CHAPTER 7

MAP FOR AGRICULTURAL DEVELOPMENT

Tetsuro Kikuchi

In this chapter, a map for future agricultural development in Palau (especially Babeldaob Island, the largest island) was drawn based on the topography, soil property and current land use conditions.

Aim of the map for future agricultural development

The aim of this map is to help the government and farmers disseminate and realize sustainable and environment-friendly agriculture in Palau. As mentioned in Chapter 3, the most dominant landscape in Palau is volcanic uplands (62%), which mainly consist of forests on the Aimeliik soils, grasslands on the Palau soils, and ferns on the Babelthuap-Ngardmau-Udorthents soils. Inadequate forest clearing or burning for agricultural development can transform the relatively fertile Aimeliik soils into the less fertile Palau soils. The Palau soils can be further degraded into the Babelthuap-Ngardmau-Udorthents soils if the vegetation is repeatedly cleared off or burned. The latter soils are highly infertile and no more suitable for agricultural production. Furthermore, the poor vegetation covers on these soils are susceptible for soil erosion that would adversely affect the downstream coral reef ecosystems and their services (e.g., fishery production, tourism) (USDA-NRCS, 2006). Such the “downward spiral” (USDA-NRCS, 2006) must be avoided.

In this map, the land of Babeldaob Island was classified into totally six categories based on the suitability for future agricultural development, which was evaluated by taking the following three factors into account: topography (especially slope), soil productivity and current land use.

Categories for future agricultural development

The description of each of the six categories and their criteria are summarized in Table 8.

Slope is one of the most critical factors that determines the suitability for agriculture. Herbaceous or annual crops (e.g., taro, vegetables) would be recommended to cultivate in the lands with flat or gentle slopes (~ ca. 12%), while fruit trees could be grown in those with more steeper slopes (~ ca. 30%).

Among the soil physicochemical properties, the content of organic matter in soil is of particular importance because soil organic matter (SOM) plays crucial roles in sustaining agricultural productions (see Chapter 3). Lowering the toxicity of soluble aluminum in soil is especially important in the volcanic uplands of Palau where Oxisols, having high contents of soluble aluminum, are prevailing. Agricultural development would be acceptable in the case that the depth of SOM above 1%, by weight, is more than 30 cm (i.e., the depth of typical plant root), unless soil amendments (e.g., organic materials, lime) are necessary.

In principle, forested lands should be conserved and not be exploited for agriculture because those soils can be easily degraded due to inadequate forest clearing or burning (especially in the case that the depth of SOM above 1% is less than 30 cm). If the slope is less than 30% and the depth of SOM above 1% is more than 30 cm, however, traditional agroforestry can be taken place with attention to deforestation.

The criteria for slope and the depth of SOM above 1%, as well as the current land use in each of the six categories are as follows:

Table 8. Descriptions and criteria of the six categories for future agricultural development

Category No.		Description	Slope (%)	Depth of soil organic matter above 1% (cm)	Current land use
1		Recommendable for agriculture	< 12	≥ 30	Non-forested*
2		Recommendable for agriculture with attention to soil erosion	12-30	≥ 30	Non-forested*
3		Soil amendment required for agriculture	< 30	< 30	Non-forested*
4		Recommendable for agroforestry with attention to deforestation	< 30	≥ 30	Forested
5	5-1	Non-recommendable for agriculture	≥ 30	-	-
	5-2		< 30	< 30	Forested
6		Others	-	-	Mines, urban lands

* Except for mines and urban lands.

Category 1 (Recommendable for agriculture): Non-forested lands (except for mines and urban lands) with flat or gentle slopes (~ 12%). The surface layer of soil containing more than 1% of SOM is thicker than the root depth (30 cm).

Category 2 (Recommendable for agriculture with attention to soil erosion): Non-forested lands with relatively steep slopes (12-30%). The surface layer of soil containing more than 1% of SOM is thicker than the root depth.

Category 3 (Soil amendment required for agriculture): Non-forested lands with flat to relatively steep slopes (~ 30%). The surface layer of soil containing more than 1% of SOM is thinner than the root depth.

Category 4 (Recommendable for agroforestry with attention to deforestation): Forested lands with flat to relatively steep slopes (~ 30%). The surface layer of soil containing more than 1% of SOM is thicker than the root depth.

Category 5 (Non-recommendable for agriculture): There are two sub-categories (5-1 and 5-2).
5-1: Lands with steep slopes (≥ 30%).
5-2: Forested lands with flat to relatively steep slopes (~ 30%). The surface layer of soil containing more than 1% of SOM is thinner than the root depth.

Category 6 (Others): Mines and urban lands.

