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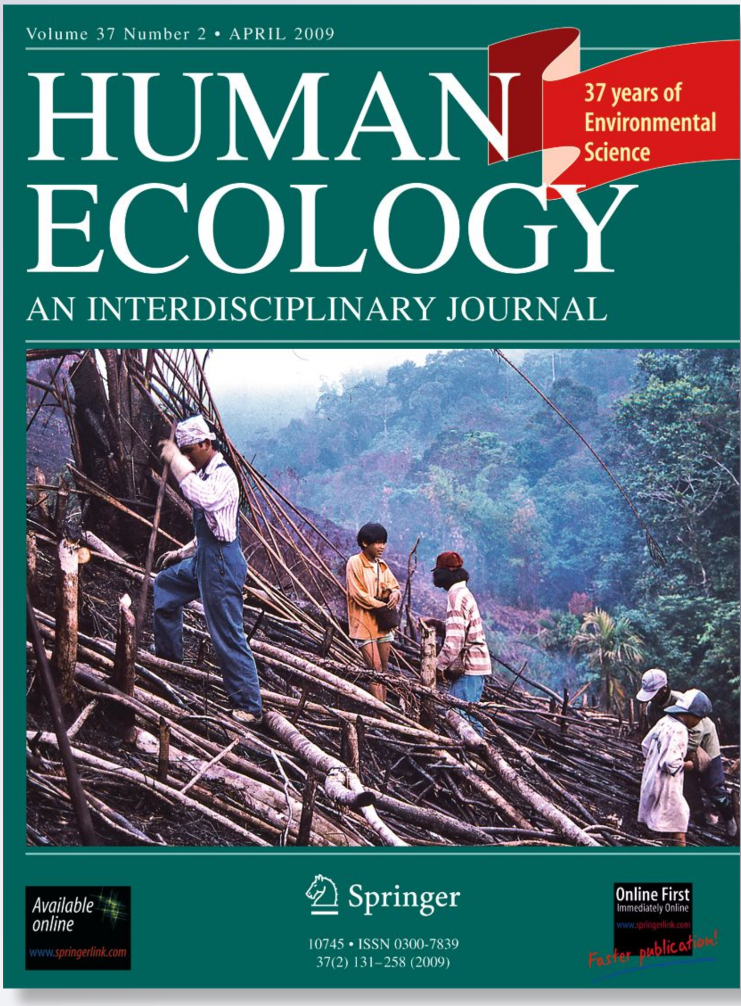

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Spatial Representation of Land Use and Population Density: Integrated Layers of Data Contribute to Environmental Planning in Vanuatu

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Abstract We propose the integration of six data layers (topography, isohyets, soil potential, household localization, vegetation types and land lease titles) to assess the constraints facing food production in Vanuatu, Melanesia. All layers are digitalized allowing area computations of polygons associated with the various data sets. For each island, the following are computed: total area, good arable land area, coconut plantations, pastures/grasslands, area under land lease titles and average accessible good land per household. Although Vanuatu is often considered as not densely populated (19 hab/km^2), results indicate great variation among islands. The average area of good land per household varies from 530 ha on the island of Tegua (North) to 0.5 ha on Futuna (South). Shifting cultivation does not appear to be a serious threat to the environment. The establishment of coconut plantations and permanent pastures represents the main cause of deforestation and contributes to increased pressure on land used for food production. The integration of layers of data is a powerful tool for improving environmental planning in an archipelago under growing human pressure and natural changes.

Keywords Data layers · Food Security · Landscapes and uses · Shifting cultivation · Vanuatu

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Introduction

Compared to other tropical regions, the relatively low population of Oceania offers opportunities for avoiding the conflicts associated with resource exploitation in developing countries. In some Pacific Islands, especially in Melanesia, the traditional customs that allowed communities to live within their environment for millennia still provide adequate sustainability. However, mining, logging and agriculture are increasingly intensive and are poorly regulated or experiencing increasing demand from international markets. If the outlook is disturbing, there is some hope in improved governance and application of customary management principles (Woinarski 2010).

In Melanesia, smallholders practice shifting cultivation of various intensities. At low population densities this cropping system requires clearing only a limited portion of forest and utilizes long fallows. It is often argued that as population increases such activities will increasingly contribute to rapid deforestation (Dixon *et al*. 2001; Jefferson *et al*. 2011). Such trends have been observed in south-east Asia where these systems are rapidly intensifying (Ducourtieux 2009). The division of the landscape into forest and/or permanent agriculture, the expansion of forest conservation, resettlement, privatization of land and the promotion of industrial agriculture based on perennial cash crops (oil palm, coconuts and rubber) all contribute to this process (Fox *et al*. 2009).

Vanuatu is a Melanesian country composed of some 80 islands stretching for 900 km in a north-west to south-east direction (Fig. 1). The archipelago covers a total surface of about 12,230 km^2 and consists entirely of islands of volcanic origin, most of them rising above 700 m with the highest point reaching 1,810 m on the largest island of Espiritu Santo (Siméoni 2009). Vanuatu was settled by *Lapita* populations coming from the north-west (Kirch 2000) about

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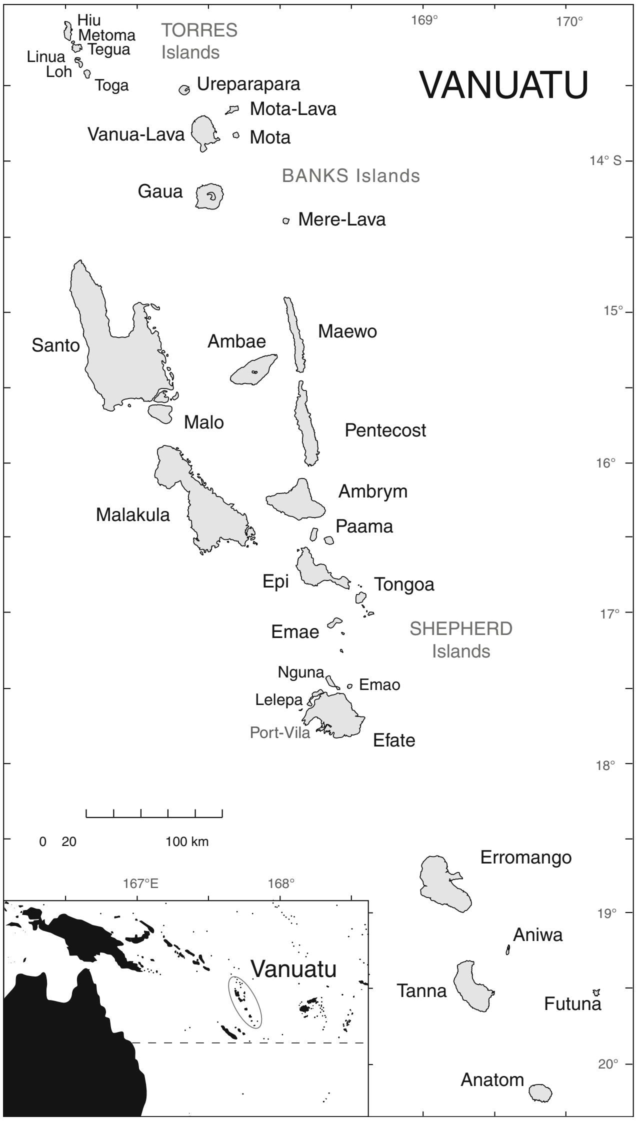

Fig. 1 The Vanuatu archipelago

3,200 years ago who brought with them many of the traditional staple food crops (Bedford 2006). The Melanesians lived in small clan-based villages and for centuries food crops and their relative importance remained unchanged. These are cultivated within diversity-rich agroforestry systems where small plots surrounded by tall trees are exploited for 3 years of annual crops. During the cultivation phase native fruit and nut trees including coconuts (*Cocos nucifera*) are interplanted and then left to grow in the fallows (Lebot *et al.* 2007). Yams (*Dioscorea* spp.) and taro (*Colocasia esculenta*) are the main staples, with bananas (*Musa* spp.) and breadfruit (*Artocarpus altilis*). Numerous other important additional crops such as leafy vegetables, including island cabbage (*Abelmoschus manihot*), a rich source of proteins and calcium, are found in almost all food gardens (Walter and Lebot 2007). Nowadays, these major traditional species are all cultivated within the same plot with other asexually propagated plants: cocoyam (*Xanthosoma sagittifolium*), sweet potato (*Ipomoea batatas*), cassava (*Manihot esculenta*) and kava (*Piper methysticum*).

