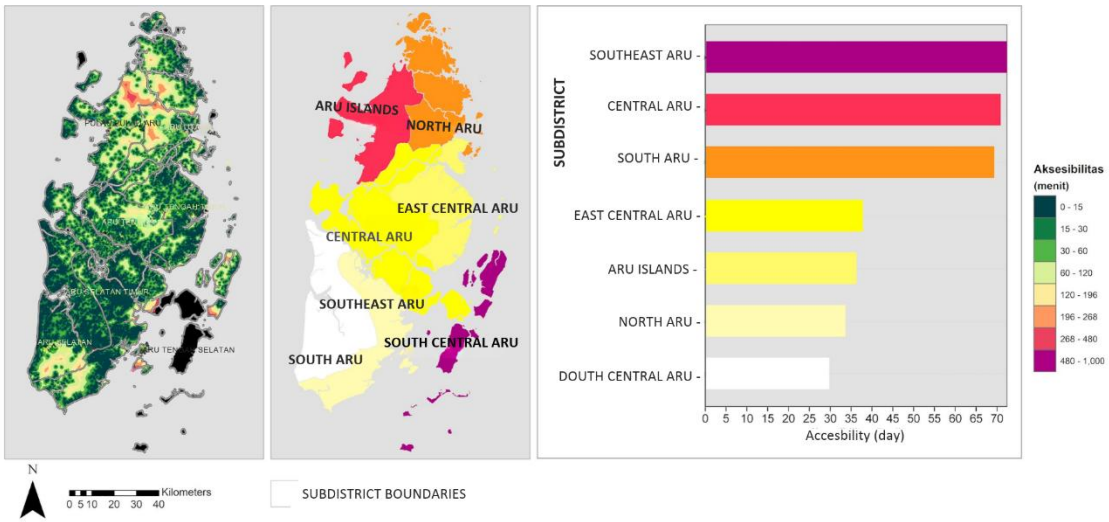


Fig. 5. Spatial distribution of sago palms in the Aru Islands

Sago plants tend to be distributed within the lowland natural forest areas of the Aru Islands. The abundant potential of sago in the region is not necessarily directly accessible or utilizable by local communities, as its utilization is influenced by infrastructural factors and the social or clan hierarchy governing access to available resources. The accessibility assessment represents the travel time, measured in minutes, required by communities at specific locations to reach the nearest sago plants based on information related to land cover, road networks, and topography.

The results of the study show that areas with a relatively high abundance of sago plants also tend to have relatively good accessibility to these resources (see Figure 6), such as in the districts of South Aru, East South Aru, and Central Aru. The people of Aru can access sago plants within approximately fifteen minutes in areas with good accessibility, while in

regions with lower accessibility, such as South Central Aru and the smaller Aru Islands, travel time can reach up to nine hours. In these latter areas, not only is the presence of sago plants limited, but the landscape, consisting mainly of small islands directly bordering the Arafura Sea, also constrains community mobility.

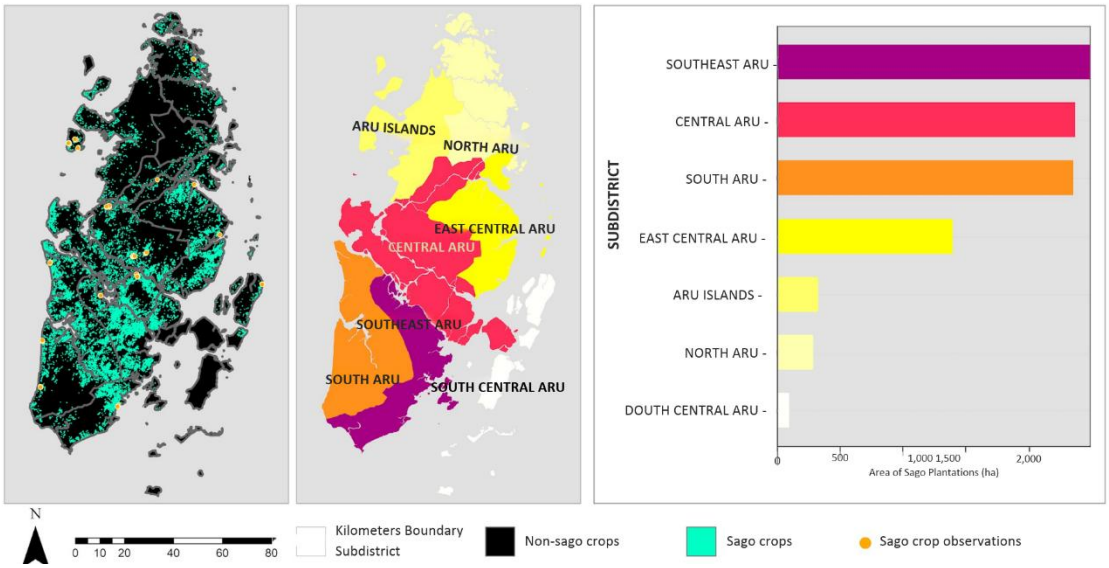


Fig. 6. Accessibility of the Aru community to sago resources (sago plants)

Field observations conducted in one of the districts in the Aru Islands, namely Central Aru, show that settlements are generally established near freshwater springs, which are often located close to sago groves, as found in villages such as Lorang, Eresin, Irloy, Murai Baru, and Algadang. The presence of sago forests serves as an ecological stabilizer and groundwater recharge area, as the plant typically grows in wetland or swamp areas. However, it is not uncommon for communities to harvest sago from groves located far from their settlements, mainly for economic reasons. Sago groves located near villages are usually reserved for household food needs, while those located farther away are accessed for commercial purposes.

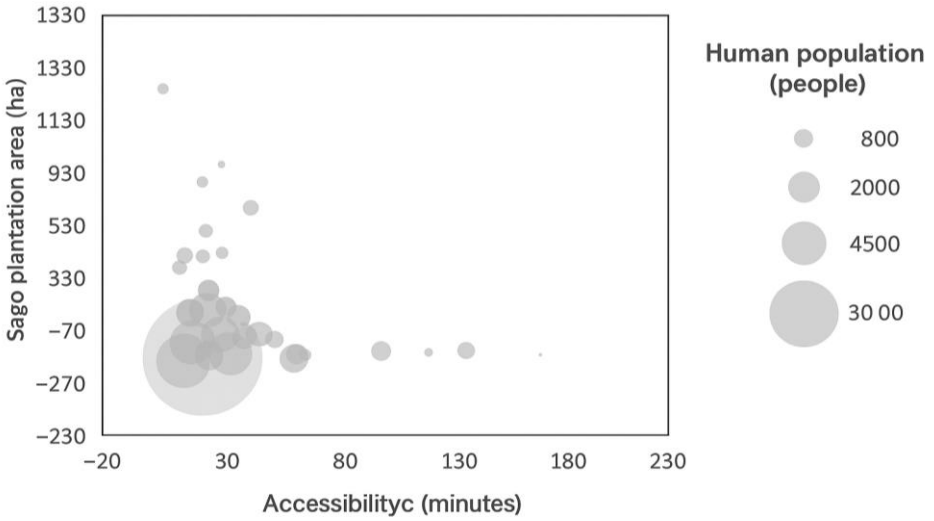


Fig. 7. Relationship between community accessibility to sago plants in the Aru Islands

Central Aru, which consists of several small islands, requires that almost all forms of transportation rely on small boats, resulting in higher operational costs compared to land-based routes. This situation makes it difficult for local communities to conduct large-scale sago harvesting, and they often rely on middlemen to finance the harvesting process. This

dependency arises primarily from the limited availability of human resources and the high cost of fuel needed for sago extraction and transport.