Source data used for drawing the map

The map was drawn by superimposing the land use map in Babeldaob Island (Iida, 2012) on the soil map in Palau (USDA-NRCS, 2009, 2019). In the soil map, the land is divided into totally 62 soil map units (polygons) based on the soil series and properties (including slope and the content of SOM). These polygons were classified into the six categories mentioned above according to the slope and the depth of SOM above 1%. Each of the constituents of Category 6 (bauxite mines and urban lands) forms a unique polygon. In the land use map, the land of Babeldaob Island is divided into forested land and the others based on the information as of 2006. A geographic information system (GIS) software QGIS (version 3.10; https://qgis.org/en/site/) was used for drawing the map and aerial calculations.

Spatial distributions of the lands for future agricultural development

Spatial distributions and surface areas of the lands of each category for agricultural development are described in Fig. 32 and Table 9, respectively. The sum of the lands recommendable for agriculture (Categories 1-3) and the lands recommendable for agroforestry (Category 4) comprised 16% and 30% of the total lands (including inland water bodies) in Babeldaob Island, respectively. On the other hand, more than half (52%) of the lands are not either suitable or exploitable for agriculture (i.e., Categories 5 and 6).

The areas of the lands of each category (except for Category 6) on the soils in typical landscapes (bottom lands, marine terraces, volcanic uplands, areas of limestone and coral sand atolls; see Chapter 3) were also calculated and summarized in Table 10. About 60% of the lands of Category 1 (recommendable for agriculture) are located on the soils in bottom lands, while the majority of the lands of Categories 2, 3 and 5 is located on the soils in volcanic uplands. For Category 4 (recommendable for agroforestry), the share of bottom lands and that of volcanic uplands are almost the same (ca. 45%).

Furthermore, the spatial distributions of the lands recommendable for agriculture or agroforestry (Categories 1-4) in each state of Babeldaob Island are shown, along with the existing agricultural farms (Kitalong, unpublished data), in Fig. 33 (33-1 ~ 33-10) and their areas are summarized in Table 11. Nearly 40% of the lands of Category 1 (recommendable for agriculture) is located in the southern - south-western part of Babeldaob Island (States of Airai and Aimeliik). Northern part (Ngaraard and Ngarchelong) also has about 20% of the lands of Category 1.

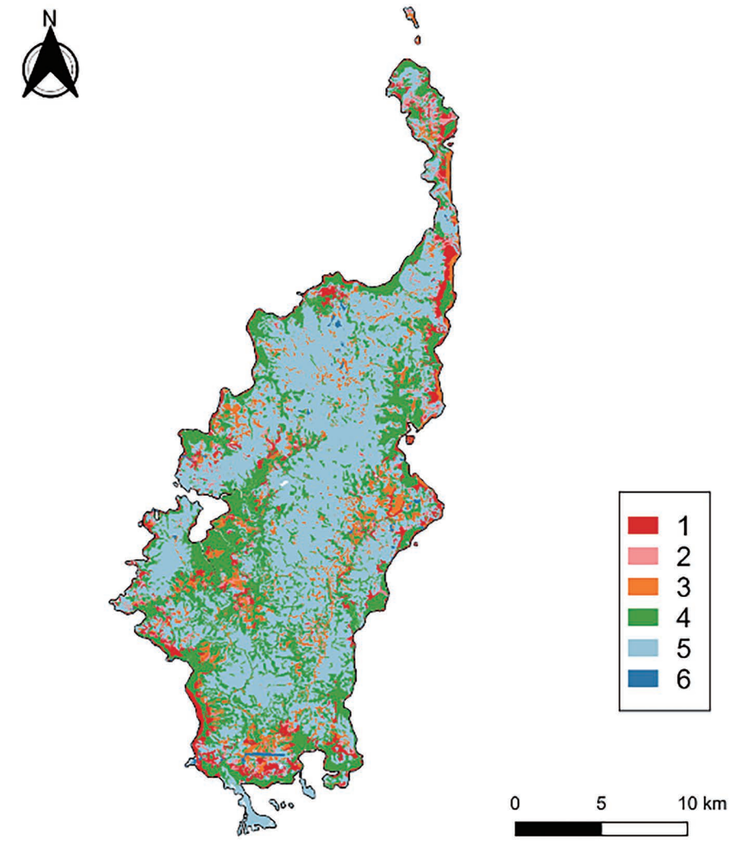

Fig. 32. Spatial distributions of the lands of each category for agricultural development in Babeldaob Island. The number of each category corresponds to that in Table 8.

Table 9. Surface areas and shares of the lands of each category for agricultural development in Babeldaob Island. The number of each category corresponds to that in Table 8.

Category	Area (ha)	Share (%)
1	2,476	6.6
2	1,141	3.1
3	2,488	6.7
4	11,197	30.1
5	19,069	51.2
6	210	0.6

Table 10. Areas and shares of the lands of each category (except for Category 6) for agricultural development on the soils in typical landscapes in Babeldaob Island. The number of each category corresponds to that in Table 8 See Chapter 3 for the details of the soils in typical landscapes.