Vegeculture, as described by Sauer (1952) and Yoshida and Matthews (2002), is an appropriate characterization of the traditional Melanesian cropping system which is always associated to arboriculture. This differentiates it significantly from the south-east Asia "swidden" cultivation system (Rerkasem *et al.* 2009). Increasing agricultural intensification appears to have developed over the last 1000 years and is recorded across a number of islands of the archipelago (Spriggs 1997) without, however, changes in the basic principles of the system.

In 2009, the Vanuatu population was 234,000. However, before the first contact with Europeans in the 1800s it was probably between 500,000 (Speiser 1991; Kirch and Rallu 2007) and 1 million (Harrisson 1937). The explorers Quiros (1606 cited in Baert 2007) and Cook (1778) both observed that these islands were densely populated. Evidently, the traditional shifting cultivation system supported a population significantly larger than it is today.

Commercial plantations, coconuts for copra, cocoa (*Theobroma cacao*), coffee (*Coffea arabica*) and livestock (*Bos taurus* and *B. indicus*) were established in the nineteenth century by European settlers (Bonnemaison 1994). When Vanuatu gained its independence from the Anglo-French Condominium of the New Hebrides on July 30th 1980, alienated land was returned to its "customary owners"—either indigenous individuals or communities whose ownership claims were based on customary practices. The concept of customary ownership became important before independence in opposition to the Western system of land tenure. Access to and rights over land are not widely shared and tend to rest with senior males who distribute them within their communities (Rodman 1995). Group ownership by families or clans exists but in most cases if a piece of land has not recently been used their ownership might be revoked by the village chief. Land disputes are usually resolved at the community level but a Land Disputes Tribunal currently addresses conflicts at the national level. Customary owners are free to lease their land to outsiders under registered leaseholds, usually of 50–75 years. Lessees are often expatriates, but increasingly indigenous citizens from other islands are also leasing land. On the expiration of leases, land can be returned to owners on payment of compensation to the lessee for capital investments (buildings, plantations and infrastructure).

In the immediate post-independence decade, development projects were initiated to increase smallholders' participation in commercial agriculture. Smallholders were encouraged to produce commodities such as copra, cocoa, coffee and meat for the export market despite the obvious handicap of Vanuatu's geographical location (Weightman

1989). Little or no attention was given to the improvement of the traditional smallholder food cropping system. More than 30 years after independence it is obvious that this emphasis on commercial production for export has not succeeded in providing local food security (VanGov 2010). Due to the costs of imported fuel, locally produced foods are expensive and in urban areas, fresh foods imported from the outer islands are more expensive than imported processed foods (wheat flour, white rice, tinned meat and fish). The production of food and agricultural products needed by a rapidly growing population (2.3 %/yr) is a major challenge. On most islands there is limited scope for increasing the area under cultivation and quantitative data are urgently needed to assess differing constraints.

This article attempts to provide such information by integrating different data layers, including GPS and GIS technologies, combined with data from field surveys. Our overall objective is to record all environmental constraints to the development of local food production. We argue that this approach is a necessary component of feasibility studies undertaken in relation to development projects in fragile insular environments. Potential applications for improving the sustainability of food crop production in Vanuatu are also discussed.

Methodology

We digitized and compiled detailed thematic maps for the *Atlas of Vanuatu* (Siméoni 2009) and augmented the resulting templates by six digitalized layers of recent data from the Vanuatu National Statistics Office (VNSO) and the Department of Lands: 1) topography; 2) rainfall; 3) agronomic potential of soils; 4) spatial distribution of households; 5) vegetation types; and 6) land lease titles. For each island the following are calculated: total island area (ha), good arable land area (good soils in ha), number of households (hld), good land per household (ha/hld), area under coconut plantations (ha), area under pasture (ha), area under land lease titles (ha) and the average area of accessible good land per household (ha). All layers are in MapInfo™ format, which allows area computations of the various polygons. Statistics obtained by the latest agricultural census (VNSO 2008) are also used to estimate areas planted with annual and perennial crops and to assess reliability of GIS data.

Topography

Aerial photography coverage of the archipelago was conducted in 1954–1955 by the French Institut Géographique National (IGN). The first colour maps were published in 1960 at 1/100 000 scale for Efate, Epi-Shepherd, Tanna and Erromango, and at 1/50 000 scale for Efate (4 sheets: NE, NO, SE, SO). A second coverage was conducted by the United Kingdom Royal Air Force in 1962–1963. In 1979, IGN maps covered the whole archipelago. In 1993, the Vanuatu Resource Information System (VANRIS) funded by AusAID, combined various natural resources data (landform, geology, soils, land use, vegetation) in digitalized maps. Finally, in 2002 the Australian Defence Force produced a new aerial coverage resulting in the publication of 62 maps (1/50 000) and 46 aerial photographs of Port-Vila and other provincial administrative centres. Digitized topographic contours were created under MapInfo™ (*VANRIS* database completed by satellite imagery) and used to generate the topography layer (Siméoni 2009).

Rainfall

The Vanuatu Meteorological Service maintains six main stations and 18 secondary stations distributed throughout the archipelago. Daily rainfall and temperature records exist for the last 50 years. Data from the records of the meteorological stations since the 1950s combined with altitudinal contours were used to develop a layer of isohyet zones throughout the archipelago (Siméoni 2009). There is significant variation from south to north, the southern part of the country being cooler and dryer. The average annual rainfall in the northern Banks Islands is around 4,000 mm and is less than 1,500 mm in Lenakel on the southern island of Tanna. On each island, under the effect of winds and altitude, the climate is differentiated into three main zones. The windward (south-east) side with high rainfall presents forests comprising taller evergreen trees. On the dryer leeward side there are semi-deciduous forests with small trees and at higher altitudes cloud forests.

Agronomic Potential and Land Use Maps

The soils of Vanuatu are quite variable because of regular volcanic activity, tectonic uplift and climatic differentiation. Between 1972 and 1978 the Institut de Recherches pour le Développement (IRD) made a thorough study of them and published the results as an *Atlas of Soils* with maps covering the soils, geology, topography and vegetation (Quantin 1980, 1982). Maps were also produced showing agronomic potential, using a system based on an American classification (USDA 1972), including one at 1/500,000 for the whole archipelago and others at 1/100,000 for the four major islands of Santo, Malakula, Efate and Tanna. The classification focussed on suitability for commercial agriculture, including adaptability to mechanisation, with recommendations for perennial cash crops or for cattle and pastures. The classification used limitations on productive land use to rank areas into seven classes of productive potential. Those limitations included soil characteristics, topography and environmental factors such as climate. The classes were ranked in descending order of potential as their limitations increased: optimum (I), good (II), average (III), mediocre (IV), poor (V), very poor (VI) and nil (VII). Classes I, II and III are the most suitable for agriculture and class IV would require major improvement to be exploited. Classes V, VI and VII are virtually useless for agriculture (Quantin 1982). Data, such as geology, landform and soil types, which are not subject to significant change, remain valid and have been used in the present study. The IRD maps have been digitized into GIS, but for assessment for food crops production the classification has been simplified into three classes: good (combining I, II, III), poor (IV) and nil (V, VI, VII) (Siméoni 2009).