This study also attempted to examine the relationship between accessibility and population distribution across districts in the Aru Islands. The findings revealed no significant correlation between the extent of sago distribution and the human population living near sago resources. This indicates that there are certain areas in the Aru Islands where sago is not the primary staple food for the local communities. These areas are typically the administrative and economic centers of the region, such as the regency capital of Dobo and several district capitals like Benjina, where alternative staple foods such as rice are commonly available, transported by mass cargo ships. The study further identified that seven villages in the Aru Islands experience a sago food deficit, while ninety-five villages have a surplus of sago. Some of the villages identified as having a sago deficit include Kolamar, Marlasi, Galai Dubu, Wangel, Siwalima, Batuley, Durjela, Gulili, and Tanah Miring.

3.3 Identification of staple foods and dietary habits of the Aru Islands community: A case study of Lorang Village

3.3.1 General condition of Lorang

Lorang Village is located in Central Aru District, Aru Islands Regency, and has an indicative customary territory covering approximately 38,000 hectares, consisting of 379 large and small islands, straits, and rivers. The village of Lorang represents the customary area of Fanugwa Lorang, which was formally recognized by the government as a village. Administratively, Lorang Village is located in Aru Tengah District, Kepulauan Aru Regency, Maluku Province. The landscape of Lorang Village includes natural forests, mangrove forests, straits, settlements, gardens, and sago groves. The Lorang community consists of ten clans: Badidi Yai, Dakael Gwarjir, Tarau Gwarjir, Gwaitedi, Leftafuran Jugir, Goini, Gwanobal Gwajir, Feldaba Gwajir, Legwadjir, and Djirmori, each of which governs different customary territories. The livelihoods of the Lorang people depend on their productive landscapes, including forests, gardens, and the sea. Based on the indicative customary territory map, the village has approximately 23,160 hectares of forest cover, while only about 230 hectares are utilized for settlements, gardens, and sago groves.

3.3.2 Food sovereignty system of the indigenous Lorang community

Food sovereignty is a concept of fulfilling food needs through local production. It embodies the right to access nutritious and culturally appropriate food produced through sustainable and environmentally friendly agricultural systems. This principle emphasizes food diversification that aligns with local culture. The food sovereignty system in Aru is founded on the preservation of natural forests and the balance between terrestrial and marine ecosystems. The indigenous communities of Aru utilize forest areas to gather fruits, medicinal plants, and hunt, gardens for farming, and marine areas for fishing and collecting crabs, which serve as their primary sources of income. The community obtains carbohydrates, proteins, vitamins, and minerals from local natural resources that remain preserved, diverse, and sustainable, forming an integrated food sovereignty system deeply embedded in their traditional life.

Qualitative data collection indicates that the productive areas of the indigenous Lorang community include forests, sago groves, gardens, hunting grounds, and marine areas. The community's gardens are located within the forest, meaning that the collection of forest product data is closely linked to agricultural yield data. From the forest, communities gather fruits, while on the forest edge they maintain gardens and sago groves. In the gardens, residents cultivate vegetables, fruits, and secondary crops, and more recently, rice. The people of Lorang select and store seeds themselves according to their household consumption needs.

Table 3. Production areas and food products of Lorang Village Community

Garden			Hunting area	Sea
Sago	Sugar cane	Katuk	Pig	Crab
Cassava	Star fruit	Ginger	Deer	Grouper fish
Corn	Coffee	Rambutan	Cuscus	White fish
Rice	Orange	Banana	Kangaroo	Mackerel Fish
Taro	Chocolate	Langsat	Swallow Bird	Yellowfin fish
Yam	Guava	Matoa	Cassowary	Shrimp
Sweet potatoes	Mango	Beans		
Spinach	Avocado	Jackfruit		
Sawi	Nutmeg	Duku		
Timun	Pumpkin	Pepaya		
Terong	Watermelon	Coconut		
Chili	Lemongrass	Durian		
Galangal	Pandan	Gayang		

Lorang Village has a sago land area of 795.24 hectares, with a production potential of 5.6 million kilograms. The availability of sago food can be categorized as a surplus when compared to the village's population of 297 people, who consume only 17,866 kilograms of sago per year. Sago serves as the primary staple food and the main source of carbohydrates for the people of Lorang Village (see Table 3). In addition to sago, the community also consumes corn, taro, yellow sweet potato, yam, and rice. A single sago tree can produce approximately 10–15 tumang, or about 100–150 kilograms of sago starch, which can sustain a family for five to seven months. This means that with just one or two days of sago processing, a family can secure its carbohydrate needs for up to half a year. The Lorang community typically eats only once or twice a day, and papeda (a dish made from sago starch) is believed to be more filling than rice. This belief is supported by scientific evidence, as sago has a low glycemic index (GI) of 40.7, attributed to its high resistant starch content, which slows down digestion in the gastrointestinal tract (Wahjuningsih et al., 2016).

In earlier times, before rice became widely available, the community substituted sago with tubers. Rice began entering Lorang Village in the early 2000s through the government's *Rastra* (Rice for Prosperity) assistance program, followed by the provision of rice seed and post-harvest equipment for processing paddy into rice. Since then, villagers have started cultivating rice in their gardens. Today, rice is the second most important staple food after sago. However, interviews indicate that local rice production remains insufficient to meet household consumption, forcing villagers to purchase rice. Across the entire Aru Islands, total rice production amounts to only 300 quintals, with a total paddy field area of 39 hectares. Central Aru District has the largest area of upland rice cultivation, totaling 26 hectares, with a productivity rate of 13.33 quintals (Statistics of Kepulauan Aru Regency, 2019). Nevertheless, this production volume is far smaller than the sago area, which covers around 500,000 hectares with a total productivity of 99,000 tons (Directorate General of Estate Crops, 2021).

There are several factors indicating that rice does not fit within the established food sovereignty system that is deeply rooted in the culture of the Aru indigenous communities. First, rice is not a native crop with a long historical connection to the Aru people, as it was introduced from outside the region, making it ecologically incompatible with Aru's natural ecosystem. Second, the absence of paddy fields and the impossibility of constructing irrigated rice fields result in a dependency on rain-fed systems, which limits productivity. Third, rice cultivation requires daily maintenance to monitor pests and diseases, whereas the livelihood of the Aru indigenous communities is not solely focused on farming but also includes hunting and fishing. Given that the Aru people are still in a transitional phase from hunter-gatherers to early-stage farmers, dedicating large portions of time to rice cultivation is not feasible. This contrasts with sago, which requires no special care and still grows abundantly and naturally in community sago groves.

Animal protein sources for the community are obtained through hunting and fishing. The sea serves as the primary livelihood base for the indigenous Lorang community. People typically fish throughout the year using paddled canoes and small motorized boats. From the sea, they catch crabs, which are sold for around 150,000 rupiahs per kilogram, with daily catches averaging two to three kilograms per household. Within a week, the Lorang community can collectively harvest between 200 and 300 kilograms of crab. However, crab is not the main protein source because almost all of it is sold, and the income from crab sales constitutes the primary source of livelihood for the Aru indigenous people. For personal consumption, the community relies on species such as grouper, white fish, yellowfin fish, and mackerel. The lush and well-preserved mangrove forests around Lorang support an abundant fish population.

Hunting provides another important source of animal protein for the Lorang indigenous community. Their game includes wild boar, deer, kangaroo, and cuscus. Hunting is traditionally conducted using bows and arrows, although air rifles are increasingly used today. The hunted animals are mainly consumed domestically, and when there is a surplus, deer meat is often processed into jerky for sale at local markets. The community does not practice long-term meat storage, as fresh meat can be readily replenished from the forest whenever needed.