Landscape	Category 1		Category 2		Category 3		Category 4		Category 5	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Bottom lands	1,470	59.4	0	0.0	0	0.0	5,096	45.5	0	0.0
Marine terraces	342	13.8	158	13.9	346	13.9	793	7.1	117	0.6
Volcanic uplands	664	26.8	983	86.1	1,908	76.7	5,308	47.4	18,582	97.4
Areas of limestone	0	0.0	0	0.0	0	0.0	0	0.0	350	1.8
Coral sand atolls	0	0.0	0	0.0	234	9.4	0	0.0	20	0.1

Note, however, that the intrusion of seawater (i.e., salt water) should be considered in the lands of Category 1 along or near the shores. The lands of Category 2 (recommendable for agriculture with attention to soil erosion) are mainly located in the southern - south-western part (Airai and Aimeliik; nearly 30%) and the northern part (Ngaraard and Ngarchelong; nearly 30%). A quarter of the lands of Category 3 (soil amendment required for agriculture) is located in the eastern part (Melekeok and Ngchesar), while each of Airai and Ngeremlengui has about 15% of them. For the lands of Category 4 (recommendable for agroforestry), about 60% is located in the southern - western part (Airai, Aimeliik, Ngatpang and Ngeremlengui).

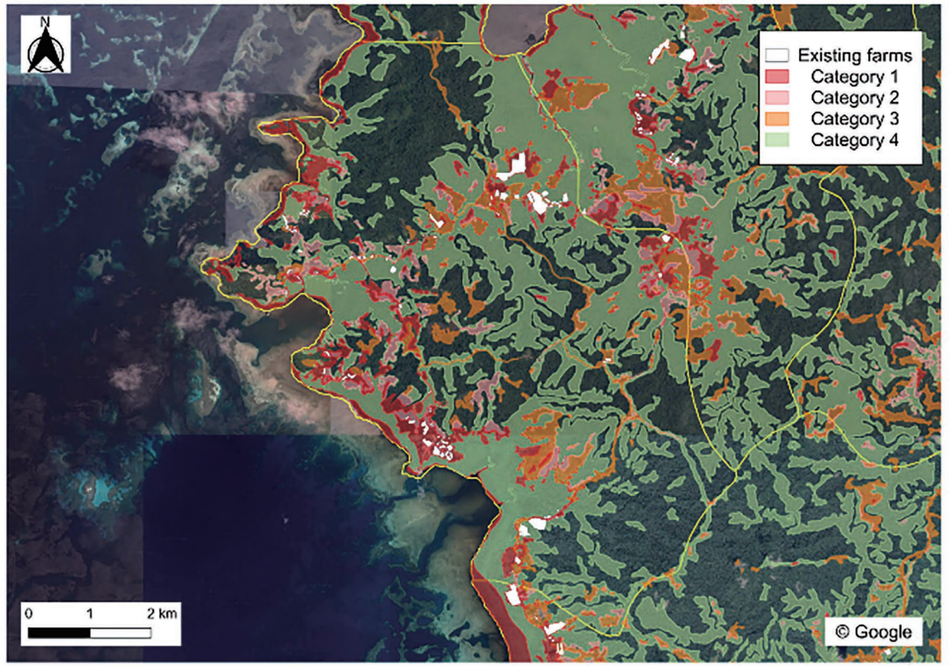

Fig. 33-1. Spatial distributions of the existing agricultural farms and the lands recommendable for agriculture or agroforestry (Categories 1-4; see Table 8) in the State of Aimeliik.