Geographical Distribution of the Population (Households)

The first population census was conducted in 1967 (Mac Arthur and Yaxley 1967) and VNSO has carried out censuses every 10 years since 1979 (VNSO 2011). The latest census (2009) is particularly valuable because all households have been recorded using GPS. The VNSO definition of one household is "those who usually eat together and share the work of preparing the food and/or the cost of work providing it." This definition is also that of the production unit for subsistence and food crops agriculture, broadly representing a family of an average size of 4.8 persons. Household listings were compiled for each of the five provinces of Vanuatu (Torba, Sanma, Penama, Malampa, Shefa, and Tafea). Every household was counted as well as the usual number of people who live there. The main dwelling occupied by the household was marked with a reference number which along with GPS location, was used to locate all of the households. The spatial distribution of the population is very heterogeneous and this mapping of population under GIS (MapInfo™) contributes to the identification of zones of high and low human pressure on arable land.

Vegetation Maps

The first coverage of the archipelago (Quantin 1980) has been digitized (Siméoni 2009). In 2010, a new set of maps was produced by the FAO project MAR (Strengthening Monitoring Assessing and Reporting on Sustainable Forest Management). This project conducted a survey of the different vegetation types using satellite images (Landsat, ASTER=Advanced Spaceborne Thermal Emission and Reflection Radiometer and GoogleEarth™) as well as high-resolution airborne radar imagery obtained between 1999 and 2003 (Schweter 2011). The data consist of geo-referenced .jpg files clipped to an index of 1:50,000 topographic map sheets covering the entire country. Multispectral satellite image data from LANDSAT and ASTER satellites were the main source of information for distinguishing vegetation, forest and land cover categories. Although the LANDSAT imagery covers the entire country, cloud cover does not allow for an interpretation of the data over some of the islands. An important source of information was found to be the high-resolution imagery freely available on GoogleEarth™. For many islands of Vanuatu recent high-resolution imagery is available for visual comparison and calibration of the classification routine. To this effect, image interpretation and online verification using GoogleEarth™ data were also done. In some cases, images of 2010 were available. The computerised analysis using the IDRISI Taiga™ software (version 15.0, Clarks Labs, Worcester, MA, US) produced a database under ArcGIS™ software (ESRI, Environmental Systems Research Institute, Inc., Redlands, CA, US), which allows the treatment of a mosaic of satellite images obtained from different vegetation types cover. Overall, 17 different types of vegetation have been identified for the whole archipelago (Schweter 2011). Extensive field surveys were conducted on Efate and Santo to assess the reliability of these results on both islands.

Agricultural Census

An agricultural census was conducted in 2007 under the auspices of the FAO and 18 major islands were studied to derive quantitative information. Data processing was conducted by VNSO with the assistance of FAO. Phase I of the census was a listing conducted in 2006, for all households whether residing in urban or rural areas. The data gathered were on gender, whether engaged in gardening, cash cropping, fishing, forestry and logging activities, and number of cattle kept on listing day. Phase I listing was used to select sample enumeration areas for Phase II conducted in 2007. There were separate questionnaires for each agricultural activity. Information from commercial farms and holdings was collected in the latter part of Phase II. The sampling method classified the 18 islands surveyed as: i) small, with number of households engaged in agricultural activities less than 500 (Torres, Paama, Erromango, Aniwa, Aneityum and Futuna); ii) medium, with number of households between 500 and 1,999 (Banks, Malo, Maewo, Ambrym, Epi and Sheperd); and iii) large, with number of households 2,000 or more (Efate, Malakula, Ambae, Pentecost, Santo and Tanna) (Fig. 1). For small islands, all households were listed and identified households were enumerated. For medium-sized islands, one-third of the sample enumeration areas in these islands was selected and all households engaged in agricultural activities were interviewed. Finally, for large islands, one third of the enumeration areas was selected. All households were listed and one third was selected to be further interviewed. Not less than 650 trained enumerators listed every household and recorded all agricultural activities (VNSO 2008).

Land Lease Titles

Except for urban land of the two major towns of Port-Vila (Efate) and Luganville (Santo) which is state owned, land in Vanuatu is held by customary land owners. Land use and management are therefore ruled by customary land rights. Since 1983 land owners are allowed to lease their lands to indigenous and non-indigenous individuals and these leases are registered by the Department of Lands. Since 2010 the Department of Lands has also maintained a GSI data base of all land leases. Lands where ownership is disputed at the village level for the purposes of the present study are considered leased although they represent less than 5 % of total area leased. The total area under leases represent a physical constraint to shifting cultivation, hence their inclusion. In many cases these leased lands consist of coconut plantations and permanent pastures and in some cases, peri-urban subdivisions.

Results

Digitized maps integrating the six data layers were produced for the whole archipelago and for the ten major islands. Integration of data layers no. 2 (good soils), 3 (population), 4 (vegetation cover) and 5 (land lease titles) allows the area measurements of 32 islands and groups of islands (islands and their surrounding islets) encompassing 100 % of the total land area of Vanuatu.

Access to Water

In Vanuatu, most communities use rain water for daily use (cooking and hygiene). Despite generous rainfall, there are few permanent rivers. In areas receiving less than 2,000 mm per year, water supply is an important determinant of village location. When rainfall is low, some villages are restricted to using water from deep wells. Communities are often located near natural springs. For rain-fed shifting cultivation and annual food crops production there are two important isohyets: 2,000 and 3,000 mm which allow the identification of three clearly differentiated zones. The three zones are present on all major islands. On the leeward (western) side of the islands, the annual rainfall is under 2,000 mm/yr and rain-fed cultivated plots may suffer from droughts during the dry season, with cassava and yams being better adapted than taro, cocoyam or sweet potato. On the windward eastern sides, annual rainfall is between 2,000 and 3,000 mm, and local constraints are minor. Various species can be cultivated (with *D. alata* yam, however, suffering from anthracnose, *Colletotrichum gloeosporioides*). Finally, above 3,000 mm, often at higher altitude, several crops (yams, cassava, sweet potato) suffer from insufficient sunlight and from water-logged soils, drastically reducing their yields. However, taro (*C. esculenta*) is well adapted to such habitats. Overall, throughout the archipelago, the "wet and the dry" as described by Barrau (1958) are responsible for the significant cultural differentiation between communities growing taro (wet) or the *D. alata* greater yam (dry) as a first crop in their 3-year cropping systems (see also Bonnemaison 1994). Two major agricultural activities, the commercial coconut plantations and cattle ranches are not well represented in the southern islands. The lack of easy access to surface water throughout the year, especially on Ambrym, Ambae, Tanna and on many smaller islands in the archipelago, contributes to low weight gains for smallholder cattle and in severe circumstances, to high mortality rates. Furthermore, limited water availability poses problems for the establishment of plantation nurseries and therefore their subsequent field establishment. Other factors are lower mean temperatures which slow down the growth of coconut trees.