Almost all food sources can be fulfilled by the indigenous community of Lorang. However, the government's rice-based policy disrupted the community's food sovereignty by providing rice aid in the early 2000s, amounting to 15 kilograms per year. The annual rice assistance was sufficient to alter the community's taste preferences and consumption patterns, which previously relied solely on sago and tubers but have now shifted to include both sago and rice. As mentioned earlier, the Lorang indigenous community is not yet capable of producing enough rice to meet their daily food needs, forcing them to purchase approximately 15 kilograms of rice per month at a cost of 189,000 rupiahs. Rice has become the second largest household expenditure after tobacco, which can reach 400,000 rupiahs per month.

Table 4. Consumption products of the indigenous community of Lorang Village

No.	Consumption product	Where It Is obtained	Amount of consumption per week	Price (if purchased)
1	Rice	Purchased in Dobo	15 kg/month	189,000
2	Sugar	Purchased in Dobo	3–4 kg/month	20,000
3	Shallot and Garlic	Purchased in Dobo	1 kg/month	40,000
4	Royco (seasoning)	Purchased in Dobo	4 sachets/month	
5	Pepper	Purchased in Dobo		
6	Coriander	Purchased in Dobo		
7	Chili	Purchased in Dobo	1 kg/month	120,000/kg
8	Coffee	Purchased in Dobo	1–3 kg/month	
9	Kerosene	Purchased in Dobo	5–6 L/month	105,000
10	Generator Fuel	Purchased in Dobo	5–6 L/day	10,000
11	Lamp Oil	Purchased in Dobo	5 L/month	50,000
12	Tobacco	Purchased in Dobo	40 ounces/month/person	10,000/ounce

Despite the abundance of food sources such as carbohydrates, proteins, and vitamins among the Aru indigenous people, this does not necessarily guarantee adequate nutrition. Data from the Directorate General of Regional Development (Ditjen Bina Pembangunan Daerah, 2021) show a 15.8 percent prevalence of stunting among children under five in the Aru Islands, with the rate in Lorang Village reaching 22.2 percent. Of the 22 children under five in Lorang, six are classified as stunted or short stature. This finding indicates that several indicators used by the National Food Security Council to assess food insecurity remain relevant, particularly those concerning women's average years of schooling, the ratio of healthcare workers, the number of stunted children, and life expectancy at birth. Women's education level plays a critical role in developing their knowledge about family nutrition once they become mothers. The number of healthcare workers is also a determining factor because without access to healthcare services such as posyandu or community health centers, communities that initially lack nutritional awareness cannot access information regarding their children's growth and development. Consequently, the interconnection between limited education and restricted access to healthcare facilities contributes to food insecurity amidst the richness of natural food resources in the Aru Islands.

3.3.3 The essential role of women in the food sovereignty system in Lorang

Women within indigenous communities play crucial roles that are deeply rooted in their identities, customary territories, and the social, economic, political, and cultural systems of their communities. Their roles extend across traditional medicine, rituals, art, food production, conservation, knowledge preservation, language, and leadership. In terms of food availability, indigenous women are the main food producers within their communities (AMAN, 2021). To understand the essential role of women in Lorang's food sovereignty system, this study collected data on gender-based division of labor in the food production process.

Gardens play a vital role in meeting the daily food needs of the Lorang indigenous community. Women hold significant responsibility in ensuring food availability, as within the family system in Lorang, women are predominantly in charge of food preparation. In agricultural activities, women are responsible for preparing seeds and harvesting crops. Thus, women play an essential role in determining which plants should be cultivated in the gardens and selecting which crops are ready to be harvested for family consumption.

Table 5. Division of labor of the indigenous Community of Lorang Village

Work/activity	Men	Women	Men & women
Sago Processing			
Planting	Yes		
Cleaning the outer layer of sago	Yes		
Cutting down	Yes		
Peeling	Yes		
Chopping	Yes		
Dipping			Yes
Soaking		Yes	
Taking the pulp		Yes	
Squeezing Sago / Guti		Yes	
Putting into the tumang	Yes		
Selling sago	Yes		
Bringing home the sale proceeds	Yes		
Saving sago earnings		Yes	
Garden			
Choosing new forest area not yet cleared			Yes
Building fences			Yes
Cutting trees			Yes
Burning the garden			Yes
Preparing seeds		Yes	

Planting crop A			
Planting crop B			
Weeding			Yes
Protecting garden from wild boars			Yes
Harvesting		Yes	
Sea			
Operating Kedo-Kedo (long distance boat)	Yes		
Rowing a canoe			Yes
Setting fish traps (bubu)	Yes		
Setting small snares			Yes
Searching for bait			Yes
Selling seafood			
Saving money from seafood sales		Yes	
Hunting Area			
Preparing supplies for the forest		Yes	
Making traps	Yes		
Processing hunting results			Yes
Selling hunting results	Yes		
Saving money from hunting sales		Yes	

The division of labor between men and women in production areas such as sago groves, gardens, and the sea can be considered relatively balanced, as most of the work in these areas is either carried out jointly or distributed evenly. However, in hunting activities, women's roles are limited to preparing supplies. An important and noteworthy finding is that women are responsible for keeping the money earned from sales in all production areas, including sago, crabs, hunted animals, and garden produce. Through this role, women hold a strategic position in planning and managing family nutrition strategies.

3.3.4 Access (rights and land tenure) and its relation to food sovereignty

Based on Figures 7 and 8 showing the area and accessibility of sago groves, it is evident that the Central Aru region, including Lorang Village, has over 2,200 hectares of sago land, with an access time of approximately one to two hours. Lorang Village has sago groves located near residential areas, allowing for easier and faster harvesting to meet daily food needs. However, access to food sources in Lorang's customary territory is not solely determined by distance or existing pathways. It is also influenced by the tenurial system practiced by the Lorang indigenous community.

The tenurial system of the Lorang community is based on clan ownership. Forests, gardens, and hunting areas are part of Lorang's customary domain, governed under communal rights known as *hak petuanan*. As previously mentioned, there are ten clans within the Lorang indigenous community, each possessing its own *hak petuanan* in the Fanugwa Loran area. Each clan controls a distinct landscape, which influences how the land is used. For instance, clans whose territories contain caves may collect swiftlet nests, which can be sold for three to five million rupiahs per kilogram. These clans often employ members of other clans during harvesting, with the profits later divided among them.

Each customary territory has its own name, land use regulations, history, and sacred sites. These elements serve as a moral guide for clans to respect and protect their respective territories. The use of customary land is categorized into forest (*unai*), mangrove (*gwakat*), garden (*gutan*), settlements, and sago groves. The *unai* is used for harvesting sago, collecting bird nests, hunting, opening gardens, fetching water, and gathering firewood. Logging for commercial purposes is strictly prohibited. Certain parts of the *unai* are considered sacred, and activities there are restricted. In the *gwakat* or mangrove forest, people fish, set crab traps (*bubu*), collect shells, and gather firewood. Similar to *unai*, cutting down trees or clearing land in *gwakat* is prohibited. These prohibitions reflect the local wisdom of the Lorang indigenous people, who consciously strive to maintain the ecosystems that sustain their livelihoods.