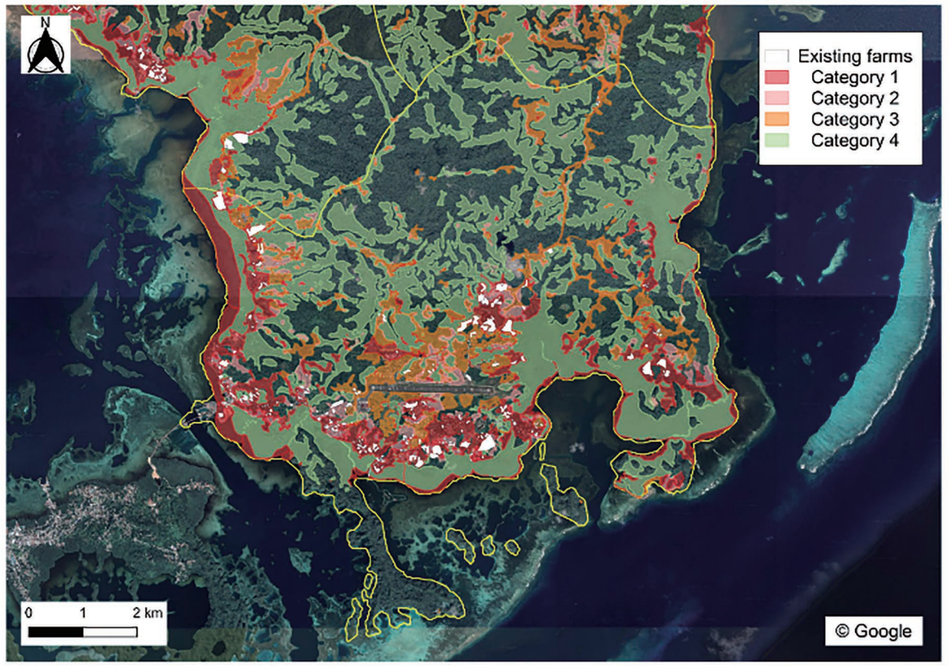

Fig. 33-2. Spatial distributions of the existing farms and the lands recommendable for agriculture or agroforestry in the State of Airai.

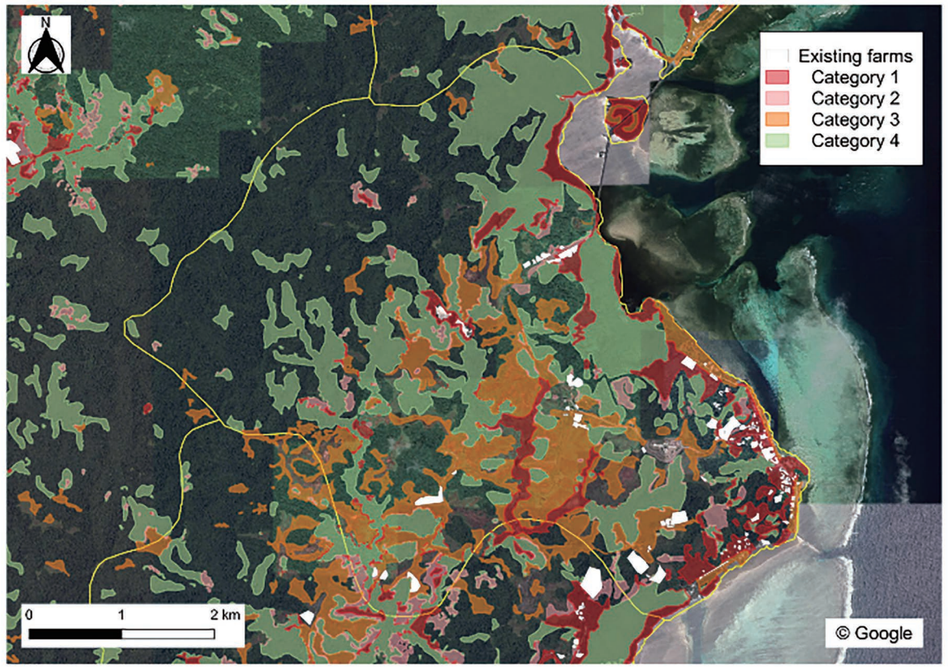

Fig. 33-3. Spatial distributions of the existing farms and the lands recommendable for agriculture or agroforestry in the State of Melekeok.

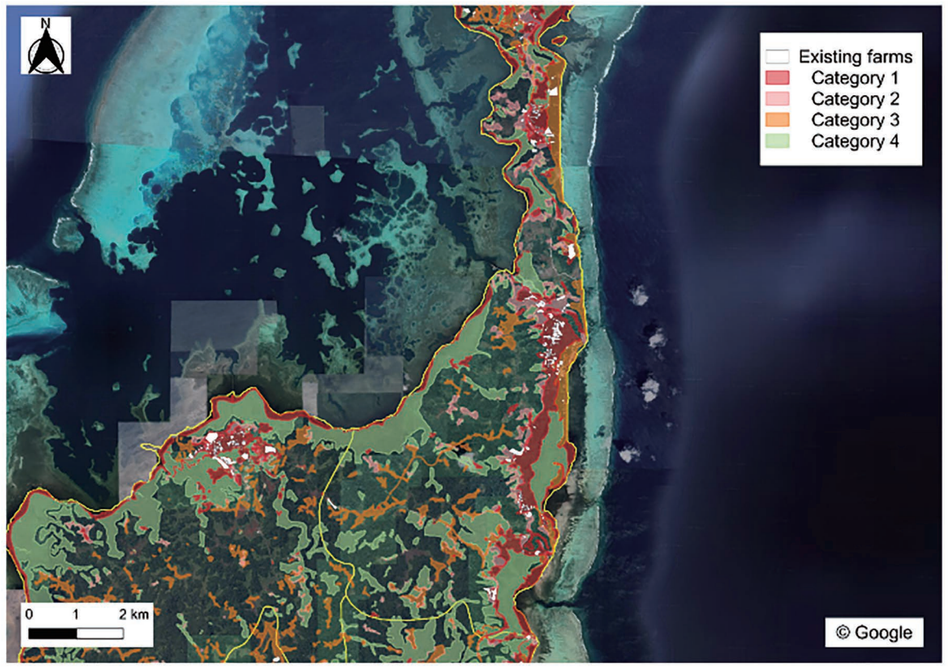

Fig. 33-4. Spatial distributions of the existing farms and the lands recommendable for agriculture or agroforestry in the State of Ngaraard.