Arable Land and Good Soils

Because of their youth and deposits of volcanic ash, Vanuatu soils are fertile and diverse. The most common are andosols on recent volcanic ashes, brown erosion soils (often deeply modified by erosion) on the oldest sedimentary chains, fersiallitic and ferrallitic soils and humus rich andosol type soils on the summits (Quantin 1980). However, much of the land is too rugged or too humid to be readily brought into cultivation. On our maps, the good arable land is represented in three different greens. The subdivision of these good soil areas according to the two major isohyets (2,000 mm and 3,000 mm/yr) results in the identification of environments suitable for different cropping systems on each of the major islands (Fig. 2). The soils data layer indicates that Vanuatu has a total potential of cultivable land (Quantin's classes I, II and III together) of 492,177 ha (4,922 km^2) or 40 % of the total land area (12,232 km^2). In some inhabited islands, the arable land is less than 30 % of the total area, e.g., the small islands of Ureparapara (4 %), Merig (0 %), Paama (25 %), Aneityum (13 %) and Futuna (6 %), but also the larger islands of Ambrym (21 %) and Erromango (20 %) (Table 1). For Erromango, the very low population (324 households) can be partly explained by the predominance of poor soils and by the fact that good soils are located in areas where malaria is endemic (Ratard 1976). The size of the population is also constrained by the topography of the island, with a leeward side boarded by high cliffs and dangerous rocks, while there is only one safe access for ships on the windward side, Port-Narvin, which is surrounded by hills, limiting sea access to the island. For individual island maps, the soils of average potential are in yellow and soils of poor potential are in grey. In Santo, most of the population is located on the windward (southeast) side of the islands (between 2,000 and 3,000 mm). In this area,

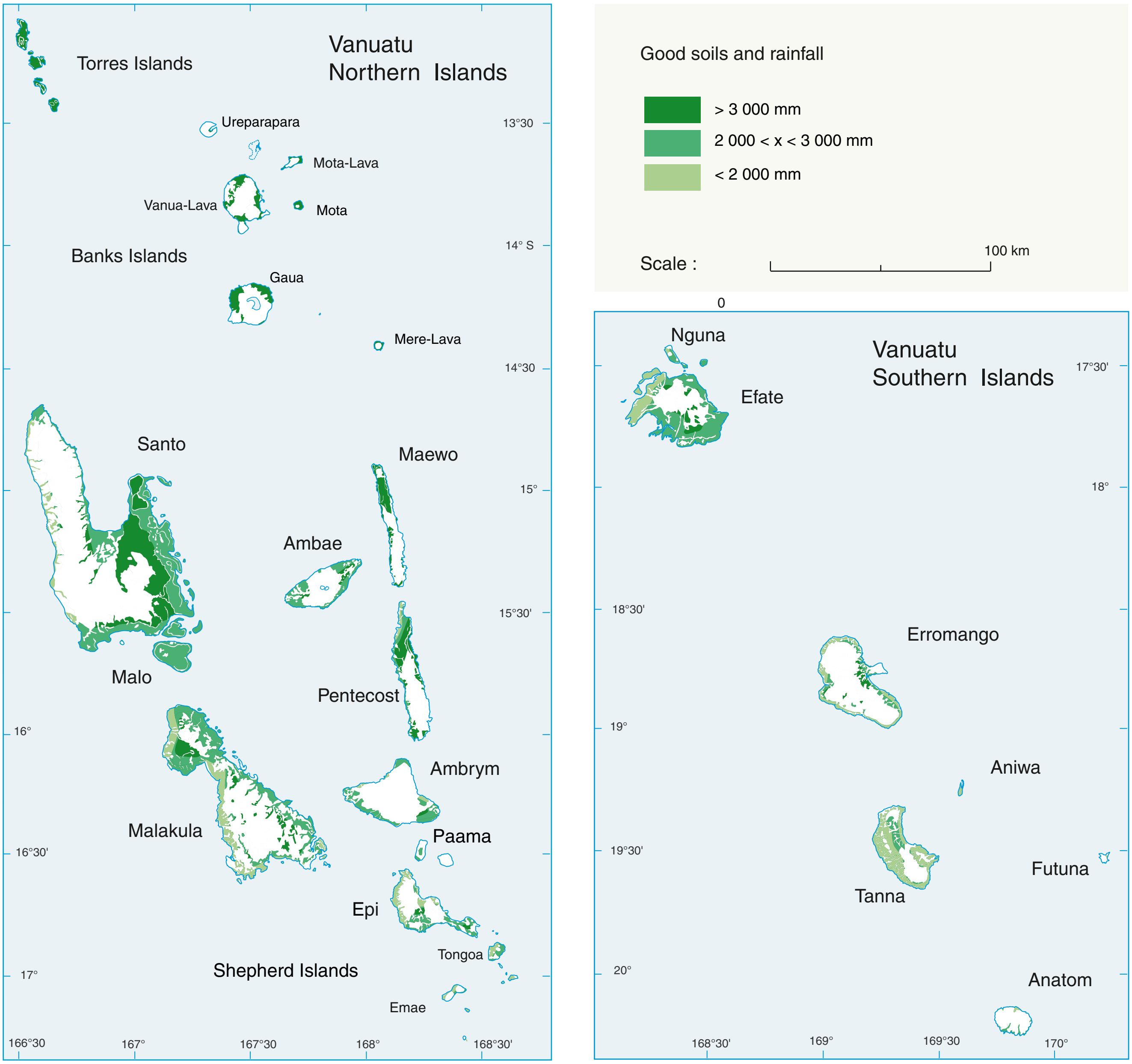

Fig. 2 Identification of environments suitable for different cropping systems on each of the major islands of Vanuatu

important plateaus covered with good soils but where rainfall is over 3,000 mm/yr are not populated (dark green). The dry areas (<2,000 mm) of the leeward side (northwest) are sparsely populated (Fig. 3).

Population Density

Results of the 2009 census allow the accurate location of 47,370 households, of which 35,767 are located in rural areas (VNSO 2011). On our maps each household is represented by a red dot. Not surprisingly, most of the rural households are located on the good arable soils. The colonisation of this archipelago started more than 3000 years ago in different waves of settlement (Bedford, 2006) with populations establishing villages on the soils most suitable for rain-fed subsistence agriculture. This is quite noticeable for Santo where there is very little population on yellow (average) and grey (poor) areas. It is also observed on the east of Santo that populations are establishing themselves along roads but that these settlements stop as soon as the road crosses an area of poor potential soils (Fig. 3).

The population density of Vanuatu is low, with a national average of only 19 hab/km^2 (VNSO 2011), which translates as a density of 48 hab/km^2 of good arable land. Although convenient, this ratio does not take into consideration the fact that good arable land suitable for shifting cultivation