Another area, the *gutan* or garden, serves as a site for cultivating food sources such as vegetables, fruits, and sago. Unlike other areas managed communally, *gutan* land, while under communal clan ownership, is managed by individual families. Families from outside the ten clans may also cultivate the land with permission from the land-owning clan. Each clan believes that crops grow better when planted within their own *gutan*. The people of Lorang continue to practice shifting cultivation, although new gardens are now rarely opened. The Lorang indigenous community also preserves sacred sites that are historically connected to their ancestors. Activities in these sacred places are highly restricted, typically prohibiting land clearing, hunting, logging, or other destructive actions. These sacred sites may take the form of forests, mangroves, sago groves, islands, springs, or rocks. Through a tenurial system grounded in local wisdom, the community consciously participates in protecting food sources.

Understanding the tenurial system practiced by the Lorang indigenous community provides deeper insight into how their food sovereignty system operates. The food sovereignty of Lorang is built upon a complex tenurial structure, where each clan adopts its own strategies for managing its territory based on differences in land area, landscape, and natural resources. This system strongly influences community access to production areas and, consequently, their livelihood strategies. The differing livelihood strategies of each clan are harmonized under a unified tenurial system within the Fanugwa Loran customary territory. This tenurial structure is shaped by how the Lorang indigenous people perceive their customary lands, including the forests. However, this system may not align with the perspective of the Government of Indonesia, represented by the Ministry of Environment and Forestry (KLHK), regarding the management of the Aru Islands. As shown in Figure 10 below, the entire Aru Islands Regency has been classified into various land use functions, with the largest portions designated as Production Forest, Convertible Production Forest, and Wildlife Reserves.

Lorang Village is divided into Production Forest (HP) and Convertible Production Forest (HPK) areas, meaning that residential zones are also located within the HPK function. HP and HPK are areas where the Ministry of Environment and Forestry (KLHK) holds full authority over their management. These areas can easily be converted into other land functions and granted to companies, such as forest management rights (HPH). Regarding the access of the Lorang Indigenous People to food sources, there is a potential restriction of access if concessions are granted in HP and HPK areas or if their land cover is converted for other purposes. Therefore, policies that accommodate the tenurial systems practiced by the Lorang Indigenous People and other indigenous communities in the Aru Islands are urgently needed (Draft Regulation on the Recognition of Indigenous Territories of Aru Islands Regency, approved at the regency level and awaiting provincial approval).

In addition to spatial distribution, physical accessibility, indigenous tenurial systems, and the land-use functions established by KLHK, access to food sources is also determined by control over production tools. In the case of fishing, for example, members of the Lorang Indigenous People who own boats with small engines can reach more distant fishing areas with higher potential yields compared to those who only have canoes. Ownership of production tools is closely tied to social class.

3.4 Threats of land cover and climate change to the food sovereignty of the Lorang indigenous community

Climate change, including shifts in the timing of rainy and dry seasons, rainfall intensity, and rising temperatures, has affected the food system in Lorang. Several changes have been observed, such as the inability to determine the beginning of the rainy or western monsoon season, making it difficult to start planting periods since the community lacks alternative supporting technologies. Garden yields are no longer optimal (field observation; reduction in yields not quantified as garden produce is consumed directly). Marine catches have also become unpredictable due to changing weather conditions. Crab production, which used to reach 300 kilograms per week, has now declined to only 100–200 kilograms per week, even

though crabs are the main source of income for the Lorang Indigenous People. The population of hunted animals such as deer and kangaroos has also decreased due to overhunting.

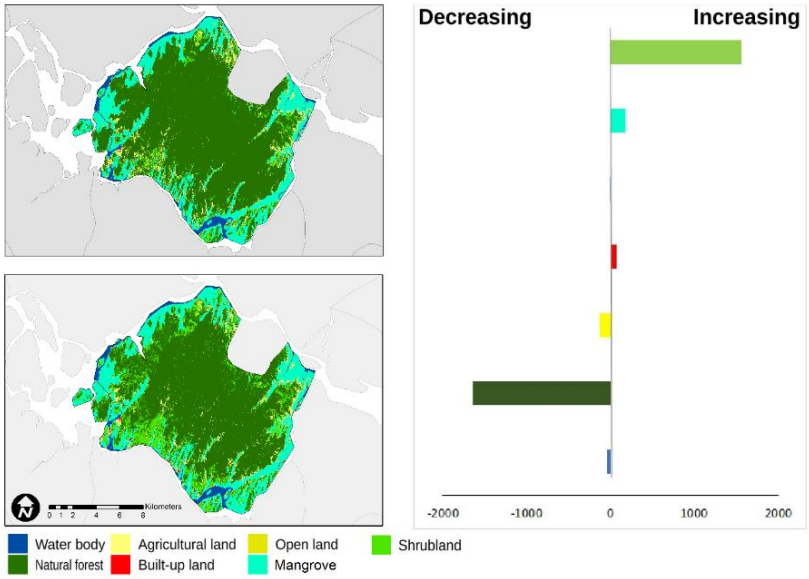


Fig. 8. Changes in land cover in the village of Lorang 2015-2020

Land-use change during the 2015–2020 period shows that Lorang Village experienced a decline in natural forest area of approximately 328.67 hectares per year. The analysis of land-cover change also found a reduction in agricultural land area by 25.89 hectares per year over the same period. In addition, we found an increase in shrubland area by 311.78 hectares per year, indicating that the loss of natural forest was predominantly caused by logging activities. The forest area in Lorang is predicted to continue decreasing to 9,025.65 hectares, representing a 30 percent loss by 2050.

3.5 Spatial distribution of fishing potential in the Aru Islands

This study also examined the potential of fisheries and their accessibility in the Aru Islands. Data from the Department of Marine and Fisheries of Aru Islands Regency (2020) indicate that the estimated fisheries potential of the regency amounts to 516,800 tons, with an allowable catch (JTB) of 205,944.80 tons per year. This consists of small pelagic resources of 123,851.17 tons per year, large pelagic resources of 26,434.32 tons per year, demersal resources of 87,003.28 tons per year, and shrimp resources of 21,111.28 tons per year. In 2009, the number of fishers in Aru Islands Regency was 18,519, with a total of 1,720 fishing groups. Based on their category, there were 14,371 full-time fishers (77.6 percent) and 4,148 part-time fishers (32.4 percent) (Department of Marine Affairs and Fisheries of the Aru Islands Regency, 2010).

Based on the spatial distribution of fishing potential using several ocean water parameters such as bathymetry/sea depth, salinity, chlorophyll, sea surface temperature, and wind speed. The spatial distribution of fishing potential in the Aru Islands shows fluctuating seasonal variations. The fisheries potential in these waters has high abundance from May to October. This is strongly influenced by the salinity of the waters around Aru, which has the highest contribution to the distribution of fisheries potential. Other factors that determine the fishing season for the Aru community are rainfall and waves. People usually recognize the west monsoon and the east monsoon seasons, where during the east monsoon season it is the safest and most profitable time with low rainfall and mild winds. The fishing zone model in the Aru Islands has relatively good performance with AUC values ranging from 0.76 to 0.88, with an average AUC value of 0.82.