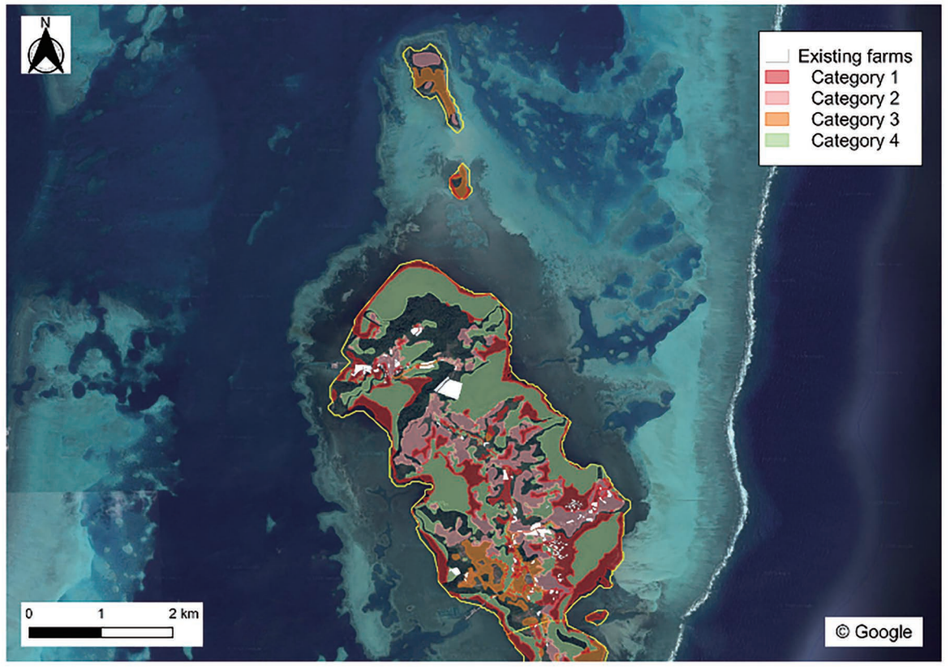

Fig. 33-5. Spatial distributions of the existing farms and the lands recommendable for agriculture or agroforestry in the State of Ngarchelong.

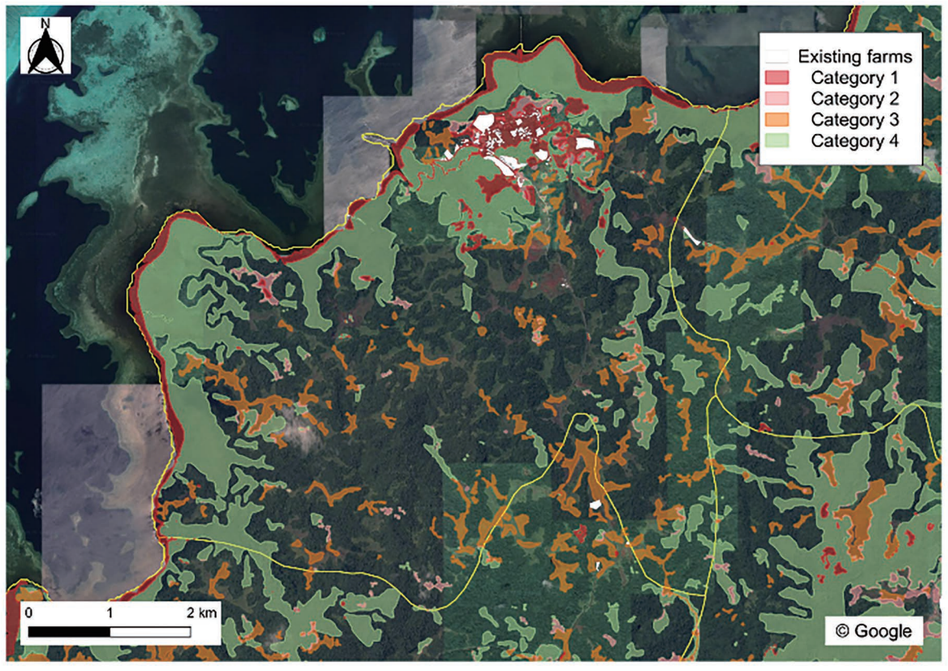

Fig. 33-6. Spatial distributions of the existing farms and the lands recommendable for agriculture or agroforestry in the State of Ngardmau