Table 1 Good land accessible per household in the main islands of Vanuatu

Provinces and Islands	Total Island Area *(ha) (1)*	Good Land *(ha) (2)*	(%)	Households *(no.) (3)*	Land/household *(ha/hld) (2/3)*	Plantations *(ha) (4)*	Pastures *(ha) (5)*	Lease titles *(ha) (6)*	Acc. good land[a] *(ha) (7)*	Acc. land/hld *(ha/hld) (7/3)*
Torba:										
Hiu	4,665	3,517	75	44	79.9	0	0	0	3,517	79.9
Linua	228	228	100	0	0	0	0	0	228	76.1
Lo	994	657	66	33	19.9	0	0	0	657	19.9
Metoma	294	215	73	1	215	7.8	0	0	207	207.4
Tegua	3,176	2,652	84	7	378.9	0	0	0	2,652	378.8
Toga	1,880	1,665	89	44	37.8	67	0	0	1,598	36.3
Ureparapara	3,953	142	4	94	1.5	54	0	0	114	1.2
Vanua-Lava	33,478	8,750	26	485	18.0	713	0	0	8,151	16.8
Gaua	29,086	8,877	31	446	19.9	1,316	0	0	7,857	17.6
Rowa	96	95	99	0	-	0	0	0	95	-
Mota-Lava	3,285	1,518	46	339	4.5	3,781	0	0	1,185	3.5
Mota	1,029	840	82	137	6.1	429	0	0	429	3.1
Merig	39	0	0	3	0	0	0	0	0	0
Mere-Lava	1,739	901	52	131	6.9	0	0	0	901	6.9
Sanma:										
Santo	406,828	165,383	41	8,247	20.1	19,230	5,146	46,866	113,901	13.8
Malo	18,379	16,929	92	966	17.5	3,202	144	2,596	12,296	12.7
Penama:										
Maewo	30,205	10,775	36	781	13.8	2,946	0	0	8,903	11.4
Pentecost	49,085	19,032	39	3,568	5.3	7,464	0	65	14,126	4.0
Ambae	40,037	14,771	37	2,271	6.5	10,785	0	0	7,500	3.3
Malampa:										
Malakula	207,517	85,119	41	6,013	14.2	11,740	243	11,350	69,438	11.5
Ambrym	67,535	14,014	21	1,587	8.8	11,205	0	81	6,270	4.0
Paama	3,195	788	25	391	2.0	0	0	5	788	2.0
Lopevi	2,861	0	0	0	-	0	0	0	0	-
Shefa:										
Epi and Lamen	44,632	16,491	37	1,228	13.4	0	0	5,704	12,969	10.6
Tongoa	4,059	2,568	63	468	5.5	0	0	0	2,568	5.5
Emae	3,316	1,108	33	154	7.2	0	0	0	1,108	7.2
Sheperd islets	1,120	493	44	129	3.8	151	0	0	441	3.4
Efate	90,007	57,556	64	13,335	4.3	3,423	9,574	67,792	18,750	1.4
Nguna	2,759	2,067	75	300	6.9	0	0	2	2,066	6.9
Pele	406	317	78	62	5.1	0	0	2	315	5.1
Emao	760	544	72	115	4.7	0	0	3	541	4.7
Mosso	2,505	2,505	100	48	52.2	0	0	501	2,004	41.7
Lelepa	762	709	91	90	7.9	0	0	34	669	7.4
Tafea:										
Erromango	89,111	18,058	20	324	55.7	577	205	3,336	17,302	53.4
Tanna	56,157	30,116	54	5,153	5.8	153	0	2,092	29,089	5.6
Aniwa	877	712	81	84	8.5	221	0	0	538	6.4
Aneityum	16,075	2,010	13	186	10.8	13	0	0	1,981	10.6
Futuna	1,048	58	6	106	0.5	78	0	0	55	0.5
Total Vanuatu	1,223,178	492,177	40	47,373	10.4	74,145	15,311	139,929	351,208	7.4

[a] the accessible good land represents the area of good soils accessible without constraints (plantations, pastures, leases) per household. Plantations include coconut trees and pastures under coconuts. Pastures correspond to pure stands. Part of the plantations and pastures are not established on good arable land

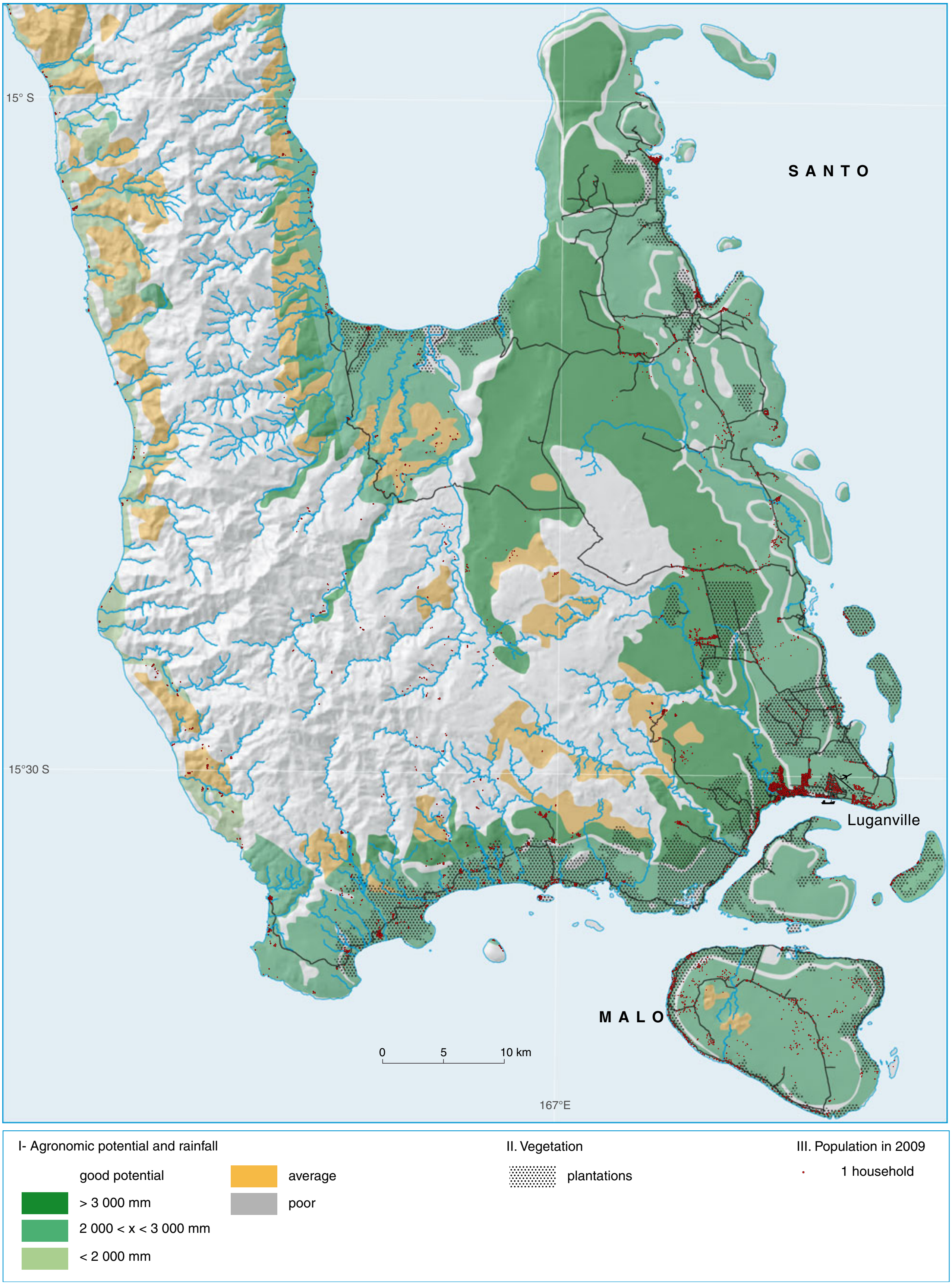

Fig. 3 Distribution of the population in Santo

and food production, which represents 40 % of the total land area, varies widely among islands from only 6 % of the total land area on the island of Futuna to 100 % of the islands of Linua (Torres group) and Mosso off northern Efate. For the present study, we express population densities in ha of good arable land per household (hectares/household rather than in hab/km^2) to allow for a better representation of constraints to settlement. The average area of good land per household varies from 530 ha on the island of Tegua (North) to only 0.5 ha/hld on Futuna (South) (Fig. 2), with a national mean of 10.2 ha/hld (Table 1). In small islands with low percentages of good arable land and high population pressures, it is obvious that there is limited scope for sustainable expansion.