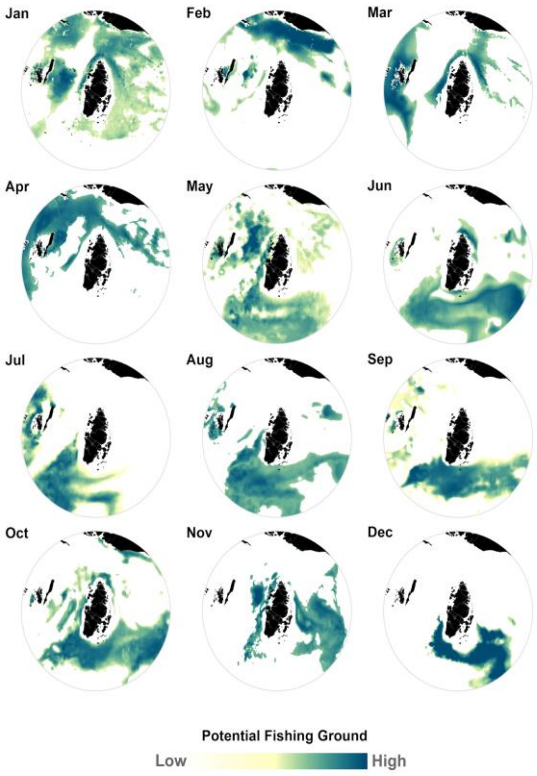


Fig. 9. Potential seasonal fishing around the Aru Islands

The area that is often used as a fishing ground is the southeastern sea of the Aru Islands. This is due to the abundant fisheries potential and the relatively smaller currents and waves in this area compared to the western sea. The utilization of this potential is generally carried out through capture fisheries using very limited means and facilities. However, there are also quite adequate facilities owned and used by fishers from outside the region. The number of fishing gear units in the districts around the Aru Islands is 12,580 units, with the dominant types being hand lines, gill nets, traps, portable sero, and purse seines. Meanwhile, the number of fishing vessels in the districts around the Aru Islands is 2,466 units, consisting of 1,048 non-motorized boats (42.5%), 626 outboard motorboats (25.4%), and 792 motorboats (32.1%) (Department of Marine Affairs and Fisheries of the Aru Islands Regency, 2010).

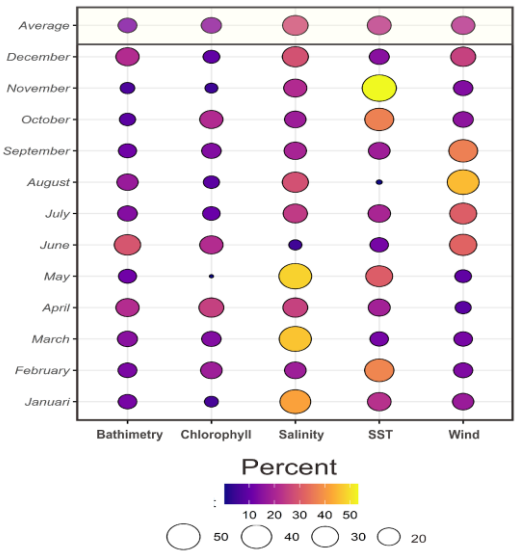


Fig. 10. Contribution of variables to the distribution model of fishing zones in the Aru Islands during seasonal variations

The proportion of these vessel types is not proportional because accessing areas with abundant fish potential requires large engine-powered boats, while nearly 50% of the boats owned by the Aru community do not have engines. This causes the ability of local communities to access their fisheries potential to be very limited. People usually only fish around small straits and rarely access the open sea unless they work for boat owners. Other fishers who usually carry out fishing activities in the Aru Islands mostly come from Central Java, East Java, South Sulawesi, and Southeast Sulawesi.

3.6 Climate and ecosystems and their influence on food sovereignty in the Aru Islands

3.6.1 Land-cover conditions and threats in the Aru Islands

This study analyzed land cover in Aru based on optical satellite imagery using machine learning for the years 2015 and 2020. The Aru Islands have a relatively large natural forest area (more than 50% of the total area of the Aru Islands). Aru also has a relatively wide mangrove ecosystem (18% of the total area of the Aru Islands), which serves as a habitat for shrimp, crabs, fish, and other crustaceans that can be good sources of protein for the Aru community.

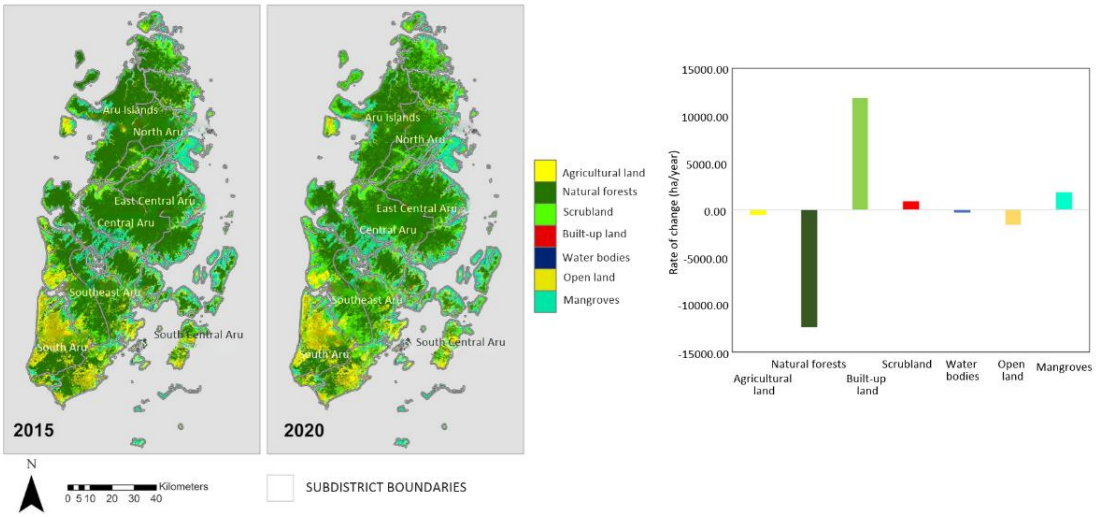


Fig. 11. Historical land cover in the Aru Islands in 2015 and 2020 and the total rate of land change in the 2015-2020 period

Agricultural land was also identified based on satellite imagery, covering 74,000 hectares in 2015 and decreasing to 71,000 hectares in 2020. The study found a decrease in agricultural land area from 2015 to 2020 at a rate of 515.34 hectares per year. This is because, in most villages in the Aru Islands, there is very little agricultural area development as well as land expansion. Communities tend to utilize existing lands, and the potential for trading agricultural products is not very significant, resulting in a general decline in agricultural areas. In addition, a loss of natural forest was found, with an average rate of approximately 12,355 hectares per year. The decrease in forest area is not entirely deforestation (i.e., conversion of natural forest to non-forest or non-vegetated land) but is mostly dominated by forest degradation into secondary forests or shrublands. An increase in shrubland area was found, with an average rate of 11,866 hectares per year. The study also showed an expansion of built-up areas at a rate of 969.59 hectares per year. The land-cover model simulation projected to the year 2050 under a business-as-usual scenario (i.e., following the historical trend of land cover in the Aru Islands) used a land expansion model based on machine learning developed by Liang et al. (2021). The projection model showed relatively good performance, with an overall accuracy (OA) of 0.83 and a Kappa coefficient of 0.75.