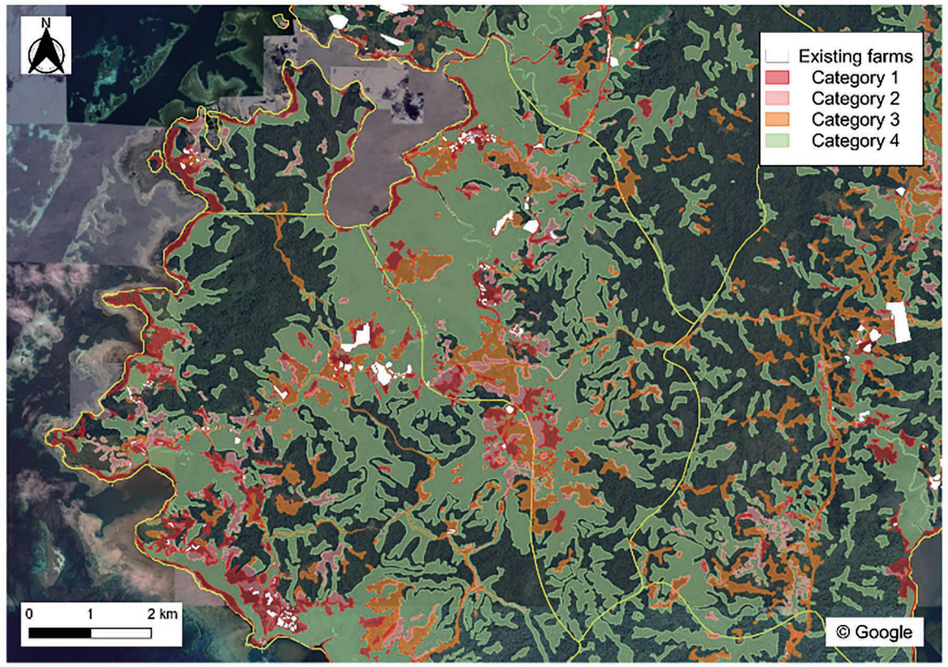

Fig. 33-7. Spatial distributions of the existing farms and the lands recommendable for agriculture or agroforestry in the State of Ngatpang.

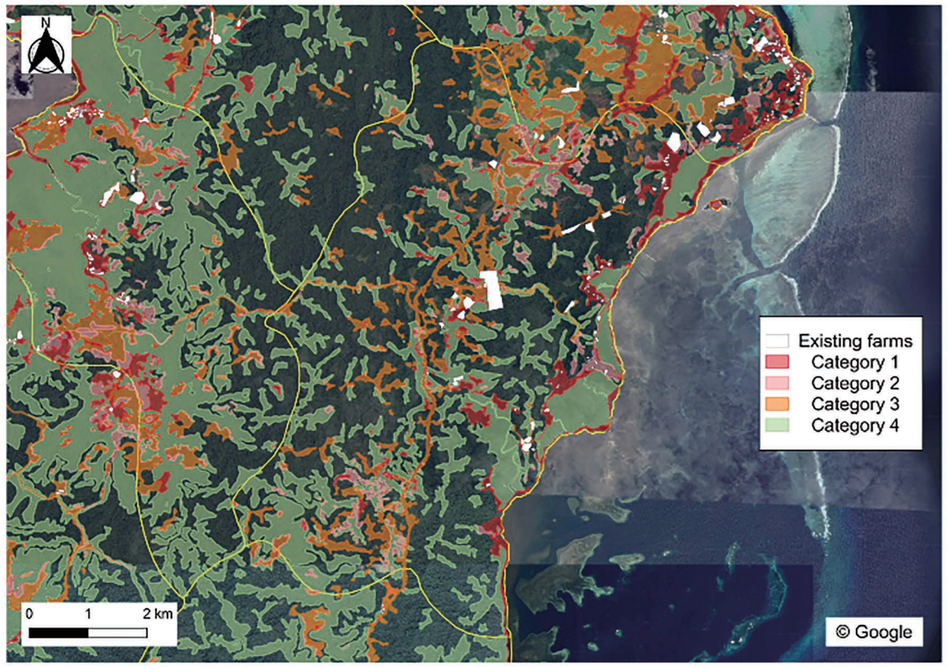

Fig. 33-8. Spatial distributions of the existing farms and the lands recommendable for agriculture or agroforestry in the State of Ngchesar.