Differences between the good land area per island and the accessible good land are obtained by removing from the good land: plantations, grasslands and areas under lease. Many coconut plantations and some pastures are established on poor coral soils. Therefore, on each island, the total area occupied by these two vegetation types does not necessarily represent a direct constraint, and only those on good soils (as well as leased land) are hence taken into consideration. For Vanuatu, the average good land potential declines to 7.3 ha of accessible good land per household when constraints such as plantations, pastures and land lease titles are also taken into consideration. For some islands, especially the most remote ones, the difference between the potential and the accessible good land is nil. Pastures are mostly established on the large islands of Efate and Santo where the two abattoirs are located. Here, the cattle industry is organised in large properties, combining improved pastures under coconut trees, managed under land lease titles. Constraints to traditional food crop systems are therefore increasing on these islands (8,515 households on Santo and 13,519 households on Efate), with the mean area of available good land per household reduced from 19.4 ha/hld to 13.4 ha/hld of accessible good land on Santo and from 4.3 hld/ha to 1.4 hld/ha on Efate. Although these ratios also include the urban population, they give an indication of the land available to supply the towns with locally grown foods (Table 1).

Vegetation Types

The vegetation of the littoral has been extensively modified during the twentieth century by European agriculture and new Melanesian settlements due to Christianisation but also for health reasons (lower incidence of malaria and dengue) and ease of communications (Barrau 1958; Bonnemaison 1994). On most islands the villages located on the ocean shores are now surrounded by coconut plantations, forcing people to walk for hours from their home to their gardens located on the deep and good soils on uplifted plateaus. With the growing population, the pressure on land next to villages is increasing. Absence of roads giving access to new land is therefore a serious constraint to cultivation.

The 17 different types of vegetation obtained under GIS (Schweter 2011) were verified in the field on Santo and Efate. Vegetation types recorded as: mid-height forest, forest, plantations, mangroves, grassland including cattle farms, grassland with scattered trees, perennial crops (i.e., coconuts), bare volcanic soils, built-up area, swamps and water appear to be quite reliable but additional field surveys would be necessary to confirm the situation on the other islands. However, vegetation types recorded as: low, low open, dense thicket, open thicket, scrub and gardening were found to be non-reliable. Gardening areas on Efate and Santo were often confused by satellite imagery with abandoned pastures infested with shrubby weeds (*Hibiscus tiliaceus*, *Psidium guayava*, *Solanum torvum*, *Sida acuta*, *Cassia tora*) resulting in overestimation of their real extent. Consequently, we rely on the counts obtained by the recent agricultural census data (VNSO 2008) to verify these measurements.

Although the crop vegetation layer still needs to be completed and confirmed by additional field surveys, for the present study we decided to use two vegetation cover categories: coconut plantations and crop area dominated by coconuts and grasslands, including cattle farms and grasslands with scattered trees and woody shrubs (Schweter 2011). The vegetation type corresponding to the coconut plantations is of great interest because it is by far the most important perennial crop in Vanuatu and it has already been shown to be measurable in a reliable manner with remote sensing and GIS in Vanuatu and elsewhere (Punithavathi *et al*. 2011). The area planted with coconuts in Vanuatu (measured with MapInfo™) is 74,145 ha (Table 1). These plantations represent a significant constraint to shifting cultivation as it is not easy, nor profitable, to cultivate food crops under coconuts. Vegetatively propagated heliophylous bananas and plantains as well as root crops such as yams, cassava, sweet potato and aroids do not tolerate shade and cannot develop properly in the compact soil texture produced by the voluminous root system of the coconut trees (Lebot 2009). Most of the coconut trees were planted by smallholders in their gardens during the cultivation phase of annual crops and were left to grow in the fallow. Planting coconut palms is a way of appropriating the land. This is the reason why coconut palms have been planted so quickly, even as high as 300 m above sea level. During the first half of the twentieth century, planting became a way of making one's ownership of the land permanent and so to increase the household's property which could be inherited (Bonnemaison 1984). In areas which are heavily populated or where so many coconuts have been planted, there is now not enough land for shifting cultivation and food crop production. This is the case in Paama, Tongoa and West Malo

(Fig. 3). In some areas such as Ndui-Ndui in West Ambae, for example, the situation is becoming so difficult that village chiefs are now banning this practice.

The vegetation cover category "grassland" is also easily identified with satellite photographs and includes natural grasslands as well as pastures. Natural grasslands (*Imperata cylindrica*, *Erianthus* spp.) are known to be unsuitable for traditional Melanesian gardening. The zones identified as grasslands but falling within the land titles boundaries of the leases are pasture areas. However, an important area of pastures is also established under coconut groves as confirmed by field surveys on Santo and Efate and by the national agricultural census. It is estimated that there are approximately 180,000 heads of cattle on these pastures (VNSO 2008).

Cash and Food Crops

Three types of activities were identified by the agricultural census: subsistence, cash cropping (copra, cocoa, kava, livestock) and large commercial plantations under leases. All crops were enumerated in the household samples surveyed. Estimations of areas planted are based on the average densities per ha. For coconuts, for example, the total number of plants counted during the 2007 survey was 9,668,000 trees (Table 2). At an average density of 130 trees per ha, the area planted is approximately 74,369 ha, a figure corresponding to the area determined by satellite imagery and GIS (vegetation type no. 13=74,145 ha) (Table 1). This correspondence indicates that field surveys are important to validate GIS data and that the agricultural census provides fairly reliable data (Table 2).

It is estimated that the 74,145 hectares of coconuts in Vanuatu produce approximately 66,600 tons of copra per year (the average yield is 900 kg of copra per ha/yr). The present annual production levels for oil (12,000 tons) and raw copra (10,000 tons) shows that an equivalent of 32,000 tons of copra is at present processed (compared to a record of 47,247 tons in 1997). The production needed for other purposes (juice, milk, pulp, animal feed) is estimated to be approximately 14,000 tons of fresh pulp (de Taffin *et al.* 1993). This indicates that approximately 15,000 ha are needed for subsistence purposes and around 60,000 ha are potentially used for commercial activities, which is more than necessary considering current levels of copra production. Many nuts are simply not harvested and farmers pick them up only if the prices are competitive. Although the international prices are currently attractive, indications are that the copra industry will continue to decline because younger farmers are not interested in this occupation. It is estimated that approximately 6,000 ha of coconuts should be replanted every year to regenerate the actual plantations but actual plantings are far less (VNSO 2008). The economic importance of copra is often overestimated because the only official figure available is the total value of oil and copra exports. In fact, farmers receive approximately 60 % of the value of the exports every year and the balance goes to the expensive processing system as there are only two oil mills on Santo and Efate, the international ports.

Results from the agricultural census indicate that the total area under food crops is quite small (approximately 7,500 ha) (Table 2). These data explain why food crops systems cannot be detected by remote sensing and satellite imagery. The total area is dispersed in very small plots

Table 2 Areas cultivated for major crops

Crops	Total number of plants	Average spacing (in m)	Average density (plants per ha)	Total area cultivated (estimated in ha)	House-holds involved
Food crops:					
Root crops	16,820,000	1×1	10,000	1,682	33,570
Bananas & plantains	2,850,000	2×3	1,666	1,711	33,570
Other food crops	2,033,000	1×1	10,000	2,126	33,570
Fruit trees[a]	1,992,190	10×10	100	1,992	33,570
Total food crops				7,511	33,570
Number of plots				97,888	
Av. plot area m^2				767	
Av. area m^2/hld				2,237	
Cash crops:					
Coconuts-copra	9,668,000	8×9	130	74,369	23,660
Kava	24,272,000	2×2	2,500	9,709	20,013
Cocoa	3,043,000	3×3	1,111	2,739	8,476
Total				86,817	

[a] *Artocarpus altilis, Citrus spp., Barringtonia edulis, B. procera, B. novae-hiberniae, Canarium harveyi, C. indicum, Gnetum gnemon, Inocarpus fagifer, Mangifera indica, Morinda citrifolia, Persea americana, Pometia pinnata, Spondias cytherea, Syzygium malaccense, Sterculia vitiensis, Terminalia catappa*

(mean garden plot area is 767 m^2) hosting many different crops intercropped in agroforestry systems, combining vegeculture and arboriculture. Native and introduced fruit and nut tree species (Lebot *et al.* 2007) represent an important resource which is now being established instead of coconuts to claim ownership on the land (Table 2).