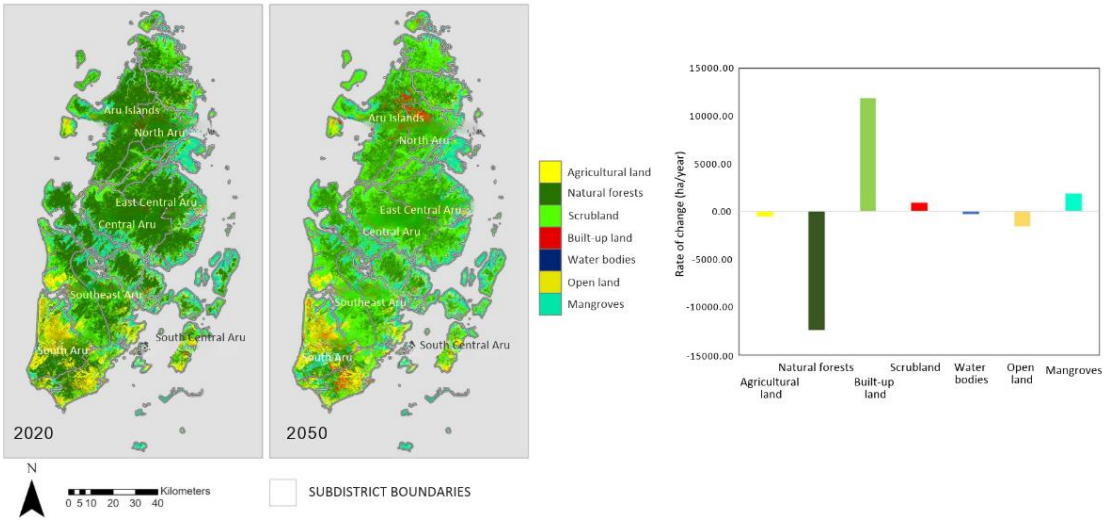


Fig. 12. Land cover projections for the Aru Islands in 2050 and total land change rates for the period 2020-2050

The land-cover projection shows that the Aru Islands will experience significant forest loss by 2050, with only 255 thousand hectares of natural forest remaining, covering just 31% of the total area of Aru. This forest loss will undoubtedly affect the livelihoods of rural communities, which are highly dependent on forest resources not only as a source of income but also as a source of food. The forest loss will also result in the loss of sago grove areas in the Aru Islands, which usually grow in wetland ecosystems within forests. The study results show that future deforestation may reduce the area of sago plantations from 14,344 hectares in 2020 to 3,025 hectares in 2050. This means that the sago area will decrease more than threefold. A significant increase in built-up land was also found, with an area of 35,570 hectares projected for 2050. The potential increase in built-up land occurs in the Aru Islands District area, where the government is currently implementing a trans-regency road construction program, which will open opportunities for future infrastructure and built-up area expansion.

3.6.2 General climate conditions

As an archipelago, Aru has climate variability influenced by the surrounding marine conditions. Ongoing climate change has significant impacts on the people, biodiversity, and ecosystems of the Aru Islands. Based on the Köppen climate classification, the Aru Islands are categorized as having a tropical Af climate, where monthly rainfall is relatively low, ranging from 100 mm to 300 mm, and the average daily air temperature ranges between 25.5 °C and 27.5 °C. The annual rainfall in the Aru Islands varies between 2,170 mm and 2,702 mm. Compared to other tropical regions in Indonesia, the annual rainfall in the Aru Islands is relatively low, so rainfall variability greatly affects agricultural productivity and fisheries potential in the Aru Islands.

The air temperature trend in the Aru Islands, based on GHCN data, shows a relatively significant increase. From 1948 to 2020, the recorded air temperature increase in the Aru Islands was 0.0309 °C. This means that every decade, the average air temperature in Aru may increase by 0.3°C. This can affect ecosystem balance, agricultural productivity, fisheries potential, and the biodiversity that inhabits it. The air temperature projection for the year 2050 in the Aru Islands shows a relatively significant increase ranging from 0.7 °C to 1.4 °C, with an average rise of about 1.07 °C under the business-as-usual scenario. The study results indicate that the most significant temperature increase occurs in the western part of the Aru Islands (e.g., Aru Selatan District), while the eastern part of the Aru Islands is projected to experience a lower temperature increase compared to the western region. The rainfall projection for the year 2050 in the Aru Islands shows variable fluctuations. The difference in annual rainfall in 2050 compared to current conditions ranges from -168 mm to 87 mm.

On average, the Aru Islands are expected to experience a decrease in annual rainfall of about 85 mm under the business-as-usual scenario. This study also found an increase in rainfall in the northeastern part of the Aru Islands.

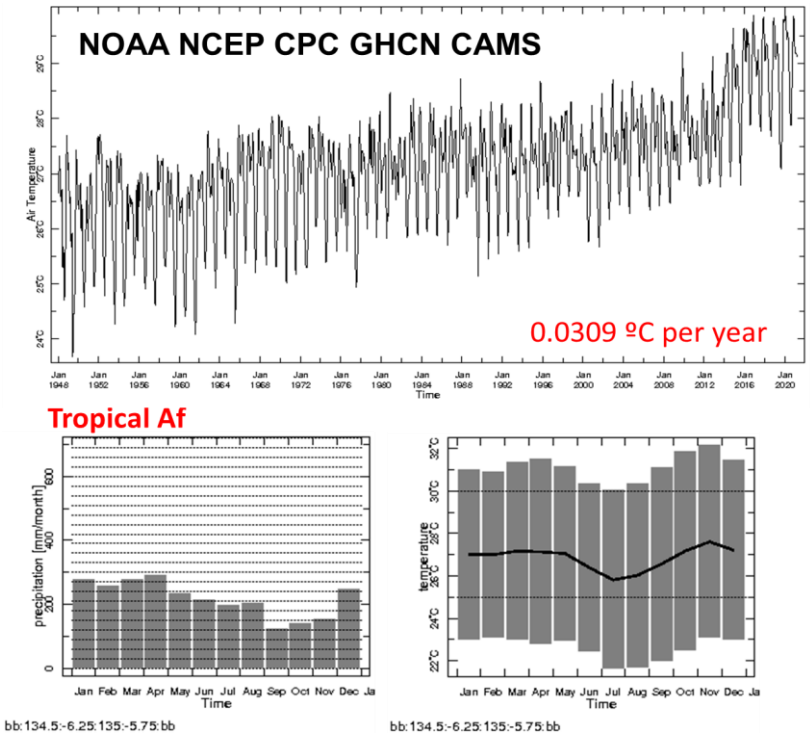


Fig. 13. Koeppen climate classification and historical trends in air temperature change in the Aru Islands

Climate change occurring in the Aru Islands certainly has several impacts on food sovereignty. According to the 2020 IPCC report, climate change greatly affects agriculture and marine resources in small island regions, leading to increased unemployment, poverty, and climate-induced migration to developed countries. In addition, climate change causes rising air and sea surface temperatures, unpredictable rainfall patterns, rising sea levels, changes in regional climate systems, and increased intensity and frequency of extreme weather events, including tropical cyclones, depressions, and droughts.