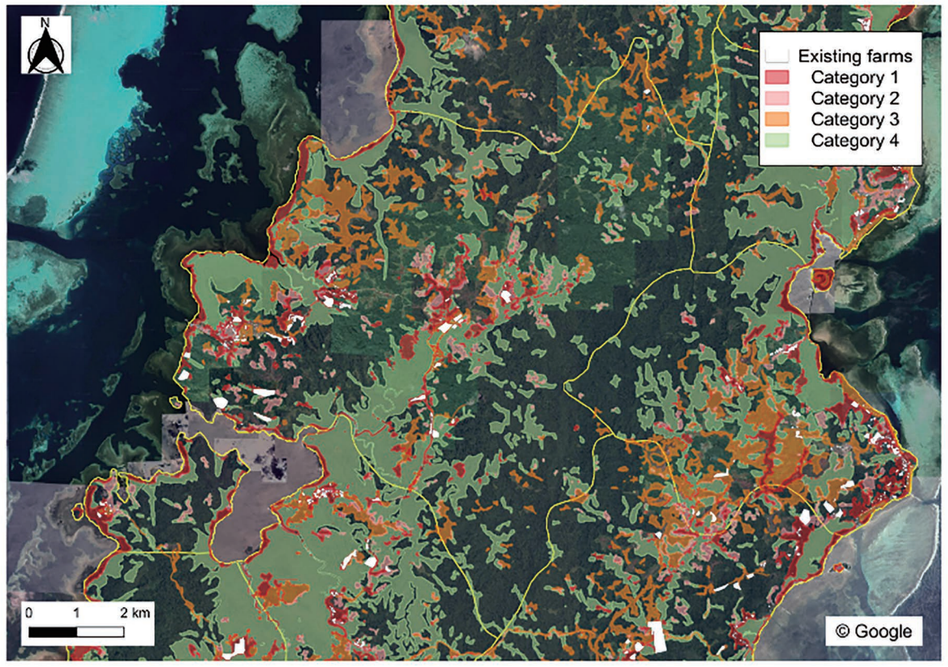

Fig. 33-9. Spatial distributions of the existing farms and the lands recommendable for agriculture or agroforestry in the State of Ngeremlengui.

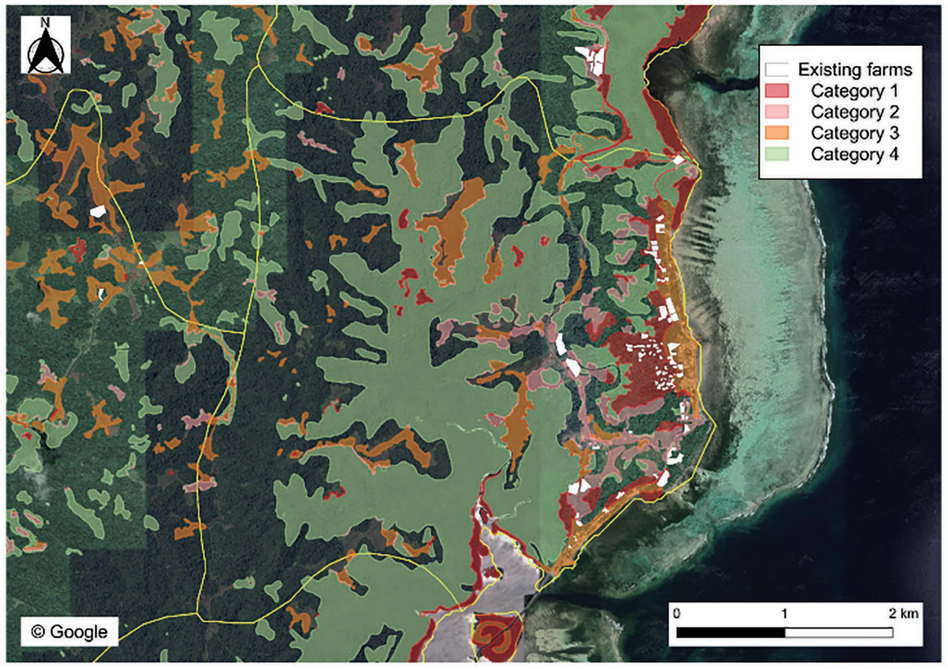

Fig. 33-10. Spatial distributions of the existing farms and the lands recommendable for agriculture or agroforestry in the State of Ngiwal.

Table 11. Areas and shares of the lands of each category for agricultural development in each state of Babeldaob Island. The number of each category corresponds to that in Table 8.