Leasing the Land

Security of land tenure is a precondition for proper investment in the agricultural sector because of the time-lag between investments and the flow of returns and the need for a recognised asset with which to secure loans, especially for long-term speculations such as perennial cash crops and cattle. It is obvious that in recent years, on Santo and Efate, the administrative and legal structures for settling land disputes and finalising leases have been very efficient at dealing with the large number of leasehold negotiations and ownership disputes. The consequences are that the leased areas represent 46,866 ha, 28 % of Santo good land and 67,795 ha or 74 % of Efate total land, indicating that soils with poor potential are also under leases. Many of these leases are registered as "agricultural" but it appears that limited agricultural development is on-going. In fact, subdivisions and land speculation are also part of some lessees' objectives. On Efate, the total area occupied under land lease titles is now a serious constraint (Fig. 4). It would appear reasonable to envisage the development of local food production to feed urban dwellers in Port-Vila, the capital of the country, but the average accessible land available per household indicates significant pressure (1.4 ha/hld). The intensive urban drift and the constant arrival of migrants from the outer islands establishing themselves as squatters are also important issues. One solution might be the creation of agricultural subdivisions aiming at establishing these migrants as farmers but this would require proper land use planning.

Discussion

The challenge for research on shifting cultivation is to link land cover information to human-environment interactions over large areas (Messerli *et al.* 2009). In the case of Vanuatu, the complete GPS localisation of all households is a unique opportunity to do so. Furthermore, the digitization of recent advances in geographical knowledge, when combined with older but highly reliable information, allows the complete spatial coverage of all islands and islets. Because shifting cultivation is practiced on all inhabited islands with varying local constraints (presence or absence of alienated land under lease, plantations and pastures), individual situations are very diverse but nationwide analysis is essential. The present integration of six data layers shows that it is possible to link across large areas the diverse interactions between human communities and their environment. While so doing, it is possible to assess the increasing levels of difficulties that local communities are facing.

Impact of Shifting Cultivation

Primary forests no longer exist on any of the islands of Vanuatu, except for the cloud forests on high land. The actual forest cover is mostly secondary growth inter-planted with native fruit and nut tree species (Mueller-Dombois and Fosberg 1998). The household (often a nuclear family) is the productive unit that exploits the land. Shifting cultivation within the limits of the land used by the family is, therefore, conducted within orchards established by previous generations. Many different species of trees are established during the cultivation phase because they are easy to maintain. Their number per plot varies according to strategies: cash cropping, subsistence or both. The Melanesian shifting cultivation system can be best described as an association of vegeculture and arboriculture, the latter to mitigate environmental risks (Walter and Lebot 2007).

This is different from the swidden type of cultivation system described in SE Asia dominated by cereals (Mertz *et al.* 2009). Although this system has traditionally been shown to be resilient in the face of rapidly changing environments, severe declines in plant diversity have also been observed when it is replaced by permanent land use systems (Rerkasem *et al.* 2009). In SE Asia, a region characterised by high population densities living in permanent settlements, the swidden cropping system is evolving rapidly as farmers are obliged to clear new plots closer to villages and to shorten fallows (Cramb *et al.* 2009, Ducourtieux *et al.* 2005). It has been shown, in Laos (Messerli *et al*. 2009) and also in the Amazon (Sirén 2007) that shorter fallow periods lead to increased pests, diseases and weed infestation and soil exhaustion. The situation in Vanuatu's most densely populated islands (<5 ha/hld) is somewhat similar to that reported in SE Asia and elsewhere in the humid tropics. Fallow improvement research appears to be necessary to find practical solutions allowing the system to remain sustainable.

The important sociocultural trait that characterises the Vanuatu cropping system is tree planting during the annual crops cycle to claim ownership of the land. In Vanuatu, as population increases, pressure on the land will increase and this socio-cultural habit might contribute to the establishment of sustainable agroforestry systems if a wide diversity of fruit and nut trees rather than coconuts are planted (Lebot *et al*. 2007).

Data generated in the present study indicate that shifting cultivation is not a significant cause of deforestation in the archipelago. Likewise, logging is a minor and limited activity

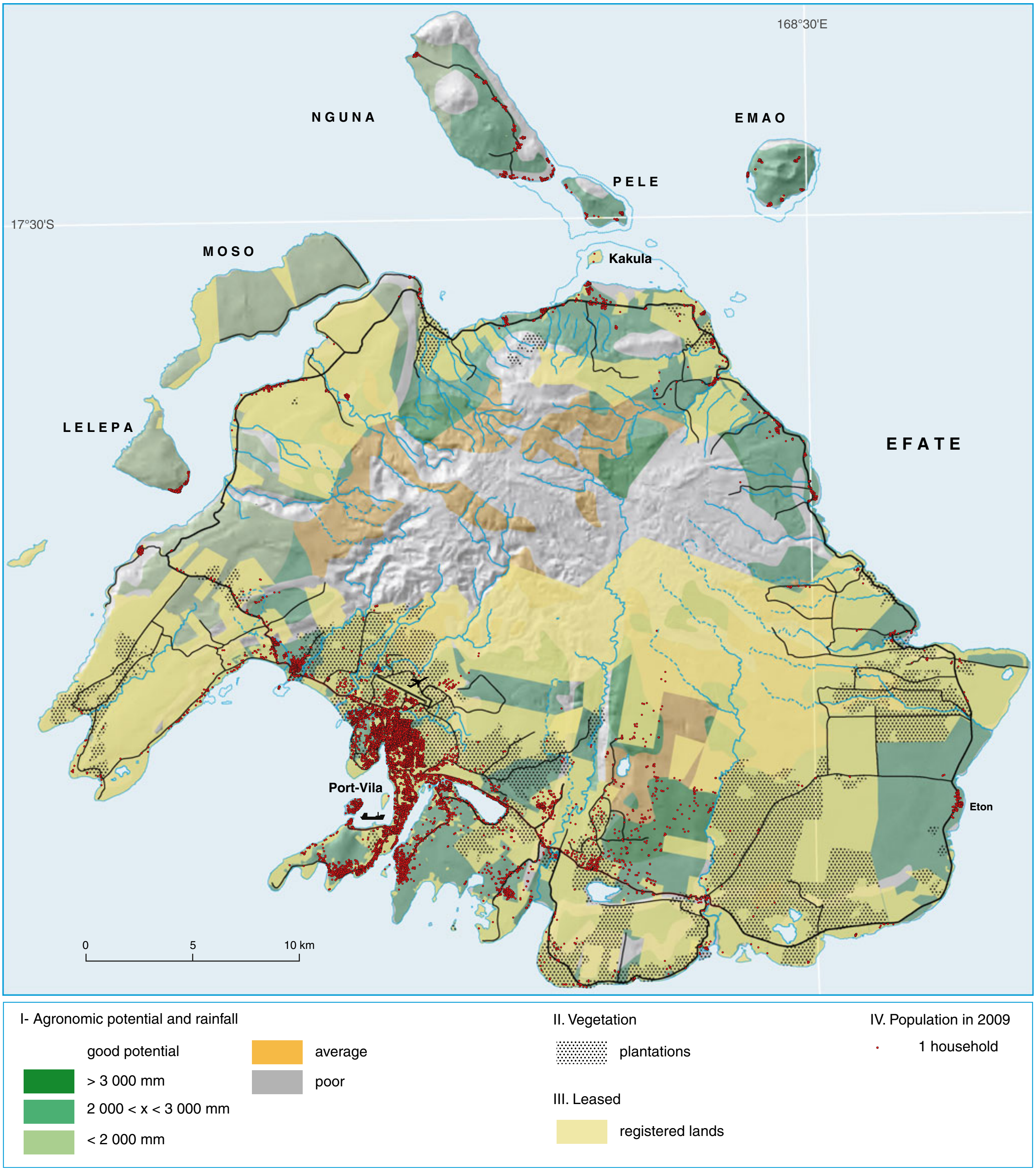

Fig. 4 Constraints to food crop production on Efate

for cultural reasons as well as inaccessibility, low stocking and poor commercial quality. Only about 20 % of the total forest area is available for logging (VanGov 2010). The establishment of coconut plantations and permanent pastures, either as pure stands or under coconut groves, represent the most important cause of deforestation (Table 1). The extent and intensity of forest clearing has increased in Vanuatu since European contact, although stabilised after independence in 1980. However, the magnitude of the impact on the environment from coconut plantations (74,145 ha) and pastures (15,311 ha) (Table 1) is more important than the total area under food crops (7,511 ha) (Table 2).