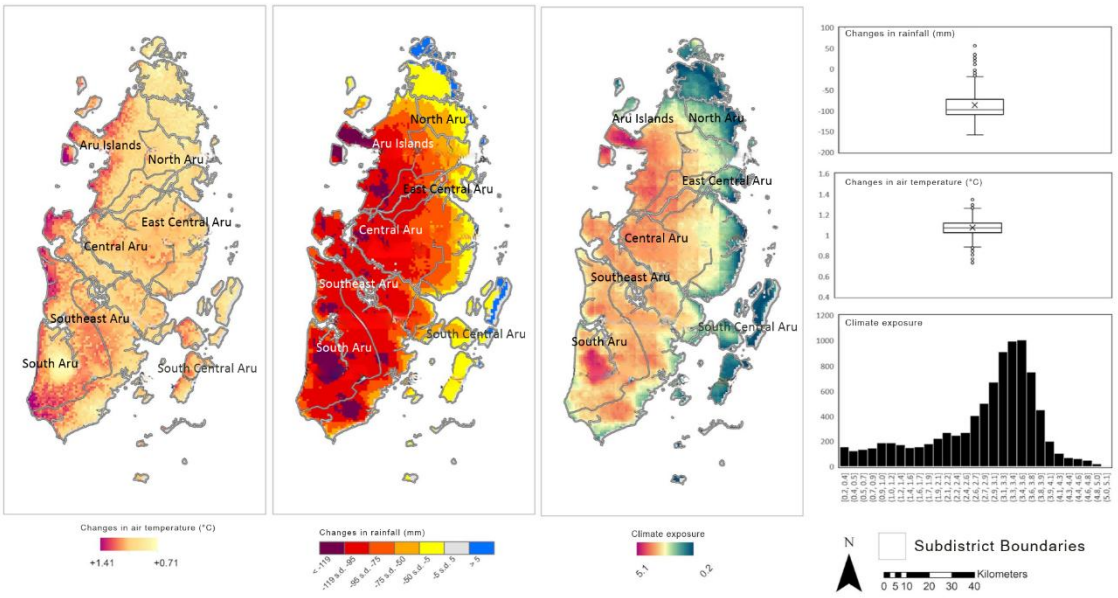


Fig. 14. Climate projections for 2050 in the Aru Islands based on the GCM model

4. Conclusions

The Aru Islands are a maritime archipelago in Indonesia that possesses rich biodiversity and local communities that interact closely with the forests within it, especially in terms of food fulfillment. However, spatial studies in the Aru Islands show that this region will experience significant climate change based on air temperature and rainfall anomalies, especially in the western part of the Aru Islands. The air temperature on the western coast of Aru will experience a very significant increase of up to +1.41 °C in 2050. In addition, rainfall will decrease by around 119 mm. The study also found an increase in rainfall in the northeastern region of the Aru Islands with an insignificant amount. Land use change analysis shows that the Aru Islands will experience a relatively significant decline in natural forest area of 255 thousand ha, covering only 31% of the total area of Aru by 2050. In addition, this study also found a decline in agricultural land of 313 ha per year. This can affect the reduction in food availability and community commodities of the Aru people in the future. The loss of natural forest also implies a reduction of sago land area by three times from the current condition. The sea around the Aru Islands has very abundant fishery potential throughout all seasons or months. However, the utilization of fisheries by the community in the Aru Islands is still very limited, so much of it has not been optimally utilized. In addition, sago plants in the Aru Islands cover an area of 14,344.82 ha. Seven villages in Aru were found to be indicated as having a sago food deficit.

Field studies focusing on Lorang Village show that food fulfillment and food sovereignty systems in Lorang Village rely on the existence and sustainability of forests and seas, the division of production roles in the community, and the tenurial system applied. Lorang Village is among the villages with a sago food surplus, with a sago land area of 795.24 hectares and a production potential of 5.6 million kg. The main source of income of the community also depends on natural products from the sea, namely *karaka* (crabs). However, Lorang Village cannot be said to be food sovereign because the community has begun to depend on staple food sources that cannot be self-produced, namely rice. The difficulty of access to education and health facilities results in the community's limited knowledge regarding nutrition, making the Aru Islands, including Lorang Village, still indicated as a priority 1 food-vulnerable area. Changes in land cover and climate, as well as the absence of legal certainty for the Lorang Indigenous People regarding the ownership of their customary territory, become potential threats not only to food sovereignty in Aru but also to the continuity of the livelihoods of the Aru Indigenous People.

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Author Contribution

A.R.O. conceptualized the research, conducted data collection and analysis, performed spatial modeling, interpreted findings, prepared and revised the manuscript, developed visualizations, and approved the final version for publication.

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References
Arnfield, J. (2017). Köppen climate classification. *Encyclopedia Britannica.* https://www.britannica.com/science/Koppen-climate-classification

Baetens, L., Desjardins, C., & Hagolle, O. (2019). Validation of Copernicus Sentinel-2 cloud masks obtained from MAJA, Sen2Cor, and FMask processors using reference cloud masks generated with a supervised active learning procedure. *Remote Sensing, 11*(4), 1–25. https://doi.org/10.3390/rs11040433

Barri, M. F., Condro, A. A., Apriani, I., Cahyono, E., Prawardani, D. D., Hamdani, A., Syam, M., Ngingi, A. J., Habibie, A., Oktaviani, A. R., et al. (2019). *Bioregion Papua: Hutan dan manusianya.* FWI. https://fwi.or.id/wp-content/uploads/2020/06/FWI-2019-Bioregion-Papua-Hutan-dan-Manusianya

Bernstein, H. (2010). *Class dynamics of agrarian change* (Vol. 1). Kumarian Press.

Bernstein, H. (2017). Food sovereignty via the 'peasant way': A sceptical view. In *Critical perspectives on food sovereignty* (pp. 131-164). Routledge. https://www.taylorfrancis.com/chapters/edit/10.4324/9781315689562-27/food-sovereignty-via-peasant-way-sceptical-view-henry-bernstein

Breiman, L. (2001). Statistical modeling: The two cultures. *Statistical Science, 16*(3), 199–215. https://doi.org/10.1214/ss/1009213726

Buis, A. (2019, June 19). *A degree of concern: Why global temperatures matter*. NASA. https://science.nasa.gov/earth/climate-change/vital-signs/a-degree-of-concern-why-global-temperatures-matter/

Bustaman, S., & Hutuely, L. (n.d.). Membangun ketahanan pangan di Provinsi Maluku berawal dari desa. Dalam *Seminar Nasional Akselerasi Inovasi Teknologi Pertanian Spesifik Lokasi Mendukung Ketahanan Pangan di Wilayah Kepulauan* (hlm. 80–85). BPTP Maluku, Pemerintah Provinsi Maluku, dan Universitas Pattimura. https://repository.pertanian.go.id/bitstreams/c655470b-f7fe-46d9-9e5e-b059272c88b8/download

Department of Marine Affairs and Fisheries of the Aru Islands Regency. (2010). Data potensi sumber daya perikanan Kabupaten Kepulauan Aru. https://kkp.go.id/

Directorate General of Estate Crops. (2021). *Statistik perkebunan unggulan nasional 2020–2022*. Ministry of Agriculture of the Republic of Indonesia. https://ditjenbun.pertanian.go.id

Dirzo, R., Young, H. S., Galetti, M., Ceballos, G., Isaac, N. J. B., & Collen, B. (2014). Defaunation in the Anthropocene. *Science, 345*(6195), 401–406. https://doi.org/10.1126/science.1251817

Fan, Y., & van den Dool, H. (2008). A global monthly land surface air temperature analysis for 1948–present. *Journal of Geophysical Research: Atmospheres, 113*(1), 1–18. https://doi.org/10.1029/2007JD008470

Farr, T. G., Rosen, P. A., Caro, E., Crippen, R., Duren, R., Hensley, S., Kobrick, M., Paller, M., Rodriguez, E., Roth, L., et al. (2007). The shuttle radar topography mission. *Reviews of Geophysics*. https://doi.org/10.1029/2005RG000183

Food Security Agency. (2018). *Food security and vulnerability atlas of Indonesia 2018*. Ministry of Agriculture of the Republic of Indonesia. https://fsva.badanpangan.go.id/fsva_2018

Food Security Agency. (2020). *Peta ketahanan dan kerentanan pangan (Food security and vulnerability atlas) 2020*. Kementerian Pertanian Republik Indonesia. https://fsva.badanpangan.go.id

Food Security Council. (2006). Kebijakan umum ketahanan pangan 2006–2009. *Jurnal Gizi dan Pangan, 1*(1), 57–63. https://doi.org/10.25182/jgp.2006.1.1.57-63