Landscape	Category 1		Category 2		Category 3	
	(ha)	(%)	(ha)	(%)	(ha)	(%)
Aimeliik	286	11.6	150	13.1	238	9.5
Airai	643	26.0	180	15.8	413	16.6
Melekeok	175	7.1	55	4.9	328	13.2
Ngaraard	349	14.1	162	14.2	255	10.2
Ngarchelong	189	7.6	167	14.6	59	2.4
Ngardmau	166	6.7	32	2.8	159	6.4
Ngatpang	166	6.7	104	9.1	225	9.0
Ngchesar	162	6.5	97	8.5	306	12.3
Ngeremlengui	257	10.4	129	11.3	389	15.6
Ngiwal	83	3.3	65	5.7	116	4.7

Landscape	Category 4		Category 5		Category 6	
	(ha)	(%)	(ha)	(%)	(ha)	(%)
Aimeliik	1,751	15.6	1,998	10.5	5	2.3
Airai	2,107	18.8	2,444	12.8	72	34.4
Melekeok	676	6.0	1,229	6.4	25	12.1
Ngaraard	789	7.0	1,791	9.4	9	4.3
Ngarchelong	390	3.5	343	1.8	0	0.2
Ngardmau	754	6.7	2,196	11.5	39	18.8
Ngatpang	1,483	13.2	1,166	6.1	7	3.6
Ngchesar	1,084	9.7	2,649	13.9	23	10.9
Ngeremlengui	1,488	13.3	4,478	23.5	27	12.9
Ngiwal	677	6.0	774	4.1	1	0.6

Locations of the existing farms in the context of the suitability for agricultural development

The areas of the existing agricultural farms in Babeldaob Island on the lands of each category for agricultural development (Table 8) were calculated for each crop type and summarized in Table 12. About 80% of the existing farms are located on the lands recommendable for agriculture or agroforestry (i.e., Categories 1-4). Especially, 69% and 51% (as the areal share) of taro and vegetables, respectively, are cultivated in the lands of Category 1 (recommendable for agriculture). Still, about 20% of farms are located in the lands that are not suitable for agriculture (i.e., Categories 5 and 6). In these farms, agricultural practices should be conducted with careful attention to soil degradation.

Table 12. Area of current crop production in each category.

	All		Taro		Cassava		Banana	
	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)
Total	**450**	**-**	**116**	**-**	**121**	**-**	**201**	**-**
Category 1	197	43.8	80	69.1	52	42.6	84	41.9
Category 2	45	9.9	8	6.5	16	12.8	20	10.2
Category 3	62	13.8	7	5.8	22	17.7	35	17.2
Category 4	47	10.5	8	7.3	6	5.2	18	8.9
Category 5	96	21.4	13	11.4	26	21.1	43	21.3
Category 6	3	0.7	0	0.0	1	0.6	1	0.6

	Betel nut		Fruit tree		Vegetables	
	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)
Total	**215**	**-**	**312**	**-**	**115**	**-**
Category 1	74	34.5	122	39.2	59	51.4
Category 2	29	13.5	36	11.6	11	9.2
Category 3	30	13.8	46	14.9	17	14.5
Category 4	23	10.9	36	11.6	7	6.5
Category 5	57	26.7	68	21.7	21	17.8
Category 6	1	0.6	3	0.9	1	0.6

Glossary

Bauxite: A residual rock-weathering product consisting of hydrated aluminum oxides; the principal commercial source of aluminum

Bottom land: The normal flood plain of a stream, subject to flooding

Fluviomarine terraces: Constructional coastal strip, sloping gently seaward and /or down valley, veneered or completely composed unconsolidated sediments(typically clay silt, sand and fine gravel). Sediments were deposited by both marine and fluvial processes, resulting from sea level fluctuations and/or stream migration

Marine terrace: See Fluviomarine terrace

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CHAPTER 8

TECHNICAL PERSPECTIVE FOR FUTURE CROP PRODUCTION

Fredrick Ikertang, Hide Omae

Soil Amendments for increased agricultural output

Before you begin farming, it is very important to get your soil tested to determine the soil type and condition. When farming in poor quality soil, you can do one or both of the following. First, you can garden using native plants and plants already adapted to your soil. Or, you can amend the soil for the type of plants you wish to grow. A soil amendment is any material, organic or inorganic, added to a soil to improve its physical and/or chemical properties, such as drainage, water retention, aeration, permeability, water infiltration and/or pH, CEC and other soil properties.. This in turn improves biological properties of the soil. The main goal for adding amendments is to improve the soil structure and chemical properties thus improving the root environment for plants. Knowing and understanding the characteristics of your soil type can help determine the amount and type of amendment to add to your soil to improve its structure. Table 13 shows that both sandy soils and clayey soils are the most challenging soil types for farmers from the viewpoint of soil physical properties. Whereas loamy soils have the ideal mixture for better crop growth due to better structure. Soil structure is one of the key properties affecting the productivity of soils and the environmental side effects of agricultural soils (Soinne et. al, 2014). For a soil amendment to work properly, it must be thoroughly incorporated or mixed well into the soil. To just bury the amendment will reduce its effectiveness and will interfere with water and air movement and root growth (Davis and Wilson, 2005).