Before the first contact with Europeans, population densities were very high throughout the Pacific (Kirch and Rallu 2007). In 1859 on Aneityum, for example, the population was 3,513 (Turner 1861: 476). As we do not know the number of households at that time, this corresponds to a density of 175 hab/km^2 of good arable land. Now, with a population of only 915, the population density on Aneityum is close to 46 hab/km^2. On Paama in 1979 the population was 2,228 giving a density of 283 hab/km^2 of good arable land. At present this island population is decreasing due to constant migration to other islands (VNSO 2011). For Vanuatu, if one hypothesises that a density of 200 hab/km^2 is possible on good arable land, then the capacity of the country could be approximately 980,000 hab, a figure similar to the estimates made by some authors regarding the population before the epidemics brought by the Europeans (Harrisson 1937). The situation was most likely easier to sustain at that time because of a wider geographical distribution of the population.

Even when long fallow periods (e.g., 10 years) are taken into consideration, the area needed for shifting cultivation (approx. 75,000 ha) is significantly less than the area presently under land lease titles (139,939 ha). Also, the example of the island of Efate indicates that these titles correspond to an important area of land being managed by a small percentage of leaseholders (Fig. 4). The comparison of the 1999 and 2009 population census data indicate that urban drift is important with Luganville and Port-Vila as the main recipients of migrants from other islands. The estimates of annual net migration by provinces, indicate that while Shefa (which includes the capital Port-Vila) gains 1.6 % of its population through migration, Tafea, Malampa, Penama and Torba, respectively lose 1.9 %, 1 %, 0.8 % and 1.6 % annually (VNSO 2011). These migrants are facing practical problems to lease land upon arrival. An increasing number of households, mostly migrants from the Shepherd islands and Tanna, are squatting on land without lease titles and this might be the source of future tensions. In Melanesia, recent events in the Guadalcanal plain, Solomon Islands, have shown that land conflicts can rapidly escalate into ethnic violence (Bennett 2002; Dinnen 2002) and that it is of utmost importance to anticipate such tensions (Liloqula 2000). The methodology and approach described in this paper might represent a practical way to clarify the spatial constraints in order to facilitate improved land use planning.

Implications for Environmental Planning

The First National Development Plan of 1982–1986 clearly stated that the objectives of the agricultural sector were to encourage the re-establishment of a strong plantation sector and the participation of private companies in joint venture agricultural projects (VNSO 1981:121). It was, however, observed that as a result of perennial cash crop establishment and increased population pressure in some areas, local subsistence production was already affected. It was also stated that although many communities were self sufficient in the 1970s, in the early 1980s rural producers were not able to satisfy local food demands, as evidenced by the rapid growth in imports of such commodities as rice, chicken and tinned fish and meat (ibid.:126). As little has been done to strengthen food crop production or to improve the traditional cropping system, the situation has worsened since Independence with the agricultural balance in increasing deficit every year (VanGov 2010).

Other studies conducted In the region at the community level have shown that local innovation supports increasing population. In Vanuatu, the introduction of American starchy crop species (*M. esculenta, I. batatas, X. sagittifolium*) at the beginning of the last century was an innovation but since then, no real improvement to the traditional system has occurred. In Bellona (Solomon Islands) where the human pressure on good arable land is high (2.25 ha/hld) (Reenberg *et al.* 2008) and in Ambae (Vanuatu) the decrease of traditional gardening based on yams and taro, its replacement by coconut plantations and intensive gardens of sweet potatoes, cocoyam and cassava has been well documented (Bonnemaison 1984). However, this scenario might be facilitated when there is the emergence of an economy where people can be absorbed into salaried employment. In such a situation, remittances from Melanesian expatriates are important to the local economy and it has been argued that remittances are essential for South Pacific economies (Fleming 2001). For Vanuatu, however, anticipation, proper planning and application of customary management principles might represent a better option for the long-term, considering the agronomic potential that still exists in many islands (Table 1). It is clear that those who obtain land leases are planning to realise this potential.

While it is obviously urgent to develop agriculture to meet the local needs of the rapidly growing population of Vanuatu (VNSO 2011), there are only two options: either to increase agricultural production or to increase food imports. The last 30 years of cash cropping developments in Vanuatu indicate that the country has rather limited scope for increasing export income. Increasing local food production so that export income can be directed towards the importation of essential commodities is therefore clearly preferable. Considering the constraints that already exist in most islands, increased production will have to come from existing agricultural land. The traditional multistrata systems host numerous species, with different varieties within species, planted simultaneously and successively. Whilst plant breeding appears to be the best option for the successful control of a number of plant diseases, this is a long term approach that needs to be combined with the introduction of selected germplasm and new cropping techniques.

Vanuatu is extremely vulnerable to natural disasters: it is in the path of tropical cyclones and thus affected by cycles of El Niño and La Niña, which future environmental changes could exacerbate, as well as subject to volcanic activity, earthquakes, flooding and drought. For example, at the beginning of 2011, the island of Futuna (0.9 ha/hld) faced starvation after a cyclone, and had to be supplied with imported food stuffs. Other recent disasters include the November 1999 Penama province earthquake and tsunami that affected about 23,000 people, and in 2002 and 2010 two 7.3 magnitude earthquakes that caused significant damage to Port-Vila infrastructure. The nation's food security relies at present on trade and international assistance. Proper agricultural planning is therefore of the utmost importance.

Conclusion and Outlook

Food security is a major issue for Vanuatu because of the fast growing population and rapid environmental changes. At present there is no alternative, sustainable and diversified, food crop system to replace shifting cultivation based on vegetatively propagated plant species within agroforestry systems. If ownership on the land could be claimed by planting fruit and nut tree species rather than coconuts, the traditional system could be intensified and would remain sustainable. For economic reasons, mostly due to the costs of energy, but also because of climatic and other constraints, cereals and pulses-based type of farming systems are not realistic. Perennial cash cropping (coconuts, cocoa and coffee), has been heavily subsidized over the last 30 years and has failed to deliver the expected development in rural areas. The cattle industry has been successful on the two largest islands equipped with abattoirs but its expansion may face serious constraints in the near future. We have presented here a practical approach for combining data obtained by various GIS layers and field surveys. By integrating six data layers (topography, rainfall, soils, population, vegetation and land leases titles), we can clearly identify in each island of Vanuatu the constraints to the development of shifting cultivation. It appears that, considering the present land uses and population densities on some islands of the archipelago, there is an urgent need for technical innovations, such as improved fallows, improved genetic materials and new, sustainable, agroforestry techniques, as well as developing feeder roads to facilitate access to good arable land.

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