FWI & P4W. (2020). *Potret aktivitas ekonomi masyarakat adat Kabupaten Kepulauan Aru.* https://fwi.or.id/sdm_downloads/potret-aktivitas-ekonomi-masyarakat-adat-kabupaten-kepulauan-aru/

Geronimo, R. C., Franklin, E. C., Brainard, R. E., Elvidge, C. D., Santos, M. D., Venegas, R., & Mora, C. (2018). Mapping fishing activities and suitable fishing grounds using nighttime satellite images and maximum entropy modelling. *Remote Sensing, 10*(10), 1–23. https://doi.org/10.3390/rs10101604

Hajima, T., Watanabe, M., Yamamoto, A., Tatebe, H., Noguchi, M. A., Abe, M., Ohgaito, R., Ito, A., Yamazaki, D., Okajima, H., et al. (2020). Development of the MIROC-ES2L Earth system model and the evaluation of biogeochemical processes and feedbacks. *Geoscientific Model Development, 13*(5), 2197–2244. https://doi.org/10.5194/gmd-13-2197-2020

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., Thau, D., Stehman, S. V., Goetz, S. J., Loveland, T. R., et al. (2013). High-resolution global maps of 21st-century forest cover change. *Science.* https://doi.org/10.1126/science.1244693

Jong, F. S., & Widjono, A. (2007). Sagu: Potensi besar pertanian Indonesia. *Jurnal Iptek Tanaman Pangan, 2*(1), 54–65. https://repository.pertanian.go.id/bitstreams/12576f53-2803-4887-ad6b-b1a52b084e30/download

Karatzoglou, A., Hornik, K., Smola, A., & Zeileis, A. (2004). *kernlab – An S4 package for kernel methods in R. Journal of Statistical Software, 11*, 1–20. https://doi.org/10.18637/jss.v011.i09

Koizumi, M., Mamung, D., & Levang, P. (2012). Hunter-gatherers' culture, a major hindrance to a settled agricultural life: The case of the Penan Benalui of East Kalimantan. *Forests, Trees and Livelihoods*, *21*(1), 1-15. https://www.tandfonline.com/doi/abs/10.1080/14728028.2012.662626

La Via Campesina. (2003, September 2). *Our world is not for sale: Priority to peoples' food sovereignty, WTO out of food and agriculture*. https://viacampesina.org/en/2003/09/peoples-food-sovereignty-wto-out-of-agriculture

Liang, X., Guan, Q., Clarke, K. C., Liu, S., Wang, B., & Yao, Y. (2021). Understanding the drivers of sustainable land expansion using a patch-generating land use simulation (PLUS) model: A case study in Wuhan, China. *Computers, Environment and Urban Systems, 85*, 101569. https://doi.org/10.1016/j.compenvurbsys.2020.101569

Louhenapessy, J. E. (2006). Potensi dan pengelolaan sagu di Maluku. Dalam M. E. Th. Hetharia, M. J. Pattinama, J. A. Leatemia, E. Kaya, J. B. Alfons, dan M. Titahena (Eds.), *Prosiding Sagu dalam Revitalisasi Pertanian Maluku* (hlm. 21–31). Badan Penerbit Fakultas Pertanian, Universitas Pattimura. https://ejournal.unpatti.ac.id/ppr_iteminfo_lnk.php

Marpaung, S., Prayogo, T., Setiawan, K. T., & Roswintiarti, O. (2018). Study on potential fishing zones (PFZ) information based on S-NPP VIIRS and Himawari-8 satellites data. *International Journal of Remote Sensing and Earth Sciences, 15*(1), 51. https://doi.org/10.30536/j.ijreses.2018.v15.a2817

McMichael, P. (2009). A food regime genealogy. *The journal of peasant studies*, *36*(1), 139-169. https://doi.org/10.1080/03066150902820354

McMichael, P. (2013). The land grab and corporate food regime restructuring. In *The new enclosures: Critical perspectives on corporate land deals* (pp. 63-83). Routledge. https://doi.org/10.1080/03066150.2012.661369

Navarro-Racines, C., Tarapues, J., Thornton, P., Jarvis, A., & Ramirez-Villegas, J. (2020). High-resolution and bias-corrected CMIP5 projections for climate change impact assessments. *Scientific Data, 7*(1), 1–14. https://doi.org/10.1038/s41597-019-0343-8

Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological Modelling, 190*, 231–259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

Riahi, K., van Vuuren, D. P., Kriegler, E., Edmonds, J., O'Neill, B. C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., et al. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change, 42*, 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009

Statistics of Kepulauan Aru Regency. (2019). *Kecamatan Aru Tengah dalam angka 2019*. BPS Kabupaten Kepulauan Aru. https://keparukab.bps.go.id

Suismono, & Hidayah, N. (2011). Pengembangan diversifikasi pangan pokok lokal. *JURNAL PANGAN*, *20*(3), 295-314. http://www.jurnalpangan.com/index.php/pangan/article/view/174

Susanto, A. N., & Bustaman, S. (2006). *Data dan informasi sumber daya lahan untuk mendukung pengembangan agribisnis di wilayah kepulauan Provinsi Maluku*. Balai Pengkajian Teknologi Pertanian Maluku, Badan Penelitian dan Pengembangan Pertanian. https://repository.pertanian.go.id/server/api/core/bitstreams/c655470b-f7fe-46d9-9e5e-b059272c88b8/content

Tatebe, H., Ogura, T., Nitta, T., Komuro, Y., Ogochi, K., Takemura, T., Sudo, K., Sekiguchi, M., Abe, M., Saito, F., et al. (2019). Description and basic evaluation of simulated mean state, internal variability, and climate sensitivity in MIROC6. *Geoscientific Model Development, 12*(7), 2727–2765. https://doi.org/10.5194/gmd-12-2727-2019

Wahjuningsih, S. B., Marsono, Y., Praseptiangga, D., & Haryanto, B. (2016). Resistant starch content and glycaemic index of sago (Metroxylon spp.) starch and red bean (Phaseolus vulgaris) based analogue ric. *Pakistan Journal of Nutrition*, *15*(7), 667-672. https://doi.org/10.3923/pjn.2016.667.672

Warren, M., Frolking, S., Dai, Z., & Kurnianto, S. (2016). Impacts of land use, restoration, and climate change on tropical peat carbon stocks in the twenty-first century: Implications for climate mitigation. *Mitigation and Adaptation Strategies for Global Change.* https://doi.org/10.1007/s11027-016-9712-1

Weiss, D. J., Nelson, A., Gibson, H. S., Temperley, W., Peedell, S., Lieber, A., Hancher, M., Poyart, E., Belchior, S., Fullman, N., et al. (2018). A global map of travel time to cities to assess inequalities in accessibility in 2015. *Nature, 553*(7688), 333–336. https://doi.org/10.1038/nature25181

Williams, J. W., Jackson, S. T., & Kutzbach, J. E. (2007). Projected distributions of novel and disappearing climates by 2100 AD. *Proceedings of the National Academy of Sciences of the United States of America, 104*(14), 5738–5742. https://doi.org/10.1073/pnas.0606292104

Yukimoto, S., Kawai, H., Koshiro, T., Oshima, N., Yoshida, K., Urakawa, S., Tsujino, H., Deushi, M., Tanaka, T., Hosaka, M., et al. (2019). The Meteorological Research Institute Earth System Model version 2.0, MRI-ESM2.0: Description and basic evaluation of the

physical component. *Journal of the Meteorological Society of Japan, 97*(5), 931–965. https://doi.org/10.2151/jmsj.2019-051

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